# Buried in The Phase Plane: Steady States Sonified

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## 1 INTRODUCTION

Buried in The Phase Plane (BTPP) is a game created in Unreal Engine 5 (UE5) utilizing the ChucK programming language as an audio engine. BTPP was inspired by the concept of steady states within nonlinear mathematical models. These steady states are determined by how the mathematical model is derived, and provide insight as to how their solutions behave. Within BTPP, the player is given a set of ”poles” and can then spawn in up to ten cubes. Detailed further, BTPP is an investigation into changing frameworks, not just individual pieces within them; it is heavily inspired by concepts like inheritance and hierarchical systems. Within the audio world, BTPP utilizes spectral physical modeling by an additive system. Each aforementioned cube represents a string that is continuously vibrating; cubes' locations are sonified through synthesis of the string within the time domain. BTPP looks to give only a degree of control to the player, and showcase how systems change due to input and their own construction.

## 2 GAME DESIGN

Within BTPP, the player will encounter two objects, cubes and poles. These cubes are spawned by the player by pressing the left mouse button, spawning up to ten. They are created with a randomized two dimensional velocity vector, which allows for them to begin navigation of the plane. As they move, their cartesian coordinates are sent to a ChucK instance via OSC. Through game time, cubes scan the space around them; for each pole, they calculate a force vector whose direction and magnitude are determined by the relative location of such. A summation of these vectors are calculated and applied to the cubes via the ‘Set Actor Location‘ function. If the cube is within an orbiting range of a pole, a tangential vector will be calculated, applying an orbiting force.

The player may notice that after some time, the poles will begin to move. Every ninety-five seconds, they receive a small randomized vector to progress across. With their new locations, these poles receive a new ”attractor” force, which influences their strength on the present cubes. By moving these poles and adjusting their strengths, the ”steady states” of the present system shift. If a player does not wish to wait ninety-five seconds for the next system, they can manually call for the poles to move by pressing the right mouse button. This can lead to rather interesting results because while the poles will still take time to move to their new locations, their change in strength will be instantaneous.

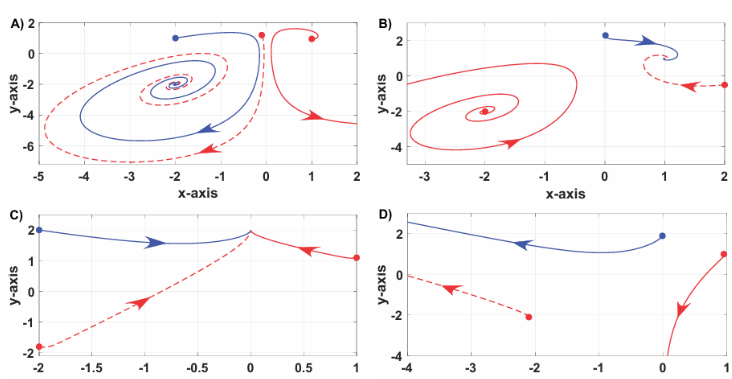
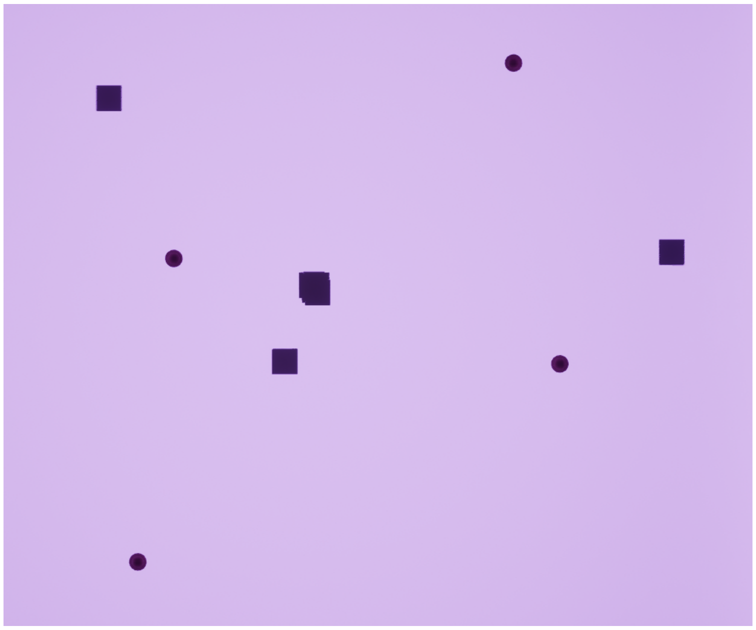



**Figure 1.** Phase plane representing steady states of nonlinear systems. Reproduced from *Introduction to Differential Equations* by Mark Holmes.



## 3 CHUCKIAN AUDIO ENGINE

As previously mentioned, the audio provided within BTPP is fueled by a ChucK instance. ChucK receives both the X and Y coordinates of all cubes. Within the OSC stream, coordinate pairs are marked with an identifier for each cube, enabling ChucK to sonify the cubes individually. After receiving the coordinate locations of all cubes within a given frame, ChucK clamps and scales these values within the range of $[-1.0, 1.0]$. ChucK manages headroom within the audio bus by creating these strings only when the corresponding cube is created.

Each cube represents a string, which is ever-vibrating at some length. This length is randomly selected at the start of the ChucK instance, along with a partial of the string. The spectrum of these vibrating strings are then calculated and synthesized with a collection of sine oscillators. The frequency of each relevant harmonic is found by the following calculation.

$$f_n = \frac{n\pi c}{L} \tag{1}$$

Where $f_n$ is the resulting frequency, $c$ is the speed of sound, $n$ is the harmonic's index and $L$ is the length of the string. As cubes traverse the plane, their horizontal coordinate determines a fractional length of their initial string, causing a siren-like effect that can be heard when all cubes are moving at high speeds. The volume of each harmonic is then calculated according to *where* the cube is upon the string's surface. This applies variation to the string's spectrum as the cube moves upwards.

## 4 SUMMARY

Within BTPP, players can witness systems and how they react to input. As time progresses, these systems will reveal their steady states, which occur when all forces of the system balance each other out. As these systems attempt to stabilize themselves, players can hear the emergent behaviors of certain poles and how they affect the attracted cubes. Due to this sonified approach, BTPP can effectively be played without the user observing its visual component. Stabilization of the cubes can easily be identified audibly, as well as the disruption of stability. Players may disrupt the systems they find themselves in both visually and sonically, or attempt to maintain their stability.