Towards Humanoid Avatar Robots for Co-Exploration of Hazardous Environments

Humanoids 2019, Workshop on Teleoperation
IHMC Robotics Team, Jerry Pratt PI
October 15, 2019

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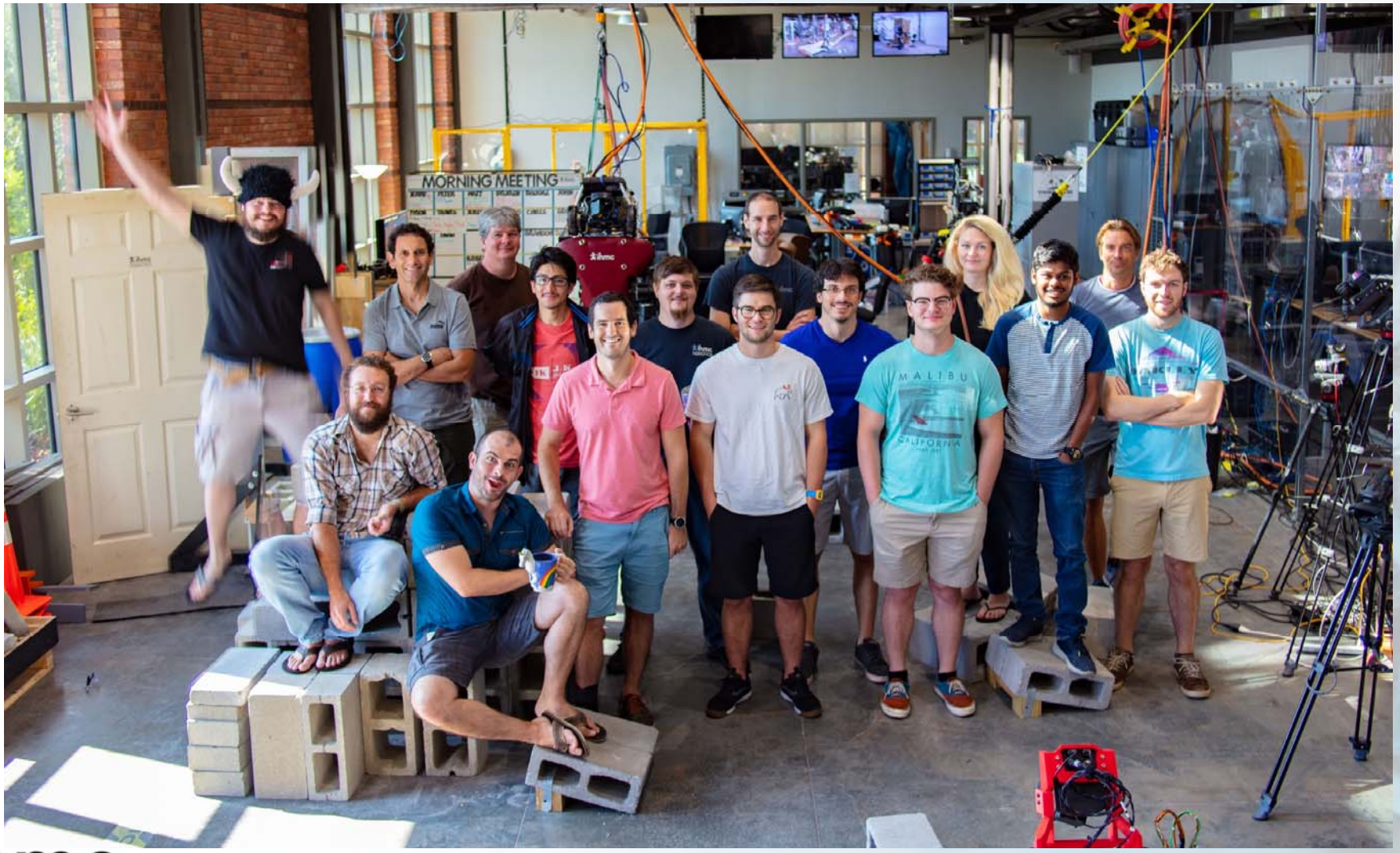

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DARPA
ROBOTICS CHALLENGE
FINALS 2015
Date: June 6, 2015
DARPA
ROBOTICS CHALLENGE
FINALS 2015
Team IHMC Robotics
$1,000,000.00
2nd Place

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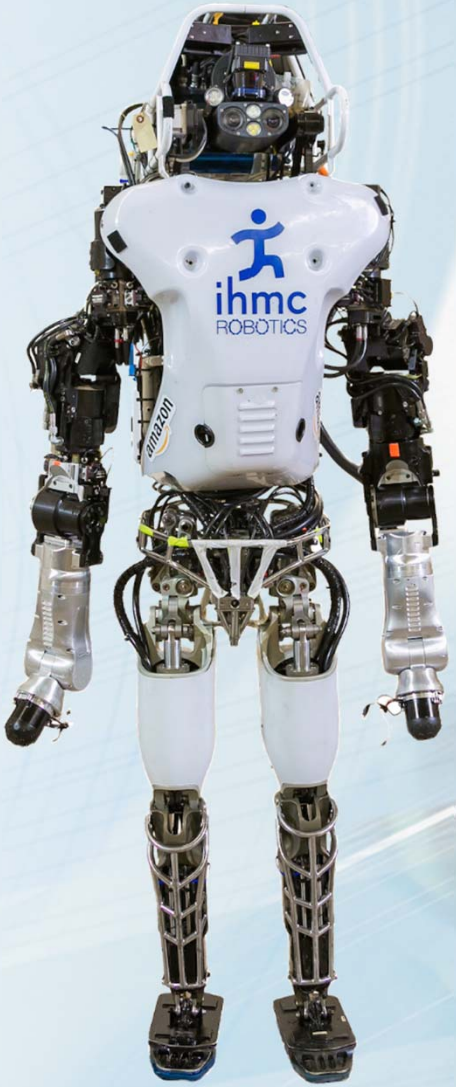
NASA JSC Valkyrie



Boston Dynamics DRC Atlas

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Funding Acknowledgement

- TARDEC: M2V2 Bipedal Robot
- Honda Research Institute: Push Recovery
- DARPA: DARPA Robotics Challenge
- NASA National Robotics Initiative: Humanoid Avatars
- NASA: Valkyrie Mobility and Manipulation
- Office of Naval Research: Humanoid Behaviors & Hardware Development

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Humanoid Avatars for Disaster Response? (DARPA Robotics Challenge)

(15x)

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Some Lessons from the DARPA Robotics Challenge

- Humanoid avatars are (almost) feasible for real world tasks, but need to be faster.
- Autonomy should be observable, predictable, and directable.
- Communication delays can be a major factor.
- Still lots of work to be done.
  - Humanoids need to survive falls and get back up!

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Commercial Wheeled Avatar Robots

From Left: AnyBots QB, RoboDynamics TiLR, Gostai Jazz Connect, Mantaro's Mantaro Bot, and VGo

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Humanoid Avatar Robots

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Humanoid Avatar Robots

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Typical VR Headset: HTC Vive

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Typical Sensors: LIDAR and Cameras

MULTISENSE SLB

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Teleoperation Using Input-Preview-Execute

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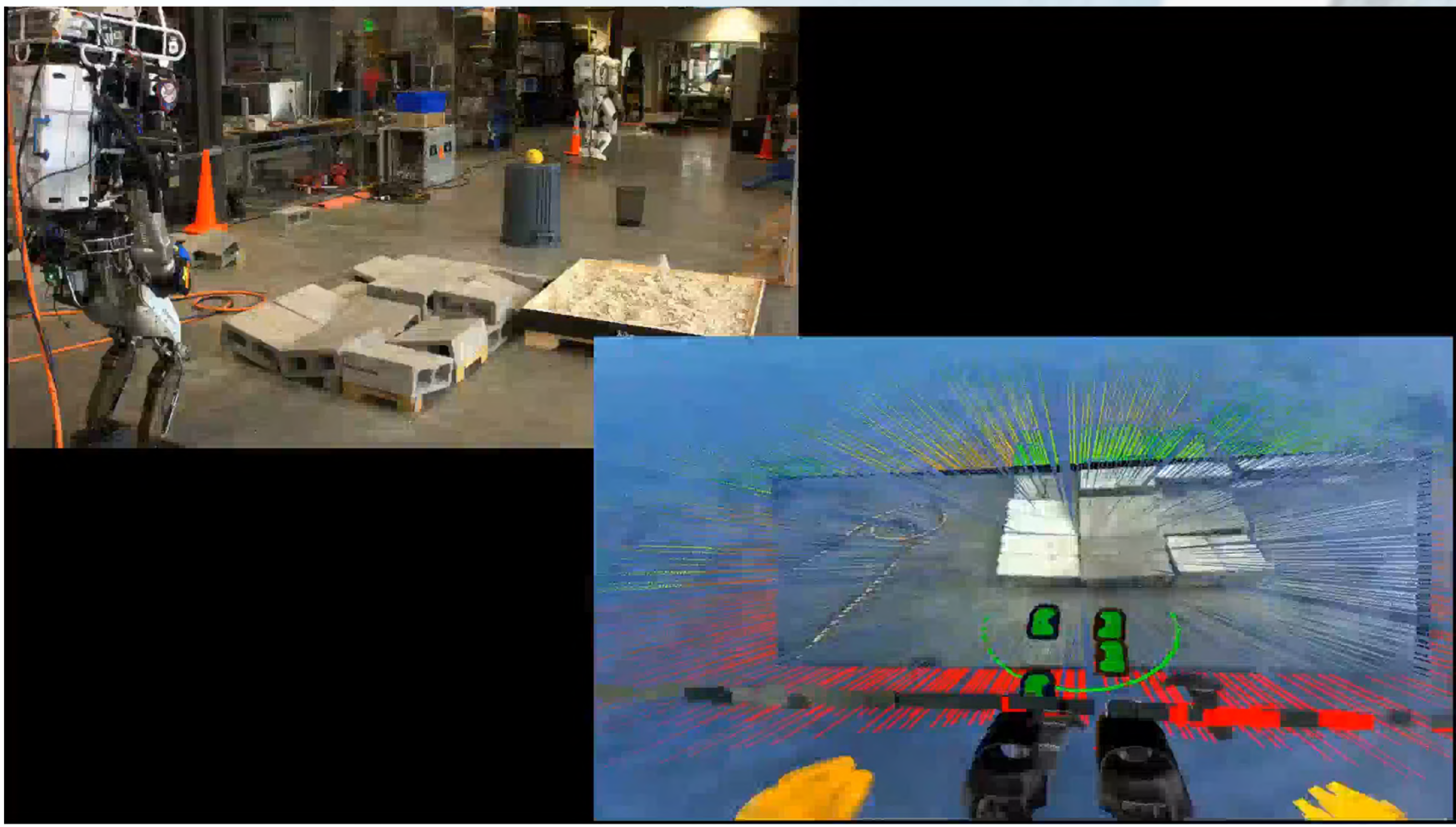
Atlas Avatar Rough Terrain and Ball Challenge: Placing Individual Footsteps.



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Marco Rubio: Humanoid Avatar Pioneer

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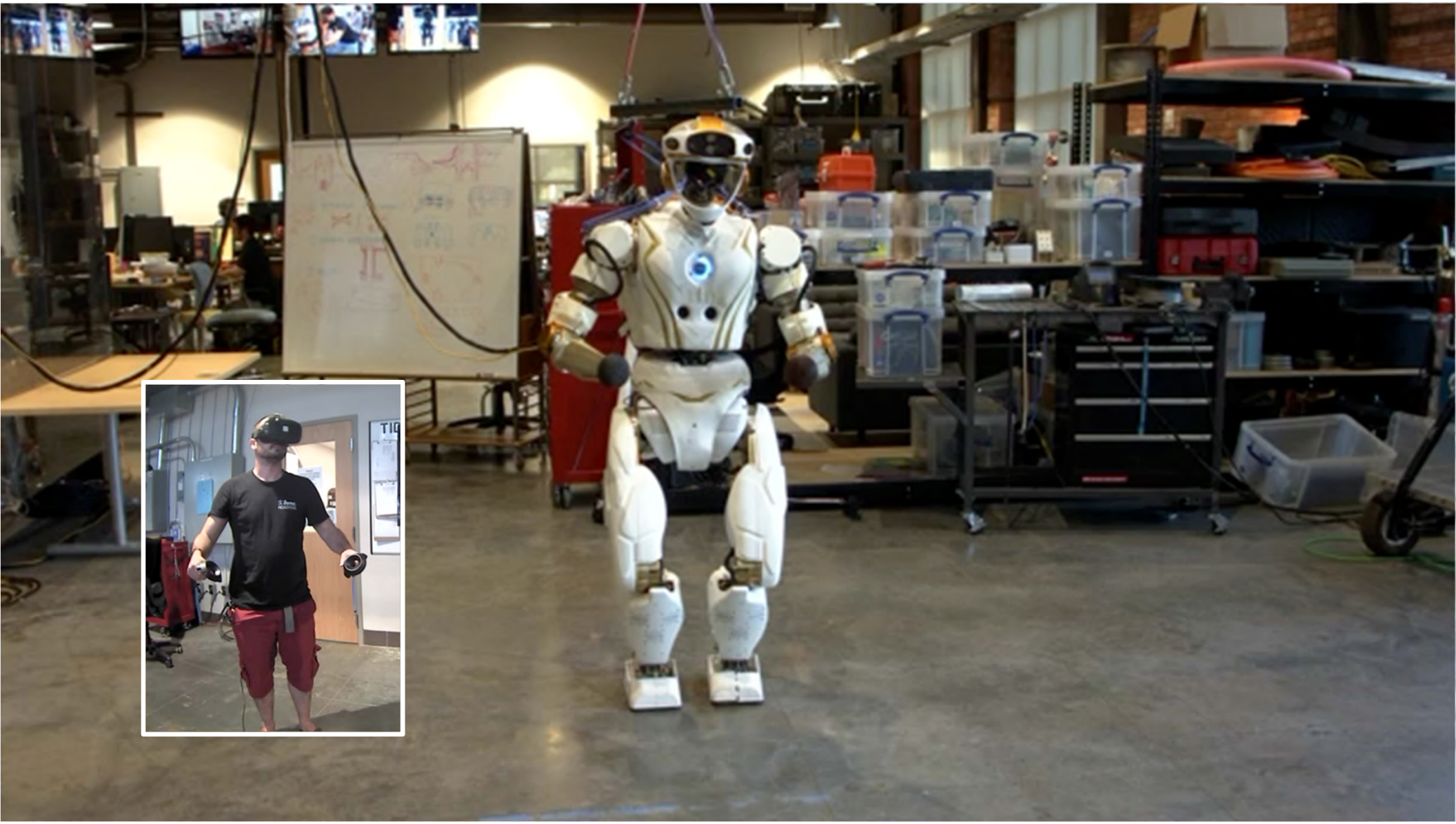
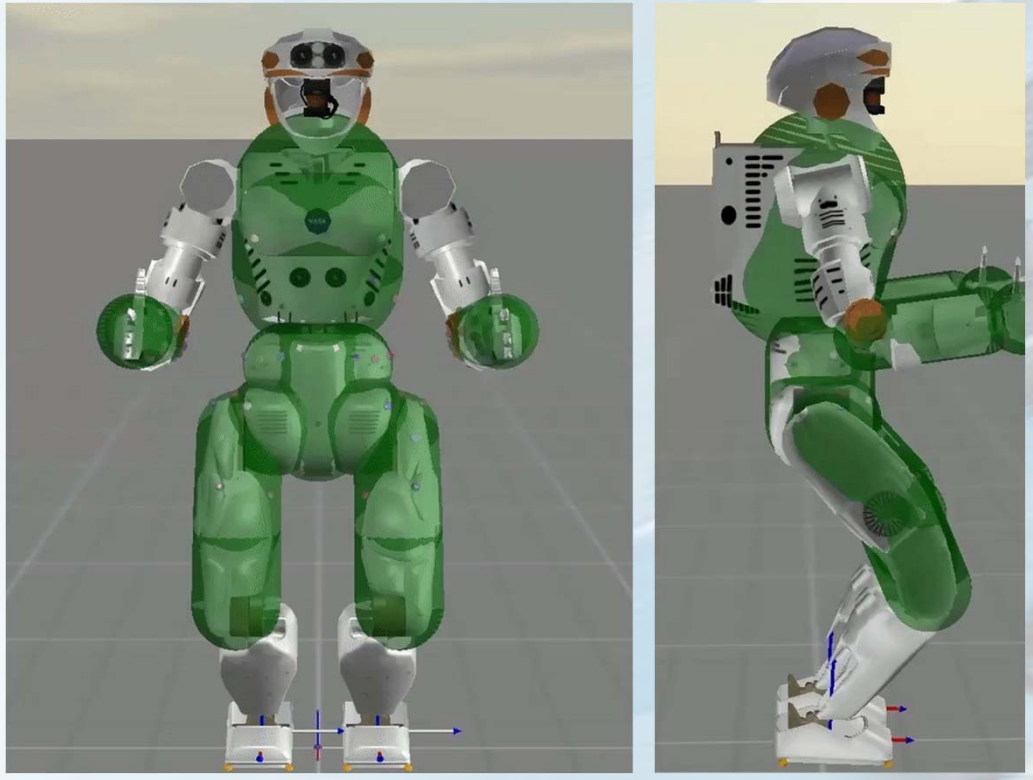


Whole Body Teleoperation

- VR interface
- Whole-body IK
- Balance
- Collision Avoidance
- Joint Position and Velocity Limits
- Streaming real-time



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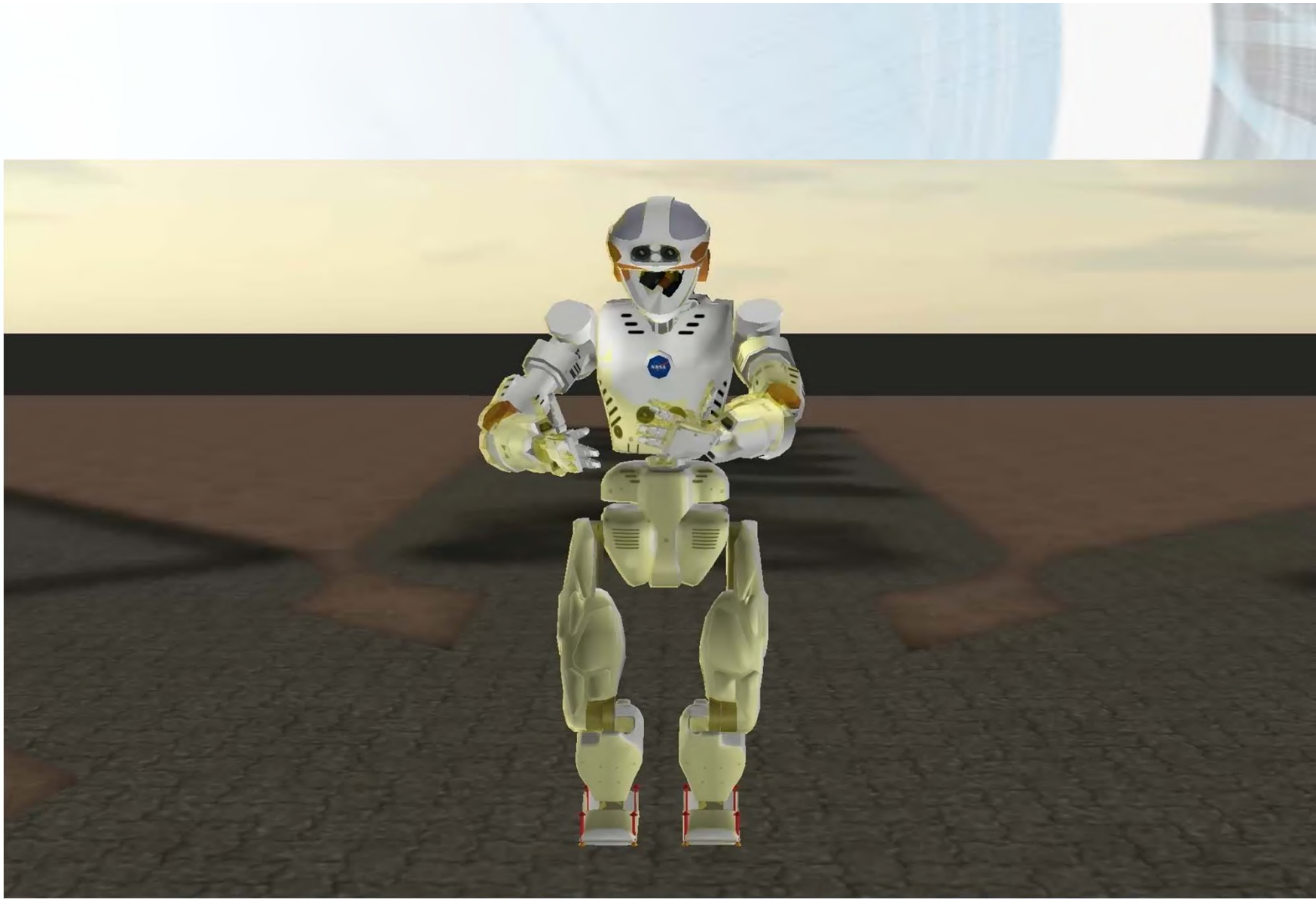

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Oculus Quest

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Humanoid

- Two legs, primarily for mobility.
- Two arms, primarily for manipulation.
- Head with vision, speech, hearing.
- Sense of gravity.
- Bipedal mode requiring active balance.
- Quadrupedal mode.

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Why Humanoid?

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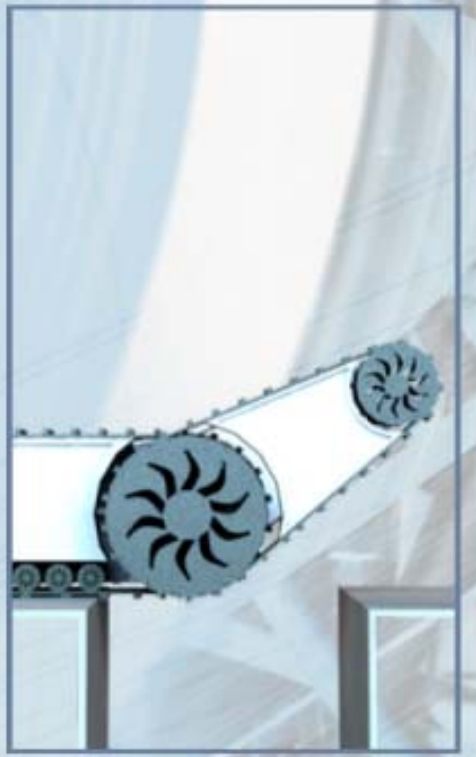
Go where people go and do what people do.

Gap Crossing



Leg Length	Leg Length	Wheel Radius	Track Length

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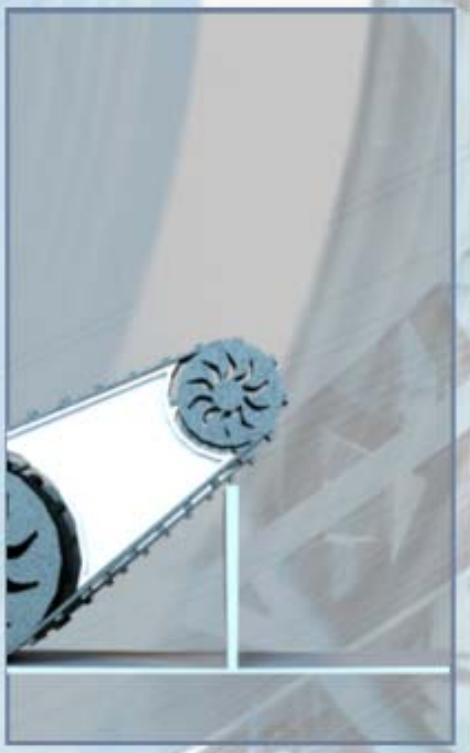
Long legs have long reach for large gap crossing.

Barriers



Leg Length	Leg Length	Wheel Radius	Track Height

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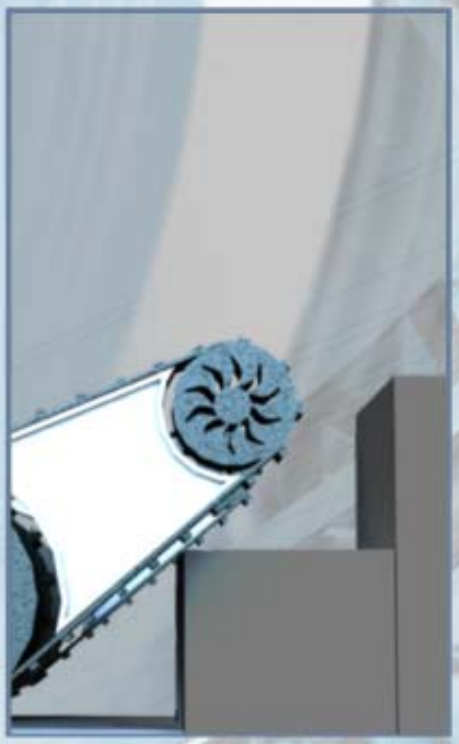
Long legs can get over large obstacles.

Steps



Leg Length	Leg Length	Wheel Radius	Track Height

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Long legs can get up high steps.

Slopes

Friction Angle	Friction Angle	Center of Mass	Center of Mass

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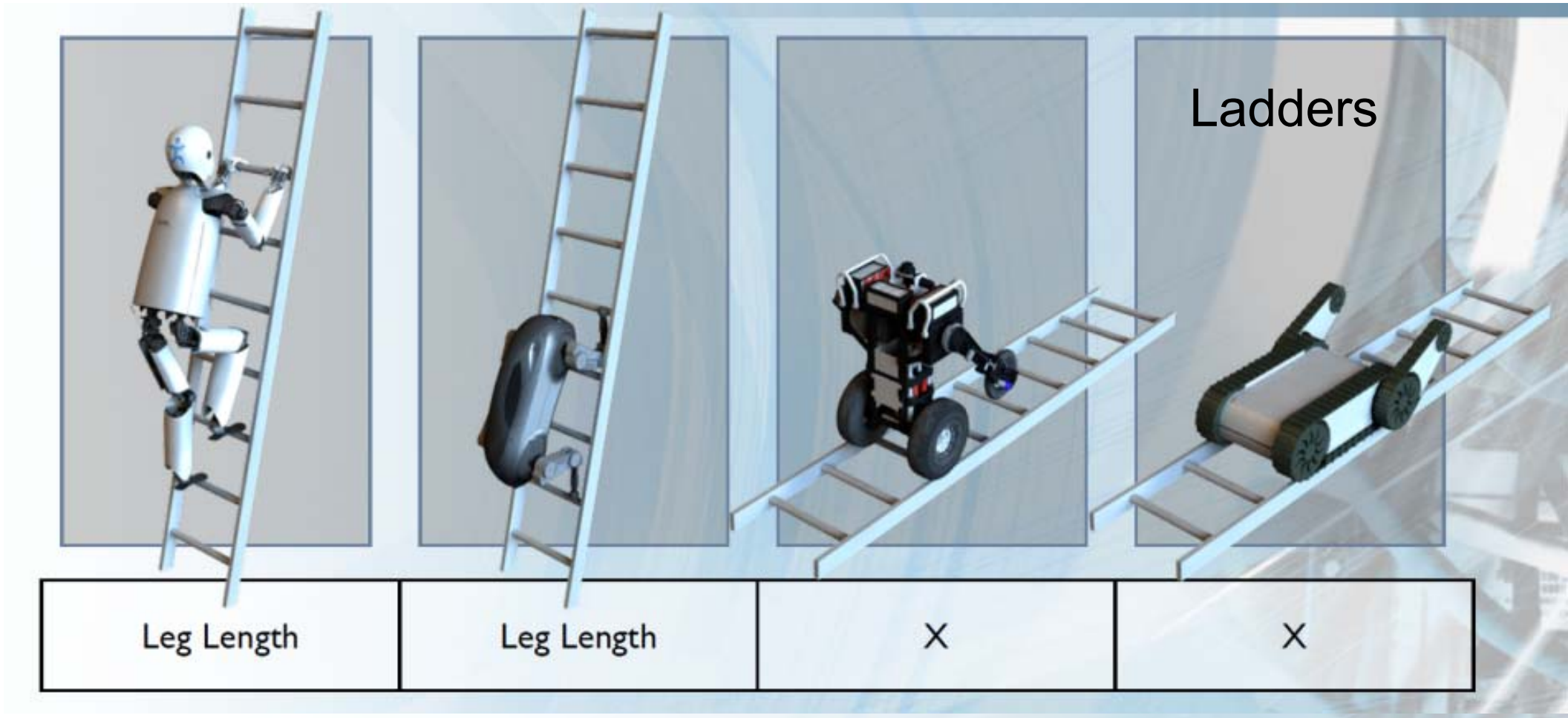
Legs, wheels, and tracks are all good at slopes.



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Two legs and two arms are great for ladders.

Yes, Dogs can climb ladders!

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Narrow Passages

Chest Thickness	Hip Width	Wheel Base	Track Base

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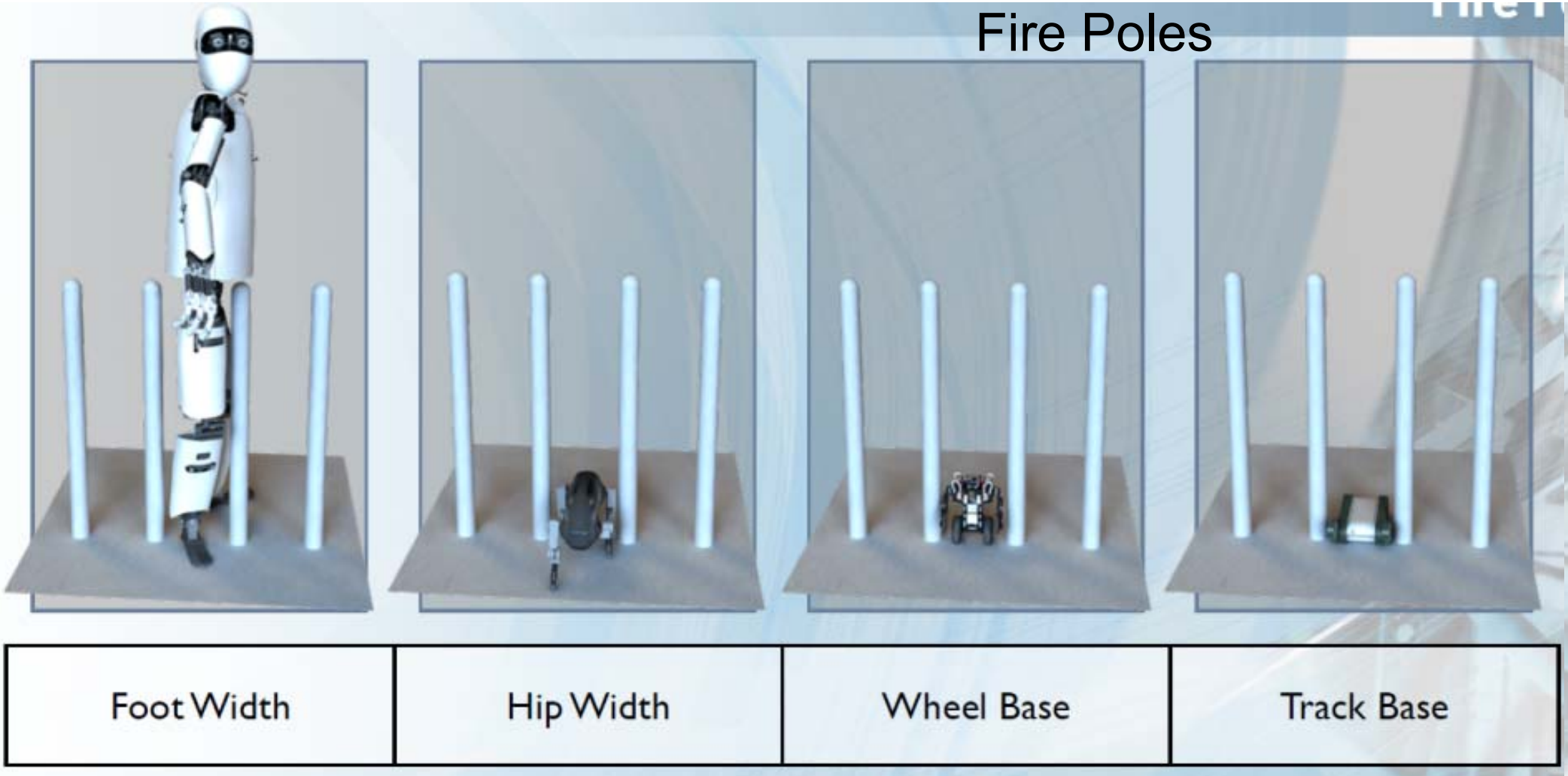
Skinny legs are great for narrow passages.

Fire Poles



Foot Width	Hip Width	Wheel Base	Track Base

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Skinny legs are great for narrow passages.

Balance Beam




Foot Width	Quad Support Width	Wheel Base	Track Base

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Narrow feet are great for narrow foot paths.

Yes, Dogs can walk over balance beams!

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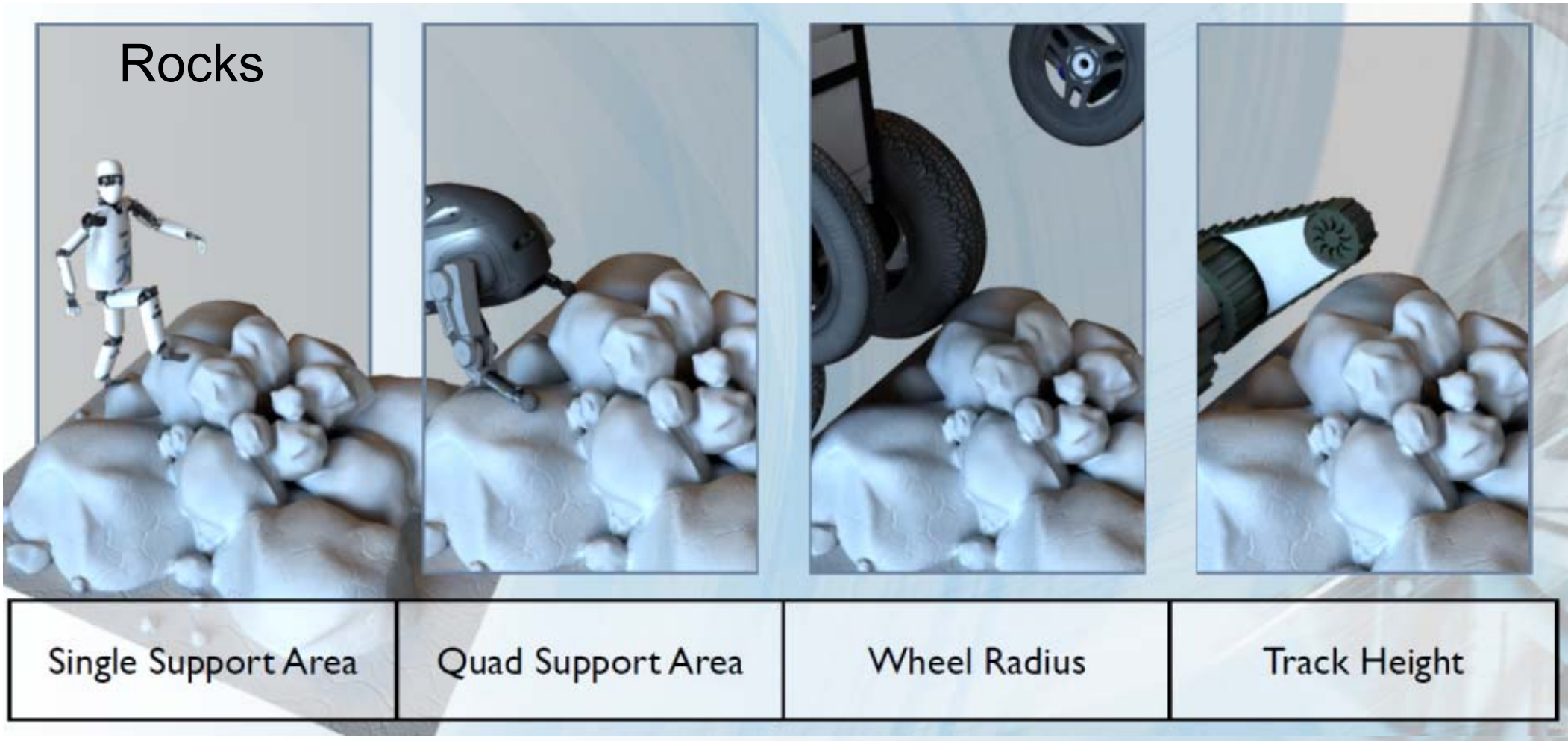

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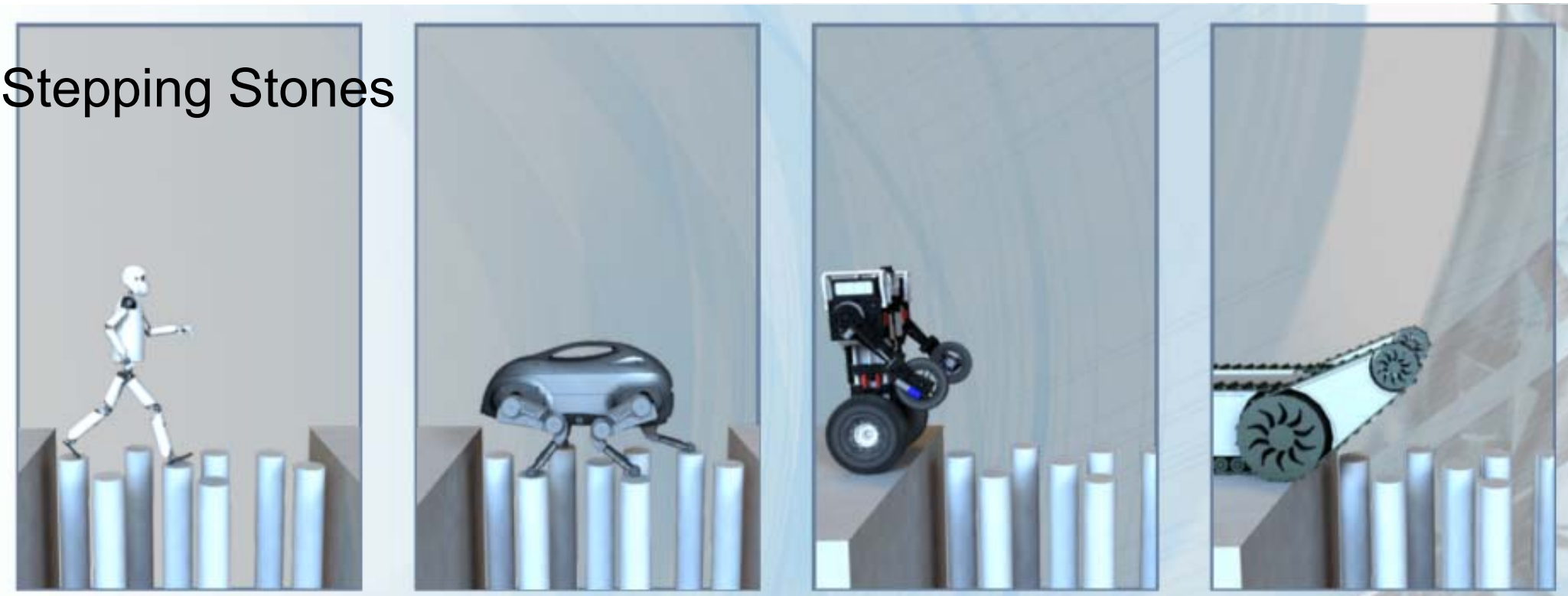
Small feet and long legs are good for non-continuous surfaces

Stepping Stones



Single Support Area	Quad Support Area	X	X

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Small feet and long legs are good for non-continuous surfaces

Corners

Shoulder Width	Length	Length/Width	Length

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Narrow body is good for corners

Under objects

Chest Thickness	Body Thickness	Wheel Diameter	Height

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Four appendages and narrow body is good for under objects

Reaching high places

Long legs and long arms are
good for reaching high places.

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Summary

	Biped	Quadruped	Wheeled	Track
Gap	Leg Length	Leg Length	Wheel Radius	Track Length
Barrier	Leg Length	Leg Length	Wheel Radius	Track Height
Step	Leg Length	Leg Length	Wheel Radius	Track Height
Slope	Friction	Friction	Center of Mass	Center of Mass
Ladder	Leg Length	Leg Length	X	X
Narrow Passage	Chest Thickness	Hip Width	Wheel Base	Track Base
Fire Poles	Foot Width	Hip Width	Wheel Base	Track Base
Balance Beam	Foot Width	Quad Support Width	Wheel Base	Track Base
Rocks	Single Support Area	Quad Support Area	Wheel Radius	Track Height
Stepping Stones	Single Support Area	Quad Support Area	X	X
Corner	Shoulder Width	Length	Length/Width	Length
Under Object	Chest Thickness	Body Thickness	Wheel Diameter	Height

Summary

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Legs are a good a general purpose solution with the potential to go where humans go and do what humans do.

Operation in a typical (disaster) environment

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Legs Require Active Balance Strategies

- Move Foot Center of Pressure
- Take a Step (Large change in Center of Pressure)
- Lunge Body or Windmill Arms (Use rotational momentum)

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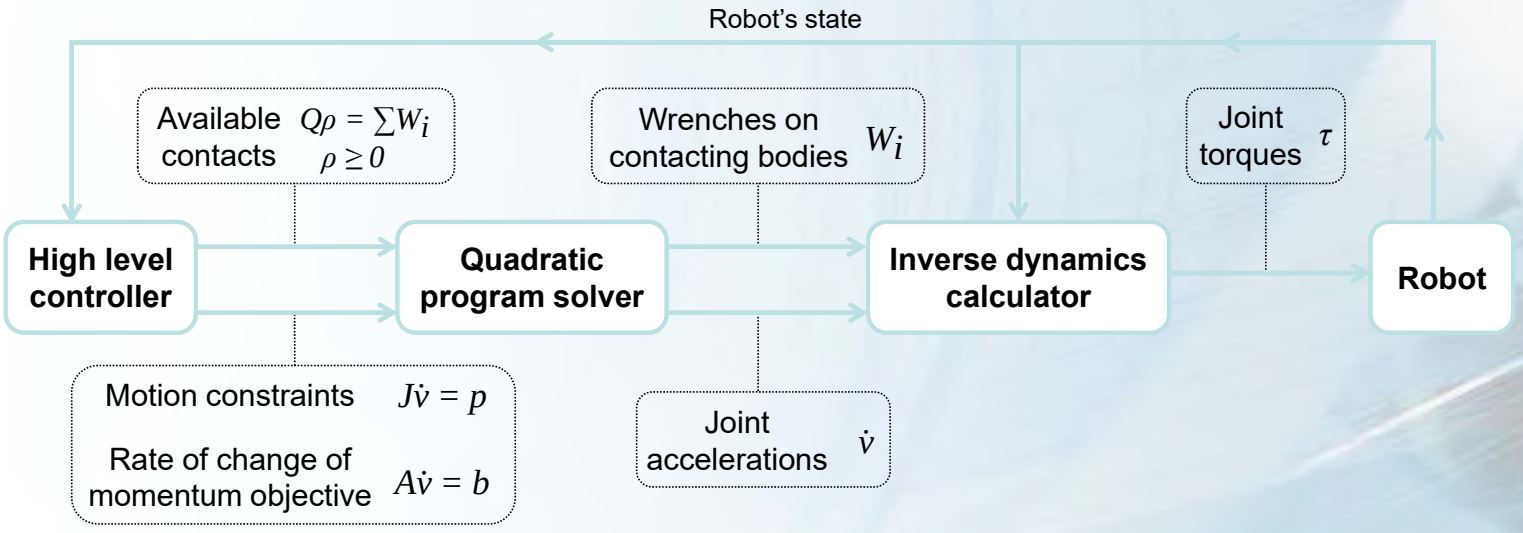
Whole Body Motion Control Framework



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Atlas Walking over Large Rocks

(4x speedup)

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Atlas Balancing on side of Piece of Plywood

(Realtime)

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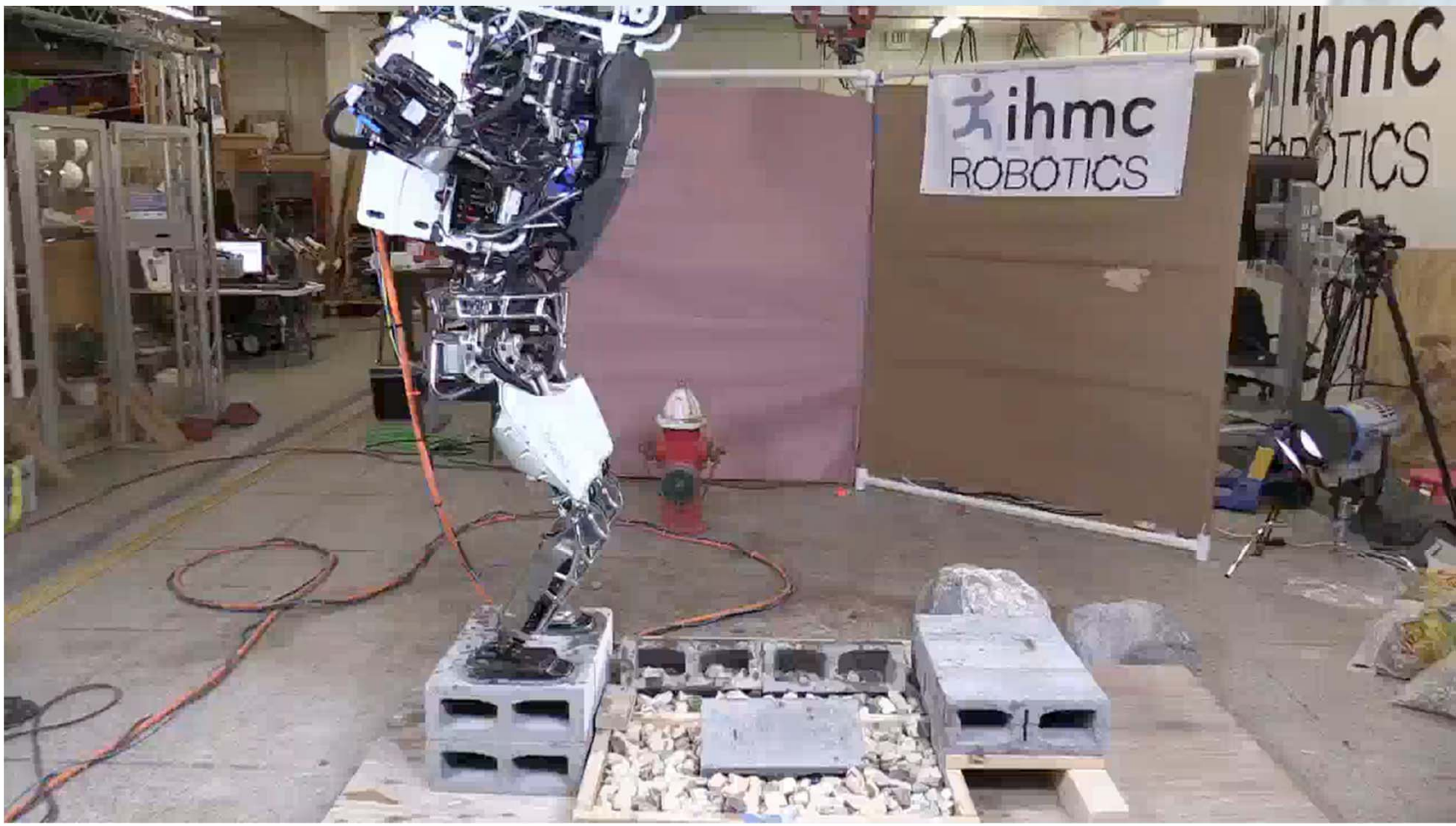
Walking Over Sideways Cinder Blocks



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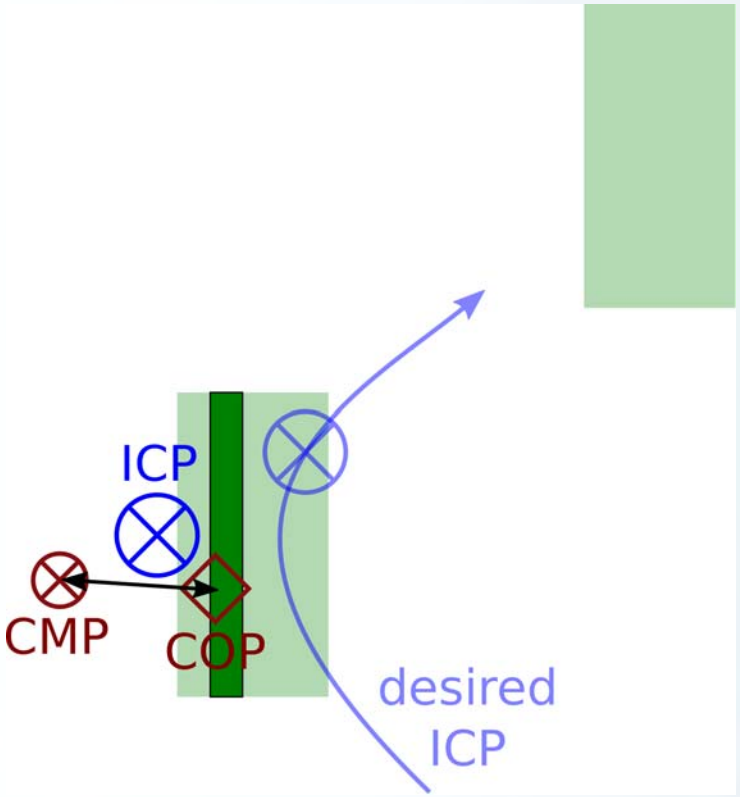
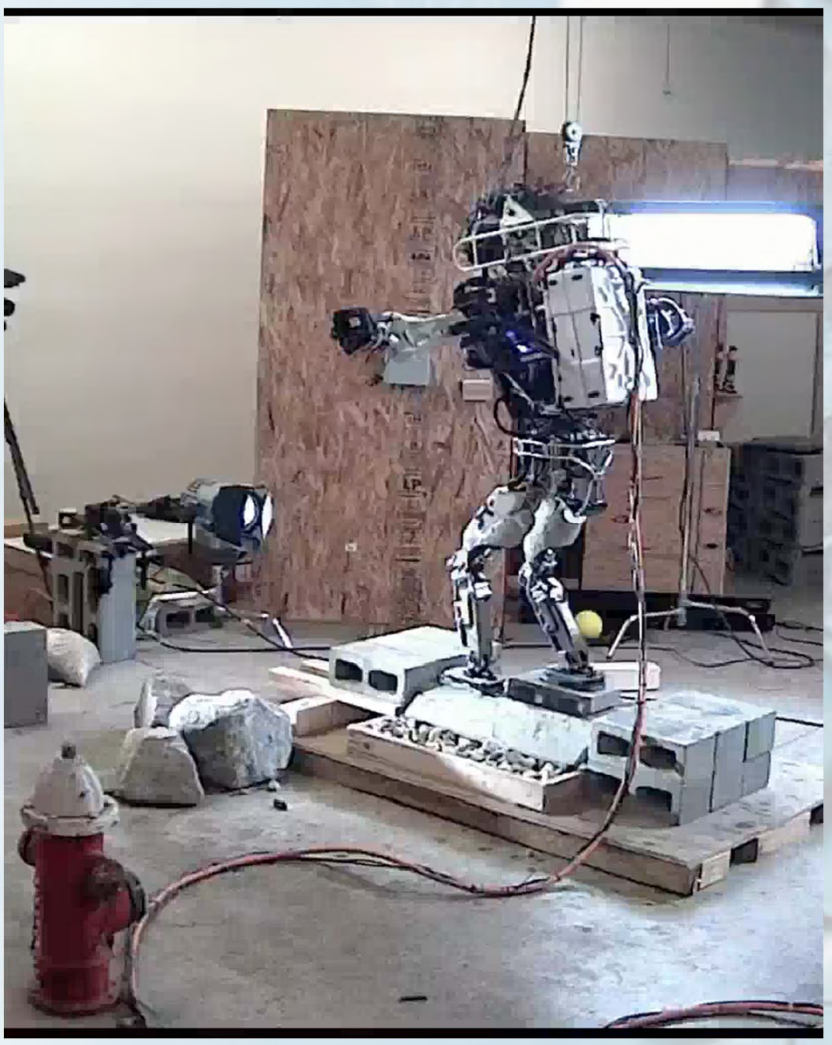
Balance Using Angular Momentum





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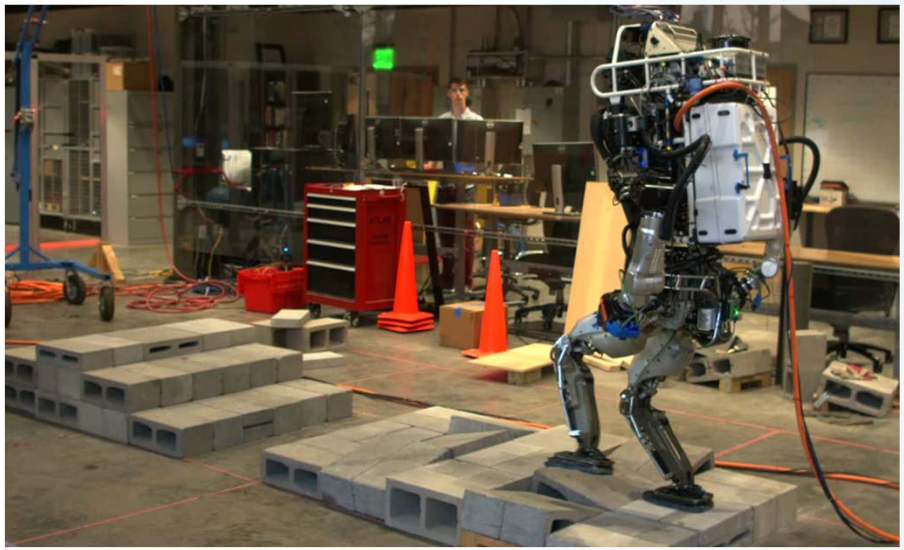
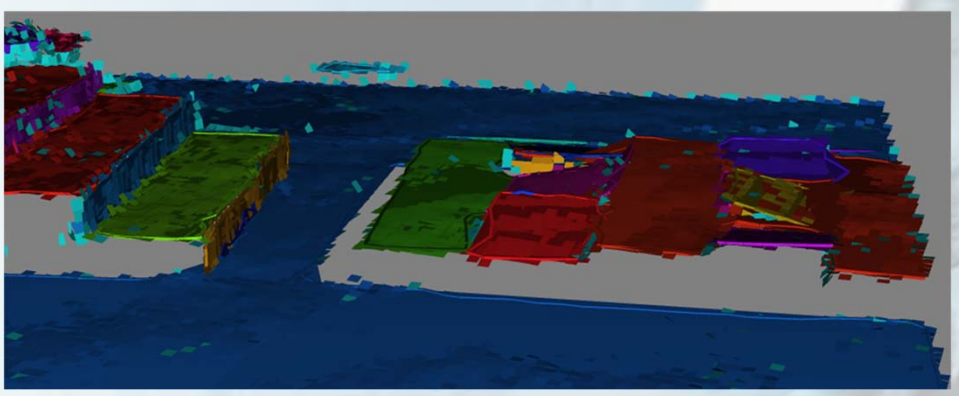
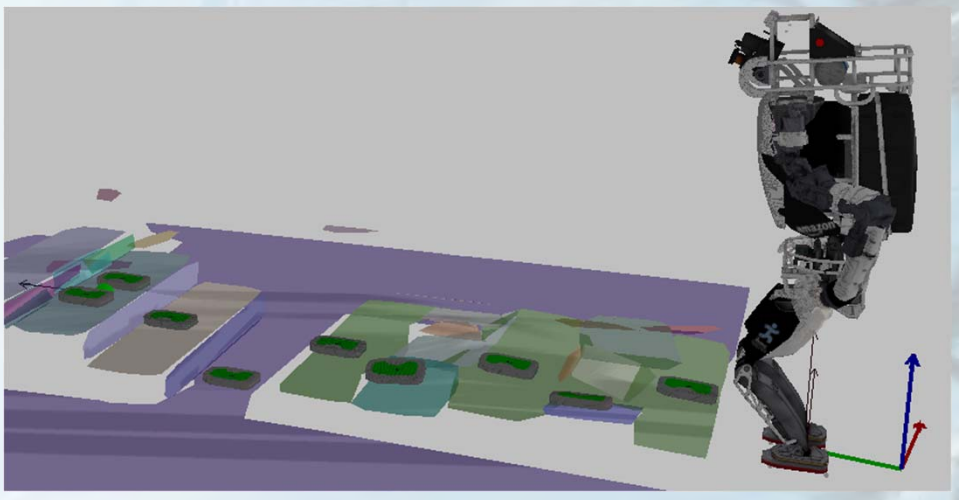
Body Path and Footstep Planning







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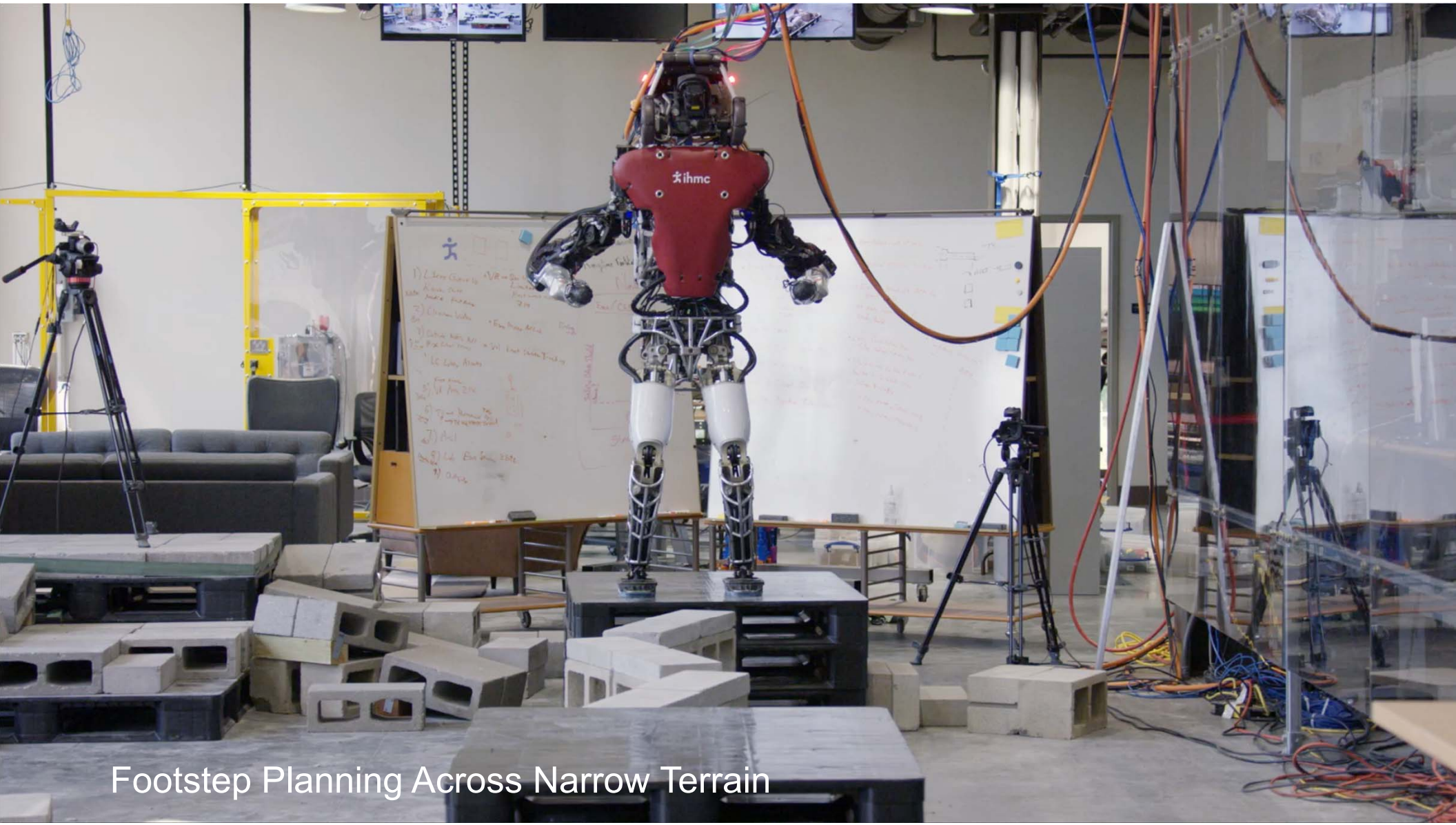
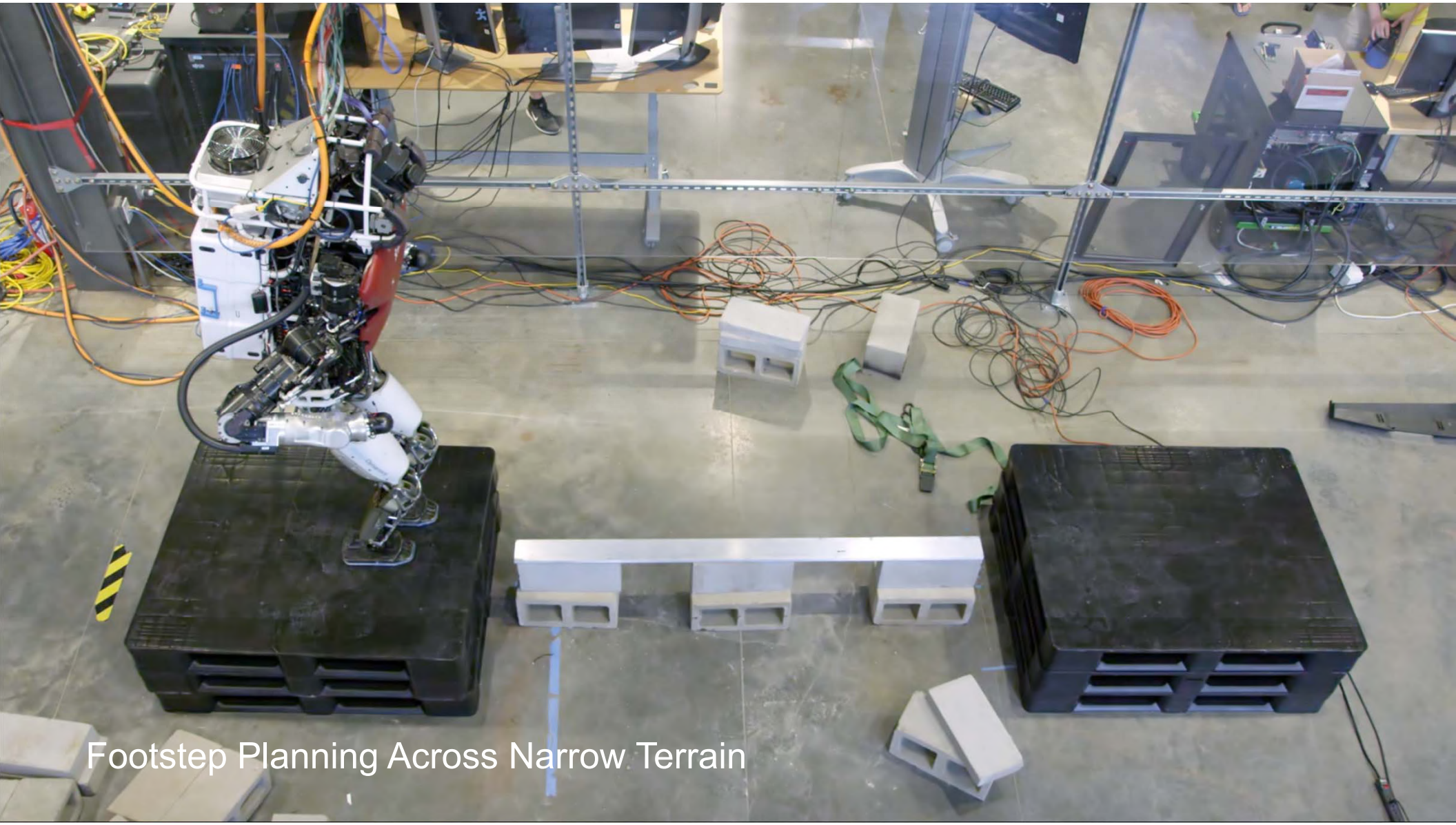
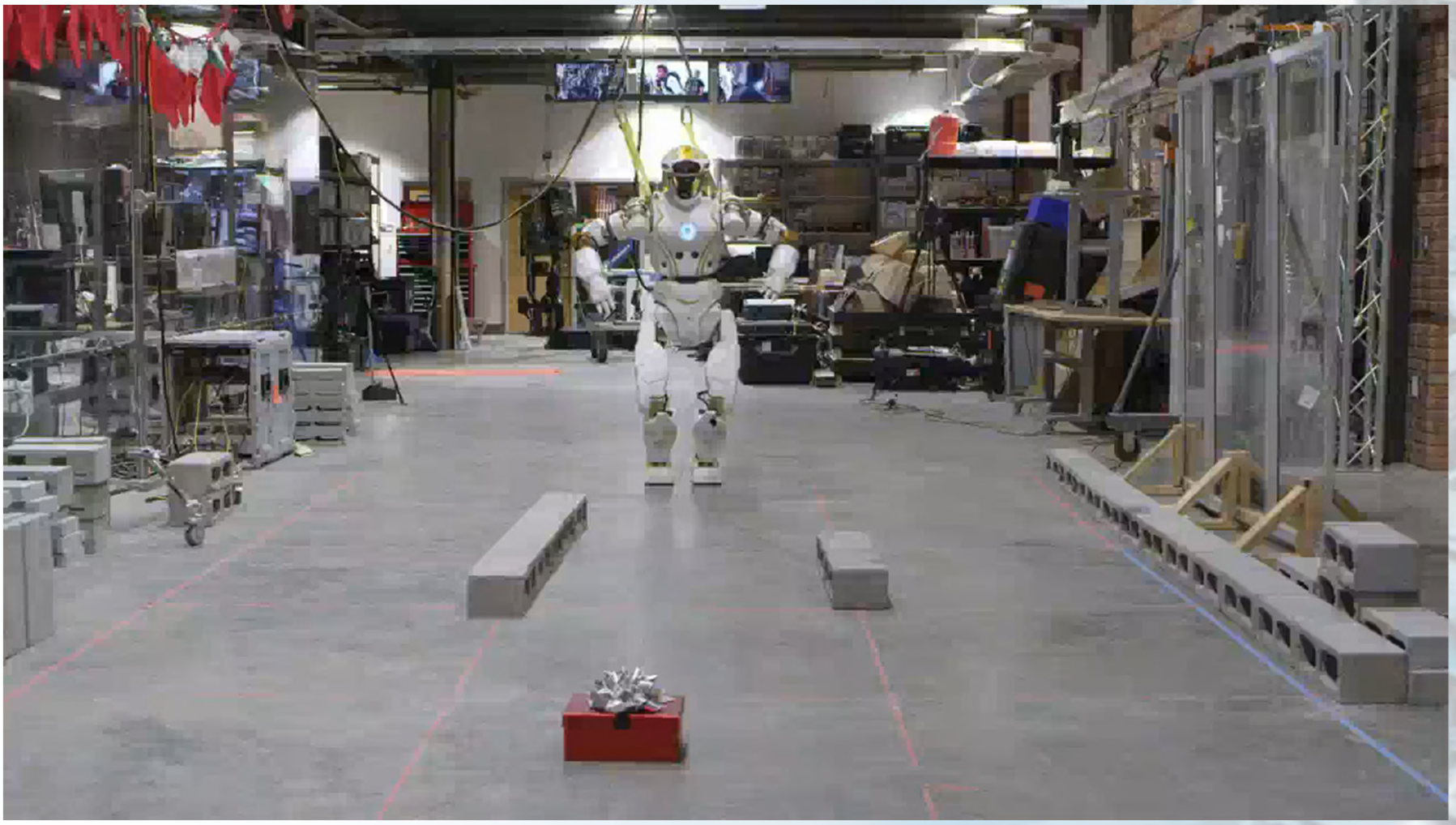


Footstep Planning Across Narrow Terrain


Footstep Planning Across Narrow Terrain

Footstep Planning Over Rough Terrain

(4x speedup)



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Potential Applications for Humanoid Avatar Robots






Require Human “Presence”, Dangerous, Expensive

Avatar system can achieve acceptable performance.

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Cooperative Humanoids for Construction?

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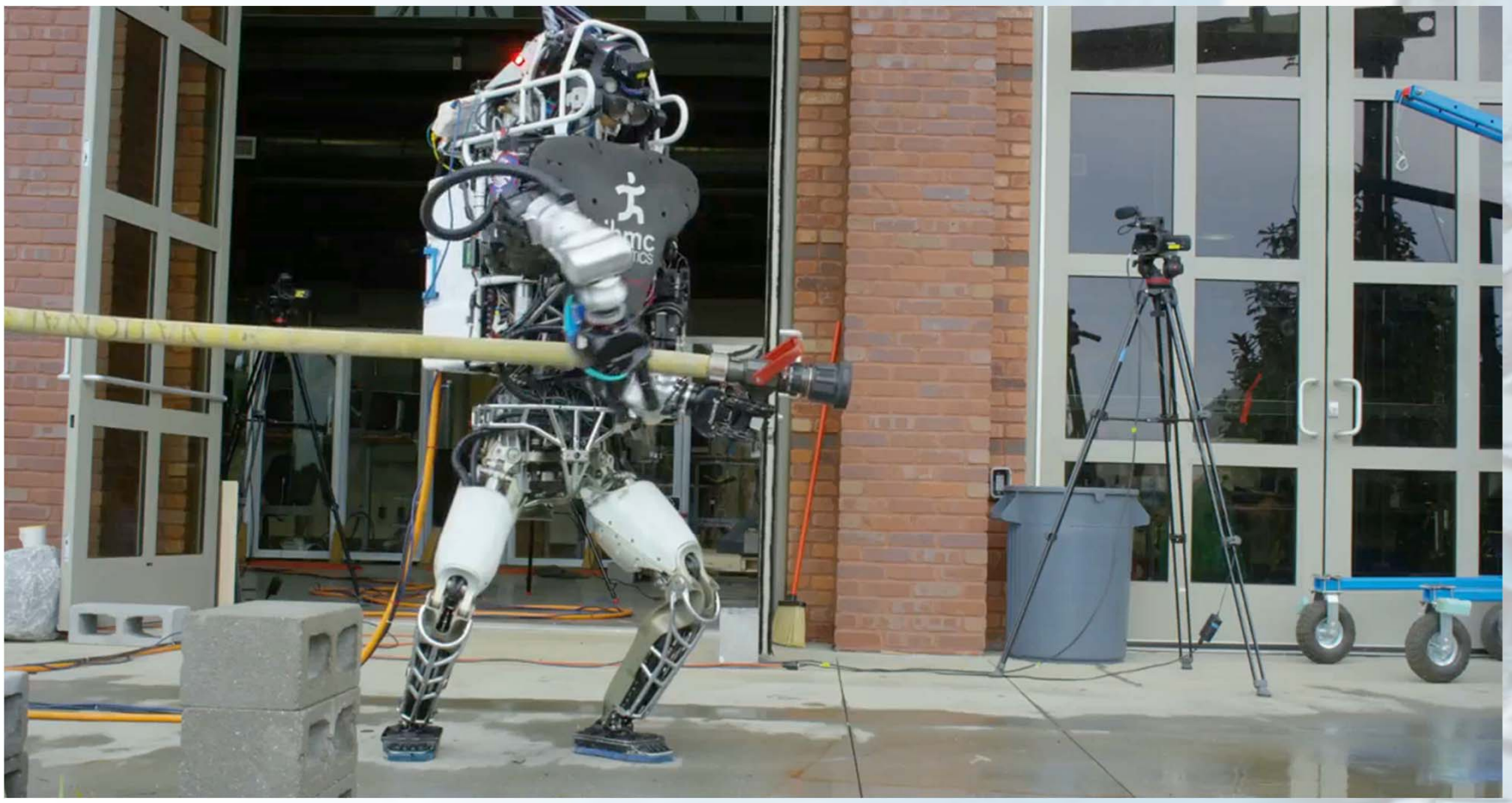
Firefighting Humanoid Avatars?

(Realtime)



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Shipboard Firefighting Humanoid Avatars?

(Realtime)

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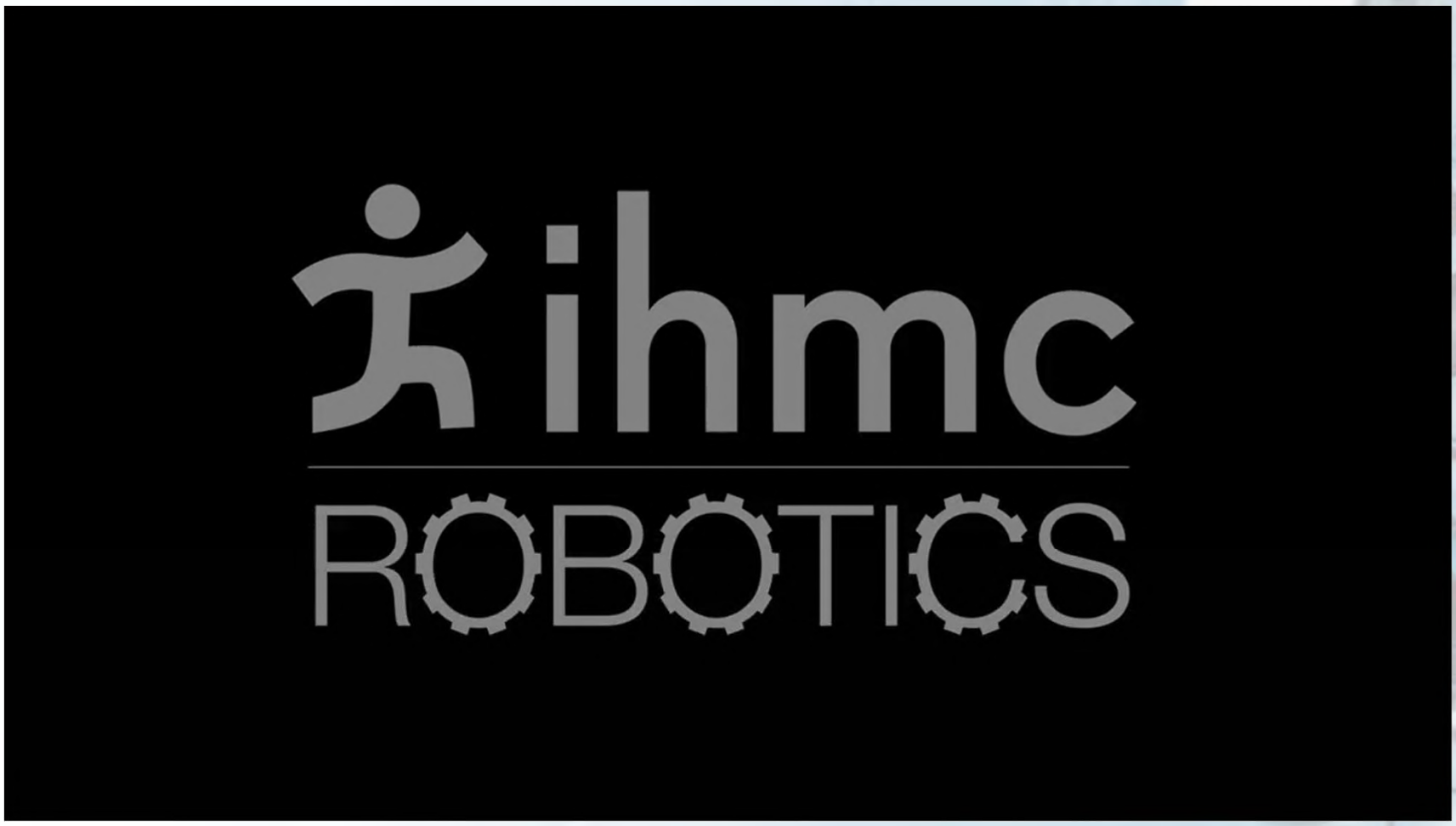
House Cleaning Humanoid Avatars?

(20x speedup)



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Entertainment Avatars?

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We have a long way to go to match human mobility!

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Enabling Trends

- Non-contact Sensors
- Computers
- Comms
- Perception
- Computer Vision
- Virtual Reality Interfaces
- Localization
- Mapping
- Obstacle Avoidance
- Deep Learning and Data Based Algorithms

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Major Challenges

- Actuators and Transmissions
- Mechanical Components
- Joint Designs
- Power Source
- Batteries
- Skin Sensing
- Robust Hands

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My Humanoids Wish List

- Actuators
  - More speed and torque.
  - Both high stiffness and low compliance.
  - High efficiency.
- Robot Structure
  - Survive self collisions. Survive falls.
  - Be able to load any part of the structure.
- Sensors
  - Foot pressure sensors that can detect ground “image”.
  - Skin sensors that can detect interaction forces.
  - Improved joint velocity sensors.
- Joint Designs
  - High range of motion
  - Compact

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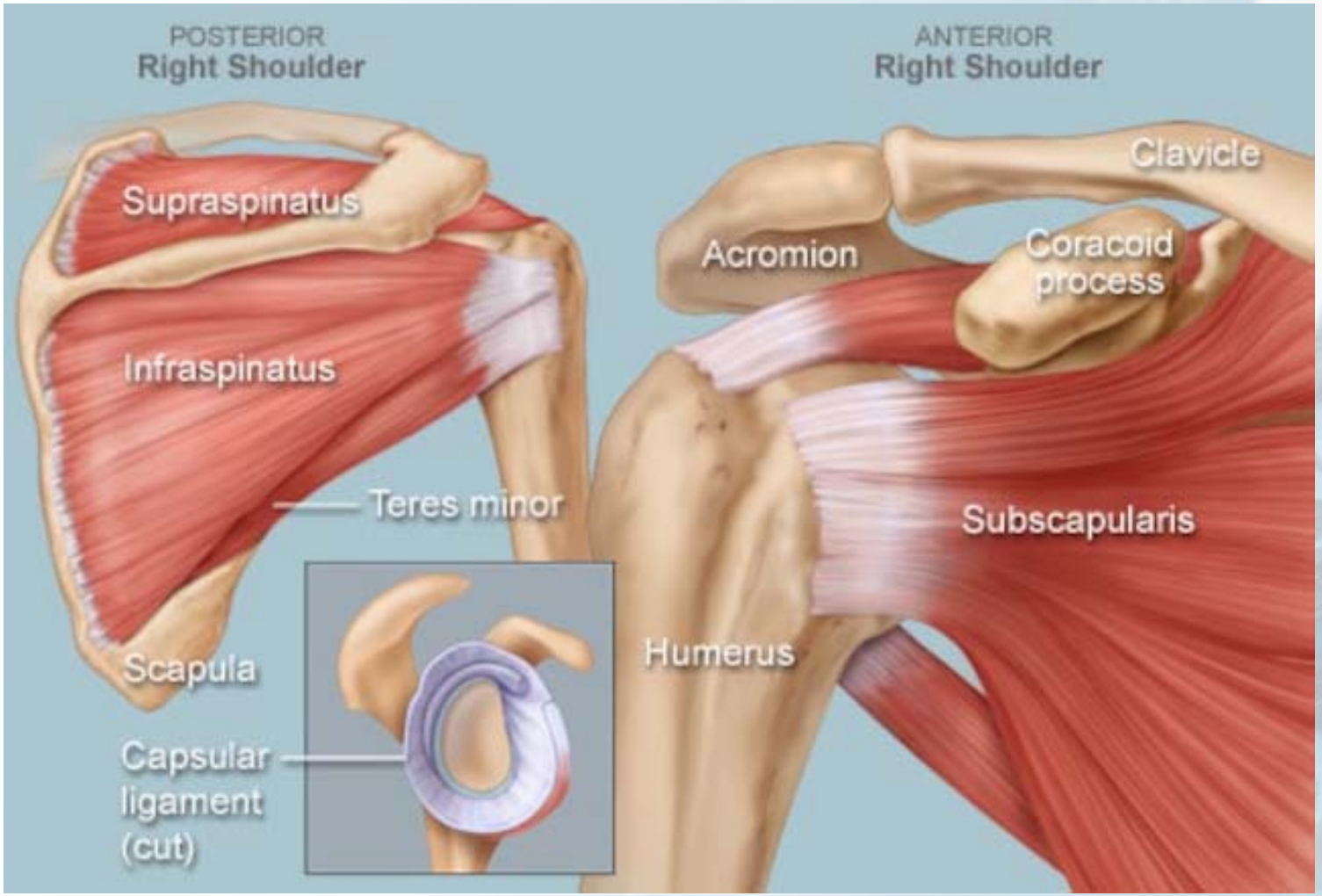
Challenge: Actuation Packaging and Joint Range of Motion



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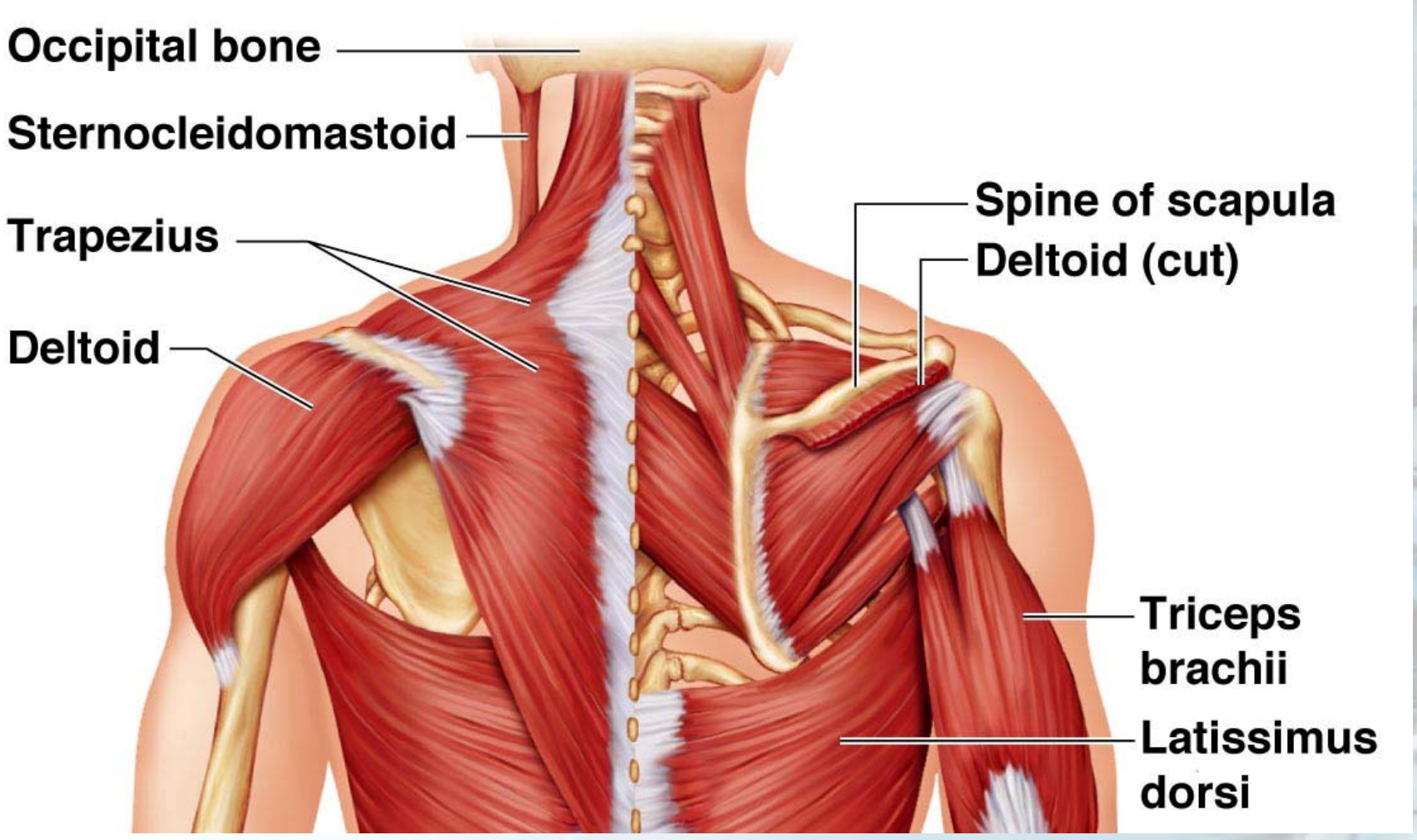
Occipital bone
Sternocleidomastoid
Trapezius
Deltoid
Spine of scapula
Deltoid (cut)
Triceps brachii
Latissimus dorsi

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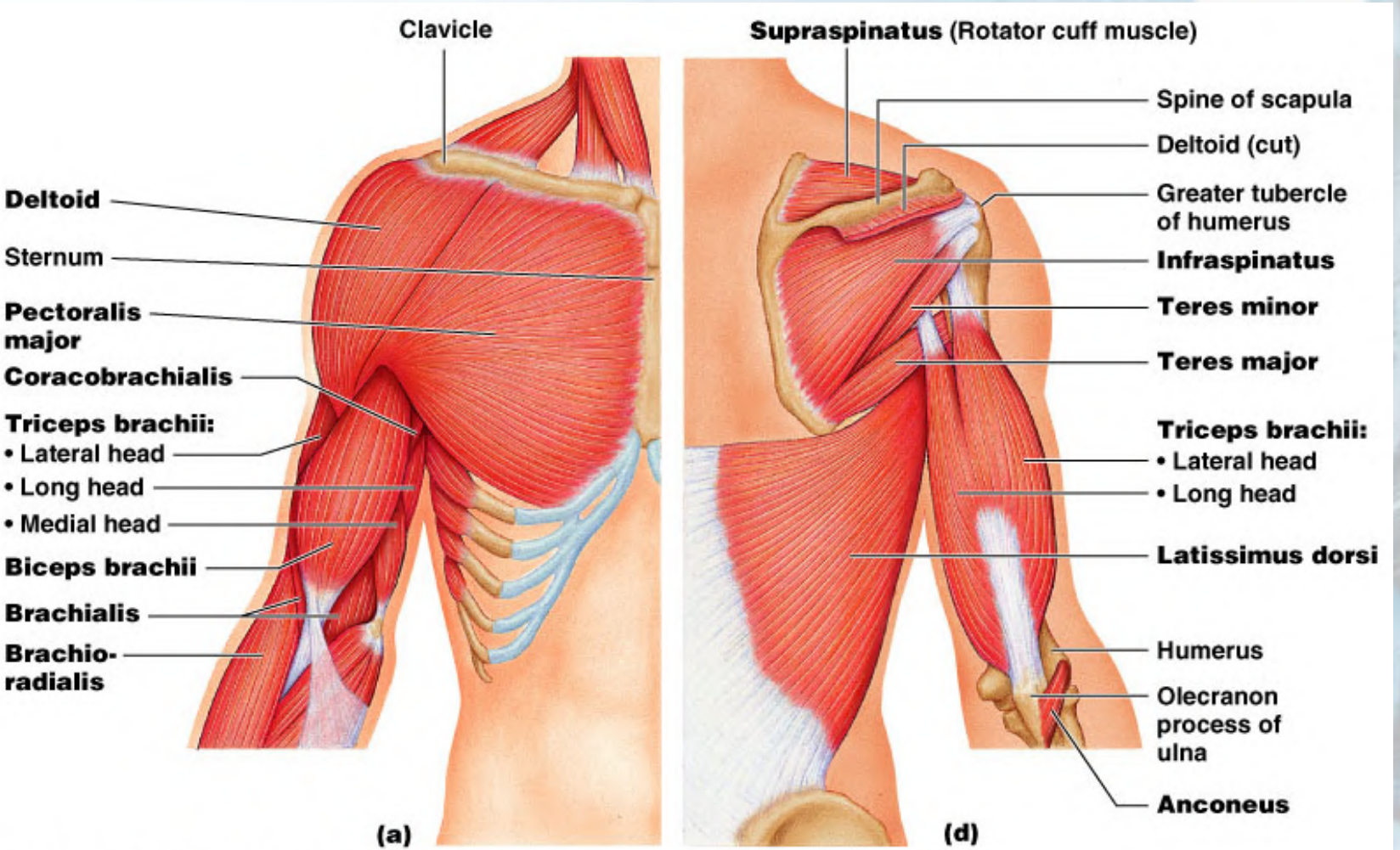

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Can we build a humanoid gymnast?

- Degrees of freedom
- Joint range of motion
- Power
- Weight
- Volume

Victor Ragusila

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Can we build a humanoid gymnast?

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Victor Ragusila

Sebastian Sanchez

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New Humanoid “Nadia” Mockup

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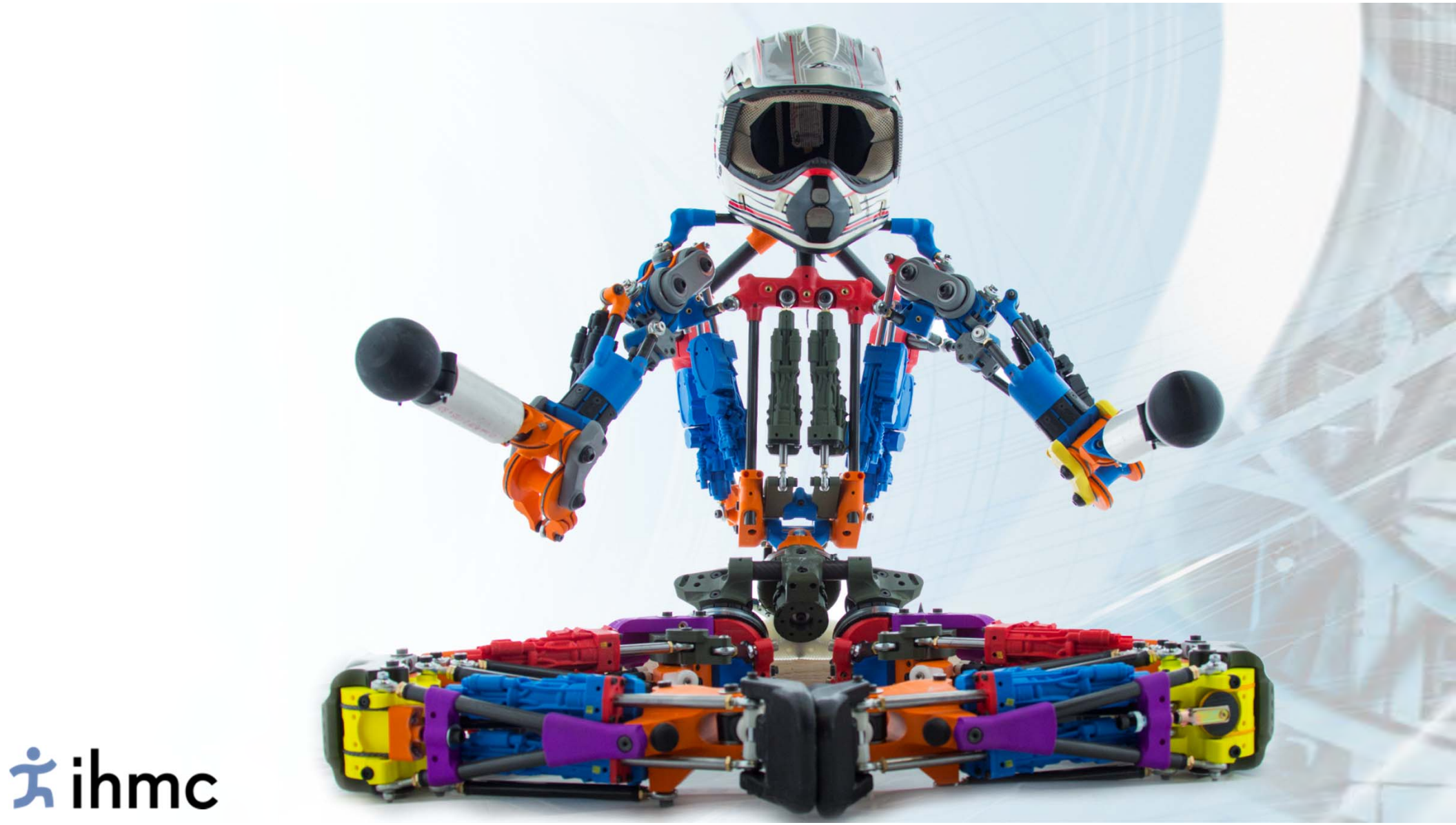
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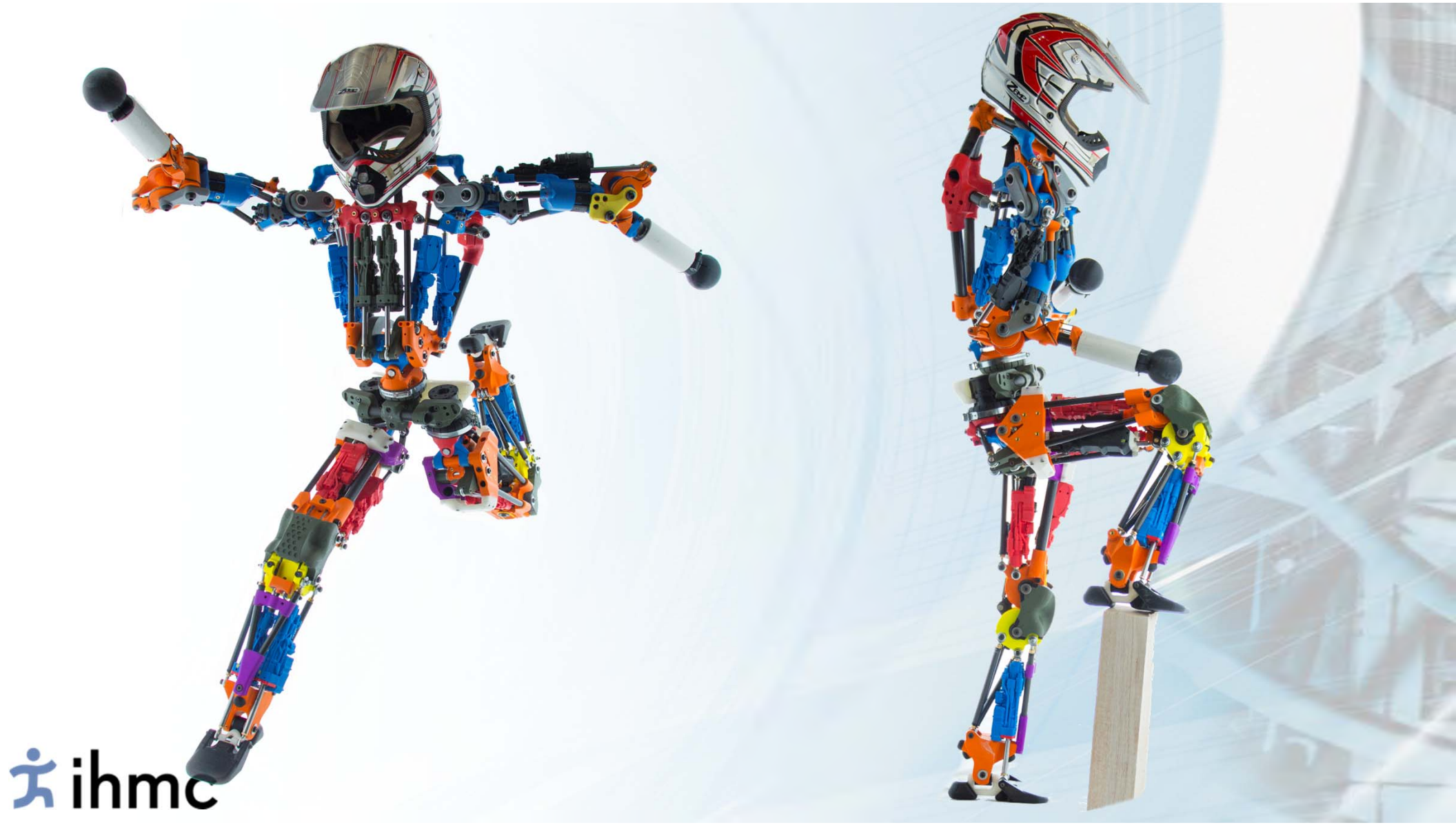
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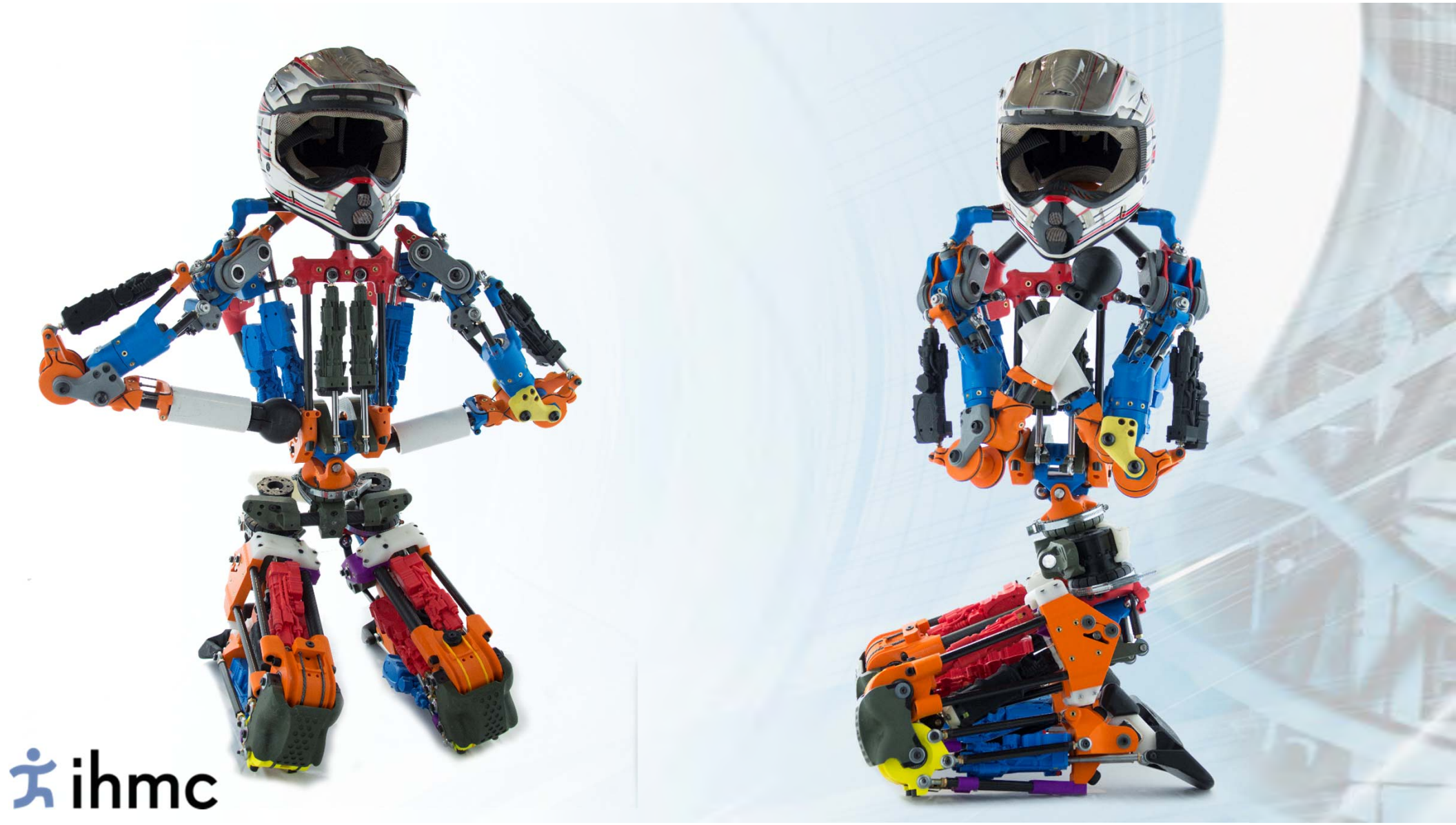
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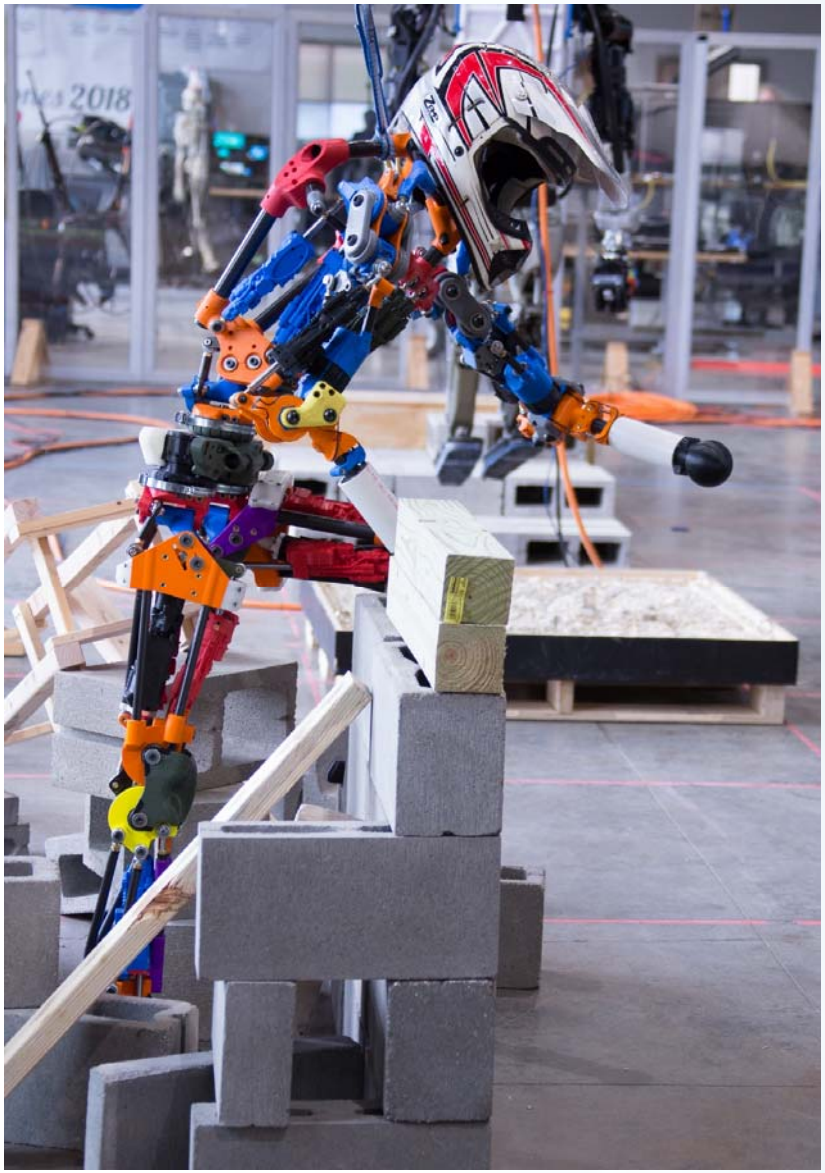

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Moog Integrated Smart Actuator

- Piston
- Position Sensor
- Pressure Sensors
- Force Sensor
- Electronics
- IMU
- Local Control System

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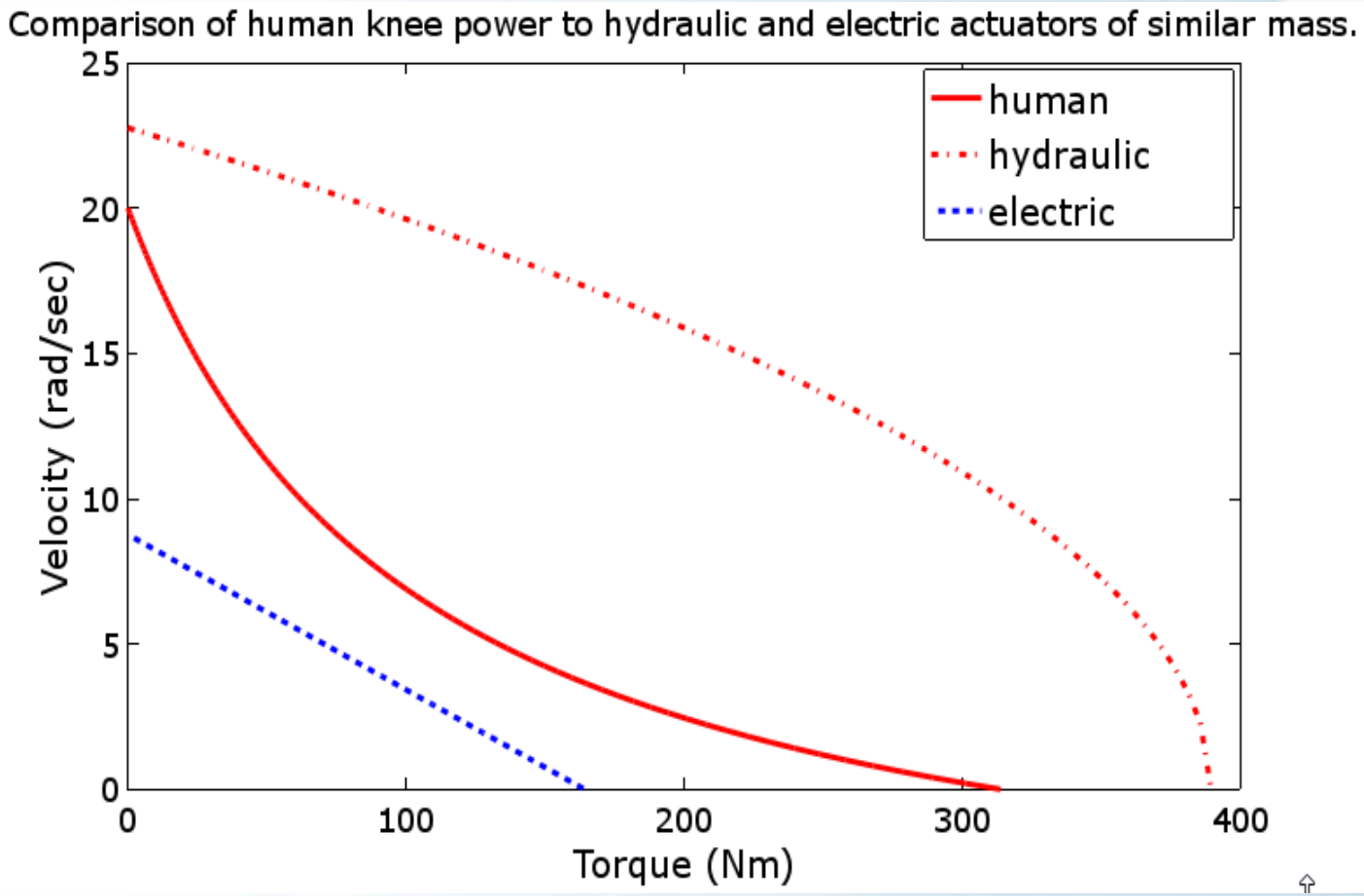
Hydraulic Actuation-> High Power to Weight



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Can we build a humanoid gymnast?

- Degrees of freedom
- Joint range of motion
- Power
- Weight
- Volume

No! But we can move *towards* the goal.

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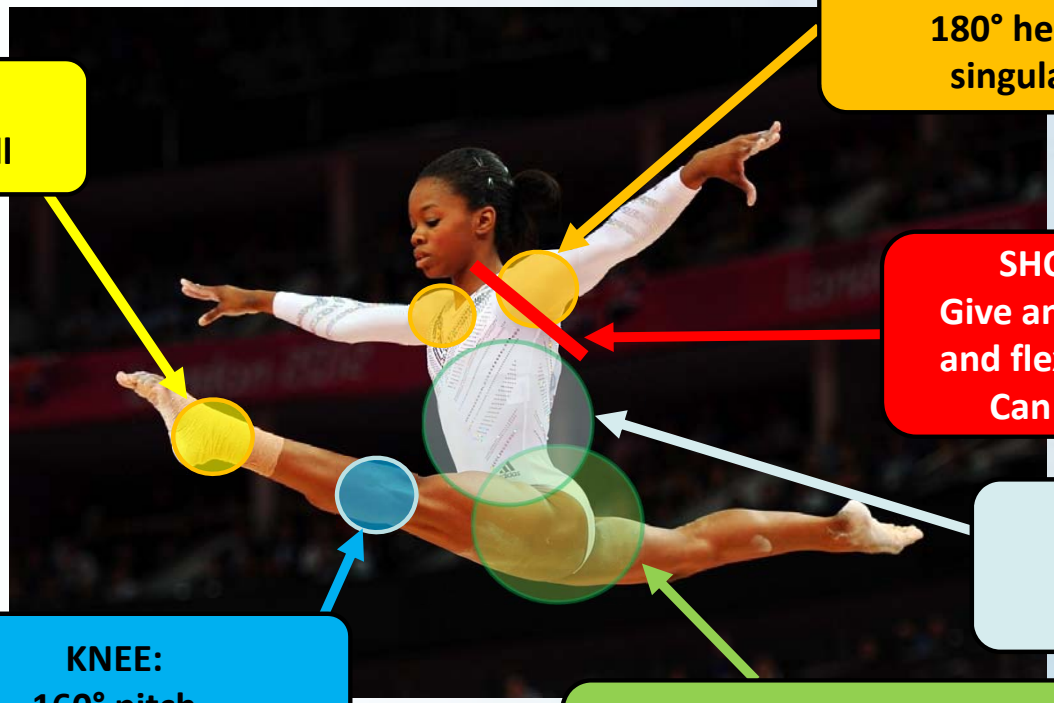
Humans are flexible



SHOULDER:
180° hemisphere,
singularity free

ANKLE:
100° pitch, ±45° roll

SHOULDER MOUNT:
Give another 60° abduction and flexion to the shoulder.
Can be used to crawl.

Torso :
140° pitch, ±45° roll/yaw

KNEE:
160° pitch

HIP :
180° pitch, ±45° roll, ±60° yaw

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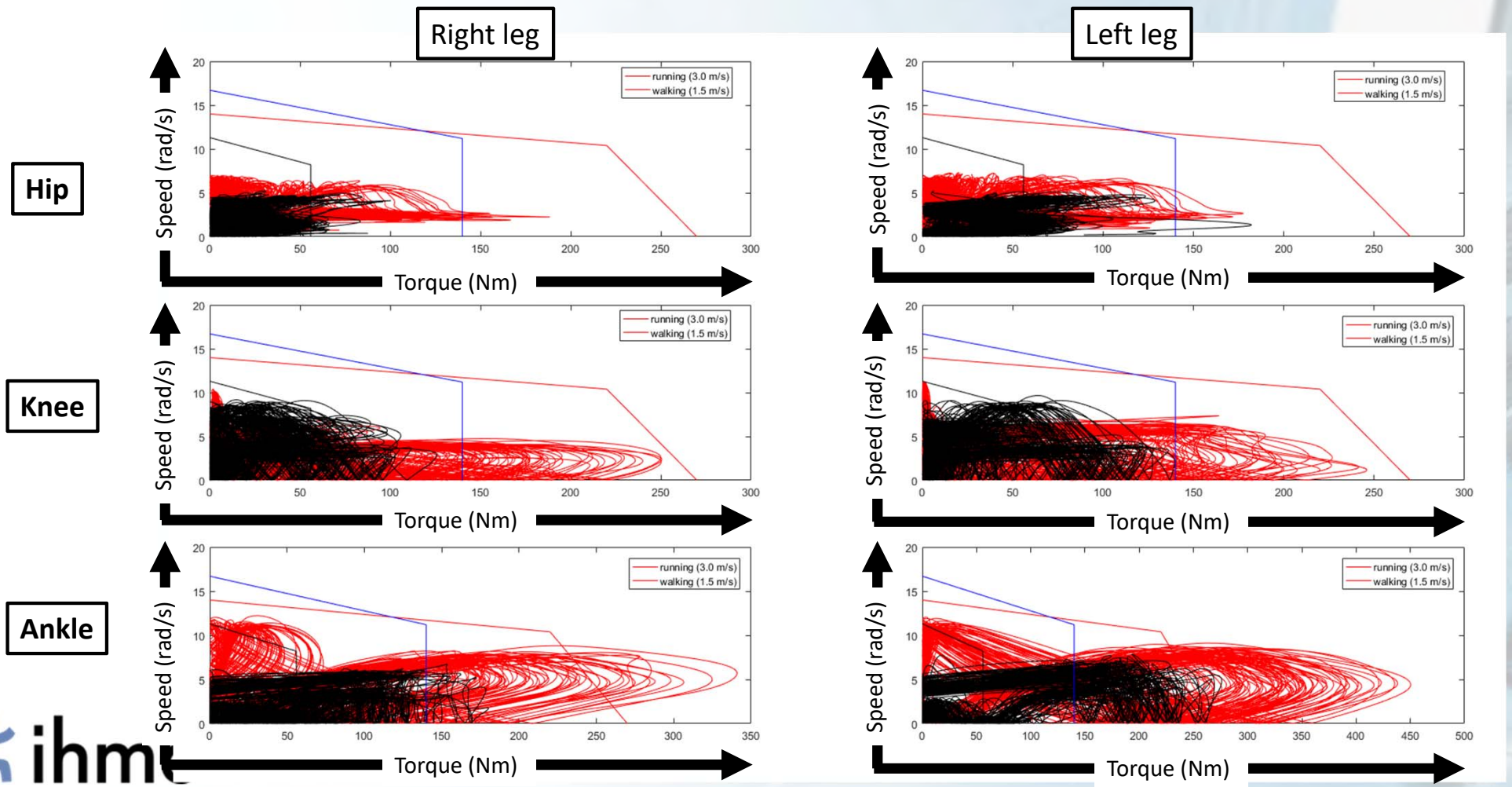
Humans are strong and fast!



Rapid Design Iterations

Quick mechanical iteration using 3D printed prototypes.

- Test multiple ideas quickly, “cheaply”.
- Catch mistakes early, try risky designs.
- Allows much more intuitive understanding of design than CAD.
- Can test in real world scenarios.

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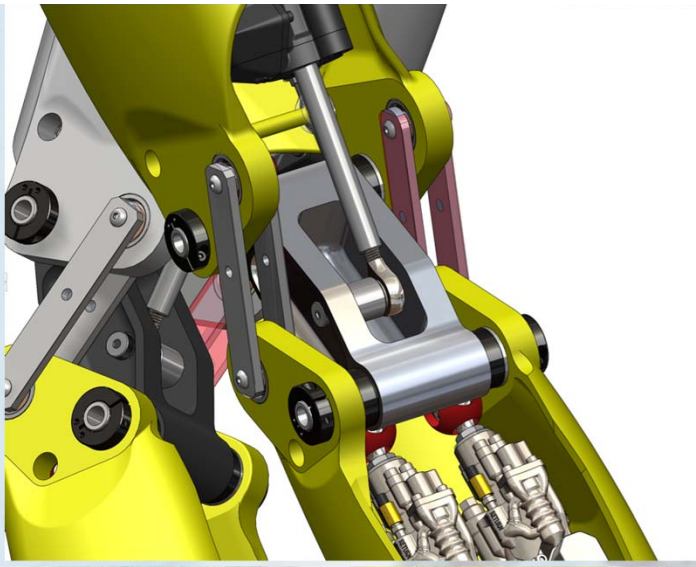
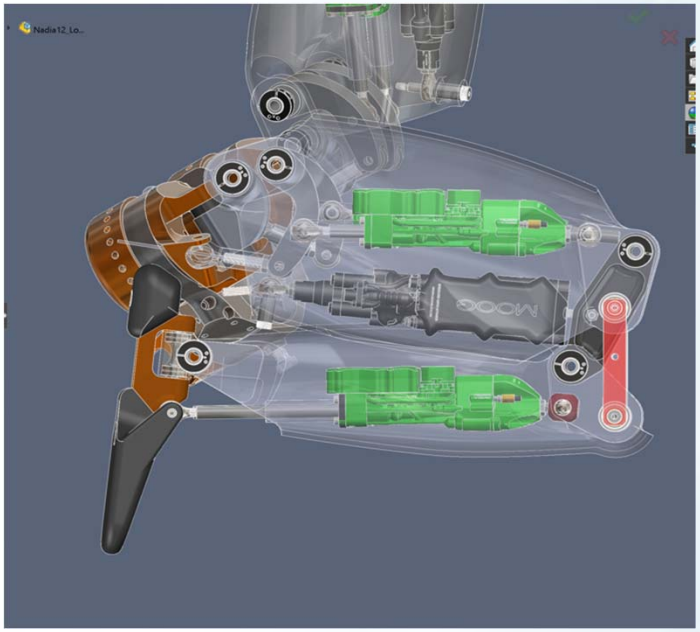
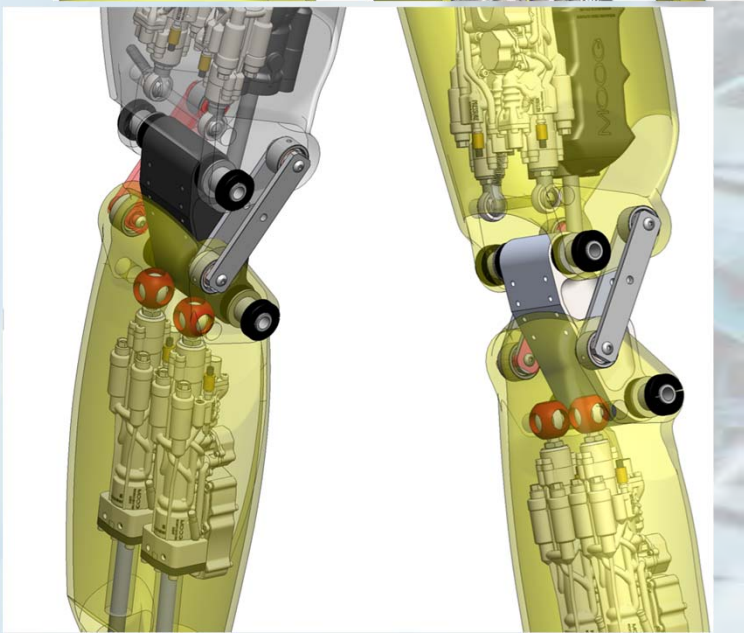
Leg Overview: Knee Cross Linkage







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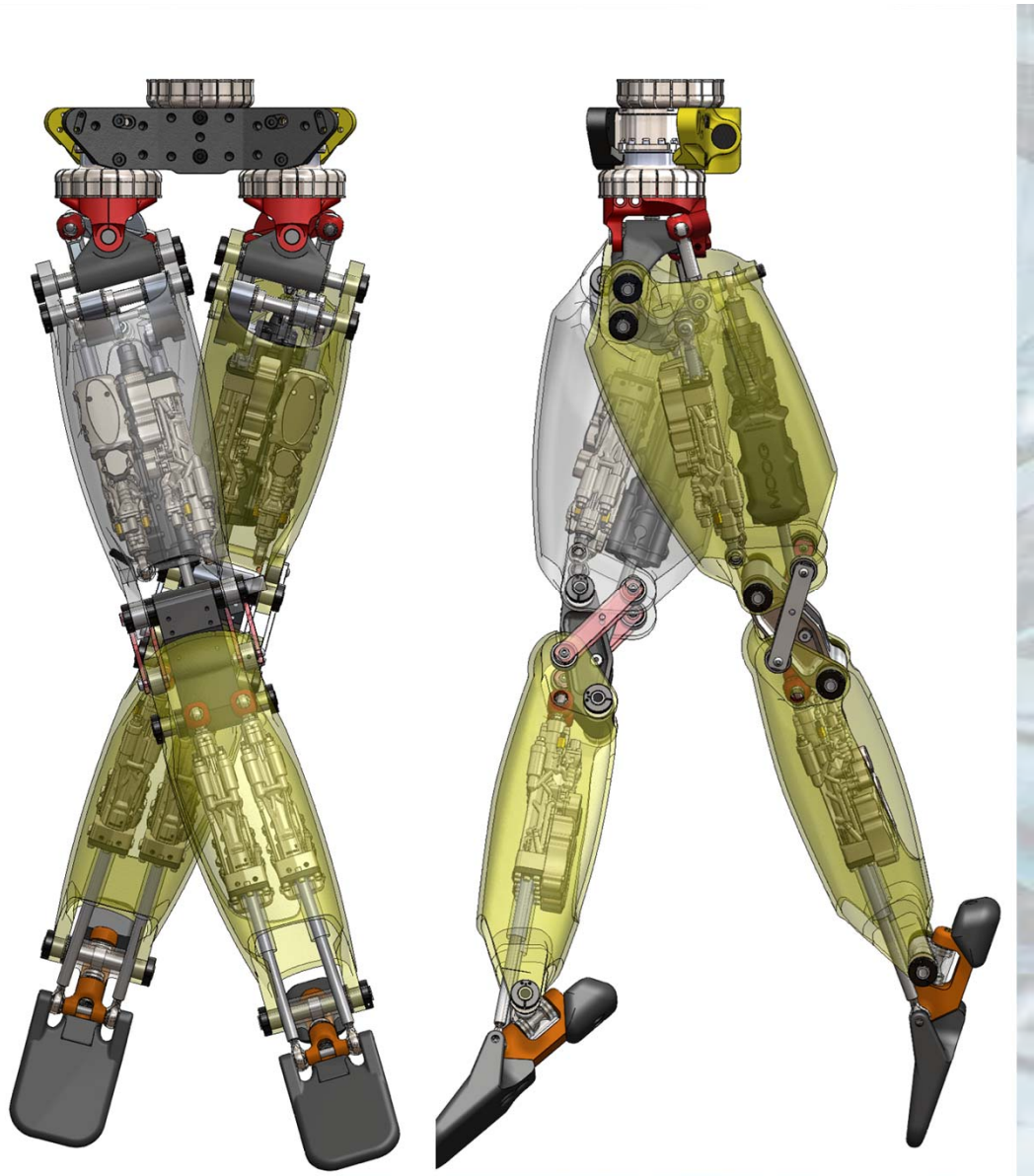
Leg Overview

Double 4-bar linkage hip

- High range of motion: 150° pitch, 90° roll
- Two actuators allow high torque.



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Carbon Fiber Exo Shells

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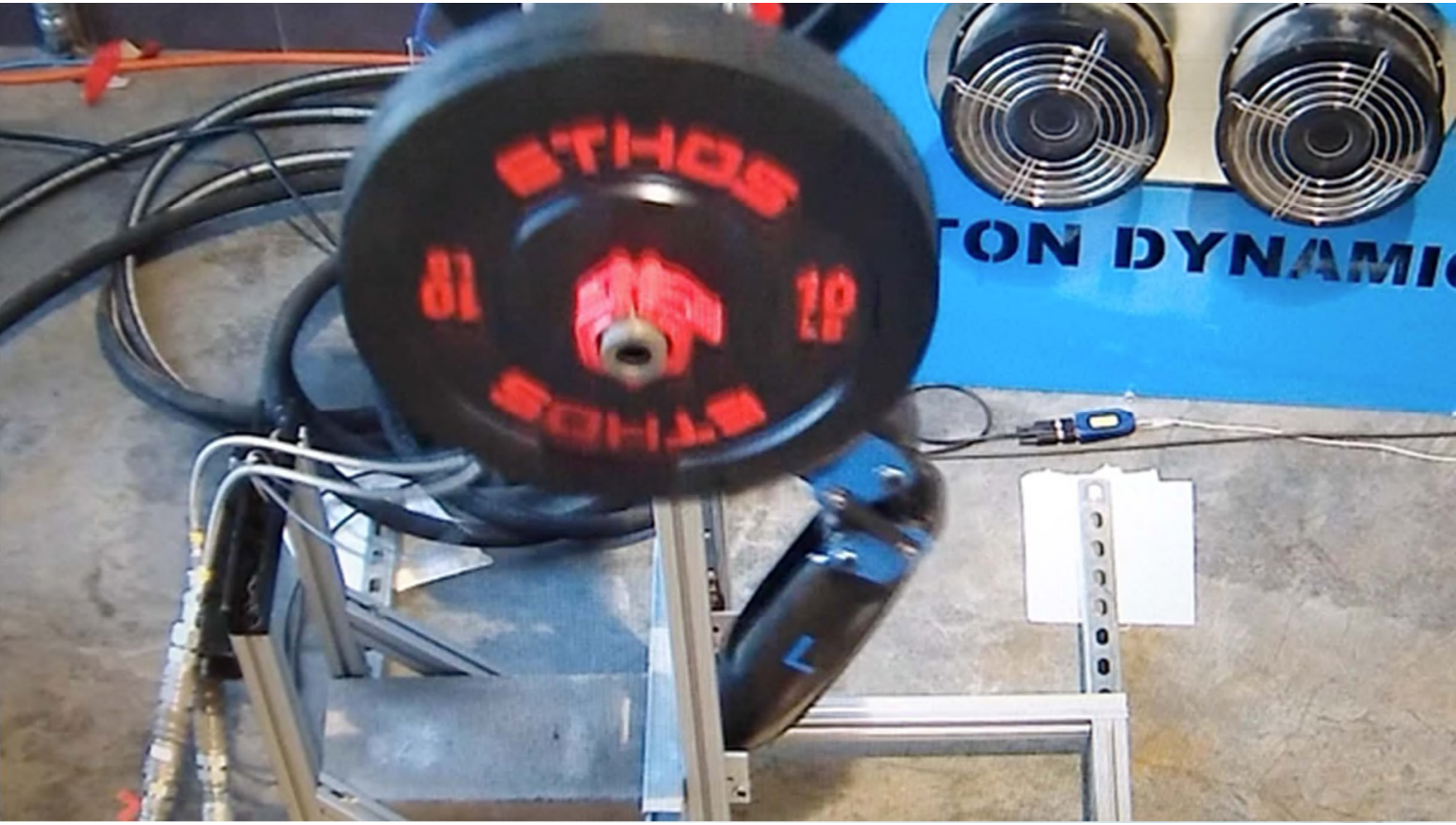
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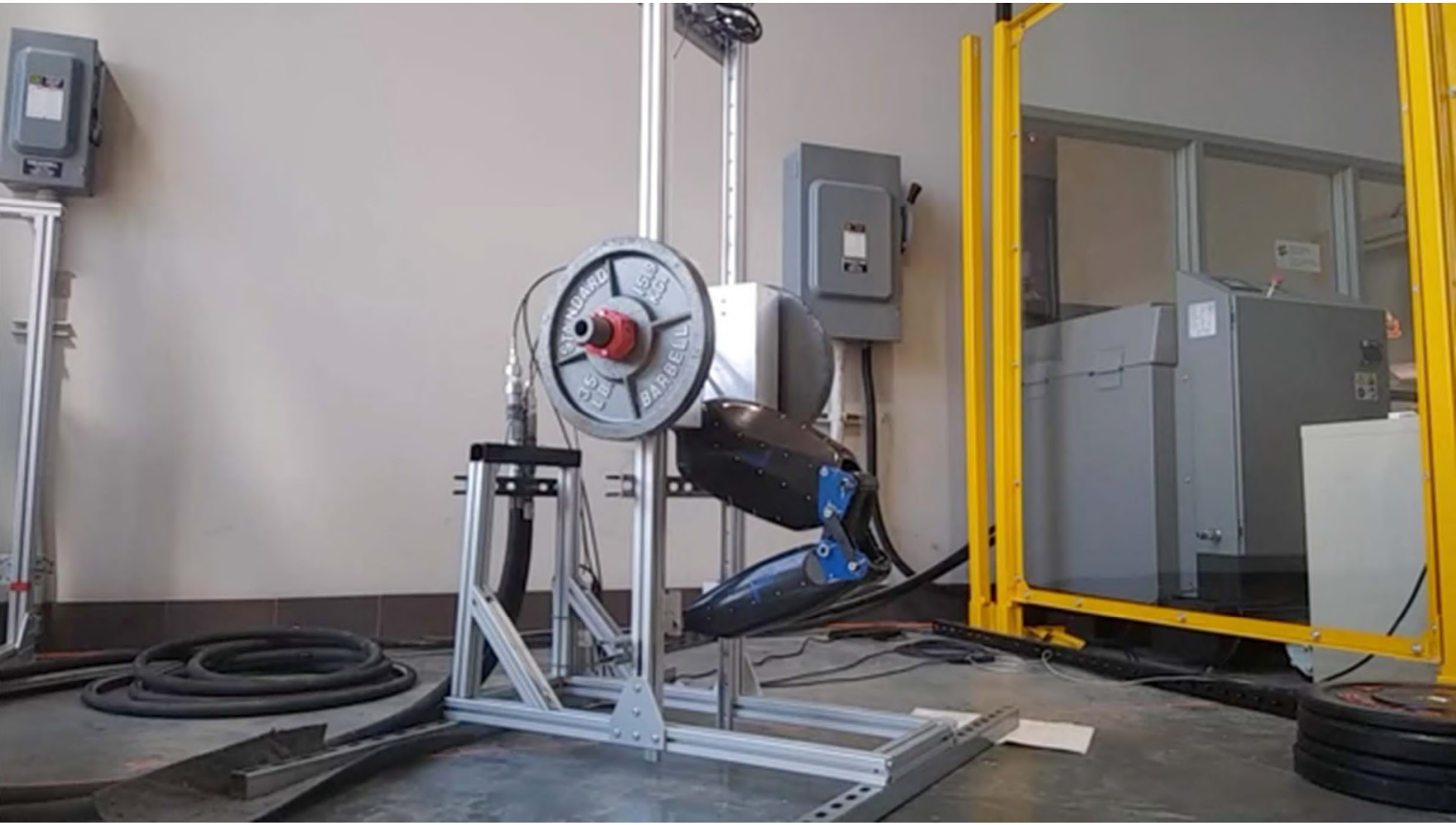
ETHOS
TON DYNAMI


STANDARD
35 LB
BARBELL

Towards Humanoid Avatar Robots for Co-Exploration of Hazardous Environments

Humanoids 2019, Workshop on Teleoperation
IHMC Robotics Team, Jerry Pratt PI
October 15, 2019

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