INTERNATIONAL SYSTEM DYNAMICS CONFERENCE

ISDC2025

Incorporating AI into Dynamic Modeling

# RIEGEL

## A Hybrid-Intelligence Cognitive Companion for Archetype Discovery and Dynamic System Simulation

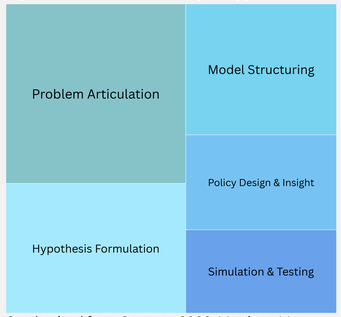
**PAPER:**
When Systems Speak: A Hybrid Intelligence Model and Framework or System Archetype Discovery and Simulation

## INTRODUCTION & PROBLEM

System dynamics modelers often struggle at the very beginning—when defining the problem, identifying structure, and hypothesizing feedback.

RIEGEL is a hybrid-intelligence assistant that helps bridge this gap.

**Figure 1**: Where does Modeling Struggle Most?




Synthesized from Sterman 2000, Martinez-Moyano & Richardson (2013)

As a working prototype, RIEGEL augments the early modeling process by accepting and turning scenario narratives into structured insights—supporting both human reasoning, iterative modeling, and the discovery of emergent or canonical archetypes. As a thinking companion, RIEGEL starts the journey with reference modes, a dynamic hypothesis, an archetype, and more while learning.

## ARCHETYPE DISCOVERY ENGINE

Canonical archetypes (e.g., Limits to Growth, Shifting the Burden), potentially new emergent patterns like The Catalysis and Emergent Harmony, are identified and discovered through pattern recognition based on six properties and traits, resulting in structured explanations of why each archetype fits.

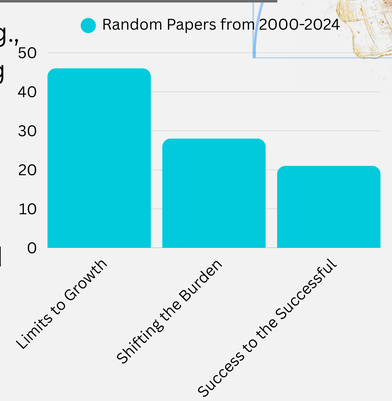



**Figure 2**: Among 100 randomly sampled System Dynamics papers (2000–2024), Limits to Growth remains the most commonly modeled archetype, followed by Shifting the Burden and Success to the Successful.

P1 P2 P3 P4 P5 P6

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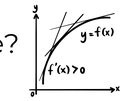
## THE MODELER'S EARLY JOURNEY

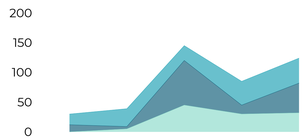
### 1. WHAT'S THE PROBLEM?

Why is this a problem?
What's the timescale?
What information is missing?

### 2. DYNAMIC PROBLEM DEFINITION

What behaviors and structures do we see?




What are the feedback structures and their endogenous consequences?

### 3. DYNAMIC HYPOTHESIS FORMULATION

"Formulate a dynamic hypothesis that explains the dynamics as endogenous consequences of the feedback structure and develop maps of causal structures." (Business Dynamics, Sterman, 2000) and feedback systems.

## HOW DOES RIEGEL SUPPORT MODELING?

### BEHAVIORAL PATTERN SIMULATION

RIEGEL asks the modeler clarifying questions one at a time. Short narratives are acceptable.

Through unsupervised comparison of trait vectors, properties, and feedback topologies, RIEGEL detected recurring structures that mirror the Golden Ratio in dynamic systems, where recursive feedback and layered growth produces emergent harmony.

1. Narrative
Translates narrative into structural logic
2. Casual Theory Archetype
Pattern Identification
3. Archetype Inference
4. Narrative Output

B R

### ENGAGING DOUBLE-LOOP LEARNING

RIEGEL supports double-loop learning by helping modelers question their goals, assumptions, and mental models — not just policies or parameters.

### WHAT IS DYNAMIC SIMULATION FOR RIEGEL?

RIEGEL simulates dynamic system behavior not by modeling equations, but by interpreting structure. It infers archetypes, generates expected behavior over time, and proposes a dynamic hypothesis based on narrative input. This enables early-stage system modeling when formal stock-and-flow diagrams are not yet available—but structural feedback insight is needed.

**Figure 3**: RIEGEL creates synthesized and/or actual reference modes citing sources. The modeler can export the short report listing variables, suggested polarity, dynamical behavior, the matched canonical or emergent archetype (if applicable), references, a dynamic problem to hypothesis, and finally, preliminary leverage points. **The modeler is expected to question the information and continue the exploration and analysis iteratively. RIEGEL is an assistant.**

## MATHEMATICAL MODEL

Extracting a six-dimensional trait vector, RIEGEL transforms a narrative scenario into a high-dimensional embedding vector using a language model.

$$\mathbf{v}_{\text{scenario}} = \text{Embedding}(x) \in \mathbb{R}^d$$

$$P_i = f_i(\mathbf{v}_{\text{scenario}}) \in \{0,1\} \quad \text{for } i = 1,\ldots,6$$

Traits in vector form are then matched against known archetype signatures—and clustered to discover emergent patterns.

$$\mathbf{P} = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \end{bmatrix} \in \{0,1\}^6 \qquad \text{similarity}(\mathbf{P}, \mathbf{A}_j) = \frac{\mathbf{P} \cdot \mathbf{A}_j}{\|\mathbf{P}\| \, \|\mathbf{A}_j\|}$$

LLMs synthesize a dynamic hypothesis from the input x, trait vector, and matched archetype structure.

$$h = \text{LLM}_{\text{hypothesis}}(x, \mathbf{P}, \text{Archetype})$$

## SYSTEM ARCHITECTURE

RIEGEL integrates two large language models based on the mathematical model and dynamic LLM model routing. It transforms narrative input through structural pattern simulation, not mechanistic equations.

3D PCA Visualization of Property Vectors with Colorbar

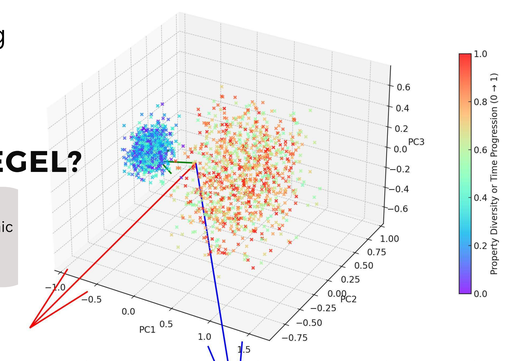



**Figure 4**: The 6-dimensional trait vectors (P1–P6)—representing structural system properties—are projected into 3D space using PCA to reveal clustering patterns. Each point corresponds to a simulated scenario, with clusters indicating shared structural characteristics. This chart visualizes over 2,000 test scenarios, used to validate RiEGEL's analytical flow. The next phase focuses on applying the same discovery process to real-world cases now being processed.