Program for Testing Target Selection Commutativity (P5)

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Goal

To determine if the cosmological inference derived from galaxy clustering is invariant under the ordering of target selection and fiber assignment. In the Causal Evolution (CE) framework, the act of "picking" a target is an event that updates the state of the dependency network. We define the commutator statistic:

$$\hat{C} = \mathcal{E}[\text{Clustering} \circ \text{Selection}] - \mathcal{E}[\text{Selection} \circ \text{Clustering}] \tag{1}$$

Under ΛCDM, $\hat{C}$ should be consistent with zero (within shot noise). A non-zero $\hat{C}$ suggests that the "Past" (galaxy distribution) is being shaped by the "Context" (survey ledger).

0. Pre-registration

- Data: DESI (Dark Energy Spectroscopic Instrument) Year 1/Year 3 data releases.
- Ledger: The `altmtl` (Alternative Merged Target List) suite.
- Statistic: Monopole and quadrupole of the two-point correlation function $\xi(s)$.
- Scale: $20 < s < 150\,h^{-1}$Mpc (Linear to quasi-linear regime).

1. Data Products

- **Primary:** DESI LRG (Luminous Red Galaxy) and ELG (Emission Line Galaxy) catalogs.
- **Context Ledger:** 128+ realizations of the DESI `altmtl` fiber assignment pipeline.
- **Simulations:** AbacusSummit N-body simulations processed through the fiber-assignment emulator.

2. The Commutator Metric

We define the test as a comparison between the baseline survey and the ensemble of alternative ledgers.

1. Let θ_{base} be the cosmological parameters $(\Omega_m, f\sigma_8)$ derived from the primary survey.
2. Let $\theta_{alt,i}$ be the parameters derived from the i-th `altmtl` realization.

3. The commutator shift is defined as:

$$\Delta\theta = \theta_{base} - \frac{1}{N}\sum_{i=1}^{N}\theta_{alt,i} \tag{2}$$

3. Fiber Assignment Context

The "Context" in P5 is the physical limitation of the fiber positioners on the focal plane.

- **Fiber Collisions:** Two galaxies closer than the fiber diameter cannot both be observed in one pass.
- **Priority Logic:** The ledger decides which galaxy gets the fiber based on a pre-defined "cost" function.
- **PbC Hypothesis:** If $\Delta\theta \neq 0$, the priority logic is effectively "writing" the clustering signal rather than just sampling it.

4. Methodology

1. **Clustering Analysis:** Compute $\xi_\ell(s)$ for each `altmtl` realization using the Landy-Szalay estimator.
2. **Covariance Estimation:** Use the variance across realizations to define the context-dependent covariance matrix $\mathbf{C}_{ctx}$.
3. **Likelihood Surface:** Compare the likelihood peaks of the baseline vs. the "average" ledger.

5. Systematics Triage

- **Angular Selection:** Check if the shift correlates with the survey footprint boundaries.
- **Redshift Evolution:** Test if $\hat{C}$ grows at lower redshifts (where the "dependency network" is more complex).
- **Shot Noise Calibration:** Use "shuffled" catalogs where fiber positions are randomized (should result in $\hat{C} = 0$).

6. Expected Sensitivity

DESI's volume is sufficient to detect "bookkeeping coupling" at the level of $\lambda \sim 10^{-3}$ in the growth rate of structure $f\sigma_8$.

7. Stop-loss Rules

- If $\Delta\theta$ is within the 1σ scatter of the AbacusSummit mocks, the null hypothesis (ΛCDM) is retained.
- If the shift is only present in ELGs but not LRGs, investigate species-specific selection bias.