Caudal - Mechanical Chaos Source

User Manual

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For the Caudal firmware version 1.2.

Introduction

For almost two decades, I have worked in the field of modeling and simulation. During that time, I have encountered many different types of chaotic systems. I first learned about the use of chaos in music when I discovered the work of composers like Iannis Xenakis. Only when I started working with modular synthesis did I make the connection that I could use the kind of models I tested in my day job to create interesting modulation sources for my patches.

Caudal was inspired by the double pendulum model available in the Wolfram System Modeler simulator. The first thing I did was to extend the model to four segments and extract the equations. With those equations, I created the first version of the module for VCV Rack. Since then, I have been exploring the literature and experimenting with different chaotic models. The Planets model was inspired by the series of books "The Three-Body Problem" by Liu Cixin. The rest of the models are inspired by different mechanical and electrical systems, but most of them present variations that are the result of my experiments.

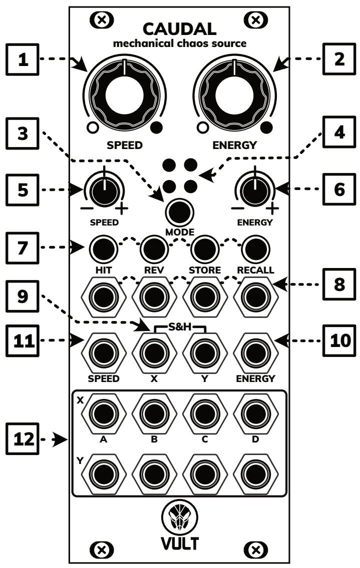
I have evaluated many different chaotic systems. This is my curated selection of the ones I found most interesting and musically useful. I hope they inspire your patches.

The Caudal Module

Caudal generates 8 distinct output signals that can be used to modulate your system. The core parameters of the simulation are Speed and Energy, which control the time scale and the level of activity in the system, respectively. By adjusting these parameters, you can shape the behavior of the chaotic signals to suit your needs.

Caudal features 8 different operation modes, each simulating a different chaotic system. These systems include:

- **Pendulum**: A four-segment pendulum swinging without friction.
- **Planets**: Four planets experiencing the effects of gravity in a micro-universe.
- **Fish Tank**: Four fish continuously navigating within their tank.
- **Fluctuations**: Four chaotic voltage generators reminiscent of the Buchla fluctuating voltage generator.
- **Coupled Oscillators**: Features 8 oscillators based on the Kuramoto model, which either lock or interfere with each other.
- **Feedback Dynamics**: A system of coupled delay differential equations using nonlinear feedback to produce chaotic signals, based on the Mackey-Glass system.



MAIN CONTROLS
1 Speed
2 Energy
MODE SELECTION
3 Mode selector
4 Mode indicator
ATTENUVERTERS
5 Speed
6 Energy
MODULATION INPUTS
11 Speed
10 Energy
SIMULATION CONTROL
7 Action buttons
8 Trigger inputs
OUTPUT SECTION
9 Sample and hold triggers
12 Output signals

Figure 1: The Caudal module

- **Analog Shift Register**: Uses 8 analog shift registers to create chaotic signals that can be locked, similar to the Turing Machine module.
- **Kicked Rotors**: Describes the dynamics of periodically kicked nonlinear rotors, modeled after the Chirikov Standard Map.

The module also includes two sets of sample and hold circuits, allowing you to capture and hold the current values of the output signals. This is useful for creating stepped versions of the chaotic signals, which can be used for generating random pitch sequences or rhythmic modulation patterns.

Four buttons and trigger inputs provide control over the simulation, allowing you to select new random states, store and recall specific configurations, and even reverse the direction of the simulation for unique effects.

Controls

You can find a summary of all controls in Figure 1.

Each knob has a corresponding CV input and attenuverter, allowing you to modulate these parameters with external control voltages.

The buttons provide manual control over the parameters, and each has a corresponding trigger input that can be used to control the parameters externally.

Speed

As its name says, the Speed control affects the temporal dynamics of the chaotic system.

Since the signals are chaotic, they do not have a fixed frequency. At low values, the outputs produce very slow-moving signals. At higher values, the signals can reach a few hundred hertz.

Energy

Controls the activity or level of chaos in the simulation. Depending on the mode, the energy affects multiple parameters of the system. The effect of the energy control in each mode is detailed in the mode descriptions below.

Buttons and Triggers

The Caudal module provides four simulation control actions, accessible via buttons and trigger inputs:

- **HIT**: Selects a new random initial state for the simulation. This instantly changes all output signals to new values and lets the simulation evolve from a different starting point.
- **STORE**: Saves the current state of the simulation. This captures a snapshot of the internal states of the model.
- **RECALL**: Restores the previously saved simulation state. The simulation will continue evolving from the recalled state, allowing you to revisit interesting configurations.
- **REV**: Reverses the direction of the simulation elements, creating the illusion of time reversal. The signals will retrace their paths before diverging into new patterns.

Each control action can be triggered manually via the corresponding button or externally via a trigger input.

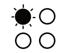
Note that not all modes are perfectly reversible or recallable. Due to the nature of some models, the exact state cannot be perfectly restored.

Operation Modes

The mode selector allows you to choose between the eight available operation modes. The mode indicator displays the currently active mode.

Check each mode's description to determine its corresponding LED combination.

Pendulum

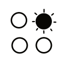


The Pendulum mode simulates a four-segment pendulum swinging in a frictionless universe. The segments are interconnected, and the motion of one segment affects the others. This creates complex, organic motion patterns that are translated into control voltages.

In this model, the energy affects parameters such as the gravity of the universe. This causes the pendulum segments to swing more wildly.

One interesting characteristic of this model is that the first segment of the pendulum swings in a more regular pattern, while the other segments produce more chaotic motion due to the interactions between them.

Planets



The Planets mode simulates four planets experiencing the effects of gravity in a confined micro-universe. This model was inspired by the classic three-body problem, but in this case we have extended it to include four bodies. The gravitational interactions between the planets create complex orbital patterns that produce smooth, slowly-varying output signals.

The energy level affects the masses of the planets, which in turn affects the strength of the gravitational interactions. At low energy levels, the planets have less mass and their orbits are more stable. As the energy increases, the planets become more massive and their interactions become more chaotic, leading to more unpredictable orbital patterns.

In some situations, one of the planets can be shot out of the planetary system. In this case, we gently return the planet so it keeps interacting with the rest.

Fish Tank

The Fish Tank mode simulates four fish navigating within their tank in search of food. The movement patterns of the fish produce organic, meandering signals that are well suited for modulating parameters where natural-sounding variation is desired.

The model simulates the dynamics of the fish bodies navigating the water. Each fish has a small brain that makes simple decisions, like choosing a direction to search for food or avoiding other fish.

Due to the nature of this model, when reversing it or recalling a saved state, the simulation will not be exact, since on a replay, the fish may make different decisions.

The energy parameter affects the fish's decisions and makes them more eager. This makes their movement more chaotic.

Fluctuations

The Fluctuations mode implements four Buchla-style fluctuating voltage generators. These produce noisy triangle waveforms with chaotic modulation, creating slowly evolving random voltages characteristic of the Buchla "Source of Uncertainty" approach.

The energy control affects the noise level into the integrator. With zero energy, the oscillators produce triangle signals. As the energy increases, the noise disturbs the triangular signal, making it oscillate in unpredictable patterns.

The X outputs produce the fluctuating voltages, while the Y outputs produce pulses that correspond to the zero-crossings of the X outputs. This allows you to use the Y outputs as triggers that are synchronized with the fluctuations in the X outputs.

Similar to the Fish Tank mode, when reversing or recalling a state, the simulation will not be exact since the noise will be different.

Coupled Oscillators

New in v1.2

Inspired by the Kuramoto model, this mode features 8 oscillators which either lock in synchrony or interfere with each other. The Speed control affects the natural frequency of the oscillators, while the Energy control determines the coupling strength between them.

One interesting aspect of our implementation of the model is that the oscillators are not locked in phase. They lock with a phase offset of 1/8 of a period between them. Additionally, this model presents multiple stable points. As you change the energy parameter, the oscillators may lock with each other but with a different phase relationship.

Feedback Dynamics

New in v1.2

Inspired by the Mackey-Glass system, this mode consists of coupled delay differential equations which use nonlinear feedback to produce chaotic signals. The resulting signals have a distinctive character that differs from the other modes, featuring sharp transitions mixed with smooth curves.

The energy in this model affects the amount of feedback, thus affecting the influence of each oscillator on itself.

This model is not perfectly reversible due to the impact of the feedback loop.

Analog Shift Register

New in v1.2

Inspired by the Turing Machine module, this model uses 8 analog shift registers to create pseudo-random signals that can be locked. The Energy control determines how likely the register values are to change, allowing you to find a balance between repeating patterns and pure chaos.

Since this is a discrete-time model, it requires a clock signal. The module internally generates a clock based on the Speed parameter, but you can also use an external clock by sending a trigger to the corresponding Sample and Hold input. When an external clock is connected, the Speed parameter becomes a clock divider/multiplier. In the lowest setting, it will divide the clock by 4, and in the highest setting, it will multiply the clock by 4.

One important difference between this model and the original Turing Machine is that in our implementation, the register values are not binary but analog. This allows us to mutate the values in a more gradual way.

Reversing this model changes the direction in which the values are shifted. Recalling a state will restore the values of the registers.

Kicked Rotors

New in v1.2

Inspired by the Chirikov Standard Map, this mode describes the dynamics of periodically kicked nonlinear rotors. The Energy control determines the kick strength, creating a transition from regular to chaotic motion. The behavior of this system can be considered an extended version of the Feigen module.

Similarly to the Analog Shift Register mode, this model is also a discrete-time system that requires a clock signal. The Speed parameter controls the internal clock, but you can also use an external clock by sending a trigger to the corresponding Sample and Hold input.

Sample & Hold

The Caudal module features two sets of sample and hold circuits, labeled X and Y. Each set is connected to all 8 output signals.

When a trigger is received at the X or Y input, the corresponding sample and hold circuit captures the current value of each output signal. The held values remain constant until the next trigger is received.

This allows you to create stepped versions of the chaotic signals, which is useful for generating random pitch sequences, rhythmic modulation patterns, or quantized control voltages.

In the Analog Shift Register and Kicked Rotors modes, the sample and hold inputs are used as clock inputs for the discrete-time models. When unconnected, the module generates an internal clock signal.

Updating the Firmware

We are constantly working on adding new features and modes to the Caudal module. For that reason, we recommend that you track the updates by subscribing to the Vult mail list or checking the Caudal product page.

To update the module, you need a way of playing back a Wave file with a sufficiently high level. The signal is expected to be in the range of 1 to 5 volts peak to peak.

To update the firmware, follow these steps:

1. Download the latest firmware file at: www.vult-dsp.com/caudal
2. Power the module as usual.
3. Enter the bootloader mode by pressing and holding the HIT and RECALL buttons, then press the Reset button on the back and release it, while keeping HIT and RECALL pressed.
4. When in bootloader mode, the module's lights will flash in a different pattern compared to the normal boot.
5. Connect the audio signal to the SPEED input jack. For instance, using the audio output from a laptop (set at maximum volume) should suffice to flash the firmware.
6. Play the firmware file using an audio player that doesn't add effects. We highly recommend using Audacity.
7. Once the playback finishes, the module will restart and boot normally.
8. If anything goes wrong, you can repeat the process.

You can check which version your module is running by counting the flashes of the LEDs when booting. The module will flash the top left LED a number of times corresponding to the major version, then a pause, and then, the top right LED will flash a number of times corresponding to the minor version. See Figure 2. For instance, if the module is running version 1.2, the top left LED will flash once, then pause, and then the top right LED will flash twice.

If you see no flashes, you are running version 1.0.

Figure 2: How to determine the version when the module is booting.

Technical Specifications

- Sampling rate: 12 kHz
- Power consumption:
  - +12V: 80 mA
  - -12V: 10 mA
  - 5V: 0 mA (not used)
- Depth: 20 mm
- Width: 10 HP

Release Notes

- v1.0 Initial release
- v1.1 Fixes behavior at very low speeds.
- v1.2 Adds four operation modes.

Licenses

Caudal Hardware module are granted a license to run it in their Vult Caudal Hardware. Any other use is not allowed by this license.

This project uses the following third-party sources:

The Caudal Bootloader uses the qpsk encoder released under the MIT license, found on:

https://github.com/float32/qpsk-examples

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