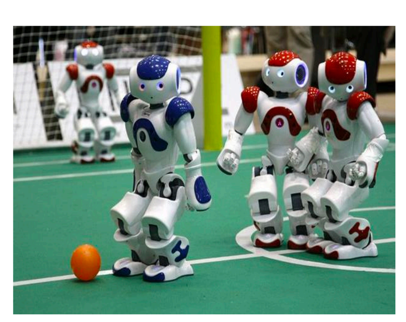
Data-Drven Control for Societal-Scale Cyber-Physical Systems

Yuanyuan Shi and Baosen Zhang
Electrical & Computer Engineering, University of Washington

Introduction

Decisions on how to best operate societal-scale cyber-physical systems (CPS) such as **energy systems, transportation networks** and **robotics** are becoming increasingly challenging because of the growing system complexity and environmental uncertainties. Recent years, with the explosion of data and rapid development of machine learning algorithms, data-driven control shows promise for addressing the aforementioned challenges.





My research explores the theoretical foundations and applications of data-driven control from two perspectives:

- **How can we design data-driven control algorithms for complex physical systems?**
- **How we analyze the interactions between multiple intelligent agents and design better platform?**

About Me

Yuanyuan Shi is a fifth-year Ph.D. candidate at the ECE department. She works in energy systems and cyber-physical systems, from the perspectives of machine learning, optimization and control.

Contact: yyshi@uw.edu

Learn System Dynamics

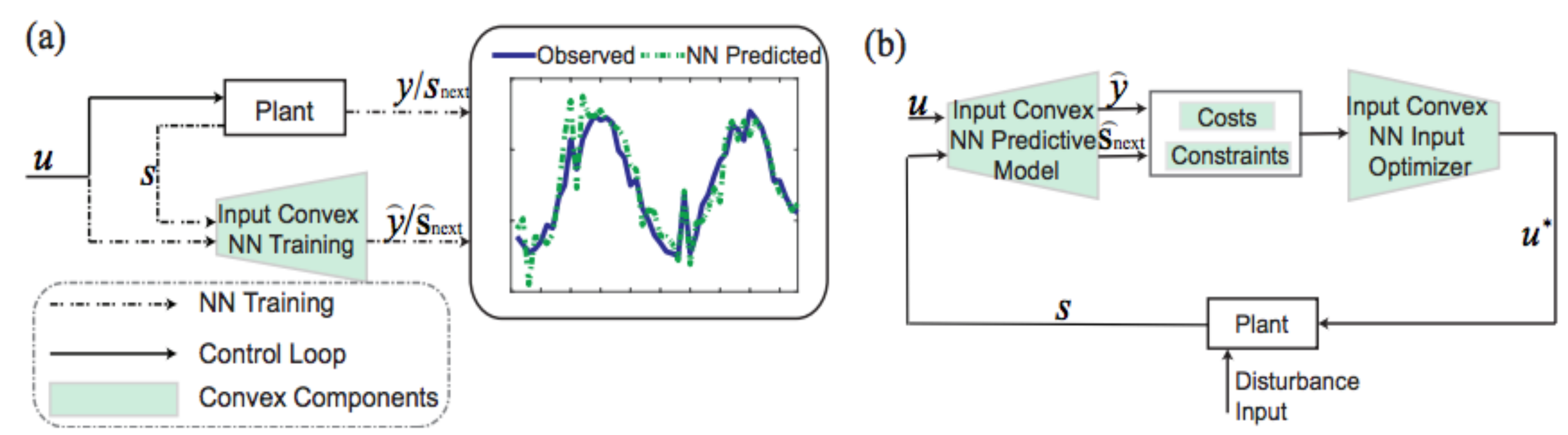
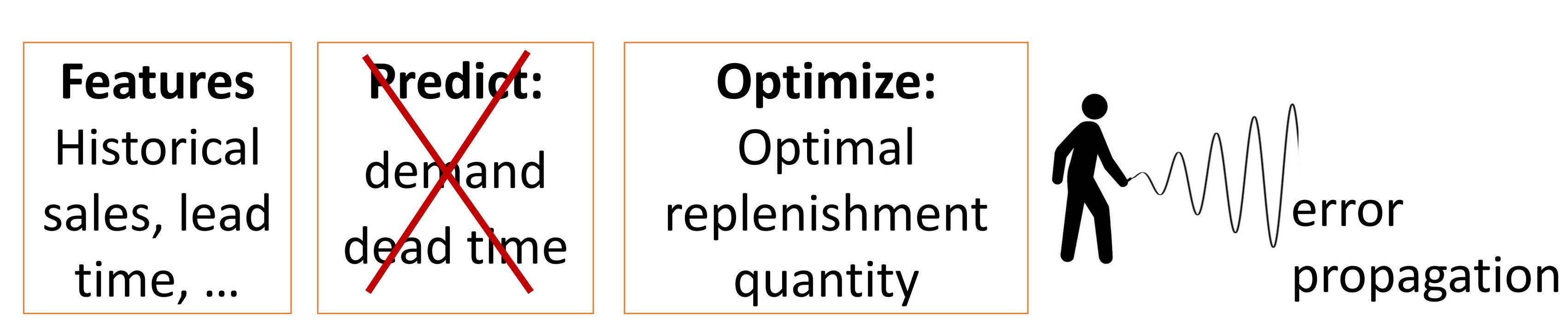


Figure 1: Model predictive control flowchart. (a) system identification (b) controller design

- We designed an **input convex neural network** (ICNN) [1] for complex system identification, where all weights of ICNN are non-negative, adding pass-through layers and use ReLU activations.
- ICNN can represent all convex functions
- ICNN is exponentially more efficient than piece-wise linear model
- Used in building energy management, robotics control and power system voltage regulation

End-to-End Learning under Uncertainty

The operation of CPS often encompass a myriad of uncertainties that come from external environment and human behavior. Most previous stochastic online controllers uses a **two-step** framework: 1) predict the uncertainties; 2) solve the optimization using the prediction, which leads to error accumulation and sub-optimality.



- We designed an **end-to-end modular neural network** for stochastic control problem that have multiple sources of uncertainties and no simple closed-form solution
- Get the label for each sample by solving dynamic programming
- Used for inventory management [2], energy storage control [3], and robotics control [4]

Interaction of multiple intelligent agents

- Energy market example
- Generators bid in quantity
- Every player is self-interest (profit maximization) and smart (learning algorithm)

Question 1: Will system still stable or can be manipulated [5]?

- Learning agents (e.g., no-regret learning, policy gradient reinforcement learning) will converge to the Nash Equilibrium
- Convergence speeds depends on the algorithms of usage

Question 2: How to design better mechanism (information, price) for societal-scale CPS?

Reference

[1] Chen, Y.*, **Shi, Y.***, & Zhang, B., Optimal Control Via Neural Networks: A Convex Approach (*equal contribution). ***International Conference on Learning Representations (ICLR),*** 2019.
[2] **Shi, Y.**, Qi, M., Ma, C.X., Yuan R., Wu D., & Shen Z. M., "A practical end-to-end inventory management model with deep learning," under revision in ***Management Science***, 2019.
[3] **Shi, Y.,** Xu, B., Tan, Y., Kirschen, D., & Zhang, B., Optimal Battery Control Under Cycle Aging Mechanisms in Pay for Performance Settings. ***IEEE Transactions on Automatic Control,*** 2018.
[4] **Shi, Y.,** Xiao, K., Mankowitz D. and et al Data-Driven Robust Reinforcement Learning for Continuous Control. ***NeurIPS Workshop on Safety and Robustness in Decision Making (NeurIPS),*** 2019.
[5] **Shi, Y.,** & Zhang, B., Learning in Cournot Games with Limited Information Feedback. ***arXiv preprint*** arXiv:1906.06612, 2019