BCQM VII Stage-2 (Geometry Cloth) Forward Plan

Pivot Programme: From molecular edges to a stable "cloth" via bin-coarsening and community structure

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1 Purpose of the pivot

Stage–2 aims to define a persistent "cloth" geometry object beyond the short, fast-mixing active slice $V_{\text{active}}(t)$. Stage–1 established that exact edge identity is seed-sensitive (molecular/foam scale), while geometry diagnostics (ball growth) can be comparatively stable. The pivot operationalises this by moving the geometry object one level up: from raw edge sets to coarse-grained structure (communities and a community super-graph).

1.1 Working diagnosis from Stage–2 experiments

In the current VII code, permissive persistence (hits1) yields a connected edge cloth and highly stable ball-growth curves at high cross-link pressure, while strict cross-bin repetition (hits2) isolates tiny recurrent motifs rather than a spanning backbone (even at longer epochs and bin coarsening). This indicates that "cloth" stability should be sought at an intermediate, coarse-grained scale: stable *classes* of geometry may emerge before stable microstructure.

2 What must be fixed before proceeding

This plan assumes the following are already in place (and verified):

- Proven code provenance: BCQM VII baseline cryptographically matched to BCQM VI v0.1.0 core files.
- Stage–2 logging: `cloth` and `cloth_ledger` in `RUN_METRICS_*`. Explicit `core_edges_used` and `core_events_used` lists are recorded for survival.
- Consolidation: ensemble outputs retained under `outputs_cloth/`; summary CSVs retained under a local `csv/` folder.

3 Pivot hypothesis and success definition

3.1 Hypothesis

If exact edges fluctuate (edge Jaccard $\ll 1$) but ball-growth geometry is stable, then a coarse-grained object — communities on the cloth core and an inter-community super-graph — should exhibit intermediate stability: greater than raw edges and robust enough to define "thread scale" structure.

3.2 Success definition

Stage–2 pivot succeeds if, in a fixed regime (start with $N = 8$, $n = 0.8$, $W_{\text{coh}} = 100$ on the hits1 connected cloth baseline):

- community partitions show moderate-to-strong agreement across seeds (NMI/ARI),
- the community super-graph is more stable than raw edge sets,
- super-graph geometry diagnostics (ball growth) are at least as stable as the current cloth ball-growth curves,
- and these conclusions survive modest variations (seeds, epoch length, binning).

4 Operational definition of the base graph for coarse-graining

4.1 Base adjacency

Use the **hits1 used-by-core cloth core** as the base object: the directed edge set `core_edges_used` and its induced event set `core_events_used`. For community detection, build the undirected projection of this edge set (treat each directed edge as an undirected adjacency).

4.2 Why hits1 baseline

hits1 yields a connected cloth and very stable ball-growth metrics at high n. It provides the "bed-sheet" substrate on which communities can be detected. hits2 is retained as a motif detector and robustness probe, but is not used as the primary base graph at this stage.

5 Test 4A: Community-structure stability

5.1 Parameters

- Fixed regime: $N = 8$, $n = 0.8$, $W_{\mathrm{coh}} = 100$, hits1 baseline.
- Seeds: 5–10 (use existing checkpoint ensembles if available).
- Epoch: start with the x10, bins=20 baseline (stable ball-growth regime), then vary.

5.2 Procedure

For each seed s:

1. Extract the cloth core edge set (hits1): `core_edges_used`.
2. Build undirected projection G_s^{core} for community detection.
3. Apply community detection:
   - Primary: Louvain modularity (fast, standard).
   - Alternative: Leiden (higher quality), or spectral clustering for comparison.
4. Record the partition vector $\mathbf{c}_s$: mapping from event to community ID, and record community count K_s.

5.3 Partition similarity observables

For each pair of seeds (s, s'), compute:

- Normalised Mutual Information (NMI) between $\mathbf{c}_s$ and $\mathbf{c}_{s'}$.
- Adjusted Rand Index (ARI) between $\mathbf{c}_s$ and $\mathbf{c}_{s'}$.
- Community-count consistency: distribution of K_s across seeds.

Interpretation guide: NMI ≈ 1 identical; NMI ≈ 0 random; NMI > 0.5 moderate; > 0.7 strong.

5.4 Super-graph stability observables

For each seed s, build a directed community super-graph G_s^{super}:

- nodes: communities from $\mathbf{c}_s$,
- edges: $C_i \to C_j$ exists if any cloth-core edge $(u \to v)$ crosses from $u \in C_i$ to $v \in C_j$,
- weights: number of crossing edges (aggregate flow).

Across seed pairs:

- Super-graph edge Jaccard (after label alignment).
- Weighted flow correlation (Pearson correlation on common edges).
- Super-graph ball growth: compare $|B(r)|/|C|$ curves across seeds via L2 distance.

5.5 Success criteria (Test 4A)

- Mean NMI > 0.5 (moderate) or > 0.7 (strong).
- Super-graph edge Jaccard $\gg$ raw edge Jaccard (e.g. > 0.2 vs ≈ 0.01).
- Super-graph ball-growth L2 distances $\lesssim$ cloth ball-growth distances on the hits1 core.

6 Test 4B: Event-filtered edge core

6.1 Rationale

Persistent events are often more stable than exact edges. Filter edges to those whose endpoints are persistent events, suppressing seed-specific micro-loops.

6.2 Procedure

For each seed s:

1. Identify persistent events E_s^{persist} using event occupancy (bin hits / number of bins), starting with a permissive threshold.
2. Define event-filtered core edges: edges $(u \to v)$ with $u, v \in E_s^{\text{persist}}$ and used by the core.

6.3 Observables and success criteria

- Edge Jaccard across seeds improves relative to raw hits1 edges.
- Cloth remains connected (no severe fragmentation).
- Ball-growth stability is maintained or improved.

7 Test 4C: Quantile-based edge persistence

7.1 Rationale

Instead of requiring explicit cross-bin repetition (hits2), keep the top $q\%$ most-used core edges over an epoch (high-traffic backbone). This is a coarse-grained persistence proxy without mutating primitives.

7.2 Procedure

For each seed s:

1. Compute per-edge occupancy $p_{\text{persist}}(u \to v) = \text{bin\_hits}(u \to v)/B$ from the run ledger.
2. Keep edges above a quantile threshold (e.g. top 10%, 20%, 30%).
3. Evaluate connectivity and geometry on this quantile cloth.

7.3 Success criteria

- Edge Jaccard increases as the quantile becomes stricter (top 10% more stable than top 30%).
- Quantile cloth remains connected at intermediate thresholds (e.g. 20%).
- Ball-growth stability maintained.

8 Implementation notes

8.1 Packages

Community detection can be implemented with `python-louvain` (Louvain) or `leidenalg` (Leiden), with graph handling in `networkx` or `igraph`. NMI and ARI can be computed with `sklearn.metrics`. For super-graph label alignment use maximum-weight bipartite matching (Hungarian algorithm; `scipy.optimize.linear_sum_assignment`).

8.2 Directed versus undirected handling

Community detection is performed on an undirected projection of the cloth core. The resulting community labels are then used to build a directed super-graph for flow stability analysis.

8.3 No new runs requirement

Test 4A and 4B can be performed offline on existing hits1 ensembles (recommended starting point). Test 4C requires per-edge occupancy counts; if these are not logged explicitly, they can be reconstructed from stored ledgers.

9 Gated execution plan

1. Gate 0: Confirm hits1 cloth baseline (connected core; stable ball-growth) in the fixed regime.
2. Gate 1: Community partitions are stable (NMI/ARI thresholds achieved).
3. Gate 2: Super-graph stability exceeds raw edge stability.
4. Gate 3: Geometry diagnostics on the super-graph are stable across seeds.
5. Gate 4: Only then attempt additional "physics" proxies (e.g. causal-frontier definitions on cloth) if desired.

10 Deliverables

- A reproducible analysis script that, given an ensemble folder, outputs: NMI/ARI matrices, super-graph stability tables, and super-graph ball-growth curves.
- A compact CSV summary similar to the existing survival tables, but at the community and super-graph level.
- A short checkpoint lab note documenting whether the pivot succeeded at Gate 1/2/3.