A Minimal Scalar Toy Universe with a Global Non-Cancelling Constraint

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Abstract

We study a minimal field–theoretic implementation of the *Origin Axiom*: the hypothesis that physically realised configurations of the universe never reach a perfectly cancelling global state. Operationally, we represent this as a constraint on a global complex amplitude $A(C)$ constructed from the fields. Configurations with $A(C)$ exactly equal to zero (or more generally lying in a small neighbourhood of a reference value A_*) are removed from the admissible configuration space.

In this paper we do not claim a fundamental derivation of known physics. Instead, we ask a narrower, technical question: can such a global "non–cancelling" rule be imposed on simple scalar field models in a way that is dynamically stable and numerically well behaved? We construct a complex scalar field on a discrete three–torus and impose the Origin Axiom as a global projection on the total field amplitude. We compare linear and nonlinear dynamics, perform a small scan over the constraint scale ϵ and coupling λ, and check simple one–dimensional twisted models where we expect the constraint to be spectrally trivial.

The main observations are: (i) in both linear and nonlinear regimes the global constraint successfully keeps $|A(t)|$ away from zero and close to a tunable scale $|A| \sim \epsilon$; (ii) the coarse–grained energy evolution is remarkably insensitive to the constraint, suggesting that the rule can be viewed as a global selection on otherwise standard dynamics; and (iii) for simple one–dimensional twisted scalar chains the vacuum energy is independent of the twist angle, so nontrivial phase effects require more structure than the minimal models considered here.

1 Introduction

The Origin Axiom, developed in a separate conceptual companion paper, starts from the idea that *absolute nothingness*—a state with no fields, no degrees of freedom, and no possibility of change—is not a coherent member of configuration space. In this view, it should be impossible for the universe to "settle" into a globally cancelling state that is, in an appropriate sense, indistinguishable from nothing. This motivates a structural rule: global configurations that cancel exactly should be excluded, even if the local dynamics are otherwise familiar.

The aim of this paper is deliberately modest and technical. We do not attempt to reconstruct cosmology or the Standard Model. Instead, we take a simple complex scalar field on a discrete three–torus and ask:

- Can we define a global complex amplitude $A(C)$ that is sensitive to large–scale cancellations?
- Can we impose a constraint that forbids $|A|$ from entering a small neighbourhood of some reference value A_*, while leaving the rest of the dynamics as standard as possible?
- How does such a constraint behave numerically in linear and nonlinear regimes, and how does its "activity" scale with its tunable parameters?

We find that a very simple implementation already exhibits clear and robust behaviour: the constraint can be tuned to keep the global amplitude away from zero while leaving the energy evolution essentially unchanged. This supports the view that a non–cancelling rule can be treated as a global selection on configuration space—a structural ingredient—rather than an additional local interaction.

We also study simple one–dimensional twisted scalar models intended as analytic checks. On both a uniform ring and a ring with a single defect bond, the total vacuum energy is numerically independent of the twist angle. These models thus serve as useful null results and constrain how and where a global phase–like parameter could have nontrivial energetic consequences.

2 Minimal lattice model

We work on a cubic lattice with periodic boundary conditions, representing a discrete three–torus T^3. Lattice sites are indexed by integer triples $\mathbf{n} = (n_x, n_y, n_z)$ with

$$n_i \in \{0, \dots, N-1\}, \qquad i \in \{x, y, z\},$$

and periodic identification $n_i \equiv n_i + N$. The total number of sites is $V = N^3$.

At each site and time step we place a complex scalar field value $\Phi_{\mathbf{n}}(t) \in \mathbb{C}$. We write $\Phi_{\mathbf{n}} = \phi_{\mathbf{n}}^{(R)} + i\phi_{\mathbf{n}}^{(I)}$, with real and imaginary parts treated symmetrically. In this toy setting we interpret the real/imaginary pair loosely as a "yin–yang" structure: two interpenetrating components that interfere but do not annihilate one another.

2.1 Discrete dynamics

We use a discrete Klein–Gordon–type dynamics for Φ. Denoting by Δ the standard nearest–neighbour lattice Laplacian,

$$(\Delta\Phi)_{\mathbf{n}} = \sum_{\hat{\mu} \in \{\pm\hat{x}, \pm\hat{y}, \pm\hat{z}\}} \Phi_{\mathbf{n}+\hat{\mu}} - 6\Phi_{\mathbf{n}},$$

the continuum equation $\ddot{\Phi} = c^2\Delta\Phi - m^2\Phi - \lambda|\Phi|^2\Phi$ motivates a leapfrog integration scheme with time step Δt:

$$\Phi_{\mathbf{n}}(t+\Delta t) = 2\Phi_{\mathbf{n}}(t) - \Phi_{\mathbf{n}}(t-\Delta t) + \Delta t^2 \left[c^2(\Delta\Phi)_{\mathbf{n}}(t) - m^2\Phi_{\mathbf{n}}(t) - \lambda|\Phi_{\mathbf{n}}(t)|^2\Phi_{\mathbf{n}}(t)\right], \tag{1}$$

with parameters c (wave speed), m (mass), and λ (self–coupling).

We monitor a discrete energy functional

$$E(t) = \sum_{\mathbf{n}} \left[\frac{1}{2}|\dot{\Phi}_{\mathbf{n}}(t)|^2 + \frac{c^2}{2}\sum_{\hat{\mu}} |\Phi_{\mathbf{n}+\hat{\mu}}(t) - \Phi_{\mathbf{n}}(t)|^2 + \frac{m^2}{2}|\Phi_{\mathbf{n}}(t)|^2 + \frac{\lambda}{4}|\Phi_{\mathbf{n}}(t)|^4\right], \tag{2}$$

computed in the code as a diagnostic of numerical stability. For the parameter choices below, the leapfrog scheme with sufficiently small Δt keeps $E(t)$ approximately conserved over the time windows we study.

2.2 Global amplitude

The key global quantity in our implementation of the Origin Axiom is the total complex amplitude

$$A(t) = \sum_{\mathbf{n}} \Phi_{\mathbf{n}}(t). \tag{3}$$

This is the simplest nontrivial linear functional on the field configuration that is sensitive to large–scale cancellation. For generic random initial data, $A(0)$ is small compared to typical local field values, and under unconstrained evolution $A(t)$ remains close to zero in the models we study.

We initialise the field with small random complex noise and explicitly subtract the mean so that $A(0) \approx 0$. This puts the system near the would–be "forbidden" global cancellation point.

3 The Origin Axiom constraint

In the conceptual paper, the Origin Axiom is stated abstractly as a condition on allowed configurations C, excluding those for which the global amplitude $A(C)$ lies in a small neighbourhood of a reference value A_*. Here we implement a specific and concrete version suitable for numerical experiments.

We focus on the simplest case $A_* = 0$. Given a tolerance $\epsilon > 0$, we define the *forbidden disc*

$$\mathcal{D}_\epsilon = \{A \in \mathbb{C} \mid |A| < \epsilon\}. \tag{4}$$

The Origin Axiom is then realised as the rule that $A(t)$ must not enter $\mathcal{D}_\epsilon$. When the unconstrained dynamics would drive the system into $\mathcal{D}_\epsilon$, we project the configuration back to the boundary $|A| = \epsilon$ by adding a small uniform complex shift.

Concretely, at each time step we check $A(t)$. If $|A(t)| \geq \epsilon$, we do nothing. If $|A(t)| < \epsilon$, we apply the additive correction

$$\Phi_{\mathbf{n}}(t) \longrightarrow \Phi_{\mathbf{n}}(t) + \delta\Phi(t) \qquad \text{for all } \mathbf{n}, \tag{5}$$

with

$$\delta\Phi(t) = \frac{1}{V}\Big(\epsilon e^{i\theta_*} - A(t)\Big), \tag{6}$$

so that the new amplitude satisfies $A'(t) = \epsilon e^{i\theta_*}$. In the simulations presented here we choose $\theta_* = \pi$, so that the global amplitude is pushed to $-\epsilon$ along the real axis, but the choice of angle is not dynamically important in this toy context.

We record a counter of how many time steps invoke this projection; we refer to these as *constraint hits*. The parameter ϵ thus plays a dual role: it sets the scale of forbidden global cancellation and also controls how frequently the constraint needs to act for a given dynamical regime.

4 Numerical experiments in three dimensions

All simulations reported here use a lattice size $N = 16$, so $V = 16^3$. Unless stated otherwise we fix $c = 1$, $m = 0.1$ and $\Delta t = 0.01$ for the linear case and $\Delta t = 0.005$ when $\lambda \neq 0$. The initial field is a small random complex field with amplitude of order 10^{-2}, mean–subtracted to enforce $A(0) \approx 0$. The same initial realisation (fixed random seed) is used throughout so that differences between runs can be attributed to the constraint.

4.1 Linear toy universe

We first consider the linear dynamics with $\lambda = 0$. We run two simulations: one unconstrained, and one with the Origin Axiom constraint at $\epsilon = 0.05$.

Figure **??** compares $|A(t)|$ for the two runs. In the unconstrained case, the global amplitude remains extremely close to zero for the entire run, with $|A(t)|$ of order 10^{-4} or less. The system sits comfortably in the would–be forbidden region near perfect cancellation. With the constraint activated, the amplitude is instead held at $|A(t)| \approx 0.05$ for the whole evolution: the projection fires at almost every time step and keeps the universe away from global cancellation.

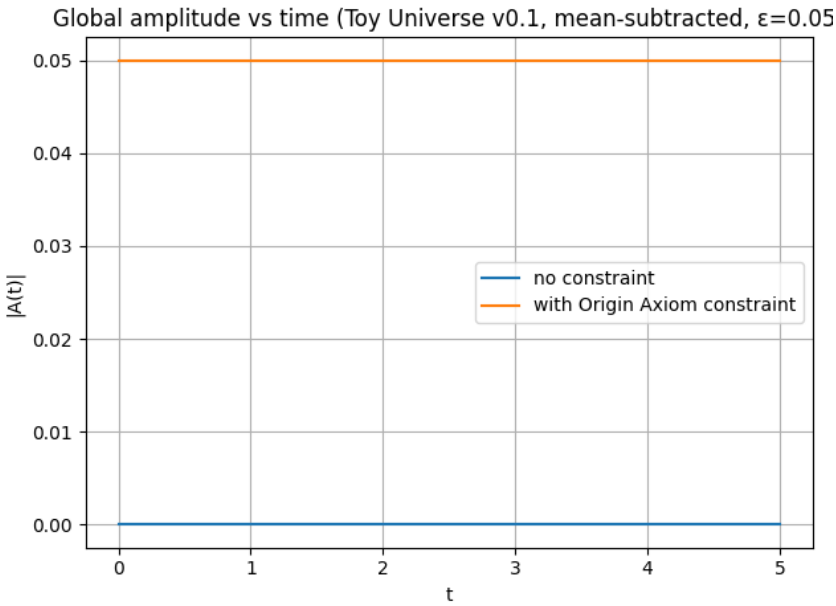

Figure 1: Linear toy universe ($\lambda = 0$) on a 16^3 lattice. Global amplitude magnitude $|A(t)|$ with and without the Origin Axiom constraint at $\epsilon = 0.05$. Without the constraint, the universe remains in a nearly cancelling state with $|A| \approx 0$. With the constraint, $|A|$ is kept at the nonzero value ϵ throughout.

Crucially, the energy evolution is almost unaffected by the constraint. Figure **??** shows that the discrete energy (**??**) for the constrained run tracks the unconstrained energy to high precision. The constraint therefore acts as a gentle global offset rather than a violent source of instability.

4.2 Nonlinear toy universe

We now turn on a moderate self–coupling $\lambda = 1$ and repeat the comparison between unconstrained and constrained dynamics.

The unconstrained run again keeps the global amplitude near zero: $|A(t)|$ remains of order 10^{-5} to 10^{-4} over the simulation window. With the constraint enforced at $\epsilon = 0.05$, the amplitude is quickly pulled to $|A| = \epsilon$ and remains there. The global rule thus continues to function as intended even when local nonlinearities are present.

Figure **??** shows the amplitude comparison, and Figure **??** shows the corresponding energy evolution. As in the linear case, the energy curves for constrained and unconstrained runs overlap almost perfectly. There is no sign of runaway behaviour or secular drift induced by the constraint, despite the fact that it fires at every time step in the constrained simulation.

4.3 Constraint activity as a function of ϵ and λ

To characterise the behaviour of the constraint more systematically, we run a small scan in the (ϵ, λ) plane. We fix the lattice and initial field as above and consider $\lambda \in \{0, 1\}$ and $\epsilon \in \{0.01, 0.03, 0.05, 0.10\}$. For each pair we evolve the system for 300 time steps with the constraint enabled and record:

- the number of constraint hits (how many time steps required a projection);
- the mean and final values of $|A(t)|$;
- the mean and standard deviation of the energy $E(t)$.