EMERGENT VACUUM, GRAVITATION, AND STANDARD MODEL STRUCTURE FROM DETERMINISTIC MECHANICS

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We created a simulation using mechanics from Valentine [6, 7] and demonstrated an emergent process for gravitation [10]. In this interim report, we describe quantum propagation from the perspective of uniqueness, and a framework for emergent physicality with the detail of standard model phenomena at all energies. In this framework, we show vacuum structure and its effects on matter, spontaneous symmetry breaking with the weak interaction, intrinsic Higgs mechanism, asymptotic freedom, charge, fermion flavors and their decays, gravitation, matter-antimatter asymmetry, and a basis for classical observation. We describe simulation methodology, initial results, and expectations.

Keywords: deterministic, physicality, vacuum, fermion, propagation, weak interaction, quantization, boson, entanglement, wavefunction, quark, generations, flavor, decay, spontaneous symmetry breaking, strong force, gravitation.

1. Introduction

In earlier work [6], we proposed foundations for deterministic physical mechanics for physics across all energies. Later [7], we applied them to challenging problems, like the black hole life cycle, asymptotic limits, dark matter, redshift, and matter-antimatter asymmetry. There, we inferred useful emergent behaviors of physical systems, and proposed methods to describe phenomena that challenge physics as a discipline.

1.1 *Review: Deterministic rules* [6]

1) Waves are bound in pairs as oscillators (**bosons**).
2) Waves propagate radially, and only at light speed, having equivalence of phase, distance, and time:

$$d\varphi = ds = dt \tag{1}$$

3) Nonunique waves, having the same phase and source, are excluded from interactions.
4) A boson's mass-energy is a function of its phases,

$$\rho = e^{-i\left(\varphi_B - \varphi_A\right)} \tag{2}$$

5) ρ modulates phase φ of other overlapping waves.
6) Two waves, from different fermions, with $\varphi = 0$ at a unique point, collapse their bosons into a **fermion**.

2. Fermion propagation

2.1 *Quantum propagation, entanglement, exclusion*

There is no continuous classical movement of the fermion. It's a quantum 'teleportation' to a new point. For example, for a conserved fermion cycle **A → D** (fig.1), two bosons from fermion **A** each collapse in events **B** or **C** respectively, then they in turn collapse to a new fermion solution **D** on the bosonic shells from **B** and **C**.

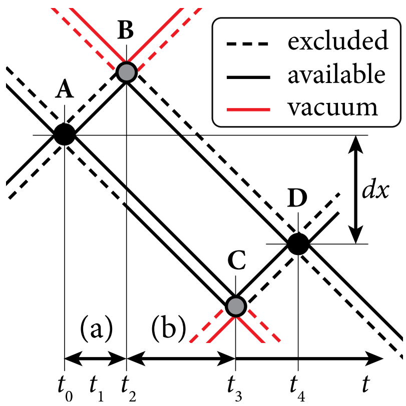

Figure 1. Propagation of a conserved fermion from **A** to **D**. Each line is a wave; each pair of lines is a boson.

We define a **shell** as the time, distance, or phase offset from a fermion event; they're all equivalent (rule 2). We can think of it as sphere expanding from a point in space and time. It is only observable at a collapse event. All propagation is fundamentally light-speed, and indirect walks give slower classical propagation.

All waves on the shell are **entangled**, share the same spatial identity (2.2), and are indistinguishable from each other unless they are unique in phase. This is how we derive **exclusion** (rule 3).

2.2 *Fermions as unique collapse conditions*

Fermions are a special condition on the continuous journeys of bosons. Fermions and bosons are the same waves, with different uniqueness properties (table 1).

For example, if the bosons of a fermion are wholly conserved over its propagation sequence **A → D** (fig.1), and correspondingly the fermion constituents are confined, then any external sensing bosons are interacting with the virtual antiparticles at **B** or **C**, or other wrappers of confined 'layers', rather than the fermion itself at **A** or **D**.

Observed properties (or net cross sections) may vary according to the combinations of possible collapse sequences, especially with 2nd and 3rd generation fermions (3.9).

Property	Bosons to collapse	Fermion	Emitted Waves
Position	Ambiguous (many shells)	Unique	Ambiguous (on-shell)
Origin	Multiple points	Collapse point	Common point
Wave phase (collapsing)	Proximate	Identical	Excluded
Wave phase (partner)	Distinct	Unique	Available
Entanglement	Not entangled	Coupled	Entangled

Table 1: Uniqueness-related properties before, during, and after fermion solutions.

3. Standard phenomena

3.1 *Weak interaction*

We identify parts of the weak interaction (fig.1):

- The **W± bosons** are the two *available* waves from fermion **A**, with non-identical phases, and mass-energy that induces interactions with other bosons.
- The **Z boson** is the *excluded* output of fermion **A**. By rule 3, "waves having the same phase and source are excluded from interactions", which screens the Z boson until fermion **B** at t_2, which is a vacuum interaction with a non-excluded wave from fermion **A**. After **B**, the two entangled waves from **A** are available as one boson.
- A **Goldstone boson** is all waves output from a fermion. For example, for 1st generation fermions, two of the four waves are non-excluded at any given time, until both its bosons are collapsed, resembling the doublet of the scalar Higgs field.

3.2 *Higgs boson*

The modulating effect of mass-energy (rule 5) is intrinsic to the structure of every boson, and the mass-energy propagates with every boson collapse. If we were to encode this as extrinsic, then it would be a sidecar boson to our massless bosons, with unjustified complexity to mirror the behavior of regular boson interactions.

3.3 *Vacuum*

Immediately after a fermion event, the fermion exists not as a point, but as a radiating shell of bosons.

By rule 2, "Waves propagate radially, and only at light speed…", we structure the vacuum as many bosons that radiated from previous fermions. These instances of discrete 'vacuum energy' have the same structure as the objective fermions of interest. These vacuum shells have two non-excluded waves available for interaction at any given time:

- **Weak-broken** (3.1) instances have two waves as one boson. Neither waves are excluded unless they share the same phase with another wave on the shell (2.1).
- Unbroken instances have one non-excluded wave from each of two bosons on the shell. Bosons may collapse independently, and when one does, any co-excluded waves in other bosons are weak-broken and becomes available for interaction.

If we were to regard vacuum as 'background' or a field, and ignore its discrete nature, then we could only interpret vacuum interactions as *spontaneous* and random. However, if we trace instances, then the vacuum is accountable, bosons are classically attributable, and we find a unified mechanism, but not a unified field, for gravitation and interactions of the standard model [7].

3.4 *Virtual particles*

For 'free' fermion **A** to reconstitute as fermion **D** (fig.1), vacuum instances create intermediate 'virtual particle' antifermions at **B** and **C**. On leaving **A**, the waves that collapsed the fermion are excluded because they have identical phase and source (rule 3). Only after **B** and **C** are those waves again available to collapse to **D**, a similar fermion to **A**.

Another example of a virtual particle is vacuum self-interaction. A vacuum boson may interact with another vacuum boson to create a fermion. This can be conserved, or it more likely radiates to vacuum [5].

3.5 *Particle size*

A conserved 'free' fermion interacts with vacuum to reconstitute around the same area in space (3.4). We derive the 'size' of this fermion from the mass-energy of the vacuum instances and the mass-energy encoded in the fermion's shell.

We found analytically [7] that the probability

$$P_H(r) = p^r \left(1 - (1-p)^{\frac{dV(r)}{dr}}\right) \quad (3)$$

(fig.2) of an expanding single-boson shell interacting with vacuum having uniform mass-energy and phase distribution, where p is the proportion of the phase cycle available for interaction due to mass-energy ρ, integrates to a 50th percentile Compton radius

$$r = (\ln 2)/\rho \quad (4)$$

for non-overlapping phases of a shell.

The profile of this interaction area is asymptote-free, and contrasts with the standard inverse-power profile of charge and gravitation. This asymptotic freedom is distinct from the screening provided by exclusion.

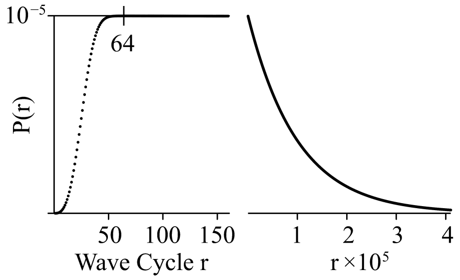

Figure 2. Plot of eq.3, $P_H(r)$ for $p=10^{-5}$.

Our profile removes the ghost bosons and Coulomb-like forces required to explain deviations from singularities and asymptotes. Without vacuum, a boson would propagate radially at light speed, and the probability of interaction with anything else does not diminish with radius. With vacuum, or any other trigger for wave collapse, the probability falls off with radius.

The asymptote-free profile also infers wells of 'lowest potential' for various phases, energies, and distributions of matter and flux. We can use these distances to infer parameters for our wave phases.

3.5.1 *Composite collapse functions, SSB*

Modulation acts independently for each wave, so mass-energy values are not associative, cannot be added, accumulated, nor canceled. Instead, we apply positive and negative modulations from the shell (Table 2), to each wave of any overlapping boson.

Boson	**Wave**	**Emitted**	**Weak-broken options**	
			1	**2**
1	1	excluded	off-shell	ρ_1
	2	$-\rho_1$	off-shell	$-\rho_1$
2	1	excluded	ρ_2	off-shell
	2	$-\rho_2$	$-\rho_2$	off-shell

Table 2: On-shell mass-energy ρ, to modulate other bosons.

For homogenous weak-broken *vacuum* bosons, we can assume positive and negative mass magnitudes are identical. The pre–weak-broken function is $[-\rho_1, -\rho_2][\rho_{vac}, -\rho_{vac}]$ and the post–weak-broken function is either $[\rho_2, -\rho_2][\rho_{vac}, -\rho_{vac}]$ or $[\rho_1, -\rho_1][\rho_{vac}, -\rho_{vac}]$. Techniques for degeneracy and spontaneous symmetry breaking are useful here.

3.6 *Electromagnetism*

An external boson may pass through the propagation sequence on path **AB**, **AC**, **BD**, or **CD** (fig.1), and the flux enables a spatial displacement from **A** to **D**, as an exception to the uniform directionality of vacuum displacements. This is how we represent **electromagnetism** and **electrodynamics**.

At this point, we need to discuss the privilege commonly assigned to more massive bosons, and how we think of vacuum. The constitution of our 'free fermion' is likely a boson with high mass-energy that we think is the particle of interest, on the same shell as a boson with low mass-energy that enabled its collapse.

From our classical observer perspective, we identify the massive boson as 'interesting' because it seems more traceable and conserved, while the interchange of lesser bosons goes unnoticed, as we think of them as hidden or ephemerally 'happening to' the massive component. Note that in this representation, neither is more fundamental than the other, because all bosons are conserved, and it's equally valid, but experimentally difficult, to trace or infer the less massive bosons.

These lesser bosons tend to propagate further before collapsing (eq.4), and many such events from vacuum become a flux through the massive particle as it propagates through collapses.

3.7 *Coherence*

Plasma is the state where matter fails to re-constitute consistently, and fermions have no continued identity.

For bosons of high mass-energy, in a vacuum of low mass-energy bosons, we picture a conserved fermion having Brownian-like motion while it retains its full identity with confined component bosons.

An electromagnetic interaction has decoherence with the interchange of bosons, but we can 'watch' the boson with high mass-energy and think of it as conserved because we observe its propagation.

If we then consider a confined composite, say of quarks, their interaction radius (eq.4) will be small, compared that of bosons from the environmental vacuum. Increasing numbers of environmental bosons, or input of high mass-energy bosons, increases the probability of decoherence of the composite structure.

Where there is no recurring composite structure, and we can identify two masses of components, we regard the bosons as a **plasma**. With the lighter components as a flux for the heavier components, the plasma has electromagnetic charged interactions.

3.8 *Matter and antimatter*

A boson has two waves, separated by $0.25+\rho$ cycles.

- For **matter**, partner waves *lag* by ≈0.25 cycles.
- For **antimatter**, partner waves *lead* by ≈0.25 cycles.

Treating this as an oscillator, the collapse-triggering wave is the reference wave, with the partner wave as the order term. This determines the sign of both its phase modulation and angular momentum.

Because the waves having $\varphi = 0$ are excluded after the fermion event, its first boson will collapse (as the weak interaction) with opposite-signed mass-energy and modulation direction. This typically leads to a repeating sequence of alternating matter and antimatter (fig.1), noting that antimatter-matter-... sequences are an equally valid perspective.

$$\mathbf{A \rightarrow BC \rightarrow (D{=}A)} \tag{5}$$

Mass-energy ρ (eq.2) modulates the phases of other overlapping waves (rule 5), allowing a boson with mass to collapse other bosons having non-excluded waves with a phase between $-\rho$ and 0 at the point bosons overlap. We call this a **phase window**.

Positive and negative mass-energy therefore have access to different phase windows of vacuum energy or confined flux. After a weak interaction (3.1) on a shell, both waves of the remaining boson are non-excluded, so it carries both signs of phase modulation, for a phase window twice as wide as a single non-excluded wave. This availability enables vacuum flux to flow through fermion networks (3.6) without the need for intermediate fermions of opposite sign.

3.8.1 *Matter-antimatter asymmetry*

- **Matter** interacts near 0 cycles, and relatively,
- **Antimatter** interacts near 0.25 cycles.

Their partner waves are near 0.25 cycles for matter, and near 0.75 cycles for antimatter.

This results in a different collapse radius for each wave of a boson, which affects all interactions. This is most significant at the smallest distances ($\ell_P/4$) and highest energies, and the imbalance lessens at large distances and lower energies as the probabilities even out.

We proposed [7] this violates matter–antimatter symmetry, making vacuum polarization more probable at high energies, like big bang fermiogenesis.

3.8.2 *Matter-antimatter labelling*

It might be misleading to classify the *fermion* with a matter or antimatter status, when *bosons* carry the sign information and mediate the charge-like behaviors. We think it's possible to label fermions with matter/antimatter labels, because we privilege bosons of higher mass-energy as representing the fermions.

3.9 *Generations, flavors, strong force*

3.9.1 *Fermion types and generations*

The fermion **types** (quark, electron, neutrino) are combinations of bosons with high mass-energy A and low mass-energy B (5.1.1):

Entity	**Generation**	**3rd**	**2nd**	**1st**
Quark (A,A)		b, t	s, c	d, u
Lepton (B,A), (A,B)		τ	μ	e
Neutrino (B,B)		ν_τ	ν_μ	ν_e
Collapses bosons		4	3	2
Collapses non-excluded waves		4–8	3–6	2–4
Collapses bosons of shell 1		2	2	1
Collapses bosons of shell 2		2	1	1
Collapses weak-broken bosons		0	0–1	0–2

Table 3: Properties for fermion generations 1, 2, and 3. "Collapses…" numbers are counts.

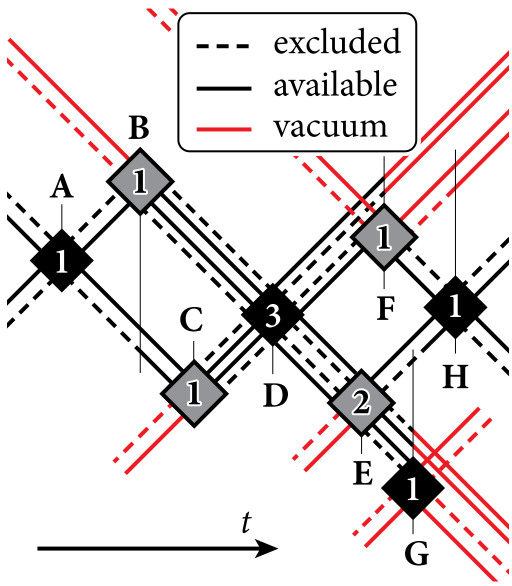

Figure 3. Example decay of a 3rd generation fermion **D**.

We define **generations** by the number of bosons with non-excluded waves that interact at the fermion event. For example:

- A 1st generation fermion event collapses non-excluded waves from 2 shells, one boson on each shell, like fermion event **A** (fig.3).
- A 2nd generation fermion event has 3 collapsing bosons, as one shell of two bosons, and one shell of one boson, like fermion event **E**.
- A 3rd generation fermion event has 4 collapsing bosons, as two shells of two bosons each, like fermion event **D**. This implies that none of the shells are yet weak-broken.

3.9.2 *Fermion flavor up-type, down-type*

Propagating quarks or leptons have the expected W boson decays:

- **Up-type** as *before* weak interaction.
- **Down-type** as *after* weak interaction. The down-type shell has one fewer propagating bosons than the up-type shell.

We represent **decay modes** as changes of boson count, between one instance of a fermion and its next reconstitution, via two anti-fermions.

The CKM matrices encode both the common up/down flavor changes, and the decays over the sequence **A → D** (fig.1).

For example, to decay **D** (fig.3), via each antifermion **E** (2nd generation) and **F** (1st generation), a vacuum boson collapses a boson from **D** in a weak interaction, which removes the exclusion constraint for the remaining waves on the **D** shell (we show them here radiating to vacuum). The confined products of **E** and **F** can then combine as a 1st generation fermion **H**.

3.9.3 *Strong force*

For quarks, by far the largest value for mass-energy, we expect A (3.9.1) to be around $10^{-19}\,\ell_P$, for a 50th percentile collapse at around 1 fm.

Quark pair production is possible with electron-type input, composed as (A, B), to provide another A with enough mass-energy to compete with the coherence of existing quarks, like a plasma state (3.7).

3.10 *Photons*

We represent **photons** as paired boson impulses, which can be received by structures similar to their sources, having a frequency that may be derived from a sparse sampling of impulses [6: 6.2.1.2]; compatible with creation and annihilation operators of quantum harmonic oscillators.

3.11 *Gravitation*

As with charge-based interactions, we represent **gravitation** as an attribution of flux origin, rather than a fundamental force. A large classical body collapses and re-radiates vacuum bosons, which may in turn collapse fermions some distance from the body. As with all collapse events, the positional solution of collapse is directly between the respective points of origin (fig.4).

Negative mass-energy does not infer repulsion. Instead, it changes the absolute phase where $\varphi = 0$, and also changes the sign of phase modulation imparted to other overlapping bosons (3.8).

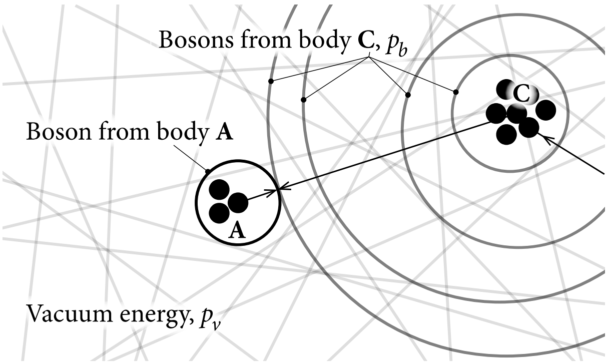

Figure 4. A large classical body collapses and re-radiates vacuum bosons, which may in turn collapse fermions some distance from the body.

4. Simulation methodology

We define the scene in flat Minowski $(3^+, 1^-)$ metric, and encode (fig.5) entities as fermions with position and time of their collapse event (rule 6).

```
fermions: [
  {
    position: [-7.5651, 16.3342, -26.5382],
    time: -30.0,
    bosons: [
      {
        waves: [
          { phase: 0.0000 }
          { phase: 0.2501 }
        ]
      }, {
        waves: [
          { phase: 0.0000 }
          { phase: 0.2500 }
        ]
      }, // …more bosons
    ]
  }, // …more fermions
]
```

Figure 5. Minimal data structure for simulating the mechanism, omitting id properties, and cached mass and exclusion.

For each fermion, we list its bosons, and each boson has two wave phases (rules 1 and 4). From this data, we can infer:

- Exclusion from wave phases (rule 3).
- Mass-energy of each boson, and its modulation signs.
- The radius of a shell of bosons at any given simulation time, from its fermion event time.

We test for collapse where spheres meet from different fermions (rule 6), and also test for the modulation condition (rule 5).

Interactions are an n-body problem, which we're not optimizing yet. The steps are:

1) Seed the scene with fermion events.
2) Test all combinations of fermions for events where spheres touch. We calculate the position and time of the interactions, regardless of current simulation time. We select events after the current simulation time.
3) Order the events by their time of interaction.
4) Commit only the first interaction to occur after the current simulation time, and repeat from step 2 as necessary.

At setup, and as the simulation runs, we continuously seed the scene with a history of distant fermion events, which then sweep over the experimental area of the scene as vacuum flux, to the required flux density and mass-energy profile.

This simulation methodology does not need time-step processing (other than to seed the vacuum flux) but can instead skip directly to the next fermion event, regardless of time or distance. We can currently process the simulation with a variety of exit or pause conditions.

4.1 *Analysis methods*

We are developing a task interface with JavaScript (interoperably a NodeJS worker or browser application) to build and run scenes with vacuum configurations and a hierarchy of matter systems. Analysis methods are:

- Single pass, intended for interactive viewing.
- Multi-pass PDF, with tracing criteria.
- Multi-pass trial, with Boolean criteria.
- Goal seek, to find input variables that meet criteria.

The simulation design includes global tracing, tagged tracing, text log, and event logs. The simulation viewer has timeline simulation and review, tracing interface and overlays, events and logs, and exports.

We'd like to use the exports in interactive web timelines and simulations, to demonstrate our work.

4.2 *Initial results*

We recently reproduced emergent gravitation in an uncalibrated simulation (4), and results are available online [10]. The simulation view (fig.6) shades boson spheres by their on-shell mass-energy. Heavy shading is for fermions with large mass, and light shading is for bosons of the almost massless vacuum flux. The massive fermions demonstrated attraction and jittery orbits, mediated by re-radiated vacuum flux.

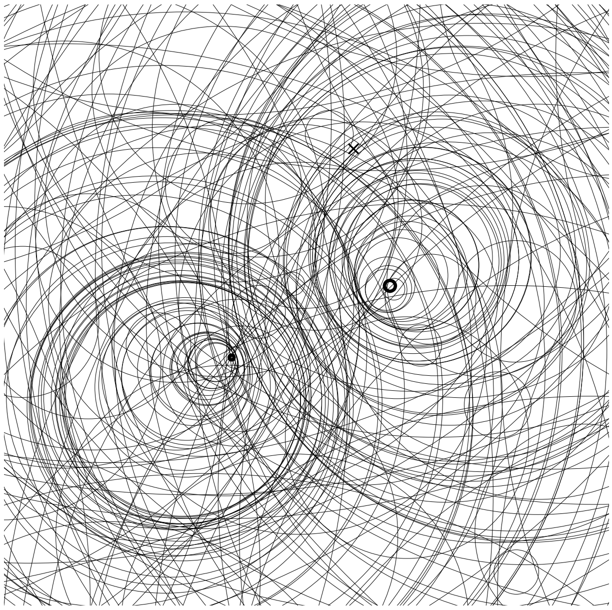

Figure 6. SVG export of spherical bosons in simulation, displayed as a 2D projection of the 3D space.

4.3 *Expectations from simulation*

We'd like to explore and demonstrate many aspects of physics, including:

1) How the classical identity of fermions is associated with the larger mass-energy boson, and how the full identity changes with charge interactions.
2) Classical attribution of force-carrier bosons, and quantum encoding of gauge fields.
3) The effect of vacuum energy density on matter and its electrons (3.5).
4) Structural coherence: fermions, composites, plasmas, and black holes.
5) Black hole life cycle.
6) Classical dynamics.
7) Relativistic dilation effects.
8) Derive quark masses from a reduced parameter set of mass-energy values.
9) Analytics on quark decay modes (3.9), to derive CKM and PMNS matrices from mass parameters.
10) Strong force $q\,\bar{q}$ pair creation.

11) Trivially simulate a hydrogen atom, and more complicated structures, in vacuum.
12) Matter-antimatter vacuum polarization from unpolarized plasma soup (3.8.1).
13) Nuclear stability
14) Vacuum statistics, as a variable for large-scale cosmological evolution and structure.

5. Unknowns

We need to find answers for the unknown aspects of our representation:

- Free parameters.
- Arbitrary design decisions, or behaviours.
- Information incompleteness.

5.1 *Free parameters*

Our representation has just three free parameters:

- The two phase offset values for partner waves, which give mass-energy values A and B (3.9).
- The fundamental wavelength of all bosons.

5.1.1 *Mass-energy parameters*

What are the A and B mass-energy values for bosons (3.9), and are they sufficient? As a first step we think we can infer or analyze an approximation from electron and top quark masses, but we'd prefer geometric solutions that we can compute exactly.

5.1.2 *Are bosons all Planck oscillators?*

Throughout, we assume that all waves have a fixed wavelength identical to the Planck length. This has implications for the precision of numbers needed for computation and simulation (5.2.5). We cannot arbitrarily scale the simulation without also changing quantized results.

5.2 *Design decisions*

5.2.1 *Mass-energy modulation function*

We have no fundamental basis for how mass-energy modulates phase (rule 5), with two undisproved options, depending on units used and shaping:

$$\rho = \varphi_B - \varphi_A - 0.25 \tag{6}$$

$$\rho = \cos(2\pi(\varphi_B - \varphi_A)) \tag{7}$$

5.2.2 *Positive and negative mass-energy modulation*

We chose to evaluate each wave separately rather than accumulate all values, or accumulate all values of sign. This allows a boson to collapse only the qualifying bosons on another shell.

5.2.3 *Commit modulated phase at collapse?*

Does fermion collapse (rule 6) commit modulated phase to actual phase? There is also a sub-choice of whether to commit one or both waves. Speculatively, bosons could then drift through phase with each collapse. This would lessen universal sychronicity for a more relativistic view, allow dark matter in unobserved phases bands, and allow more quantum tunneling. Given that mass-energy values are tiny (5.2.5), we think phase drift would annihilate too many fermions, unless phase drift was self-correcting in larger systems.

5.2.4 *Homogenous vacuum phase distribution?*

Are the fermion events of vacuum flux homogenous over the whole phase range, or is it localized around phases where matter collapses?

5.2.5 *Numeric precision*

The simulation uses Planck units. If we combine cosmological distances with sub-Planck phase-precision distances, then double-precision calculations [IEEE-754], commonly supported natively by computer hardware, is insufficient.

From eq.4 , we need precision that exceeds $v=12$ significant decimal figures at both the 50th percentile radius of interaction, $10^{u}\,\ell_P$, and at its reciprocal phase value $10^{-u}\,\ell_P$, with $w=10$ more digits beyond 50th percentile, for a total of $2u+v+w$ significant figures, or $(2u+v+w)(\ln 10)/(\ln 2)$ bits for mantissa.

BigNumber libraries like decimal.js [11] achieve this, with code written differently, and slow execution.

Scenario, radius	u	digits_{10}	bits_2
Planck scale	1	24	80
Strong force	19	60	200
Naive atom	24	70	233
Human scale, 1 mm	31	84	280
Human scale, 1 m	35	92	306
Observable universe	60	142	472

Table 4: Numerical precision required to simulate energies at scale

5.3 *Information incompleteness*

Our mechanism does not address how all the bosons of the universe originated, because its rule set (1.1) conserves all bosons, while creating and annihilating fermions.

We could modify the modulation function (rule 5, 5.2.3), to split off any modulated value into new units, and destroy units when values cancel, conserving mass-energy.

Fundamentally, interacting systems need only have two states and a means for them to couple [8]. Our oscillator bosons couple unique states by continuously changing phase over emergent space. We do not explain here how:

- Phase emerges into a manifold with a flat $(3^+, 1^-)$ metric, and geometric algebra infers dimensionality of only 3 or 1.
- The universe is a set of boson information units.

To describe how to achieve a universe of discrete units, Bastin, Kilminster, Noyes, Etter, Manthey [1] explored a 'bit-bang' hypothesis. We explored geometric algebra [2], to transform closed and open terms in 16-dimensional expansions, symmetric in bases $3{\times}D_2$ [3], and later as oscillators in continuous $3{\times}C_2$ [9], giving the a physical context for information. Rowlands [4] explored a 'rewrite system' as a fundamental basis for a single unit to self-replicate.

As-is, our mechanism could offer insights into all but the first phases of the 'big bang' hypothesis, but we're not committed to big bang as a satisfactory explanation.

6. Conclusions

Our representation encodes phenomena of the standard model, and gravitation, in a single uniform mechanism. It does not describe a unified field, because that would summarize the discrete interactions as statistics, losing vital information with at high energies, along with complications with the uncertainty principle.

We eagerly anticipate simulation results, and to offer values for parameters, or insights into mechanics, that are difficult to discover by other means.

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