Introduction to Neural Networks

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Module 1.1: Course Overview

My Brain

The Hemispheres of the Brain

- Brain lateralization: certain functions seem to be specialized into one hemisphere. Some interesting symmetries!

LEFT BRAIN FUNCTIONS	RIGHT BRAIN FUNCTIONS
Small Picture	Big Picture
Verbal Communication	Nonverbal Communication
Small Muscle Control	Large Muscle Control
Intelligence Quotient	Emotional Quotient
Word Reading	Comprehension
Math Calculations	Math Reasoning
Processing Information	Interpreting Information
Conscious Actions	Unconscious Actions
Positive Emotions	Negative Emotions
Receiving Auditory Input	Interpreting Auditory Input
Linear and Logical Thinking	Gets Abstract Concepts
Curious and Impulsive Actions	Cautious and Safe Actions
Like Routine/Sameness	Likes Newness, Novelty
Activates Immunity	Suppresses Immunity

What are Neural Networks?

- Originated as mathematical models of biological neurons.
- Evolved into large scale, massively parallel collections of computing entities.
- Single neurons are *relatively* simple.
- Many interconnected neurons are complex.
- Simple computation.
- Complex computation.

A bit of History

- McCulloch and Pitts (1943) devised neural network models in the context of automata and computation;
- Donald Hebb (1940) established concepts now referred to as *Hebbian learning* covered later in the course.
- Alan Turing (1940) developed the foundation of computing theory with his Turing machine.
- John von Neumann (1940) devised other computing paradigms.
- Stanislaw Ulam (1940) worked on cellular automata and computing theory.
- Developments in electronics, nuclear science, radar, computers and cryptanalysis.

A great deal of intellectual ferment during World War II.

What are Neural Networks?

- Neural networks are an attempt to mimic the behavior, in some respects, of the brain—a network of nerve tissues.
- Neural networks are mathematical models inspired by biological neurons.
- Each nerve or neuron is considered to be a relatively simple device.
- When combined with other similar neurons in a network, they become an exceedingly complex system that seem to give rise to ‘emergent’ behavior.
- Mathematical capabilities to perform logic.
- Mathematical properties of dynamical systems.

Why do people study them?

- Curiosity about how brains work.
- Curiosity about consciousness, thinking and computing.
- Curiosity about ‘complex systems’ and ‘emergent’ behavior.
- Many recent advances and insights into ‘network theory’.
  - Keywords: clustering, network analysis, pathways, degrees of contact, data-mining, complexity theory …
  - Maximal Information-based Nonparametric Exploration---data mining.

But, What are Neural Networks?!

- Essentially, they are simple, mathematical models of neurons.
- Have roots in
  - Neuroscience
  - Mathematics and statistics
  - Physics
  - Computer science
  - Engineering
- Requires use of mathematical tools to study and analyze them and gain insights into what they CAN and CANNOT do.
  - Linear algebra, Calculus, Vector Calculus, metric spaces and dynamical systems, optimization methods.

Application Areas

- Modeling systems.
- Time series processing.
  - Forecasting, prediction.
- Signal processing.
  - Filtering, noise reduction…
- Pattern recognition.
  - Speech recognition,
  - Natural language processing,
  - Biometrics,
  - Classification
- Control system engineering.

From Simple to Complex

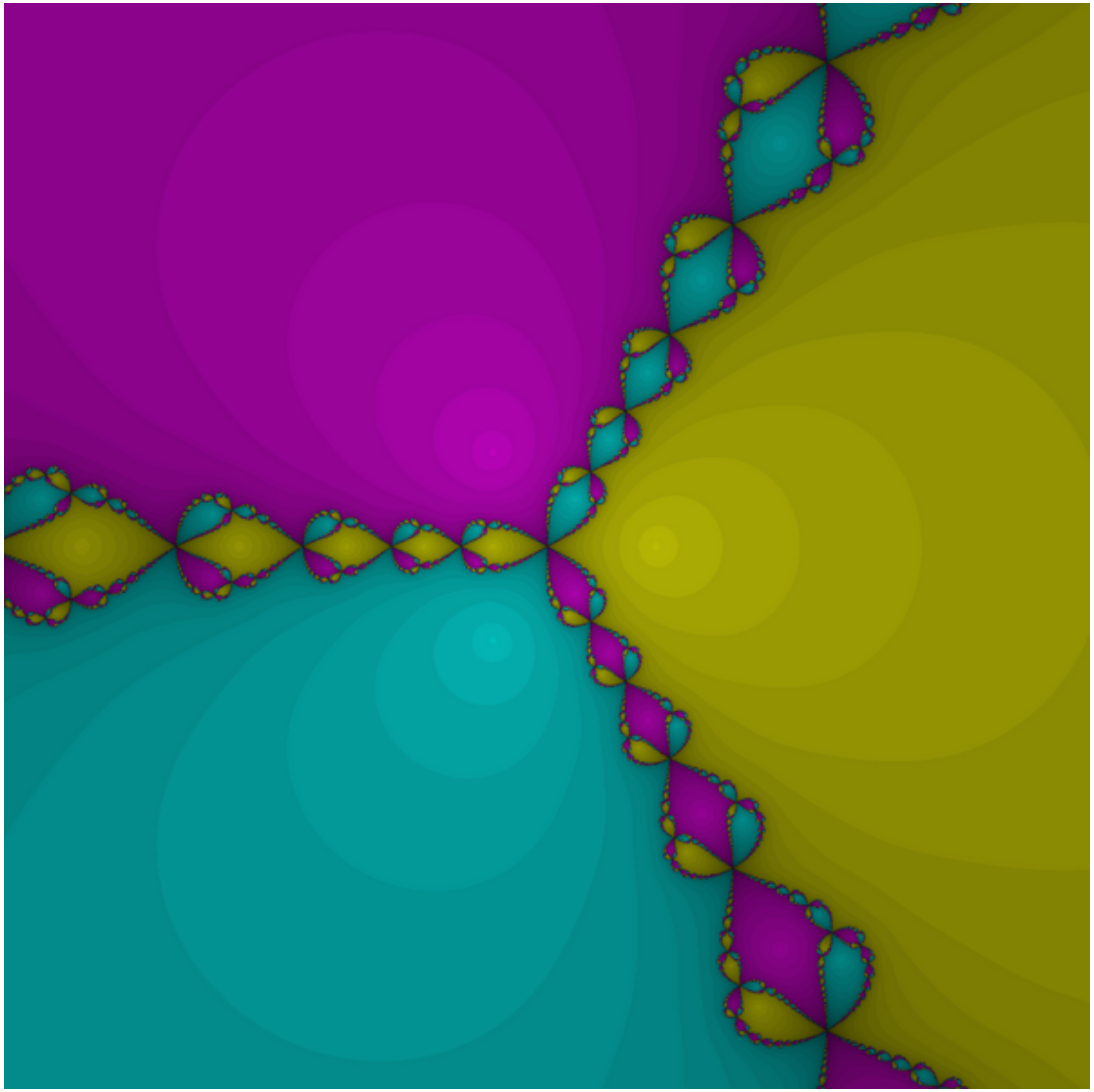
- Let's start with a simple polynomial --- how complex can that be? $f(z) = z^3 - 1$

- Let's explore something where a mathematical quantity changes over time according to some formula.

Newton's Method

- In complex plane, what are the roots of:

$$f(z) = z^3 - 1$$



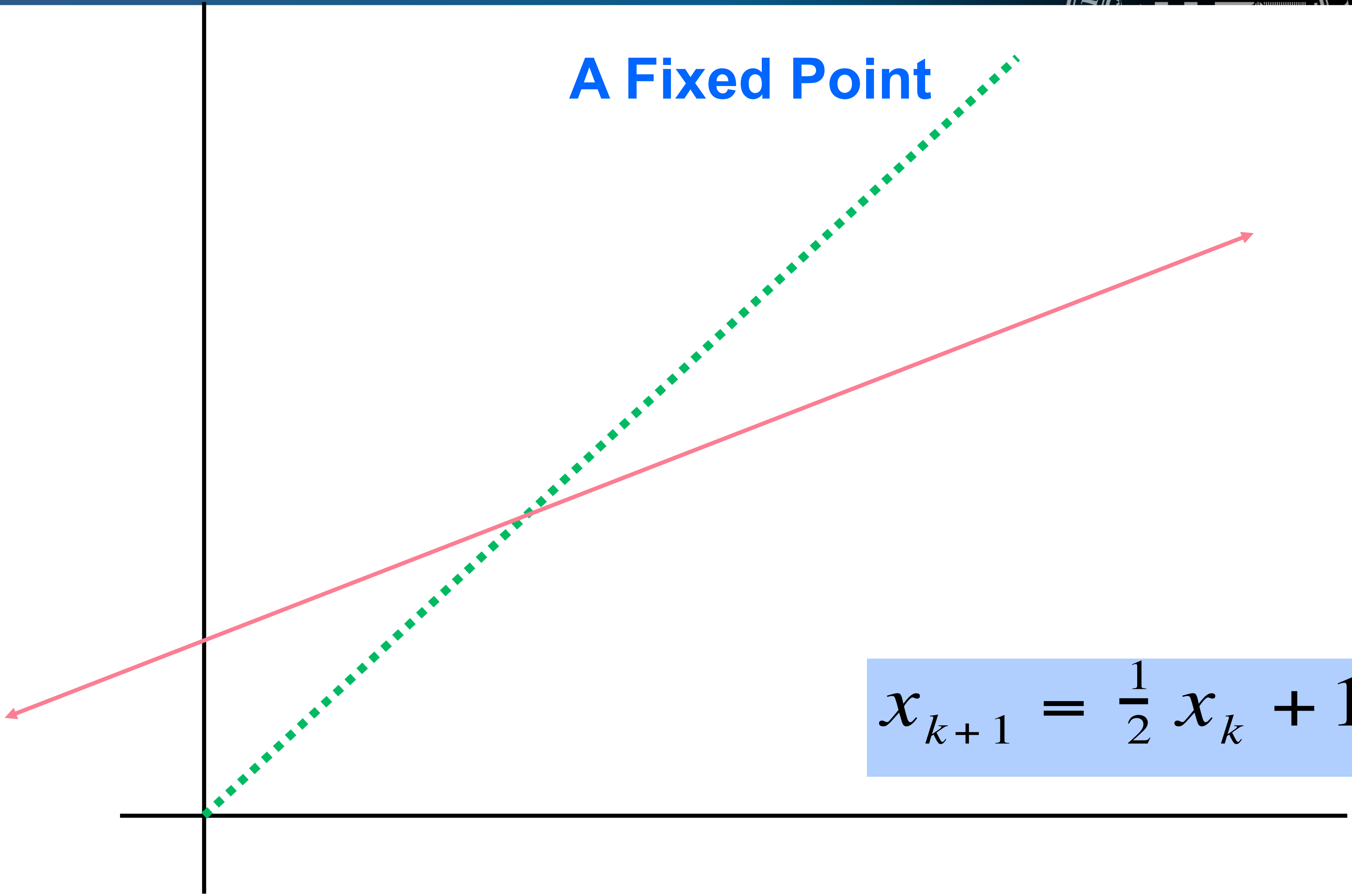
A Simple Dynamical System

$$x_{k+1} = f(x_k)$$

$$\lim_{k \to \infty} x_k = x^* \quad \Rightarrow \quad x^* = f(x^*)$$

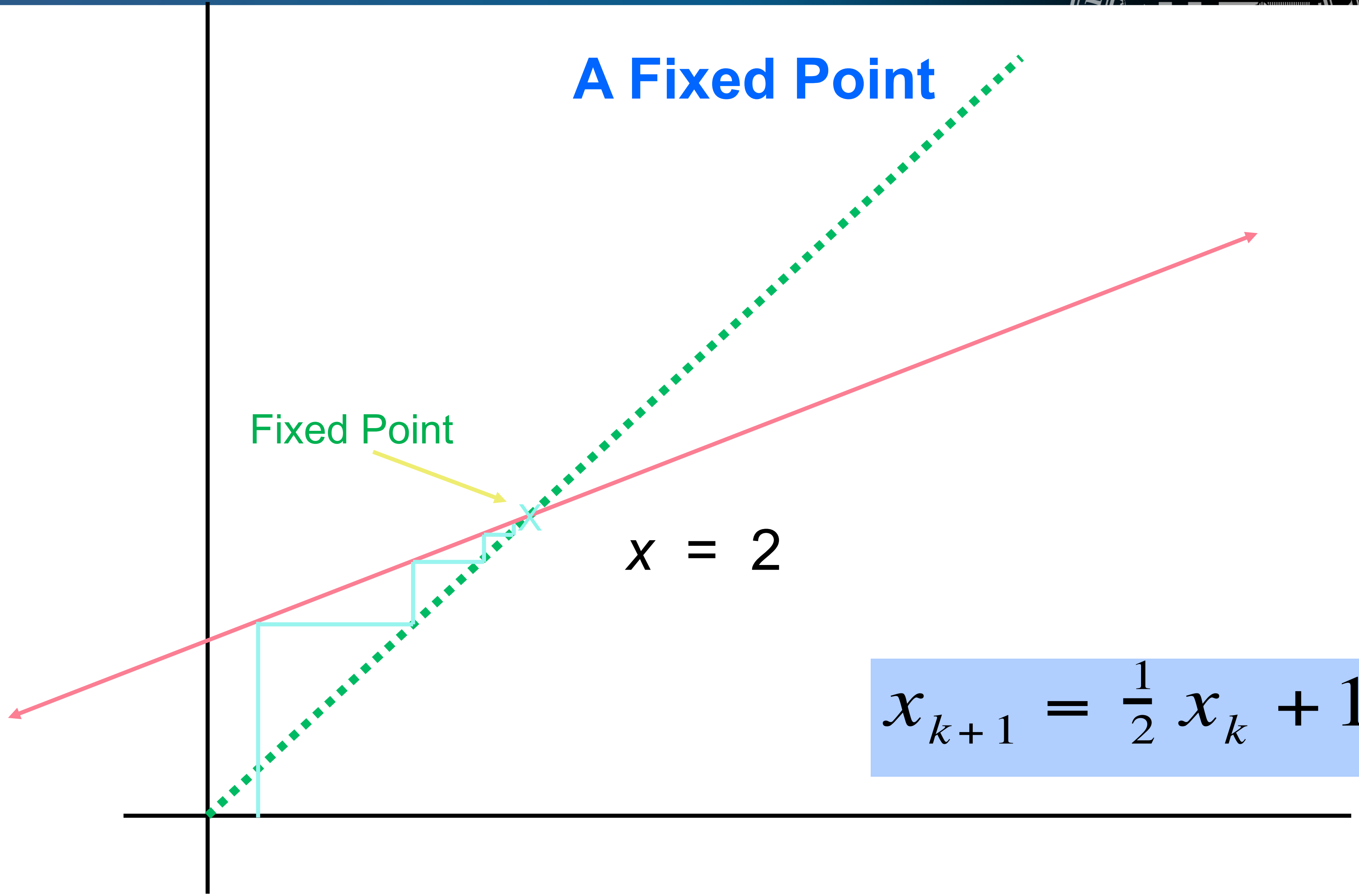
A Fixed - Point

A Fixed Point



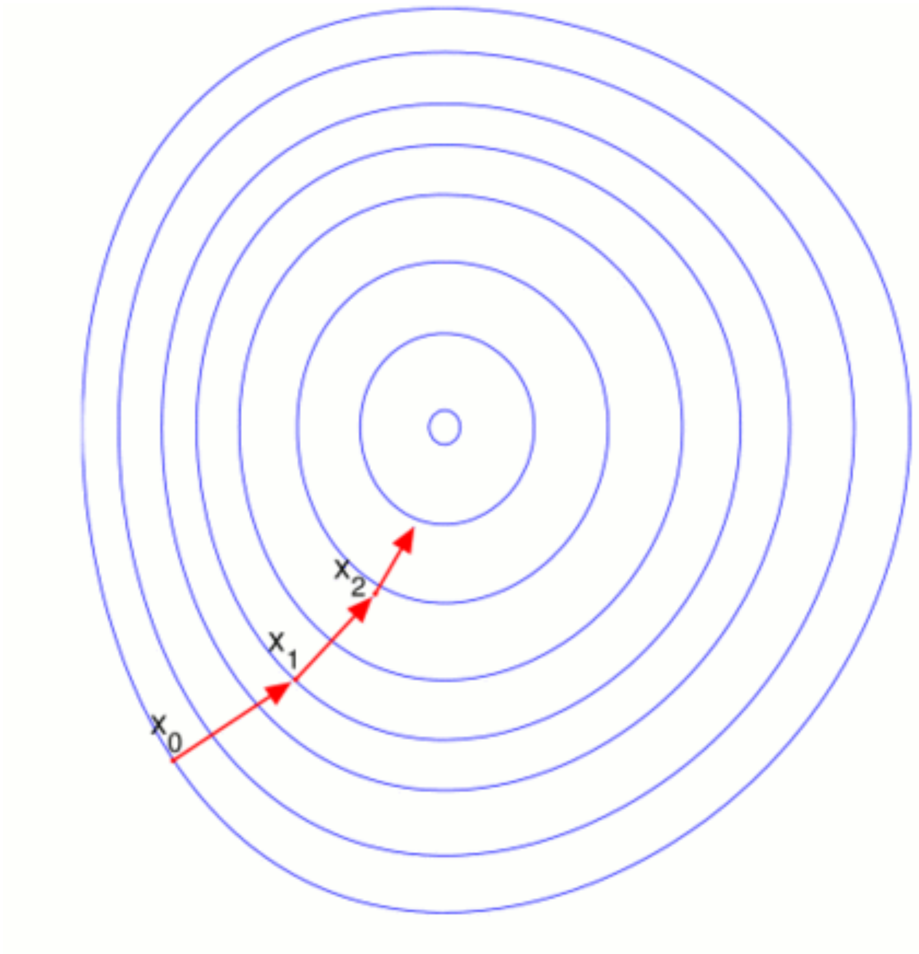
$$x_{k+1} = \frac{1}{2} x_k + 1$$

A Fixed Point

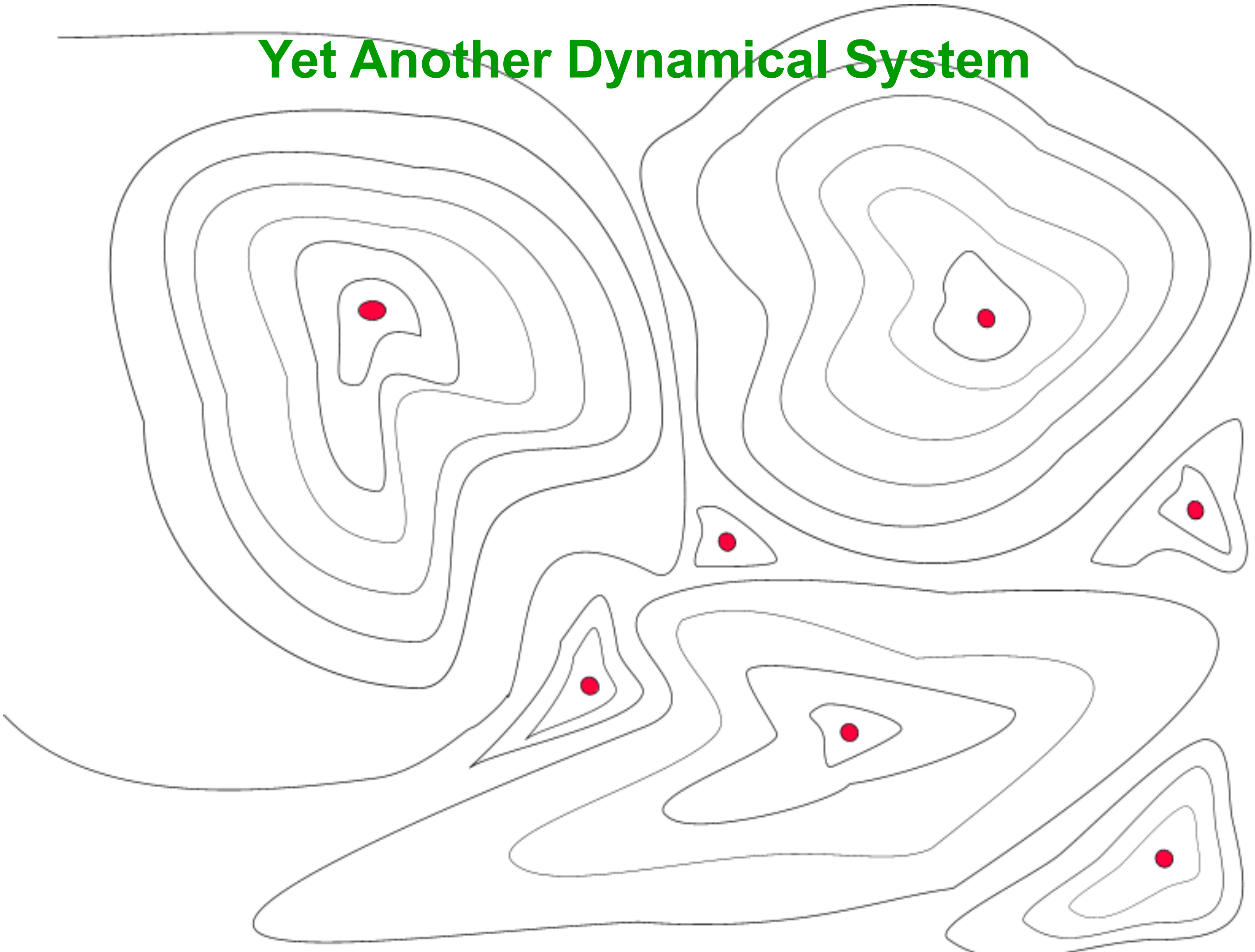


$$x_{k+1} = \frac{1}{2} x_k + 1$$

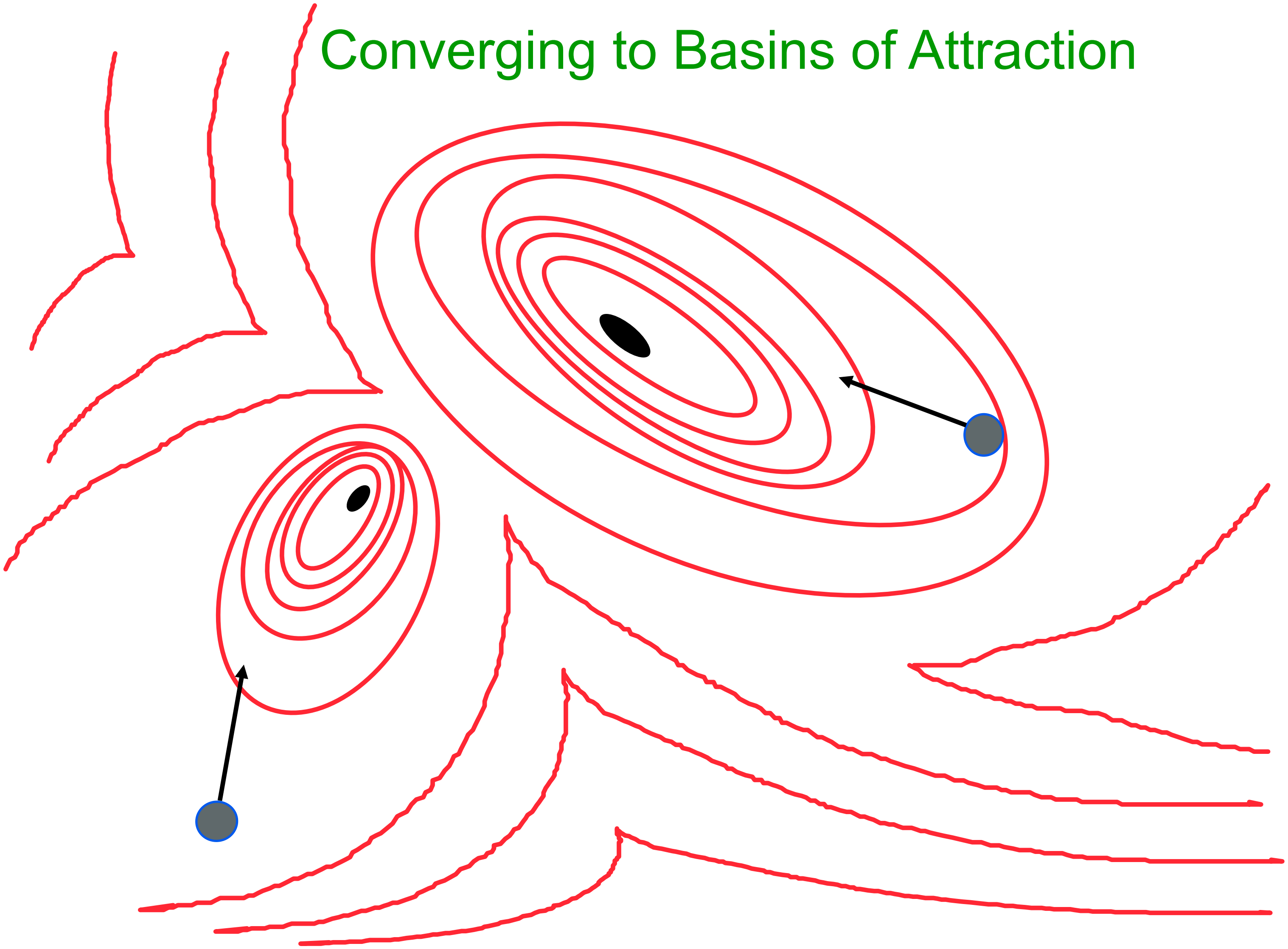
Another Dynamical System



Yet Another Dynamical System

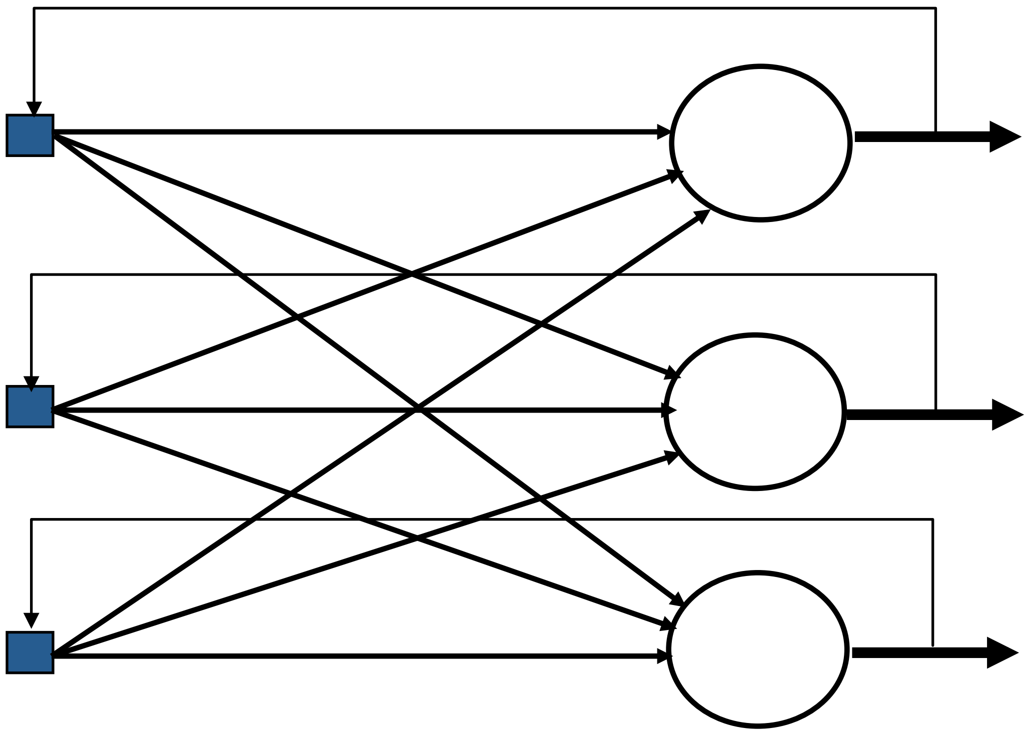


Converging to Basins of Attraction



Attractor Neural Nets

Hopfield Net



Some topics we'll cover:

- Simple mathematical relationships and theory
- Some 'systems' theory
- Some numerical methods and algorithms
- Some optimization methods

The Principle Theme

- **Using computers to perform experiments, investigate ideas and develop and test new theories!**