HARVARD UNIVERSITY
The Graduate School of Arts and Sciences

Code the Universe: Visualizing Nature through Generative Art

Harvard University, January@HarvardGriffinGSAS

Instructor: Sudhan Chitgopkar
Lecture Times: Mon, Wed, Fri 4:30 - 6 PM
Course Website: sudhan.dev/ctu

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Location: Harvard (Room TBA), Online
Term: 01/08/2024 — 01/19/2024

1 Instructor

Sudhan Chitgopkar (sudhanchitgopkar@g.harvard.edu) is a Master's student in Harvard's Computational Science & Engineering Master's program. He has been exploring Generative Art and visualization for 3 years, and has given one of the most viewed TEDx talks on the subject. Sudhan's interests in generative art are specifically focused on visualizing patterns that exist in nature – from fractals to artificial life simulations and everything in between.

2 Course Description

What do fractals, flocks of birds, and figure skating have in common?

Code the Universe is a practical, beginner's guide to generative and algorithmic art with a focus on visualizing the beautiful natural and mathematical phenomena that makes up our everyday world. Over our two weeks together, we'll

- get acquainted with the field of generative art and tools of the trade
- dive into discussions about beautiful natural phenomena
- do live-coding demonstrations visualizing everything from bouncing light rays to birds to the solar system

You'll leave Code the Universe with a few of your own pieces of generative art, and the tools you need to visualize whatever interests you most! **All experience levels are welcome.**

3 Course Objectives

This course seeks to (1) help students develop an interest and understanding in the math that surrounds them and (2) build the skills necessary to visualize patterns and phenomena interesting to them in nature and beyond.

To that end, this course will spend the first two lectures introducing students to the landscape of Generative Art and the tools (and math) which may help them visualize the natural world. The last four lectures will investigate all sorts of puzzles and phenomena in nature which are fascinating and beautiful, giving students an understanding of how to visualize them.

Students should leave this course able to identify different types of patterns in nature and where they come from, and the ability to create art out of these patterns.

4 Course Policies & Expectations

This course will consist of 6 lectures, each covering a topic integral to a foundational understanding of Generative Art and visualizing natural phenomena. Students enrolled in the course are expected to attend each lecture to keep up with course material having reviewed the pre-lecture material. This material is intentionally short, quite accessible, and quite fun! Even a brief glance through most of the material, especially for later modules, will provide a brief insight into how beautiful and complex the visualizations of lecture material can be.

Students are also highly encouraged to complete the coding assignments (see "Assignments" section) between each lecture and submit their work for feedback or help with questions. Coding assignments may be submitted at any point throughout the course for feedback, though it would be prudent to keep up with coding assignments as the implementation for concepts presented build on top of each other throughout the course.

5 Materials & Access

All materials for this course are free/publicly available. Pre-lecture readings/videos are all accessible via YouTube or are freely available academic papers, and are linked in the course schedule. All assignments and code developed during the course will be hosted on the course web-page under a public license, and students are encouraged to modify this code as they wish.

6 Assignments

Students can expect optional but *highly encouraged* readings/videos and one coding assignment after each class. While it is possible to follow the course without doing any work outside of class, this course is much more interesting and enriching if you tinker with the code we write and the visualizations we make by yourself. Some of the most interesting visualizations come from asking yourself "why?" and "what if?" questions that can't be answered without getting your hands dirty and trying to write/rewrite/modify the questions and code we explore.

Though optional, any coding assignments turned in will be returned by the next class with feedback from the instructor so that you can gauge your progress or get help with any particularly annoying bugs in your code. Three different coding assignments will be available for students to complete after each lecture. One will be geared towards beginners, focused on modifying some of the parameters of the code shown in class to better understand how/why it works. Intermediate assignments will focus on implementing some of the examples shown in class from scratch, and incorporating minor modifications to them. Advanced assignments will focus on optimizing the code shown in class or making more significant, structural modifications to the models presented and implementing visualizations for them.

7 Academic Integrity

Generative art and creative coding is a pursuit that is, well, creative! To that end, students are encouraged to take full advantage of any and all resources they find helpful – from generative AI to Stack Overflow to one another! It is the instructor's hope that students will continue to engage with this content beyond this course and that they fully understand which tools may be helpful in their visualization pursuits. Students must, however, acknowledge/cite sources for code that they have taken from others and not pass off the work of others as their own.

8 Accommodations for Students with Disabilities

Harvard University values inclusive excellence and providing equal educational opportunities for all students. Our goal is to remove barriers for disabled students related to inaccessible elements of instruction or design in this course. If reasonable accommodations are necessary to provide access, please contact the Disability

Access Office (DAO). Accommodations do not alter fundamental requirements of the course and are not retroactive. Students should request accommodations as early as possible, since they may take time to implement. Students should notify DAO at any time during the semester if adjustments to their communicated accommodation plan are needed.

9 Course Schedule

Lecture 1: State-of-the-(Generative)-Art

What is generative art, why should we care about it, and why might we want to use it to visualize different patterns in nature?

This lecture will cover:

- Motivations
  - The value of generative art as a practical and creative medium
  - The effect of AI on the generative art landscape
- Tools
  - The landscape of Generative Art tools (i.e. Processing, TouchDesigner, DeepDream) and the audiences they're catered to
  - A primer on Processing and its many flavors (P5, Processing-Py, CProcessing, Processing)
- Styles
  - A brief look into different generative artists who use Processing, their styles, and what we can learn from them
- First Steps
  - Our very first sketch(es)!
  - Processing installation/setup
  - Experiments with points, lines, and colors

Pre-lecture Readings/Videos:

- Visualizing Math's Biggest Question with Generative Art
- Examples with Processing
- What is Generative Art?

Lecture 2: A (Random) Walk Down Memory Lane

How can we use this new tool along with some math that you learned in middle school to model physics on Earth and in space?

This lecture will cover:

- Walks & Agents
  - Coding agents that enjoy going on a stroll!
- Physics
  - Modeling gravity, velocity, acceleration, and collision
  - Coding a simple game of pool in less than 30 lines with 6th grade math!

- Coordinate Systems
  - Polar vs Cartesian systems
  - Thinking in 3D (and our first 3D sketch!)
- Light Rays & Coffee
  - Visualizing our first pattern in nature!

Pre-lecture Readings/Videos:

- Visualizing Random Walks in Three Dimensions
- Ellipse-billiard Simulation
- The reflection of light rays in a cup of coffee

Lecture 3: Fractals, Chaos, and Something Strange

What does your circulatory system have in common with broccoli and beaches? What role does randomness play in our lives? Did that butterfly really cause a tornado?

This lecture will cover:

- Fractals
  - Fractals and their ubiquity
  - Fractal mathematics
  - Coding snowflakes!
- Chaos & Randomness
  - The Chaos Game and Sierpinski
  - Coding the Chaos Game!
  - Extending the Chaos Game to three dimensions!
- Strange Attractors
  - An introduction to dynamical systems
  - Understanding strange attractors
  - Animating the generation of a few attractors!

Pre-lecture Reading/Videos:

- The Beauty of Fractal Geometry
- Double Pendulum Simulation
- Strange Attractors and the Butterfly Effect

Lecture 4: Life

Why do individual actions have global effects? How do flocks of birds and schools of fish organize? Why is there a perfectly straight trail of ants walking towards my sandwich?

This lecture will cover:

- Conway's Game of Life
  - Zero-player games and their utility
  - Coding Conway's Game of Life & variations
  - Cellular Automata & the effects of local changes
- Flocking Behavior
  - Understanding flocking/schooling behavior
  - Coding your own (artificial) life form!
  - Modeling predator-prey dynamics and evolution
- Ant Colonies
  - Understanding ant path-finding behavior
  - Ant Colony Optimization and its applications

Pre-lecture Readings/Videos:

- Inventing Game of Life
- Epic Conway's Game of Life
- Programmable Self Assembly in a Thousand-Robot Swarm
- Ant and Slime Simulations

Lecture 5: Getting Lost (and Finding Your Way Out)

How can we make different mazes? Now how do we solve the mazes that we've made? What makes a maze "perfect?" Why did the maze-maker get a divorce? (He got lost in his work.)

This lecture will cover:

- Basics of Mazes
  - Mazes in the natural world
  - Mazes in history, mythology, and pop culture
  - Perfect mazes and why they're interesting
- Maze Generation
  - Different maze generation algorithms and how they work
  - Recursion and scale
  - Coding our own perfect mazes!
  - Visualizing all the (3x3) mazes we can make
- Maze Solving
  - Different maze solving algorithms
  - Computational complexity theory

    - Solving the maze we made!

Pre-lecture Reading/Videos:

- The Sound of Maze Generation
- Can Water Solve a Maze?
- The Fastest Maze Solving Competition on Earth

Lecture 6: Beyond Nature

How can the tools we've learned help us visualize data or sound? How can we take our pieces from the digital to the analog? Where do we go from here?

This lecture will cover:

- Other Visualizations
    - Data visualization in politics and government
    - Music and sound visualization
- Pen-plotting
    - Hardware and software tools for analog visualization
    - Constraints of the analog (and how to escape them)
- Wrap-up
    - Some more generative artists to follow
    - How to decompose and recreate your favorite generative art
    - Puzzles to think about the next time you're on a walk

Pre-lecture Videos/Readings:

- Sounds of Space
- Drawing Machines