

# Any system that evolves (changes) in time according to some rules









## Josh Proctor Institute for Disease Modeling





![](_page_6_Picture_0.jpeg)

![](_page_6_Picture_1.jpeg)

![](_page_7_Picture_0.jpeg)

![](_page_8_Picture_0.jpeg)

![](_page_8_Figure_1.jpeg)

Guckenheimer and Holmes, Springer, 1983

![](_page_8_Picture_3.jpeg)

**Increasing Nonlinearity** 

## **Dynamical Systems:** Poincare and Geometry

## Dynamics

![](_page_9_Figure_2.jpeg)

## $\mathbf{x}_{k+1} = \mathbf{F}_t(\mathbf{x}_k),$

## Haller, 2002;

![](_page_9_Figure_6.jpeg)

## Discrete-time update

## MODERN DATA-DRIVEN DYNAMICAL SYSTEMS

## ODERN DATA-DRIVEN DYNAMICAL SYSTEM faculty.washington.edu/sbrunton/DataBook.pdf databookuw.com

### **Steve Brunton**

![](_page_11_Figure_2.jpeg)

### Uploads

![](_page_11_Picture_4.jpeg)

Simulating the Logistic Map

![](_page_11_Picture_6.jpeg)

**Discrete-Time** 

Simulating the Lorenz System

COM

![](_page_11_Picture_12.jpeg)

## **DATA-DRIVEN** SCIENCE AND ENGINEERING

Machine Learning, **Dynamical Systems**, and Control

Steven L. Brunton • J. Nathan Kutz

![](_page_11_Picture_16.jpeg)

15

**Often EQUATIONS ARE UNKNOWN or partially known:** Model discovery with machine learning

## **NONLINEAR dynamics are still poorly understood:**

![](_page_12_Picture_2.jpeg)

## **HIGH-DIMENSIONALITY often obscures dynamics:**

![](_page_12_Picture_4.jpeg)

**Patterns exist, facilitating reduction** 

![](_page_13_Picture_0.jpeg)

![](_page_13_Picture_1.jpeg)

## **Open-Loop**

![](_page_14_Figure_1.jpeg)

# Relies on good model Can't stabilize unstable dynamics Over-reacts to noise and disturbances Not robust to uncertainties

![](_page_14_Figure_3.jpeg)

## Closed-Loop (Feedback)

![](_page_15_Figure_1.jpeg)

**Feedback signal** 

![](_page_15_Picture_3.jpeg)

## Time delays kill robust performance

## Limited Sensors (robustness vs. performance)

![](_page_16_Figure_1.jpeg)

## Model Predictive Control

![](_page_17_Figure_1.jpeg)

## **Bad Model**

![](_page_18_Picture_1.jpeg)

## Good Model

![](_page_18_Picture_3.jpeg)

## **Playing Atari Games**

![](_page_19_Picture_1.jpeg)

## **Robot Catch**

Reinforcement Learning: Policy after 15 Trials Kober, J.; Peters, J.; Learning Motor Primitives in Robotics

![](_page_20_Picture_3.jpeg)

## First Steps

![](_page_21_Picture_1.jpeg)