



Computing to understand complex systems

Nisha Chandramoorthy
Assistant Professor, CSE, Georgia Tech

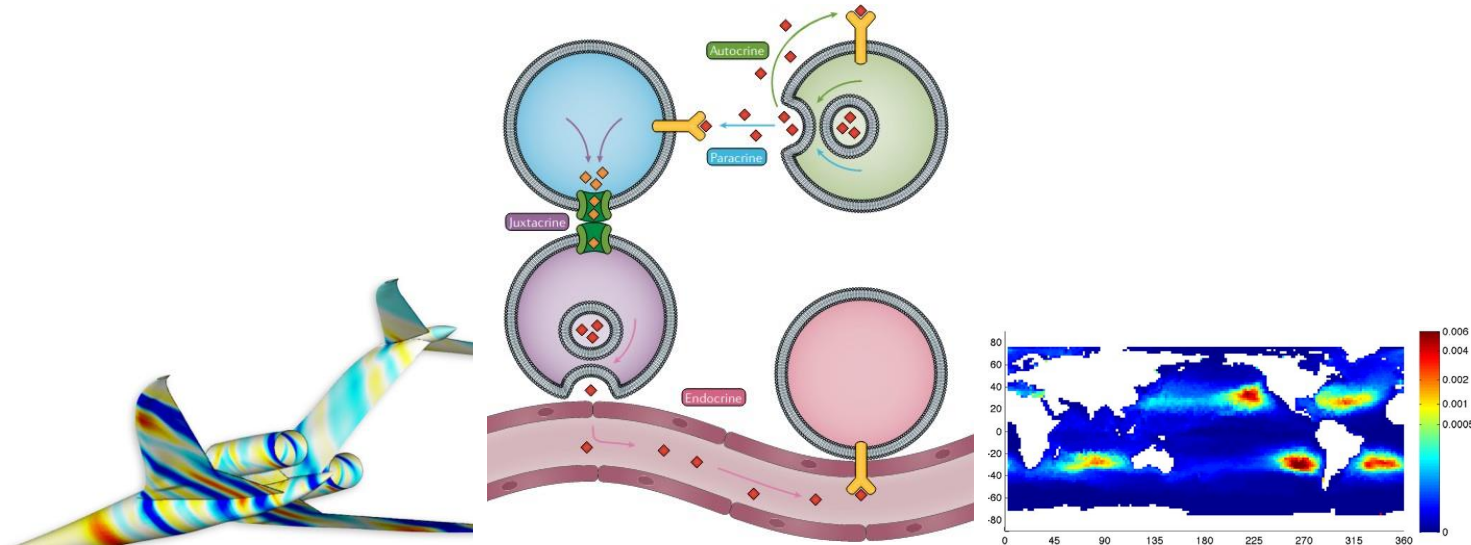
Email: nishac@gatech.edu

Today's goal: interactive learning!

1. What engineering and scientific questions are they interested in?
2. How do they construct and use mathematical models to answer those questions?
3. How do they build and use machine learning tools for those questions?
4. What background does one need for these questions?
5. What are related career options for someone in their field?
6. What does the day-to-day of that researcher entail?

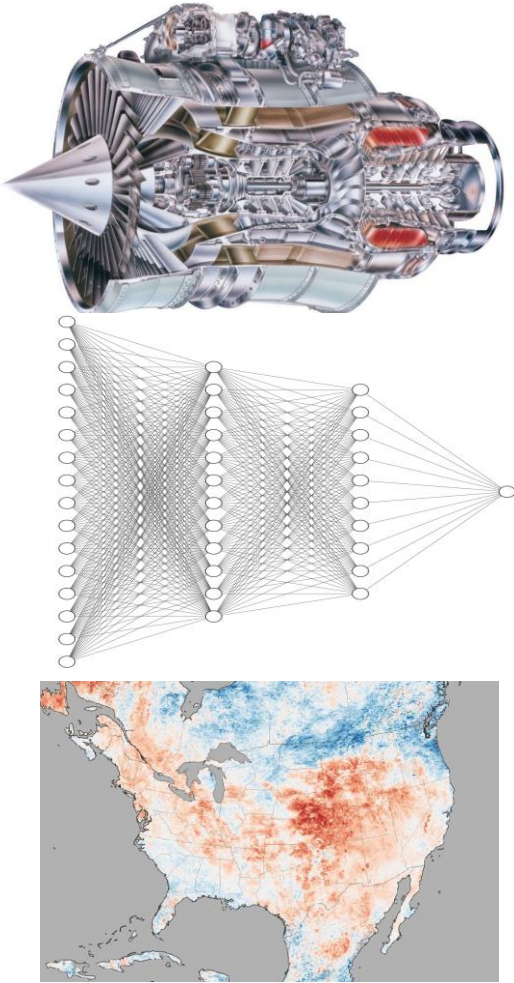
Computational dynamics + statistics

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

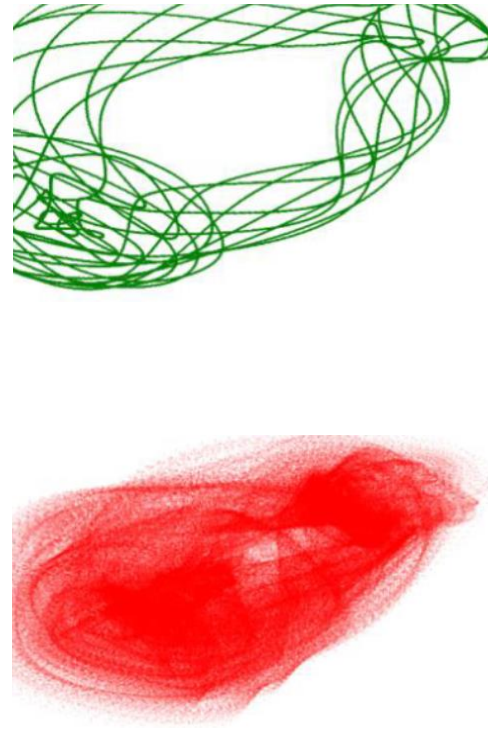


Left: Aftosmis et al 2015; Center: Armingol et al 2021; Right: Froyland et al 2014

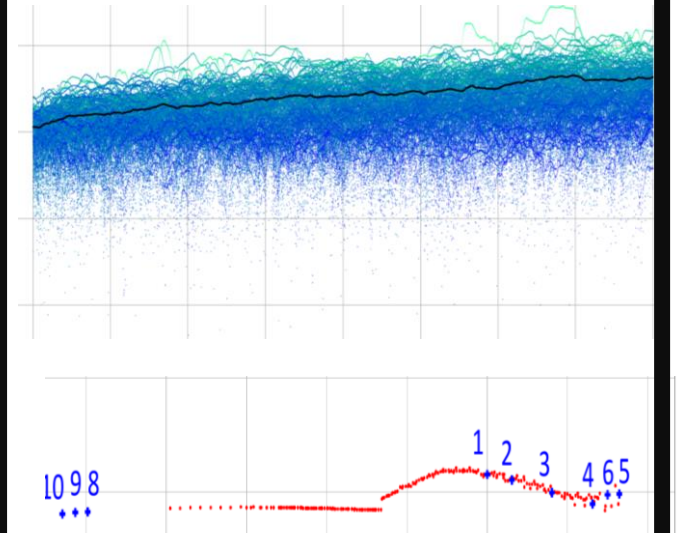
Application areas



Information from numerical models



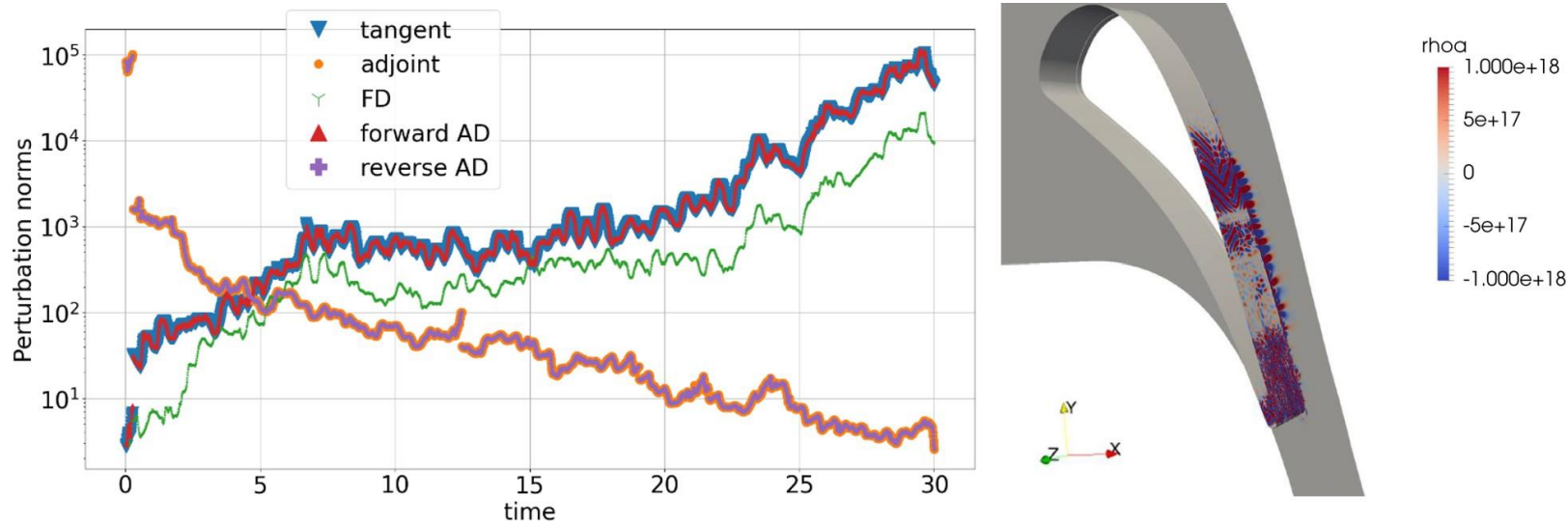
Computational methods development



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

Insights obtained from rigorous algorithms and analyses

Computing with **chaotic** systems



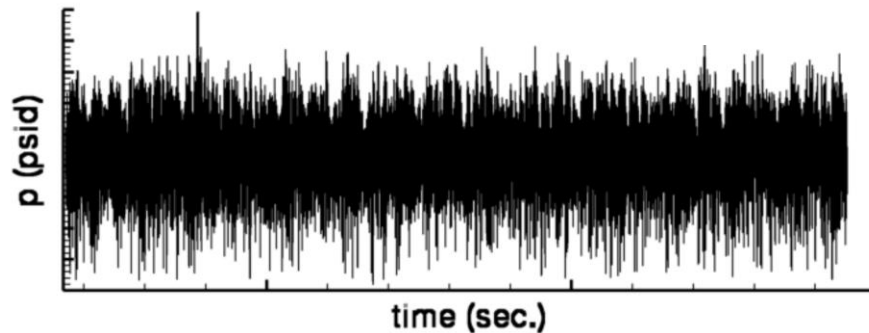
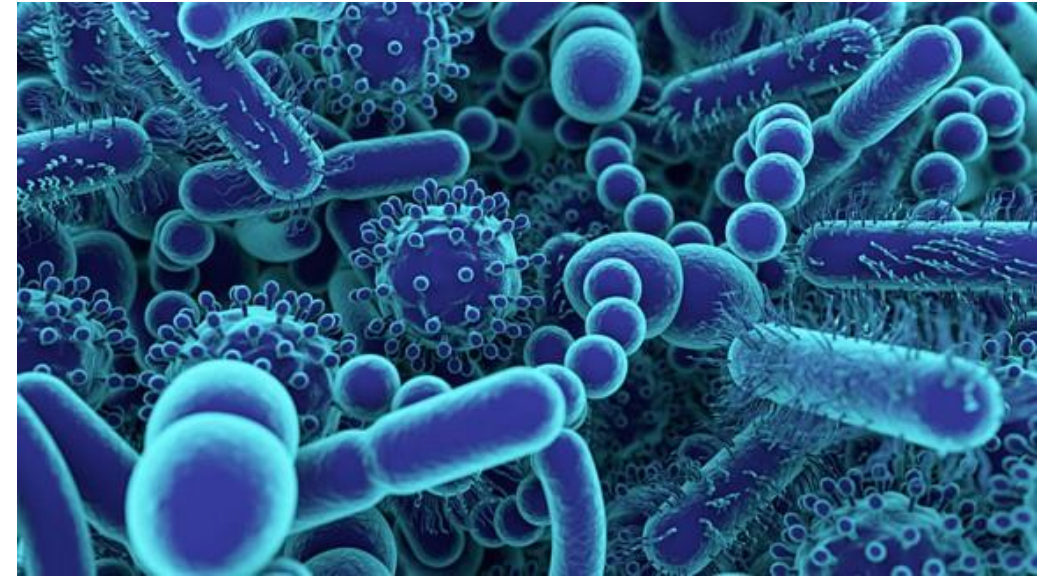
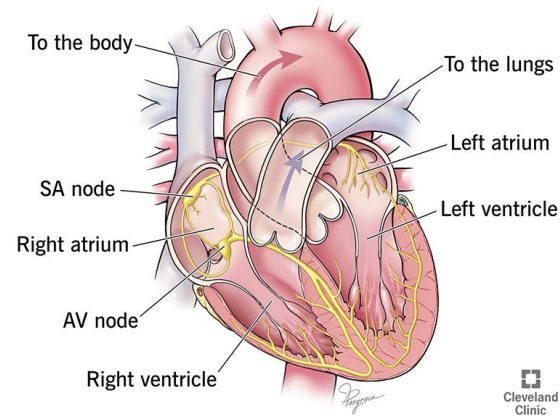
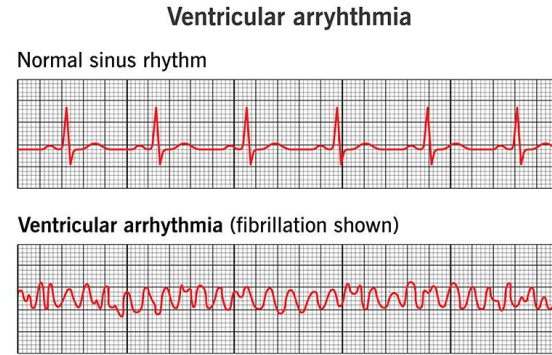
Goal: Tractable computation of **linear response**

$$\frac{d}{ds} \lim_{N \rightarrow \infty} \langle J \rangle_N, \quad (1)$$

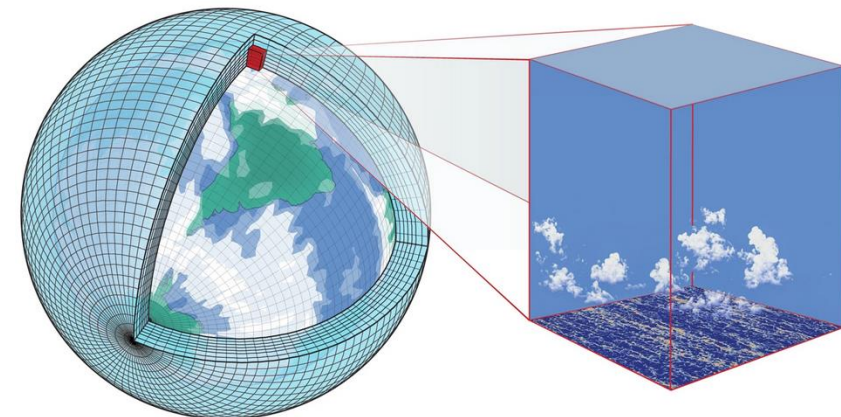
s: **Design input**, $\langle J \rangle_N$: N-time average of an observable J.

Downstream applications: optimization, data assimilation, model selection, mechanistic understanding etc.

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

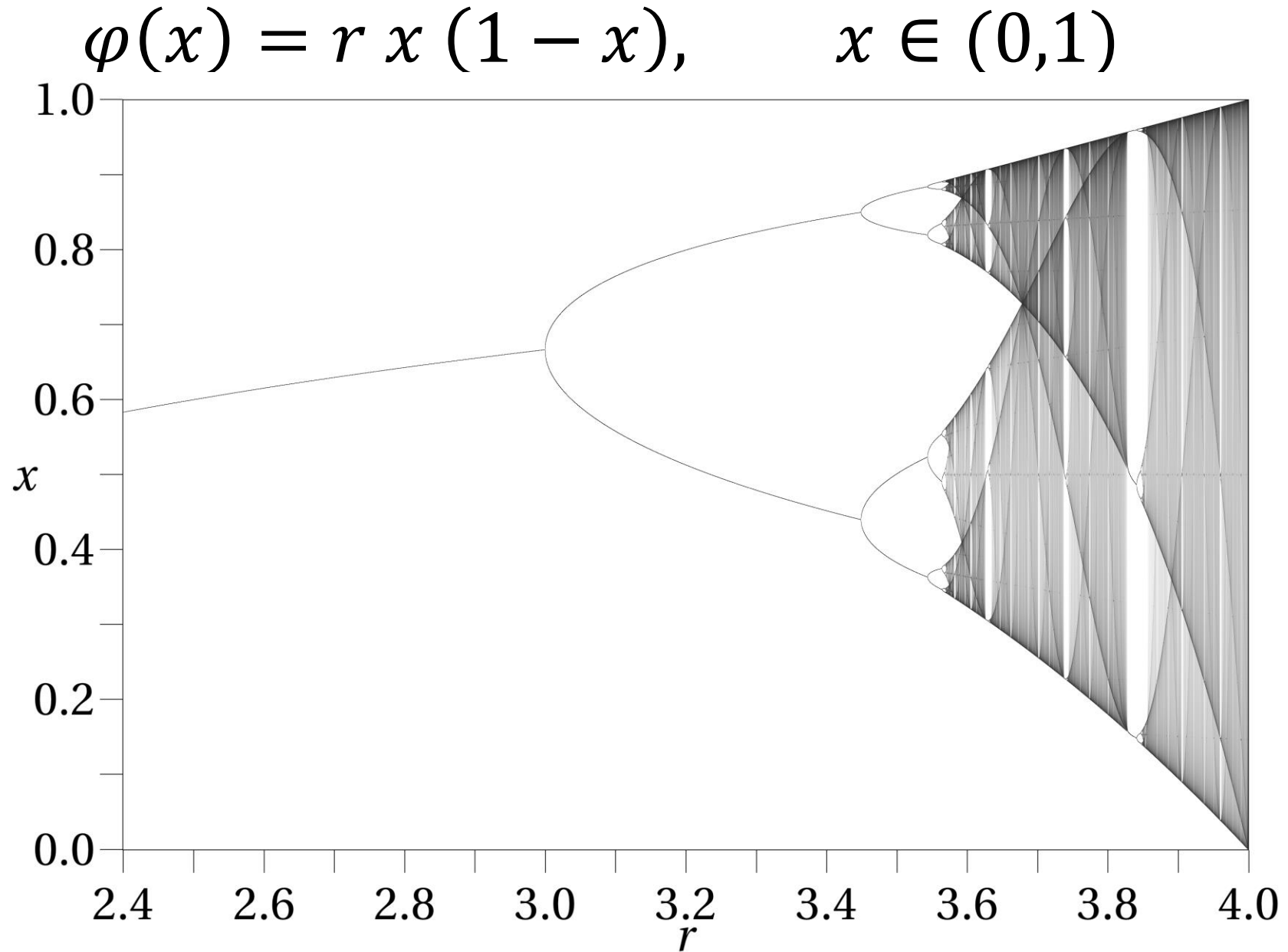


Alter et al 2015



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

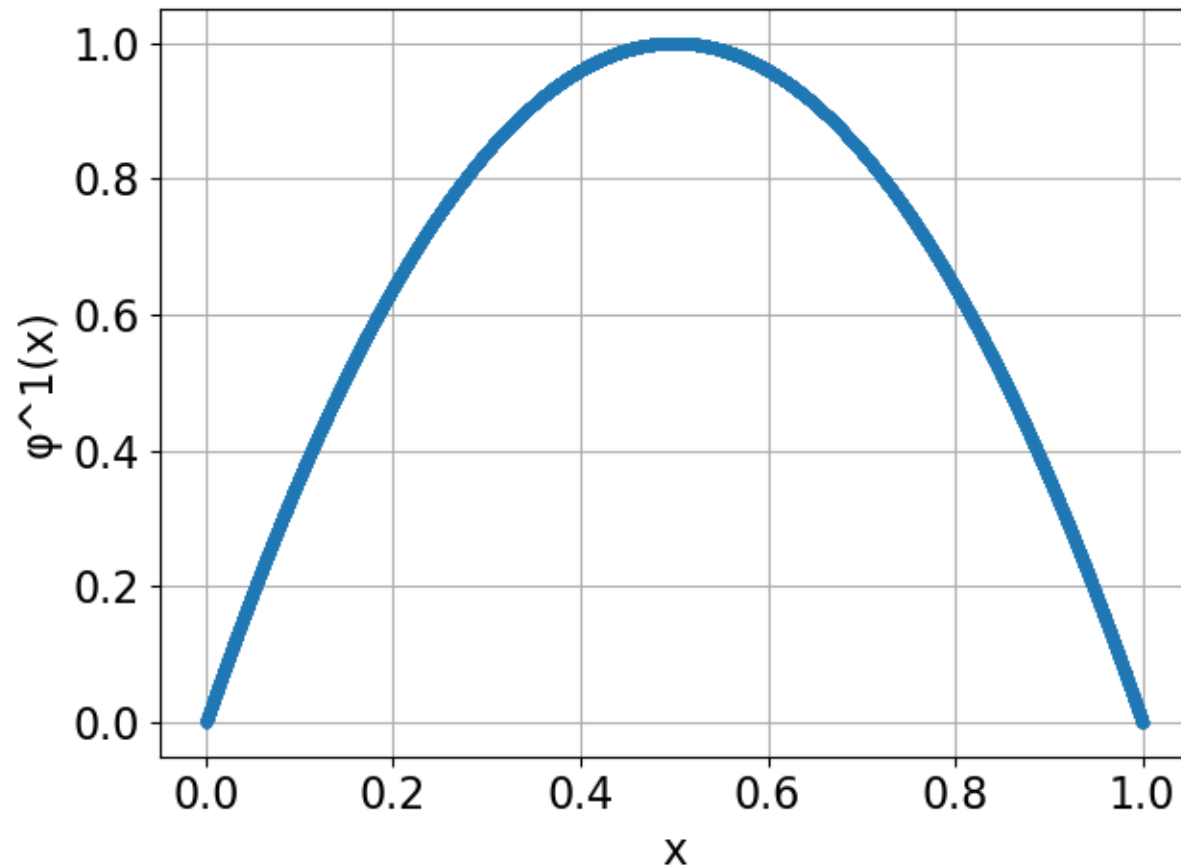
Today: the logistic map



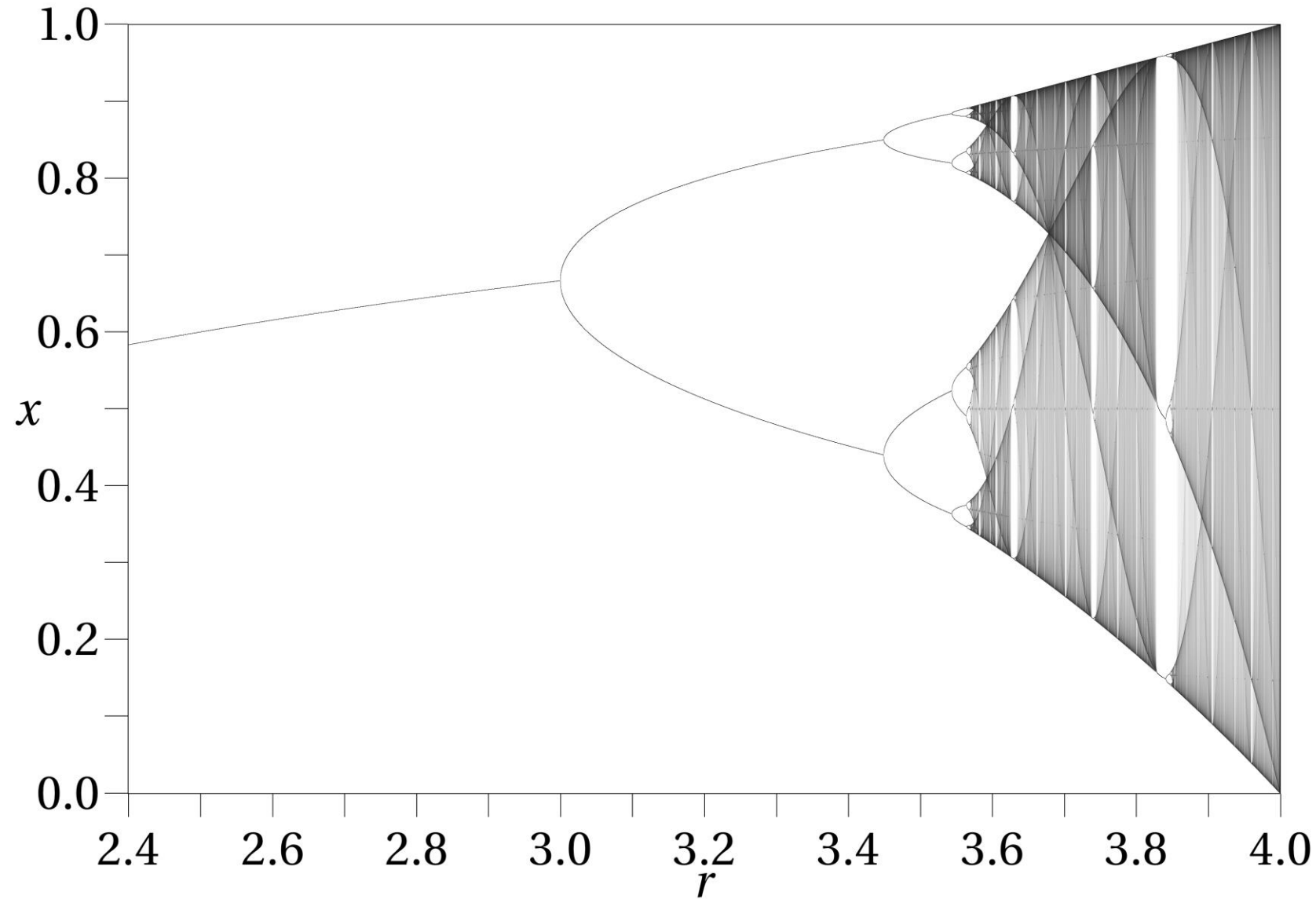
Today: the logistic map

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

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

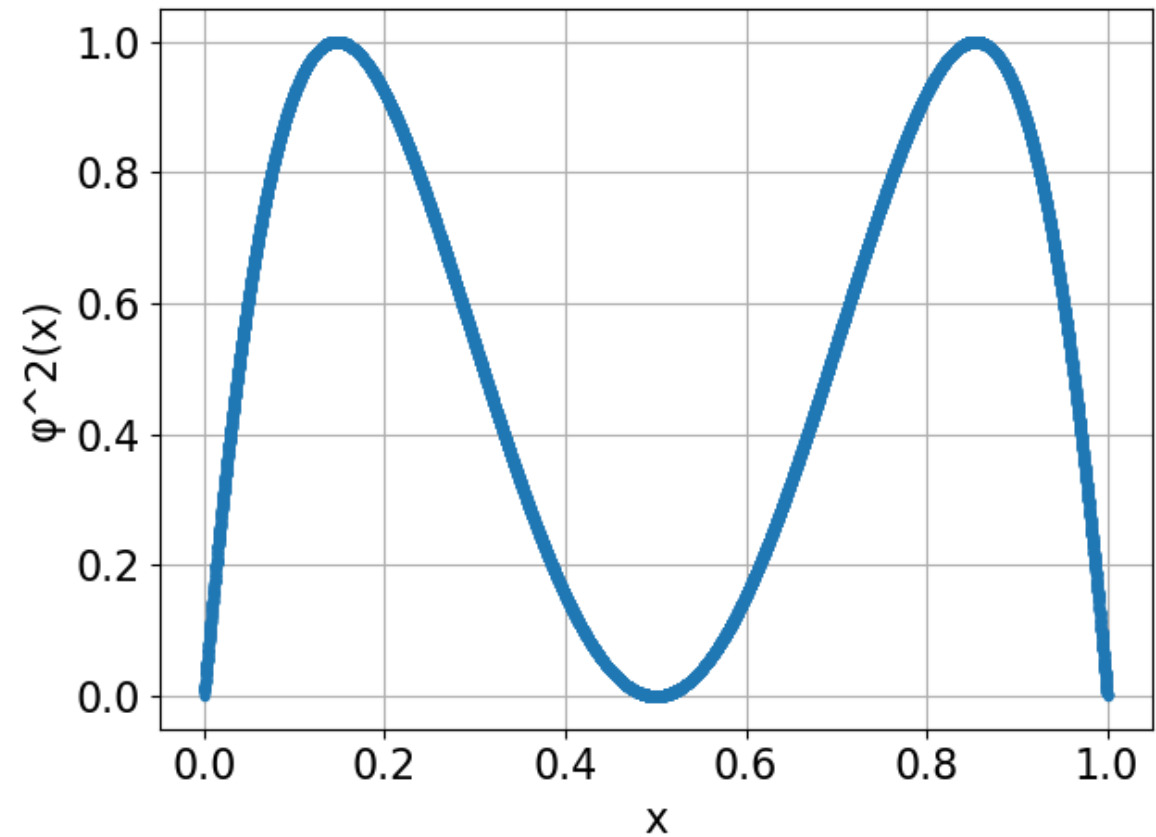
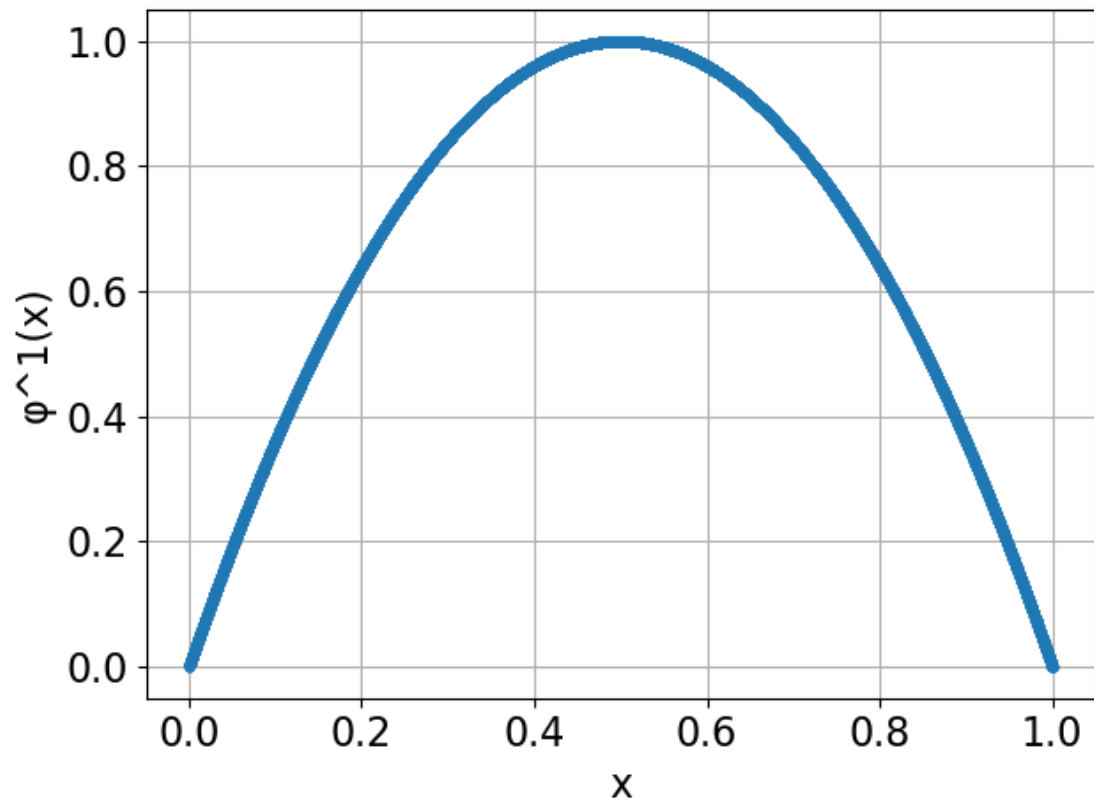


Bifurcations: qualitatively different behavior of orbits as parameters are varied

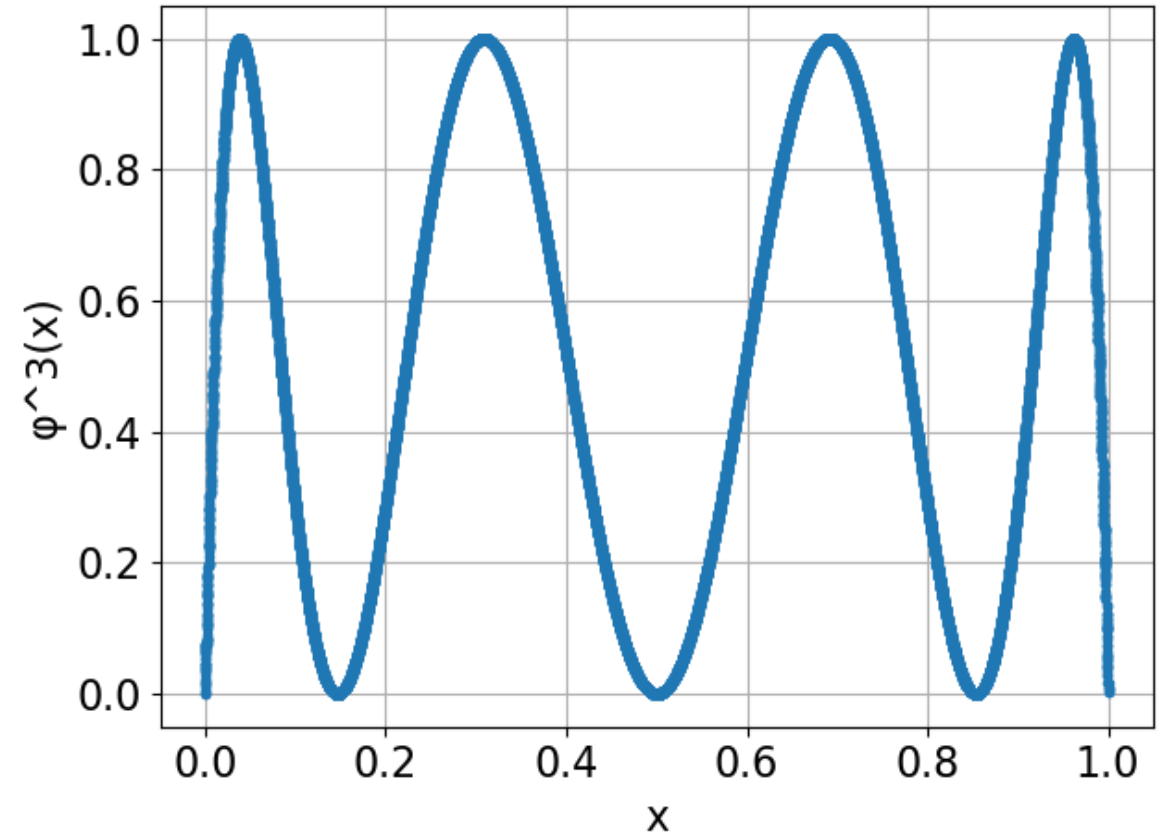
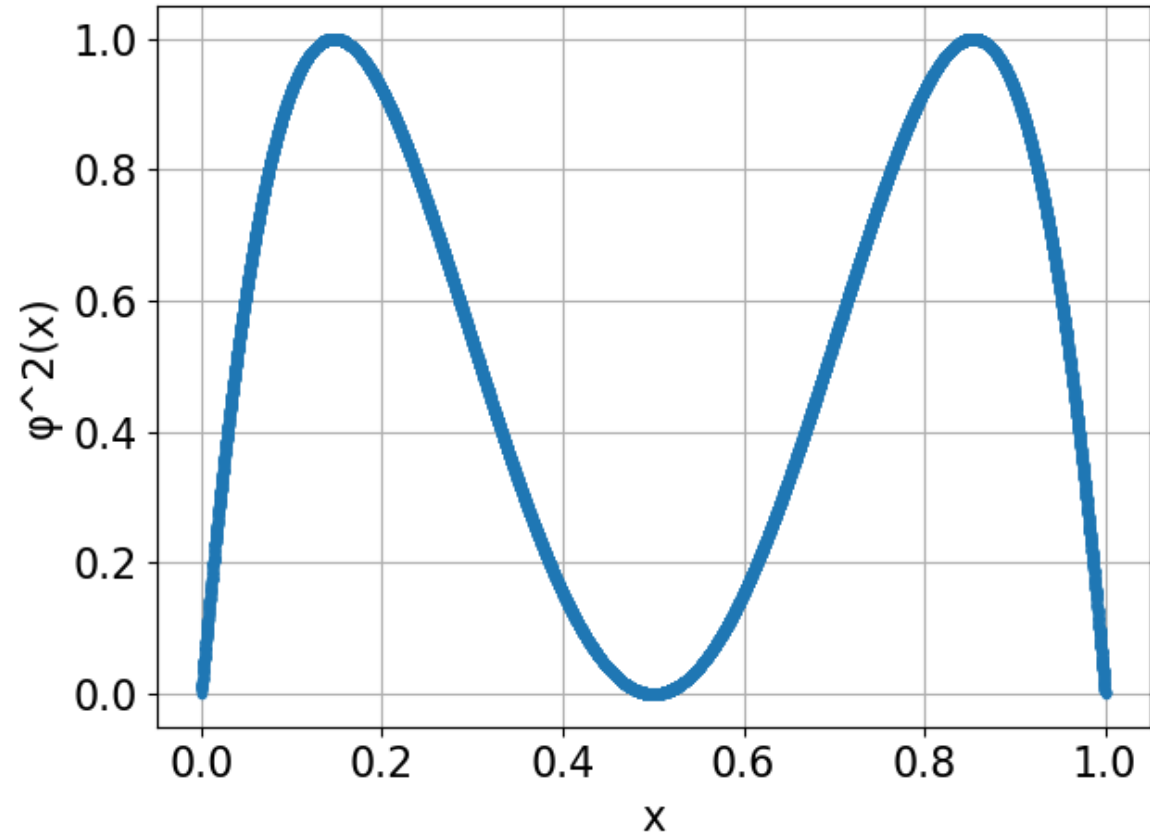


- Introduced chaos to the world of ecology
- Model of competition within a population
- Number of competing interactions quadratic
- x refers to percent of maximum population
- Fix rate $r = 4$
- Question: at a given time, is the population as likely to be < 50 percent as > 50 percent?

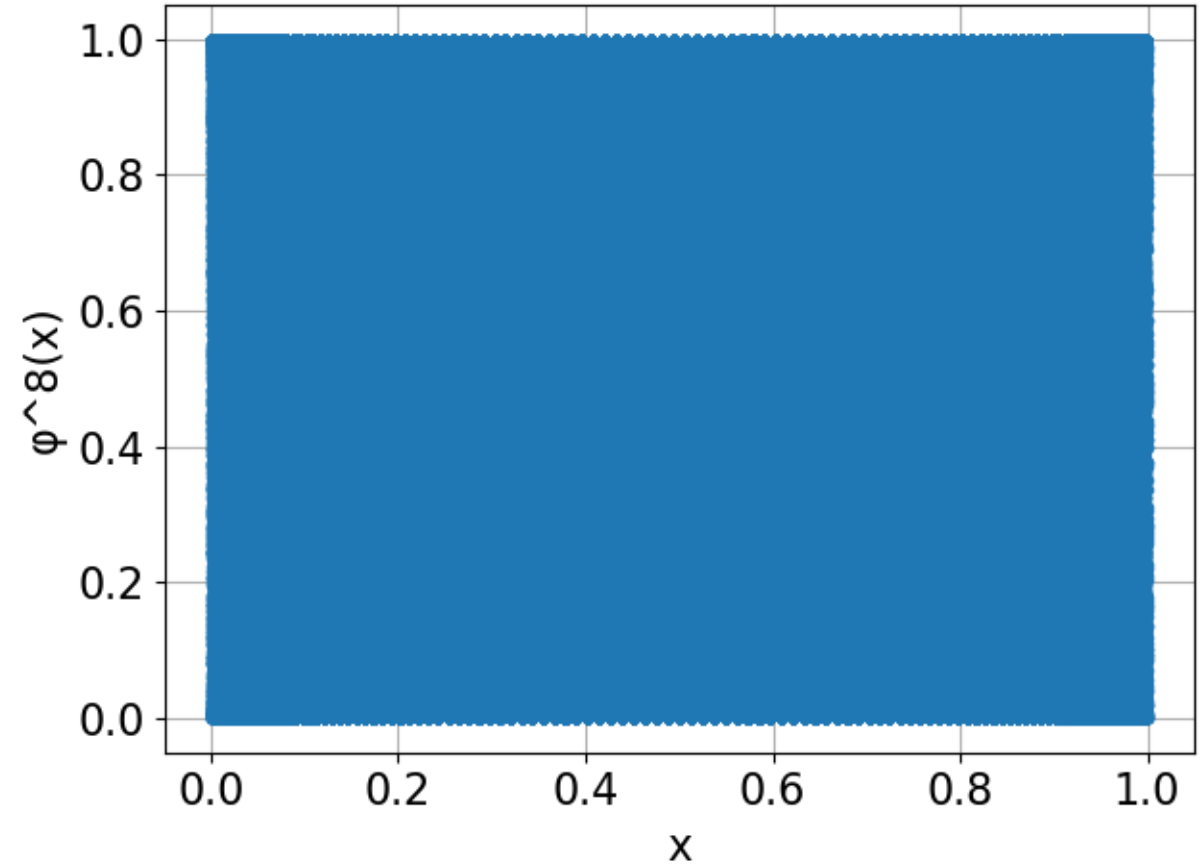
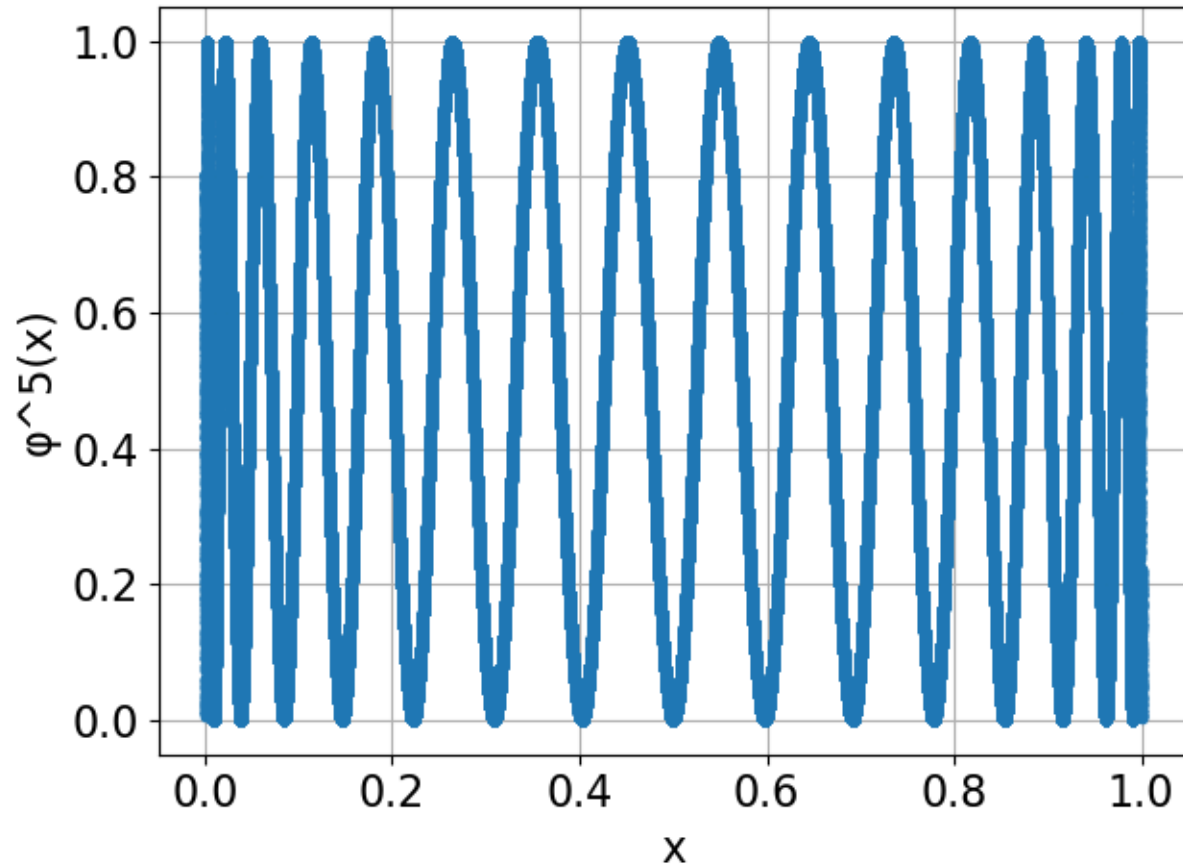
Evolution of ensembles under the dynamics



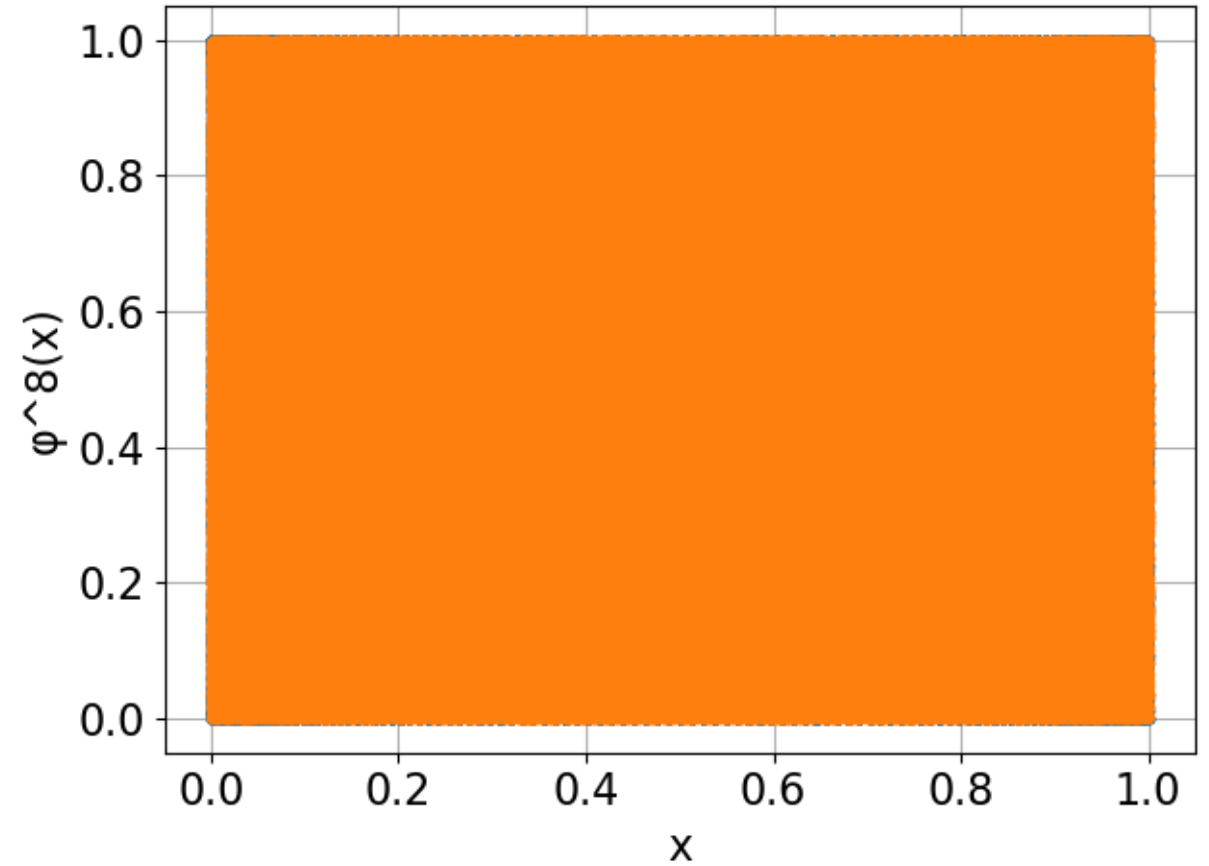
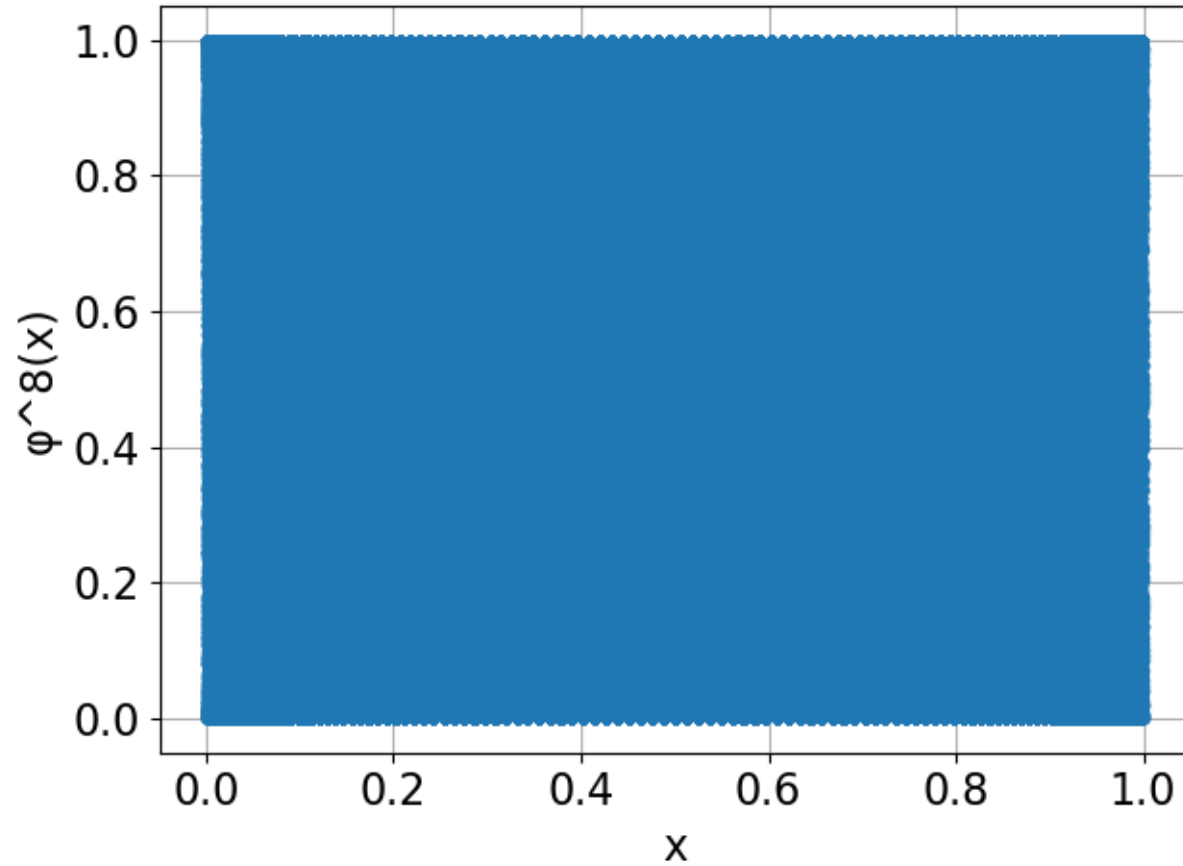
Long-term dynamical behavior of orbits



Chaotic systems: deterministic but appear random

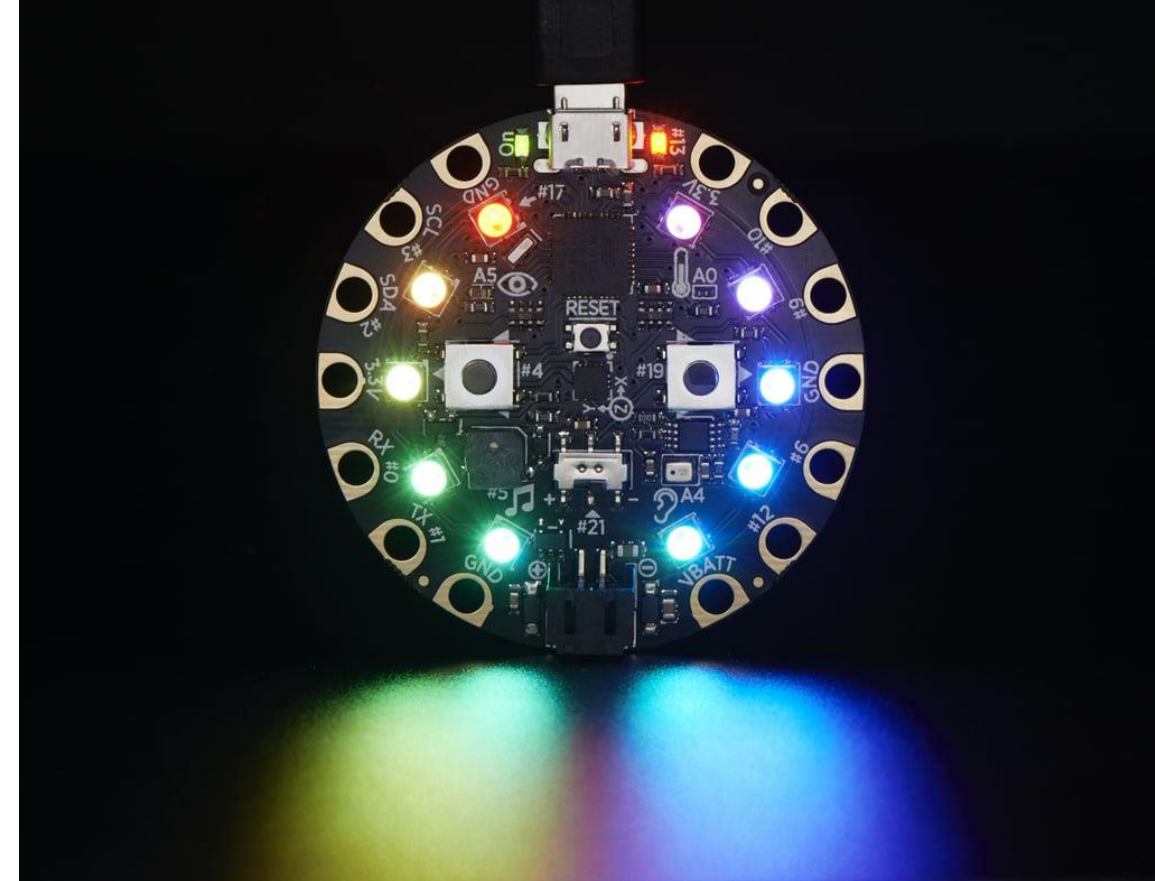


Chaotic systems: deterministic but appear random



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!

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 $0.25 < x < 0.5$?

Answer 1: Yes, equally likely!

Answer 2: No, less than 0.25 is more likely!

