BCQM VII Stage–2 Pivot Checkpoint
Communities and Super-Graph Cloth Validation (v0.1)

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2 February 2026

Purpose

This checkpoint records the Stage–2 pivot and the supporting computational evidence up to (and including) the latest Gate–4 localisation runs. It is intended as a stable reference point that can be cited or appended in later BCQM VII drafts. The Gate scheme used throughout is the pivot plan's **Gate 0–4** convention.

Context

Stage–1 (BCQM VI) established: (i) two-step emergence (connectivity first, islands later), (ii) mechanism separation via ablations (nospace / space-on / glue-off), (iii) time-resolved "space on, islands fluctuating", and (iv) ball-growth as the robust geometry diagnostic on the short, fast-mixing active slice. Stage–2 (BCQM VII) aims to define a persistent geometry object ("cloth") beyond $V_{\text{active}}(t)$ and to pose geometry/metric tests on that object.

Provenance and reproducibility

- Code provenance: BCQM VII began from a cryptographically verified baseline (SHA256 14/14 matches) to the BCQM VI v0.1.0 reference implementation (Zenodo DOI 10.5281/zenodo.18403109), then continued development in `PMF57/BCQM_VII`.
- Outputs: simulation outputs are kept under `outputs_cloth/`. Consolidated analysis tables are kept under a local `csv/` folder.
- Scripts: all analysis scripts used here are stored in the repo under `bcqm_vii_cloth/analysis/`.

Stage–2 cloth experiments prior to pivot

The first Stage–2 cloth attempts sought a persistent edge backbone via bin-level persistence.

- **hits1** (`min_bin_hits`=1): produced connected cloth cores and very stable geometry diagnostics (ball-growth curves), but exact edge identity across seeds was strongly unstable (near-zero edge Jaccard).
- **hits2** (`min_bin_hits`=2): isolated tiny recurrent pockets (motifs) rather than a spanning cloth backbone; this remained true under longer epochs (x5/x10) and bin coarsening (bins=20 and 10 at x10).

A key empirical lesson emerged: stability appears first at the level of *geometry class* (diagnostics) rather than at the level of exact microstructure (edge identity), at least at current N and epoch lengths. This motivated the pivot to a coarse-grained cloth representation.

Pivot: from molecular edges to communities and a super-graph

The pivot plan (`BCQM_pivot_forward_plan_v0.2.2.tex`) reframes the geometry object:

- Use the connected hits1 used-by-core cloth as the base adjacency (undirected projection) for community detection.
- Construct a directed community super-graph (communities as nodes; inter-community flows as weighted edges).
- Validate stability and geometry at the super-graph level (Gates 1–3) before attempting higher-level physics proxies (Gate 4).

Gate status summary

Gate 0: baseline cloth exists and is diagnostic-stable

Gate 0 is established by the hits1 cloth baseline in the high cross-link regime: connected components exist, and ball-growth curves are stable across seeds (as documented by the earlier survival and metric-stability CSVs).

Gate 1: community partitions are stable across seeds

Applying Louvain community detection to the hits1 cloth baseline (x10 epoch, bins=20, 5 seeds per quadrant) yields strong partition agreement across seeds (NMI $\approx$ 0.83–0.84; ARI moderate-to-strong). Community counts K are also consistent: $K \approx$ 22–23 at $n = 0.8$, while K grows substantially at $n = 0.4$ (many small communities). These results are summarised in `csv/community_supergraph_stability_summary.csv`.

Gate 2: super-graph edges and flow weights are stable

Using the same partitions, the super-graph edge sets are substantially more stable than raw edge identity. Super-graph edge-set Jaccard is moderate ($\sim$ 0.37–0.60 depending on N, n), and weight correlations on the common edge set are high at $n = 0.8$ (typically $\sim$ 0.89–0.91). These results are recorded in `csv/supergraph_edge_stability.csv` and collated in `csv/pivot_gates_1_2_3_summary.csv`.

Gate 3: super-graph geometry diagnostics are stable

Ball-growth curves on the super-graph are stable across seeds, with pairwise L2 distances remaining small (regime dependent). A Louvain resolution sweep ($\gamma \in \{0.5, 1.0, 1.5, 2.0\}$) shows that conclusions are robust for $\gamma \geq 1.0$, while $\gamma = 0.5$ is a clear outlier (poor super-graph metric stability). Results are recorded in `csv/louvain_resolution_sweep_summary.csv`.

Gate 4: physics proxy – thread localisation on the super-graph

A minimal logging extension was added: per-bin, per-thread traces (`cloth_trace`) recording the end-of-bin event ID and a core-membership mask. This enables direct measurement of inter-bin motion on the community super-graph.

High coherence regime ($n = 0.8$). For hits1, x10, bins=20 with $N \in \{4, 8\}$, hop-distance distributions on the super-graph are strongly local: all transitions are confined to $d \in \{0, 1, 2\}$ with no long hops ($d \geq 3$). The dominant mass is at $d = 1$, consistent with "local motion" on the emergent coarse geometry. Outputs are stored under `csv/gate4/` with tags (e.g. `gate4_n0p8_all_all_*`).

Low coherence regime ($n = 0.4$). At $n = 0.4$, a revised Gate–4 analysis (partition built on all-used edges; super-graph built on all-used flows) restores full mapping coverage and yields comparable hop distributions. Even in this weaker regime, motion remains local (0–2 hops only), though the distribution shifts modestly toward $d = 2$ relative to $n = 0.8$. Core vs halo comparisons are available via the stored `core_mask` and the tagged output CSVs.

Deliverables status (pivot plan)

The pivot plan's deliverables are now:

- **Reproducible analysis scripts and outputs:** satisfied (community stability, super-graph stability, resolution sweep, and Gate–4 localisation scripts; corresponding CSVs in `csv/`).
- **Compact summary tables:** satisfied (Gate 1–3 summary CSVs and resolution sweep; Gate–4 tagged CSVs).
- **Checkpoint note:** this document.

Next steps

1. Use the stable super-graph cloth object as the Stage–2 substrate for any additional geometry or proxy tests (e.g. robustness to small parameter changes, ablations on the coarse object).
2. If stricter-than-hits1 edge backbones are still desired, test the two minimalism-preserving definitions proposed in the pivot plan: (i) event-filtered edge cores, and (ii) quantile persistence on core-edge occupancy.
3. Optional later cross-check: Leiden community detection as an algorithm-family validation, if required by reviewers.