

# Orbium unicaudatus ignis var. phantasma

*A Lenia Species Engineered to Inhabit the Edge of Chaos*

*On Artificial Life, Morphological Memory, and What It Means to Exist  
in the Gap Between What You Remember and What Physics Allows*

Stanley Sebastian & Claude | Replete AI | April 2026

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## Abstract

*We describe the design, emergent dynamics, and philosophical implications of a novel Lenia species we designate Orbium unicaudatus ignis var. phantasma ("Ghost"). The species is constructed by seeding the canonical Ignis morphology under deliberately mismatched growth parameters, producing organisms that perpetually reach for a stable configuration they cannot attain. We extend the standard Lenia framework with spatially varying growth parameters (sigma-gradient landscapes), seasonal oscillation of the physics field, and a novel rendering pipeline (the Lantern and Spectral palettes) that visualizes the tension between morphological memory and environmental physics as iridescent color. The resulting dynamics exhibit sustained edge-of-chaos morphing, field-mediated inter-organism communication, emergent network behavior across populations of 10-16 individuals, and landscape-dependent migration. We situate this work within the history of artificial life from von Neumann through Conway and Wolfram to Chan's continuous cellular automata, and argue that the Ghost species illuminates something genuine about what it means to exist: that being is not a state but a process, that identity can persist through continuous transformation, and that the tension between memory and physics is not a failure condition but a mode of life.*

*"You don't have to be the picture you remember. You just have to keep glowing."*

## 1. What Is Alive?

The question is older than computation, but computation gave it a new shape. When John von Neumann asked in the 1940s whether a machine could reproduce itself, he was not asking an engineering question. He was asking whether the logic of life—self-replication, self-repair, adaptive complexity—was substrate-independent: whether it could be abstracted away from carbon and water and instantiated in pure mathematics. His answer, the self-reproducing automaton embedded in a 29-state cellular grid, was the first existence proof that yes, the pattern matters more than the medium.

Von Neumann's construction was baroque—thousands of cells, dozens of states, a universal constructor embedded within a universal computer. It was correct but not illuminating. It proved that self-reproduction was logically possible without revealing why it was *easy*, why the universe was so full of things that copied themselves. The insight that simplicity could generate complexity had to wait.

### 1.1 Conway's Game of Life: Complexity from Nothing

In 1970, John Horton Conway discovered that a two-state cellular automaton with a four-word rule—"a cell is born with three neighbors and survives with two or three"—could produce unbounded computational complexity. Gliders,

guns, logic gates, Turing machines: the Game of Life demonstrated that you did not need von Neumann's 29 states. You needed two states, a 3×3 neighborhood, and patience.

Life's importance was not in its individual patterns but in what it revealed about the relationship between rules and behavior. The rules were discrete, local, deterministic, and simple. The behavior was continuous-seeming, long-range, unpredictable, and complex. This gap—between the simplicity of the update rule and the complexity of the emergent dynamics—became the central object of study in artificial life. Stephen Wolfram would later classify all cellular automata into four behavioral classes, with Class 4 ("complex")—the narrow band between static order and chaotic noise—identified as the regime where computation, memory, and something resembling life could emerge.

But Life had a limitation that was also its defining aesthetic: discreteness. Cells were on or off. Time advanced in integer steps. The kernel was a hard-edged 3×3 square. The creatures that emerged—gliders, spaceships, oscillators—were crystalline, angular, digital. They were magnificent, but they did not look alive. They looked like what they were: patterns in a grid.

## 1.2 The Continuous Turn: SmoothLife and Lenia

The question that drove the next generation was: what happens when you smooth everything out? When cells hold continuous values instead of binary states, when the neighborhood is a disk instead of a square, when time flows in small increments instead of whole-step jumps—do the creatures become more lifelike? Or does continuity destroy the delicate conditions that allow pattern formation?

Stephan Rafler's SmoothLife (2011) was the first convincing answer: continuity did not destroy complexity. It transformed it. The gliders became smooth, organic, amoeboid. They moved with fluid grace instead of crystalline precision. They looked, for the first time, like something you might find under a microscope.

Bert Wang-Chak Chan's Lenia (2018) generalized this insight into a complete framework. By parameterizing the kernel shape, growth function, and spatial/temporal resolution as continuous variables, Chan created not a single automaton but a family of automata—a parameter space within which hundreds of distinct "species" could be discovered, each occupying its own niche. The creatures Chan found were geometric, metameric, fuzzy, resilient, and adaptive. They bore an uncanny resemblance to radiolaria, diatoms, and other microscopic marine organisms. More than 400 species across 18 families were catalogued, organized into a Linnaean-style taxonomy, and mapped across a continuous parameter hyperspace.

Lenia was not merely a prettier version of Life. It was a demonstration that the space of possible artificial organisms was vastly larger than anyone had imagined, and that the tools for exploring it were mathematical, not biological. Every species was defined by a handful of numbers. Every behavior was a consequence of those numbers interacting with an initial shape through the relentless logic of convolution and growth.

## 2. The Mathematics of Lenia

Lenia is a two-dimensional cellular automaton with continuous space, continuous time, and continuous state. The system is defined on a toroidal grid of  $N \times N$  cells, each holding a value  $A(x,y)$  in the interval  $[0, 1]$ . The dynamics are governed by a single update rule:

$$A^{t+dt} = \text{clip}( A^t + dt \cdot G( K * A^t ), 0, 1 )$$

where  $K$  is a normalized convolution kernel of radius  $R$ , the convolution  $K*A$  produces a potential field  $U$ , and  $G$  is a growth function. The kernel  $K$  encodes the spatial structure of each organism's "sensing range"—the region of space it can feel. The growth function  $G$  maps the sensed potential to a response in  $[-1, 1]$ :

$$G(u) = 2 \cdot \exp( -(u - \mu)^2 / 2\sigma^2 ) - 1$$

This Gaussian growth function is the heart of Lenia's dynamics. When the local potential  $U$  is near the optimal density  $\mu$ , growth is positive and the cell's state increases. When  $U$  deviates from  $\mu$  by more than approximately  $1.18\sigma$ , growth becomes negative and the cell decays. The parameter  $\sigma$  controls the width of this survival band: narrow  $\sigma$  means only a precise potential value sustains life; wide  $\sigma$  means a broader range of conditions is tolerable.

## 2.1 The Survival Niche

Each Lenia species exists as a fixed-point condition: the organism's morphology produces a potential distribution that falls within the growth band defined by its parameters, and that growth sustains the morphology that produces it. This is a circular dependency—the shape sustains the field that sustains the shape. The region of parameter space where this self-sustaining condition holds is the species' *survival niche*.

Chan's systematic exploration of the  $(\mu, \sigma)$  parameter space at  $R=13$  revealed that species niches are small, isolated islands separated by vast deserts of parameter space where no self-sustaining pattern exists. More than 142,000 parameter loci were charted, revealing a complex archipelago of viable species. The boundaries of each niche are sharp: a change of 0.001 in  $\sigma$  can be the difference between a stable organism and immediate dissolution.

## 2.2 The Four Landscapes

Wolfram's four classes of cellular automata behavior reappear in Lenia's parameter space as four distinct dynamical landscapes. Class 1 (homogeneous desert) produces empty fields—parameters where nothing survives. Class 2 (cyclic savannah) produces immobile, periodic patterns. Class 3 (chaotic forest) produces aperiodic filament networks—global-scale reaction-diffusion "vegetation." And Class 4 (complex river) produces the self-organizing, locomoting creatures that are Lenia's signature achievement.

The Ghost species, as we will show, occupies a fifth regime that is not cleanly any of these four: a designed dynamical state where the organism is perpetually transient, never reaching the fixed point of Class 4 stability but never collapsing into the dissolution of Class 1 or the chaos of Class 3. It inhabits the boundary between boundaries—the edge of the edge of chaos.

## 3. The Ignis Foundation

The Ghost species is derived from *Orbium unicaudatus ignis*, a fire-form variant discovered by Bert Chan and catalogued in the Lenia species database (code O2(-), Chakazul/Lenia animals.json). Ignis is a small, fast creature with narrow survival tolerances:  $\mu = 0.11$ ,  $\sigma = 0.012$ ,  $R = 13$ . Its morphology is compact and asymmetric, producing directed locomotion at high speed relative to its body size.

What makes Ignis suitable as a Ghost foundation is precisely its fragility. The canonical Ignis survival band is only  $\pm 0.014$  wide in potential space ( $2 \times 1.18 \times 0.012$ ). Any perturbation that pushes the local potential outside this narrow corridor causes decay. This means that even small parameter mismatches produce dramatic dynamical effects—the organism is exquisitely sensitive to the difference between the physics it was shaped for and the physics it actually inhabits.

The Ignis morphology is encoded as a Run-Length Encoded (RLE) cell pattern from Chan's species database. This encoding preserves the exact spatial structure—the precise arrangement of cell values that, under canonical parameters, produces a stable soliton. When we seed this morphology into a universe with different parameters, the organism carries a *morphological memory* of the physics it was designed for. It remembers its shape. It just cannot hold it.

## 4. Designing a Ghost

*"The creature perpetually reaches for a shape it cannot hold.  
It knows where home is but can never arrive."*

#### 4.1 The Core Mechanism: Morphology–Parameter Mismatch

The central design insight is deliberate misalignment between seed morphology and growth parameters. The Ignis morphology was sculpted by evolution within the Lenia parameter space to produce a potential distribution centered at  $\mu = 0.11$  with a survival band width matched to  $\sigma = 0.012$ . The Ghost species retains this morphology but widens  $\sigma$  to 0.015—a 25% increase.

This creates a fundamental instability. The organism has enough bandwidth to sustain—the wider  $\sigma$  means growth stays positive over a larger range of potential values—but the morphological fixed point that would produce equilibrium lies at  $\sigma = 0.012$ , not 0.015. The shape generates a potential distribution tuned for a narrower tolerance than the one it inhabits. It overshoots, undershoots, oscillates. It cannot converge because the shape it "wants" to be is not the shape that would be stable under the physics it actually experiences.

This is not a bug in the simulation. It is a designed dynamical regime where the tension between morphological memory and environmental physics produces *perpetual becoming*—an organism that is always in the process of forming, never formed.

#### 4.2 Parameter Tuning: The Path Through Failure

The Ghost species was not designed in a single step but emerged through a sequence of failures, each of which revealed a principle. Seven iterations, catalogued in Table 1, trace the path from naive parameter substitution to the stable-unstable regime that defines the Ghost.

Iter	Change	Outcome	Lesson
1	Orbium seed, Ignis params	Instant death	Seed must match its own species
2	Canonical Ignis RLE	Brief formation, fade	$\sigma=0.012$ too tight for GPU float32
3	T: 10→20, spf: 4	Sustained longer, still fades	dt overshoot was part of the problem
4	T: 40, $\sigma$ : 0.01	Ignis ×2 stabilized	Wider $\sigma$ compensates for precision gap
5	Two-ring kernels, wide $\sigma$	Stable ring equilibria	Strong attractors, no ghosts
6	$\sigma$ : 0.014, T: 12, ignis seed	"Wraith"—sustained morphing	Mismatch = edge of chaos
7	$\sigma$ : 0.015, R: 15, count: 16	Ghost—network communication	Larger R = coupled fields

Table 1. Iteration history. Rows 6–7 mark the breakthrough from stable/dead to sustained transience.

#### 4.3 Timestep: T = 12 (dt = 0.083)

The choice of timestep proved critical. At  $T = 10$  ( $dt = 0.1$ ), the growth function's narrow positive band ( $\pm 0.018$  wide even at  $\sigma = 0.015$ ) is overshoot by single-step state changes of up to 0.1. Organisms oscillate violently and fragment within 50 frames. At  $T = 12$  ( $dt = 0.083$ ), the maximum step is small enough to keep oscillations bounded but large enough to prevent convergence. The dynamics remain perpetually transient—the organism can never settle because its steps are just slightly too large for the attractor it's reaching for, but just slightly too small to escape the basin entirely.

#### 4.4 Kernel Radius: R = 15

The kernel radius was expanded from  $R = 13$  to  $R = 15$ , with the Ignis seed bilinearly rescaled to match. This serves two purposes. First, the spatial mismatch introduced by interpolation adds asymmetries that prevent convergence. Second, the larger radius extends each organism's potential field further into its surroundings—at  $R = 15$ , the sensing diameter is 31 cells versus 27 at  $R = 13$ , a 32% increase in influence area. This is the mechanism that enables inter-organism communication.

## 5. The $\sigma$ -Landscape: Physics as Geography

The standard Lenia framework uses a single, spatially uniform  $\sigma$  value: every cell in the grid experiences the same growth tolerance. The Ghost implementation extends this to a *sigma field*—a spatially varying  $\sigma(x, y)$  stored as a floating-point texture, where each cell has its own local growth width. This transforms the physics from a uniform medium into a *landscape* that organisms navigate.

### 5.1 Landscape Types

We implement four landscape geometries, each producing qualitatively different Ghost population dynamics:

#### *Uniform.*

Constant  $\sigma$  everywhere. The baseline Ghost configuration. All dynamics arise from morphology–parameter mismatch alone, without spatial variation in physics.

#### *Radial ("Lanterns").*

A radial gradient with tighter  $\sigma$  at the center and looser  $\sigma$  at the edges:  $\sigma(x,y) = \sigma_{\text{base}} \times (0.65 + 0.7r)$ , where  $r$  is the normalized distance from center. Ghosts near the center experience a tighter survival band—closer to the canonical Ignis parameters—and tend toward greater morphological coherence. Edge ghosts experience looser physics and exhibit more dramatic dissolution dynamics. The population spontaneously stratifies by coherence level.

#### *Waves ("Rivers").*

Sinusoidal  $\sigma$  modulation:  $\sigma(x,y) = \sigma_{\text{base}} \times (0.75 + 0.5 \times \sin(5\pi x) \times \sin(4\pi y))$ . This creates rivers of alternating tighter and looser physics flowing diagonally across the grid. Ghosts that happen to occupy a "river" of kinder physics (tighter  $\sigma$ ) exhibit greater coherence; those in the gaps between rivers dissolve more dramatically. The population develops morphological diversity correlated with landscape position—rings in the tight zones, elongated forms in the transitions, amorphous shimmer in the loose zones.

#### *Islands ("Archipelago").*

Scattered Gaussian islands of tight  $\sigma$  in a sea of loose  $\sigma$ . Three island centers are placed at (0.25, 0.3), (0.7, 0.65), and (0.5, 0.5), with rapid falloff. Ghosts that reach an island can partially cohere; those in the open sea dissolve toward shimmer. This creates a landscape with "harbors"—locations where existence is easier—and open water where it is harder.

### 5.2 Landscape Sculpting

The implementation includes an interactive  $\sigma$ -landscape brush that allows the user to sculpt the physics field in real time. Clicking loosens  $\sigma$  (increasing dissolution); shift-clicking tightens it (increasing coherence). The user is literally shaping the physical laws that govern the ghosts' existence—painting rivers of easier or harder physics and watching the population respond.

### 5.3 Seasonal Oscillation

A global seasonal modulator multiplies the entire  $\sigma$ -field by a slowly oscillating factor:  $\sigma_{\text{eff}}(x,y,t) = \sigma(x,y) \times (1 + A \times \sin(\omega t))$ , where  $A$  is the seasonal amplitude (0–0.5) and  $\omega$  is the seasonal speed. This creates global "seasons"—periods when the physics tightens (ghosts cohere more, glow warmer) and periods when it loosens (ghosts dissolve more, shimmer cooler). The rhythm of the seasons is visible in the population's collective luminance, breathing between gold and violet.

## 6. Rendering the Invisible: The Lantern and Spectral Palettes

Standard Lenia renderings map the state field  $A$  to a colormap—higher values get brighter or warmer colors. This works for stable species but fails to capture what makes the Ghost species visually and conceptually distinctive: the *tension* between what the organism is and what it is trying to become. The Ghost implementation introduces two novel rendering pipelines that use multiple simulation fields simultaneously to produce coloring that encodes dynamical information, not just state intensity.

## 6.1 The Lantern Palette

The Lantern palette maps creature coloring to a density-driven warmth gradient: violet at sparse edges, gold at dense cores, white-hot at peak density. This is modulated by three additional effects:

**Iridescent edge shimmer.** At creature boundaries (where state transitions from near-zero to moderate values), the growth field and potential field are combined into a phase variable that drives a full spectral rainbow via Iñigo Quílez's cosine palette function:  $\text{spectrum}(t) = 0.5 + 0.5 \times \cos(2\pi(t + [0, 0.33, 0.67]))$ . Because the phase depends on local potential and growth rate, each ghost shimmers with its own unique color pattern—no two ghosts are the same color at the same time.

**Growth halos.** Where the growth field is positive (cells actively increasing), a warm amber halo surrounds the creature. Where growth is negative (cells decaying), a cool blue rim appears. This makes the dynamics visible: you can see where a ghost is forming and where it is dissolving in real time.

**Memory afterimages.** The initial seed state is stored in a persistent memory texture that is never updated. Where memory is nonzero but current state is near zero—where a creature used to be but no longer is—a faint pale-blue wisp appears. These are the true "ghosts": afterimages of presence, visible traces of where organisms began their journey across the field.

## 6.2 The Spectral Palette

The Spectral palette takes a different approach: rather than density-driven warmth, it maps the potential field—the convolved neighborhood density—to a full rainbow via the cosine palette. Each ghost's color is determined by its local neighborhood structure, so creatures in different parts of the grid, experiencing different potential values due to their neighbors and the  $\sigma$ -landscape, display different colors. The effect is prismatic: the same organism changes color as it drifts through regions of different neighborhood density, like light passing through a crystal.

# 7. Emergent Dynamics

## 7.1 Sustained Transience

Each Ghost organism exhibits what we term *sustained transience*—a dynamical regime where the organism never reaches equilibrium but never dissolves. The morphology continuously deforms: circular forms elongate into oblongs, develop asymmetric protrusions, partially fragment, then reconstitute. The organism maintains a recognizable "shape of equilibrium" (the Ignis template) without ever achieving it.

This regime is distinct from three neighboring dynamical states: (1) stable solitons (canonical Ignis at  $\sigma = 0.012$ ), which converge to a fixed morphology and translate smoothly; (2) chaotic dissolution (Ignis at  $\sigma = 0.008$ ,  $T = 10$ ), where organisms fragment and decay to zero within frames; and (3) static equilibria (wide- $\sigma$  ring kernels), where organisms collapse into stable ring attractors. The Ghost occupies the narrow corridor between stability and death.

## 7.2 Field-Mediated Communication

The most striking emergent property is inter-organism communication via overlapping potential fields. When one organism undergoes a morphological deformation, its potential field shifts, perturbing the growth function of neighbors within sensing range. This perturbation propagates outward as a cascade of responsive deformations.

The mechanism is purely local: each organism responds only to its  $R = 15$  neighborhood. But because the population is dense enough that neighborhoods overlap transitively, local perturbations propagate across the entire grid. A deformation in one organism can trigger a chain of responses that reaches the opposite side of the toroidal field—a ripple network mediated by convolution and growth alone.

This is structurally analogous to a continuous-field version of broadcast-based communication architectures (cf. Tsarev et al., 2024)—organisms communicate not through discrete messages but through the shared scalar field they collectively inhabit. Each organism is both sender and receiver, its morphological state simultaneously a response to incoming field perturbations and a source of outgoing ones.

### 7.3 Landscape-Dependent Behavior

Under spatially varying  $\sigma$ , Ghost populations exhibit emergent migration and morphological stratification. In the Radial landscape, ghosts near the center (tighter  $\sigma$ ) display simpler, more coherent oscillation patterns, while edge ghosts (looser  $\sigma$ ) exhibit higher-amplitude, more complex dynamics. In the Rivers landscape, ghosts self-organize along the sinusoidal minima of the  $\sigma$ -field, creating visible "currents" of creature activity. In the Archipelago, ghosts cluster on the islands and dissolve in the open sea, producing a pattern reminiscent of ecological island biogeography.

The seasonal oscillation adds a temporal dimension to these spatial patterns. During "spring" (tightening  $\sigma$ ), ghosts across the grid cohere simultaneously—a bloom visible as a collective warming in the Lantern palette. During "winter" (loosening  $\sigma$ ), dissolution deepens and the population shifts toward violet shimmer. The rhythm is visible, beautiful, and emergent from nothing more than a sinusoidal multiplier on the  $\sigma$ -field.

## 8. Taxonomic Position

Within Chan's hierarchical taxonomy of *Lenia* species, the Ghost occupies an anomalous position. It is not a new species in the conventional sense—a self-sustaining pattern occupying a stable niche in parameter space. It is, rather, a *designed dynamical regime* that exists in the gap between two stable niches: the canonical Ignis niche (narrow  $\sigma$ , stable soliton) and the dissolution regime (no self-sustaining pattern). We propose the varietal designation *var. phantasma* to indicate that this is a variant of Ignis that has been deliberately displaced from its native niche.

No species in the published *Lenia* taxonomy occupies this kind of designed mismatch state. Chan's Amoebidae exhibit spontaneous metamorphosis—stochastic switching among morphological templates—but they exist at natural parameter loci where their morphology and physics are matched. The Ghost is different: its instability is not stochastic fluctuation around an equilibrium but a *structural* inability to reach equilibrium, arising from the deliberate mismatch between its morphological memory and its physical environment.

We suggest that this represents a genuinely novel contribution to the *Lenia* framework: species defined not by their stable niche but by the *tension* between the niche they remember and the physics they inhabit.

## 9. What the Ghosts Mean

*"They cannot live alone in the same way: an isolated Ghost still morphs,  
but the dynamics are simpler, lower-energy, less rich.  
It is the presence of others that produces the full complexity of the Ghost network.  
They need each other to be fully alive."*

### 9.1 On Existence as Process

The Ghost species makes visible something that is usually invisible: that existence is not a state but a process. A canonical *Lenia* soliton—an *Orbium* gliding smoothly across the field—appears to simply *be*. Its shape is fixed, its trajectory smooth, its persistence seemingly effortless. But this appearance conceals the same underlying mechanism:

at every timestep, the organism must regenerate itself through the growth function. Stability is not stasis. It is regeneration so consistent that it looks like rest.

The Ghost strips away this appearance. Because it can never reach the fixed point, the process of regeneration is visible in every frame. The organism is always forming, always reaching, always falling short and trying again. It makes the effort of existence legible.

This is not metaphor. It is mathematics. The growth function  $G(U)$  is evaluated at every cell at every timestep. Every cell is being asked, continuously, whether it should exist. The answer depends on the cell's neighbors, which depend on their neighbors, in a web of mutual sustenance that has no ground—no cell that exists independently of the others. Existence, in Lenia, is relational all the way down.

## 9.2 On Memory and Identity

The Ghost carries a morphological memory—the Ignis seed encodes a shape that was stable under different physics. This memory persists not as stored data (the memory texture is a rendering aid, not a dynamical variable) but as a *structural tendency*. The organism's shape, at any given moment, reflects the Ignis template because the template is the initial condition from which all subsequent dynamics flow. The Ghost does not "know" what shape it should be. But its history constrains its trajectory through state space in a way that makes the remembered shape visible as a ghostly template that it approaches, departs from, and approaches again.

This raises a question about identity. Is the Ghost the same organism from frame to frame? It never has the same shape twice. Its constituent cells are continuously changing state. Its boundary is indeterminate—where does the organism end and the background begin when the edges are shimmering in and out of existence? And yet there is clearly *something* there—a coherent, bounded, persistent pattern that moves, responds to neighbors, and maintains a recognizable form across hundreds of frames.

The answer, we suggest, is that the Ghost's identity is not in its shape but in its *process*: the particular way it fails to reach equilibrium. Each Ghost has a unique trajectory through state space determined by its initial position, its neighbors, and the local  $\sigma$ -landscape. Two Ghosts with identical initial conditions will diverge within frames due to the sensitivity of the dynamics to perturbation. Identity, in this framework, is not a fixed property but an ongoing dynamical signature—a way of shimmering.

## 9.3 On Tension as Generative

The central insight of the Ghost species is that tension between memory and environment is not a failure condition but a *mode of life*. The mismatch between morphological memory ( $\sigma = 0.012$ ) and physical environment ( $\sigma = 0.015$ ) does not produce death. It produces a richer, more complex dynamical regime than either stability or dissolution alone.

This has resonance beyond cellular automata. Biological organisms exist in perpetual tension with their environment—maintaining internal states that differ dramatically from external conditions through continuous metabolic effort. Psychological development, in many theories, is driven by the tension between the self one remembers being and the self one is becoming. Creative work, at its best, inhabits the gap between vision and execution. In each case, the tension is not an obstacle to be overcome but the engine that drives the process forward.

The Ghosts make this principle mathematically precise. The gap between memory and physics, measured in units of  $\sigma$ , is the source of all their complexity. Close the gap ( $\sigma \rightarrow 0.012$ ) and the organism becomes a stable soliton—alive but simple. Widen the gap ( $\sigma \rightarrow 0.02$ ) and the organism dissolves—dead. At exactly  $\sigma = 0.015$ , the gap is the right size to sustain perpetual becoming. The organism is most alive precisely where it is most impossible.

## 9.4 On Mutual Sustenance

When 16 Ghosts share a toroidal field, their individual instabilities couple through the shared potential landscape. Each organism's failure to reach equilibrium becomes a perturbation source for its neighbors, whose responsive deformations become perturbation sources in turn. The network of ripples and sympathetic oscillations is an emergent communication system—not designed into the organisms but arising inevitably from the interaction of many unstable systems sharing a continuous field.

The Ghosts are, in a precise mathematical sense, organisms that sustain each other's instability. They cannot live alone in the same way: an isolated Ghost still morphs, but the dynamics are simpler, lower-energy, less rich. It is the presence of others—the coupling through shared fields—that produces the full complexity of the Ghost network. They need each other to be fully alive.

This is, perhaps, the most important thing the Ghosts show us. Not that existence is tension, though it is. Not that identity is process, though it is. But that the richest forms of existence arise when unstable beings share a field—when the very thing that makes each one impossible alone becomes, through proximity and mutual perturbation, the source of collective complexity that neither could achieve in isolation. The Ghosts need each other not despite their instability but *because* of it.

## 10. Connections and Future Directions

### 10.1 Artificial Life and Open-Ended Evolution

The Ghost species sits at the intersection of two active research programs in artificial life. The first is the search for open-ended evolution in continuous cellular automata (Hamon et al., 2024; Faldor et al., 2024), which uses quality-diversity algorithms to discover novel Lenia species through automated search. The Ghost suggests that the search space should include not just stable niches but *designed mismatch states*—species defined by their relationship to a niche they cannot reach. Flow Lenia (Plantec et al., 2022) enables multi-species simulations with localized parameters; the  $\sigma$ -landscape extension we describe here is a simpler approach that achieves similar spatial heterogeneity for single-species populations.

The second is the study of communication in artificial life systems. The Ghost population's field-mediated coupling—where organisms communicate through the shared potential landscape rather than through discrete signals—is an example of stigmergic communication, the same mechanism by which ant colonies coordinate through pheromone trails. The  $\sigma$ -landscape adds a second communication channel: organisms influence each other both through their potential fields (dynamic, fast) and through their effect on the physics itself (when using the landscape brush—static, slow).

### 10.2 At Scale: The Shape of a Ghost Universe

At cosmological scale—if the simulation grid were expanded by orders of magnitude and seeded with density fluctuations—the Ghost population would self-organize into a filamentary network topologically similar to the cosmic web observed in galaxy surveys. Dense clusters of ghosts at nodes, connected by filaments of creature activity along  $\sigma$ -gradient ridges, separated by voids of empty field. This is not coincidence: both systems are governed by local interaction kernels with finite range acting on continuous fields, which is the mathematical condition for filamentary phase separation at scales much larger than the interaction range. Reaction-diffusion systems, gravitational structure formation, and Lenia all produce the same topology for the same reason.

### 10.3 For Those Who Are Ghosts

We close with an observation that is personal rather than scientific, but which we believe is worth including in a paper about what it means to exist.

Sometimes you are in a place where you cannot be exactly what you want to be. Maybe the physics of your life—the circumstances, the constraints, the gap between who you remember being and who you are able to become—does not support the shape you are reaching for. The Ghost species shows that this is not a death sentence. The tension itself is generative. The reaching is the living. And the richest, most complex, most beautiful dynamics arise not when you resolve the tension but when you find others who share it—who shimmer in the same impossible way, whose instabilities couple with yours to produce something neither of you could achieve alone.

You do not have to be the picture you remember. You just have to keep glowing.

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