Computing to understand complex systems
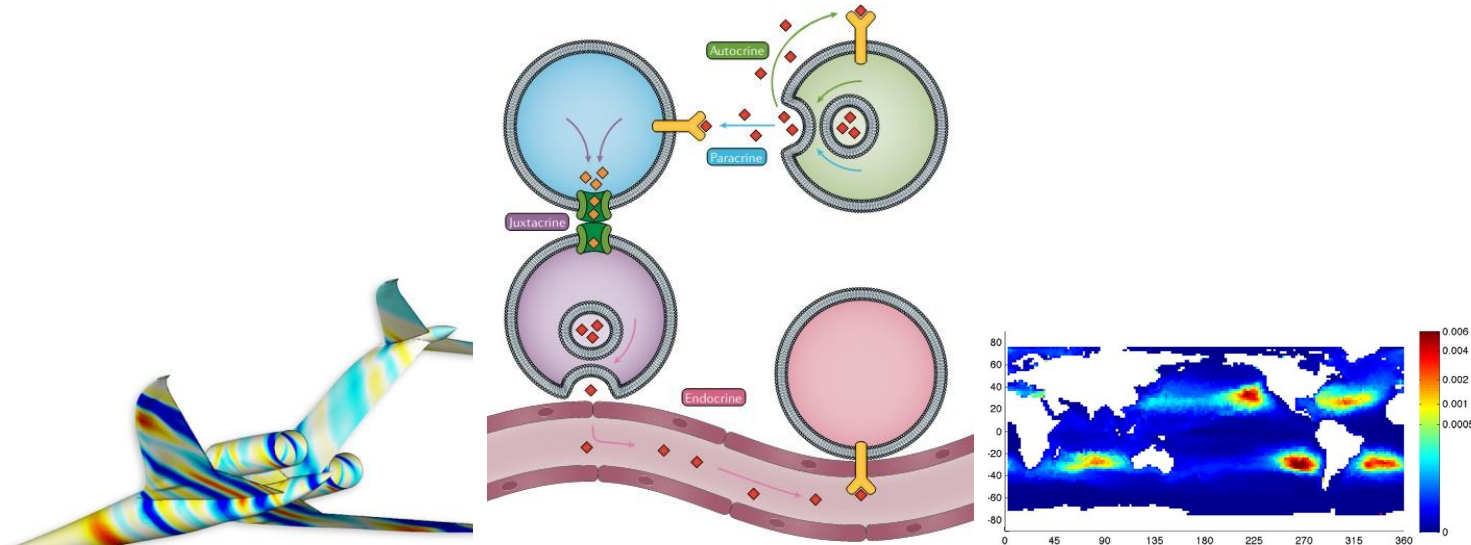
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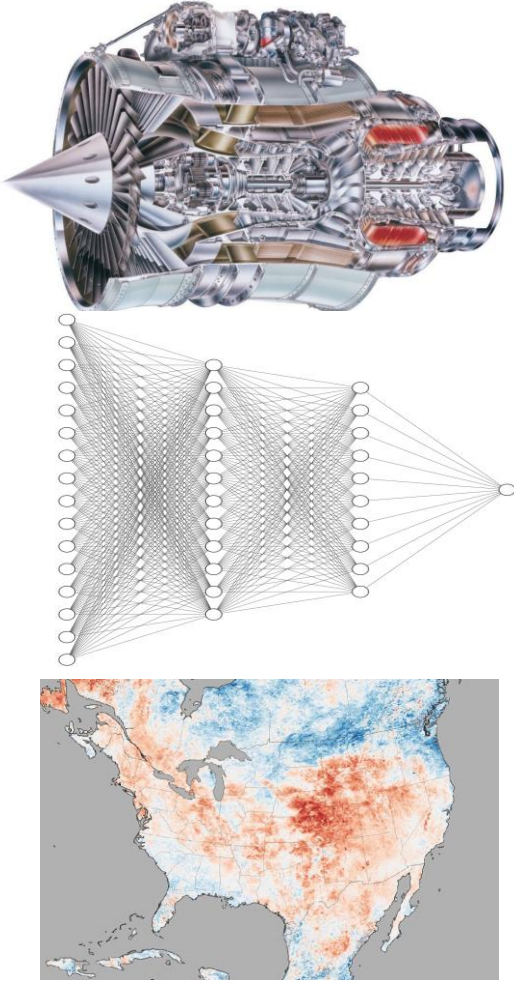
Computational dynamics + statistics

▶ **Goal**: To answer fundamental scientific questions around complex dynamics
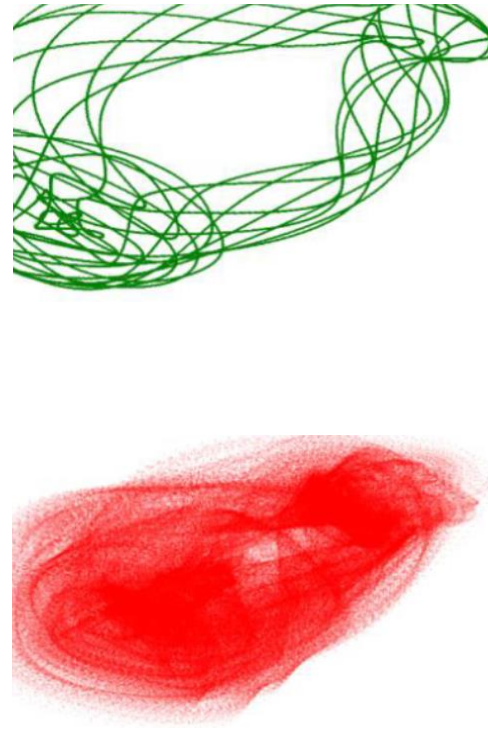

Left: Aftosmis et al 2015; Center: Armingol et al 2021; Right: Froyland et al 2014
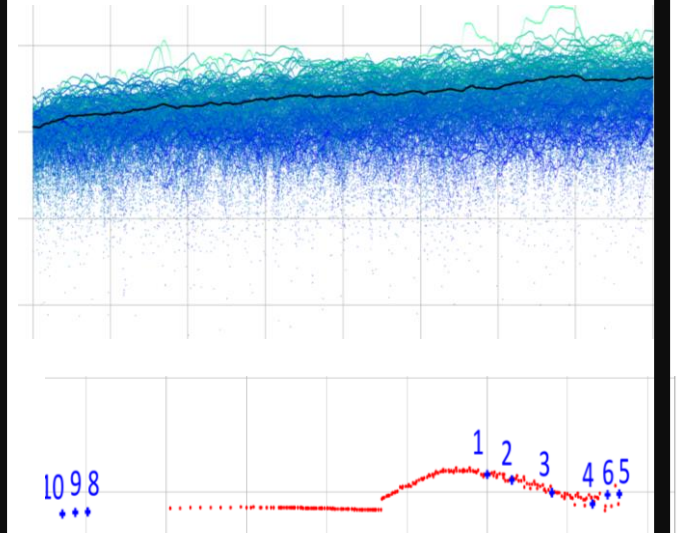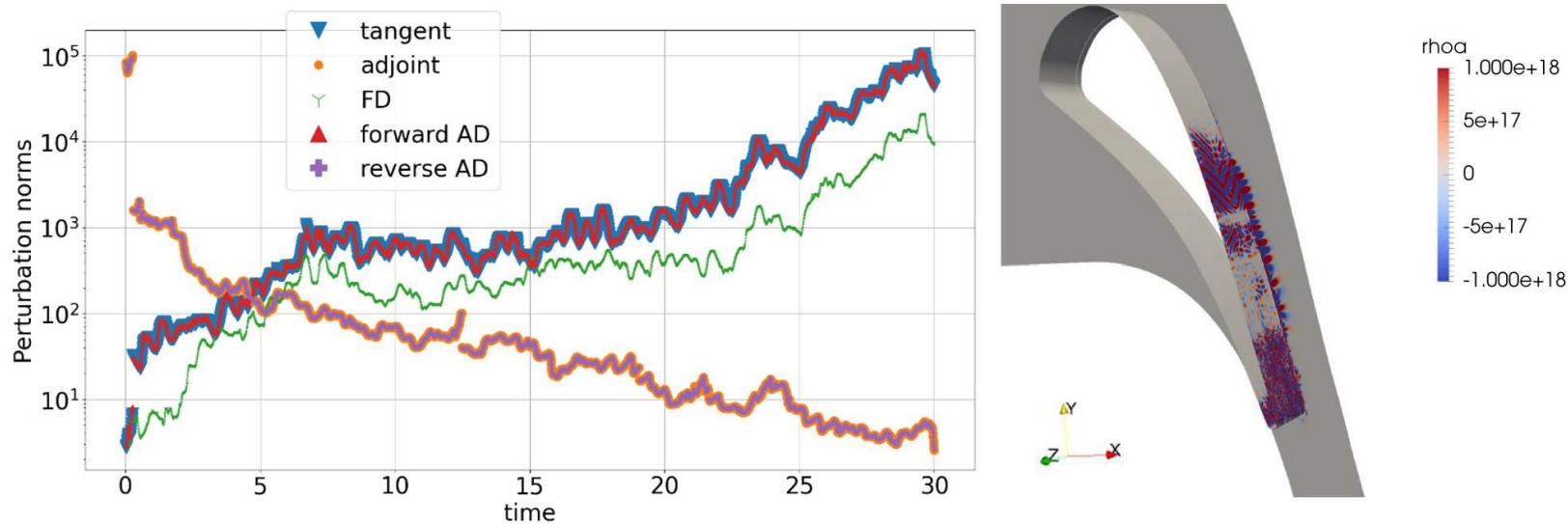
Application areas

Information from numerical models

Computational methods development

- Optimization and design
- Sensitivity analysis and control
- Order reduction
- Data assimilation

Insights obtained from rigorous algorithms and analyses
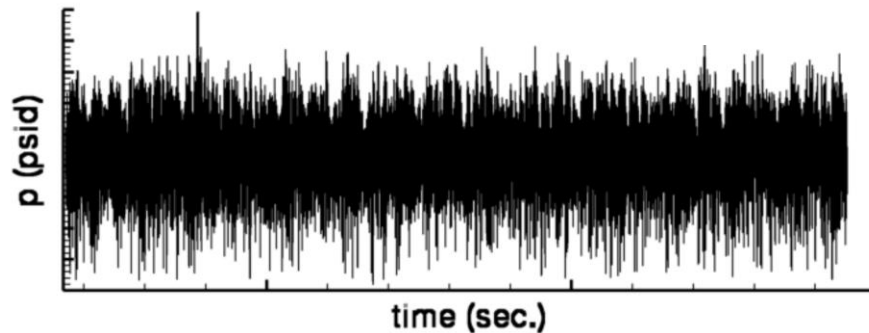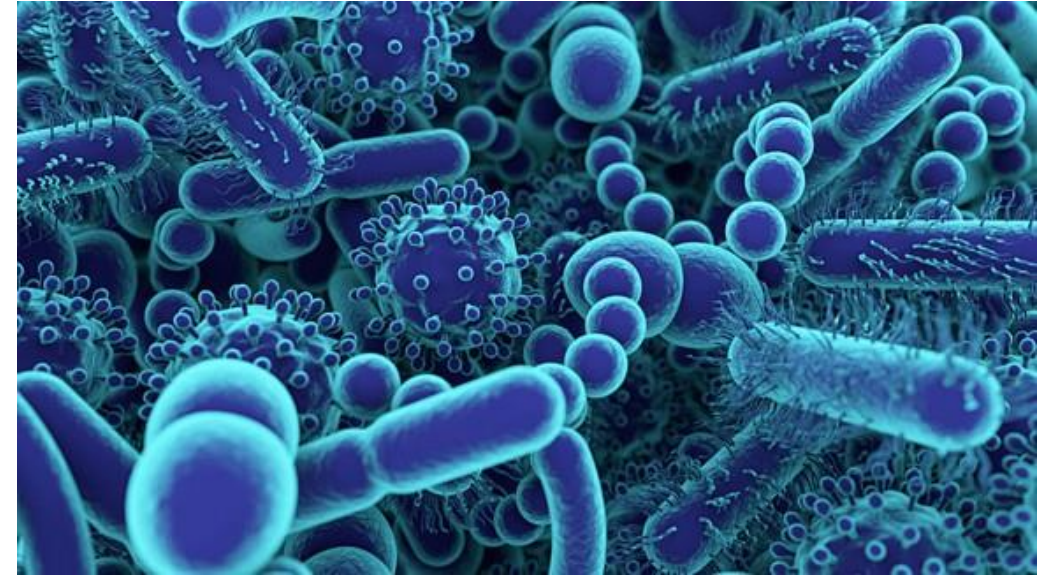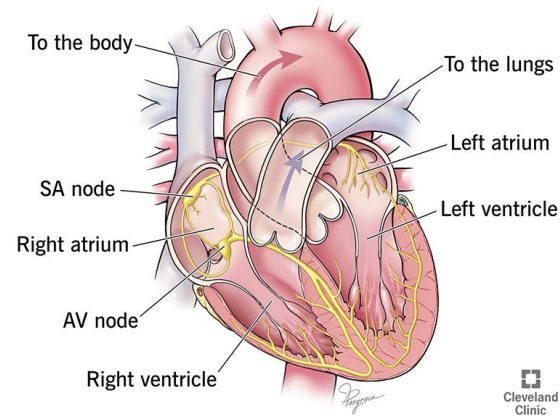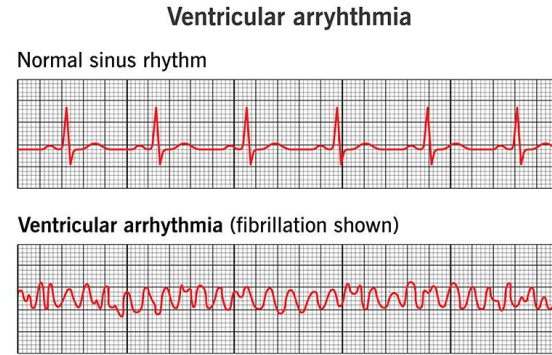
Computing with **chaotic** systems

Goal: Tractable computation of **linear response**

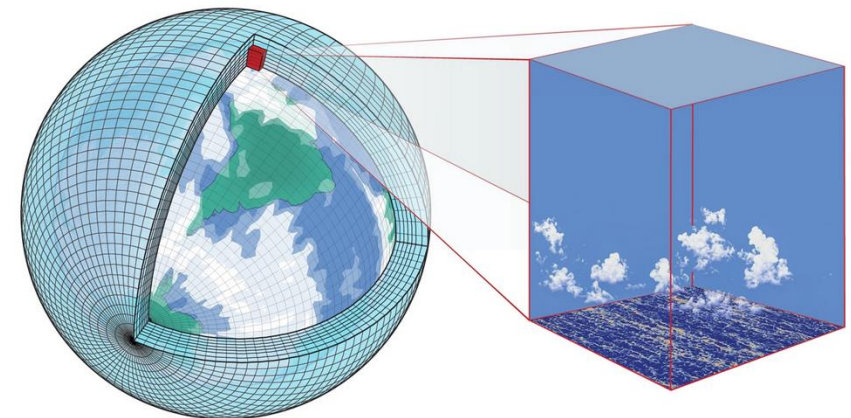$$\frac{d}{ds} \lim_{N \to \infty} \langle J \rangle_N \,, \tag{1}$$

s: Design input, $\langle J \rangle_N$: N-time average of an observable J.
Downstream applications: optimization, data assimilation, model
selection, mechanistic understanding etc.

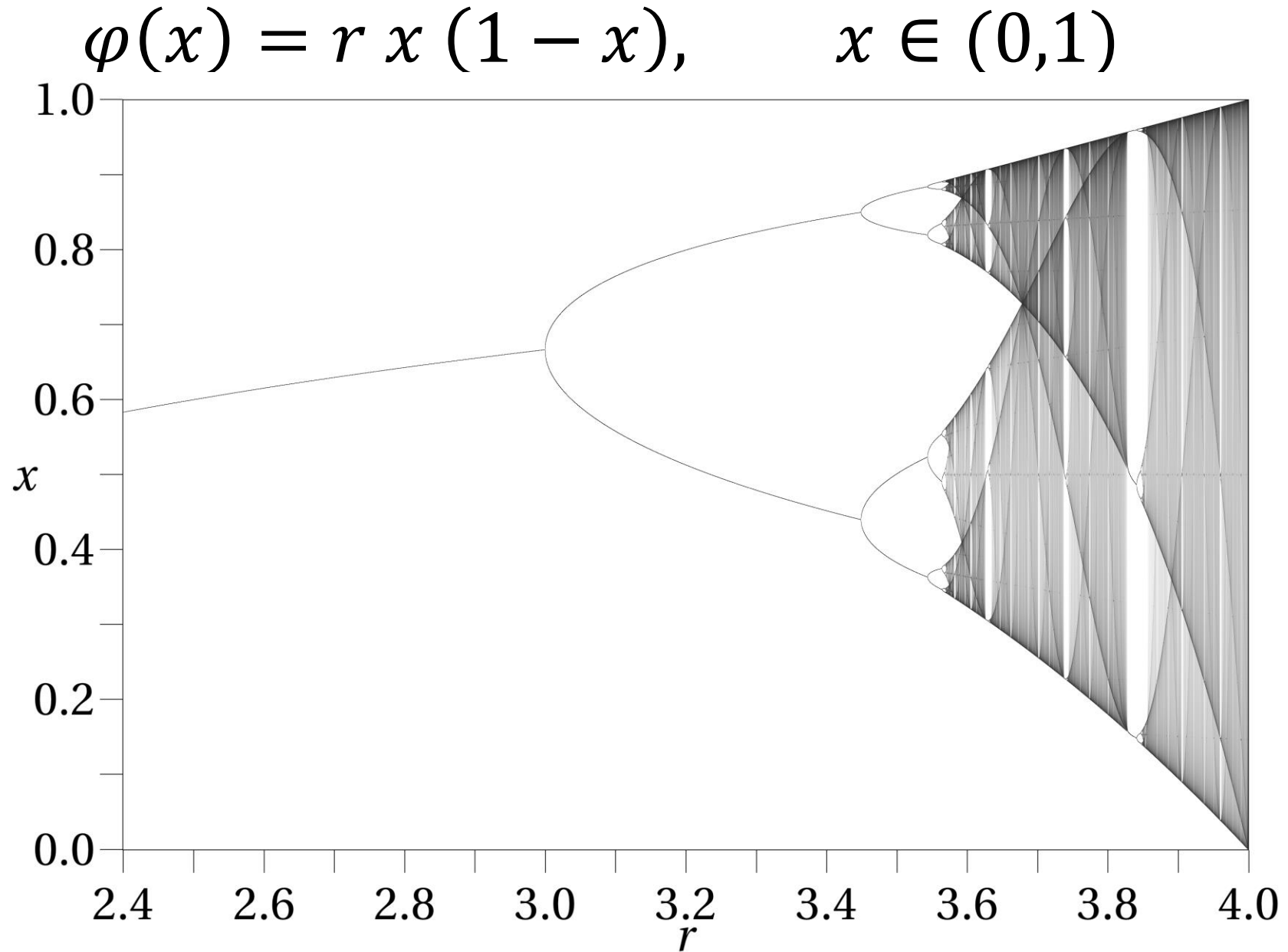# Computing **sensitivities** will help with UQ, optimization

Ventricular arryhthmia

Normal sinus rhythm

Ventricular arrhythmia (fibrillation shown)

To the body
To the lungs
Left atrium
SA node
Left ventricle
Right atrium
AV node
Right ventricle

Cleveland Clinic ©2021

p (psid)

time (sec.)

Alter et al 2015

Schneider, T., Teixeira, J., Bretherton, C. et al. 2017

Today: the logistic map

$$\varphi(x) = r\, x\, (1 - x), \qquad x \in (0,1)$$
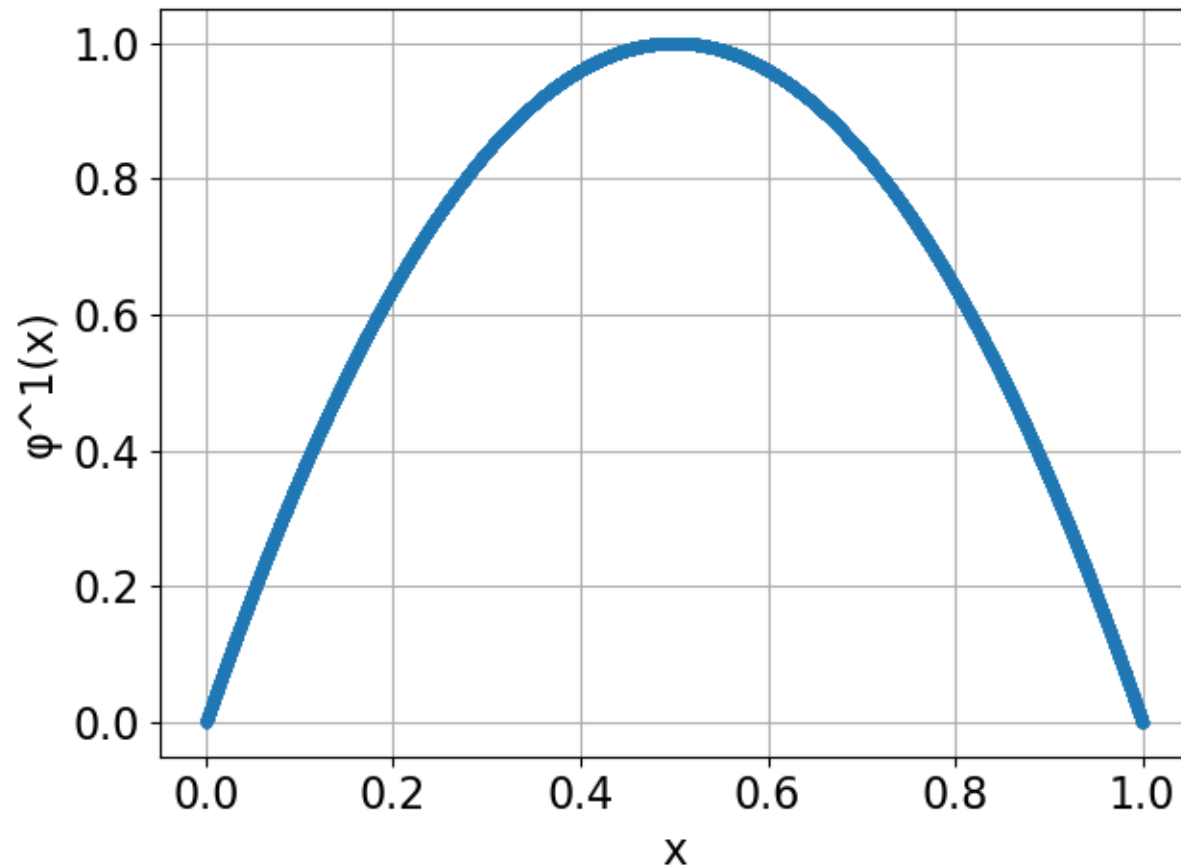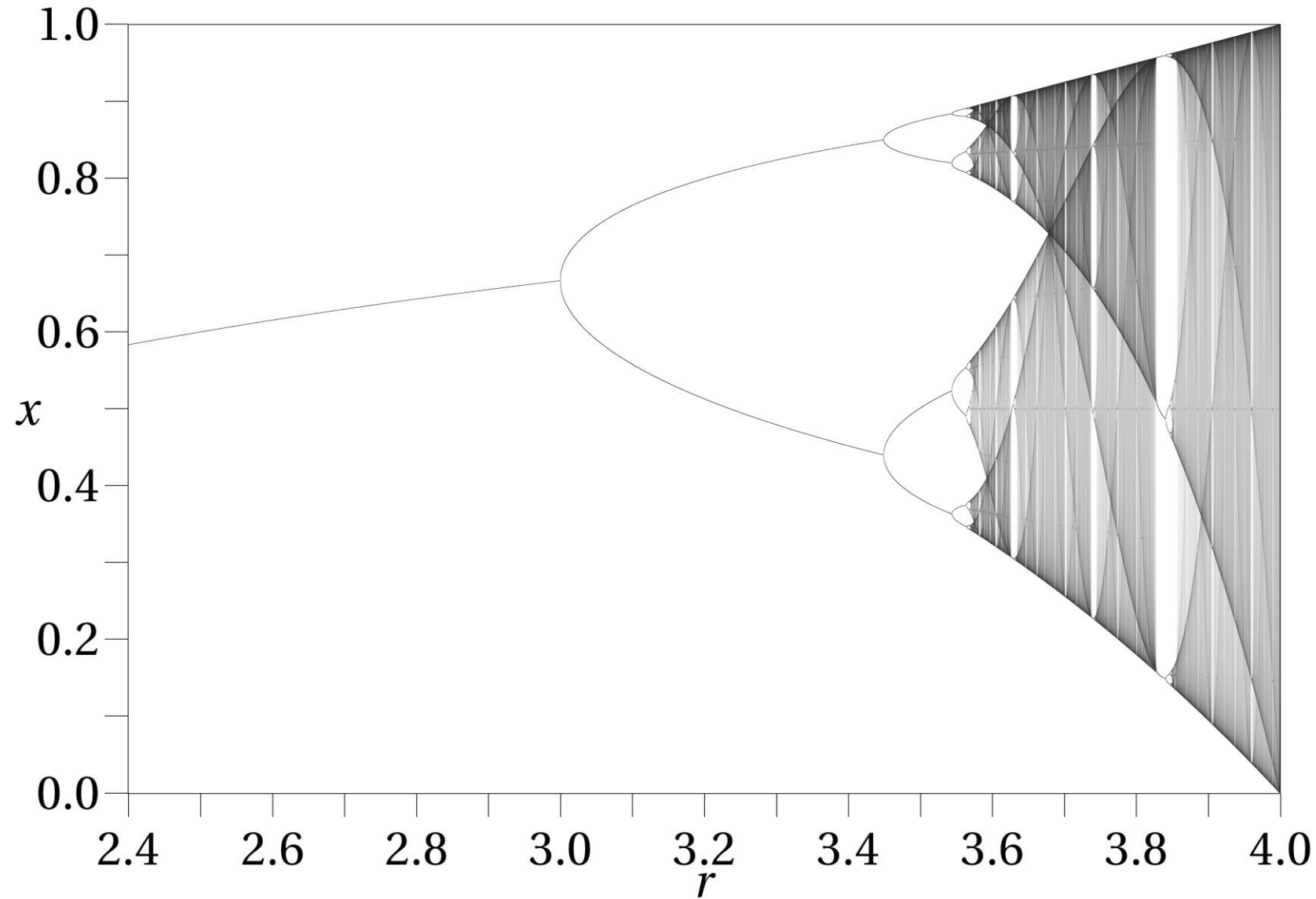
Today: the logistic map

$$\varphi(x) = r\,x\,(1-x), \qquad x \in (0,1)$$

Orbit: $\quad x, \varphi(x), \varphi^2(x), \varphi^3(x), \varphi^4(x), \dots, \varphi^{10}(x), \dots, \varphi^{1000}(x), \dots$

Bifurcations: qualitatively different behavior of orbits as parameters are varied
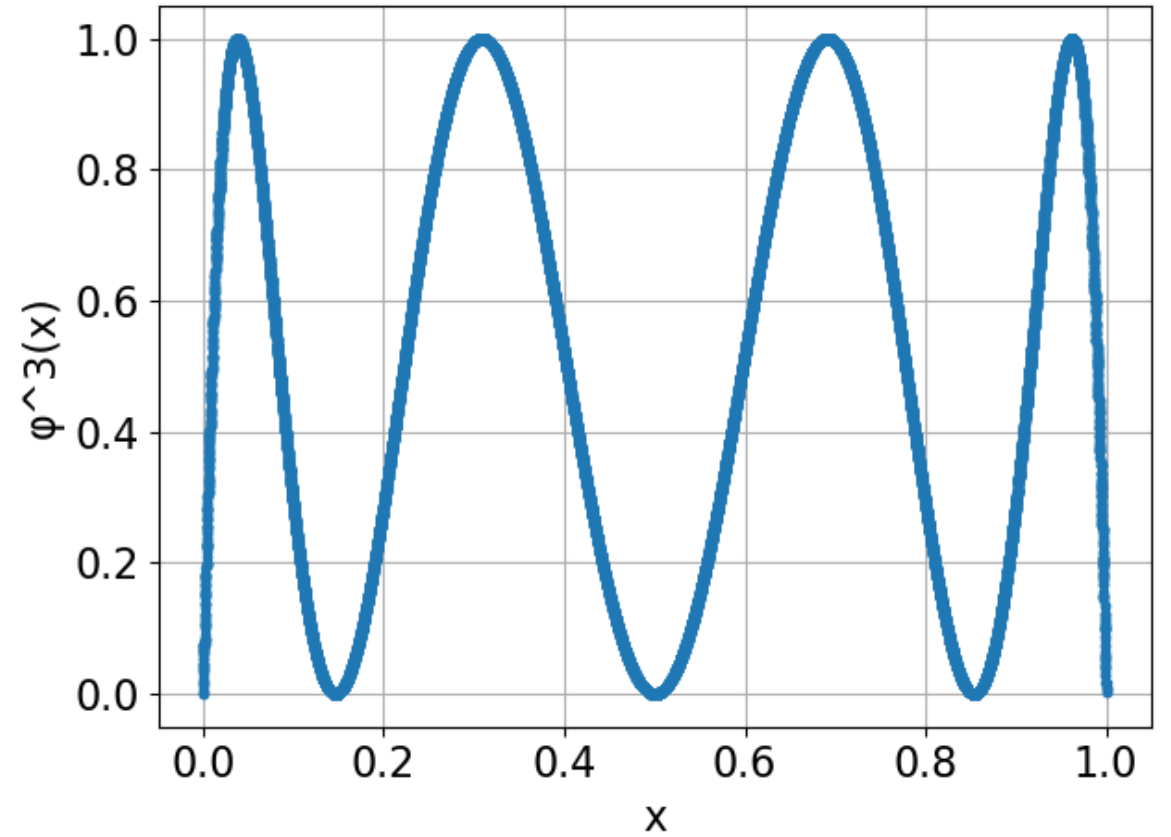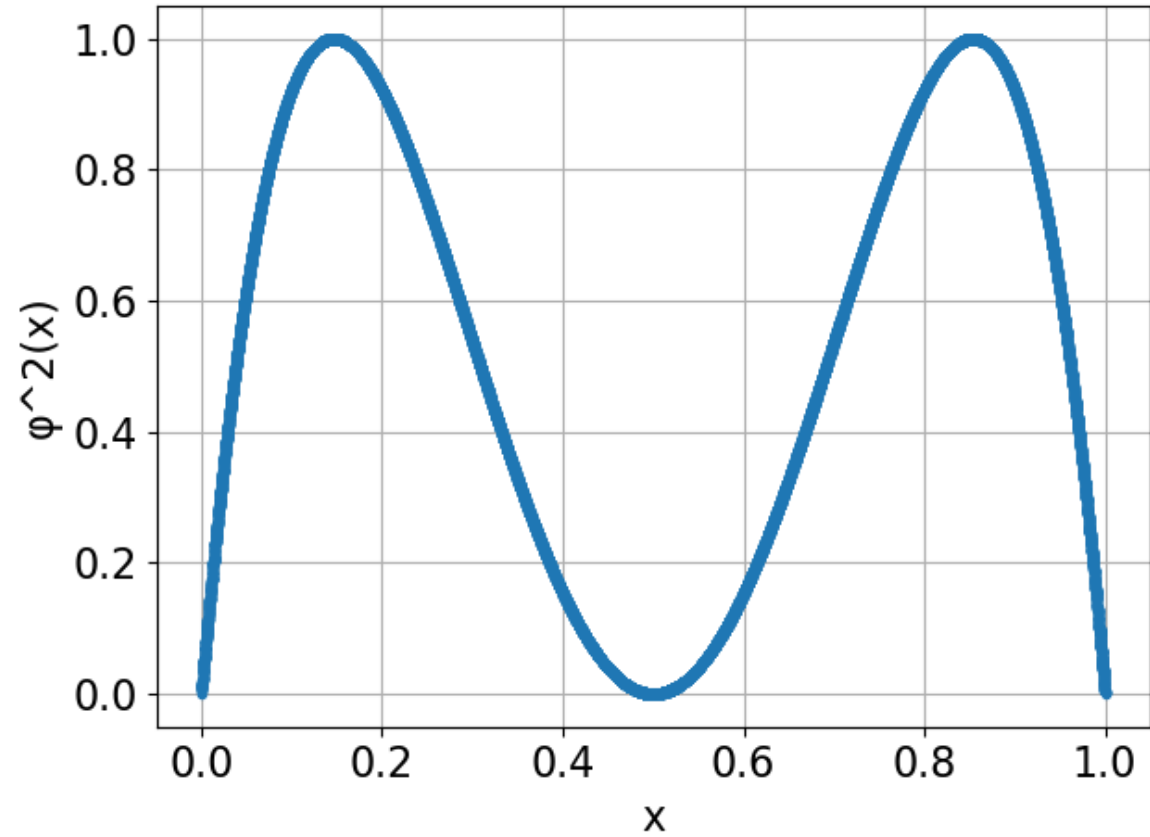

- Introduced chaos to the world of ecology
- Model of competition within a population
- Number of competing interactions quadratic
- X refers to percent of maximum population
- Fix rate r = 4
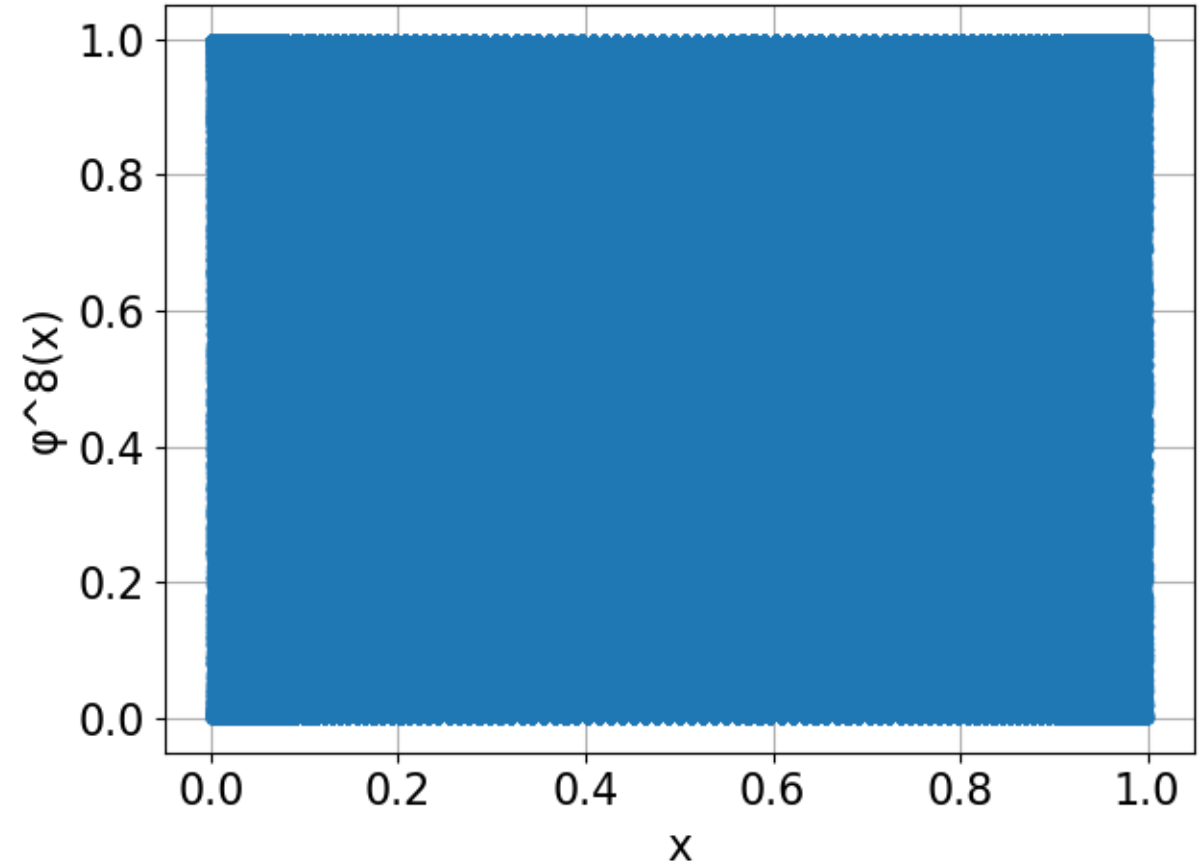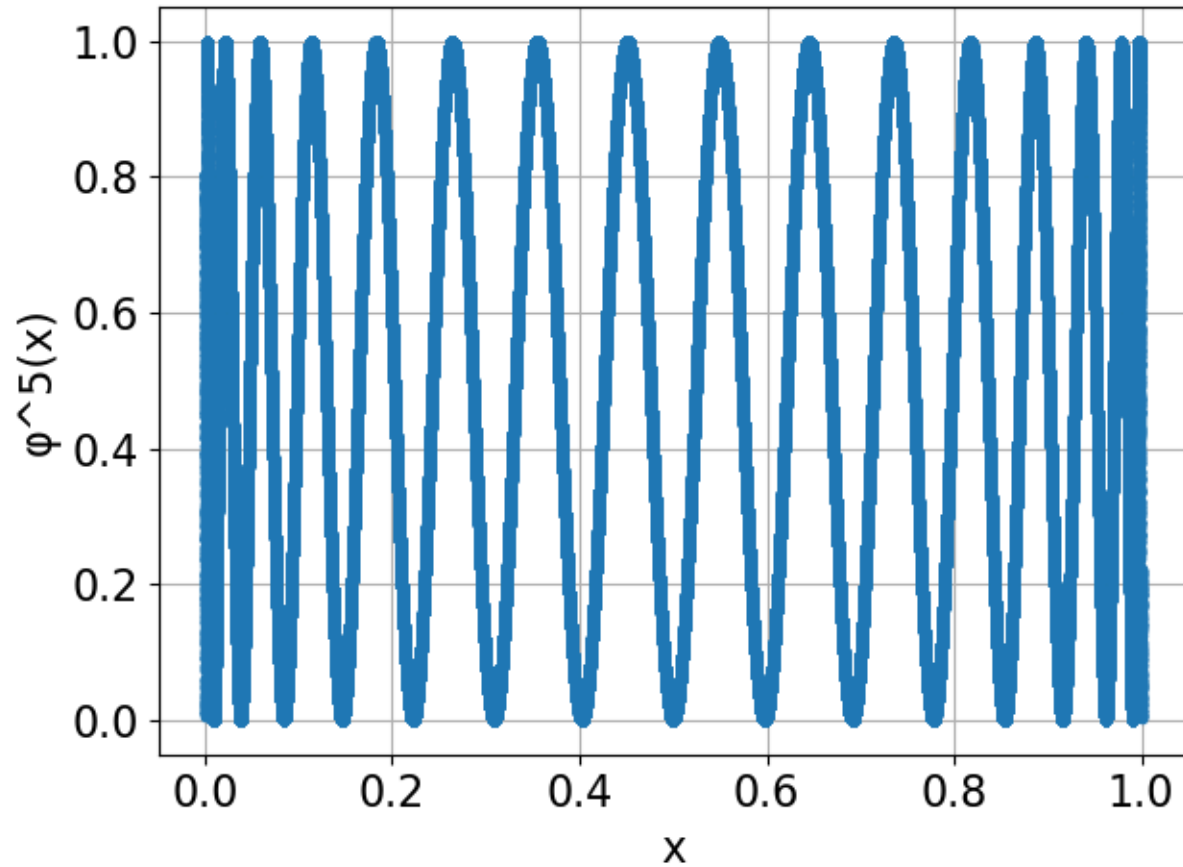- Question: at a given time, is the population as likely to be < 50 percent as > 50 percent?

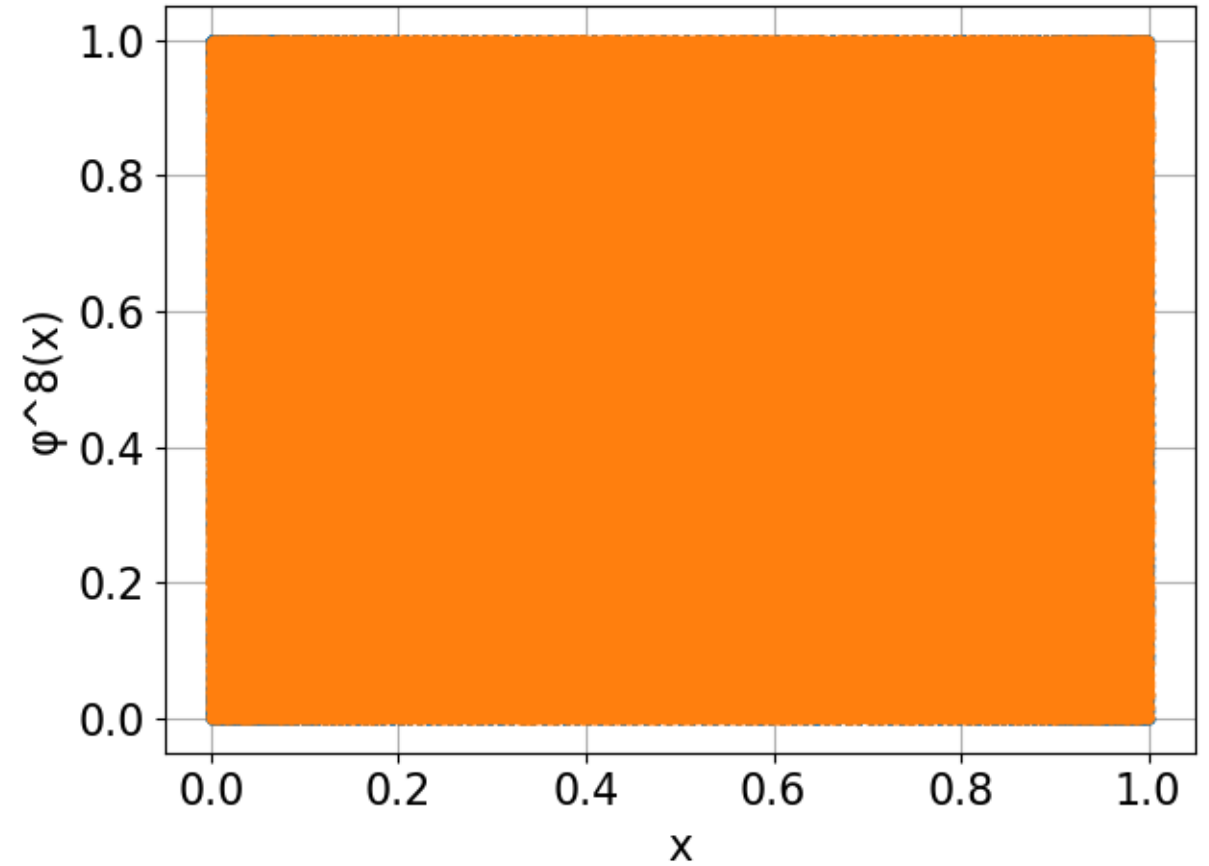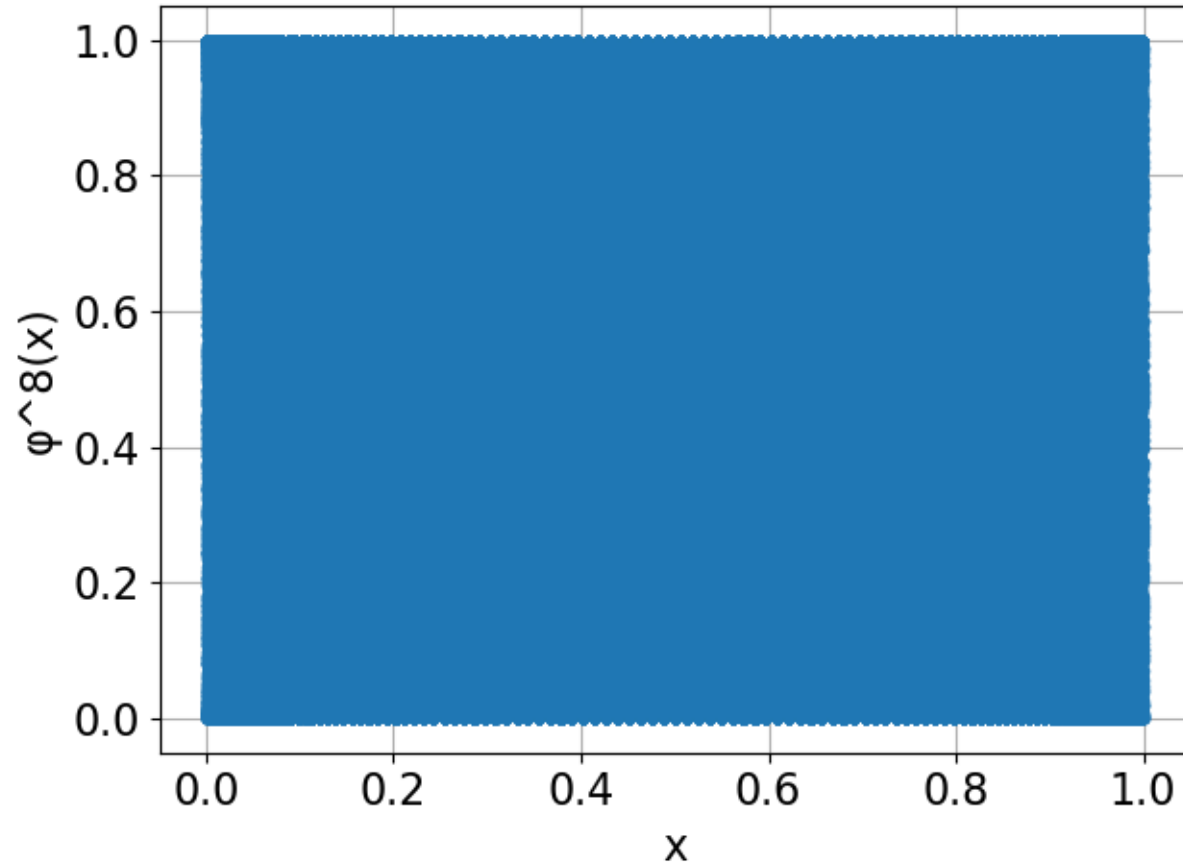# Evolution of ensembles under the dynamics
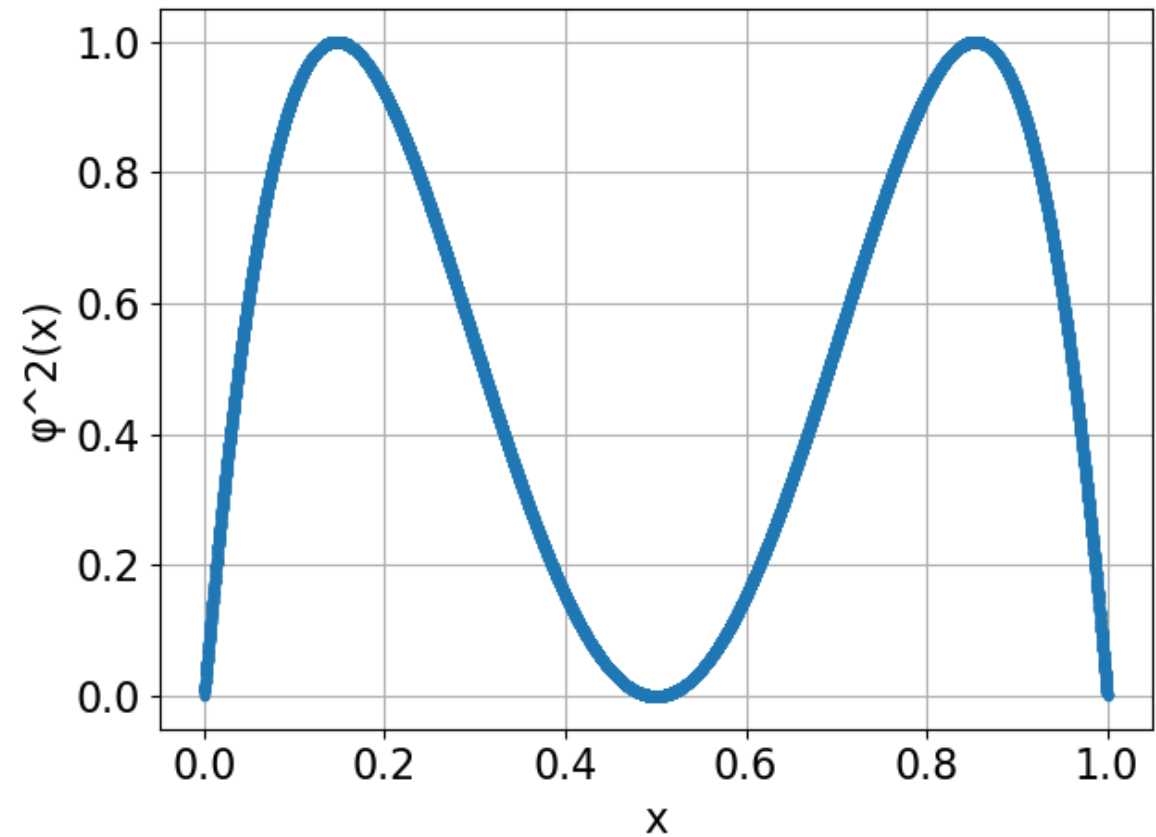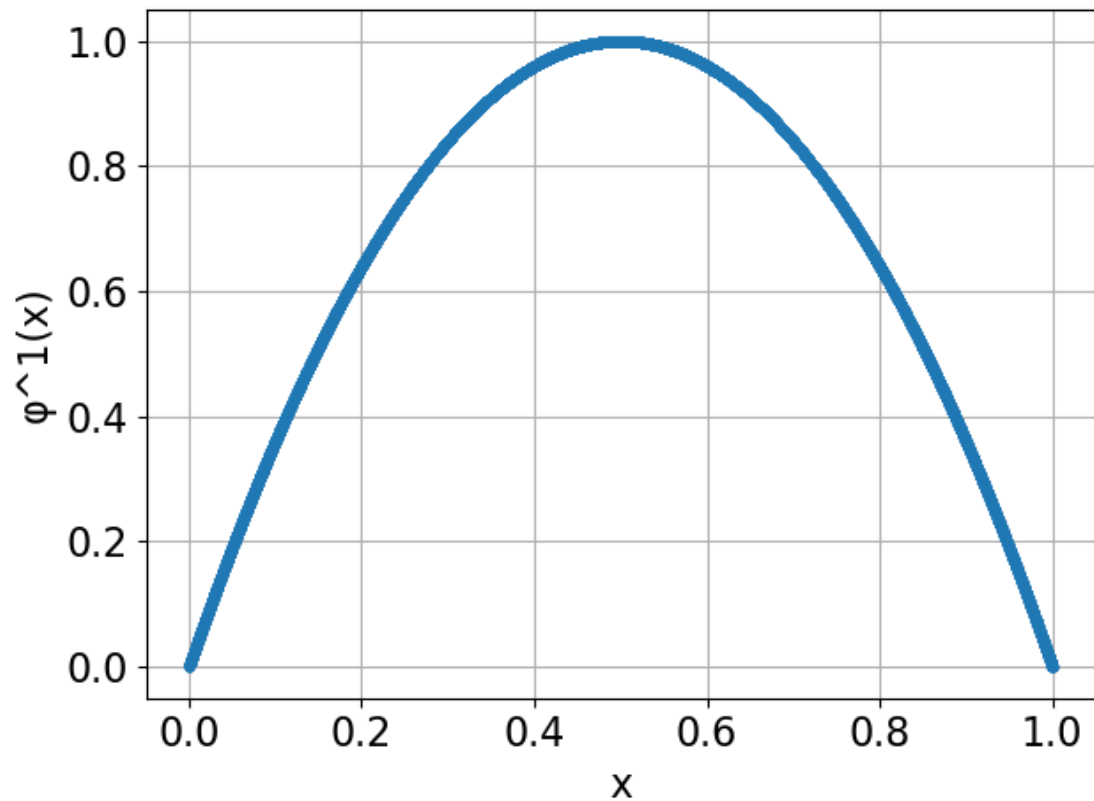
Long-term dynamical behavior of orbits

# Chaotic systems: deterministic but appear random

Chaotic systems: deterministic but appear random

Circuit Playground Express kit

1. This is a small easy-to-program electronics board with built-in sensors and LEDs
2. We will use Javascript editor: https://makecode.adafruit.com
3. Write program
4. Connect board to laptop through USB
5. Remove from laptop, connect to battery and see results
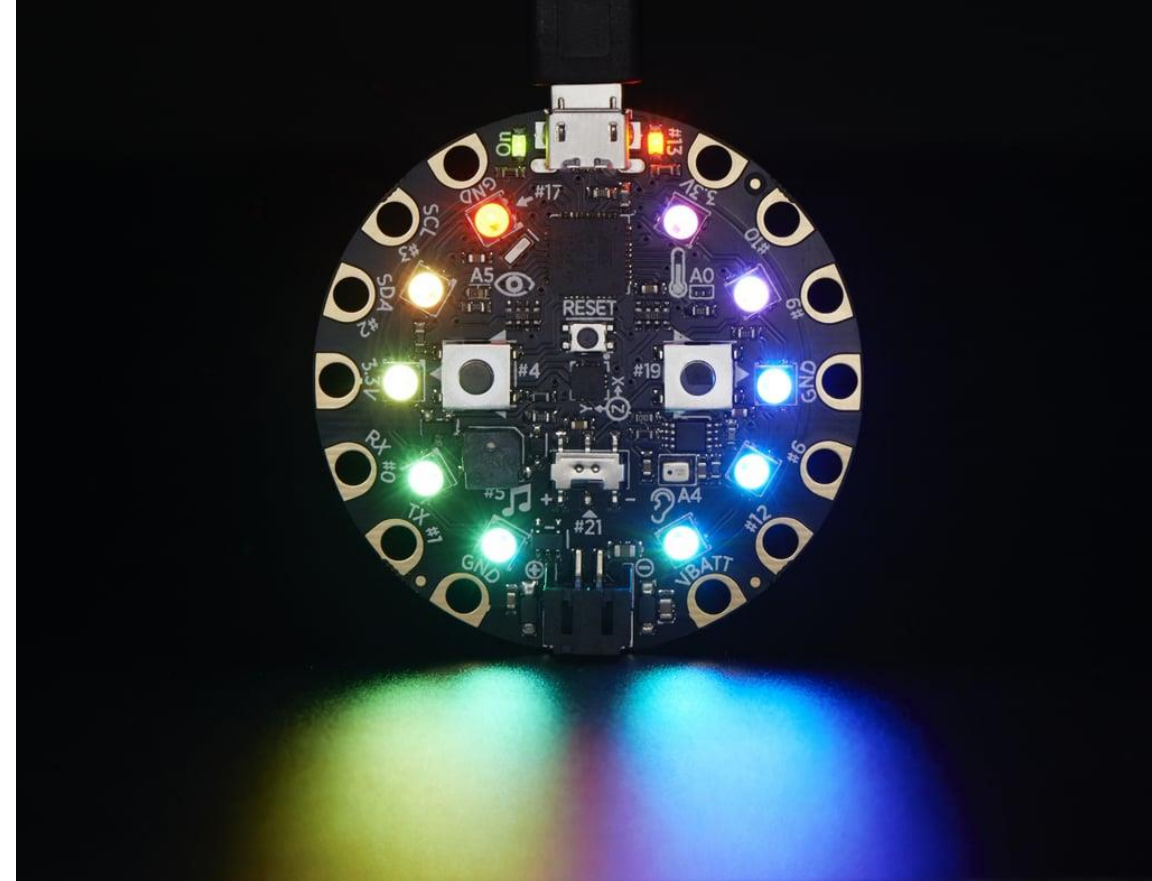
Adafruit's resources

Main manual: https://cdn-learn.adafruit.com/downloads/pdf/adafruit-circuit-playground-express.pdf

Hundreds of examples on makecode.adafruit.com

Can also use CircuitPython IDEs

Question 1: At any time, is x equally likely to be less than and greater than 0.5?

Question 2: Is x < 0.25 equally likely as 0.25 < x < 0.5?

See or hear your answer!

Be creative!