# Embodied Game of Life with Diffusive Food: A Minimal Arena for Open-Ended Evolution

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**Abstract**

We describe a simple artificial-life environment: Conway's Game of Life (GoL) embedded in a continuous food field that diffuses and is consumed by alive cells. Diffusion is *faster near living tissue* to promote organism formation and *food sharing along connected structures*. GoL remains the base logic; food influences survival through tiny, local, probabilistic gates. The aim is to study open-ended evolutionary dynamics where structures must forage, coordinate, and compete for resources.

*Note: this document was written with the help of AI.*

## Design Rationale (Why These Choices)

- **Keep GoL dynamics familiar.** Use standard GoL to propose births/survivals; apply only small, local gates so recognizable structures (gliders, oscillators, etc.) still emerge.
- **Embodiment via diffusion + consumption.** Food flows by diffusion and is consumed where cells are alive. This creates local deficits that surrounding regions refill.
- **Faster diffusion around life.** Diffusivity is higher near living cells. This supports formation of *organisms* (connected tissue) and enables *passive sharing* of food along those connections—favoring coordinated morphologies over isolated cells.
- **Simple, conservative transport.** No velocities or forces. Transport is just diffusion; total food is conserved during transport and only decreases by consumption (and optional tiny decay).

## Environment (Short)

**Grid:** 2-D torus with binary life $C \in \{0,1\}^{H\times W}$ and food $F \in [0,1]^{H\times W}$.
**Tick order:** (1) GoL proposal $\to$ (2) soft food gates $\to$ (3) optional central seeding $\to$ (4) diffusion $\to$ (5) consumption.

**Soft food gates (clear and local).** Let $T_1$ (scarcity) and $T_2$ (abundance) be fixed food thresholds with $0 < T_1 < T_2 < 1$. Use small amplitudes $\varepsilon_d, \varepsilon_r \ll 1$ and a smooth switch $\sigma(x) = 1/(1+e^{-x})$:

$$\phi_d(F) = \sigma\big(\alpha(T_1 - F)\big), \qquad \phi_r(F) = \sigma\big(\alpha(F - T_2)\big).$$

After computing classic GoL:

- If GoL says *"alive stays alive"*, keep it alive with probability $1 - \varepsilon_d\,\phi_d(F)$ (slightly easier to die when food is very low).
- If GoL says *"cell dies"*, allow a tiny rescue with probability $\varepsilon_r\,\phi_r(F)$ (rare survival when food is very high).
- If GoL says *"birth"*, accept it as-is (keeps births crisp).

**Diffusion (why it helps organisms).** Compute a simple life density $\rho = \text{mean}_{3\times3}(C)$ and set

$$D = D_{\text{dead}} + (D_{\text{alive}} - D_{\text{dead}})\,\rho, \quad 0 < D_{\text{dead}} \le D_{\text{alive}}.$$

Food diffuses with coefficient $D$: where tissue is present ($\rho$ large), diffusion is faster. Because alive cells also consume food, this combination creates *inward flux toward connected clusters* and then *rapid sharing* along them. (Implementation tip: use standard finite-difference/finite-volume diffusion with periodic wrap; choose $\Delta t \le 1/(4D_{\max})$.)

**Consumption (only sink).** On alive cells, apply a stable multiplicative uptake

$$F \leftarrow F \cdot e^{-\mu\,\Delta t} \quad \text{(only where } C = 1\text{)},$$

and optionally a tiny global leak $-\lambda F \Delta t$.

**Central seeding (optional).** In a small centered $D \times D$ square, flip dead sites to alive with a tiny probability $p_{\text{seed}}$ each tick to keep exploration going.

## Evolution Experiment (Free, Ongoing)

We do *not* impose an external fitness function or reset episodes. The simulation runs indefinitely; variation and selection arise from the physics plus the stochastic gate. Local consumption and diffusion set the ecological pressures (access to food, connectivity for sharing). Small stochastic deviations from deterministic GoL keep the rule close to its classical behavior while allowing novelty. In this free regime, lineages that happen to forage, move, replicate, and maintain connected tissue tend to persist and spread, while others fade. Because the stochastic rule can be made arbitrarily close to deterministic GoL (turing complete), complex foraging and movement programs can in principle emerge and be maintained by resource-driven differentials alone.

## Suggested Defaults (Absolute Scale)

- **Food range:** $F \in [0, 1]$, initialize near 0.6, clamp to $[0, 1]$.
- **Gates:** $T_1 = 0.20$, $T_2 = 0.85$, $\varepsilon_d = 0.005$, $\varepsilon_r = 0.002$, $\alpha = 6$.
- **Diffusion:** $D_{\text{dead}} = 0.04$, $D_{\text{alive}} = 0.22$, time step $\Delta t = 0.5$.
- **Consumption:** $\mu = 0.8$ (no global leak by default, $\lambda = 0$).
- **Seeding (opt.):** $D = 32$ on $256\times256$, $p_{\text{seed}} = 10^{-4}$.

## What to Look For

Foraging swarms (glider streams feeding tissue), diffusion "corridors" that enable sharing, arms races between dismantlers and defenders, and niche formation between mobile and high-retention strategies. Track flip rate vs. GoL (should stay very small), total/consumed food, cluster sizes, and glider flux.