Technische Hochschule Brandenburg
University of Applied Sciences
Fachbereich Technik

Complex Systems Modeling

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Kremers, Enrique. (2013). Modelling and Simulation of Electrical Energy Systems through a Complex Systems Approach using Agent-Based Models.

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Course Info

- Course website & syllabus

  https://moodle.th-brandenburg.de/course/view.php?id=10371

- Course structure
  - Lectures/Labs/Homework & Projects

Course Overview

Focus:

How to design, build, simulate, visualize, analyze, document, and compare complex systems models.

Along the way we will also explore:

- A bit of philosophy of modeling/complex systems
- Intro/intermediate programming
- Some probability, statistics, machine learning
- Some network (graph) theory & data analysis
- A bit of collective behavior, pattern formation, & game theory
- Models in social, biological, and physical systems

Goals of the Course

- Learn about models and model-building - How and why to build models for a given problem.
- Develop familiarity and competencies in Python and some familiarity with IDEs
- Leave the class with some nicely built complex systems models and the insight that mathematics is quite useful.

Course Outline

- Part I: Fundamentals of Complex Systems Modeling (CSM)
- Part II: Systems with Few Variables
- Part III: Systems with Many Variables
- (Part IV): CSM & Machine Learning

Literature:

Introduction to the Modeling and Analysis of Complex Systems by Hiroki Sayama

+ Scripts + Online Ressources

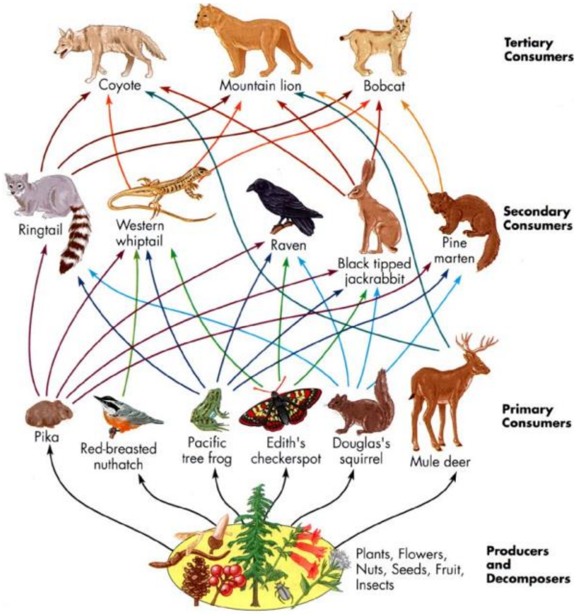
Setup for Coding in Python

- google colab as a cloud solution
- use your own laptops via anaconda, miniconda
- We will take care of this next week!
- However, for much of the class you can code in whatever language is comfy for you if you prefer (e.g. R, MATLAB, Octave)

Prior Background

- A background in complex systems is not required, but hopefully you have a strong interest!
- Some basic programming and basic math/stats, background is **strongly** encouraged.

What is a complex System?



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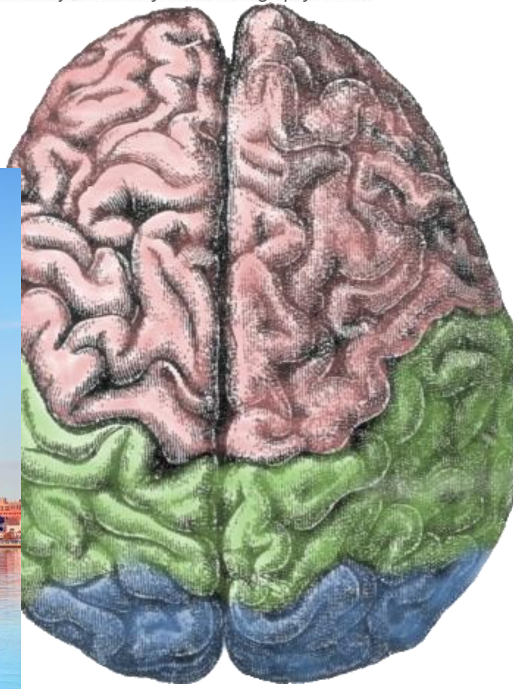
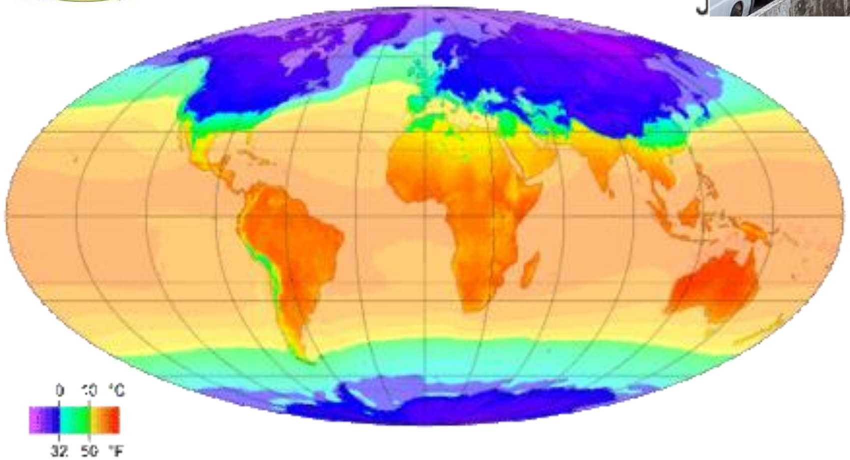
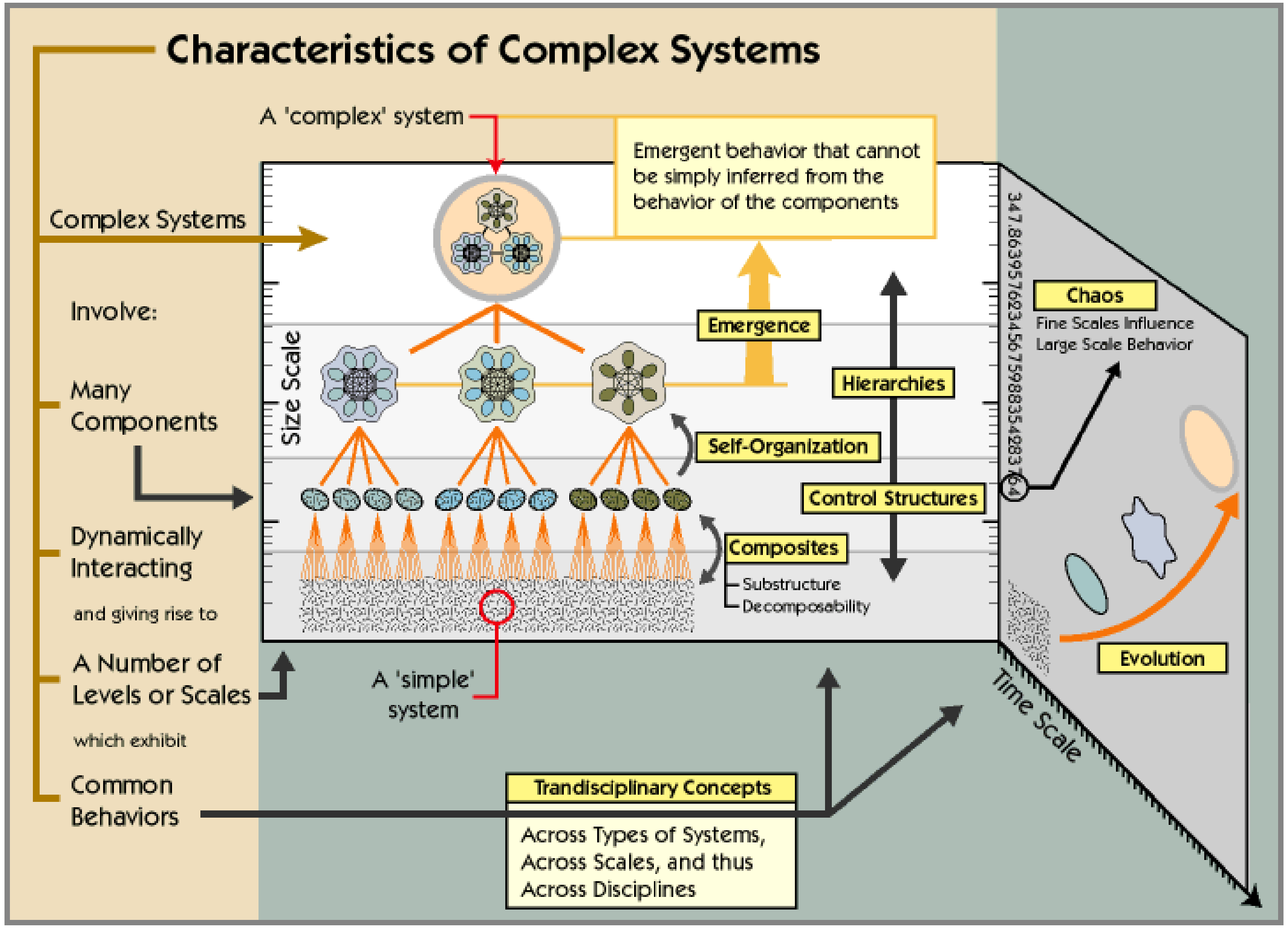




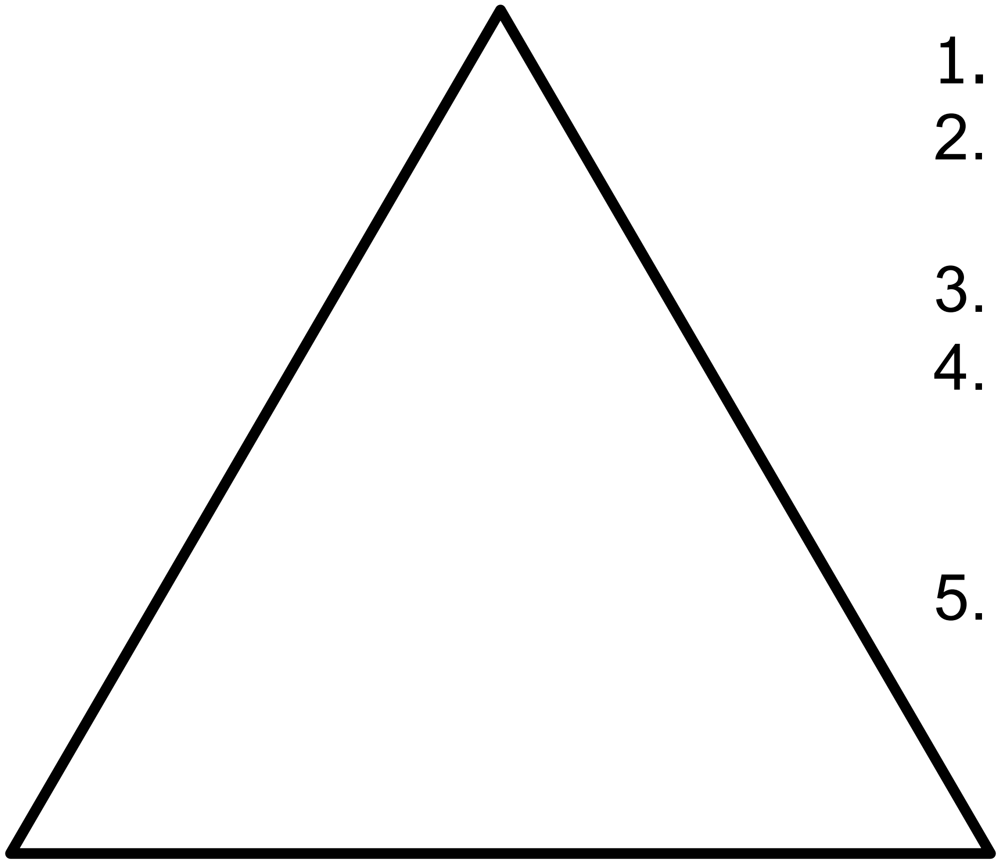
What is a Complex System?

A collection of simple components that interact on different spation and temporal scales, often in nonlinear ways to give rise to macroscopic emergent behavior.



https://necsi.edu/visualizing-complex-systems-science

The Chaos Game



1. Start with a Triangle
2. Mark a point at random within the triangle (can really be anywhere but this is simpler)
3. Randomly pick a vertex
4. Mark your next point: the point halfway between your current point and the vertex you chose

5. Repeat 3. & 4.

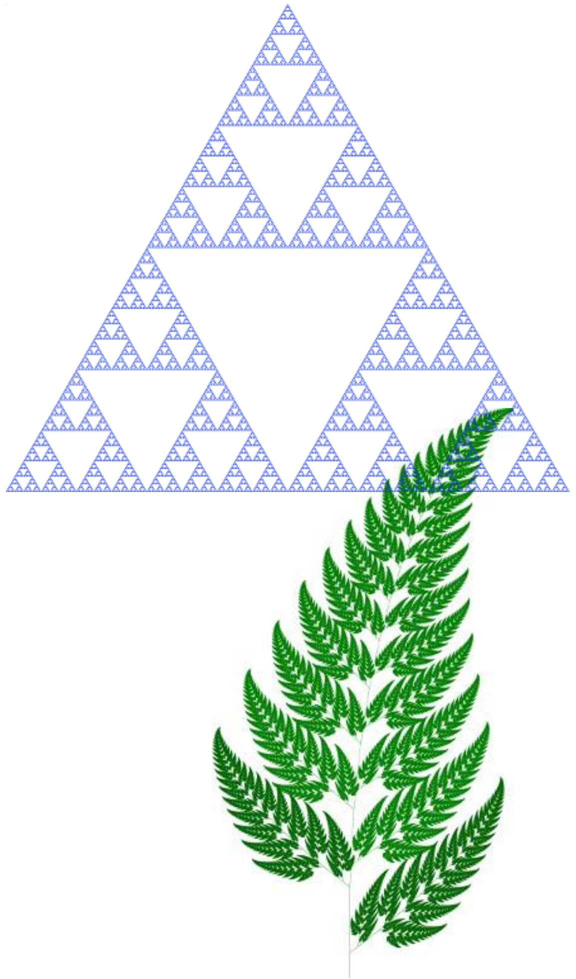
Interactive game is from: http://math.bu.edu/DYSYS/chaos-game/node4.html

The Chaos Game

https://www.youtube.com/watch?v=IGlGvSXkRGI

The Chaos Game

- Generates a fractal! This is called the **Sierpiński gasket** or Sierpiński triangle
- Fractals are objects that exhibit self-similarity (ferns, trees, snowflakes, rivers, & more)
- Simple rules can generate surprising emergent patterns!



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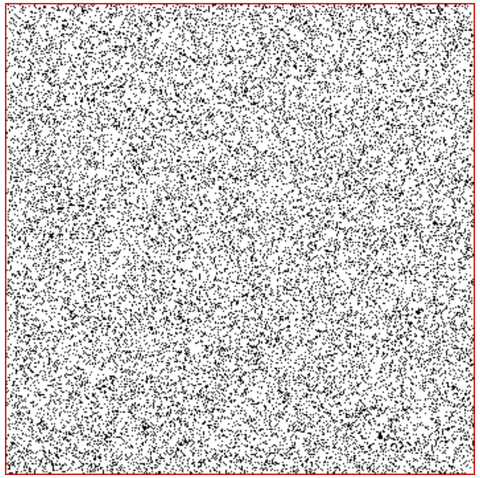
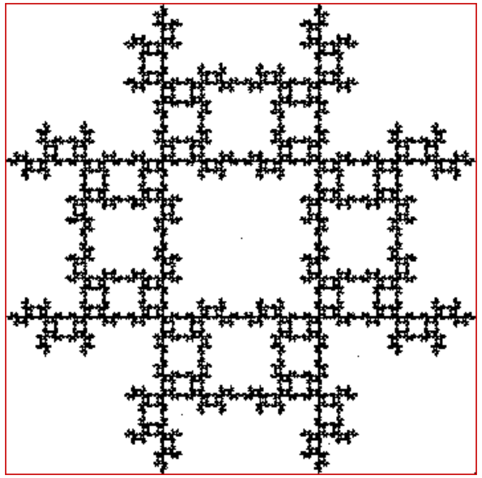
The Chaos Game

- The Sierpinski gasket is an attractor for this process
- Why does this work? A little intuition—think about transformations—discuss
- Does it work with other shapes?



nope, but use a square and don’t choose the same vertex twice



many other variations!

Complex Systems

- Emergent behavior
- Self-organization
- Adaptive interactions
- Fat-Tail behavior
- Chaos
- Nonlinearity, tipping points, etc.

For your notes 1/2

Complex Systems

A **complex system** consists of many interacting parts, where the overall behavior of the system cannot be easily predicted by just looking at the individual components. The Chaos Game is a simple example of how complexity arises from very basic rules:

1. **Simple Rules**: The only rules in the Chaos Game are that you pick a point, choose a random vertex, and move halfway toward it. These are extremely simple instructions.
2. **Unpredictable on a Small Scale**: At first, the position of each new point appears random. There is no immediate way to predict where the next point will fall based only on the previous point. However, over time...
3. **Complex, Predictable Behavior on a Large Scale**: Despite the randomness and simplicity of each individual step, when repeated many times, the system produces a highly structured, complex outcome—the Sierpinski Triangle. This shape is predictable and orderly, but the path to it involves randomness and local unpredictability.

For your notes 1/2

Emergent Behavior

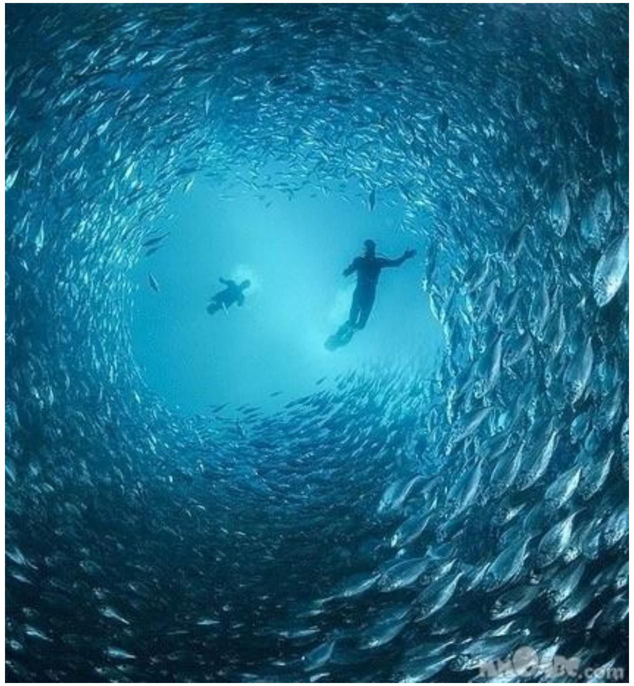
Emergence refers to a phenomenon where larger patterns or behaviors arise from the interaction of smaller, simpler elements, without any central control or guiding force. The Sierpinski Triangle in the Chaos Game is a perfect example of emergent behavior:

1. **Local Rules, Global Pattern**: In the Chaos Game, no one is “directing” the points to create the Sierpinski Triangle. Each step follows the same local rule: move halfway toward a randomly chosen vertex. But when you look at the system as a whole, a complex and highly organized pattern—the fractal triangle—emerges from this simple, local behavior.
2. **Self-Organization**: The Chaos Game shows **self-organization**, where a structure emerges naturally from the interactions of the system's components (the random points and the simple movement rule). You don’t need to “plan” or design the Sierpinski Triangle. It forms on its own as a result of the interactions.

Example

Flock of geese/school of fish

- Forms a large, organized pattern
- But no ‘group mind’ or leader
- Birds follow local rules
- Result is emergent, organized behavior

https://www.youtube.com/watch?v=e8Prw9AZ9jw

Complex Systems

- Emergent behavior
- Self-organization
- Adaptive interactions
- Fat-Tail behavior
- Chaos
- Nonlinearity, tipping points, etc.

Models?

In a few words, what does a model mean to you?