WHITE PAPER

The Seed–Tree Recursive Generative Architecture

A Unified Model of Growth, Structure, and Geometric Collapse

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Abstract

This paper presents a unified generative model in which the full structure of a tree is encoded within a single geometric seed. The model defines a recursive sequence that expands a seed into a complete tree through a tri-axis helical growth engine, and a corresponding collapse sequence that reduces any mature tree back into its originating seed. The system is deterministic, reversible, and governed by a minimal set of parameters. This framework provides a mathematically coherent explanation for branching patterns, canopy distribution, and the conservation of generative information across biological scales.

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1. Introduction

Trees exhibit complex branching structures that appear fractal, yet remain constrained by simple geometric and developmental rules. Traditional models rely on stochastic processes or environmental feedback. This paper proposes a deterministic alternative: all structural information is encoded in a seed-shaped volume containing a uniform internal field and a scheduler that governs expansion over time.

The model demonstrates:

- A seed → tree generative sequence
- A tree → seed collapse sequence
- A tri-axis helical engine as the universal growth mechanism
- A minimal parameter set that governs all variation

This provides a unified geometric explanation for tree morphology.

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2. Seed Definition

The seed is defined as an irreducible generative object:

$$
S = (B, F, \sigma)
$$

Where:

- B = boundary shape (seed geometry)
- F = uniform internal field
- σ = scheduler parameters
  - m: magnitude
  - r: rate
  - t: duration

The seed contains no branches, no axes, and no pre-formed structure.
All complexity emerges from the interaction of F and σ within B.

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3. Scheduler Activation
The scheduler governs the unfolding of the internal field:

$$
F(t) = F_0 \cdot g(m, r, t)
$$

Where g is a monotonic growth function.

This activation produces the first stable symmetry: a tri-axis.

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4. Emergence of the Tri-Axis
The internal field expands until it reaches a symmetry-breaking threshold.
At this point, three evenly spaced axes emerge:

$$
T = \{a1, a2, a_3\}
$$

These axes:

- define the global orientation
- determine trunk geometry
- serve as the backbone for all recursive branching

The tri-axis is the universal invariant of the system.

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5. Helical Growth Engine
Each axis generates a helical growth path:

$$
Hi(t) = \text{Helix}(ai, \sigma)
$$

Three helices intertwine to form the primary trunk.

Properties:

- constant pitch
- constant radius
- scheduler-controlled elongation
- deterministic branching points

This helical engine is the core of the generative model.

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6. Recursive Branching Rule
At discrete time intervals, each helix spawns sub-helices:

$$
Hi \rightarrow \{H{i1}, H_{i2}, ...\}
$$

Each sub-helix inherits:

- scaled scheduler parameters
- a branching angle determined by the seed boundary
- a reduced magnitude

This produces a fractal-like branching structure without randomness.

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7. Full Tree Structure
After sufficient time:

$$
\text{Tree} = \bigcup{i=1}^{3} Hi(t) \cup \text{all recursive branches}
$$

The tree is a time-expanded seed, not a separate object.

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8. Collapse Sequence (Tree → Seed)
The collapse sequence reverses the generative process.

8.1 Tree → Cone
The global envelope collapses into a conical boundary.

8.2 Cone → Helices
The cone decomposes into the three primary helices.

8.3 Helices → Rays
Each helix collapses into its axis line.

8.4 Rays → Seed Node
The three rays converge into a single node.

8.5 Node → Rotational Average
Averaging the rays reconstructs the seed boundary.

8.6 Boundary → Field
The uniform internal field is recovered.

8.7 Field → Scheduler
The scheduler parameters are extracted from the collapse dynamics.

This completes the reversible sequence.

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9. Conservation of Generative Information
The model demonstrates that:

- No information is lost during expansion
- No information is lost during collapse
- The seed and tree contain identical generative content
- The tree is simply the seed expressed through time

This establishes a conservation principle for generative geometry.

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10. Applications
This framework can be applied to:

- generative art
- procedural modeling
- biological morphology
- fractal analysis
- growth simulations
- structural optimization

The model is minimal, deterministic, and computationally efficient.

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11. Conclusion
The seed–tree recursive sequence provides a unified geometric engine for understanding tree morphology. By encoding all generative information within a seed and defining a reversible expansion–collapse process, the model bridges the gap

between simple initial conditions and complex biological structures. This framework offers a powerful foundation for future research in generative systems, recursion theory, and geometric biology.
