Differentiable and Expressive Simulators for Closing the Sim-to-Real Gap in Robotics

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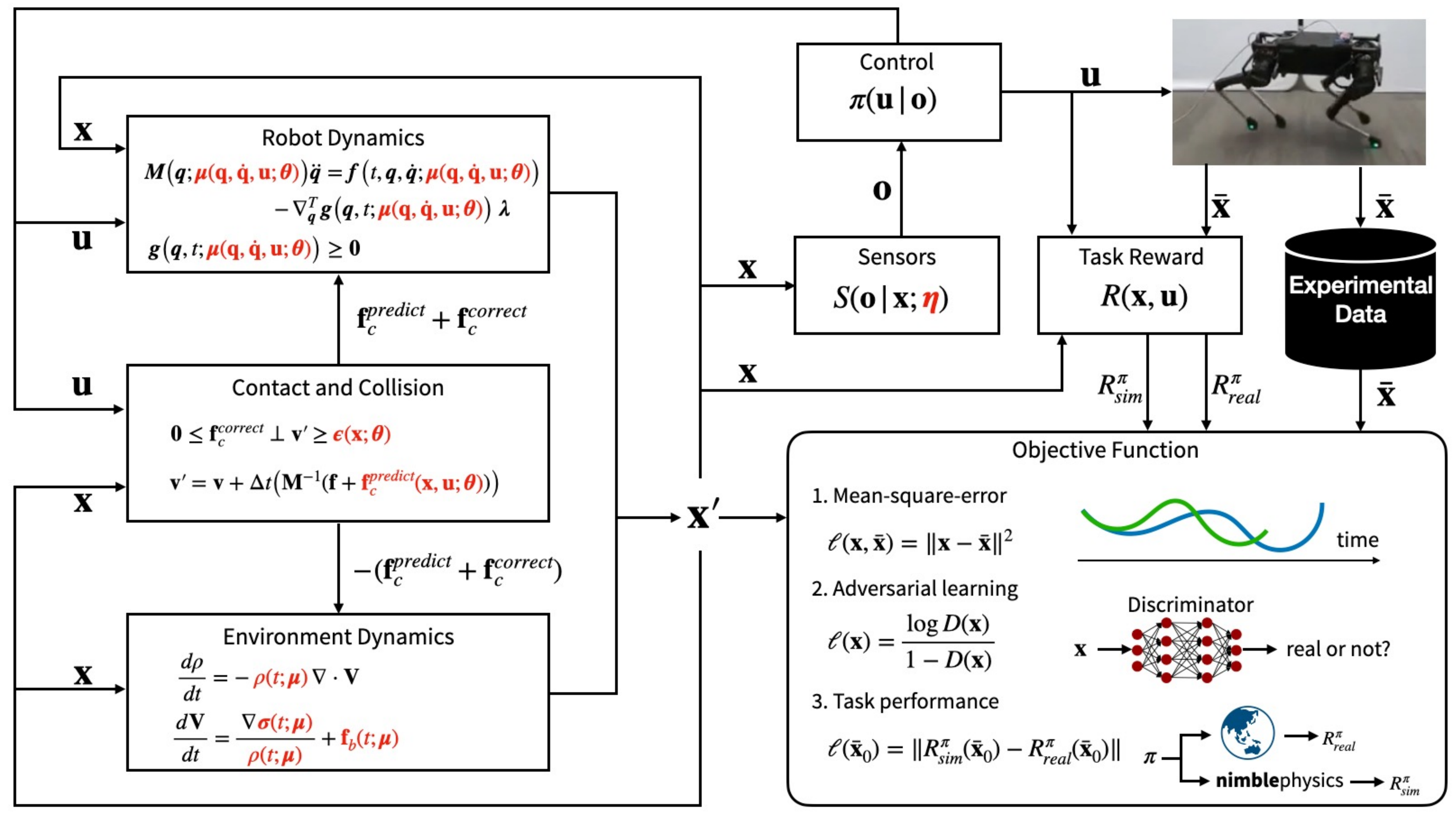
Motivation: Simulation provides a risk-free sandbox for developing controllers or designs in robotics, but robots developed in simulation often fail when deployed in the real world due to the *sim-to-real gap*, which could be caused by a simplified simulation space and dynamics, or a sub-optimal choice of model parameters.

Objectives: Our main goal is to reduce, and whenever possible eliminate, the sim-to-real gap by making the simulation tools (1) more accurate and expressive to predict the real world and (2) less laborious and robot-specific for researchers and engineers.

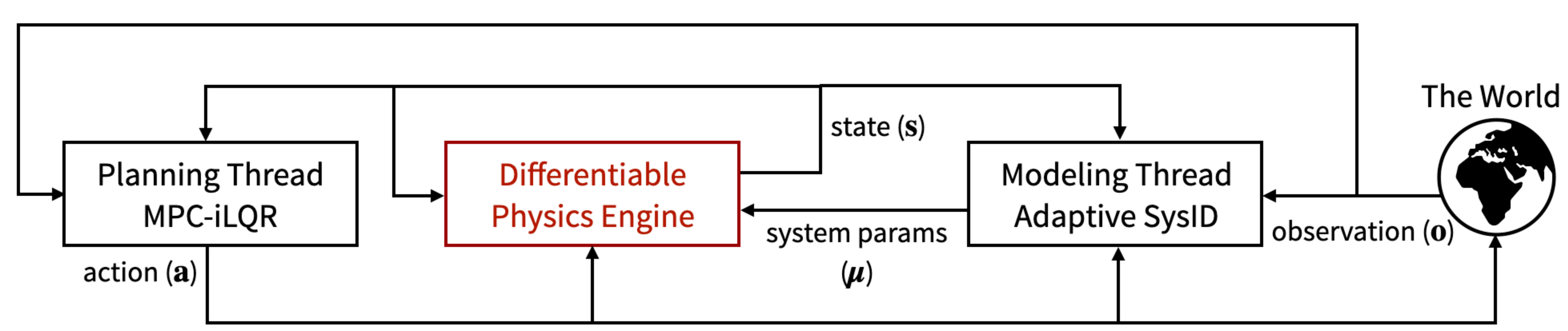
Solution: Develop **differentiable** and **expressive** simulators. A simulator is expressive if it can capture the physics of interest. A "differentiable simulator" is one that in addition to predicting the time evolution of a robot, can also produce gradient information, i.e., how a function depending on the state of the digital robot changes when the parameters in the simulator change.

Broader Impacts:

- Algorithmic outcomes will make impacts on autonomous vehicles, robot-enabled farming, rover design, military vehicles, rescue robots, food processing industry, pharmaceutical industry, warehouse automation, manufacturing automation.
- Software outcomes will be transitioned into two existing simulation platforms, DART/NimblePhysics and Chrono.
- Education outcomes will broaden participation in computing via the "Promoting the Computational Science Initative" (ProCSI) at University of Wisconsin-Madison and AI4All at Stanford.

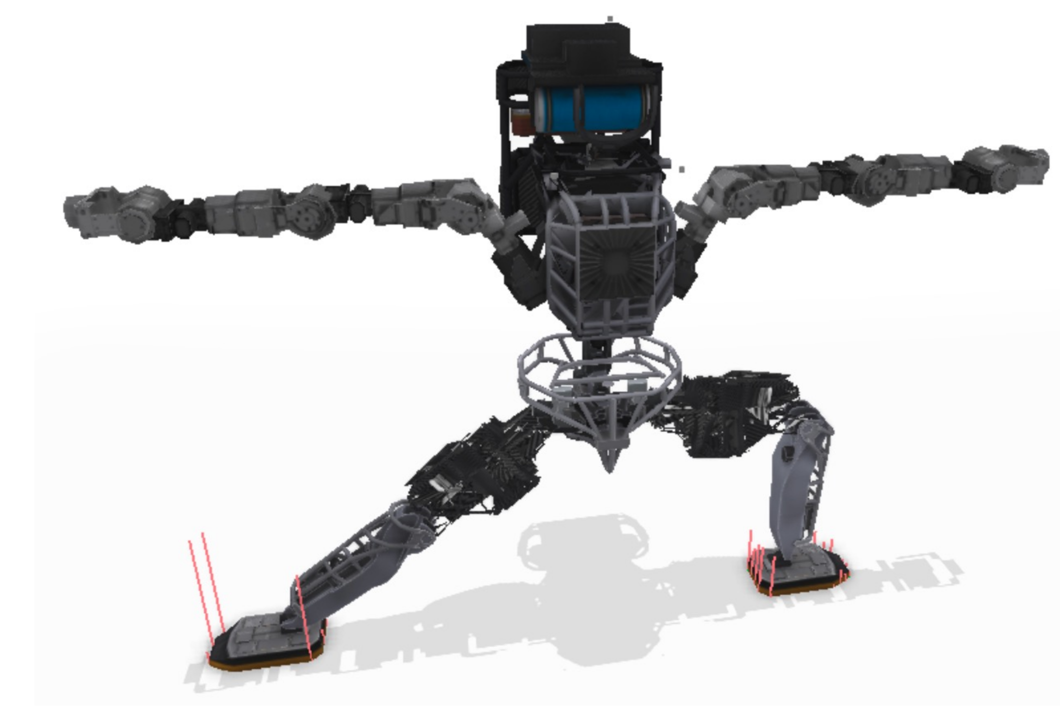


Real-time Model Predictive Control and System Identification Using Differentiable Simulation



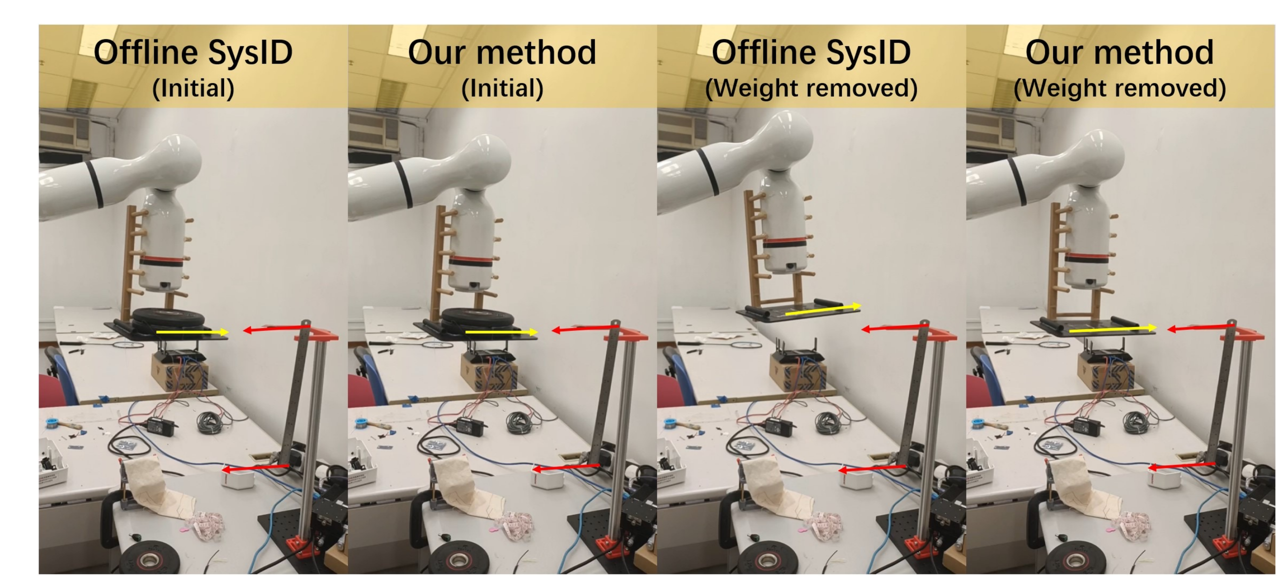
We develop a differentiable simulation framework that performs online motion planning and system identification (SysID) *simultaneously* using incoming observations in real time. We introduce an adaptive online system identification method that monitors the changes in the environment and assesses the confidence of estimated parameters, using numerical analysis of the dynamic equations. Meanwhile, our planning algorithm replenishes the planned action buffer faster than real time while keeping the plan up-to-date. The dual-threaded method provides a unique opportunity to actively control a trajectory for SysID---we can assist SysID by planning a trajectory that will produce parametrically exciting observations.

NimblePhysics: A Differentiable Physics Simulator



We develop a differentiable physics engine, Nimble (nimblephysics.org), that supports Lagrangian dynamics and hard contact constraints for articulated rigid body simulation. We provide an open-source implementation of a complete set of features, in a fully differentiable fork of the DART physics engine.

K. Werling, D. Omens, J. Lee, I. Exarchos, and C. K. Liu, Fast and Feature-Complete Differentiable Physics for Articulated Rigid Bodies with Contact. RSS (2022)



S. Chen, K. Werling, A. Wu, and C. K. Liu, Real-time Model Predictive Control and System Identification Using Differentiable Simulation. IEEE RA-L (2023)

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