Collatz Box Universes Explorer Suite

Long-Term Mission Statement

This project aims to explore and visualize generalized Collatz sequences from novel, multi-dimensional perspectives. Moving beyond single-sequence analysis, the goal is to reveal the intricate tapestry of patterns, behaviors, and relationships that define vast "Box Universes." By providing intuitive, multi-level tools and models (like 9-nets, 2D parameter slicers, and 3D spatial explorers), this approach seeks to offer a unique "visual intuition" and fresh context for the Collatz problem. Through the synthesis of information across different visualization "lenses," the project intends to inspire new hypotheses, facilitate deeper understanding, and unlock insights that no single perspective could reveal alone.

The Generalized Collatz Rule

The core of this project revolves around a generalized Collatz function:
For any number n:
- If $n \pmod{X} = 0$, then $n \to n / X$
- Otherwise, $n \to (n \cdot Y) + Z$

(The standard Collatz conjecture uses X=2, Y=3, Z=1)

Exploring the Box Universe: A Multi-Level Perspective (LOD)

Your Box Universe Explorer suite is composed of eight distinct applications, each designed to provide a unique and complementary "Level of Detail" (LOD) or perspective for understanding generalized Collatz sequences. Together, they form a powerful toolkit for comprehensive exploration:

Highest Level (Rule-Set Overview): box-universe-viewer.html (Box Universe Viewer)

- **Focus:** Understanding the global behavior of different Collatz rules (X,Y,Z) when applied to a single fixed starting number (N).
- **Visualization:** A 3D grid where each cube represents a unique rule-set, color-coded to indicate its overall outcome (convergence, divergence, cycles, or classic Collatz).
- **Insight:** Discover broad patterns in the properties of the rules themselves, identifying regions of stability, chaos, or specific cyclic behaviors across the parameter space.

Intermediate Level (Rule-Set Iteration & Comparison): slicer.html (2D Pseudo-3D Slicer)

- **Focus:** Systematically comparing many different Collatz rules by generating and displaying their corresponding 2D 9-net sequence visualizations in a grid or slideshow.

- **Visualization:** Creates a dynamic grid or slideshow of multiple 2D 9-nets, where each 9-net depicts a sequence's path for a distinct (N, X, Y, Z) rule combination from user-defined ranges.
- **Insight:** Build visual intuition and identify trends as rule parameters are varied, allowing for rapid comparison of sequence patterns across a slice of the rule space.

Deep Level (Number Space Exploration): box-universe-fps.html (Box Universe FPS)

- **Focus:** Immersive exploration of the 3D number space for a single, fixed Collatz rule.
- **Visualization:** Constructs a 3D cube grid where each cube represents a unique number. Cubes are initially colored by parity (even/odd). You can navigate this space using FPS controls, interactively slice through layers, and animate the sequence path of a clicked number directly within the 3D grid.
- **Insight:** Understand the spatial distribution of number properties and observe how sequences dynamically "travel" or "flow" through this abstract 3D representation of numbers.

Specific Sequence Detail & History: index.html (Box Universe Explorer)

- **Focus:** Detailed analysis of individual generalized Collatz sequences and maintaining a history of these calculations.
- **Visualization:** Displays a single sequence's numerical progression and its path on a 2D 9-net canvas, along with comprehensive statistical properties (steps, min/max, sum, average, std dev). It also logs a history of generated sequences, each with its own 9-net.
- **Insight:** Provides granular quantitative analysis and a 2D visual record of an individual sequence's journey under a specified rule.

Geometric/Fractal LOD: collatz-dragon.html (Collatz Dragon Explorer)

- **Focus:** Revealing the hidden geometric and fractal properties inherent in Collatz sequences by transforming sequence operations into a visual path.
- **Visualization:** Generates a 2D fractal "Dragon Curve" based on the binary path of a sequence's operations (divisible by X vs. multiply/add).
- **Insight:** Offers an artistic and abstract perspective on sequence behavior, emphasizing geometric self-similarity and recursive patterns.

Dynamic Geometric Trajectory LOD: collatz-line-explorer.html (Collatz Line Universe Explorer)

- **Focus:** Visualizing the dynamic, step-by-step 3D geometric progression of a single Collatz sequence as an evolving line.
- **Visualization:** Creates a dynamic 3D line (or point trail) where the geometry itself embodies the sequence's progression and the type of Collatz operation at each step. The line "draws itself" over time with different colors for step types.
- **Insight:** Provides a qualitative and abstract view of how sequences "draw themselves"

through a 3D space, showing unique "signatures" for each sequence.

Radial/Cyclic LOD: radial-animator.html (2D Pseudo-3D Slicer - Radial Animator)

- **Focus:** Animating the progression of a Collatz sequence as a radial graph, emphasizing cyclic patterns and modular relationships.
- **Visualization:** Displays numbers on a circular path based on their value modulo a chosen number, with lines connecting successive elements in the sequence. The visualization animates the sequence step-by-step.
- **Insight:** Highlights how numbers distribute and transition within modular arithmetic, revealing potential cycles and attractors in a dynamic, radial format.

Radial/Cyclic LOD: radial-viewer.html (Radial Viewer)

- **Focus:** Providing a static or single-sequence view of the radial representation of a Collatz sequence.
- **Visualization:** Plots numbers on a circle based on their value modulo a chosen number, with lines connecting the sequence steps, similar to radial-animator.html but without the continuous animation.
- **Insight:** Offers a clear, concise view of the modular distribution and path of a specific sequence for focused analysis.

Key Features

Your Box Universe Explorer is composed of these applications, each designed to provide a distinct and complementary approach to understanding generalized Collatz sequences:

index.html (Box Universe Explorer - Quantitative Analysis Tool & Launchpad)

- **Customizable Generalized Collatz Rules:** Input specific parameters for N (starting number), X (divisor), Y (multiplier), and Z (adder) to define your unique Box Universe.
- **Classic Collatz Quick Access:** Visual indicator (gold star) to highlight when parameters match the classic Collatz (X=2, Y=3, Z=1).
- **Step-by-Step Sequence Generation:** Observe the exact numerical progression of the sequence, step by step, as it evolves.
- **Interactive 9-Net Visualization:** A dynamic 3x3 grid (the "9-net") visually represents the sequence, with each square corresponding to a step.
- **Color-Coded Steps:** Distinguish between "divisible" steps (N/X) and "multiply-add" steps (N*Y+Z) for immediate qualitative insight into the rule applied.
- **Number Truncation:** Large numbers within the 9-net squares are gracefully truncated with an ellipsis (...) for readability, while retaining their full value in the sequence history.
- **Sequence History Display:** A comprehensive list of all numbers generated in the sequence, up to convergence or a defined limit.
- **Cycle and Divergence Detection:** Automatically identifies and highlights if and when a sequence enters a cycle or exceeds safe calculation limits.

- **Comprehensive Statistics:** Displays detailed metrics including steps, min/max values, sum, average, standard deviation, stopping time, and paradoxical occurrences.
- **Customizable Colors:** Personalize the colors for divisible and multiply-add steps to suit your visual preferences.
- **Launchers for 2D & 3D Explorers:** Provides direct links to other visualization tools, passing defined parameters for seamless transition.

slicer.html (2D Pseudo-3D Slicer - Qualitative Exploration Tool)

- **Multi-Universe Display:** Simultaneously visualize multiple 9-nets based on user-defined ranges for N, X, Y, and Z. Each 9-net represents a distinct ruleset or parameter combination.
- **Parameter Range Filtering:** Define specific minimum and maximum values for N, X, Y, and Z to focus your exploration on particular regions of the parameter space.
- **Dynamic Slideshow Exploration:** Animate through the parameter space by continuously varying one chosen parameter (N, X, Y, or Z) while holding others constant.
- **Adjustable Playback Speed:** Control the pace of the animation to observe changes at your preferred rate.
- **Axis Selection:** Easily switch which parameter is being animated to explore different dimensions of the Box Universe space.
- **Visual Pattern Recognition:** Designed to help users quickly identify visual trends, similarities, and anomalies across many Box Universes as parameters change.
- **Classic Collatz Ruleset Marker:** Visually highlights the cell or 9-net corresponding to the classic Collatz (X=2, Y=3, Z=1) for easy identification.
- **Clear 9-Net Presentation:** Each 9-net maintains the color-coding and number truncation features for consistent visual cues.
- **Customizable Colors:** Personalize the colors for divisible and multiply-add steps.

box-universe-fps.html (Box Universe FPS - 3D Number Space Explorer)

- **3D Number Grid Visualization:** Renders a generalized Box Universe as a 3D grid of cubes, where each cube represents a unique number based on its X, Y, Z coordinates.
- **Parity-Based Coloring:** Cubes are colored based on whether the number they represent is even or odd, providing an immediate visual layer of mathematical meaning.
- **FPS Camera Controls:** Navigate the 3D space with WASD keys and mouse-look for immersive "walk-through" or "fly-through" exploration.
- **Generalized Collatz Logic Integration:** Calculates and applies Collatz sequences based on user-defined (or URL-passed) X, Y, Z rule parameters.
- **URL Parameter Initialization:** Dynamically configures the initial 3D view (N, X, Y, Z rules, slice axis, slice value, animation speed, even/odd colors) directly from URL parameters.
- **Interactive Sequence Path Animation:** When a number-cube is clicked (when controls are unlocked), its Collatz sequence path is highlighted and animated through the 3D grid, revealing its trajectory.
- **3D Slicing Functionality:** Allows users to interactively slice the 3D view along X, Y, or Z axes, revealing specific layers of the Box Universe.
- **Customizable Colors:** Choose distinct colors for even and odd numbers, enhancing

visual analysis.

- **"Reset View" Functionality:** A button to easily reset the camera to a default viewing angle, and clear any active sequence paths.
- **"Share Link" Feature:** Generates and copies a URL that captures the current 3D view parameters, enabling easy sharing of specific explorations.
- **Basic Responsiveness:** Designed to adapt to different screen sizes.
- **On-Screen Parameter Display:** Shows current N, X, Y, Z rules, animation speed, and slice values directly in the UI.

box-universe-viewer.html (Box Universe Viewer - 3D Rule Space Explorer)

- **Real-time 3D Grid of Rulesets:** Visualizes a 3D grid where each cube's position (X, Y, Z coordinates) directly corresponds to a unique set of Collatz rules.
- **Color-Coded Sequence Behavior:** Cubes are color-coded to communicate the outcome of sequences under that specific ruleset (e.g., green for convergence to 1, blue for cycles, red for divergence/overflow).
- **UI Input for Rule Ranges:** Allows users to define specific ranges for X, Y, and Z parameters, as well as a fixed starting number (N), to focus the exploration.
- **Firebase Integration (Planned):** Designed for user-specific data saving and retrieval of explored ruleset outcomes.
- **Smooth Camera Controls:** Utilizes OrbitControls for intuitive navigation, including rotation, panning, and zooming of the 3D ruleset grid.
- **Sequence Calculations Optimized:** Performance-optimized calculations to quickly determine and display the behavior of numerous rulesets.
- **Legend Box:** Provides a clear visual key that describes the meaning of each cube color.
- **Classic Collatz Highlight:** The cube representing the classic Collatz ruleset (X=2, Y=3, Z=1) is uniquely highlighted for easy identification.

collatz-dragon.html (Collatz Dragon Explorer - Directional Sequence Mapper)

- **Collatz Logic to Binary Path Translation:** Converts each step of a generalized Collatz sequence into a binary decision (divisible by X or not), which dictates the "turns" in the dragon curve.
- **Canvas-Based Fractal Visualization:** Draws the sequence as a dynamic, evolving dragon curve on a 2D canvas.
- **Responsive Layout:** The visualization adapts gracefully to different screen sizes.
- **Real-time Statistics:** Displays key sequence statistics such as max value reached, total steps, stopping time, and detection of paradoxical behavior.
- **Gold Star for Classic Collatz:** A visual indicator highlights when the classic Collatz rule (X=2, Y=3, Z=1) is being used.
- **Cross-Program Navigation Links:** Provides direct buttons to open the current parameters in the 2D Pseudo-3D Slicer, 3D Box Universe FPS, and Box Universe Viewer for multi-faceted exploration.

collatz-line-explorer.html (Collatz Line Universe Explorer - Dynamic

3D Trajectory)

- **Dynamic 3D Line Visualization:** Generates and animates a unique 3D line (or trail of points) for each Collatz sequence.
- **Color-Coded Path Segments:** Segments of the line are colored based on the type of Collatz operation (divisible by X vs. multiply/add), providing immediate visual feedback.
- **Interactive 3D Scene:** Allows users to orbit and zoom around the generated 3D line using standard camera controls.
- **Customizable Collatz Rules:** Input fields for N (start number), X (divisor), Y (multiplier), and Z (adder) to define the sequence.
- **Responsive Canvas:** The 3D visualization canvas adjusts its size to fit the screen.
- **Clear Scene Functionality:** A button to easily clear the current 3D line from the scene.
- **Error Handling:** Provides on-screen messages for invalid inputs or potential issues (e.g., X=0, sequence overflow).

radial-animator.html (2D Pseudo-3D Slicer - Radial Animator)

- **Animated Radial Graph:** Visualizes the Collatz sequence as points moving along a circular path, with lines connecting successive numbers.
- **Modulus-Based Plotting:** Numbers are positioned on the circle based on their value modulo a user-defined or default modulus, highlighting modular arithmetic patterns.
- **Dynamic Progression:** The animation shows the sequence unfolding step-by-step, making cyclic behaviors and transitions visually apparent.
- **Customizable Parameters:** Takes N, X, Y, Z, and modulus parameters, allowing for diverse radial explorations.
- **Responsive Canvas:** The visualization adapts to different screen sizes.

radial-viewer.html (Radial Viewer)

- **Static Radial Graph:** Displays a single Collatz sequence as a static radial graph.
- **Modulus-Based Plotting:** Similar to the Radial Animator, numbers are plotted on a circle based on their value modulo a chosen number.
- **Clear Visual Representation:** Provides a concise snapshot of a sequence's modular distribution and path without continuous animation.
- **URL Parameter Support:** Can be initialized with N, X, Y, Z, and modulus parameters directly from the URL.

Technologies Used

- **HTML5:** Structure and content.
- **CSS3 (Tailwind CSS):** Modern, utility-first styling for a clean and responsive user interface.
- **JavaScript:** Core logic for Collatz calculations, canvas drawing, and interactive elements.
- **Three.js:** For all 3D visualizations (box-universe-viewer.html, box-universe-fps.html, collatz-line-explorer.html).
- **Font Awesome:** For various icons used throughout the interface.
- **MathJax:** For rendering mathematical formulas (like the generalized Collatz rule) in

index.html.

How to Use

To explore the Collatz Box Universes:
1. **Access the Project:** This project is designed to be hosted on GitHub Pages. You can access it directly via a URL like https://YOUR_GITHUB_USERNAME.github.io/YOUR_REPOSITORY_NAME/.
2. **Start at the Main Hub:** Begin with index.html to define your core parameters and launch into the various specialized visualization tools.
3. **Input Parameters:** Use the input fields to define your starting number (N) and the generalized Collatz rule parameters (X, Y, Z).
4. **Visualize & Explore:** Click "Generate" or "Launch" buttons to see the visualizations. Experiment with different parameters and explore how the sequences behave!
5. **Utilize Navigation Links:** Many tools include buttons to seamlessly transition to other viewers, passing the current parameters for continued exploration.

How This Environment Helps Your Portfolio

- **Organized Code:** Each tool (HTML/JS) acts as a modular, maintainable building block, demonstrating strong project organization.
- **Clear Documentation:** Project goals, components, and design principles are clearly outlined, showcasing your communication skills.
- **Scalable & Complementary Design:** Each visualization targets a unique layer of the exploratory process, proving your ability to design a comprehensive system.
- **Cross-Tool Integration:** Shared parameter passing and visual consistency across views highlight your attention to user experience and integrated system design.
- **Innovative Visualizations:** The unique 9-net, 3D rule space, 3D number space, fractal, and dynamic line visualizations demonstrate creativity and technical prowess in data representation.

This evolving suite is both a computational research toolkit and an expressive portfolio centerpiece, showing off analytical, visual, and architectural thinking.