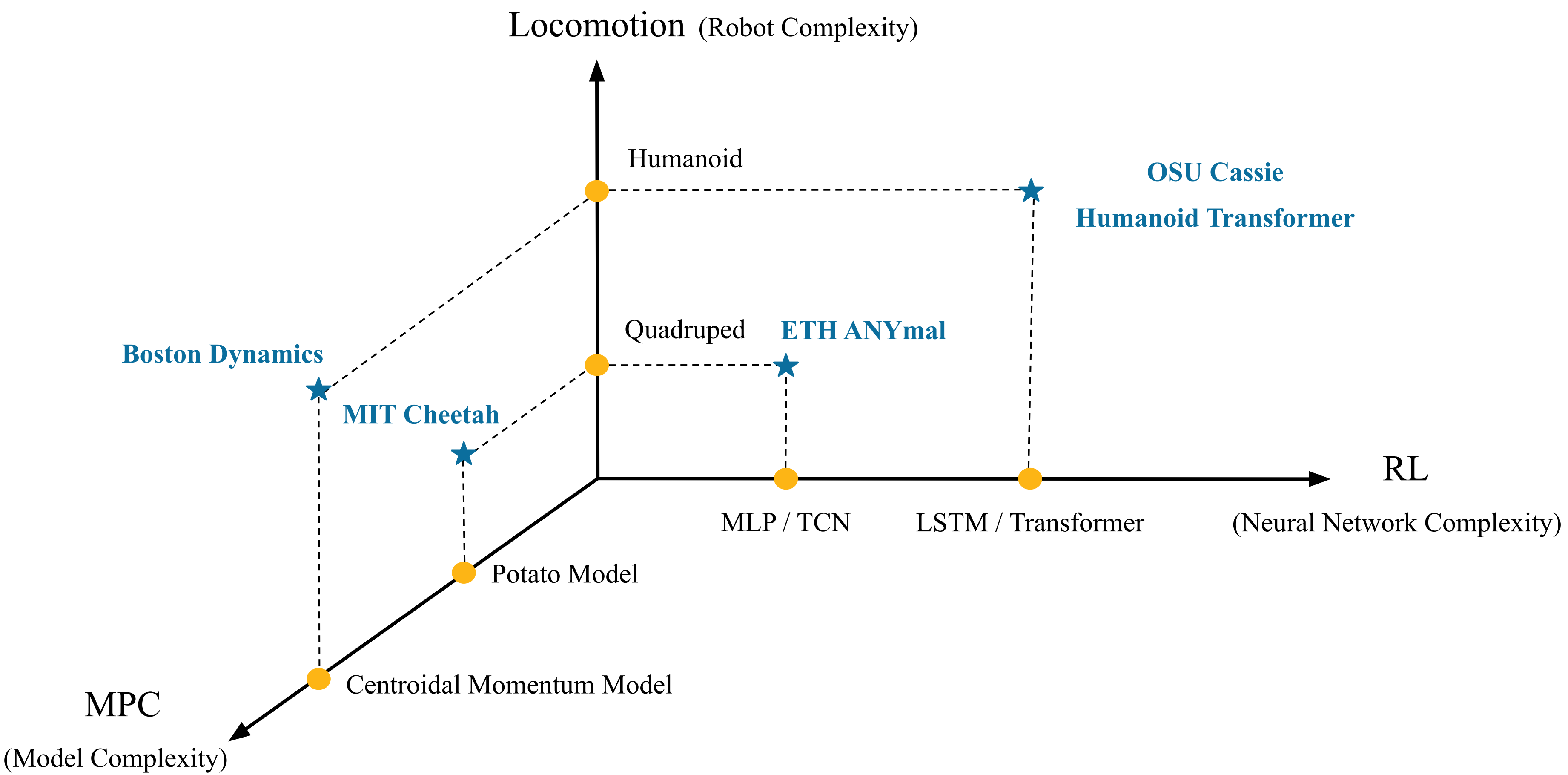
Predictive Control and Reinforcement Learning for Legged Robots: Part 2

Bike Zhang

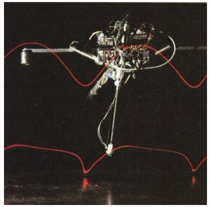
Berkeley Mechanical Engineering

Apr. 20, 2023
EECS 206B Guest Lecture

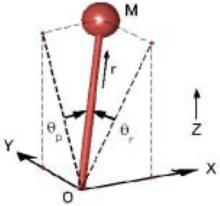


Locomotion (Robot Complexity)
Humanoid
OSU Cassie
Humanoid Transformer
Quadruped
ETH ANYmal
Boston Dynamics
MIT Cheetah
RL
MLP / TCN
LSTM / Transformer
(Neural Network Complexity)
Potato Model
Centroidal Momentum Model
MPC
(Model Complexity)

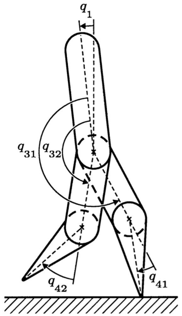
History of legged robot



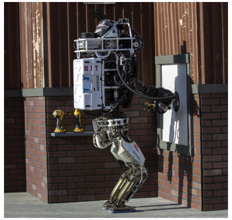
Legged Robots that Balance
Marc Raibert



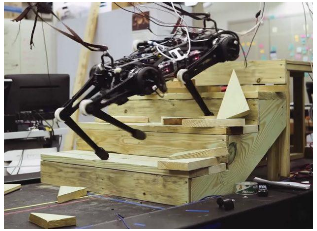
Linear Inverted Pendulum
Shuuji Kajita



Hybrid Zero Dynamics
Jessy Grizzle



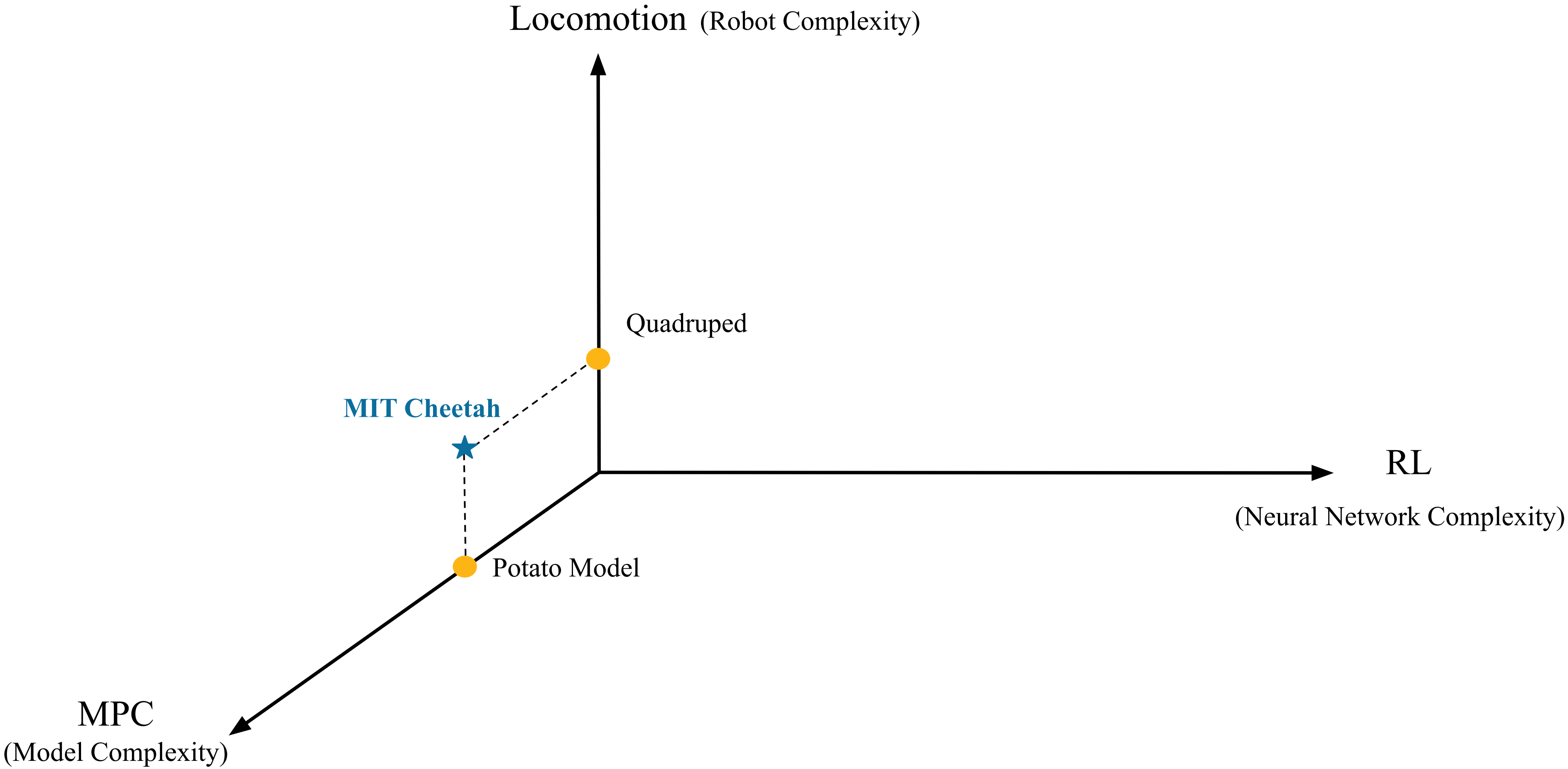
DARPA Robotics Challenge



Model Predictive Control
Sangbae Kim

Reinforcement Learning
Marco Hutter

1980s — 1990s — 2000s — 2010s — 2020s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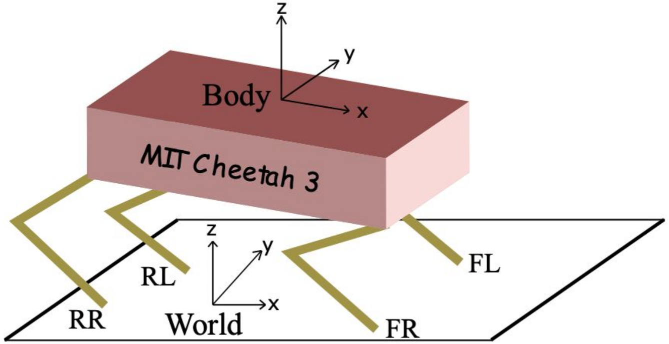
MIT Cheetah

https://youtu.be/q6zxCvCxhic

Convex Model Predictive Control

Stance Phase



Potato Model

Assumption:

- Ignore leg dynamics
- Base roll and pitch are small

Output:

- Ground reaction force

Swing phase:

- Raibert heuristic

Di Carlo, Jared, et al. "Dynamic locomotion in the mit cheetah 3 through convex model-predictive control." *International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2018.

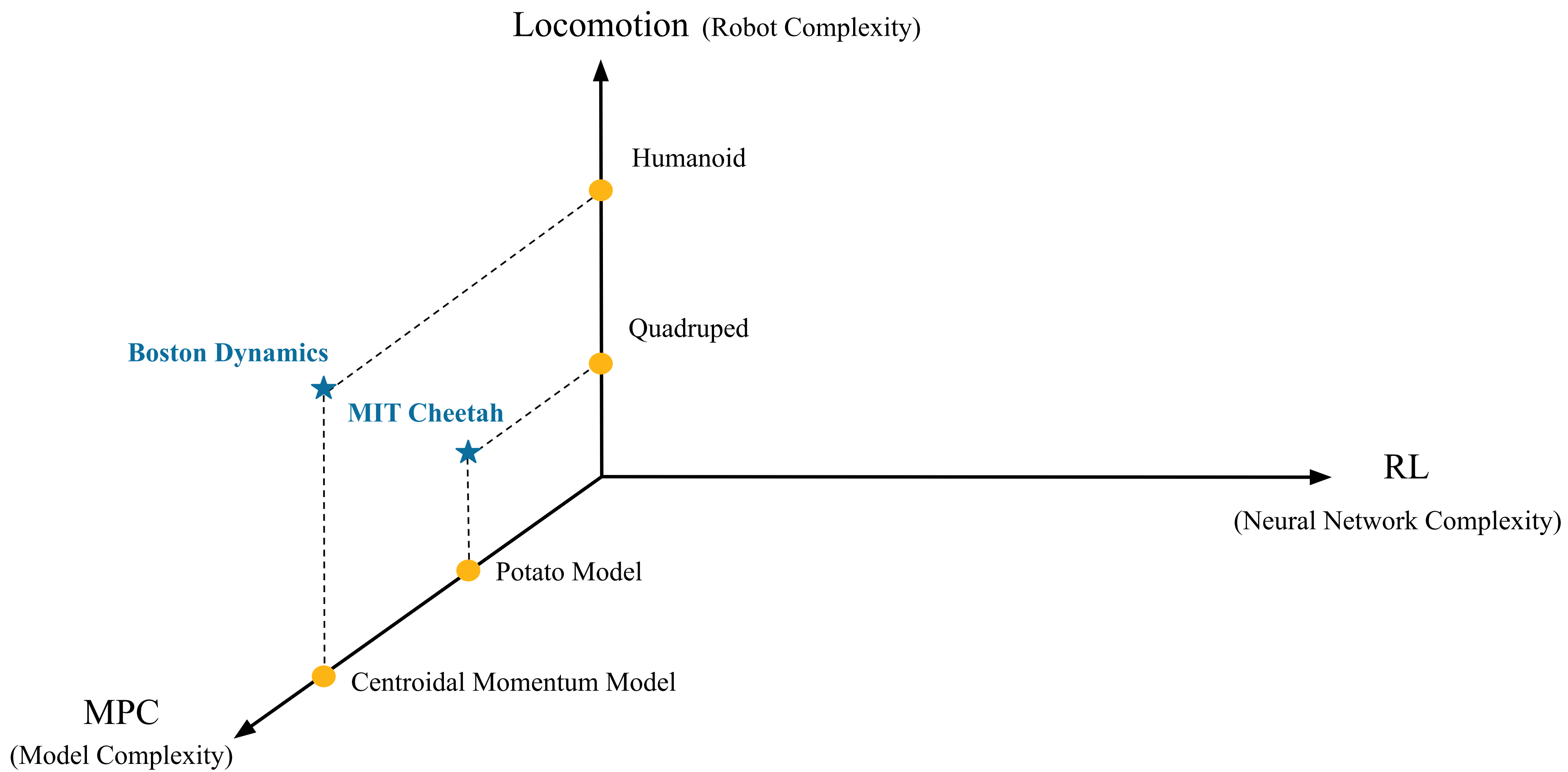
Convex Model Predictive Control

Advantages:

- Potato model
- Convex MPC

Disadvantages:

- Strong assumptions
- Swing phase



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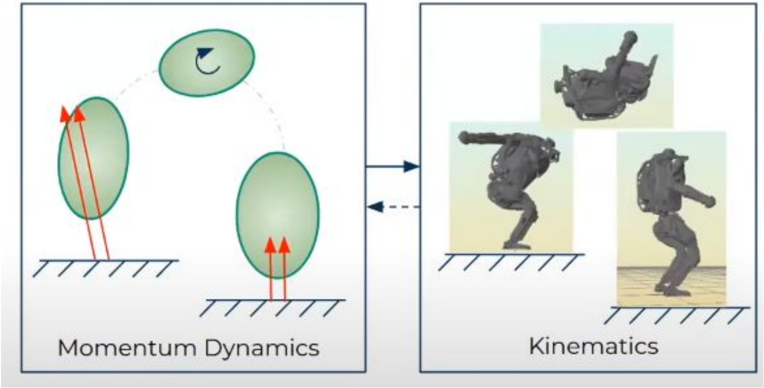
Boston Dynamics Atlas

https://youtu.be/-e1_QhJ1EhQ

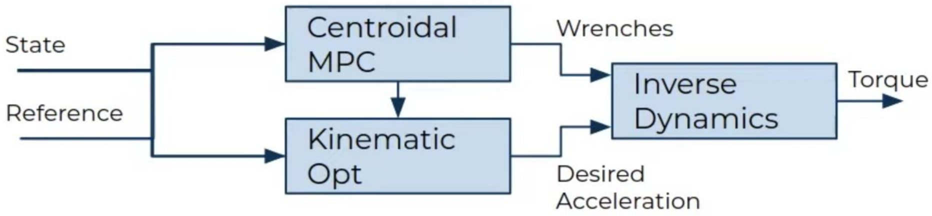
Boston Dynamics Atlas



Offline nonlinear trajectory optimization
Create template behaviors

Online model predictive control
Adapt & execute behaviors

Boston Dynamics Atlas



- *Variables*: wrenches, COM, linear/angular momentum, angular excursion, contact positions, dt
- *Cost*: track [retargeted] reference
- Linearize and solve at every control tick
- Exploit problem structure for speed
- Solve kinematic optimization to derive consistent touchdown configurations

https://youtu.be/mlTLxpKdHfA

Boston Dynamics Atlas

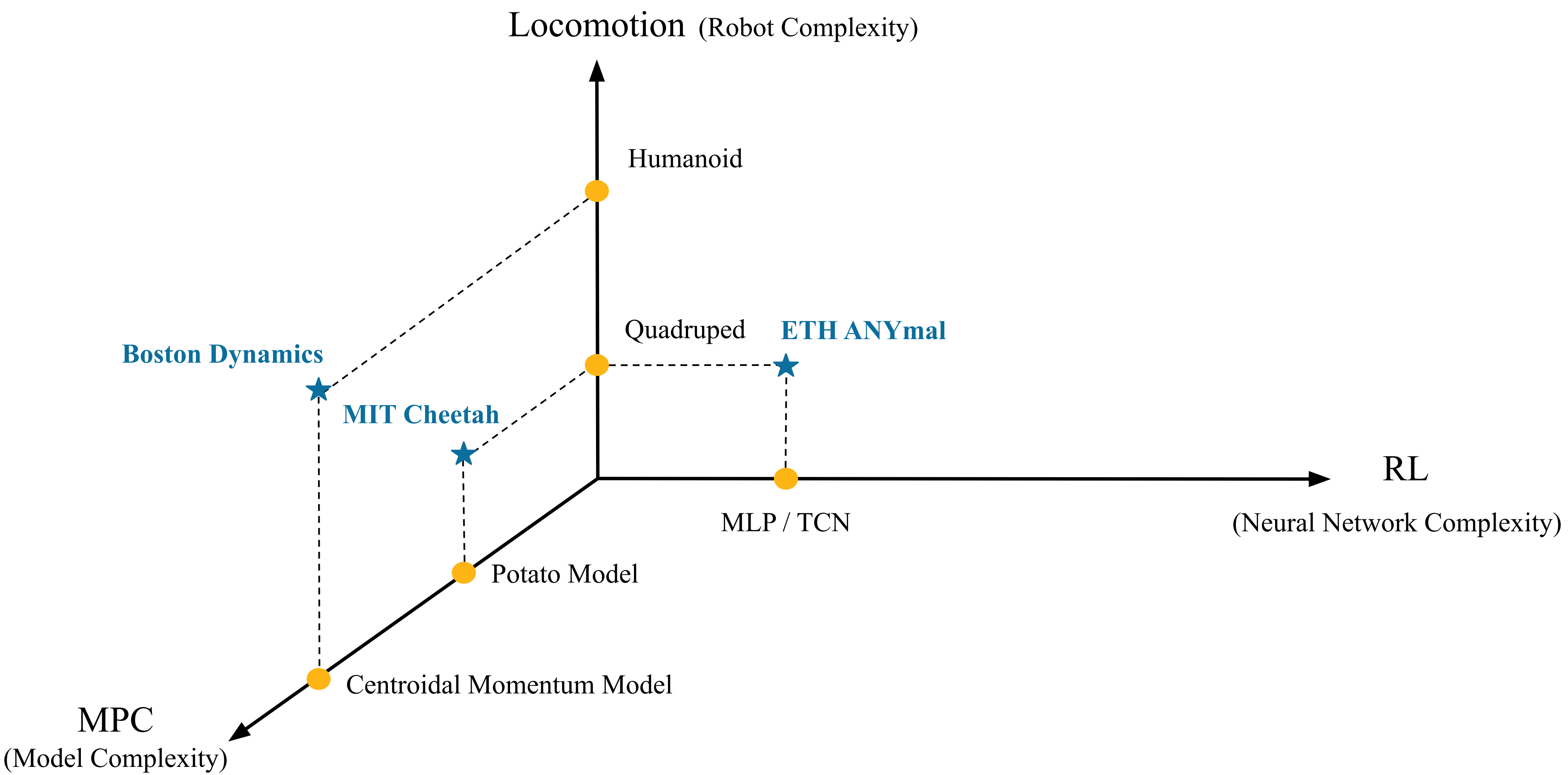
Advantages:

- Centroidal momentum + kinematics
- Online linearized MPC
- For both stance and swing phases

Disadvantages:

- Contact assumptions
- Structured terrain

Go1 Demo



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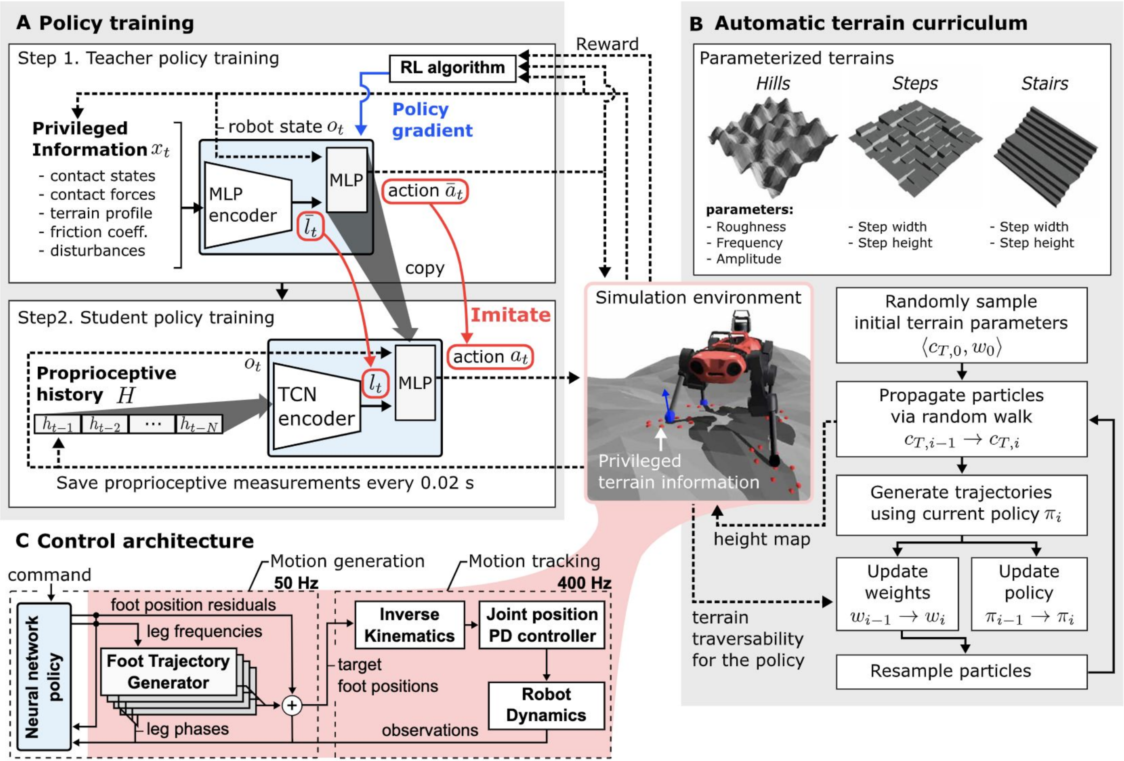
ETH ANYmal

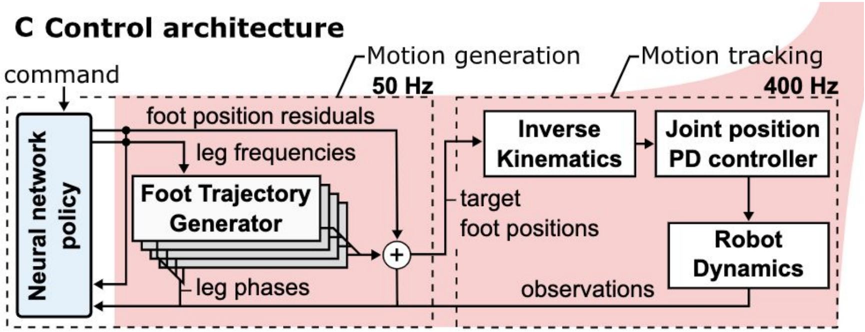

Learning
Quadrupedal
Locomotion
over
Challenging
Terrain

ETH ANYmal



Lee, Joonho, et al. "Learning quadrupedal locomotion over challenging terrain." *Science robotics* (2020).

ETH ANYmal

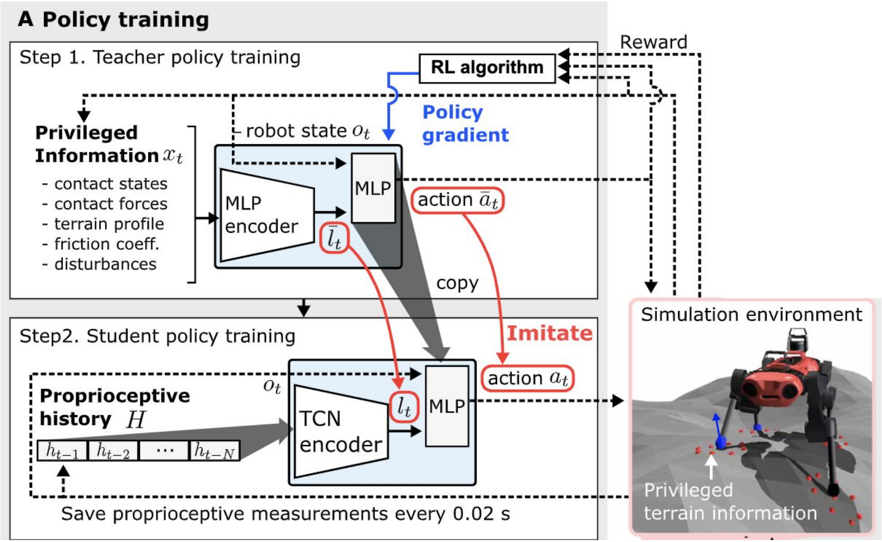


Discussion:

- Multi-rate architecture
- Joint position control

Lee, Joonho, et al. "Learning quadrupedal locomotion over challenging terrain." *Science robotics* (2020).

ETH ANYmal

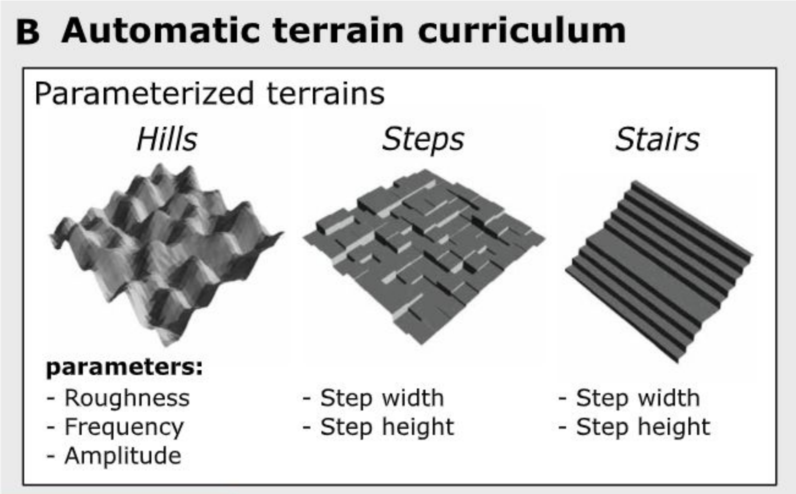


Discussion:

- Teacher-student structure
- Privileged information
- Proprioceptive history

Lee, Joonho, et al. "Learning quadrupedal locomotion over challenging terrain." *Science robotics* (2020).

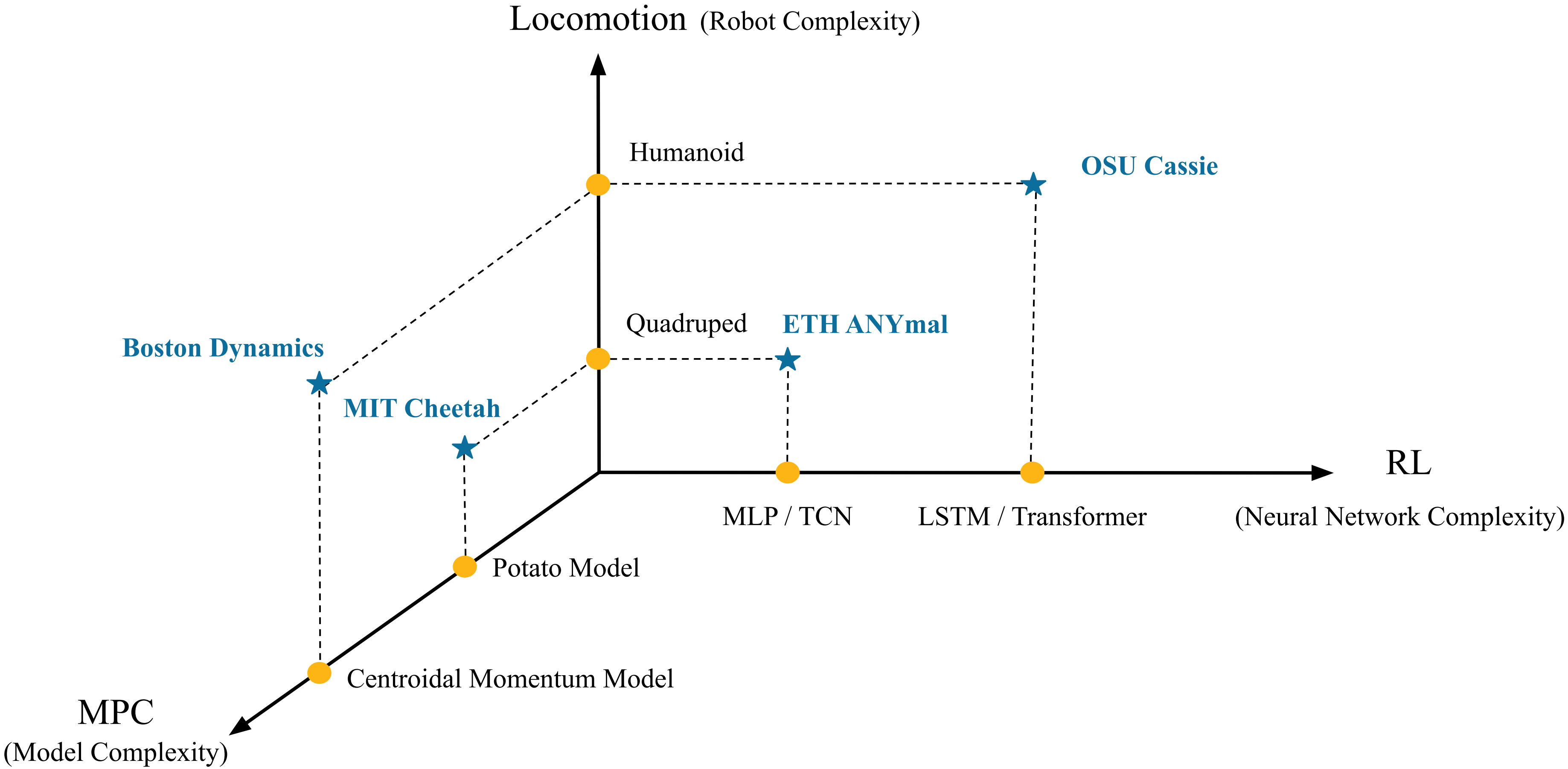
ETH ANYmal



Discussion:

- Domain randomization
- Curriculum learning

Lee, Joonho, et al. "Learning quadrupedal locomotion over challenging terrain." *Science robotics* (2020).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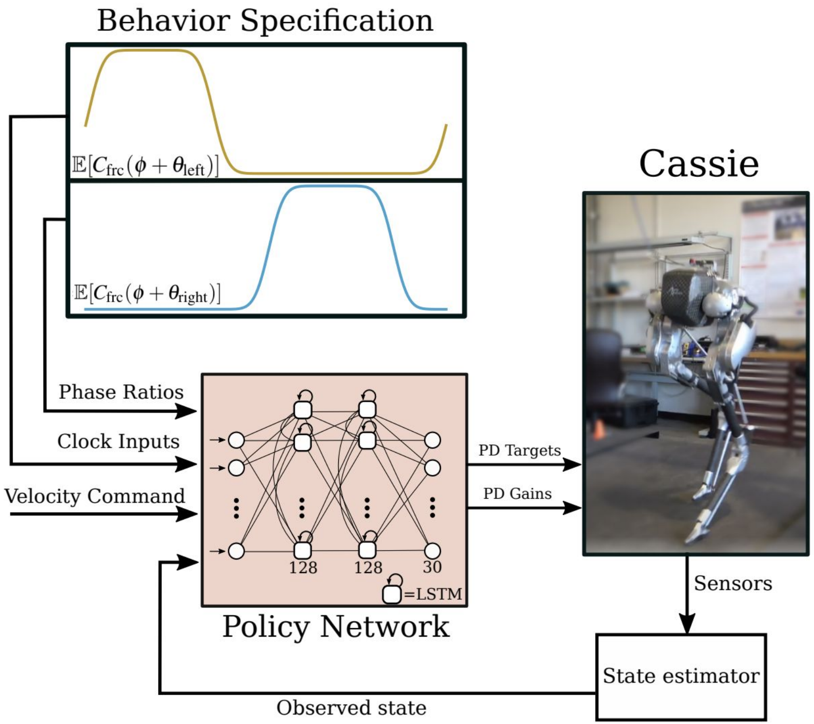
OSU Cassie

https://youtu.be/Wb0tIWBrjmc

OSU Cassie

https://youtu.be/MPhEmC6b6XU

OSU Cassie

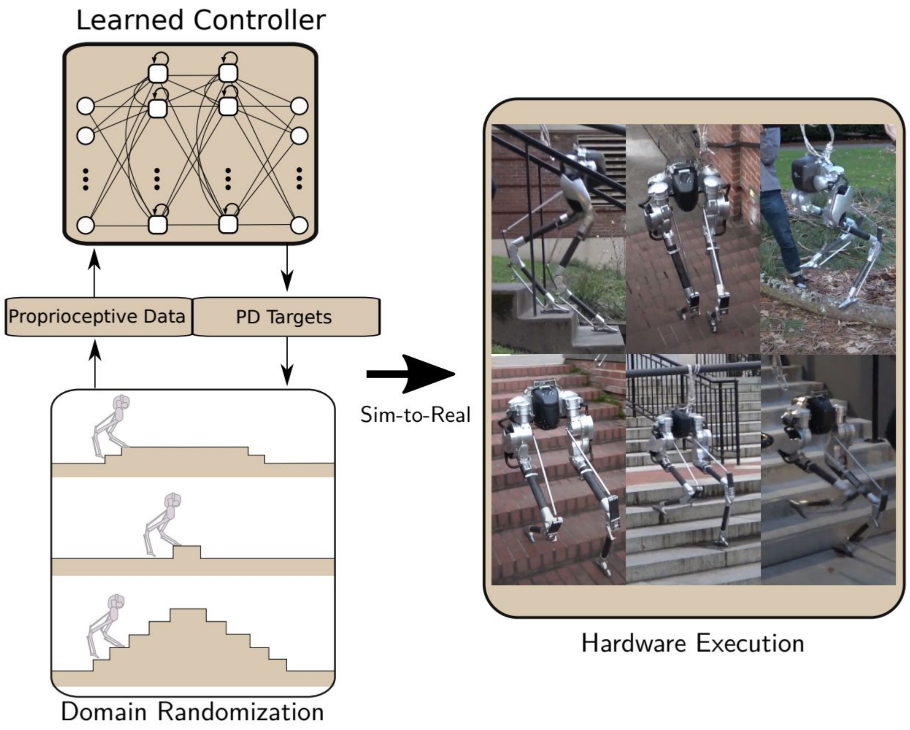


Discussion:

- Periodic reward
- LSTM

Siekmann, Jonah, et al. "Sim-to-real learning of all common bipedal gaits via periodic reward composition." *International Conference on Robotics and Automation (ICRA)*. IEEE, 2021.

OSU Cassie



Discussion:

- Domain randomization

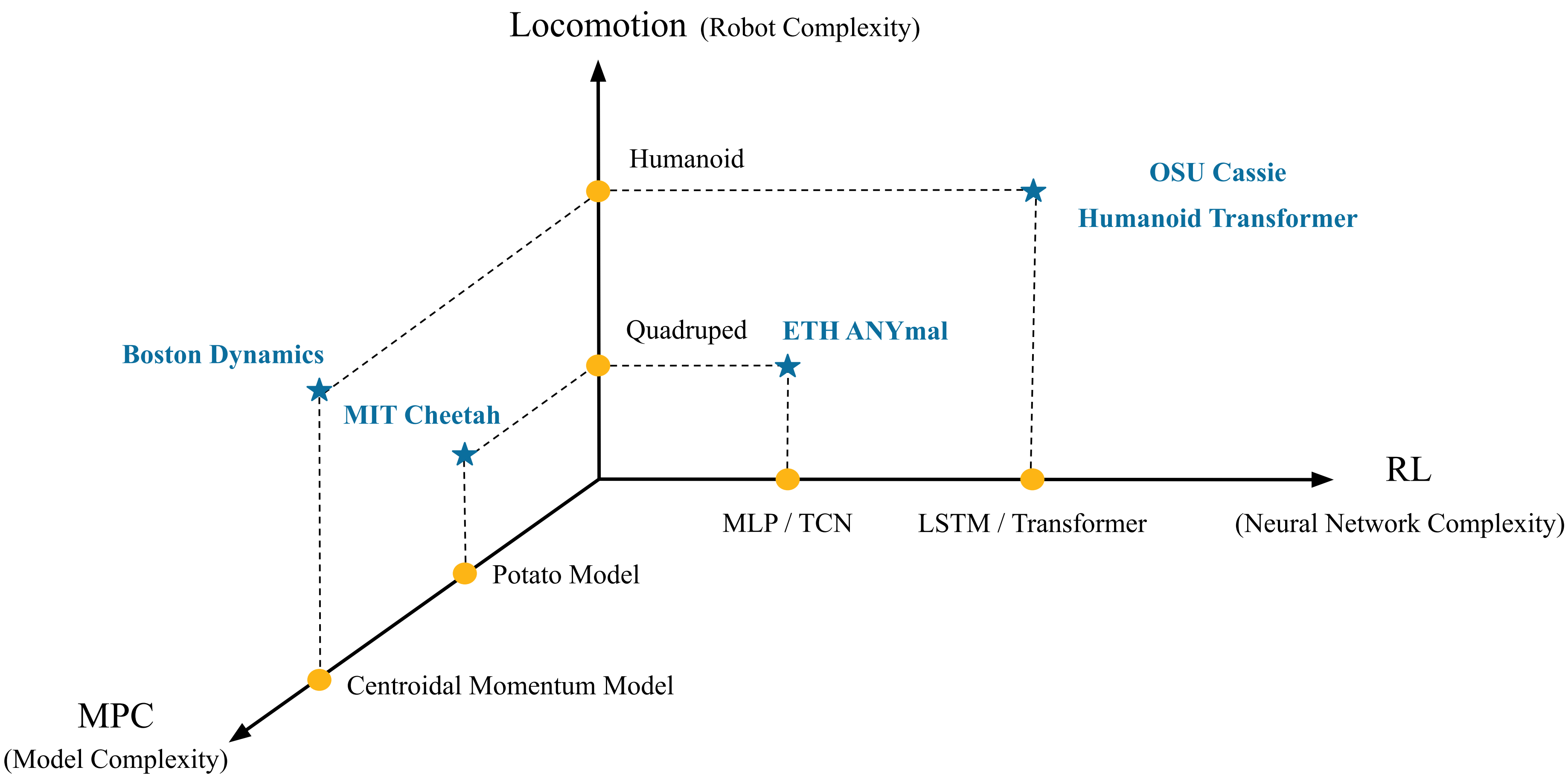
Siekmann, Jonah, et al. "Blind bipedal stair traversal via sim-to-real reinforcement learning." *Robotics: Science and Systems (RSS)*. 2021.

OSU Cassie Runs a 5k

https://youtu.be/dY57qnD_O7U

OSU Cassie for 100M Run

https://youtu.be/DdojWYOK0Nc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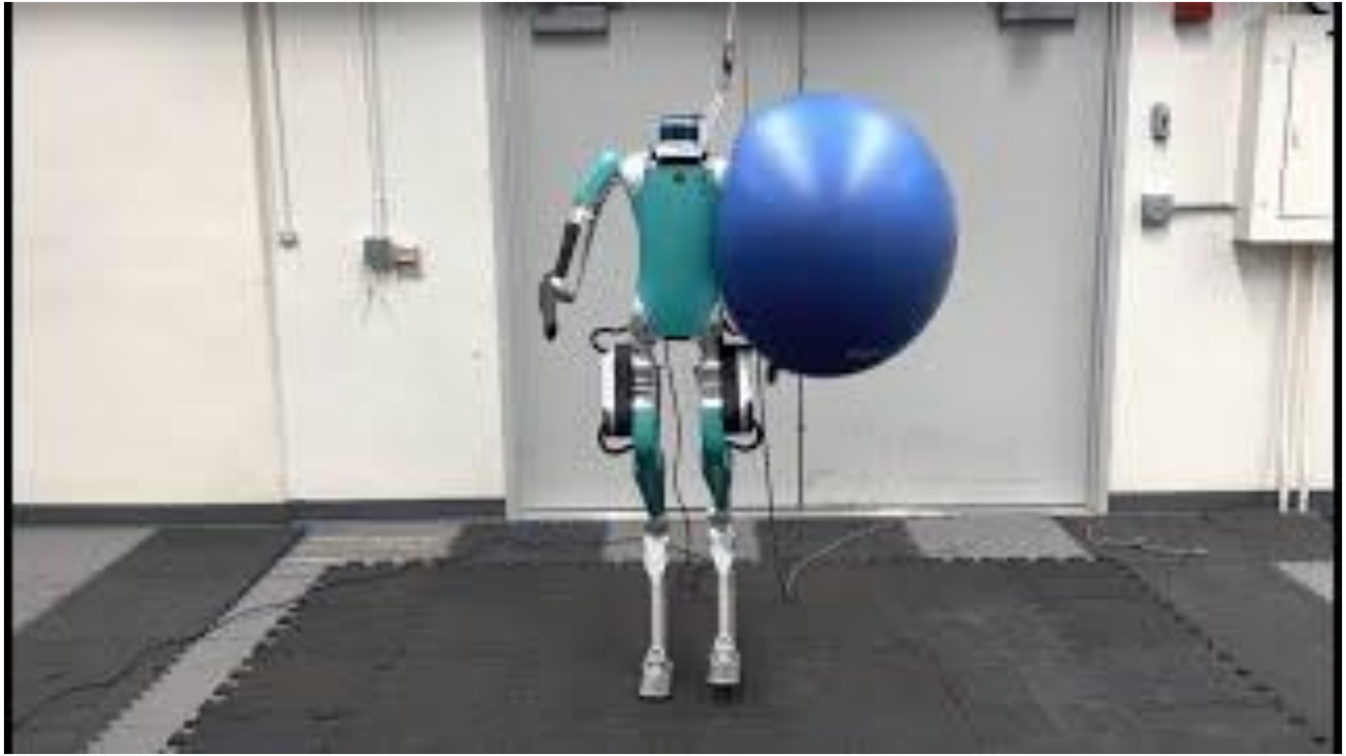
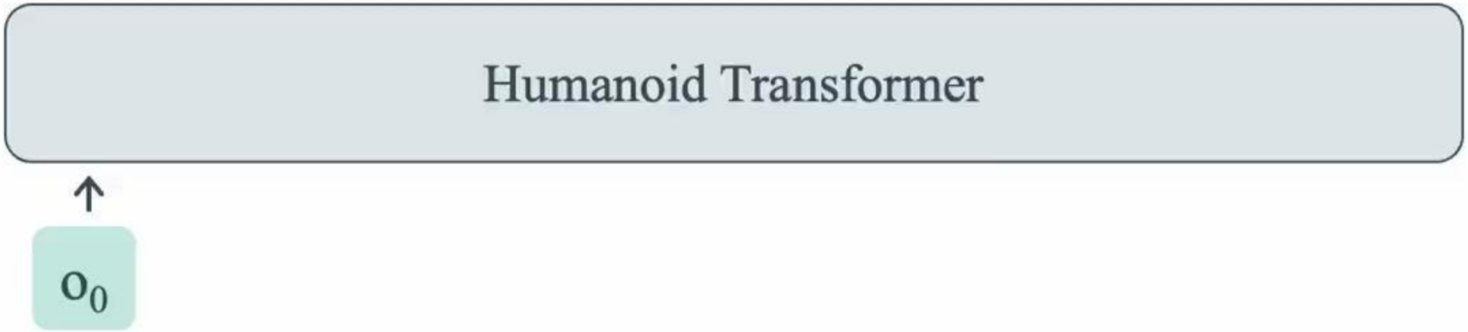
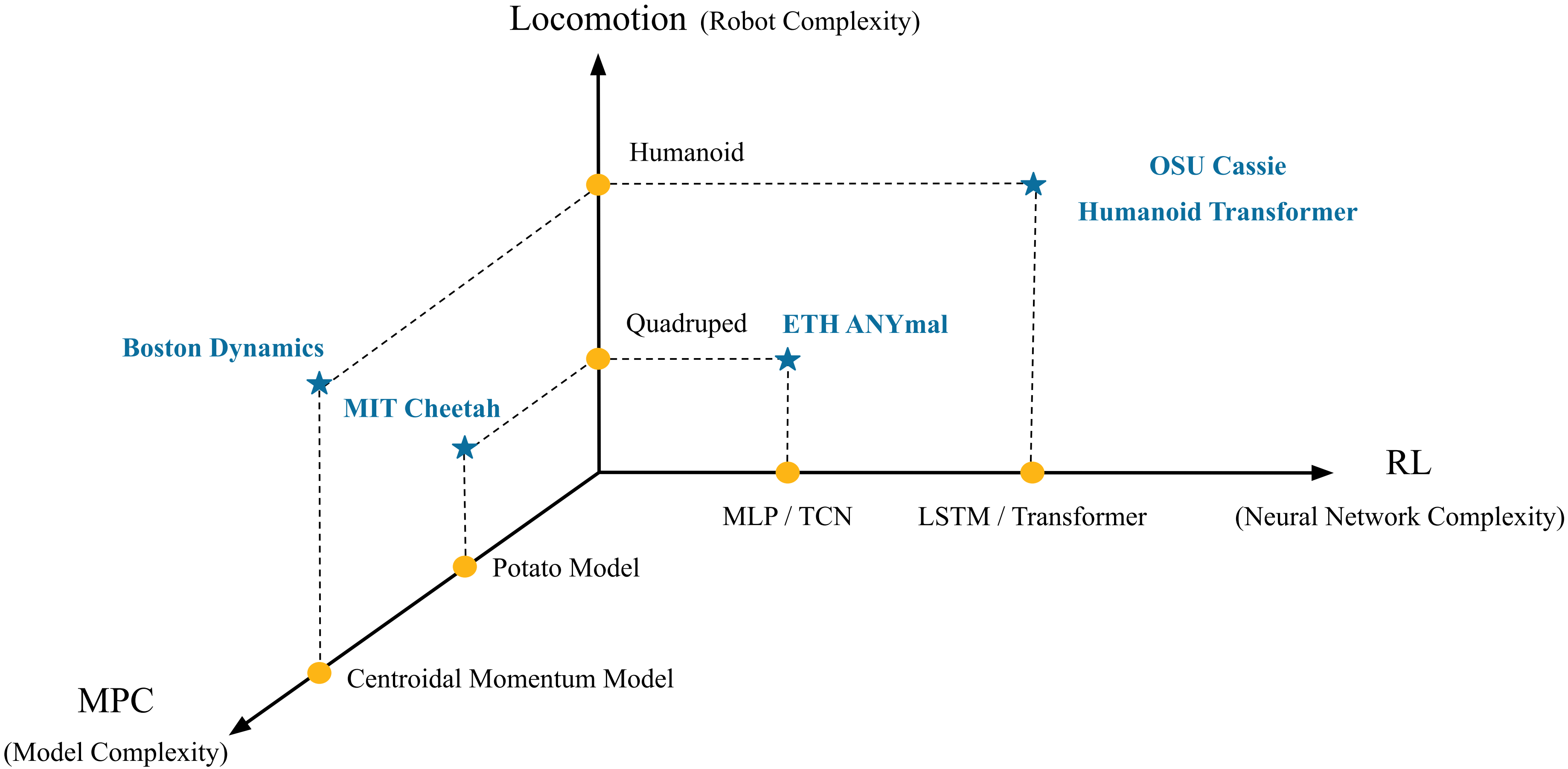
Humanoid Transformer



Humanoid Transformer



Radosavovic, Ilija, et al. "Learning Humanoid Locomotion with Transformers." *arXiv preprint arXiv:2303.03381* (2023).



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Discussion: MPC & RL for Legged Robots

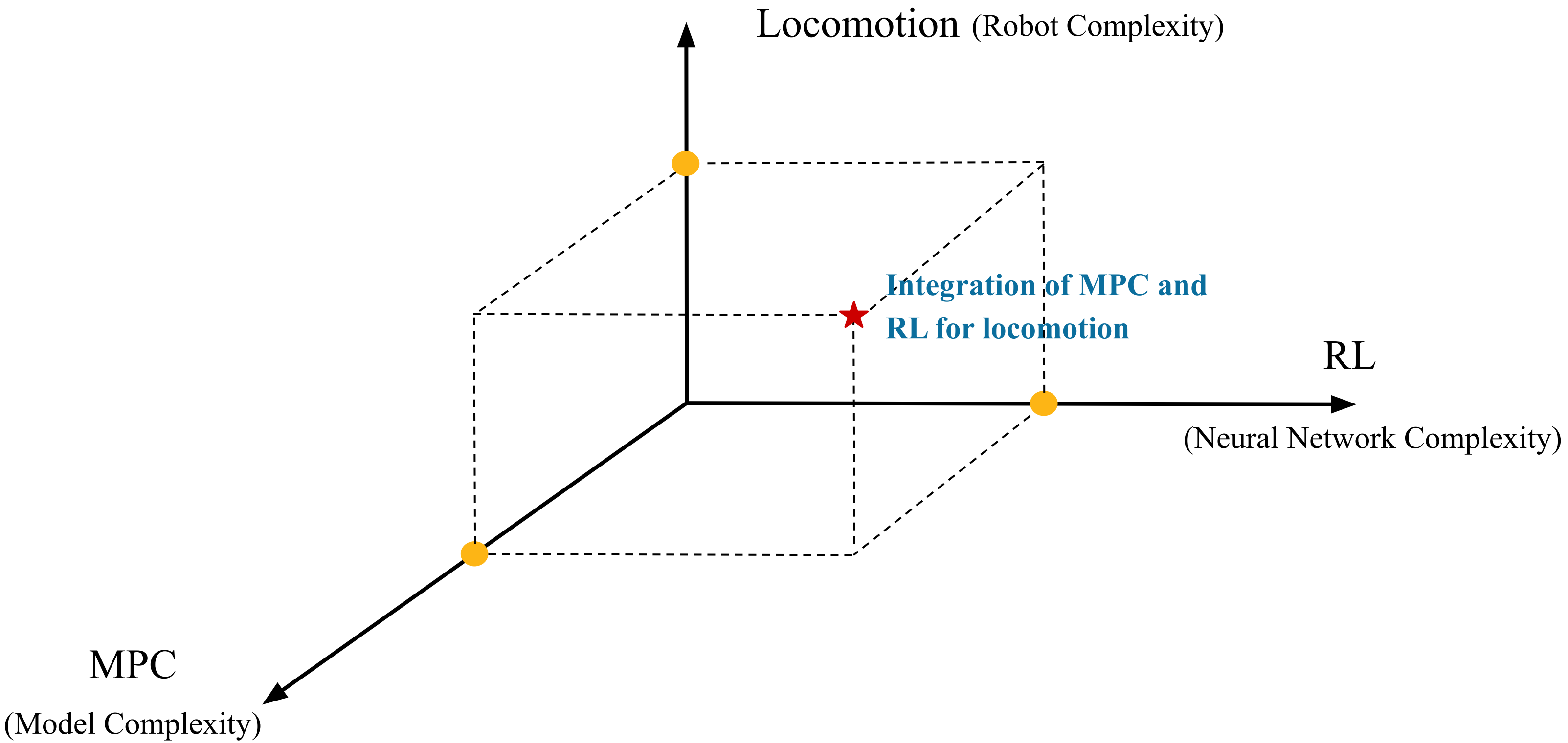
MPC:

- Explicit formulation with guarantee
- Good choice for engineering product

RL:

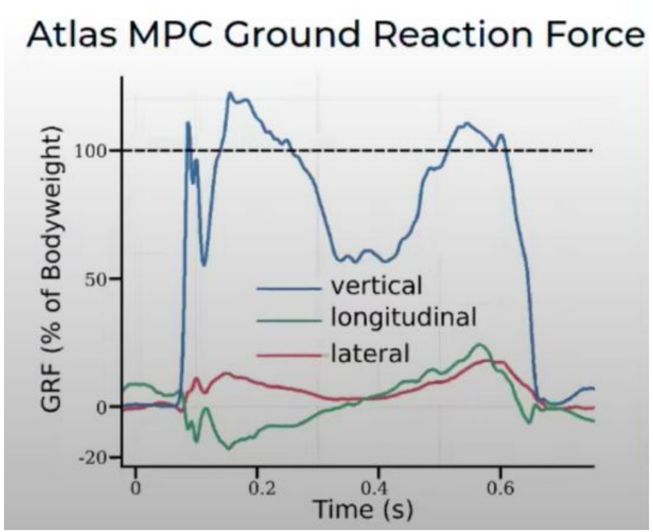
- Easy to robustify a policy
- Easy to integrate with vision, etc

Discussion: MPC & RL for Legged Robots



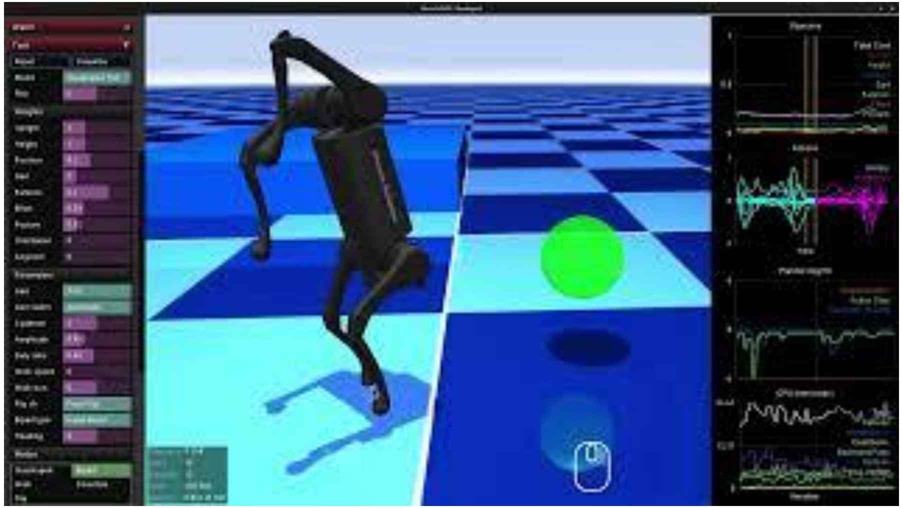
Special Topic: Contact

- Discussion on contact sequence, contact position and contact timing
- Contact detection



Special Topic: Simulator

- MuJoCo v.s. Isaac Gym



MuJoCo

Isaac Gym

https://youtu.be/esLuwaWz4oE, https://youtu.be/8sO7VS3q8d0