BCQM VII Draft Insert
Stage–2 Pivot Record: From molecular edges to cloth communities (v0.1)

Peter M. Ferguson
Independent Researcher

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How to use this document

This is a *partial draft insert* intended to capture a specific Stage–2 decision point in BCQM VII while the computational evidence is fresh. It can be pasted into the eventual BCQM VII paper as a section (or appendix) documenting (i) the empirical trigger, (ii) the failed "rescue" attempts, and (iii) the pivot to the next geometry object.

1 Stage–2 pivot record (cloth geometry)

1.1 Motivation

Stage–1 (BCQM VI) established that the active slice $V_{\mathrm{active}}(t)$ is a fast-mixing, "channels + shortcuts" object and that return-probability spectral dimension is structurally unstable there; ball growth is the robust geometry diagnostic. Stage–2 in BCQM VII set out to define a persistent geometry object ("cloth") beyond $V_{\mathrm{active}}(t)$, extracted from long runs with minimal additional assumptions.

The initial Stage–2 working hypothesis was that a cloth backbone might be identified by *persistent directed edges* ("roads") used by the lockstep-supported core, with concurrency retained as a separate short-run channel activity indicator.

1.2 Empirical trigger: microstructure instability versus metric stability

Ensembles (5 seeds per quadrant) demonstrated a robust pattern:

- Event-level cloth cores (persistent "places") become highly stable at high cross-link pressure (e.g. $n = 0.8$), with high Jaccard overlap across seeds under permissive persistence.
- Edge-level identity is strongly seed-sensitive: exact core edge sets exhibit near-zero Jaccard overlap across seeds, even when the cloth core is connected.
- Despite edge identity instability, the *geometry diagnostic* on the connected cloth (ball-growth fraction $|B(r)|/|C|$) can be highly stable across seeds in the high-n regime.

This indicates that stability emerges first at the level of *geometry class* (diagnostics) rather than at the level of exact edge microstructure, at least at the current scale.

1.3 Attempted rescues and negative results

A stricter persistence rule was tested to see whether edge microstructure could be stabilised:

- hits1: `min_bin_hits`=1 produced connected cloth cores and excellent metric stability but poor edge-set Jaccard.

- hits2: `min_bin_hits`=2 isolated tiny recurrent pockets (motifs) rather than a spanning cloth, yielding small components and poor or trivial stability.

Two "rescue" strategies were attempted for hits2:

1. **Longer epochs** (x5 and x10). Longer runs increased sample size but did not convert hits2 into a connected backbone: the strict edge core remained a collection of small recurrent motifs, and exact edge identity remained seed-sensitive.
2. **Bin coarsening** (x10 with fewer, longer bins: 20 and 10). Coarsening bins did not rescue hits2 into a cloth backbone; it remained a motif detector. The calibration run (hits1, x10, bins=20) retained extremely stable metric-level behaviour at high n.

1.4 Interpretation: channel activity versus cloth

The experiments support a clear hierarchy:

- Edge concurrency captures short-run *channel activity* (tailgating / co-selection) and is not, by itself, a stable cloth backbone at current sampling scales.
- Strict cross-bin repetition (hits2) behaves as a *motif detector* selecting seed-specific recurrent pockets.
- A connected cloth baseline (hits1) yields a stable *geometry diagnostic* even when micro-structure varies.

Thus, the failure mode is not "insufficient binning"; it is that strict persistence at the current scale selects microscopic loops rather than the sought cloth background.

1.5 Pivot decision: coarse-grained cloth via communities and a super-graph

Given the above, Stage–2 pivots from "edge identity as cloth" to "coarse-grained cloth":

- Define the base cloth object as the connected hits1 used-by-core cloth core.
- Apply community detection on its undirected projection to obtain stable mesoscopic structure.
- Build a directed community super-graph (communities as nodes; inter-community flows as edges) and test stability at that level (NMI/ARI for partitions; super-graph stability; super-graph ball growth).

The pivot reframes the objective: rather than forcing edge-level stability prematurely, seek stability in a coarse-grained geometry object that may be the natural "cloth" analogue of a macroscopic bed-sheet built from microscopic yarn.

1.6 Reproducibility pointers (local artefacts)

At the time of this decision:

- Raw run folders (bring-up and ensembles) are retained under `outputs_cloth/`.
- Summary tables (Jaccard survival and metric-distance results, including the bin-coarsening comparison table) are consolidated under a local `csv/` folder.
- The pivot forward plan is recorded as `BCQM_pivot_forward_plan_v0.2.x.tex`.

Gate mapping (pivot plan). In the Gate 0–4 scheme of the pivot plan, Gate 0 (hits1 cloth baseline) is established by the connected hits1 ensembles and their metric-stability results. The next two paragraphs summarise the evidence for Gates 1–3 (community partition stability, super-graph edge stability, and super-graph geometry/ball-growth stability); Gate 4 concerns subsequent "physics proxy" tests and is not addressed here.

Stage–2 pivot evidence: community and super-graph stability. We tested the pivot hypothesis that a stable "cloth" geometry emerges more naturally at a coarse-grained level than at exact edge identity by applying Louvain community detection to the undirected projection of the hits1 used-by-core cloth (x10 epoch, bins=20, 5 seeds per quadrant). Partition similarity across seeds is strong (NMI ≈ 0.83–0.84) with moderate-to-strong ARI (≈ 0.54–0.64), indicating that community structure is reproducible even when micro-edge identity is not.

Using the same partitions, we built a directed community super-graph in which nodes are communities and weighted edges represent aggregate inter-community flows. Geometry diagnostics on the super-graph (ball-growth fraction curves) remain stable across seeds: for instance, at $(N = 8, n = 0.4)$ the pairwise L2 distance between normalised super-graph ball-growth curves is $d_{\mathrm{L2}} = 0.0085 \pm 0.0053$, while at $(N = 4, n = 0.8)$ it is 0.0170 ± 0.0139. At high cross-link pressure $(n = 0.8)$, the community count is also consistent across seeds ($K \approx 22$–23 for both $N = 4$ and $N = 8$), and the super-graph remains connected with a similar component size. A consolidated summary table is provided in `csv/community_supergraph_stability_summary.csv`.

Stage–2 pivot evidence: super-graph edge stability (Gate 2). Using the Louvain partitions from the hits1 cloth baseline (x10 epoch, bins=20, 5 seeds per quadrant), we constructed a directed community super-graph (communities as nodes; weighted inter-community flows as edges). Pairwise stability across seeds shows that coarse-graining substantially improves structural reproducibility: the unweighted super-graph edge-set Jaccard is 0.60 ± 0.10 for $(N = 4, n = 0.4)$, 0.53 ± 0.10 for $(N = 4, n = 0.8)$, 0.42 ± 0.05 for $(N = 8, n = 0.4)$, and 0.37 ± 0.06 for $(N = 8, n = 0.8)$. In addition, the relative strengths of inter-community flows are consistent: the Pearson correlation of crossing-edge weights on the common super-edges is 0.66 ± 0.10 for $(N = 4, n = 0.4)$, 0.91 ± 0.02 for $(N = 4, n = 0.8)$, 0.74 ± 0.03 for $(N = 8, n = 0.4)$, and 0.89 ± 0.03 for $(N = 8, n = 0.8)$. These results are recorded in `csv/supergraph_edge_stability.csv` and summarised alongside Gates 1 and 3 in `csv/pivot_gates_1_2_3_summary.csv`.

Gate 3 tightening: Louvain resolution sweep. To check that the community/super-graph conclusions are not an artefact of a single partition setting, we repeated the Gate 1–3 analysis across a Louvain resolution sweep ($\gamma \in \{0.5, 1.0, 1.5, 2.0\}$) on the same hits1 baseline ensemble (x10 epoch, bins=20). For $\gamma \geq 1.0$, partition similarity remains strong (NMI ≈ 0.82–0.85, ARI moderate-to-strong) and super-graph geometry stability remains in-family (super-graph ball-growth distances d_{L2} remain small). The low-resolution case $\gamma = 0.5$ is an outlier with markedly poorer super-graph metric stability (notably at $(N = 8, n = 0.8)$). These results are recorded in `csv/louvain_resolution_sweep_summary.csv` and support the claim that Gate 3 is robust to benign community-resolution choices.

Gate 4 probe: thread localisation on the community super-graph. Using the traced runs (hits1, x10, bins=20; $N = 8$, $n = 0.8$, 5 seeds), we mapped each thread's end-of-bin event ID to a Louvain community label and measured inter-bin motion on the corresponding community super-graph. All runs produced a connected super-graph with $K \approx 21$–23 communities. The hop-distance distribution between consecutive bins is strongly local: averaged across seeds, $\mathrm{P}(d = 0) \approx 0.068$, $\mathrm{P}(d = 1) \approx 0.747$, $\mathrm{P}(d = 2) \approx 0.184$, and no transitions with $d \geq 3$ were observed. The mean hop distance is $\langle d \rangle \approx 1.116$ and the per-bin community-change rate is high in this regime (mean jump-rate ≈ 0.932), indicating frequent movement but typically only to neighbouring communities rather than long-range teleports. This supports the interpretation that threads respect the emergent cloth neighbourhood structure at the super-graph level.

Gate 4 (physics proxy): thread localisation on the community super-graph. To move beyond "stability of objects" and test whether threads *respect* the emergent coarse geometry, we added minimal Stage–2 logging (`cloth_trace`) that records, at each logged bin boundary, (i) each thread's end-of-bin event ID and (ii) a core-membership mask. Using Louvain partitions on the hits1 cloth baseline and the corresponding community super-graph, we mapped each thread's end-of-bin event to a community label and measured the shortest-path hop distance on the super-graph between consecutive bins.

In the high-coherence regime ($n = 0.8$, hits1, x10 epoch, bins=20; $N \in \{4, 8\}$), inter-bin motion is strongly local: all transitions lie in $d \in \{0, 1, 2\}$ with no long-range hops ($d \geq 3$), and the distribution is dominated by $d = 1$. In the lower-coherence regime ($n = 0.4$), using an "all-used" partition/super-graph construction restores full mapping coverage and again yields local motion (0–2 hops only), with a modest shift of probability mass from $d = 1$ to $d = 2$ relative to $n = 0.8$. Tagged Gate–4 outputs are stored under `csv/gate4/` (e.g. `gate4_n0p8_all_all_*` and `gate4_n0p4_all_all_*`) and can be regenerated using the repo analysis script `bcqm_vii_cloth/analysis/gate4_thread_localisation.py`.