Boundary-Condition Quantum Mechanics V: Emergent Spacetime from Lockstep Bundles

Peter M. Ferguson
Independent Researcher

12th January 2026

Abstract

Boundary–Condition Quantum Mechanics (BCQM) represents the history of a system as a single realised "thread" of events inside a more primitive event graph, defined before any spacetime geometry is assumed, guided by propensity kernels and constrained by a finite coherence horizon W_{coh}. Earlier papers (BCQM I–IV) [1] [2] [3] [4] [5] [6] [7] showed that single threads naturally live in a diffusive inertial–noise universality class with $\beta \approx 1/2$, and that modest bundles of threads begin to suppress centre–of–mass noise without ever becoming perfectly ballistic. This paper, BCQM V, develops the next step in that story: a lockstep hierarchy in which long–lived bundles of threads play the dual roles of "matter" and "spacetime background".

At the Stage 1 level we stay entirely pre–spacetime and work with one–dimensional event–chain simulations. We introduce four glue axes that sustain partial lockstep between threads (shared bias, phase locking, domains, and cadence disorder) on top of the BCQM III/IV hop kernel. Using these as independent and combined controls, we map out how bundle clock quality and residual inertial noise scale with bundle size and glue strength, and use this to define an operational effective mass $m_{\mathrm{eff}} \propto 1/A_a(W_{\mathrm{coh}})$. The results show that (i) single threads and weakly glued bundles are confined to a diffusive universality class, (ii) phase–centric and cadence–centric glue produces high–Q clock–like bundles, and (iii) the underlying hop kernel together with weak domains generates a stiff, long–lived lockstep background that is naturally interpreted as proto–spacetime.

We close by outlining how these Stage 1 diagnostics extend to higher–dimensional, multi–bundle graphs, where diffusion–based distances and lockstep–deformation variables can be promoted to genuine geometric and gravitational degrees of freedom in later BCQM stages.

Research context

Boundary–Condition Quantum Mechanics (BCQM) is a staged research programme built on pre–spacetime event graphs. At the primitive level there are only realised events, directed edges, and complex propensity kernels constrained by a finite coherence horizon W_{coh}. Spacetime geometry, fields, and familiar dynamical laws are not put in by hand; they are intended to emerge from the statistics of many such threads and bundles.

Stage 1 of the programme, developed in BCQM I–IV, established two key ingredients. First, single realised threads on a toy lattice naturally exhibit diffusive inertial noise with an amplitude scaling $A(W_{\mathrm{coh}}) \propto W_{\mathrm{coh}}^{-\beta}$, where β is the inertial–noise scaling exponent, and the single–thread diffusive regime studied in BCQM III/IV has $\beta \approx 1/2$ for a wide class of slip laws. In particular, the $\mathrm{W}_{\mathrm{coh}}$-blind control model of BCQM IV_b was found to have $\beta \approx 0$ within numerical uncertainty, while the soft-rudder single-thread model of BCQM IV_c with slip law $q(W_{\mathrm{coh}}) = 2/W_{\mathrm{coh}}$ yielded $\beta \approx 0.5$ consistently across more than an order of magnitude in W_{coh}. Second, when many such threads are bundled with modest correlations, their centre–of–mass (COM) noise is suppressed but never truly ballistic: the bundle behaves like a stiffer, better clock, but it still lives in a diffusive universality class inherited from its constituents.

The BCQM IV_d bundle simulations revealed an unexpected twist. For certain glue rules the bundles became *too* stiff to be good candidates for ordinary matter: their lockstep was so strong, and their residual inertial noise so small, that interpreting them as individual matter–carrying bundles in an emergent spacetime picture would make the background unrealistically rigid. This suggested inverting the interpretation. In the emerging "lockstep hierarchy" picture, the most rigid, high–quality lockstep bundles are identified with a proto–spacetime background, while softer defects and less–coherent sub–bundles play the role of matter–like excitations.

BCQM V documents and tests this inversion at the Stage 1 level. It introduces four operational glue axes (shared bias, phase locking, domains, and cadence disorder) on top of the BCQM III/IV hop kernel, and uses one–dimensional bundle simulations to map out which combinations yield diffusive, clock–like, and background–like regimes. The focus is on diagnostics and structure: defining the lockstep hierarchy, quantifying clock quality and persistence length, and showing that realistic matter–like bundles and stiff background–like bundles can coexist in the same event–graph dynamics.

The present paper does *not* attempt to derive explicit field equations, realistic cosmological solutions, or numerical values for physical constants. Those tasks are reserved for later stages (BCQM VI and beyond), where higher–dimensional, multi–bundle graphs and projection operators will be introduced. BCQM V should instead be read as bridging work: it translates the Stage 1 event–graph machinery into a concrete lockstep hierarchy and identifies the regimes that future emergent–geometry constructions will have to reproduce.

How to read this paper. For readers coming directly to BCQM V, it is helpful to keep three threads in mind:

- *Stage 1 numerics:* Sections 2 and 4 work entirely on pre–spacetime event graphs, quantifying lockstep, clock quality, and residual inertial noise for bundles of threads.
- *Emergent spacetime sketch:* Section 3 outlines how a dominant lockstep band can be reinterpreted as an emergent time parameter τ and a coarse–grained spacetime background, without postulating a manifold at the primitive level.
- *Pre–gravity bookkeeping:* Section 5 collects the variables that will later play the role of "sources" and "responses" when genuine geometric and gravitational dynamics are introduced in Stage 2 and BCQM VI.

1 Foundations and scope

For convenience we collect here the main diagnostics used throughout:

- Q_{clock} – an operational clock quality, defined from hop–count statistics along a bundle and roughly measuring the sharpness of its tick intervals;
- ℓ_{lock} – a lockstep persistence length, i.e. the typical number of hops over which threads in a bundle maintain a common direction and timing before decorrelating;
- $A_a(W_{\text{coh}})$ – the amplitude of the bundle centre–of–mass inertial noise spectrum as a function of coherence horizon, inherited from BCQM III/IV;
- m_{eff} – an effective mass defined, at this Stage 1 level, via $m_{\text{eff}} \propto 1/A_a(W_{\text{coh}})$, so that stiffer bundles with smaller residual COM noise correspond to larger effective inertia.

We will say that a bundle is in *lockstep* when its threads maintain a high degree of directional and timing alignment over many hops, as measured by large direction–persistence and clock–quality diagnostics. In that regime the bundle moves as an effectively single, stiff degree of freedom.

For any bundle we track its centre–of–mass (COM) position along the toy lattice, defined simply as the average position of its constituent threads at each hop.

1.1 Position of BCQM V in the series

BCQM V sits between the Stage 1 inertial-noise/bundle models (BCQM III[3] and IV[4]) and the later emergent-gravity work. Its role is to turn the qualitative lockstep hierarchy picture into a concrete bridge towards an emergent spacetime description.

Here we briefly summarise:

- the primitives of BCQM (events, edges, complex propensity kernels, coherence horizon);
- the main results of BCQM III (inertial noise and emergent inertia) and BCQM IV (single-thread diffusive universality class and bundle suppression of COM noise);
- the new lockstep hierarchy: single threads, local bundles, dominant/global lockstep.

BCQM V should therefore be read as a Stage 1 bridge paper. Its primary task is conceptual and programmatic: to make the lockstep hierarchy precise and to test it on simple bundle simulations, not to derive full field equations or a realistic cosmology. The glue-axes numerics below are used as sanity checks and as a phenomenological map of regimes rather than as precise fits to any particular physical system.

Already in BCQM III the inertial–noise mechanism and the appearance of constants as conversion factors hinted at a cosmological reading: a small universal floor in the inertial noise, plausibly tied to large–scale structure, and a common origin for inertial mass and spacetime stiffness. BCQM V does not attempt a full cosmology, but the lockstep hierarchy and glue–axes diagnostics identify exactly the kind of bundle statistics that, once projected into an emergent metric at Stage 2, would be mis–read in a spacetime–first description as dark matter (through mis–calibrated inertia and background stiffness) or dark energy (through slow drifts or defect pressure in the dominant lockstep background). A dedicated BCQM VI note will be needed to turn these qualitative hooks into a quantitative cosmological model.

1.2 Pre-spacetime ontology recap

BCQM remains a pre-spacetime theory at the primitive level. The fundamental ingredients are:

- realised events (nodes) and directed edges between them;
- complex-valued propensity kernels K that generate candidate edges within a finite coherence horizon W_{coh};
- threads as realised chains of events on a single primitive.

There is no fundamental manifold, no coordinate time, and no primitive mass parameter. These are all emergent descriptors to be recovered at higher levels.

1.3 Lockstep hierarchy and objectives

We adopt the lockstep hierarchy:

1. single threads: diffusive, noisy, poor clocks;

2. local bundles: glued multi-thread structures with suppressed COM noise and good local clocks;
3. dominant/global lockstep: highly extended, deeply glued patterns in which the bulk of primitive hops are in near lockstep.

BCQM V has three concrete objectives:

- **(i) Projection to emergent spacetime:** define a way to read off an effective time parameter and metric-like structure from the dominant/global lockstep of many threads, without postulating a background manifold by hand.
- **(ii) Local bundles as matter:** show how local lockstep bundles, with masses defined via the BCQM III/IV inertial-noise mapping, move relative to that background lockstep.
- **(iii) Book-keeping for back-reaction:** identify the minimal additional assumptions needed to describe how local bundles distort the dominant lockstep (a precursor of curvature/gravity), while deferring a full dynamical gravity model to later work.

2 Dominant lockstep and emergent time

In this section we formalise what is meant by the dominant/global lockstep at the event-thread level, and we construct a coarse-grained time parameter τ from the bulk lockstep.

2.1 Defining dominant/global lockstep

Here we will introduce quantitative measures of lockstep:

- hop-direction correlations across many threads;
- glue parameters (shared bias, hierarchical coupling, domains);
- measures of persistence length and coherence depth along bundles.

The goal is to identify regimes in which a large population of threads behaves as a single effective "clock" with small fluctuations.

A useful derived diagnostic is the *clock quality* of a given multi-thread system. Abstractly, if τ labels the effective ticks of a bundle or domain, we can define

$$Q \;\equiv\; \frac{\langle \Delta\tau \rangle}{\sigma_{\Delta\tau}},$$

the mean tick interval divided by its standard deviation. In the discrete toy models this reduces to simple statistics of hop increments: if Δk denotes the hop-count intervals between successive centre-of-mass "ticks", we estimate the operational clock quality as $Q_{\text{clock}} = \langle \Delta k \rangle / \sigma_{\Delta k}$. These expectations are made concrete in the glue-axes diagnostics of Fig. 1 and Table 1, and, crucially, Q_{clock} is defined purely in terms of hop-count statistics on the pre-spacetime graph. Only after identifying high-Q bundles do we introduce an emergent tick parameter τ that labels their coarse-grained ticks in Stage 2. but even at this summary level the scaling expectations already capture the hierarchy:

- single threads have $Q = \mathcal{O}(1)$ (poor clocks);
- N-thread bundles with modest glue have $Q \sim \sqrt{N}$ by the law of large numbers;
- dominant/global lockstep corresponds to $Q \gg \sqrt{N}$, signalling synchronisation and resonance across very large populations.

At this Stage 1 level, Q is defined purely in terms of discrete hop-count statistics; nothing in its definition presupposes a background continuum time. Only once high-Q bundles have been identified do we interpret their tick index as an emergent worldline parameter τ. A schematic depiction of such a dominant lockstep bundle, whose ticks define a global τ and within which local matter bundles live as defects, is given in Fig. 2. Experimentally, we test these scaling expectations using the original BCQM IV_d B-series bundle runs, augmented with lockstep diagnostics on top of the inertial-noise pipeline. In practice this means tracking overall bundle alignment, direction-persistence and COM clock quality for the configurations B1, B2 and B3, and checking that $Q \sim \sqrt{N}$ holds for modest shared-bias glue while more structured or hierarchical glue (studied in follow-up lab models) pushes the system towards a high-Q resonance regime. Later, the concrete code diagnostics (based on centre-of-mass increments and inertial noise) will serve as operational proxies for this abstract Q.

2.2 Constructing a coarse-grained time parameter τ

We then define a coarse-grained bundle/worldline time τ based on the bulk lockstep. Key points:

- τ is an emergent parameter labelling ticks of a stiff bundle or domain, not a fundamental background time.
- For local bundles, τ will later be related to proper-time-like parameters in the emergent spacetime description.
- The law of large numbers and glue-induced synchronisation turn noisy primitive hops into smooth τ-parametrised trajectories.

2.3 Glue mechanisms sustaining lockstep

We will often refer to an instantaneous lockstep length $\ell_{\text{lock}}(W_{\text{coh}}, N)$, defined here as a diagnostic measure of how long, in units of hops, a given bundle moves as if it were in near-perfect lockstep. Concretely, for each bundle we examine contiguous segments of the trajectory over which the centre-of-mass motion stays within a small tolerance of a straight, single-direction path, and take ℓ_{lock} to be the maximum length of such a segment in a run. This is not a new fundamental constant, just a convenient way to summarise "how rigid" a given glue configuration is.

The same four glue mechanisms that appeared in the BCQM IV bundle studies and in the dedicated glue-axes code runs sustain lockstep at all three levels of the hierarchy:

1. **Shared history:** threads that have overlapped in their realised past events have a higher propensity to remain correlated.
2. **Interference/propensity:** constructive interference of propensity weights in certain directions biases hops so that many threads prefer the same channels.
3. **Domains:** slowly varying environmental or background conditions define domains in which threads experience similar effective kernels.
4. **Hop coherence:** temporal depth along threads (finite coherence horizon and memory) favours sequences of aligned hops rather than frequent reversals.

Local matter bundles typically require all four mechanisms to operate coherently over a finite population, whereas the dominant/global lockstep can be viewed as the regime in which these same mechanisms act at maximum strength over large populations of threads.

In the BCQM V bundle simulations these conceptual glue mechanisms are realised as four operational glue axes on top of the BCQM III/IV hop-coherence/slip law: shared bias, phase locking, domains and cadence. At this Stage 1 level the glue axes should be read as a phenomenological coarse–graining of how the primitive event-graph kernels correlate threads, not as four new fundamental forces: they are simply the minimal way, within a one-dimensional soft-rudder kernel, to expose the four ways in which the primitives above can generate correlations. Concretely:

- *Shared bias* tilts each thread's hop propensity slightly toward the bundle's current preferred direction, suppressing random reversals and making the COM motion more pointer-like.
- *Phase locking* weakly couples internal phase variables so that threads tend to oscillate in step, improving clock quality without by itself forcing extreme stiffness.
- *Domains* assign threads to slowly varying background regions that share similar effective kernels, allowing extended patches of correlated behaviour and domain-wall defects.
- *Cadence disorder* introduces small variations in microscopic hop cadence between threads and, when combined with the other axes, lets us probe how "in step" or "out of step" timing affects lockstep stability and diagnostics such as Q_{clock}. In the code this is implemented by assigning each thread a slightly different preferred hop interval L_i drawn from a prescribed distribution and quantifying disorder via the variance $\sigma_L^2 = \langle (L_i - \langle L \rangle)^2 \rangle$.

At this stage the glue axes should be read as a phenomenological parametrisation of how primitive kernels can correlate threads, not as four new fundamental forces. They package distinct ways in which the event-graph dynamics can favour collective motion; later Stage 2/VI work will have to derive or constrain them from explicit kernel constructions. The single-axis A-series runs show that shared bias alone produces pointer-like bundles with reduced COM noise, phase locking alone produces good bundle clocks (high Q_{clock}) without extreme stiffness, and domains by themselves mostly act as a spectator axis. In the concrete A-series simulations used here, phase locking alone already increases Q_{clock} by a factor of a few between $N = 1$ and modest bundle sizes such as $N = 16$, while the corresponding suppression of COM noise remains well below the single-thread diffusive ceiling, consistent with the picture that A-series glue improves clock quality more than it stiffens bundles. The cadence axis, when switched on alone or even made very strong, does not by itself generate long-lived lockstep; instead it modulates how often threads can respond to the other glue axes. In bias-dominated regimes it effectively strengthens the coupling between threads that already prefer the same directions, while in phase-dominated regimes it behaves more like an effective temperature for the bundle clock, sharpening or smearing the tick statistics depending on its value. The C-series runs then map out the co-operative regimes: bias plus cadence gives stiff pointer-like bundles, phase lock plus cadence gives high-quality clocks, and the combination of bias, phase lock and cadence at moderate N produces bundles that are both stiff and clock-like. In practice, the representative C-series scans show order-of-magnitude increases in ℓ_{lock} and substantial reductions in $A_a(W_{\mathrm{coh}})$ for intermediate bundle sizes (e.g. $N \sim$ 8–32), before very large bundles become fragile or over-averaged, reinforcing the existence of a "sweet spot" N_* rather than a monotonic stiffening with N. For fixed glue parameters there is typically an intermediate bundle size N_* at which both the persistence length and lockstep diagnostics peak: very small bundles are dominated by single-thread noise, while very large bundles become fragile or effectively over–averaged. This "sweet spot" behaviour will be important in Stage 2 when we relate bundle size to effective inertial mass, and to the distinction between local matter bundles and a background lockstep network. , in line with the lockstep hierarchy picture developed in BCQM III/IV. The B-series lockstep diagnostics on the original BCQM IV_d soft-rudder bundles, together with the A-series and C-series glue-axes runs in BCQM V, demonstrate how phase locking and cadence are needed to reach the high-Q, stiff regimes used in the lockstep hierarchy.

Complementary long-duration bundle runs with all glue axes active show that these lockstep regimes remain statistically stable over many coherence times, supporting their interpretation as robust pre-spacetime phases rather than transient artefacts. An important side-effect of strong

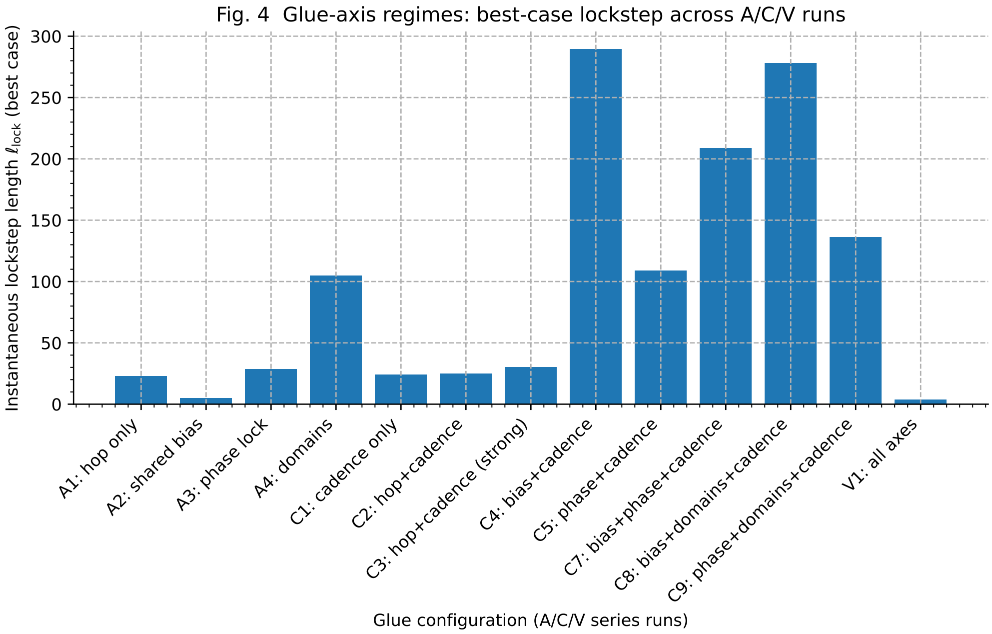

Figure 1: Best-case instantaneous lockstep length ℓ_{lock} for a set of A-series (single-axis), C-series (axis-combination) and V1 (all-axes) glue configurations in the BCQM V bundle simulations. For each run we select the largest W_{coh} in the grid and, within that, the largest bundle size N. Hop-only and pure-bias runs remain in a weak-to-moderate lockstep regime, while phase locking and cadence—especially in combination—are required to reach the high-lockstep regimes used in the lockstep hierarchy.

lockstep is that it acts as a connectivity bridge.

In weakly glued regimes the finite coherence horizon W_{coh} naturally segments the event graph into many overlapping but only partially connected "causal bubbles". Within each bubble we can define a local notion of time and distance, but these charts do not yet combine into a single global spacetime.

Dominant/global lockstep is precisely the regime in which these local bubbles percolate. A high-Q bundle or domain provides enough overlap and coherence that local charts can be glued together consistently into a large-scale spacetime description.

3 Projection from event graph to emergent spacetime

This section sketches how to project the event-thread dynamics and dominant lockstep into an emergent spacetime description. The aim is not to provide a full mathematical theory of the projector but to make plausible the route from graph-level quantities to continuum-like structures. No projector is implemented or fitted in the simulations reported here; all projector constructions in this section should be read as conceptual targets for later Stage 2 work rather than as additional numerical claims.

3.1 Projector concept and kernel-based geometry

We outline a projector from the event graph and its kernels to a lower-dimensional geometry:

- use the spectrum of appropriate operators (e.g. kernel or adjacency operators) to define an effective embedding;

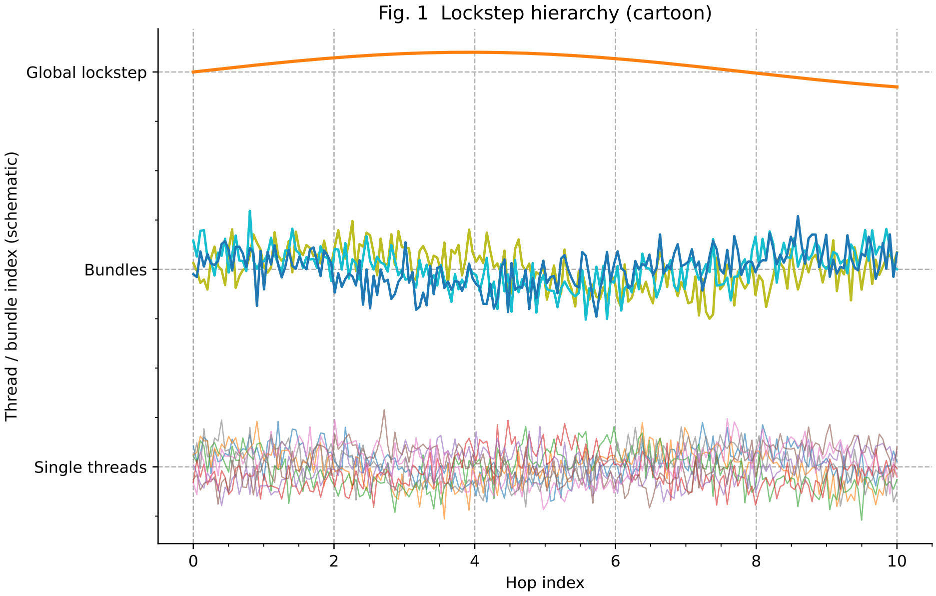

Figure 2: Schematic lockstep hierarchy at the event-thread level. The bottom layer shows many thin, noisy single threads with short persistence and poor clock quality. The middle layer shows a few coherent bundles (thicker strands) where threads are partially aligned and the centre-of-mass motion defines a modest-quality local time parameter. The top layer shows a wide, almost straight dominant lockstep band representing the bulk of threads moving in step; its ticks define the emergent global time parameter τ. Local matter bundles live within this dominant lockstep background and inherit their inertial properties from its residual centre-of-mass inertial noise.

- interpret distances and causal relations in terms of spectral or diffusion metrics on the graph;
- relate regions of strong, coherent lockstep to smooth patches of emergent spacetime.

3.2 Causal ordering and metric-like structure

We then indicate how:

- the partial order induced by realised events and edges gives a causal structure;
- the statistics of hop lengths and correlations feed into an effective metric or at least a conformal structure;
- the dominant lockstep pattern picks out preferred time-like directions in this emergent geometry.

3.3 Minimal working example: diffusion-based metric

As a minimal working example of a graph-based “distance”, we may define a diffusion metric between events. Let $P_{\text{diff}}(E_1 \to E_2 \mid W_{\text{coh}})$ be the probability that a suitably defined diffusion process on the event graph, constrained by the coherence horizon W_{coh}, reaches E_2 starting from E_1. We can then introduce

$$d(E_1, E_2) \;=\; -\log P_{\text{diff}}(E_1 \to E_2 \mid W_{\text{coh}}),$$

which is small when there are many short, high-propensity paths between E_1 and E_2 and large when connection is rare or requires long excursions.

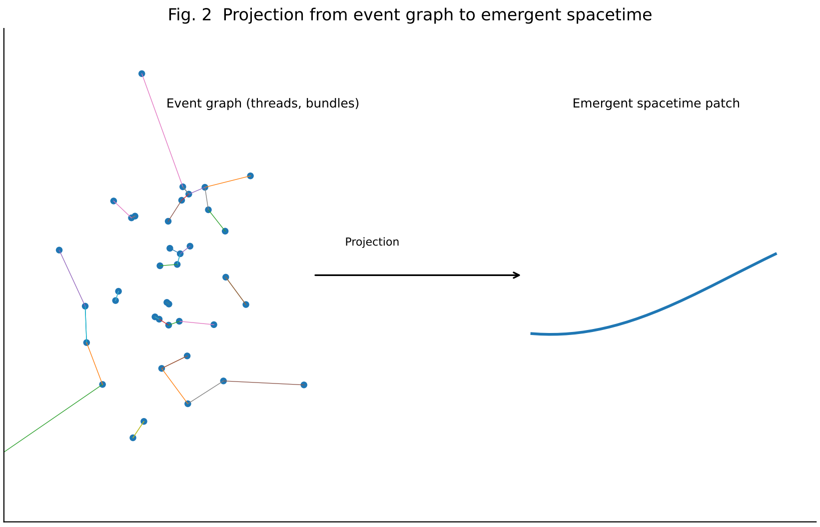

Figure 3: Cartoon of an event graph with many threads and bundles, together with an arrow indicating a projection to an emergent spacetime manifold. Regions of strong lockstep are mapped to smooth patches with well-defined time and spatial directions.

This construction:

- does not assume any background manifold or coordinate system;
- depends only on the event graph, the propensity kernels, and the coherence horizon;
- is naturally sensitive to lockstep: in stiff, highly glued regions diffusion is sharply peaked and $d(E_1, E_2)$ exhibits stable, low-noise behaviour, whereas in noisy regions it is more smeared out.

In a finite-horizon theory like BCQM, however, $P_{\text{diff}}(E_1 \to E_2 \mid W_{\text{coh}})$ will be strongly suppressed when E_1 and E_2 are separated by more than a few coherence horizons. In practice this means that a single diffusion-based metric is best thought of as charting a local “causal bubble” rather than a fully global geometry. Long-range structure must be reconstructed by patching together many such local charts, and this is precisely where dominant/global lockstep enters: only when lockstep is strong enough to percolate through the graph can these local metric patches be glued into a coherent large-scale spacetime.

In this paper we use such diffusion-based distances only as toy examples, but they show how a metric-like structure can emerge directly from the BCQM primitives. A systematic use of diffusion-based metrics on higher-dimensional, multi-bundle graphs is deferred to Stage 2 of the BCQM programme (and to BCQM VI), where genuine emergent-geometry tests will be performed.

4 Local bundles as matter on the emergent background

Here we reinterpret local lockstep bundles as matter-like objects moving on the emergent background defined by the dominant lockstep.

4.1 Mass from inertial noise and stiffness

Using the BCQM III/IV framework, we:

- recall how inertial noise spectra of bundle COM motion define an effective inertia m_{eff};

Table 1: Qualitative bundle taxonomy in terms of glue axes and lockstep properties.

Effective role	Dominant glue pattern	Phenomenology
"Particle-like" bundle	Shared bias ± cadence	Stiff bundles with low-to-moderate Q_{clock}
"Clock-like" bundle	Phase lock ± cadence	High Q_{clock} with moderate stiffness
Mixed "matter-in-spacetime"	Bias + phase lock + cadence	Both stiff and high Q_{clock} for moderate N
"Spacetime-like" background	Hop coherence + weak domains (many threads)	Long-lived lockstep with small residual fluctuations in thread directions

- adopt the identification "mass = stiffness of the local lockstep bundle", i.e. mass is inversely related to residual COM noise;
- emphasise that no primitive mass parameter is introduced at the event-thread level.

In BCQM III and BCQM IV this relationship was summarised in terms of an acceleration-noise amplitude $A_a(W_{\text{coh}})$ that scales with the coherence horizon as

$$A_a(W_{\text{coh}}) \;\approx\; A_0\, W_{\text{coh}}^{-\beta}, \tag{1}$$

where β is the inertial-noise exponent: $\beta \approx 0$ for the W_{coh}-blind control model (BCQM IV_b), $\beta \approx 1/2$ for single-thread soft-rudder dynamics (BCQM IV_c), and in the BCQM IV_d bundle runs the fitted COM exponents β_{COM} approach this diffusive ceiling from below for realistic glue strengths, reinforcing the conclusion that $\beta \approx 1/2$ is the natural single-thread universality limit. Operationally we treat the effective inertial mass as inversely proportional to this amplitude,

$$m_{\text{eff}} \;\propto\; \frac{1}{A_a(W_{\text{coh}})}, \tag{2}$$

so that stiffer bundles with smaller residual COM noise correspond to larger effective mass.

Numerically, BCQM III and BCQM IV already showed that single primitive threads live in a diffusive universality class (with inertial-noise exponent $\beta \approx 1/2$), while bundle centre-of-mass motion can suppress this noise without fine-tuning the single-thread slip law. The BCQM V glue-axes simulations sharpen this picture: by scanning combinations of shared bias, phase locking, domains and cadence we identify regimes where bundles are stiff, low-noise defects with good clock quality Q_{clock} (our candidates for massive matter) and regimes where lockstep percolates into a dominant background phase, which we interpret as the emergent spacetime domain.

Concretely, in the shared-bias–only runs with modest bundle size N the best bundles reach Q_{clock} values only of order unity, whereas adding phase locking and cadence glue at comparable N produces high-quality "clock bundles" with Q_{clock} larger by a factor of a few. In long-duration all-axes runs the dominant background domains exhibit lockstep persistence lengths ℓ_{lock} of order 10^2 hops, while softer, matter-like bundles show significantly shorter ℓ_{lock} within the same event-graph dynamics.

All glue-axes simulations used in this paper are implemented in an open-source Python package, and the full set of configuration files, output summaries and RUN_REPORT documents are available in the associated public code repository on GitHub. Selected long-duration convergence runs, with substantially increased hop counts and ensemble sizes, confirm that the lockstep diagnostics and phase characterisation used in BCQM V are stable under extended evolution. These materials are sufficient to reproduce all numerical figures and scaling statements reported here.

In practice the background may also carry a coarse-grained phase coherence across domains, but in BCQM V we keep this glue modest and reserve strong phase locking for clock-like and matter-like bundles.

4.2 Bundle motion and worldlines

We discuss how local bundles move relative to the background lockstep and its emergent geometry:

- define bundle worldlines parametrised by τ;
- describe how, in the continuum picture, these worldlines approximate geodesic-like motion in the emergent spacetime;
- explain how deviations from perfect lockstep or additional noise appear as forces or fluctuations around inertial trajectories.

4.3 Matter as soft-in-rigid defects

The bubble–droplet picture developed earlier can be translated directly into the lockstep language. The dominant/global lockstep behaves like a rigid phase: it has very high clock quality, extremely low residual noise, and defines the effective background spacetime. Local matter bundles are then soft defects in this rigid phase: regions where lockstep is still strong enough to bind threads together, but observably weaker than in the background.

In this view:

- spacetime corresponds to the dominant, rigid lockstep domain;
- particles correspond to softer, finite bundles whose stiffness (inverse residual noise) is what we call mass;
- interactions can be thought of, at least heuristically, as changes in the defect structure: bundles merging, splitting, or reconfiguring within the rigid background.

This reinterpretation does not introduce new primitives, but it makes the unification of mass and spacetime as two phases of the same lockstep mechanism more concrete.

5 Back-reaction and pre-gravity book-keeping

In this section we do not attempt a full theory of gravity or curvature. Instead we identify the variables and structures that later work should use to describe back-reaction: how local bundles modify the dominant lockstep and, through the projector, the emergent geometry.

5.1 Lockstep deformation variables

We outline candidate quantities that could play a role analogous to stress–energy and curvature:

- bundle densities, glue strengths, and noise spectra as “sources”;
- changes in lockstep coherence, hop statistics, and spectral properties of the projector as “responses”;
- simple schematic relations between these, to be fleshed out in future work.

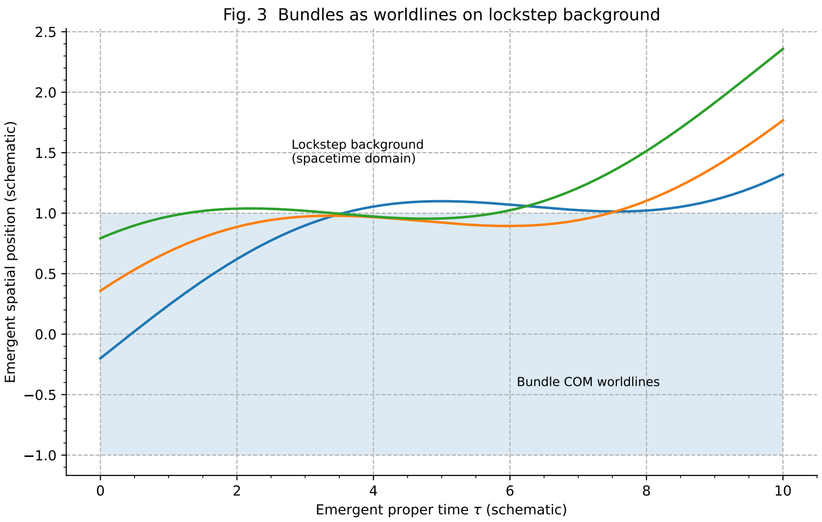

Figure 4: Schematic of local bundles (thick strands) moving on an emergent spacetime background defined by the dominant lockstep. Their centre-of-mass trajectories are parametrised by τ and interpreted as massive worldlines.

5.2 Non-Riemannian signatures and candidate curvature

Because the projector from event graph to spacetime is built from finite-horizon, lockstep-sensitive kernels, there is no guarantee that the emergent geometry will be exactly Riemannian. In particular, if lockstep is strongly disrupted in some region, the diffusion-based distances between events may exhibit failures of the triangle inequality or other non-metric features. In the present framework it is natural to interpret such pre-metric deviations from simple additivity (for example failures of triangle relations in the diffusion distance) as candidates for curvature- or stress–energy-like structure in the event graph: they are precisely the places where local bundles and glue patterns distort the global lockstep.

BCQM V does not attempt to derive explicit field equations from these distortions. In particular, Stage 2 (and BCQM VI) will have to disentangle genuinely metric effects from torsion-like or defect-driven contributions once higher-dimensional, multi-bundle graphs are available, but BCQM V highlights these deviations as the most likely footprints of emergent gravity. Later stages of the programme will need to translate this intuition into concrete relations between lockstep deformation variables and the effective geometry experienced by bundles.

5.3 Scope boundary for BCQM V

We close this section by making the scope explicit:

- BCQM V does *not* propose a full dynamical law for emergent gravity;
- it sets up the book-keeping needed to talk coherently about back-reaction in later papers;
- it emphasises that both mass (local bundles) and spacetime (dominant lockstep) share a common origin in the statistics of event-thread lockstep and inertial noise.

6 Outlook and role in the BCQM programme

Finally we summarise the main conceptual moves of BCQM V and place them in the wider BCQM programme:

- one mechanism — lockstep plus finite-horizon noise — generates both mass and spacetime as emergent structures at different scales;
- BCQM V provides the bridge between Stage 1 (inertial noise and bundles) and the later emergent-gravity work;
- future papers will:
  - make the projector from graph to spacetime precise;
  - develop explicit dynamical equations for back-reaction (curvature);
  - test the framework against toy models and, where possible, observational or experimental signatures.

    Looking ahead to Stage 2, the natural next step is to embed many such bundles in a shared higher-dimensional event graph (for example a two-dimensional graph) while reusing the same glue axes. In that setting we expect large, long-lived regions of dominant lockstep across many threads to play the role of an emergent spacetime background phase, while smaller, stiff, clock-like bundles moving within that background define effective matter worldlines with proper-time ticks. The existence of an intermediate “sweet spot” bundle size N_*, already visible in the BCQM V glue-axes numerics, hints that there may be preferred scales for such matter bundles once the full Stage 2 event graph is in place.

    Preliminary non-BCQM toy models on two-dimensional graphs suggest that there should be a narrow parameter window in which a clean background lockstep phase and a persistent population of defects coexist. The bundle phase diagram extracted in BCQM V — diffusive single threads, stiff and clock-like bundles, and dominant/global lockstep — provides exactly the ingredients needed to make that emergent-spacetime programme concrete in BCQM VI.

    From the present Stage 1 perspective the lockstep-hierarchy picture is therefore falsifiable: if, in higher-dimensional simulations based on the same primitives, no choice of microscopic kernel yields regimes with both high-Q_{clock} bundles and extensive, long-lived background lockstep, then the BCQM route to emergent spacetime would be empirically disfavoured.

    Conceptually, this emphasis on a single emergent time direction as the primary order parameter is also in the spirit of time-first perspectives in the literature (for example, in work by Matsas and collaborators [8]), where once time is operationally defined much of the remaining spacetime and unit structure can be reconstructed around it.

The broader idea that simple or disordered primitives can give rise to effective laws and symmetries at larger scales has precedents in other programmes, such as random-dynamics approaches to emergent gauge symmetry and spacetime in high-energy physics, and experiments on Brownian spin-locking and order-from-noise in condensed-matter systems. BCQM V can be read as a concrete realisation of a similar “order from noise” principle in which both spacetime and mass arise from the statistics of event-thread lockstep.

References

[1] Peter M. Ferguson. *Boundary-Condition Quantum Mechanics (BCQM)*. 2025. DOI: 10.5281/zenodo.17191306. URL: https://doi.org/10.5281/zenodo.17191306.

[2] Peter M. Ferguson. *Boundary-Condition Quantum Mechanics II: From Quantum Events to Spacetime*. 2025. DOI: 10.5281/zenodo.17398294. URL: https://doi.org/10.5281/zenodo.17398294.

[3] Peter M. Ferguson. *Boundary-Condition Quantum Mechanics III: A Stochastic Growth Model for Causal Event Chains and the Emergence of Inertia*. 2025. DOI: 10.5281/zenodo.17632453. URL: https://doi.org/10.5281/zenodo.17632453.

[4] Peter M. Ferguson. *Boundary-Condition Quantum Mechanics IV: Inertial Noise and the Emergent Action*. 2025. DOI: 10.5281/zenodo.17650149. URL: https://doi.org/10.5281/zenodo.17650149.

[5] Peter M. Ferguson. *Boundary-Condition Quantum Mechanics IV_b: Baseline inertial-noise spectra form a W_coh-blind event-chain control model*. 2025. DOI: 10.5281/zenodo.17815888. URL: https://doi.org/10.5281/zenodo.17815888.

[6] Peter M. Ferguson. *Boundary-Condition Quantum Mechanics IV_c: Diffusive inertia and the limits of binary hop kernels*. 2025. DOI: 10.5281/zenodo.17921862. URL: https://doi.org/10.5281/zenodo.17921862.

[7] Peter M. Ferguson. *Boundary-Condition Quantum Mechanics IV_d: Bundle formation, graph–Darwinism, and inertial rigidity from shared edges*. 2025. DOI: 10.5281/zenodo.18034190. URL: https://doi.org/10.5281/zenodo.18034190.

[8] George E. A. Matsas et al. ‘The number of fundamental constants from a spacetime-based perspective’. In: *Scientific Reports* 14 (2024), p. 22594. DOI: 10.1038/s41598-024-71907-0.