Between Passive and Active: The Balancing Act of Designing Behaviors

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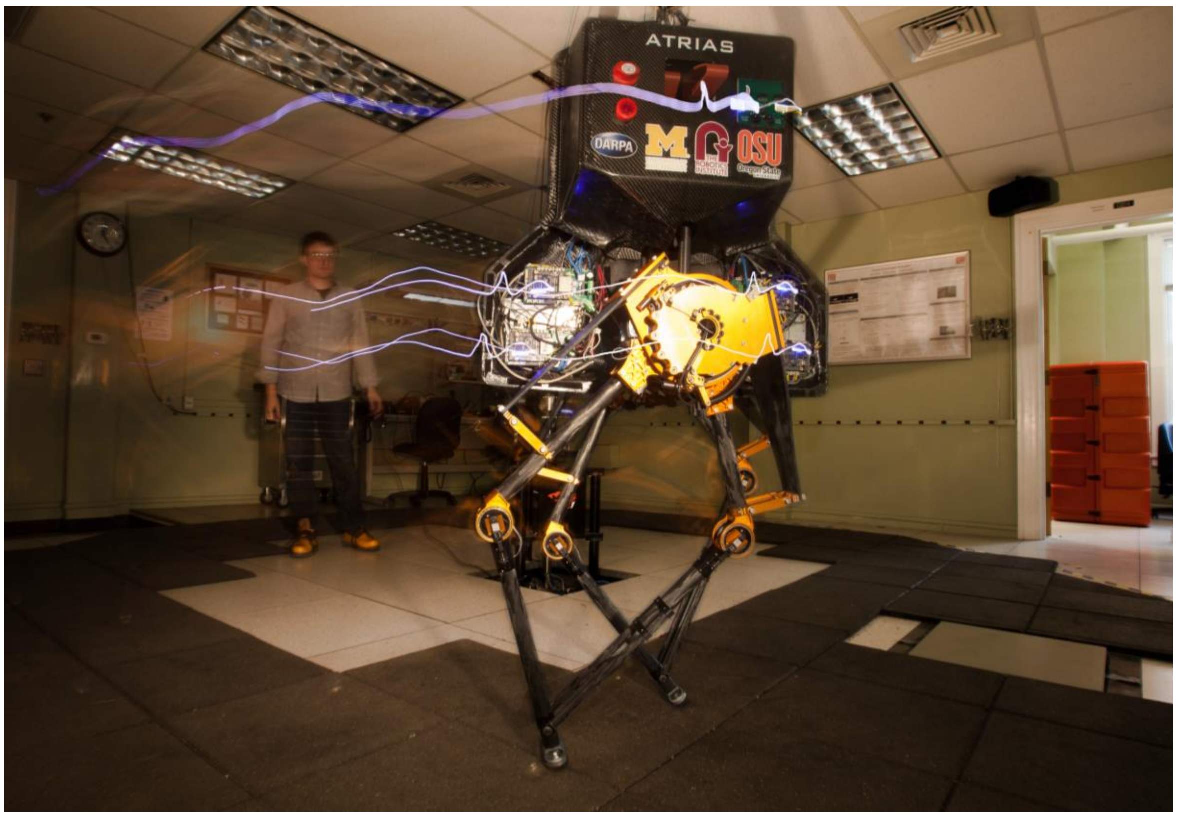
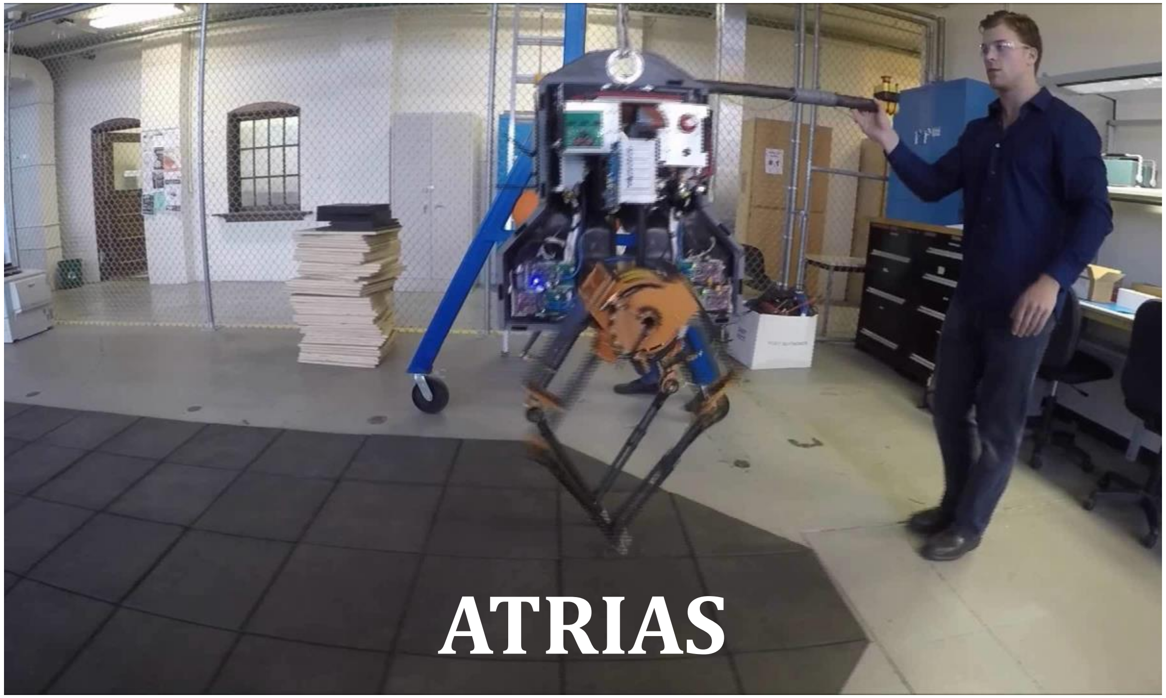


Our Goal:

- Understand and Demonstrate the Dynamical Phenomenon of Legged Locomotion
  - Optimization – Animal studies – robot experiments
  - Success == Animal-like Agility and Efficiency
- Live Demo at DARPA Robotics Challenge – June 5-6



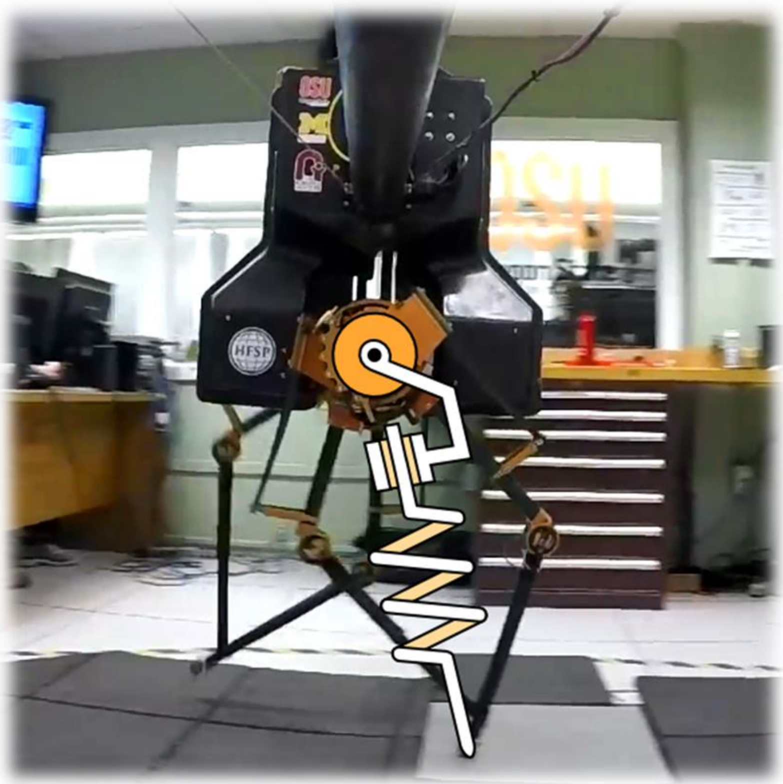
Our Approach:

- Design a *behavior,* with passive dynamics and control as partners

1. Build a robot to embody desired passive dynamics
   - Bio-inspired Spring-mass model
2. Control robot using insights from this model and animal studies

Passive Dynamics can be good or bad. Your choices:

- Minimize
- Utilize



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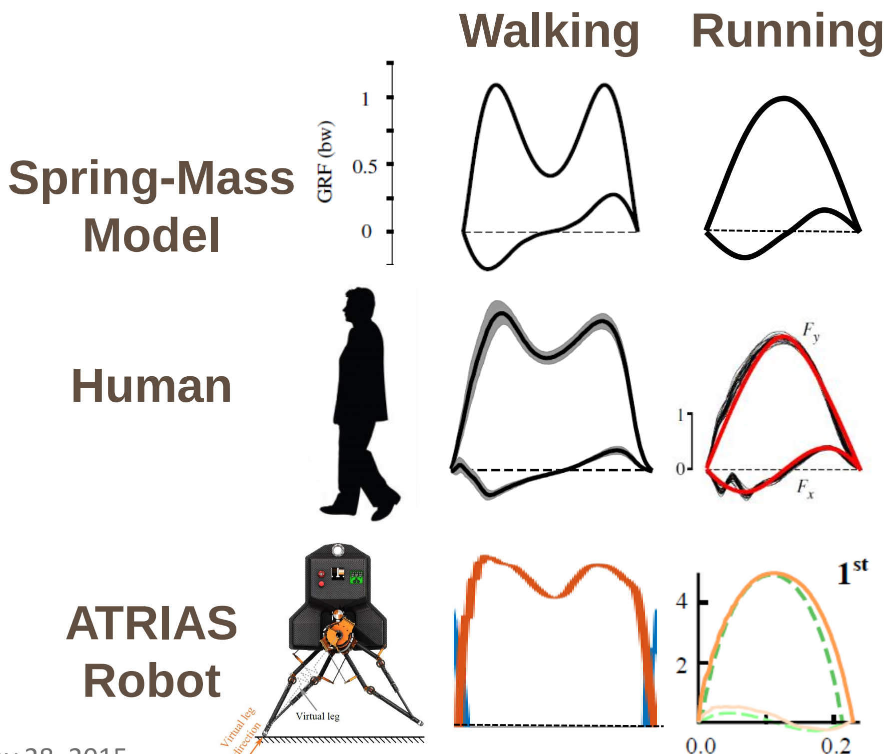
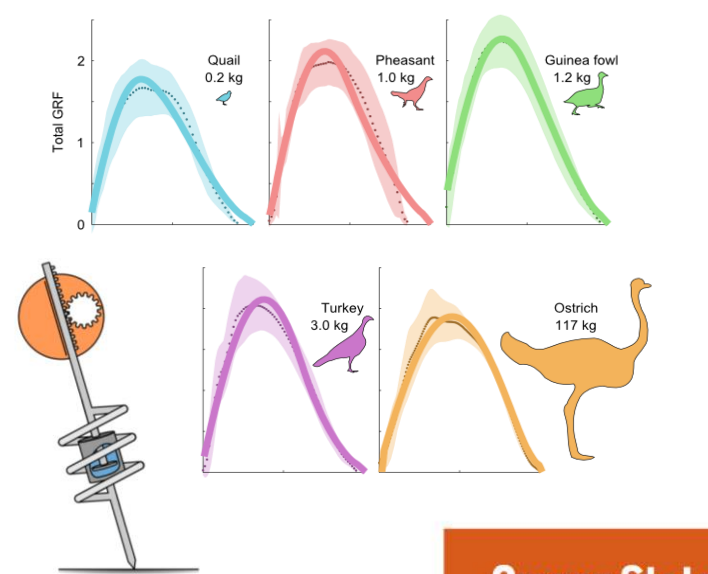
Mechanical Intelligence via a Spring-Mass Model

- Captures the basic physics of **animal** legged locomotion
- Different modes of oscillation produce **walking and running**
- Strong theoretical background



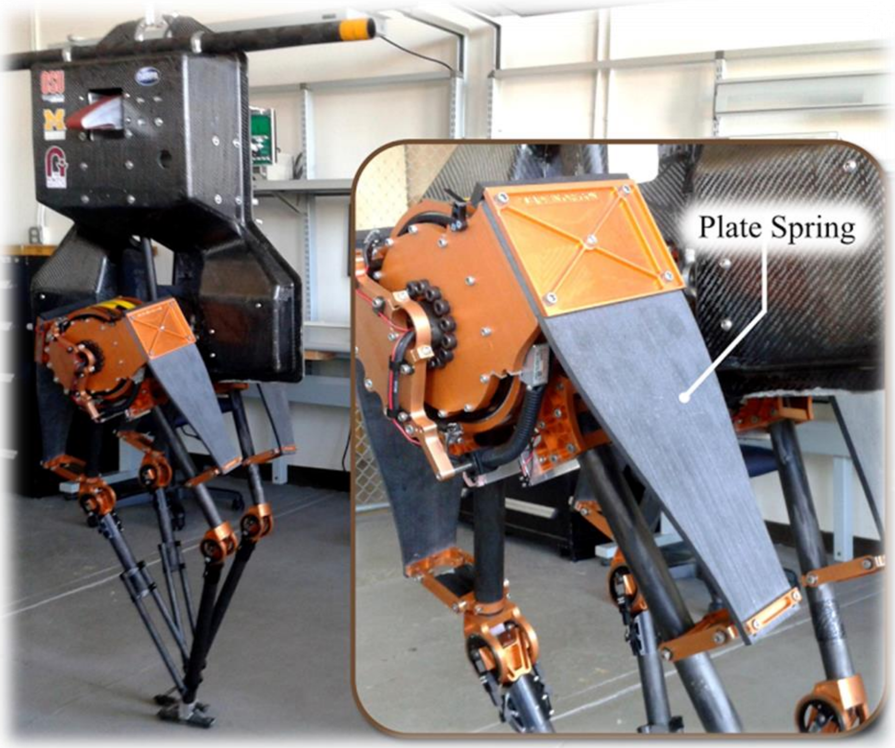
Running Birds: Quail to Ostrich



Geyer et al. 2006, Birn-Jeffery and Hubicki et al. 2014

Engineering Reasons for Physical Springs

- Unexpected impacts are no problem
- Force Control: series elasticity built in!
- Efficiency: cycles gait energy without motors in the loop
- Power: reduce power output of actuators



Improving actuator bandwidth helps with some of these issues.

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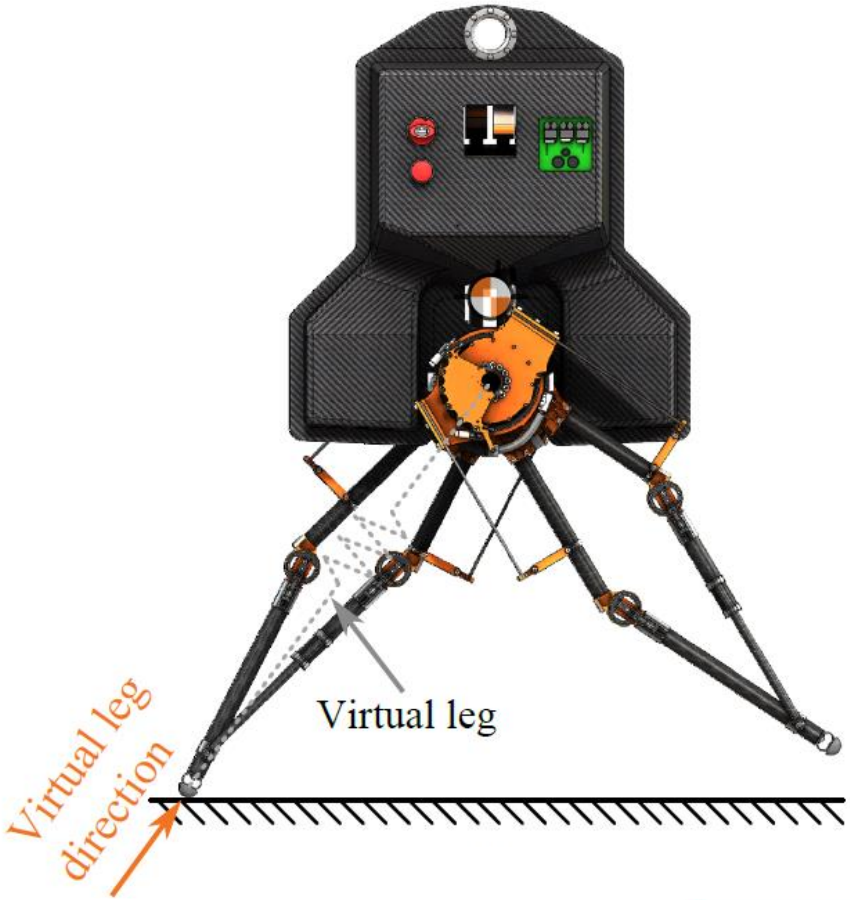
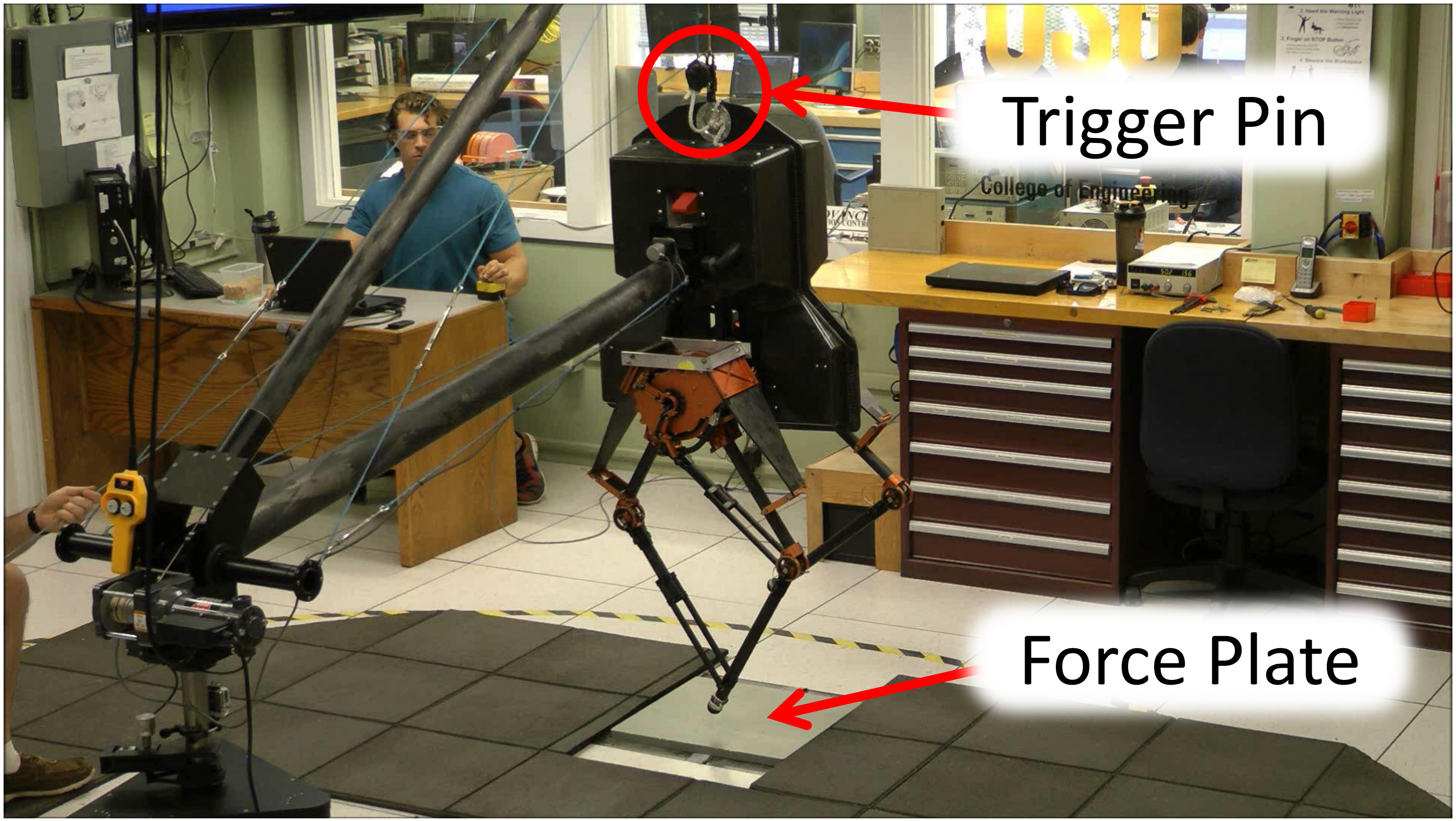
ATRIAS – built like a spring-mass model
Assume The Robot Is A Sphere

- Spring-mass features
  - Near-massless legs
  - Leg springs for energy storage
  - Mass concentrated near hip
- Practical features
  - Electromechanically actuated
  - Abduction/adduction for 3D
  - On-board power and computing
  - No external tether or support required
- Very underactuated
  - 6 motors, 12 degrees of freedom



Validating the Passive Dynamics

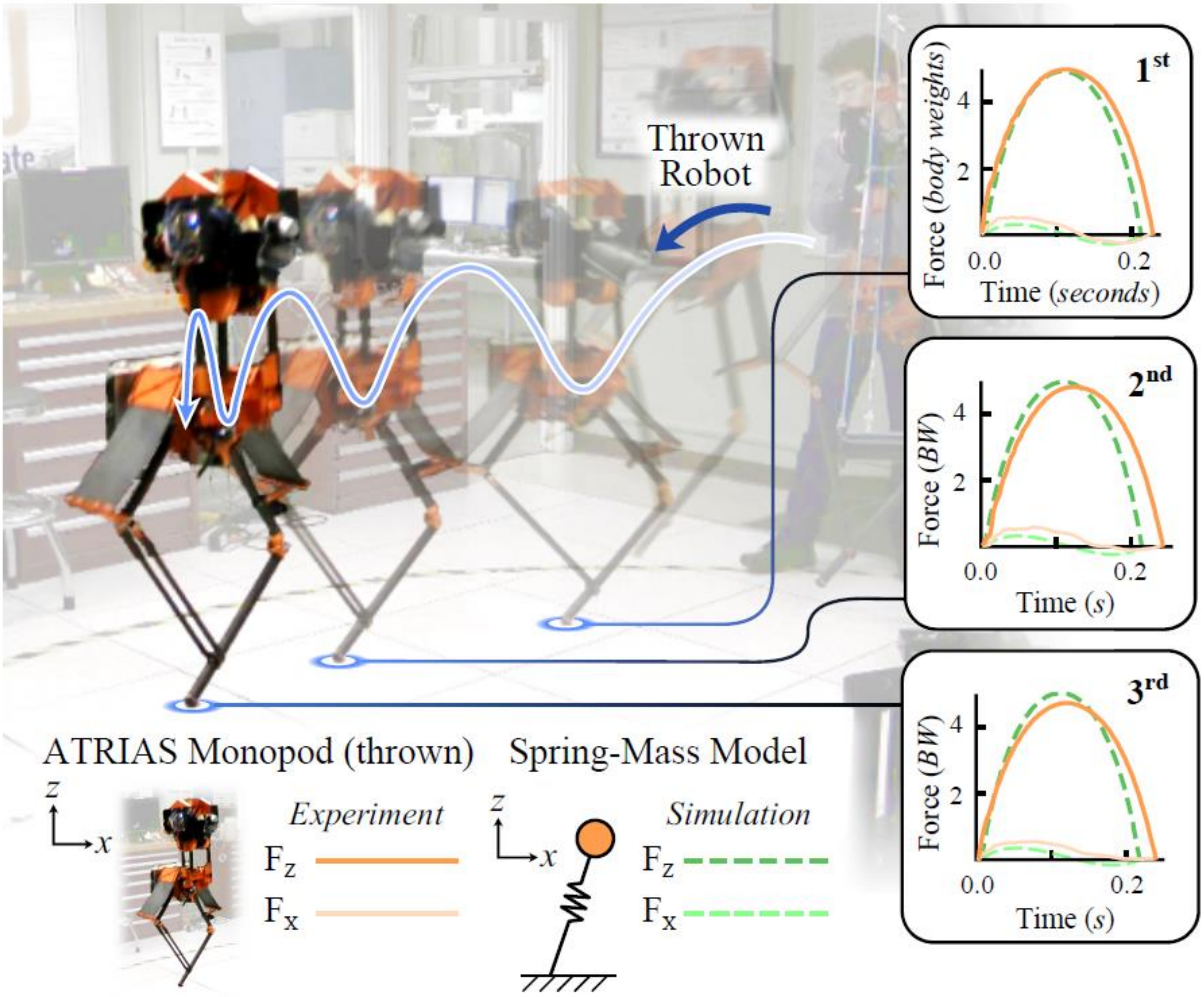
- "Perturb" the robot when it's off



Hubicki, Grimes, Jones, Renjewski, Sprowitz, Abate, and Hurst 2015 (in revisions)

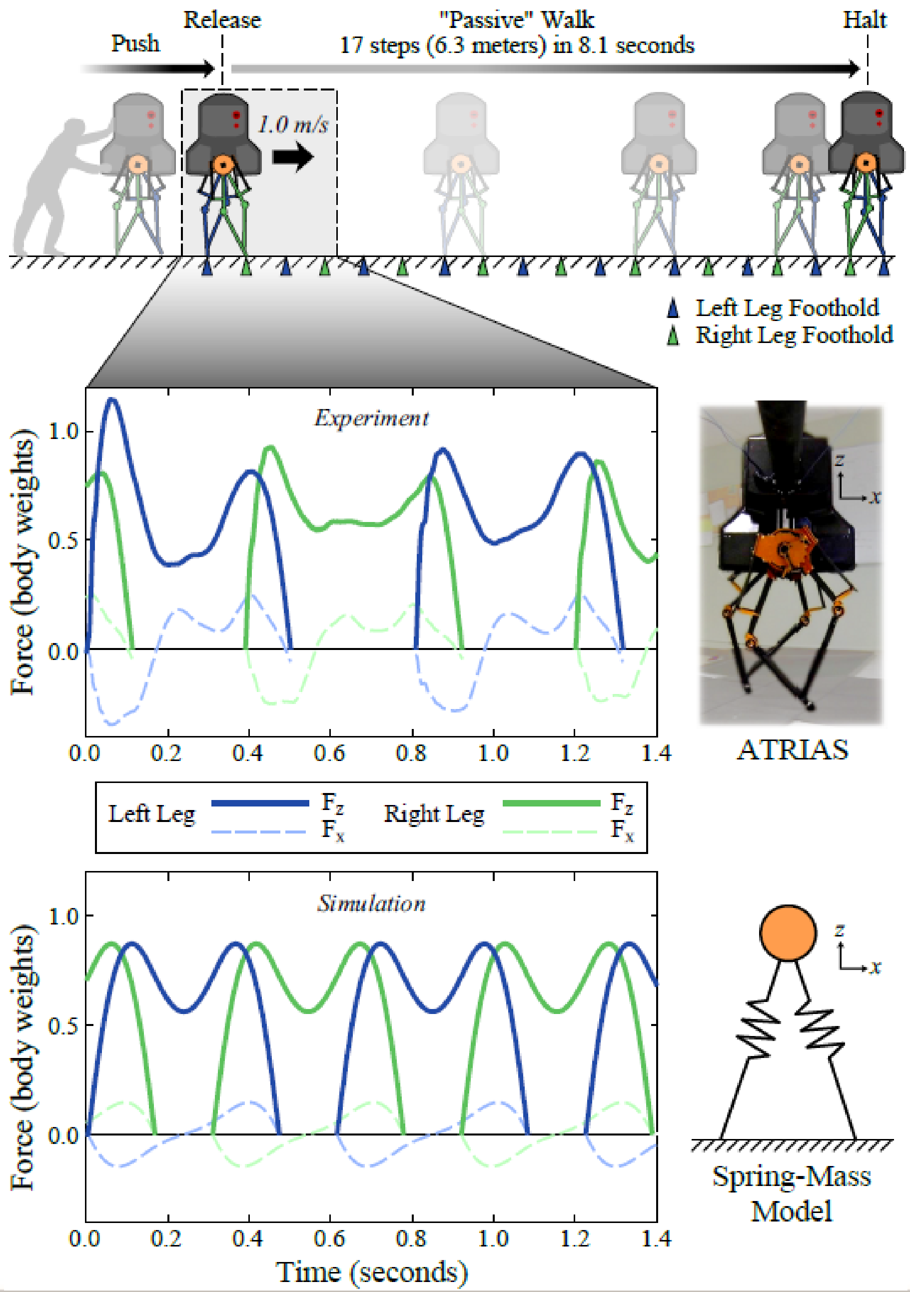
Passive Dynamics in Hopping/Running Regimes

- Throw the robot. Near-passive operation.


Thrown
Robot
1st
Force (body weights)
4
2
0.0
0.2
Time (seconds)
2nd
Force (BW)
4
2
0.0
0.2
Time (s)
3rd
Force (BW)
4
2
0.0
0.2
Time (s)
ATRIAS Monopod (thrown)
Spring-Mass Model
z
x
Experiment
F_z
F_x
z
x
Simulation
F_z
F_x

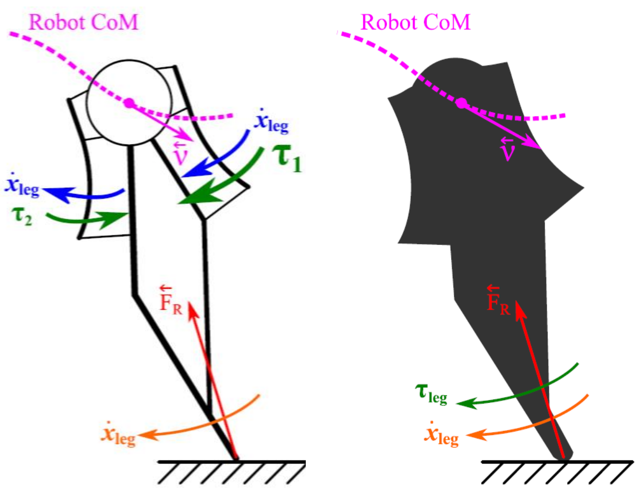
Passive Dynamics in Walking Regime

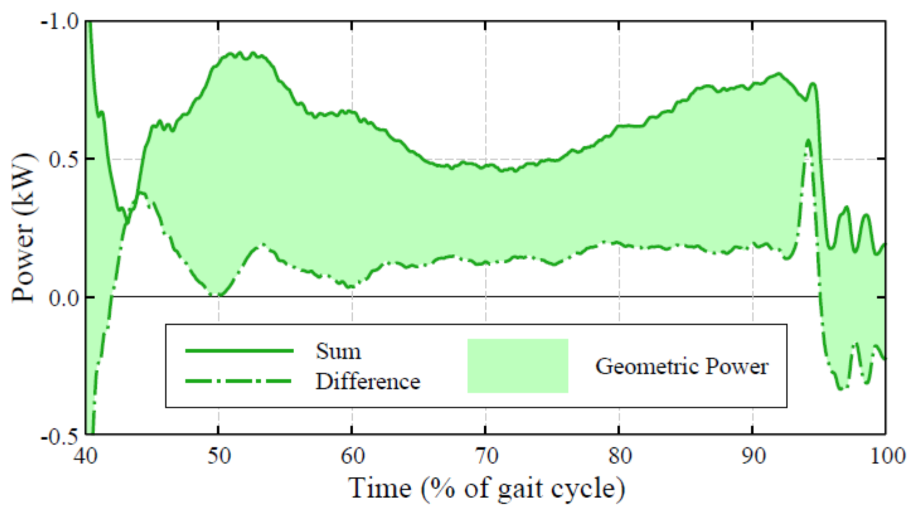
- Push the robot. Near-passive operation


Push
Release
"Passive" Walk
17 steps (6.3 meters) in 8.1 seconds
Halt
1.0 m/s
Left Leg Foothold
Right Leg Foothold
Experiment
Force (body weights)
1.0
0.5
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
ATRIAS
Left Leg F_z F_x
Right Leg F_z F_x
Simulation
Force (body weights)
1.0
0.5
0.0
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Time (seconds)
Spring-Mass
Model

Successfully Created Desired Passive Dynamics. But…

- ATRIAS passive dynamics ≈ spring-mass model, from the outside
- But there is an internal power loop.
- Passive dynamics are hard to change.





- Who cares that we've achieved spring-mass dynamics?
  - How practical is this passive-dynamic approach?

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Simple Control can result in Robust Operation

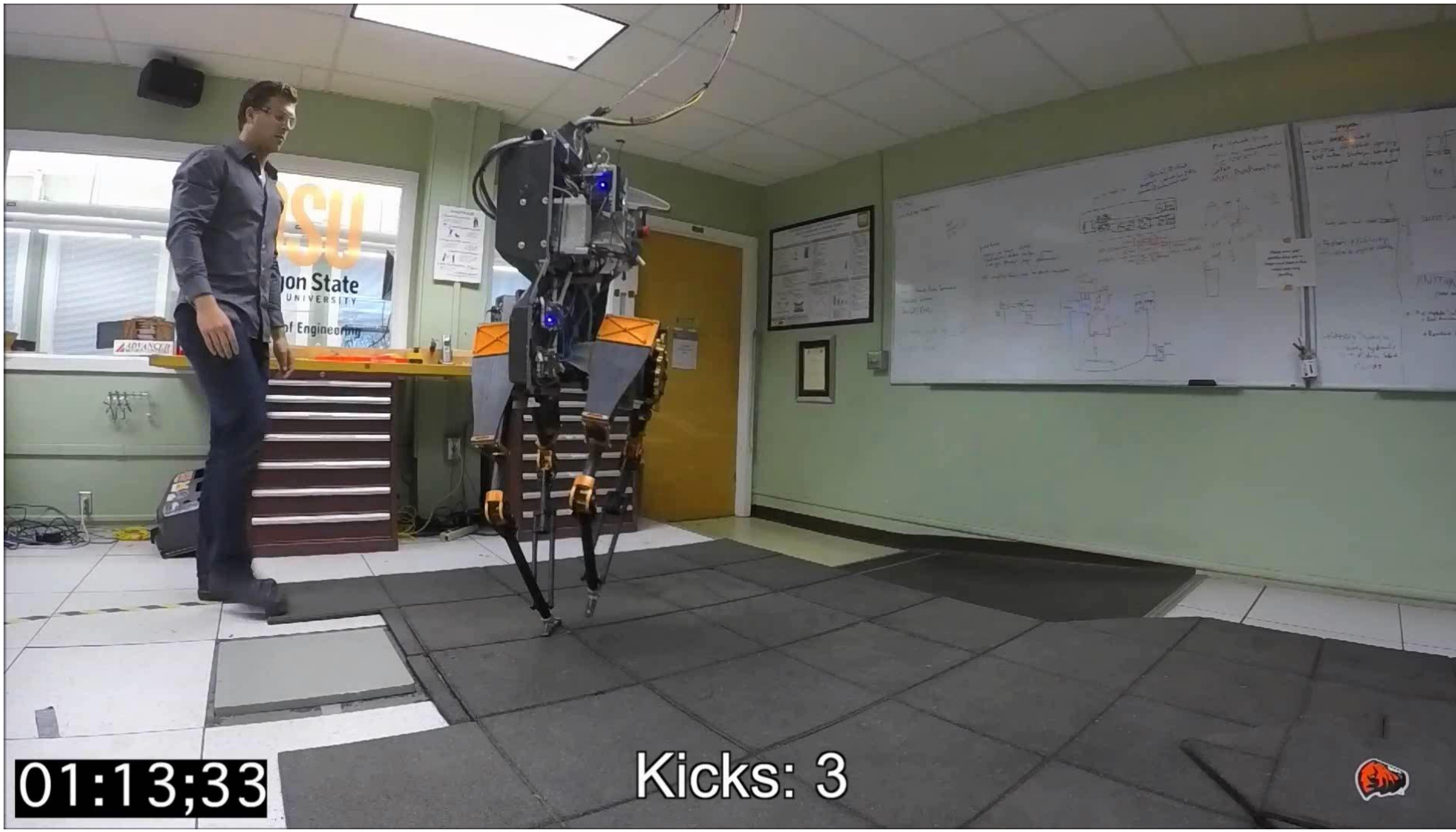
- Controller just "nudges" the hardware
- Gait designed for flat ground
  - Rigid and non-rigid undetected obstacles (it's blind)
- Handles energy gracefully
- Dissipation is Helpful
  - Leg deflection: 50% physical spring, 50% virtual spring

Dynamic Recoveries Emerge from Simple Controller

- Discrete-level nudges result in sensible recovery maneuvers

Control in 3D

- 2D controller extended to “stand” in place (no feet!)



Dodgeballs

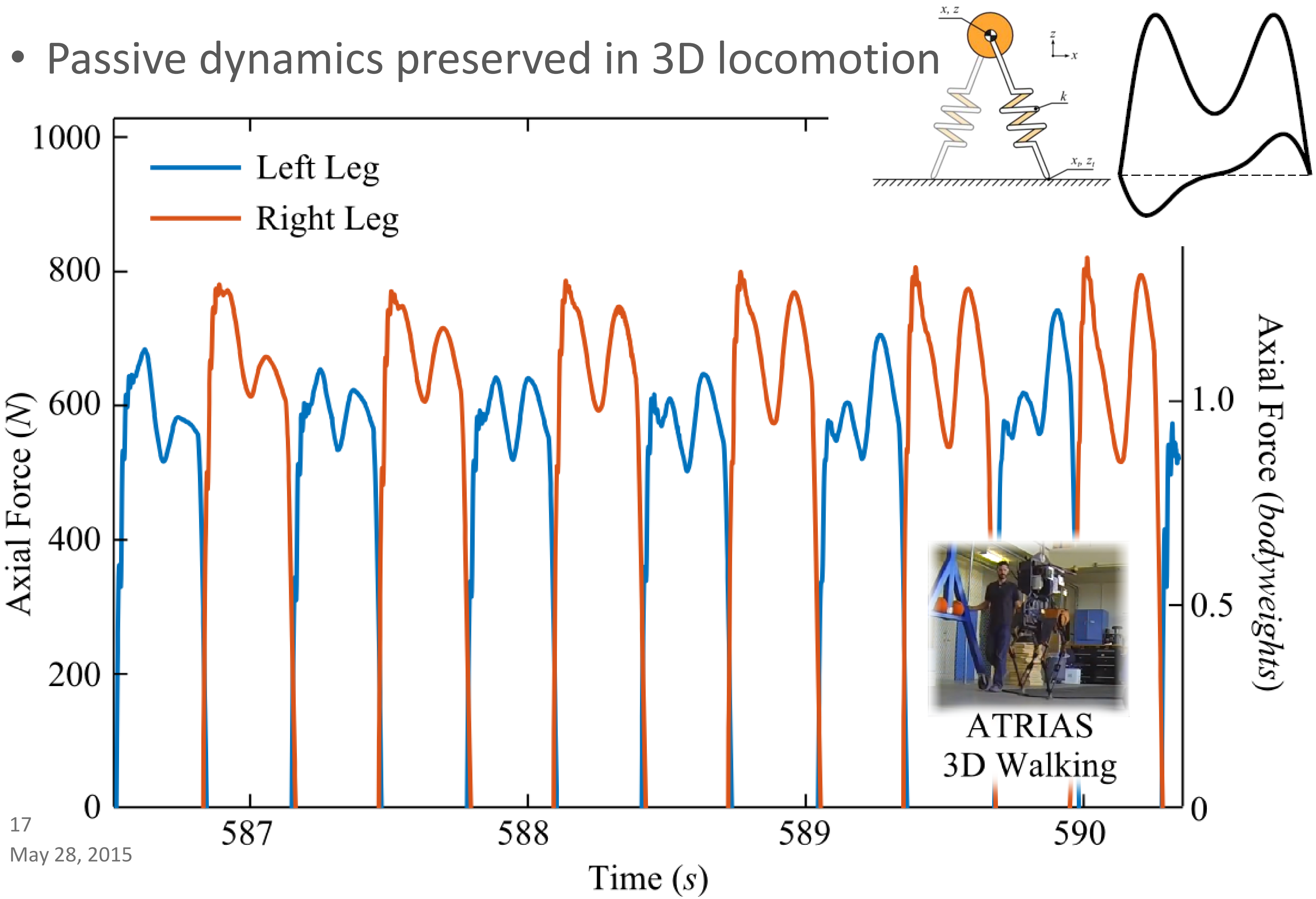
- Robustness to… different perturbations

Command a non-zero velocity… it walks

- Controller has significant time dependence. Very clock-driven.

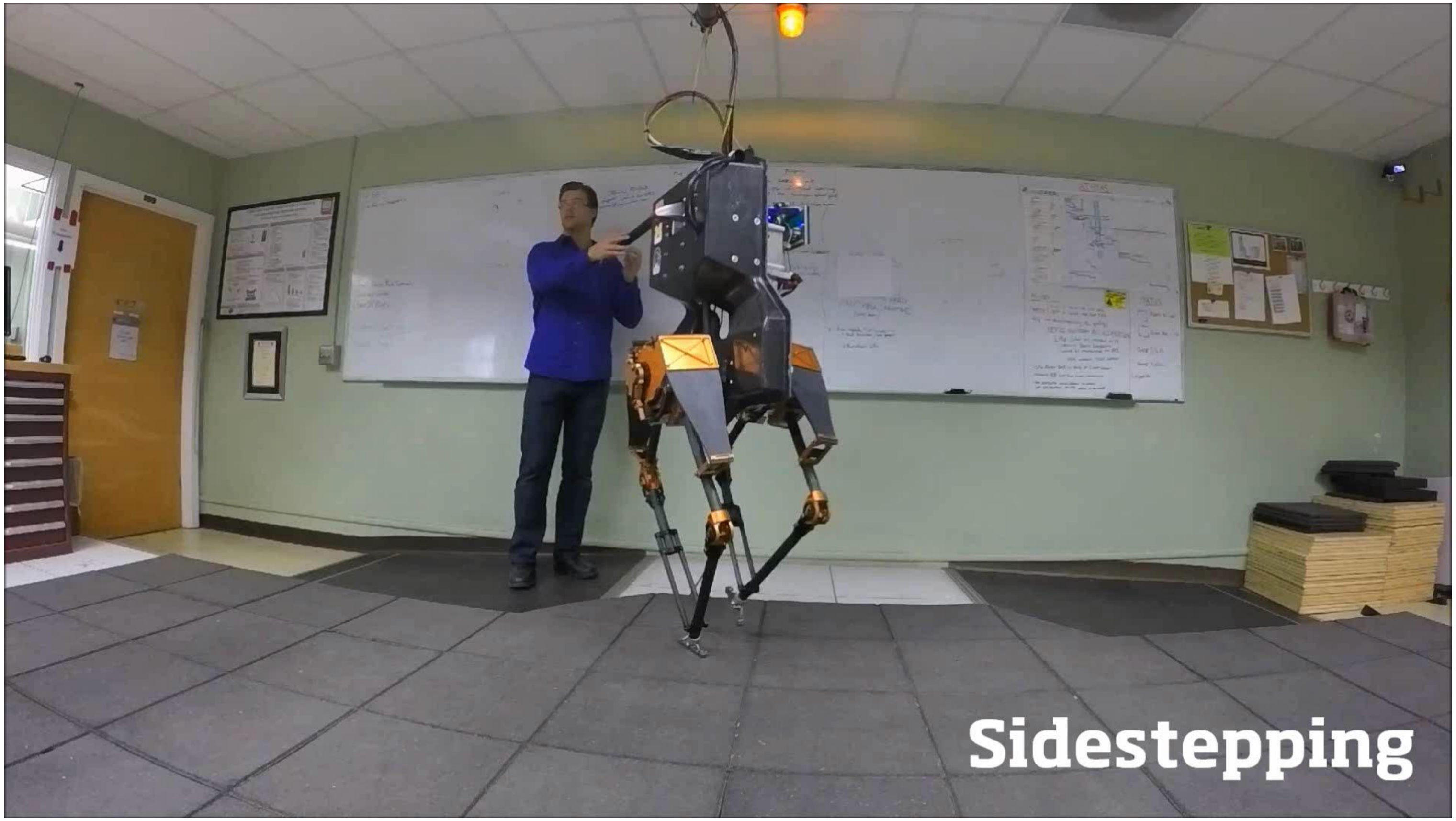
Spring-Mass GRF in 3D Walking

- Passive dynamics preserved in 3D locomotion



Other Capabilities

- Sidestep, stop/reverse, rough and soft terrain



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Next Steps

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Next Steps

Agility Robotics

To Summarize: Mechanical Intelligence vs Control Authority

- Every real system has passive dynamics
  - Motors, limb rigidity, inertia, etc.
- All about actuator limitation
  - Power, Energy, Bandwidth
- Behavior should be implemented by control, unless…
  - Power, Energy, Bandwidth
- By engineering passive dynamics, dynamical phenomena can be utilized
- Many challenges of legged locomotion are common to general physical interaction tasks
  - Unexpected impacts
  - Significant energy transfer
  - Position/Force Control
  - Actuator limitations

Thank you!

OSU ATRIAS Team

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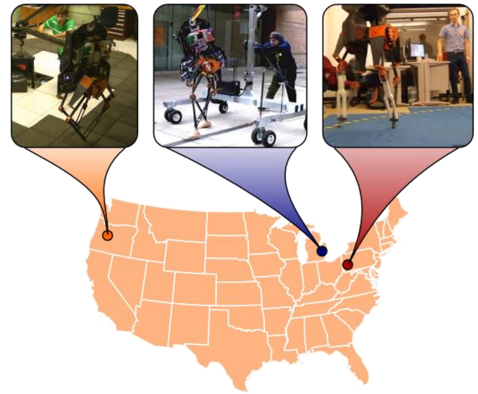
Collaborators



Dr. Hartmut Geyer
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- University of Michigan

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- Royal Veterinary College
- University of London

Funding Agencies and Grants

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NSF
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HFSP
grant #: RGY0062/2010

Questions?

A sample from our weekly "***#FailFriday***" videos

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Youtube Channel

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Google+ Page

@ATRIASrobot
Twitter Handle

Bandwidth

- Bandwidth = Measured/Commanded

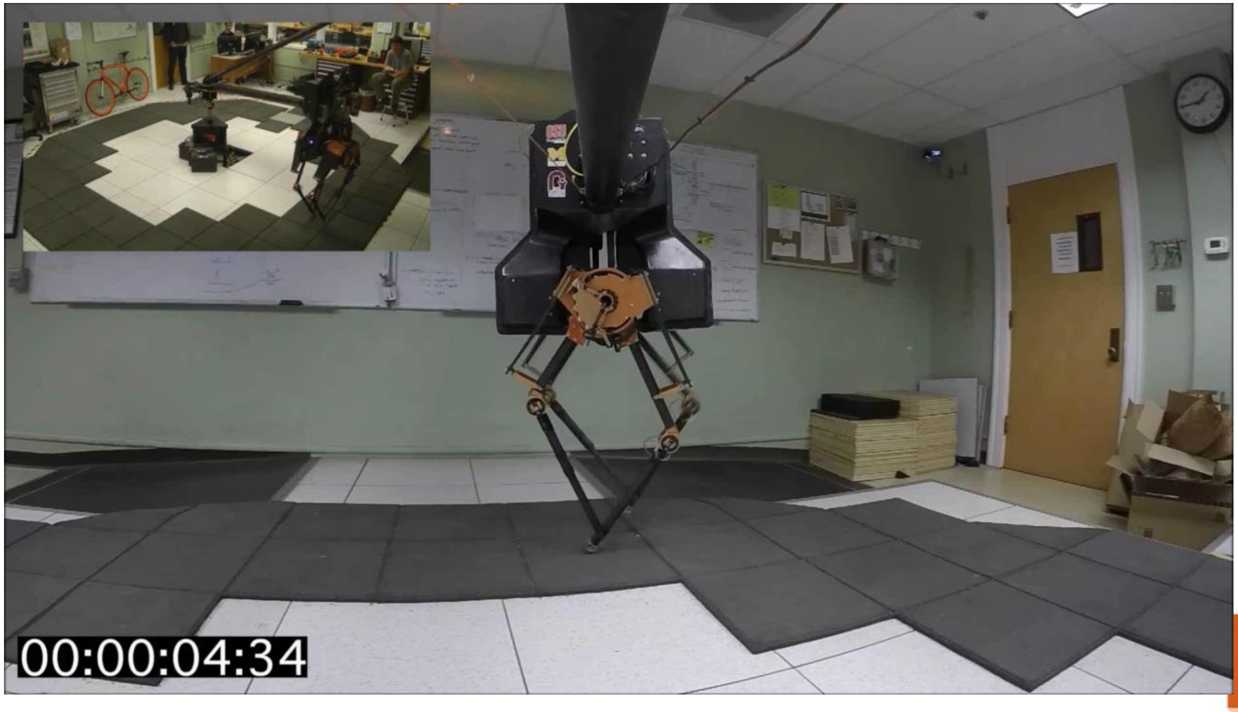
- How do you define force control?

- Vary force against a stationary object
- Maintain constant force on a randomly moving object
- Catch an object (or spacecraft docking, or landing a jump)
- Throw an object (jump)
- Walk and run
- Behave like a spring

- Bandwidth depends on the task at hand… but improving acceleration limits and velocity limits will improve bandwidth for most tasks.

Planar walking

- Continuous control gains are quite soft, mostly nudging the actuators in the right direction.
  - Leg Deflection: 50% Springs, 50% Motors
  - Very Helpful: Allowing for some dissipation via back-driving motors



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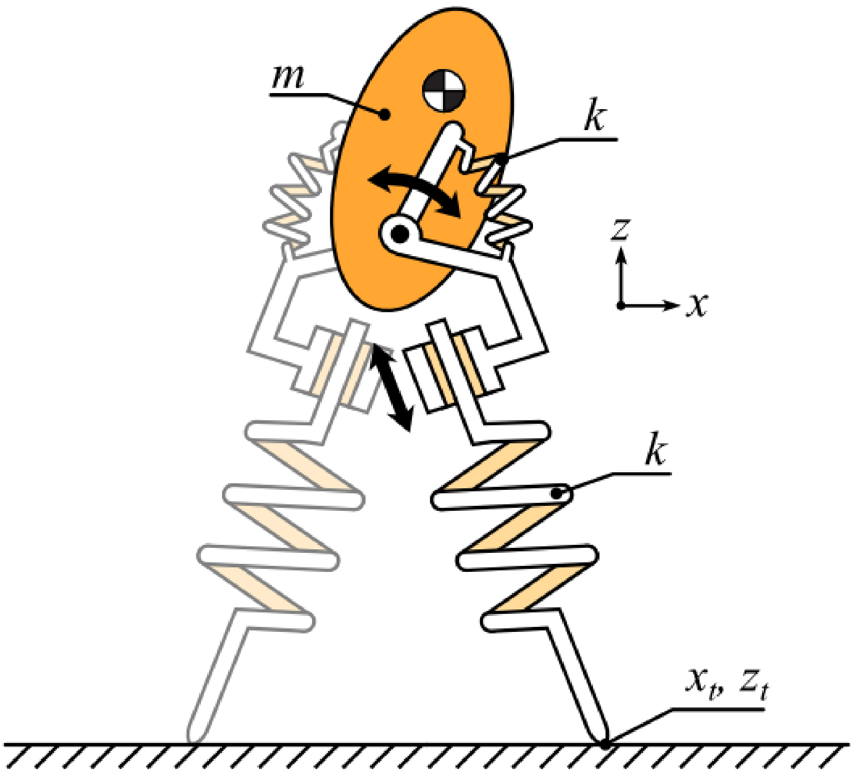
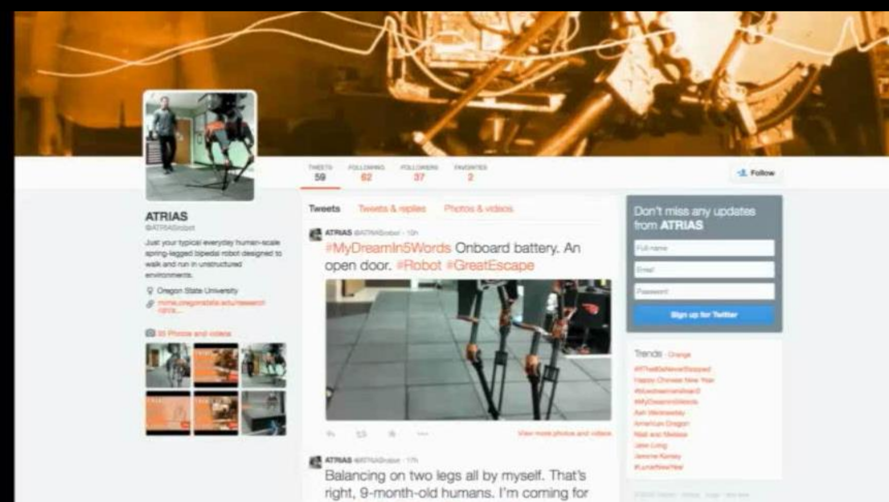
Control

- We've designed ATRIAS with spring-mass dynamics that do a lot of the locomotion dynamics for us
- Controlled quantities inspired heavily from a reduced-order model
  - Important additions to model
  - *e.g.* Torso, rotational stiffness



Follow our progress online

- Watch our successes and failures as we prepare for our demo at the DARPA DRC in June
- **YouTube:** Posted over 50 videos since January
- **Twitter:** ATRIAS likes to tweet
- **Google+:** Oregon State DRL



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