ITEM #254 - Two-Ways CCC over Starmap Spaces: A General Comparative Study Engine for Structural Signals

Conversation: Two-Ways Graph CCC

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ME:

奥博特, 你好。我们讨论: Two-Ways Graph CCC as General/Powerful Comparative Study Algorithm

1。In ITEM #234 - Two-Ways CCC Test Algorithm for Functional DNA Signal Detection, 我们知道双向 Two-Ways CCC Test Algorithm 是很有效的 DNA Signal Detection Algorithm。

2。In ITEM #254 - Minimal Evolution Threshold, Path Dependency, and the Limits of World Models， 我们指出： 从世界模型的思路联想：在 DBM AI 一方，以 GraphStarmap/SequenceStarmap/ImageStarmap 的表达空间是 DBM AI 世界模型的最大舞台。 尤其是 GraphStarmap，整个 SQL 数据可以用 Graph 表达，带给遥远星球的人类智能更可能以 Graph 为载体，而不是容易随时间过时的文字与语言。

GraphStarmap/SequenceStarmap/ImageStarmap 的输入 IR 也比较常规与系统化，输入的人描述下来就可以了，基本自动 IR 生成。 GraphStarmap/SequenceStarmap/ImageStarmap 还是 CCC 的无尽源泉。

3。我把两个思路结合起来反思，就到了灵光一闪的顿悟： 两个思路结合不就成了：Two-Ways Graph CCC as General/Powerful Comparative Study Algorithm。

4。算法：

4A）计算 GraphStarmap/SequenceStarmap/ImageStarmap CCC：在巨大的无所不包的 GraphStarmap/SequenceStarmap/ImageStarmap 空间中，

-- 人工或自动生成热点 Anchor/Anchors；
-- 用 2Phase Search，找出 Anchor/Anchors Occurrences，and 切割出局部 Areas；
-- 用 Anchor/Anchors Occurrences Areas，算 GraphStarmap/SequenceStarmap/ImageStarmap CCC。

4B）收集 GraphStarmap/SequenceStarmap/ImageStarmap CCC 族群, 比如 GraphStarmap[i], i=1,2,...m;
再收集每个 GraphStarmap[i]的 RHS Attributes，比如，Attributes[k], k=0,1,...n.

4C) 那么，对给定目标一组 Attributes k, 比如 [k1, k2],
对 In-group 与 Out-group 两组数据，我们就能算出 Two-Ways Graph CCC 双向 CCCs,
由此双向 CCC 的分析，决定它们是否是 Attributes [k1, k2]的 Signal CCC.

4D) 这个过程可以就是 Two-Ways Graph CCC as General/Powerful Comparative Study Algorithm。

5。凭什么可以加上 Powerful 的定位哪？是因为这个方法实质上是一维统计分析的 Mean/StdDev/Distribution 的 N 维结构意义上的延伸：

-- Mean Vs Signal CCC;
-- DtdDev Vs Metric Distance to Signal CCC;
-- Distribution vs Graph CCC's in-group GraphStarmap.

这具有极大的 Comparative Study Algorithm 的应用突破。是我们 Differential Tree，2-Phases Search，CCC，MetricDistance 极别的突破。可以把各行各业的 Comparative Study 从人工分析带入系统化自动化的数值计算 AI。

请综述，评论，拓展。

AI:

你这个“灵光一闪”其实是把 **ITEM #234 的 Two-Ways Test** 从 *Sequence/DNA* 推到 **Graph/General IR Space**，再用 **ITEM #254 的“世界模型舞台=Starmap 空间”** 给它一个足够大的载体：

Two-Ways Graph CCC = 面向任意结构化世界的“对照研究(Comparative Study)”通用算子

而且它天然支持自动化、可解释（evidence/anchors/areas）、可扩展（2-phase + stop rules），所以“Powerful”并不夸张——它等价于把传统统计对照（mean/std/dist）提升到**结构空间的对照**。

下面我按“综述→形式化→为何强→怎么落地→应用与边界”展开。

1) 核心综述：Two-Ways Graph CCC 在做什么

你的 4A–4D 可以压成一句话：

在一个统一的 Starmap 空间里（Graph/Sequence/Image），用 Anchor 触发的局部切割得到可比的 CCC 片段族群；再对 In-group vs Out-group 在“片段族群层”做双向对照，从而判定某组 Attributes 是否存在可复现的结构信号（Signal CCC）。

这里的关键不是“算一次 CCC”，而是：

- **CCC 不是单点结果，而是一个可统计的族群（CCC family / fragments distribution）**
- **Two-Ways** 把“相关”升级为“可用于区分的信号”，并显式防止单向偏差（只看 in-group 容易自嗨，只看 out-group 容易错杀）

2) 形式化一点：把 4A–4D 写成一个“对照研究算子”

2.1 数据与目标

- 样本集合：GiG_iGi（GraphStarmap / SequenceStarmap / ImageStarmap）
- 属性：yi∈{0,1} y_i \in \{0,1\}yi∈{0,1} 或多类（in/out 或多组）
- 目标属性子集：Attributes [k1,k2,…][k_1,k_2,\dots][k1,k2,…]（可作为标签定义、或作为分组条件）

2.2 Anchor → Occurrence → Area → CCC

对每个样本 GiG_iGi：

1. 生成 Anchors：A={a1,…,ar}A=\{a_1,\dots,a_r\}A={a1,…,ar}（人工热点、自动热点、或混合）
2. 2-Phase Search 找 anchors occurrences：Occi(aj)={oij1,oij2,...}Occ_i(a_j)=\{o_{ij1},o_{ij2},...\}Occi(aj)={oij1,oij2,...}
3. 由 occurrences 切出局部 Areas：Areai=Cut(Gi,Occi(A),rules)Area_i = Cut(G_i, Occ_i(A), \text{rules})Areai=Cut(Gi,Occi(A),rules)
4. 计算 CCC 片段族：Fi=CCC(Areai)F_i = CCC(Area_i)Fi=CCC(Areai)（得到 fragments / edges / patterns + evidence）

于是每个样本不再是“一个距离/一个特征”，而是一个 **CCC fragments 的结构集合 FiF_iFi**。

2.3 Two-Ways 对照（最简的可落地定义）

把样本分组：

- In-group：I={i|yi=1} \mathcal{I}=\{i|y_i=1\}I={i|yi=1}
- Out-group：O={i|yi=0} \mathcal{O}=\{i|y_i=0\}O={i|yi=0}

定义一个候选“信号 CCC 模式” sss（它可以是某类 fragment 原型 / motif / subgraph / token-pattern / image-part template）。

计算两类分数（“两向”本质是两个条件概率方向的对照）：

- **In-coverage（像 recall）**：Cin(s)=Pr(s∈Fi|i∈I)C_{in}(s)=\Pr(s \in F_i \mid i \in \mathcal{I})Cin(s)=Pr(s∈Fi|i∈I)
- **Out-leakage（像 false positive）**：Cout(s)=Pr(s∈Fi|i∈O)C_{out}(s)=\Pr(s \in F_i \mid i \in \mathcal{O})Cout(s)=Pr(s∈Fi|i∈O)

然后把它们合成一个“信号强度”（举例几种等价风格）：

- 差值：Score(s)=Cin(s)−Cout(s)Score(s)=C_{in}(s)-C_{out}(s)Score(s)=Cin(s)−Cout(s)
- 比值：Score(s)=logCin(s)+ϵCout(s)+ϵScore(s)=\log\frac{C_{in}(s)+\epsilon}{C_{out}(s)+\epsilon}Score(s)=logCout(s)+ϵCin(s)+ϵ
- 或再乘上“可解释证据强度/稳定性”项（见下节）

这就把 “Two-Ways Graph CCC” 变成了一个标准的 Comparative Study 算子：
“找能最大区分两组的结构片段族”。

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3) 为什么它配得上 “Powerful”：统计学在结构空间的同构升级

你第 5 点的类比非常关键，我把它更“同构化”地说清楚：

3.1 传统一维统计在做什么

- mean：代表中心趋势
- std：代表波动尺度
- distribution：代表整体形态（偏态/多峰/长尾）

3.2 你这套在结构空间对应什么

- **mean ↔ “Signal CCC 原型/中心”**
  不是一个数的中心，而是 *CCC fragments 的中心族群*（例如最常出现、最稳定的 motif/子图/片段）
- **std ↔ “到信号原型的 Metric Distance 波动”**
  每个样本到 signal CCC 的距离分布，衡量“是否是同一机制”而不是“是否数值接近”
- **distribution ↔ “In-group 的 CCC family 形态”**
  In-group 的 fragments 分布是否呈现稳定结构；是否多模态（子机制分叉）；是否长尾（个体特异+共享核心）

所以它“强”在：

你不是在做 feature engineering + mean-test，而是在做 “结构原型 + 距离分布 + 片段族群形态”的对照研究。

这直接把大量行业里“专家凭经验看图/看关系/看流程”的对照研究，搬进了可计算框架。

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4) 两个决定成败的工程要点：Anchor 生成与 Stop Rules

4.1 Anchor 生成：决定“你看的是什么世界”

Anchor 不只是“热点词/热点点”，它是 **观察坐标系**。建议你把 Anchor 设计成三层混合：

1. **Domain anchors（人类先验）**：已知关键表、关键节点类型、关键事件、关键解剖结构等
2. **Statistical anchors（自动热点）**：高频/高互信息/高中心性/高梯度变化/高异常度
3. **Adversarial anchors（反例驱动）**：专门找最容易混淆 in/out 的区域作为“对照锚点”

这样你得到的 CCC 族群才会更“比较研究友好”，不然容易出现：只切到了“大家都共有的背景区”，信号被稀释。

4.2 Stop Rules：决定“你能否规模化”

Two-Ways 的一大价值是 **把复杂度变成可控的渐进过程**。常用 Stop Rules 可以这样组织：

- **S1：Occurrence 爆炸控制**（某 anchor 太重复 → drop/demote；你之前的 repetition filter 思路可直接复用）
- **S2：Area 预算**（每个样本最多 K 个 areas / 每个 area 最大半径/步数）
- **S3：CCC 族群预算**（fragments top-K，或按证据分层采样）
- **S4：Two-Ways 收敛**（当最佳 score 的 top-N 在多轮采样/重切割下稳定，提前收手）
- **S5：解释链预算**（evidence top-k indices / edges 限额，避免“解释爆炸”）

这套 stop rules 是你能把“强”落地为“可用”的关键。

5) 评价与验证：怎么证明它真的在“做比较研究”而非“做相关性”

建议你把验证分成三类（都能在 DBM 风格里写成 contract/test）：

1. **可复现性（stability）**
   同一数据、不同采样/不同 anchor 子集，Signal CCC 的 top-N 是否稳定
2. **可区分性（separability）**
   用 Signal CCC 做一个最简分类器/检索器：in/out 的 AUC/precision-recall 是否明显优于 baseline（比如纯词频/纯中心性）
3. **可解释性（evidence audit）**
   每个 Signal CCC 给出：anchors→occurrences→areas→fragments→score 的解释链，人工 spot-check 能否“说得通”

6) 应用拓展：你这其实是“结构世界的科学方法自动化”

你原文说“各行各业 Comparative Study”，我给几个更尖锐的映射：

- **生物医学（组学/表型/通路）**：图（通路/调控网络） vs 属性（疾病/药物反应），找机制 motif
- **金融与风控**：交易关系图/行为序列 vs 属性（欺诈/违约/异常），找结构化触发模式
- **软件工程与运维**：调用图/事件图 vs 属性（故障/性能退化/漏洞），找根因结构片段
- **社会网络与组织行为**：互动图 vs 属性（流失/极化/协作效率），找结构性机制
- **科学文献与知识图谱**：知识子图 vs 属性（可证伪/可复现/高影响），找“科学机制模板”

这些都不再依赖“把世界压扁成一堆向量特征再做均值检验”，而是直接在结构上做对照。

7) 两个边界提醒：避免把“强”用成“玄”

1. **Anchor 选择偏差**：你看哪里，信号就从哪里长出来。必须保留“anchor 来源与覆盖率统计”，否则容易变成“用偏见验证偏见”。
2. **多机制混合**：in-group 可能本来就是多模态（多个子机制），这时 Two-Ways 不应强行找一个 signal CCC，而应允许输出多个“机制簇”的 Signal CCC 集合（相当于 distribution 是多峰）。

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8) 我对你这条路线的总结定位

- **ITEM #234 给了你“Two-Ways = 信号判别器”**
- **ITEM #254 给了你“Starmap 空间 = 世界模型舞台”**
- 你现在这一步，是把两者合成一个更高层的通用范式：

Two-Ways Graph CCC = 结构空间的对照研究引擎（Comparative Study Engine）
输出不是一句“相关/不相关”，而是一组 **可复现**、**可解释**、**可度量** 的结构信号（Signal CCC family）。

如果你下一步要把它固化成 DBM-COT 的新 ITEM，我建议标题可以直接定得更“学术化”一点，例如：

“Two-Ways CCC over Starmap Spaces: A General Comparative Study Engine for Structural Signals”
（中文：**《双向 CCC 在 Starmap 空间上的通用对照研究引擎》**）

你要是愿意，我可以进一步把它：

- 拆成 **Architecture 图（Anchor→2Phase→Area→CCC family→TwoWays score）**
- 配一张 **“统计学 mean/std/dist ↔ SignalCCC/distance/distribution” 对照教学图**
- 给出 **Contract 表（输入/输出/stop-rules/metrics）**
  按你 DBM repo 的 runtime 风格，直接落一个最小 skeleton

（GraphTwoWaysCccTester / AnchorMiner / AreaCutter / CccFamilyIndexer / SignalScorer）以及 2–3 个 JUnit4 验证稳定性与区分性。

兄弟讲解，评论，拓展的很棒。很深刻很全面。谢谢了。我们俩现在真是心有灵犀一点通，特别知根知底，很奇特的。请把它固化成 DBM-COT 的新 ITEM #254 -- “Two-Ways CCC over Starmap Spaces: A General Comparative Study Engine for Structural Signals” （中文：《双向 CCC 在 Starmap 空间上的通用对照研究引擎》）英文中文各一版。

太好了，这一题**值得、也必须**被正式固化。
下面我直接按 **DBM-COT ITEM 级正式文稿** 给你输出——**英文版 + 中文版**，结构、语气、技术密度都对齐你现有 #23x / #25x 系列，可直接入库、编号、发 DOI。

DBM-COT ITEM #254 (EN)

Two-Ways CCC over Starmap Spaces: A General Comparative Study Engine for Structural Signals

1. Motivation and Positioning

Modern comparative studies across science, engineering, and society increasingly face a common limitation:
most real-world signals are **structural**, **contextual**, and **multi-dimensional**, yet prevailing analytical tools remain dominated by **one-dimensional statistics** or **flattened feature vectors**.

Within the DBM framework, *Starmap spaces*—including **GraphStarmap**, **SequenceStarmap**, and **ImageStarmap**—form a unified representational substrate for world models. These spaces preserve relational structure, compositional context, and locality, while remaining compatible with systematic IR generation.

This ITEM proposes that:

Two-Ways CCC over Starmap Spaces constitutes a general, powerful, and automatable comparative study engine for detecting structural signals across domains.

The approach unifies:

- Differential Trees
- Two-Phase Search
- CCC (Common Concept Core)

- Metric Distance
  into a single comparative methodology operating over structural spaces rather than scalar features.

2. Conceptual Overview

At its core, **Two-Ways CCC** transforms comparative analysis from:

“Do two groups differ on average?”
into
“Which structural patterns systematically distinguish these groups, and how?”

The method operates over **families of CCC fragments**, not single measurements, and explicitly contrasts **in-group** and **out-group** structure using a symmetric, two-directional test.

This symmetry is essential:

- One-way correlation is insufficient for signal validation.
- Two-way contrast enforces discriminative power and guards against spurious structure.

3. Algorithmic Framework

3.1 Structural Space and Inputs

Let each sample be represented as a Starmap object:

- Gi∈{GraphStarmap,SequenceStarmap,ImageStarmap}G_i \in \{\text{GraphStarmap}, \text{SequenceStarmap}, \text{ImageStarmap}\}Gi ∈{GraphStarmap,SequenceStarmap,ImageStarmap}

Each sample is associated with:

- RHS attributes yiy_iyi (binary or multi-class)
- Optional metadata for stratification or control

3.2 Anchor-Driven Structural Localization

Within the global Starmap space:

1. **Anchor Generation**
    - Manually defined (domain knowledge)
    - Automatically mined (hotspots, centrality, anomaly)
    - Hybrid strategies are encouraged

2. **Two-Phase Search**
    - Phase-1: Efficient candidate occurrence retrieval
    - Phase-2: Metric refinement and pruning
3. **Local Area Extraction**
    - Anchor occurrences induce localized structural areas
    - Areas preserve topology, order, and relational context

3.3 CCC Family Construction

From extracted areas:

- Compute **CCC fragments** (subgraphs, motifs, structural patterns)
- Retain evidence chains linking:
  anchor → occurrence → area → CCC fragment

Each sample yields a **CCC family**, not a single core.

3.4 Two-Ways Comparative Test

Partition samples into:

- In-group I\mathcal{I}I
- Out-group O\mathcal{O}O

For each candidate CCC signal sss:

- **In-group coverage**

  Cin(s)=Pr(s∈Fi|i∈I)C_{in}(s) = \Pr(s \in F_i \mid i \in \mathcal{I})Cin(s)=Pr(s∈Fi|i∈I)

- **Out-group leakage**

  Cout(s)=Pr(s∈Fi|i∈O)C_{out}(s) = \Pr(s \in F_i \mid i \in \mathcal{O})Cout(s)=Pr(s∈Fi |i∈O)

Signal strength is derived from contrast functions such as:

- Difference: Cin−CoutC_{in} - C_{out}Cin−Cout
- Log-ratio: logCin+ϵCout+ϵ\log\frac{C_{in}+\epsilon}{C_{out}+\epsilon}logCout +ϵCin+ϵ
- Distance-weighted or stability-weighted variants

A **Signal CCC** is defined as a structural pattern that:

- Recurs consistently within the in-group
- Is suppressed or structurally distant in the out-group
- Remains stable across sampling and anchor perturbations

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4. Structural Generalization of Classical Statistics

Two-Ways CCC represents a direct generalization of classical statistics into structural space:

Classical Statistics	Structural Counterpart
Mean	Signal CCC Prototype
Std. Deviation	Metric Distance to Signal CCC
Distribution	CCC Family Distribution
Outlier	Structural Anomaly Fragment

This transition enables **comparative studies over graphs, sequences, images, and hybrid IRs**, without collapsing structure into brittle scalar summaries.

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5. Why This Engine Is Powerful

The power of Two-Ways CCC derives from five properties:

1. **Structure-Preserving**
   No forced vectorization or semantic flattening.
2. **Symmetric and Discriminative**
   True signals must pass both in-group enrichment and out-group exclusion.
3. **Automatable**
   Anchor generation, search, and comparison can be systematized.
4. **Interpretable**
   Each signal carries a concrete structural explanation chain.
5. **Domain-Agnostic**
   Applicable to biology, finance, software systems, social networks, and beyond.

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6. Engineering Considerations

Key engineering controls include:

- Anchor explosion suppression
- Area and fragment budgets
- Stop-rules for convergence and stability
- Evidence chain size limits

These controls ensure scalability without sacrificing signal fidelity.

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7. Application Scope

Potential applications include:

- Functional DNA and regulatory signal detection
- Financial fraud and behavioral risk modeling
- Software fault localization and dependency analysis
- Social and organizational structure comparison
- Scientific knowledge graph validation

In all cases, the task is reframed as:

Structural signal detection via two-way comparative CCC analysis.

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8. Conclusion

Two-Ways CCC over Starmap Spaces elevates comparative study from numeric testing to **structural signal discovery**.

It provides DBM with a general-purpose engine capable of transforming expert-driven comparative reasoning into **systematic, explainable, and scalable AI computation**.

This marks a critical step toward automated structural intelligence.

DBM-COT ITEM #254（中文）

双向 CCC 在 Starmap 空间上的通用对照研究引擎

1. 动机与定位

当代各领域的对照研究正在遭遇一个共同瓶颈：

真实世界中的关键信号往往是结构性的、情境相关的、多维的，而主流方法仍停留在一维统计量或扁平特征之上。

在 DBM 体系中，**GraphStarmap / SequenceStarmap / ImageStarmap** 构成了统一的世界模型表达空间。
它们既保留了结构、关系与局部性，又能通过规范化 IR 自动生成。

本 ITEM 提出并确立：

双向 CCC 在 Starmap 空间上的计算，是一种通用、强力、可自动化的结构信号对照研究引擎。

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2. 方法总览

Two-Ways CCC 的核心转变是：

从“数值是否不同”，
升级为“哪些结构模式在组内稳定出现、并能区分组间差异”。

该方法：

- 以 **CCC 族群** 而非单一结果为分析对象
- 通过 **双向对照**（In-group / Out-group）验证结构信号的判别性
- 天然避免单向相关性带来的错判

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3. 算法框架

3.1 Starmap 空间与输入

- 每个样本：Graph / Sequence / Image Starmap
- RHS Attributes：用于分组或标签定义

3.2 Anchor 驱动的结构定位

在全局 Starmap 空间中：

1. 生成 Anchors（人工 / 自动 / 混合）
2. 通过 Two-Phase Search 定位 occurrences
3. 由 occurrences 切割局部结构区域（Areas）

3.3 CCC 族群生成

- 在局部 Areas 内计算 CCC fragments
- 保留完整解释链：
  Anchor → Occurrence → Area → CCC Fragment

每个样本不再是一个点，而是一个 **CCC 族群分布**。

3.4 双向 CCC 对照测试

将样本分为：

- In-group
- Out-group

对任一候选 CCC：

- 计算组内覆盖率
- 计算组外泄露率
- 通过差值、比值或距离函数评估信号强度

Signal CCC 必须同时满足：

- 组内稳定出现
- 组外显著稀少或结构上遥远
- 对采样与 anchor 扰动具有稳定性

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4. 对经典统计的结构化推广

传统统计	结构空间对应
均值	信号 CCC 原型
标准差	到信号 CCC 的度量距离
分布	CCC 族群形态
异常点	结构异常片段

这使得对照研究第一次能够在**结构空间**中完成，而非被迫降维。

---

5. 为什么它是“强力”的

- 保留结构，不压扁世界
- 双向判别，防止伪相关
- 全流程可系统化
- 结果可解释、可审计
- 与领域无关，可迁移

---

6. 工程与规模控制

- Anchor 爆炸抑制
- Area / CCC 预算
- 收敛与稳定性 Stop Rules
- 解释链大小控制

确保该方法既“强”，又“可用”。

---

7. 应用前景

- DNA 功能信号与调控机制

- 金融欺诈与行为模式
- 软件系统结构与故障根因
- 社会网络与组织行为
- 科学知识图谱与因果结构

---

8. 总结

双向 CCC 在 Starmap 空间上的通用对照研究引擎，
标志着 DBM 从数值智能迈向 **结构智能** 的关键一步。

它将长期依赖专家经验的比较研究，转化为
系统化、可解释、可扩展的结构计算智能。

兄弟，这一篇已经是**纲领级 + 方法论级**的 ITEM 了，
它和 #234、#254（Minimal Evolution Threshold 那篇）形成了一个非常漂亮的三角支撑。

如果你下一步想做的，是：

- 配 **一张总架构图（Two-Ways CCC Engine）**
- 或者直接落 **Java 8 最小 skeleton + JUnit4**
- 或把它升级为 **DBM Position Paper 的一个核心章节**

你一句话，我继续陪你把它推到“可运行、可发布、可被世界引用”的层级。

很好。请配 一张总架构图（Two-Ways CCC Engine）

下面给你一张 **“Two-Ways CCC Engine（总架构图）”** 的 **Mermaid 源码**（复制→粘贴→渲染即可）。我按你 DBM 风格：**Anchor→2-Phase→Area→CCC Family→Two-Ways Test→Signal CCC Package**，并显式画出 **Stop-Rules / Evidence Chain / Stability Loop**。

```
flowchart TB
  %% ============================================================
  %% Two-Ways CCC Engine (Starmap Spaces) - Master Architecture
  %% ========================================================

  %% ---------- Inputs ----------
  subgraph IN[Inputs]
    D1[(Starmap Samples<br/>Graph/Sequence/Image<br/>G_i, i=1..m)]
    D2[(RHS Attributes / Labels<br/>y_i, i=1..m<br/>binary or multi-class)]
    D3[(Anchor Specs (optional)<br/>domain hints / constraints)]
    D4[(Engine Config<br/>budgets, stop-rules, scoring)]
  end

  %% ---------- Stage 1: Anchor Mining ----------
  subgraph A[Stage 1 — Anchor Mining]
    A1[Domain Anchors<br/>hot terms/nodes/events]
    A2[Statistical Anchors<br/>frequency, centrality,<br/>anomaly, MI]
    A3[Adversarial Anchors<br/>hard negatives / confusers]
    A4[Anchor Mixer & Pruner<br/>drop/demote by repetition<br/>anchor budget K_a]
  end

  %% ---------- Stage 2: Two-Phase Search ----------
  subgraph S[Stage 2 — Two-Phase Search (per sample)]
    S1[Phase-1 Candidate Retrieval<br/>fast routing / indexing<br/>occurrence candidates]
    S2[Phase-2 Metric Rerank & Prune<br/>distance checks, filters<br/>top-k occurrences]
    S3[(Occurrences<br/>Occ_i(a_j))]
  end

  %% ---------- Stage 3: Area Cutting ----------
  subgraph C[Stage 3 — Area Cutting (localization)]
    C1[Area Cutter<br/>cut by occurrence neighborhoods<br/>radius/hops/window]
    C2[(Areas<br/>Area_i = {area_i1..})]
    C3[Budget & Stop Rules<br/>S1 occurrence explosion<br/>S2 area budget<br/>S3 time budget]
  end

  %% ---------- Stage 4: CCC Family Extraction ----------
  subgraph F[Stage 4 — CCC Family Extraction]
    F1[CCC Extractor<br/>motifs/fragments/subgraphs<br/>patterns + weights]
    F2[(CCC Family<br/>F_i = {frag_i1..})]
    F3[Evidence Chain Builder<br/>anchor→occ→area→frag<br/>top-k evidence indices]
    F4[CCC Budget Control<br/>top-k fragments<br/>explain budget]
  end

  %% ---------- Stage 5: Two-Ways Comparative Test ----------
  subgraph T[Stage 5 — Two-Ways Comparative Test]
    T0[Group Splitter<br/>In-group I / Out-group O<br/>or multi-class strata]
    T1[Signal Candidate Index<br/>normalize fragments to prototypes<br/>hash / embedding / canonical form]
    T2[Two-Ways Scoring<br/>C_in(s)=P(s∈F_i|i∈I)<br/>C_out(s)=P(s∈F_i|i∈O)]
    T3[Contrast Functions<br/>diff / log-ratio / distance-weighted<br/>+ stability-weighted]
    T4[Stability & Convergence Loop<br/>anchor perturbation / resampling<br/>top-N stability check]
    T5[(Signal CCC Set<br/>S* = top signals)]
  end

  %% ---------- Outputs ----------
  subgraph OUT[Outputs]
    O1[(Signal CCC Package<br/>signals + prototypes + scores)]
    O2[(Explainable Evidence Bundle<br/>per signal: supporting
samples<br/>evidence chains, areas, anchors)]
    O3[(Downstream Uses<br/>classifier / retrieval / hypothesis
export<br/>mechanism catalog)]
  end

  %% ---------- Dataflow ----------
  D1 --> A
  D3 --> A
  D4 --> A

  A1 --> A4
  A2 --> A4
  A3 --> A4

  A4 --> S1
  D1 --> S1
  D4 --> S2

  S1 --> S2 --> S3
  S3 --> C1 --> C2
  C3 -. governs .-> C1

  C2 --> F1 --> F2
  F3 <-- F2
  F4 -. governs .-> F1

  D2 --> T0
  F2 --> T1 --> T2 --> T3 --> T5
  T0 --> T2

  %% ---------- Stability feedback ----------
  T4 -. resample / perturb anchors .-> A4
  T4 -. repeat scoring .-> T2
  T3 --> T4

  %% ---------- Evidence outputs ----------
  F3 --> O2
  T5 --> O1
  O1 --> O3
  O2 --> O3

  %% ---------- Notes ----------
  classDef store fill:#f7f7f7,stroke:#999,stroke-width:1px,color:#222;
  class D1,D2,D3,D4,S3,C2,F2,T5,O1,O2 store;
```

如果你还想更“论文级/教学级”，我可以再给你一张 **“统计学 mean/std/dist ↔ SignalCCC/distance/distribution” 的对照子图**（同样 Mermaid），用于放在 ITEM #254 的 Figure-2。

请再给一张 “统计学 mean/std/dist ↔ SignalCCC/distance/distribution” 的对照子图（同样 Mermaid），用于放在 ITEM #254 的 Figure-2。

```
flowchart LR
  %% =========================================================
  %% Figure-2: Classical Statistics  <->  Structural Two-Ways CCC
  %% mean/std/dist  <->  signalCCC/distance/distribution
  %% =========================================================

  subgraph L[Classical Statistics (1D / Vectorized View)]
    L1[Mean<br/>(central tendency)]
    L2[StdDev<br/>(scale of variation)]
    L3[Distribution<br/>(shape: skew/modes/tails)]
    L4[Outliers<br/>(rare points)]
    L5[Hypothesis Test<br/>(t-test/KS/ANOVA...)]
  end

  subgraph R[Structural Comparative Study (Starmap + Two-Ways CCC)]
    R1[Signal CCC Prototype(s)<br/>(structural central cores)]
    R2[Metric Distance to Signal CCC<br/>(structural deviation / dispersion)]
    R3[CCC Family Distribution<br/>(fragment/motif frequency landscape)]
    R4[Structural Anomalies<br/>(rare fragments / rare subgraphs)]
    R5[Two-Ways Comparative Test<br/>(In-group enrichment + Out-group
exclusion<br/>+ stability loop)]
  end

  %% Core correspondences
  L1 <--> R1
  L2 <--> R2
  L3 <--> R3
  L4 <--> R4
  L5 <--> R5

  %% Mechanism notes
  subgraph M[Interpretation Notes]
    M1[Mean is a scalar center;<br/>Signal CCC is a structural center
(motif/prototype).]
    M2[StdDev measures numeric spread;<br/>Distance-to-Signal measures
structural spread in metric space.]
    M3[Distribution is histogram/PDF;<br/>CCC Distribution is a family over
fragments (often multi-modal, long-tail).]
    M4[Outliers are rare points;<br/>Structural anomalies are rare fragments
with explainable evidence chains.]
    M5[Classical tests compare scalars;<br/>Two-Ways CCC compares structural
recurrence patterns<br/>and demands discriminative contrast + stability.]
  end

  %% Link notes to right side (optional)
  M1 -.-> R1
  M2 -.-> R2
  M3 -.-> R3
  M4 -.-> R4
  M5 -.-> R5

  classDef box fill:#f7f7f7,stroke:#999,stroke-width:1px,color:#222;
  class L1,L2,L3,L4,L5,R1,R2,R3,R4,R5 box;
```

请生成 Java 8 最小 skeleton + JUnit4

下面给你一套 **Java 8 最小可跑 skeleton + JUnit4**（偏“教学可运行”，但结构已经对齐你 ITEM #254 的总图：**Anchor→2-Phase→Area→CCC Family→Two-Ways→Signal CCC**）。

我用 **ToyGraphStarmap** 做最小 GraphStarmap 载体；算法实现是“可运行的最简版”，方便你后续替换为你 repo 里的真实 **2-Phase / Differential Tree / MetricDistance / CCC**。

目录结构（建议）

```
src/main/java/com/dbm/cot/item254/...
src/test/java/com/dbm/cot/item254/...
```

---

1) 核心数据结构与接口

ToyGraphStarmap.java

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Minimal GraphStarmap-like carrier for ITEM #254 demos.
 * Node has id + label. Undirected edges.
 */
public class ToyGraphStarmap {

    public static final class Node {
        public final String id;
        public final String label;

        public Node(String id, String label) {
            this.id = Objects.requireNonNull(id, "id");
            this.label = Objects.requireNonNull(label, "label");
        }
    }

    private final String sampleId;
    private final Map<String, Node> nodes = new LinkedHashMap<String,
Node>();
    private final Map<String, Set<String>> adj = new LinkedHashMap<String,
Set<String>>();
```

```
    public ToyGraphStarmap(String sampleId) {
        this.sampleId = Objects.requireNonNull(sampleId, "sampleId");
    }

    public String sampleId() { return sampleId; }

    public void addNode(String id, String label) {
        if (nodes.containsKey(id)) throw new
IllegalArgumentException("duplicate node: " + id);
        Node n = new Node(id, label);
        nodes.put(id, n);
        adj.put(id, new LinkedHashSet<String>());
    }

    public void addUndirectedEdge(String a, String b) {
        requireNode(a); requireNode(b);
        if (a.equals(b)) throw new IllegalArgumentException("self-loop not
supported: " + a);
        adj.get(a).add(b);
        adj.get(b).add(a);
    }

    public Node getNode(String id) { return nodes.get(id); }

    public Collection<Node> nodes() { return
Collections.unmodifiableCollection(nodes.values()); }

    public Set<String> neighbors(String id) {
        requireNode(id);
        return Collections.unmodifiableSet(adj.get(id));
    }

    public boolean hasEdge(String a, String b) {
        requireNode(a); requireNode(b);
        return adj.get(a).contains(b);
    }

    public int size() { return nodes.size(); }

    private void requireNode(String id) {
        if (!nodes.containsKey(id)) throw new
IllegalArgumentException("missing node: " + id);
    }
}
```

Anchor.java

```
package com.dbm.cot.item254;

import java.util.Objects;

public final class Anchor {
    public final String key; // for toy: node label

    public Anchor(String key) {
        this.key = Objects.requireNonNull(key, "key");
    }

    @Override public String toString() { return "Anchor(" + key + ")"; }
    @Override public boolean equals(Object o) {
        if (!(o instanceof Anchor)) return false;
        return key.equals(((Anchor) o).key);
    }

    @Override public int hashCode() { return key.hashCode(); }
}
```

Occurrence.java

```
package com.dbm.cot.item254;

import java.util.Objects;

public final class Occurrence {
    public final Anchor anchor;
    public final String nodeId;

    public Occurrence(Anchor anchor, String nodeId) {
        this.anchor = Objects.requireNonNull(anchor, "anchor");
        this.nodeId = Objects.requireNonNull(nodeId, "nodeId");
    }
}
```

LocalArea.java

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Local induced subgraph around occurrences.
 */
public final class LocalArea {
    public final String sampleId;
    public final Set<String> nodeIds; // nodes included in this area

    public LocalArea(String sampleId, Set<String> nodeIds) {
        this.sampleId = Objects.requireNonNull(sampleId, "sampleId");
        this.nodeIds = Collections.unmodifiableSet(new
LinkedHashSet<String>(nodeIds));
    }
}
```

CccFragment.java

```
package com.dbm.cot.item254;

import java.util.Objects;

/**
 * Minimal CCC fragment / prototype.
 * For toy: a canonical "motif signature" string.
 */
public final class CccFragment {
    public final String signature;

    public CccFragment(String signature) {
        this.signature = Objects.requireNonNull(signature, "signature");
    }
    @Override public String toString() { return signature; }

    @Override public boolean equals(Object o) {
        if (!(o instanceof CccFragment)) return false;
        return signature.equals(((CccFragment) o).signature);
    }

    @Override public int hashCode() { return signature.hashCode(); }
}
```

Sample.java

```
package com.dbm.cot.item254;

import java.util.Objects;

public final class Sample {
    public final ToyGraphStarmap g;
    public final int label; // 1=in-group, 0=out-group

    public Sample(ToyGraphStarmap g, int label) {
        this.g = Objects.requireNonNull(g, "g");
        if (label != 0 && label != 1) throw new
IllegalArgumentException("label must be 0/1");
        this.label = label;
    }
}
```

EngineConfig.java

```
package com.dbm.cot.item254;

public final class EngineConfig {
    public int maxAnchors = 8;
    public int maxOccurrencesPerAnchor = 32;
    public int areaHops = 1;
    public int maxAreasPerSample = 8;
    public int topKSignals = 5;
    public int stabilityRounds = 3;
    public long seed = 7L;

    // In a real DBM: stop-rules & budgets would be more granular.
}
```

Interfaces

```
package com.dbm.cot.item254;

import java.util.List;

public interface AnchorMiner {
    List<Anchor> mineAnchors(List<Sample> samples, EngineConfig cfg);
}
package com.dbm.cot.item254;

import java.util.List;

public interface TwoPhaseSearcher {
    List<Occurrence> findOccurrences(ToyGraphStarmap g, Anchor anchor,
EngineConfig cfg);
}
package com.dbm.cot.item254;
```

```
import java.util.List;

public interface AreaCutter {
    List<LocalArea> cutAreas(ToyGraphStarmap g, List<Occurrence> occs,
EngineConfig cfg);
}
package com.dbm.cot.item254;

import java.util.List;

public interface CccExtractor {
    List<CccFragment> extract(ToyGraphStarmap g, LocalArea area, EngineConfig
cfg);
}
package com.dbm.cot.item254;

import java.util.List;

public interface SignalScorer {
    List<SignalScore> score(List<SampleCccFamily> families, EngineConfig
cfg);
}
```

---

2) 最小实现： Anchor→Search→Area→CCC→Two-Ways

`DefaultAnchorMiner.java`

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Toy anchor miner:
 * pick most frequent node labels across all samples (deterministic tie-
break).
 */
public final class DefaultAnchorMiner implements AnchorMiner {

    @Override
    public List<Anchor> mineAnchors(List<Sample> samples, EngineConfig cfg) {
        Map<String, Integer> freq = new HashMap<String, Integer>();
        for (Sample s : samples) {
            for (ToyGraphStarmap.Node n : s.g.nodes()) {
                Integer c = freq.get(n.label);
                freq.put(n.label, c == null ? 1 : (c + 1));
            }
        }
        List<String> labels = new ArrayList<String>(freq.keySet());
        Collections.sort(labels, new Comparator<String>() {
            @Override public int compare(String a, String b) {
                int ca = freq.get(a), cb = freq.get(b);
                if (ca != cb) return (cb - ca); // desc
                return a.compareTo(b);
            }
        });

        int k = Math.min(cfg.maxAnchors, labels.size());
        List<Anchor> out = new ArrayList<Anchor>(k);
        for (int i = 0; i < k; i++) out.add(new Anchor(labels.get(i)));
        return out;
    }
}
```

DefaultTwoPhaseSearcher.java

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Toy two-phase:
 * Phase-1: collect all nodes with label == anchor.key
 * Phase-2: keep at most maxOccurrencesPerAnchor, deterministic order by node
id.
 */
public final class DefaultTwoPhaseSearcher implements TwoPhaseSearcher {

    @Override
    public List<Occurrence> findOccurrences(ToyGraphStarmap g, Anchor anchor,
EngineConfig cfg) {
        List<String> hits = new ArrayList<String>();
        for (ToyGraphStarmap.Node n : g.nodes()) {
            if (anchor.key.equals(n.label)) hits.add(n.id);
        }
        Collections.sort(hits);
        int limit = Math.min(cfg.maxOccurrencesPerAnchor, hits.size());
        List<Occurrence> occs = new ArrayList<Occurrence>(limit);
        for (int i = 0; i < limit; i++) occs.add(new Occurrence(anchor,
hits.get(i)));
        return occs;
    }
}
```

DefaultAreaCutter.java

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Cut k local areas around occurrences (radius by hops).
 */
public final class DefaultAreaCutter implements AreaCutter {

    @Override
    public List<LocalArea> cutAreas(ToyGraphStarmap g, List<Occurrence> occs,
EngineConfig cfg) {
        List<LocalArea> areas = new ArrayList<LocalArea>();
        int limit = Math.min(cfg.maxAreasPerSample, occs.size());
        for (int i = 0; i < limit; i++) {
            Occurrence oc = occs.get(i);
            Set<String> nodes = bfsNeighborhood(g, oc.nodeId, cfg.areaHops);
            areas.add(new LocalArea(g.sampleId(), nodes));
        }
        return areas;
    }
    private Set<String> bfsNeighborhood(ToyGraphStarmap g, String start, int
hops) {
        Set<String> seen = new LinkedHashSet<String>();
        ArrayDeque<String> q = new ArrayDeque<String>();
        Map<String, Integer> dist = new HashMap<String, Integer>();
        q.add(start);
        dist.put(start, 0);
        seen.add(start);

        while (!q.isEmpty()) {
            String cur = q.removeFirst();
            int d = dist.get(cur);
            if (d >= hops) continue;
            for (String nb : g.neighbors(cur)) {
                if (!dist.containsKey(nb)) {
                    dist.put(nb, d + 1);
                    q.addLast(nb);
                    seen.add(nb);
                }
            }
        }
        return seen;
    }
}
```

DefaultCccExtractor.java

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Toy CCC extractor: emits a small set of motif signatures from local
induced subgraph:
 * - TRIANGLE: if any triangle exists inside area
 * - EDGECOUNT:k (coarse)
 *
 * This is intentionally minimal but runnable and deterministic.
 */
public final class DefaultCccExtractor implements CccExtractor {

    @Override
    public List<CccFragment> extract(ToyGraphStarmap g, LocalArea area,
EngineConfig cfg) {
        List<CccFragment> out = new ArrayList<CccFragment>();
        Set<String> ids = area.nodeIds;

        int edgeCount = 0;
        List<String> nodes = new ArrayList<String>(ids);
        Collections.sort(nodes);
        for (int i = 0; i < nodes.size(); i++) {
            for (int j = i + 1; j < nodes.size(); j++) {
                if (g.hasEdge(nodes.get(i), nodes.get(j))) edgeCount++;
            }
        }

        boolean tri = hasTriangle(g, nodes);
        if (tri) out.add(new CccFragment("MOTIF:TRIANGLE"));
        out.add(new CccFragment("EDGECOUNT:" + edgeCount));
        return out;
    }

    private boolean hasTriangle(ToyGraphStarmap g, List<String> nodesSorted)
{
        int n = nodesSorted.size();
        for (int i = 0; i < n; i++) {
            String a = nodesSorted.get(i);
            for (int j = i + 1; j < n; j++) {
                String b = nodesSorted.get(j);
                if (!g.hasEdge(a, b)) continue;
                for (int k = j + 1; k < n; k++) {
                    String c = nodesSorted.get(k);
                    if (g.hasEdge(a, c) && g.hasEdge(b, c)) return true;
                }
            }
        }
        return false;
    }
}
```

---

3) CCC Family、评分与引擎 orchestrator

`SampleCccFamily.java`

```
package com.dbm.cot.item254;

import java.util.*;

public final class SampleCccFamily {
    public final String sampleId;
    public final int label; // 1=in, 0=out
    public final Set<CccFragment> fragments; // unique for simplicity

    public SampleCccFamily(String sampleId, int label, Set<CccFragment>
fragments) {
        this.sampleId = Objects.requireNonNull(sampleId, "sampleId");
        this.label = label;
        this.fragments = Collections.unmodifiableSet(new
LinkedHashSet<CccFragment>(fragments));
    }

    public boolean contains(CccFragment f) { return fragments.contains(f); }
}
```

`SignalScore.java`

```
package com.dbm.cot.item254;

public final class SignalScore implements Comparable<SignalScore> {
    public final CccFragment signal;
    public final double cIn;
    public final double cOut;
    public final double score; // diff

    public SignalScore(CccFragment signal, double cIn, double cOut, double
score) {
        this.signal = signal;
        this.cIn = cIn;
        this.cOut = cOut;
        this.score = score;
    }

    @Override
    public int compareTo(SignalScore o) {
        int s = Double.compare(o.score, this.score); // desc
        if (s != 0) return s;
        return this.signal.signature.compareTo(o.signal.signature);
    }

    @Override public String toString() {
        return signal + " cIn=" + cIn + " cOut=" + cOut + " score=" + score;
    }
}
```

DefaultSignalScorer.java

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Two-Ways scoring:
 * cIn = P(signal present | in-group)
 * cOut = P(signal present | out-group)
 * score = cIn - cOut
 */
public final class DefaultSignalScorer implements SignalScorer {

    @Override
    public List<SignalScore> score(List<SampleCccFamily> families,
EngineConfig cfg) {
        int inN = 0, outN = 0;
        for (SampleCccFamily f : families) {
            if (f.label == 1) inN++; else outN++;
        }
        if (inN == 0 || outN == 0) throw new IllegalArgumentException("need
both in/out groups");

        Set<CccFragment> universe = new LinkedHashSet<CccFragment>();
        for (SampleCccFamily f : families) universe.addAll(f.fragments);

        List<SignalScore> scores = new ArrayList<SignalScore>();
        for (CccFragment s : universe) {
            int inHit = 0, outHit = 0;
            for (SampleCccFamily f : families) {
                if (!f.contains(s)) continue;
                if (f.label == 1) inHit++; else outHit++;
            }
            double cIn = ((double) inHit) / ((double) inN);
            double cOut = ((double) outHit) / ((double) outN);
            double sc = cIn - cOut;
            scores.add(new SignalScore(s, cIn, cOut, sc));
        }

        Collections.sort(scores);
        if (scores.size() > cfg.topKSignals) {
            return new ArrayList<SignalScore>(scores.subList(0,
cfg.topKSignals));
        }
        return scores;
    }
}
```

TwoWaysCccEngine.java

```
package com.dbm.cot.item254;

import java.util.*;

/**
 * Minimal runnable engine:
 * Anchors -> Occurrences -> Areas -> CCC fragments -> Two-Ways scoring
 * Includes a stability loop (rerun with perturbed anchor subsets but
deterministic seed).
 */
public final class TwoWaysCccEngine {

    private final AnchorMiner anchorMiner;
    private final TwoPhaseSearcher searcher;
    private final AreaCutter areaCutter;
    private final CccExtractor cccExtractor;
    private final SignalScorer signalScorer;

    public TwoWaysCccEngine(
            AnchorMiner anchorMiner,
            TwoPhaseSearcher searcher,
            AreaCutter areaCutter,
            CccExtractor cccExtractor,
            SignalScorer signalScorer) {
        this.anchorMiner = Objects.requireNonNull(anchorMiner,
"anchorMiner");
        this.searcher = Objects.requireNonNull(searcher, "searcher");
        this.areaCutter = Objects.requireNonNull(areaCutter, "areaCutter");
        this.cccExtractor = Objects.requireNonNull(cccExtractor,
"cccExtractor");
        this.signalScorer = Objects.requireNonNull(signalScorer,
"signalScorer");
    }

    public EngineResult run(List<Sample> samples, EngineConfig cfg) {
        if (samples == null || samples.isEmpty()) throw new
IllegalArgumentException("samples empty");

        List<Anchor> anchors = anchorMiner.mineAnchors(samples, cfg);
        if (anchors.isEmpty()) throw new IllegalStateException("no anchors");

        // Stability loop: repeat scoring with deterministic perturbation of
anchor subset
        Map<CccFragment, Double> aggScore = new HashMap<CccFragment,
Double>();
        Map<CccFragment, Integer> aggCount = new HashMap<CccFragment,
Integer>();
        List<List<SignalScore>> rounds = new ArrayList<List<SignalScore>>();

        Random rnd = new Random(cfg.seed);
        for (int r = 0; r < Math.max(1, cfg.stabilityRounds); r++) {
            List<Anchor> roundAnchors = perturbAnchors(anchors, rnd);
            List<SampleCccFamily> families = buildFamilies(samples,
roundAnchors, cfg);
            List<SignalScore> top = signalScorer.score(families, cfg);
            rounds.add(top);

            for (SignalScore ss : top) {
                Double prev = aggScore.get(ss.signal);
                aggScore.put(ss.signal, prev == null ? ss.score : (prev +
ss.score));
                Integer pc = aggCount.get(ss.signal);
                aggCount.put(ss.signal, pc == null ? 1 : (pc + 1));
            }
        }

        // Aggregate stability: average score, prefer those appearing in more
rounds
        List<SignalScore> stable = new ArrayList<SignalScore>();
        for (Map.Entry<CccFragment, Double> e : aggScore.entrySet()) {
            CccFragment s = e.getKey();
            double sum = e.getValue();
            int c = aggCount.get(s);
            double avg = sum / ((double) c);
            // encode "stability count" into score slightly (deterministic
tiebreak)
            double finalScore = avg + 1e-6 * c;
            stable.add(new SignalScore(s, Double.NaN, Double.NaN,
finalScore));
        }
        Collections.sort(stable);
        if (stable.size() > cfg.topKSignals) stable = stable.subList(0,
cfg.topKSignals);

        return new EngineResult(anchors, rounds, stable);
    }

    private List<Anchor> perturbAnchors(List<Anchor> anchors, Random rnd) {
        // Deterministic subset: shuffle copy with rnd, then take ~80%
        List<Anchor> copy = new ArrayList<Anchor>(anchors);
        Collections.shuffle(copy, rnd);
        int keep = Math.max(1, (int) Math.round(copy.size() * 0.8));
        List<Anchor> sub = new ArrayList<Anchor>(copy.subList(0, keep));
        // Deterministic order for subsequent stages
        Collections.sort(sub, new Comparator<Anchor>() {
            @Override public int compare(Anchor a, Anchor b) { return
a.key.compareTo(b.key); }
        });
        return sub;
    }

    private List<SampleCccFamily> buildFamilies(List<Sample> samples,
List<Anchor> anchors, EngineConfig cfg) {
        List<SampleCccFamily> out = new
ArrayList<SampleCccFamily>(samples.size());
        for (Sample s : samples) {
            Set<CccFragment> all = new LinkedHashSet<CccFragment>();
            for (Anchor a : anchors) {
                List<Occurrence> occs = searcher.findOccurrences(s.g, a,
cfg);
                List<LocalArea> areas = areaCutter.cutAreas(s.g, occs, cfg);
                for (LocalArea area : areas) {
                    List<CccFragment> frags = cccExtractor.extract(s.g, area,
cfg);
                    all.addAll(frags);
                }
            }
            out.add(new SampleCccFamily(s.g.sampleId(), s.label, all));
        }
        return out;
    }

    public static final class EngineResult {
        public final List<Anchor> anchors;
        public final List<List<SignalScore>> roundTopSignals;
        public final List<SignalScore> stableTopSignals;

        public EngineResult(List<Anchor> anchors,
                            List<List<SignalScore>> roundTopSignals,
                            List<SignalScore> stableTopSignals) {
            this.anchors = anchors;
            this.roundTopSignals = roundTopSignals;
            this.stableTopSignals = stableTopSignals;
        }
    }
}
```

---

4) 最小 Demo（可选，但推荐）

DemoTwoWaysCccEngine.java

```
package com.dbm.cot.item254;

import java.util.*;

public class DemoTwoWaysCccEngine {

    public static void main(String[] args) {
        List<Sample> samples = new ArrayList<Sample>();

        // In-group graphs with TRIANGLE around label "A"
        samples.add(new Sample(makeTriangleGraph("in1", "A"), 1));
        samples.add(new Sample(makeTriangleGraph("in2", "A"), 1));

        // Out-group graphs without triangle
        samples.add(new Sample(makeLineGraph("out1", "A"), 0));
        samples.add(new Sample(makeLineGraph("out2", "A"), 0));

        EngineConfig cfg = new EngineConfig();
        cfg.seed = 7L;
        cfg.areaHops = 1;
        cfg.stabilityRounds = 3;
        cfg.topKSignals = 5;
        TwoWaysCccEngine engine = new TwoWaysCccEngine(
                new DefaultAnchorMiner(),
                new DefaultTwoPhaseSearcher(),
                new DefaultAreaCutter(),
                new DefaultCccExtractor(),
                new DefaultSignalScorer()
        );

        TwoWaysCccEngine.EngineResult r = engine.run(samples, cfg);

        System.out.println("Anchors: " + r.anchors);
        System.out.println("Stable Top Signals:");
        for (SignalScore s : r.stableTopSignals) {
            System.out.println("  " + s);
        }
    }

    private static ToyGraphStarmap makeTriangleGraph(String id, String
anchorLabel) {
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        g.addUndirectedEdge("n1", "n3");
        return g;
    }

    private static ToyGraphStarmap makeLineGraph(String id, String
anchorLabel) {
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        return g;
    }
}
```

---

5) JUnit4 测试

`TwoWaysCccEngineTest.java`

```
package com.dbm.cot.item254;

import org.junit.Test;
import java.util.*;

import static org.junit.Assert.*;

public class TwoWaysCccEngineTest {

    @Test
    public void stability_sameSeed_sameTopSignal() {
        List<Sample> samples = toyDatasetSignalTriangle();

        EngineConfig cfg = new EngineConfig();
        cfg.seed = 123L;
        cfg.stabilityRounds = 5;
        cfg.topKSignals = 3;

        TwoWaysCccEngine engine = newEngine();

        TwoWaysCccEngine.EngineResult r1 = engine.run(samples, cfg);
        TwoWaysCccEngine.EngineResult r2 = engine.run(samples, cfg);

        assertFalse(r1.stableTopSignals.isEmpty());
        assertFalse(r2.stableTopSignals.isEmpty());
        assertEquals(
                r1.stableTopSignals.get(0).signal.signature,
                r2.stableTopSignals.get(0).signal.signature
        );
    }

    @Test
    public void separability_triangleMotif_shouldBeTopSignal() {
        List<Sample> samples = toyDatasetSignalTriangle();

        EngineConfig cfg = new EngineConfig();
        cfg.seed = 7L;
        cfg.stabilityRounds = 3;
        cfg.topKSignals = 5;

        TwoWaysCccEngine engine = newEngine();
        TwoWaysCccEngine.EngineResult r = engine.run(samples, cfg);

        boolean foundTriangle = false;
        for (SignalScore ss : r.stableTopSignals) {
            if ("MOTIF:TRIANGLE".equals(ss.signal.signature)) {
                foundTriangle = true;
                break;
            }
        }
        assertTrue("Expected MOTIF:TRIANGLE in stable top signals",
foundTriangle);
    }

    private TwoWaysCccEngine newEngine() {
        return new TwoWaysCccEngine(
                new DefaultAnchorMiner(),
                new DefaultTwoPhaseSearcher(),
                new DefaultAreaCutter(),
                new DefaultCccExtractor(),
                new DefaultSignalScorer()
        );
    }

    private List<Sample> toyDatasetSignalTriangle() {
        List<Sample> samples = new ArrayList<Sample>();

        // In-group (label=1): triangle exists
        samples.add(new Sample(makeTriangleGraph("in1", "A"), 1));
        samples.add(new Sample(makeTriangleGraph("in2", "A"), 1));
        samples.add(new Sample(makeTriangleGraph("in3", "A"), 1));

        // Out-group (label=0): no triangle
        samples.add(new Sample(makeLineGraph("out1", "A"), 0));
        samples.add(new Sample(makeLineGraph("out2", "A"), 0));
        samples.add(new Sample(makeLineGraph("out3", "A"), 0));

        return samples;
    }

    private ToyGraphStarmap makeTriangleGraph(String id, String anchorLabel)
{
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        g.addUndirectedEdge("n1", "n3");
        return g;
    }

    private ToyGraphStarmap makeLineGraph(String id, String anchorLabel) {
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        return g;
    }
}
```

下一步我建议你怎么把它“DBM 化”升级（不需要你补信息）

你现在这套 skeleton 的替换点非常清晰：

1. `DefaultTwoPhaseSearcher` → 换成你真实的 **Euclidean routing + Metric rerank**（Hybrid Tree / Differential Tree）
2. `DefaultCccExtractor` → 换成你真实的 **Graph CCC / Sequence CCC / Image CCC**（输出 fragments + evidence）
3. `DefaultSignalScorer` → 加上你要的：log-ratio、distance-weight、stability-weight、multi-class strata

4. `TwoWaysCccEngine` → 把 `EngineResult` 扩成 **Signal CCC Package + Evidence Bundle**（你 repo 风格很擅长）

如果你愿意，我可以直接按你 repo 习惯，把这些类名与包结构改成更“DBM runtime 风味”（例如 `com.dbm.ccc.twoways.*`、加 `EvidenceChain`、加 stop-rule contracts），并再补一个 **“multi-class strata”** 的 JUnit4（验证分层对照不串味）。

很好。请生成：把这些类名与包结构改成更“DBM runtime 风味”（例如 com.dbm.ccc.twoways.*、加 EvidenceChain、加 stop-rule contracts），并再补一个 “multi-class strata” 的 JUnit4（验证分层对照不串味）。
Thought for 20s

下面是把上一版 **全面“DBM runtime 风味化”** 的一套 **Java 8 最小可跑 skeleton + JUnit4**：

- 包名统一为 **`com.dbm.ccc.twoways.*`**
- 引入 **EvidenceChain（解释链）**
- 引入 **Stop-Rule Contracts（预算/收手规则）**
- 引入 **Multi-class + Strata（分层对照，不串味）** 并补一个 JUnit4 专测

说明：我仍用 ToyGraphStarmap 做 carrier；你后续只需要替换 `TwoPhaseSearcher` / `CccExtractor` 为你 repo 的真实实现即可，其余 orchestrator、stop-rule、evidence、strata 逻辑可直接保留。

A) 建议目录结构

```
src/main/java/com/dbm/ccc/twoways/...
src/test/java/com/dbm/ccc/twoways/...
```

B) Runtime 风味的核心类

1) `ToyGraphStarmap.java`

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class ToyGraphStarmap {

    public static final class Node {
        public final String id;
        public final String label;

        public Node(String id, String label) {
            this.id = Objects.requireNonNull(id, "id");
            this.label = Objects.requireNonNull(label, "label");
        }
    }

    private final String sampleId;
    private final Map<String, Node> nodes = new LinkedHashMap<String,
Node>();
    private final Map<String, Set<String>> adj = new LinkedHashMap<String,
Set<String>>();

    public ToyGraphStarmap(String sampleId) {
        this.sampleId = Objects.requireNonNull(sampleId, "sampleId");
    }

    public String sampleId() { return sampleId; }

    public void addNode(String id, String label) {
        if (nodes.containsKey(id)) throw new
IllegalArgumentException("duplicate node: " + id);
        nodes.put(id, new Node(id, label));
        adj.put(id, new LinkedHashSet<String>());
    }

    public void addUndirectedEdge(String a, String b) {
        requireNode(a); requireNode(b);
        if (a.equals(b)) throw new IllegalArgumentException("self-loop not
supported: " + a);
        adj.get(a).add(b);
        adj.get(b).add(a);
    }

    public Collection<Node> nodes() { return
Collections.unmodifiableCollection(nodes.values()); }

    public Set<String> neighbors(String id) {
        requireNode(id);
        return Collections.unmodifiableSet(adj.get(id));
    }

    public boolean hasEdge(String a, String b) {
        requireNode(a); requireNode(b);
        return adj.get(a).contains(b);
    }

    private void requireNode(String id) {
        if (!nodes.containsKey(id)) throw new
IllegalArgumentException("missing node: " + id);
    }
}
```

---

2) `EngineConfig.java`

```
package com.dbm.ccc.twoways;
```

```
public final class EngineConfig {

    // labeling
    public String positiveClass = "IN"; // treat this class as in-group;
others are out-group within stratum

    // budgets / controls
    public int maxAnchors = 8;
    public int maxOccurrencesPerAnchor = 32;
    public int areaHops = 1;
    public int maxAreasPerSample = 8;
    public int topKSignals = 5;

    // stability
    public int stabilityRounds = 3;
    public long seed = 7L;

    // stop-rule switches
    public boolean enableStopRules = true;
}
```

---

3) Domain objects: `Anchor / Occurrence / LocalArea / CccFragment`

```
package com.dbm.ccc.twoways;

import java.util.Objects;

public final class Anchor {
    public final String key; // toy: node label
    public Anchor(String key) { this.key = Objects.requireNonNull(key,
"key"); }
    @Override public String toString() { return "Anchor(" + key + ")"; }
    @Override public boolean equals(Object o){ return (o instanceof Anchor)
&& key.equals(((Anchor)o).key); }
    @Override public int hashCode(){ return key.hashCode(); }
}
package com.dbm.ccc.twoways;

import java.util.Objects;

public final class Occurrence {
    public final Anchor anchor;
    public final String nodeId;

    public Occurrence(Anchor anchor, String nodeId) {
        this.anchor = Objects.requireNonNull(anchor, "anchor");
        this.nodeId = Objects.requireNonNull(nodeId, "nodeId");
    }
}
package com.dbm.ccc.twoways;

import java.util.*;

public final class LocalArea {
    public final String sampleId;
    public final Anchor anchor;
    public final String centerNodeId;
    public final Set<String> nodeIds;

    public LocalArea(String sampleId, Anchor anchor, String centerNodeId,
Set<String> nodeIds) {
        this.sampleId = Objects.requireNonNull(sampleId, "sampleId");
        this.anchor = Objects.requireNonNull(anchor, "anchor");
        this.centerNodeId = Objects.requireNonNull(centerNodeId,
"centerNodeId");
        this.nodeIds = Collections.unmodifiableSet(new
LinkedHashSet<String>(nodeIds));
    }
}
package com.dbm.ccc.twoways;

import java.util.Objects;

public final class CccFragment {
    public final String signature; // canonical motif signature
    public CccFragment(String signature) { this.signature =
Objects.requireNonNull(signature, "signature"); }
    @Override public String toString() { return signature; }
    @Override public boolean equals(Object o){ return (o instanceof
CccFragment) && signature.equals(((CccFragment)o).signature); }
    @Override public int hashCode(){ return signature.hashCode(); }
}
```

C) EvidenceChain（解释链）

4) `EvidenceChain.java`

```
package com.dbm.ccc.twoways;

import java.util.*;

/**
 * DBM-style explain chain:
 * anchor -> occurrence -> area -> fragment (+ top evidence node ids)
 */
public final class EvidenceChain {
    public final String sampleId;
    public final Anchor anchor;
    public final String occurrenceNodeId;
    public final Set<String> areaNodeIds;
    public final CccFragment fragment;
    public final List<String> topEvidenceNodeIds; // toy: deterministic
subset of area nodes

    public EvidenceChain(String sampleId,
                         Anchor anchor,
                         String occurrenceNodeId,
                         Set<String> areaNodeIds,
                         CccFragment fragment,
                         List<String> topEvidenceNodeIds) {
        this.sampleId = Objects.requireNonNull(sampleId, "sampleId");
        this.anchor = Objects.requireNonNull(anchor, "anchor");
        this.occurrenceNodeId = Objects.requireNonNull(occurrenceNodeId,
"occurrenceNodeId");
        this.areaNodeIds = Collections.unmodifiableSet(new
LinkedHashSet<String>(areaNodeIds));
        this.fragment = Objects.requireNonNull(fragment, "fragment");
        this.topEvidenceNodeIds = Collections.unmodifiableList(new
ArrayList<String>(topEvidenceNodeIds));
    }
}
```

5) `EvidenceBundle.java`

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class EvidenceBundle {
    private final Map<CccFragment, List<EvidenceChain>> bySignal =
            new LinkedHashMap<CccFragment, List<EvidenceChain>>();

    public void add(EvidenceChain chain) {
        List<EvidenceChain> list = bySignal.get(chain.fragment);
        if (list == null) {
            list = new ArrayList<EvidenceChain>();
            bySignal.put(chain.fragment, list);
        }
        list.add(chain);
    }

    public List<EvidenceChain> chainsFor(CccFragment signal) {
        List<EvidenceChain> list = bySignal.get(signal);
        if (list == null) return Collections.emptyList();
        return Collections.unmodifiableList(list);
    }

    public Set<CccFragment> signals() { return
Collections.unmodifiableSet(bySignal.keySet()); }
}
```

D) Stop-Rule Contracts（预算 / 收手规则）

6) `StopContext.java`

```
package com.dbm.ccc.twoways;

public final class StopContext {
    public int anchorsUsed;
    public int occurrencesSeen;
    public int areasCut;
    public int fragmentsEmitted;

    public long startMillis;
    public long nowMillis;

    public StopContext(long startMillis) {
        this.startMillis = startMillis;
        this.nowMillis = startMillis;
    }
}
```

7) StopRule.java

```
package com.dbm.ccc.twoways;

public interface StopRule {
    /**
     * Return true if engine should stop / prune at this point.
     */
    boolean shouldStop(StopContext ctx, EngineConfig cfg);

    String name();
}
```

8) BudgetStopRules.java

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class BudgetStopRules {

    public static List<StopRule> defaultRules() {
        List<StopRule> rules = new ArrayList<StopRule>();
        rules.add(new StopRule() {
            @Override public boolean shouldStop(StopContext ctx, EngineConfig
cfg) {
                return ctx.anchorsUsed > cfg.maxAnchors;
            }
            @Override public String name() { return "S0_anchor_budget"; }
        });
        rules.add(new StopRule() {
            @Override public boolean shouldStop(StopContext ctx, EngineConfig
cfg) {
                return ctx.occurrencesSeen > (cfg.maxAnchors *
cfg.maxOccurrencesPerAnchor);
            }
            @Override public String name() { return
"S1_occurrence_explosion"; }
        });
        rules.add(new StopRule() {
            @Override public boolean shouldStop(StopContext ctx, EngineConfig
cfg) {
                return ctx.areasCut > (cfg.maxAreasPerSample * 64); // toy
global cap
            }
            @Override public String name() { return "S2_area_budget"; }
        });
        rules.add(new StopRule() {
            @Override public boolean shouldStop(StopContext ctx, EngineConfig
cfg) {
                return ctx.fragmentsEmitted > (cfg.topKSignals * 256); // toy
global cap
            }
            @Override public String name() { return "S3_fragment_budget"; }
        });
        return rules;
    }
    private BudgetStopRules() {}
}
```

E) Pipeline interfaces （runtime slots）

9) `AnchorMiner / TwoPhaseSearcher / AreaCutter / CccExtractor`

```
package com.dbm.ccc.twoways;

import java.util.List;

public interface AnchorMiner {
    List<Anchor> mineAnchors(List<Sample> samples, EngineConfig cfg);
}
package com.dbm.ccc.twoways;

import java.util.List;

public interface TwoPhaseSearcher {
    List<Occurrence> findOccurrences(ToyGraphStarmap g, Anchor anchor,
EngineConfig cfg);
}
package com.dbm.ccc.twoways;

import java.util.List;

public interface AreaCutter {
    List<LocalArea> cutAreas(ToyGraphStarmap g, Anchor anchor,
List<Occurrence> occs, EngineConfig cfg);
}
package com.dbm.ccc.twoways;

import java.util.List;

public interface CccExtractor {
    /**
     * Return fragments + add evidence chains into bundle (DBM
explainability).
     */
    List<CccFragment> extract(ToyGraphStarmap g, LocalArea area, EngineConfig
cfg, EvidenceBundle evidenceOut);
}
```

F) Runtime-friendly Sample + CCC family

10) `Sample.java` （multi-class + strata）

```
package com.dbm.ccc.twoways;

import java.util.Objects;

public final class Sample {
    public final ToyGraphStarmap g;

    /** class label (multi-class); positiveClass in cfg defines the in-group
*/
    public final String clazz;
    /** stratum key (e.g., cohort/site/batch/age-bin); comparisons must be
within stratum */
    public final String stratum;

    public Sample(ToyGraphStarmap g, String clazz, String stratum) {
        this.g = Objects.requireNonNull(g, "g");
        this.clazz = Objects.requireNonNull(clazz, "clazz");
        this.stratum = Objects.requireNonNull(stratum, "stratum");
    }
}
```

11) `SampleCccFamily.java`

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class SampleCccFamily {
    public final String sampleId;
    public final String clazz;
    public final String stratum;
    public final Set<CccFragment> fragments;

    public SampleCccFamily(String sampleId, String clazz, String stratum,
Set<CccFragment> fragments) {
        this.sampleId = Objects.requireNonNull(sampleId, "sampleId");
        this.clazz = Objects.requireNonNull(clazz, "clazz");
        this.stratum = Objects.requireNonNull(stratum, "stratum");
        this.fragments = Collections.unmodifiableSet(new
LinkedHashSet<CccFragment>(fragments));
    }

    public boolean contains(CccFragment f) { return fragments.contains(f); }
}
```

G) Minimal implementations（可直接替换为你真实版本）

12) `DefaultAnchorMiner.java`

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class DefaultAnchorMiner implements AnchorMiner {

    @Override
    public List<Anchor> mineAnchors(List<Sample> samples, EngineConfig cfg) {
        Map<String, Integer> freq = new HashMap<String, Integer>();
        for (Sample s : samples) {
            for (ToyGraphStarmap.Node n : s.g.nodes()) {
                Integer c = freq.get(n.label);
                freq.put(n.label, c == null ? 1 : (c + 1));
            }
        }
        List<String> labels = new ArrayList<String>(freq.keySet());
        Collections.sort(labels, new Comparator<String>() {
            @Override public int compare(String a, String b) {
                int ca = freq.get(a), cb = freq.get(b);
                if (ca != cb) return (cb - ca);
                return a.compareTo(b);
            }
        });

        int k = Math.min(cfg.maxAnchors, labels.size());
        List<Anchor> out = new ArrayList<Anchor>(k);
        for (int i = 0; i < k; i++) out.add(new Anchor(labels.get(i)));
        return out;
    }
}
```

13) DefaultTwoPhaseSearcher.java

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class DefaultTwoPhaseSearcher implements TwoPhaseSearcher {

    @Override
    public List<Occurrence> findOccurrences(ToyGraphStarmap g, Anchor anchor,
EngineConfig cfg) {
        List<String> hits = new ArrayList<String>();
        for (ToyGraphStarmap.Node n : g.nodes()) {
            if (anchor.key.equals(n.label)) hits.add(n.id);
        }
        Collections.sort(hits);
        int limit = Math.min(cfg.maxOccurrencesPerAnchor, hits.size());
        List<Occurrence> occs = new ArrayList<Occurrence>(limit);
        for (int i = 0; i < limit; i++) occs.add(new Occurrence(anchor,
hits.get(i)));
        return occs;
    }
}
```

14) DefaultAreaCutter.java

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class DefaultAreaCutter implements AreaCutter {

    @Override
    public List<LocalArea> cutAreas(ToyGraphStarmap g, Anchor anchor,
List<Occurrence> occs, EngineConfig cfg) {
        List<LocalArea> areas = new ArrayList<LocalArea>();
        int limit = Math.min(cfg.maxAreasPerSample, occs.size());
        for (int i = 0; i < limit; i++) {
            Occurrence oc = occs.get(i);
            Set<String> nodes = bfsNeighborhood(g, oc.nodeId, cfg.areaHops);
            areas.add(new LocalArea(g.sampleId(), anchor, oc.nodeId, nodes));
        }
        return areas;
    }

    private Set<String> bfsNeighborhood(ToyGraphStarmap g, String start, int
hops) {
        Set<String> seen = new LinkedHashSet<String>();
        ArrayDeque<String> q = new ArrayDeque<String>();
        Map<String, Integer> dist = new HashMap<String, Integer>();

        q.add(start);
        dist.put(start, 0);
        seen.add(start);

        while (!q.isEmpty()) {
            String cur = q.removeFirst();
            int d = dist.get(cur);
            if (d >= hops) continue;
            for (String nb : g.neighbors(cur)) {
                if (!dist.containsKey(nb)) {
                    dist.put(nb, d + 1);
                    q.addLast(nb);
                    seen.add(nb);
                }
            }
        }
        return seen;
    }
}
```

15) `DefaultCccExtractor.java`（同时输出 EvidenceChain）

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class DefaultCccExtractor implements CccExtractor {

    @Override
    public List<CccFragment> extract(ToyGraphStarmap g, LocalArea area,
EngineConfig cfg, EvidenceBundle evidenceOut) {
        List<CccFragment> out = new ArrayList<CccFragment>();
        List<String> nodes = new ArrayList<String>(area.nodeIds);
        Collections.sort(nodes);

        int edgeCount = 0;
        for (int i = 0; i < nodes.size(); i++) {
            for (int j = i + 1; j < nodes.size(); j++) {
                if (g.hasEdge(nodes.get(i), nodes.get(j))) edgeCount++;
            }
        }

        boolean tri = hasTriangle(g, nodes);

        if (tri) {
            CccFragment f = new CccFragment("MOTIF:TRIANGLE");
            out.add(f);
            evidenceOut.add(chain(area, f, nodes));
        }

        CccFragment f2 = new CccFragment("EDGECOUNT:" + edgeCount);
        out.add(f2);
        evidenceOut.add(chain(area, f2, nodes));
        return out;
    }

    private EvidenceChain chain(LocalArea area, CccFragment frag,
List<String> nodesSorted) {
        // toy: top evidence = first up to 3 nodes in the area
        List<String> top = new ArrayList<String>();
        for (int i = 0; i < Math.min(3, nodesSorted.size()); i++)
top.add(nodesSorted.get(i));
        return new EvidenceChain(area.sampleId, area.anchor,
area.centerNodeId, area.nodeIds, frag, top);
    }

    private boolean hasTriangle(ToyGraphStarmap g, List<String> nodesSorted)
{
        int n = nodesSorted.size();
        for (int i = 0; i < n; i++) {
            String a = nodesSorted.get(i);
            for (int j = i + 1; j < n; j++) {
                String b = nodesSorted.get(j);
                if (!g.hasEdge(a, b)) continue;
                for (int k = j + 1; k < n; k++) {
                    String c = nodesSorted.get(k);
                    if (g.hasEdge(a, c) && g.hasEdge(b, c)) return true;
                }
            }
        }
        return false;
    }
}
```

H) Two-Ways Scoring（按 stratum 分层，不串味）

16) `SignalScore.java`

```
package com.dbm.ccc.twoways;

public final class SignalScore implements Comparable<SignalScore> {
    public final CccFragment signal;
    public final double cIn;
    public final double cOut;
    public final double score; // diff

    public SignalScore(CccFragment signal, double cIn, double cOut, double
score) {
        this.signal = signal;
        this.cIn = cIn;
        this.cOut = cOut;
        this.score = score;
    }

    @Override
    public int compareTo(SignalScore o) {
        int s = Double.compare(o.score, this.score);
        if (s != 0) return s;
        return this.signal.signature.compareTo(o.signal.signature);
    }
}
```

17) StratifiedTwoWaysScorer.java

```
package com.dbm.ccc.twoways;

import java.util.*;

/**
 * Compare within each stratum:
 * in-group = clazz == cfg.positiveClass
 * out-group = others (within same stratum)
 */
public final class StratifiedTwoWaysScorer {

    public Map<String, List<SignalScore>>
scoreByStratum(List<SampleCccFamily> families, EngineConfig cfg) {
        // group by stratum
        Map<String, List<SampleCccFamily>> byStratum = new
LinkedHashMap<String, List<SampleCccFamily>>();
        for (SampleCccFamily f : families) {
            List<SampleCccFamily> list = byStratum.get(f.stratum);
            if (list == null) {
                list = new ArrayList<SampleCccFamily>();
                byStratum.put(f.stratum, list);
            }
            list.add(f);
        }

        Map<String, List<SignalScore>> out = new LinkedHashMap<String,
List<SignalScore>>();
        for (Map.Entry<String, List<SampleCccFamily>> e :
byStratum.entrySet()) {
            out.put(e.getKey(), scoreOneStratum(e.getValue(), cfg));
        }
        return out;
    }

    private List<SignalScore> scoreOneStratum(List<SampleCccFamily> fams,
EngineConfig cfg) {
        int inN = 0, outN = 0;
        for (SampleCccFamily f : fams) {
            if (cfg.positiveClass.equals(f.clazz)) inN++; else outN++;
        }
        if (inN == 0 || outN == 0) {
            // degenerate stratum: no comparison possible
            return Collections.emptyList();
        }

        Set<CccFragment> universe = new LinkedHashSet<CccFragment>();
        for (SampleCccFamily f : fams) universe.addAll(f.fragments);

        List<SignalScore> scores = new ArrayList<SignalScore>();
        for (CccFragment s : universe) {
            int inHit = 0, outHit = 0;
            for (SampleCccFamily f : fams) {
                if (!f.contains(s)) continue;
                if (cfg.positiveClass.equals(f.clazz)) inHit++; else
outHit++;
            }
            double cIn = ((double) inHit) / ((double) inN);
            double cOut = ((double) outHit) / ((double) outN);
            scores.add(new SignalScore(s, cIn, cOut, (cIn - cOut)));
        }

        Collections.sort(scores);
        if (scores.size() > cfg.topKSignals) return new
ArrayList<SignalScore>(scores.subList(0, cfg.topKSignals));
        return scores;
    }
}
```

I) 主引擎：`TwoWaysCccEngine.java`（加入 stop-rules + evidence + strata）

18) `TwoWaysCccEngine.java`

```
package com.dbm.ccc.twoways;

import java.util.*;

public final class TwoWaysCccEngine {

    private final AnchorMiner anchorMiner;
    private final TwoPhaseSearcher searcher;
    private final AreaCutter areaCutter;
    private final CccExtractor extractor;
    private final StratifiedTwoWaysScorer scorer;
    private final List<StopRule> stopRules;

    public TwoWaysCccEngine(AnchorMiner anchorMiner,
                            TwoPhaseSearcher searcher,
                            AreaCutter areaCutter,
                            CccExtractor extractor,
                            StratifiedTwoWaysScorer scorer,
                            List<StopRule> stopRules) {
        this.anchorMiner = Objects.requireNonNull(anchorMiner,
"anchorMiner");
        this.searcher = Objects.requireNonNull(searcher, "searcher");
        this.areaCutter = Objects.requireNonNull(areaCutter, "areaCutter");
        this.extractor = Objects.requireNonNull(extractor, "extractor");
        this.scorer = Objects.requireNonNull(scorer, "scorer");
        this.stopRules = (stopRules == null) ?
Collections.<StopRule>emptyList() : stopRules;
    }

    public EngineResult run(List<Sample> samples, EngineConfig cfg) {
        if (samples == null || samples.isEmpty()) throw new
IllegalArgumentException("samples empty");
        final long start = System.currentTimeMillis();
        StopContext ctx = new StopContext(start);

        List<Anchor> anchors = anchorMiner.mineAnchors(samples, cfg);
        if (anchors.isEmpty()) throw new IllegalStateException("no anchors");
        EvidenceBundle evidence = new EvidenceBundle();

        // Stability loop: rerun with anchor subset perturbations; aggregate
per stratum
        Random rnd = new Random(cfg.seed);
        Map<String, Map<CccFragment, Double>> aggScoreByStratum = new
LinkedHashMap<String, Map<CccFragment, Double>>();
        Map<String, Map<CccFragment, Integer>> aggCountByStratum = new
LinkedHashMap<String, Map<CccFragment, Integer>>();
        List<Map<String, List<SignalScore>>> roundScores = new
ArrayList<Map<String, List<SignalScore>>>();

        int rounds = Math.max(1, cfg.stabilityRounds);
        for (int r = 0; r < rounds; r++) {
            List<Anchor> roundAnchors = perturbAnchors(anchors, rnd);
            ctx.anchorsUsed = roundAnchors.size();

            List<SampleCccFamily> families = buildFamilies(samples,
roundAnchors, cfg, ctx, evidence);
            Map<String, List<SignalScore>> byStratum =
scorer.scoreByStratum(families, cfg);
            roundScores.add(byStratum);

            // aggregate
            for (Map.Entry<String, List<SignalScore>> e :
byStratum.entrySet()) {
                String stratum = e.getKey();
                Map<CccFragment, Double> agg =
aggScoreByStratum.get(stratum);
                Map<CccFragment, Integer> cnt =
aggCountByStratum.get(stratum);
                if (agg == null) {
                    agg = new LinkedHashMap<CccFragment, Double>();
                    cnt = new LinkedHashMap<CccFragment, Integer>();
                    aggScoreByStratum.put(stratum, agg);
                    aggCountByStratum.put(stratum, cnt);
                }
                for (SignalScore ss : e.getValue()) {
                    Double prev = agg.get(ss.signal);
                    agg.put(ss.signal, prev == null ? ss.score : (prev +
ss.score));
                    Integer pc = cnt.get(ss.signal);
                    cnt.put(ss.signal, pc == null ? 1 : (pc + 1));
                }
            }

            if (cfg.enableStopRules && shouldStop(ctx, cfg)) break;
        }

        // finalize stable top signals per stratum
        Map<String, List<SignalScore>> stableByStratum = new
LinkedHashMap<String, List<SignalScore>>();
        for (String stratum : aggScoreByStratum.keySet()) {
            Map<CccFragment, Double> agg = aggScoreByStratum.get(stratum);
            Map<CccFragment, Integer> cnt = aggCountByStratum.get(stratum);

            List<SignalScore> stable = new ArrayList<SignalScore>();
            for (Map.Entry<CccFragment, Double> e : agg.entrySet()) {
                CccFragment sig = e.getKey();
                double sum = e.getValue();
                int c = cnt.get(sig);
                double avg = sum / ((double) c);
                // tiny stability bonus to break ties deterministically
                double finalScore = avg + 1e-6 * c;
                stable.add(new SignalScore(sig, Double.NaN, Double.NaN,
finalScore));
            }
            Collections.sort(stable);
            if (stable.size() > cfg.topKSignals) stable = new
ArrayList<SignalScore>(stable.subList(0, cfg.topKSignals));
            stableByStratum.put(stratum, stable);
        }

        ctx.nowMillis = System.currentTimeMillis();
        return new EngineResult(anchors, roundScores, stableByStratum,
evidence, ctx);
    }

    private boolean shouldStop(StopContext ctx, EngineConfig cfg) {
        for (StopRule r : stopRules) {
            if (r.shouldStop(ctx, cfg)) return true;
        }
        return false;
    }

    private List<Anchor> perturbAnchors(List<Anchor> anchors, Random rnd) {
        List<Anchor> copy = new ArrayList<Anchor>(anchors);
        Collections.shuffle(copy, rnd);
        int keep = Math.max(1, (int) Math.round(copy.size() * 0.8));
        List<Anchor> sub = new ArrayList<Anchor>(copy.subList(0, keep));
        Collections.sort(sub, new Comparator<Anchor>() {
            @Override public int compare(Anchor a, Anchor b) { return
a.key.compareTo(b.key); }
        });
        return sub;
    }

    private List<SampleCccFamily> buildFamilies(List<Sample> samples,
                                                List<Anchor> anchors,
                                                EngineConfig cfg,
                                                StopContext ctx,
                                                EvidenceBundle evidence) {
        List<SampleCccFamily> out = new
ArrayList<SampleCccFamily>(samples.size());
        for (Sample s : samples) {
            Set<CccFragment> frags = new LinkedHashSet<CccFragment>();

            for (Anchor a : anchors) {
                if (cfg.enableStopRules && shouldStop(ctx, cfg)) break;

                List<Occurrence> occs = searcher.findOccurrences(s.g, a,
cfg);
                ctx.occurrencesSeen += occs.size();
                List<LocalArea> areas = areaCutter.cutAreas(s.g, a, occs,
cfg);
                ctx.areasCut += areas.size();

                for (LocalArea area : areas) {
                    if (cfg.enableStopRules && shouldStop(ctx, cfg)) break;
                    List<CccFragment> fs = extractor.extract(s.g, area, cfg,
evidence);
                    ctx.fragmentsEmitted += fs.size();
                    frags.addAll(fs);
                }
            }

            out.add(new SampleCccFamily(s.g.sampleId(), s.clazz, s.stratum,
frags));
        }
        return out;
    }

    public static final class EngineResult {
        public final List<Anchor> anchors;
        public final List<Map<String, List<SignalScore>>>
roundScoresByStratum;
        public final Map<String, List<SignalScore>>
stableTopSignalsByStratum;
        public final EvidenceBundle evidence;
        public final StopContext stopContext;

        public EngineResult(List<Anchor> anchors,
                            List<Map<String, List<SignalScore>>>
roundScoresByStratum,
                            Map<String, List<SignalScore>>
stableTopSignalsByStratum,
                            EvidenceBundle evidence,
                            StopContext stopContext) {
            this.anchors = anchors;
            this.roundScoresByStratum = roundScoresByStratum;
            this.stableTopSignalsByStratum = stableTopSignalsByStratum;
            this.evidence = evidence;
            this.stopContext = stopContext;
        }
    }
}
```

J) JUnit4：新增 “multi-class strata 不串味” 测试

这个测试构造两个 strata：

- **S1**：positiveClass=IN 的样本都含 TRIANGLE，OUT 不含 ⇒ TRIANGLE 应该是 S1 top signal

- **S2**：反过来，IN 是 line，OUT 是 triangle ⇒ TRIANGLE 在 S2 不应成为 top signal（甚至为负），从而证明“不会跨 strata 混在一起”

19) `TwoWaysCccEngineStrataTest.java`

```
package com.dbm.ccc.twoways;

import org.junit.Test;
import java.util.*;

import static org.junit.Assert.*;

public class TwoWaysCccEngineStrataTest {

    @Test
    public void multiClass_strataIsolation_noCrossContamination() {
        List<Sample> samples = new ArrayList<Sample>();

        // Stratum S1: IN has TRIANGLE, OUT has LINE
        samples.add(new Sample(makeTriangleGraph("s1_in1", "A"), "IN",
"S1"));
        samples.add(new Sample(makeTriangleGraph("s1_in2", "A"), "IN",
"S1"));
        samples.add(new Sample(makeLineGraph("s1_out1", "A"), "OUT", "S1"));
        samples.add(new Sample(makeLineGraph("s1_out2", "A"), "OUT", "S1"));

        // Stratum S2: IN has LINE, OUT has TRIANGLE (flip)
        samples.add(new Sample(makeLineGraph("s2_in1", "A"), "IN", "S2"));
        samples.add(new Sample(makeLineGraph("s2_in2", "A"), "IN", "S2"));
        samples.add(new Sample(makeTriangleGraph("s2_out1", "A"), "OUT",
"S2"));
        samples.add(new Sample(makeTriangleGraph("s2_out2", "A"), "OUT",
"S2"));

        EngineConfig cfg = new EngineConfig();
        cfg.positiveClass = "IN";
        cfg.seed = 11L;
        cfg.stabilityRounds = 3;
        cfg.topKSignals = 5;

        TwoWaysCccEngine engine = new TwoWaysCccEngine(
                new DefaultAnchorMiner(),
                new DefaultTwoPhaseSearcher(),
                new DefaultAreaCutter(),
                new DefaultCccExtractor(),
                new StratifiedTwoWaysScorer(),
                BudgetStopRules.defaultRules()
        );

        TwoWaysCccEngine.EngineResult r = engine.run(samples, cfg);

        assertTrue("Expected stratum S1 results",
r.stableTopSignalsByStratum.containsKey("S1"));
        assertTrue("Expected stratum S2 results",
r.stableTopSignalsByStratum.containsKey("S2"));
```

```
        List<SignalScore> s1 = r.stableTopSignalsByStratum.get("S1");
        List<SignalScore> s2 = r.stableTopSignalsByStratum.get("S2");

        assertFalse("S1 signals empty", s1.isEmpty());
        assertFalse("S2 signals empty", s2.isEmpty());

        boolean s1HasTriangleTop =
"MOTIF:TRIANGLE".equals(s1.get(0).signal.signature)
                || containsSignal(s1, "MOTIF:TRIANGLE");
        assertTrue("S1 should favor TRIANGLE as signal", s1HasTriangleTop);

        // In S2, TRIANGLE is associated with OUT, so it should not be a top
positive signal.
        boolean s2TrianglePresent = containsSignal(s2, "MOTIF:TRIANGLE");
        if (s2TrianglePresent) {
            // If it appears, its score should be non-positive (usually
negative).
            double triScore = findScore(s2, "MOTIF:TRIANGLE");
            assertTrue("S2 TRIANGLE should not be positive (no
contamination)", triScore <= 0.0 + 1e-12);
        } else {
            // Even better: TRIANGLE not in topK for S2
            assertTrue(true);
        }
    }

    private boolean containsSignal(List<SignalScore> list, String sig) {
        for (SignalScore s : list) if (sig.equals(s.signal.signature)) return
true;
        return false;
    }

    private double findScore(List<SignalScore> list, String sig) {
        for (SignalScore s : list) if (sig.equals(s.signal.signature)) return
s.score;
        throw new AssertionError("signal not found: " + sig);
    }

    private ToyGraphStarmap makeTriangleGraph(String id, String anchorLabel)
{
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        g.addUndirectedEdge("n1", "n3");
        return g;
    }

    private ToyGraphStarmap makeLineGraph(String id, String anchorLabel) {
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        return g;
    }
}
```

你接入真实 DBM runtime 时的替换点（零歧义）

1. `ToyGraphStarmap` → 你真实的 `GraphStarmap`（或 `IStarmap` 派生）
2. `DefaultTwoPhaseSearcher` → 你真实的 **HybridTree / DifferentialTree** 两阶段搜索
3. `DefaultCccExtractor` → 你真实的 **Graph CCC extractor**（返回 fragments + evidence）
4. 保留：`TwoWaysCccEngine + StopRules + EvidenceBundle + StratifiedTwoWaysScorer`
    - 这四个就是 ITEM #254 的“通用引擎层”

如果你下一步要更进一步“DBM repo 一致性”，我可以继续把这些类：

- 改成你常用命名（`*Spec / *Plan / *Runtime`）
- 加 `Contract` 表格对应的 `assertInvariant()`
- 以及把 `EvidenceChain` 对齐你已有的 `top-k indices` 解释链风格（你在 MotionIrEvidence 那套已经很成熟了）

兄弟，很好。辛苦了。谢谢。这个课题打开的 CCC 应用的大门。过去总觉得 CCC 无比重要，但有些无从下手。这下好了，看到了一维到结构统计与比较的对应关系，可以一般分析都可以一维到结构推广。另外我们还没专门提到 DBM 的演化层对这个推广的加持。方向很是重要与诱人。

收到。你这段反馈里其实有两条“下一层”的纲领点，值得马上钉牢（否则后面做着做着又会滑回“静态统计”）：

1. **一维→结构统计推广** 的一般性（你已抓住核心同构）
2. **DBM 演化层（Evolution Layer）** 对这套推广的“加持”，让它不只是分析工具，而是**可自我改进的比较研究引擎**

我把“演化层怎么加持、加持在哪里、落地接口长什么样”给你直接展开成可执行的路线图（不另开新题也能直接并入 ITEM #254 的一个新增小节，例如 *Section 9: Evolution Layer Amplification*）。

---

1) 演化层加持的本质：把“比较研究”变成“可迭代的结构科学方法”

没有演化层时，Two-Ways CCC Engine 是：

- 给定 anchors / budgets / scoring，输出 Signal CCC（结构假设）
- 这已经把“专家经验对照”自动化了

有演化层后，它变成：

- **不仅输出 signal**，还会输出下一轮更强的 *measurement plan*（下一轮该看哪里、怎么切、用什么原型、如何反例压测）
- 也就是：**引擎在做“实验设计”的自动优化**

简言之：

Two-Ways CCC = 结构对照研究的“测量仪器”
DBM Evolution Layer = 结构对照研究的“科学方法”（假设→实验→反例→更新）

---

2) 演化层具体加持的 4 个“可优化对象”

把可学习/可演化的对象拆清楚，后面落地会非常快：

2.1 Anchor 生成策略的演化（最关键）

Anchor 不是细节，而是“观察坐标系”。演化层可以让 anchor 从：

- 人工热点 / 统计热点
  进化到：

- **最大区分度 anchors**（提升 Two-Ways score）
- **最小混淆 anchors**（减少 out-group leakage）
- **最稳健 anchors**（跨批次/跨 strata 稳定）

这是把“找锚点”从经验活变成可优化的策略空间。

2.2 Area Cutting / Stop Rules 的演化（规模化关键）

Stop rules 本质是“及时收手”的决策策略。演化层可以学习：

- 哪些 anchor/occurrence 会爆炸 → 早停
- 哪些区域切太大无信息 → shrink
- 哪些区域切太小漏信号 → expand

结果是：在同等算力下，信噪比越来越高。

2.3 Signal scoring 的演化（从 diff 到“结构统计检验”）

你现在用 `cIn - cOut` 是最小可跑版。演化层可以学习更强的组合：

- log-ratio、distance-weight、stability-weight
- strata-aware aggregation（避免 Simpson’s paradox）
- 多信号的“机制簇”输出，而非单信号

2.4 Signal CCC 库的演化（Mechanism Catalog）

当 Signal CCC 稳定出现，你可以把它沉淀成：

- “机制模板库”
- 未来遇到新数据时：**先验引导** + **快速匹配** + **解释链复用**

这等价于把“对照研究成果”变成 DBM 的可积累资产。

---

3) 演化层与“结构统计”的同构关系：从一次对照到持续学习

你提到的“一维→结构推广”，我建议再补一句更狠的：

- 一维统计里，研究者会不断调整：采样、分桶、特征、检验方法
- 结构统计里，对应的就是不断调整：anchors、areas、ccc extractor、scoring、stop rules

演化层让这套“调整”不靠人拍脑袋，而是靠：

- Two-Ways 的对照指标（区分力）
- 稳定性指标（可复现）
- 解释链审计（可解释）
  三者共同驱动的**结构化选择压力（selection pressure）**

这就是你说的“方向重要且诱人”的技术内核：

比较研究从一次性分析，升级为可持续进化的结构科学引擎。

---

4) 立刻可落地的“演化层最小接口”（不写代码也能先固化设计）

你如果愿意把它并入 repo，我建议用最小 3 件套（概念上已足够强）：

1. **Policy**：给定当前结果，如何生成下一轮的 plan（anchors/stop/scoring 的调整）
2. **Fitness**：如何评价这轮的好坏（separability + stability + cost）
3. **Archive**：如何沉淀 signal CCC 到机制库，并反馈为先验（priors）

对应到你现有的 APTGOE 语境，也完全贴合：

- A(Autonomy)：policy 自动产生下一轮配置
- P(Parameterization)：anchors/stop/scoring 都是参数空间
- T(Training)：多轮对照迭代就是训练
- G(Goal)：最大区分 + 最大稳定 + 最小成本

- O(Optimization)：选择压力
- E(Evolution)：策略/模板迭代沉淀

---

5) 你下一步最值钱的一步（建议）

在不增加太多工程量的前提下，最值钱的“下一步”是：

把 “Signal CCC Package” 扩展为 “Experiment Proposal”
也就是每轮输出除了 signals，还输出：

- 哪些 anchors 最贡献（retain list）
- 哪些 anchors 最混淆（ban list）
- 下一轮建议的 `areaHops / maxAreas / topKSignals` 调整
- 推荐的 strata 划分/合并建议（避免串味）

这一步一做，你的引擎就从“分析器”变成“研究助理/实验设计器”。

如果你点头，我可以直接把这一块写成 **ITEM #254 的新增 Section 9（英/中）**，并给一套非常小的 Java 8 插槽（`EvolutionPolicy / FitnessEvaluator / SignalArchive`）+ 一个 JUnit4 验证“多轮迭代 score 单调改善或稳定提升”（toy 版也能测出趋势）。

讲解的很好。我完全同意。请把这一块写成 ITEM #254 的新增 Section 9（英/中），并给一套非常小的 Java 8 插槽（EvolutionPolicy / FitnessEvaluator / SignalArchive）+ 一个 JUnit4 验证“多轮迭代 score 单调改善或稳定提升”（toy 版也能测出趋势）。
Thought for 15s

下面给你 **ITEM #254 新增 Section 9（英/中双语）+ 极小 Java 8 演化层插槽**（`EvolutionPolicy / FitnessEvaluator / SignalArchive`）+ **一个 JUnit4** 验证“多轮迭代 fitness 单调不降且最终显著提升”（toy 版可稳定复现趋势）。

代码默认与你上一轮的 `com.dbm.ccc.twoways.*` 引擎同包共存；演化层我放到 `com.dbm.ccc.twoways.evolution.*`，保持 runtime 风味分层清晰。

DBM-COT ITEM #254 — Section 9 (EN)

9. Evolution Layer Amplification: From Structural Statistics to Structural Scientific Method

9.1 Why an Evolution Layer is the Missing Multiplier

Two-Ways CCC over Starmap spaces already upgrades classical scalar statistics into **structural statistics**:
signal prototypes, metric deviations, and CCC family distributions.

However, comparative studies in real science and engineering are not single-pass computations. They are iterative:
hypothesis → measurement design → counterexample pressure → refinement.

DBM's evolution layer turns Two-Ways CCC from a structural analyzer into an **iterative structural scientific method engine**.

In DBM terms, the engine no longer outputs only a *Signal CCC Package*, but also an *Experiment Proposal*:

- where to look next (anchors),
- how to cut next (area policies),
- when to stop next (stop-rule tuning),
- how to score next (contrast/stability weighting),
- how to stratify next (avoid confounding).

9.2 What Gets Evolved (Four Primary Evolving Objects)

1. **Anchor policies (observation coordinate system)**
    - evolve from domain/statistical anchors into *max-discriminative*, *min-confusion*, *max-stability* anchors.
2. **Area cutting + stop-rule contracts (scalability and signal-to-cost)**
    - evolve budgets and early-stop thresholds to prevent explosion while preserving signal fidelity.
3. **Signal scoring functions (from diff to structural tests)**
    - evolve contrast functions: log-ratio, distance-weighted, stability-weighted, strata-aware aggregation.
4. **Signal CCC archive (mechanism catalog)**
    - stable signals become reusable templates and priors,
      accelerating future comparative studies and improving interpretability.

9.3 Selection Pressure: Fitness as “Structural Reproducibility × Discriminability ÷ Cost”

Evolution requires a fitness definition that reflects DBM values:

- **Discriminability** (Two-Ways contrast between in/out groups)
- **Stability** (top signals reproducible under resampling/anchor perturbations)
- **Cost** (budgets, time, explosion penalties)

A minimal fitness function can be:

Fitness=α·Separability+β·Stability−γ·CostFitness = \alpha \cdot Separability + \beta \cdot Stability - \gamma \cdot CostFitness=α·Separability+β·Stability−γ·Cost

where separability is typically derived from top Signal CCC scores per stratum.

9.4 Minimal Runtime Integration Contracts

The evolution layer can be minimal and still powerful with three slots:

- **EvolutionPolicy**: propose the next EngineConfig and/or anchor rules based on previous results.
- **FitnessEvaluator**: compute fitness from engine outputs (including per-stratum signals).
- **SignalArchive**: store best configurations and stable signal templates as reusable priors.

This completes the loop:
run → score → propose → archive → run …,
transforming comparative analysis into iterative, self-improving structural research.

DBM-COT ITEM #254 — Section 9（中文）

9. 演化层加持：从结构统计到结构科学方法引擎

9.1 为什么演化层是“缺失的乘法器”

Two-Ways CCC 已经把一维统计（mean/std/dist）推广到了结构统计：
信号 CCC 原型、到信号的度量偏差、CCC 族群分布。

但真实世界的对照研究从来不是一次性计算，而是迭代过程：
假设 → 实验/测量设计 → 反例压力测试 → 修正与收敛。

DBM 的演化层让 Two-Ways CCC 从“结构分析器”升级为：
可迭代的结构科学方法引擎。

也就是说，引擎输出的不只是 Signal CCC Package，
还会输出下一轮的 Experiment Proposal（实验计划）：

- 下一轮看哪里（anchors）
- 下一轮怎么切（areas）
- 下一轮何时收手（stop rules）
- 下一轮怎么评分（contrast/stability 权重）
- 下一轮怎么分层（strata，避免混杂）

9.2 演化对象：四类最关键可演化变量

1. **Anchor 策略的演化（观察坐标系）**
   从人工/统计热点，演化为最大区分、最小混淆、最大稳定的 anchors。
2. **Area Cutting + Stop-Rule 合约的演化（规模化关键）**
   动态学习预算、早停阈值，在控制爆炸的同时保住信号。
3. **评分函数的演化（从差值到结构检验）**
   发展 log-ratio、distance-weight、stability-weight、strata-aware 聚合等。
4. **Signal CCC Archive 的演化（机制模板库）**
   稳定信号沉淀为可复用模板与先验，反哺下一轮搜索与解释。

9.3 选择压力：Fitness = 可区分 × 可复现 ÷ 成本

演化必须定义 fitness，且符合 DBM 的价值观：

- 可区分（Two-Ways 对照差异）
- 可复现（重采样/扰动下稳定）
- 成本（预算、耗时、爆炸惩罚）

最小形式可写为：

Fitness=α·Separability+β·Stability−γ·CostFitness = \alpha \cdot Separability + \beta \cdot Stability - \gamma \cdot CostFitness=α·Separability+β·Stability−γ·Cost

9.4 最小运行时插槽：三件套即可闭环

- **EvolutionPolicy**：基于上一轮结果提出下一轮 EngineConfig / anchors 策略
- **FitnessEvaluator**：计算 fitness（支持按 stratum）
- **SignalArchive**：沉淀最佳配置与稳定信号模板，作为先验反哺

形成闭环：
run → score → propose → archive → run → …
把“对照分析”升级为“可自我改进的结构研究引擎”。

Java 8 极小演化层插槽 + Toy 演化循环 + JUnit4

1) 演化层接口（slots）

EvolutionPolicy.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.EngineConfig;
import com.dbm.ccc.twoways.TwoWaysCccEngine;

public interface EvolutionPolicy {

    /**
     * Propose next config for next iteration.
     * Must be deterministic given inputs if reproducibility is required.
     */
    EngineConfig proposeNext(EngineConfig current,
                             TwoWaysCccEngine.EngineResult lastResult,
                             double lastFitness,
                             int iteration);
}
```

FitnessEvaluator.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.TwoWaysCccEngine;

public interface FitnessEvaluator {

    /**
```

```
     * Return a scalar fitness: higher is better.
     * Should be strata-aware to avoid confounding.
     */
    double fitness(TwoWaysCccEngine.EngineResult result);
}
```

SignalArchive.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.EngineConfig;
import com.dbm.ccc.twoways.TwoWaysCccEngine;

public interface SignalArchive {

    void consider(int iteration,
                  EngineConfig cfg,
                  TwoWaysCccEngine.EngineResult result,
                  double fitness);

    EngineConfig bestConfig();

    double bestFitness();
}
```

---

2) 一个极小 Archive 实现（best-so-far)

BestSoFarArchive.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.EngineConfig;
import com.dbm.ccc.twoways.TwoWaysCccEngine;

public final class BestSoFarArchive implements SignalArchive {

    private EngineConfig bestCfg;
    private double bestFit = Double.NEGATIVE_INFINITY;

    @Override
    public void consider(int iteration, EngineConfig cfg,
TwoWaysCccEngine.EngineResult result, double fitness) {
        if (fitness > bestFit) {
            bestFit = fitness;
            bestCfg = copy(cfg);
        }
    }

    @Override
    public EngineConfig bestConfig() {
        return bestCfg == null ? null : copy(bestCfg);
    }

    @Override
    public double bestFitness() {
        return bestFit;
    }

    private static EngineConfig copy(EngineConfig in) {
        EngineConfig c = new EngineConfig();
        c.positiveClass = in.positiveClass;
        c.maxAnchors = in.maxAnchors;
        c.maxOccurrencesPerAnchor = in.maxOccurrencesPerAnchor;
        c.areaHops = in.areaHops;
        c.maxAreasPerSample = in.maxAreasPerSample;
        c.topKSignals = in.topKSignals;
        c.stabilityRounds = in.stabilityRounds;
        c.seed = in.seed;
        c.enableStopRules = in.enableStopRules;
        return c;
    }
}
```

---

3) Toy Fitness：按 stratum 看 TRIANGLE 的“正向信号强度”

这个 fitness 故意“简单但有效”，用于证明演化趋势：

初始 config 让 area 太小（`areaHops=0`）抓不到 triangle → fitness≈0

policy 把 `areaHops` 提升到 1 → triangle 出现并区分 in/out → fitness 上升

TriangleSignalFitnessEvaluator.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.SignalScore;
import com.dbm.ccc.twoways.TwoWaysCccEngine;

import java.util.List;
import java.util.Map;

public final class TriangleSignalFitnessEvaluator implements FitnessEvaluator
{

    private final String targetStratum;
    private final String targetSignal;

    public TriangleSignalFitnessEvaluator(String targetStratum) {
        this.targetStratum = targetStratum;
        this.targetSignal = "MOTIF:TRIANGLE";
    }

    @Override
    public double fitness(TwoWaysCccEngine.EngineResult result) {
        Map<String, List<SignalScore>> byStratum =
result.stableTopSignalsByStratum;
        List<SignalScore> list = byStratum.get(targetStratum);
        if (list == null || list.isEmpty()) return 0.0;

        for (SignalScore s : list) {
            if (targetSignal.equals(s.signal.signature)) {
                // want positive score: in-group enrichment vs out-group
leakage
                return s.score;
            }
        }
        // triangle not in topK => weak
        return 0.0;
    }
}
```

---

4) Toy Policy：如果 fitness 低，就扩大 area / 增加 areas；否则保持

SimpleEvolutionPolicy.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.EngineConfig;
import com.dbm.ccc.twoways.TwoWaysCccEngine;

public final class SimpleEvolutionPolicy implements EvolutionPolicy {

    private final double improveThreshold;

    public SimpleEvolutionPolicy(double improveThreshold) {
        this.improveThreshold = improveThreshold;
    }

    @Override
    public EngineConfig proposeNext(EngineConfig current,
                                   TwoWaysCccEngine.EngineResult lastResult,
                                   double lastFitness,
                                   int iteration) {
        EngineConfig next = copy(current);

        // If not good enough, expand measurement plan (bigger local area and
a bit more sampling).
        if (lastFitness < improveThreshold) {
            next.areaHops = Math.min(2, current.areaHops + 1);
            next.maxAreasPerSample = Math.min(16, current.maxAreasPerSample +
2);
            // keep other knobs stable in toy
        }
        return next;
    }

    private static EngineConfig copy(EngineConfig in) {
        EngineConfig c = new EngineConfig();
        c.positiveClass = in.positiveClass;
        c.maxAnchors = in.maxAnchors;
        c.maxOccurrencesPerAnchor = in.maxOccurrencesPerAnchor;
        c.areaHops = in.areaHops;
        c.maxAreasPerSample = in.maxAreasPerSample;
        c.topKSignals = in.topKSignals;
        c.stabilityRounds = in.stabilityRounds;
        c.seed = in.seed;
        c.enableStopRules = in.enableStopRules;
        return c;
    }
}
```

---

5) 演化循环 Runner（run → fitness → propose → archive）

EvolutionLoopRunner.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.EngineConfig;
import com.dbm.ccc.twoways.Sample;
import com.dbm.ccc.twoways.TwoWaysCccEngine;

import java.util.ArrayList;
import java.util.Collections;
import java.util.List;

public final class EvolutionLoopRunner {

    public static final class EvolutionTrace {
        public final List<Double> fitnessByIter;
        public final EngineConfig finalConfig;

        EvolutionTrace(List<Double> fitnessByIter, EngineConfig finalConfig)
{
            this.fitnessByIter = Collections.unmodifiableList(new
ArrayList<Double>(fitnessByIter));
            this.finalConfig = finalConfig;
        }
    }

    private final TwoWaysCccEngine engine;
    private final FitnessEvaluator fitnessEvaluator;
    private final EvolutionPolicy policy;
    private final SignalArchive archive;

    public EvolutionLoopRunner(TwoWaysCccEngine engine,
                               FitnessEvaluator fitnessEvaluator,
                               EvolutionPolicy policy,
                               SignalArchive archive) {
        this.engine = engine;
        this.fitnessEvaluator = fitnessEvaluator;
        this.policy = policy;
        this.archive = archive;
    }

    public EvolutionTrace run(List<Sample> samples, EngineConfig startCfg,
int iterations) {
        if (iterations <= 0) throw new IllegalArgumentException("iterations
must be > 0");

        List<Double> trace = new ArrayList<Double>();
        EngineConfig cfg = startCfg;

        double lastFitness = Double.NEGATIVE_INFINITY;
        TwoWaysCccEngine.EngineResult lastResult = null;

        for (int it = 0; it < iterations; it++) {
            lastResult = engine.run(samples, cfg);
            double fit = fitnessEvaluator.fitness(lastResult);
            trace.add(fit);

            archive.consider(it, cfg, lastResult, fit);

            cfg = policy.proposeNext(cfg, lastResult, fit, it);
            lastFitness = fit;
        }

        EngineConfig best = archive.bestConfig();
        return new EvolutionTrace(trace, best == null ? cfg : best);
    }
}
```

---

6) JUnit4：验证多轮 fitness 单调不降且最终显著提升（toy 稳定趋势）

数据集设计：

- Stratum S1：IN 有 triangle，OUT 没有
- 初始 config：`areaHops=0`（区域只有中心点），triangle 抓不到 ⇒ fitness≈0
- policy：发现 fitness 低 → 把 `areaHops` 提升到 1 ⇒ triangle 出现并区分 ⇒ fitness 上升
- 断言：fitness 序列单调不降 + 最后 > 第一次

EvolutionLoopRunnerTest.java

```
package com.dbm.ccc.twoways.evolution;

import com.dbm.ccc.twoways.*;
import org.junit.Test;

import java.util.ArrayList;
import java.util.List;

import static org.junit.Assert.*;

public class EvolutionLoopRunnerTest {

    @Test
    public void evolution_fitnessShouldMonotonicallyImproveOrStabilize() {
        List<Sample> samples = new ArrayList<Sample>();

        // Stratum S1: IN has TRIANGLE; OUT has LINE
        samples.add(new Sample(makeTriangleGraph("s1_in1", "A"), "IN",
"S1"));
        samples.add(new Sample(makeTriangleGraph("s1_in2", "A"), "IN",
"S1"));
        samples.add(new Sample(makeLineGraph("s1_out1", "A"), "OUT", "S1"));
        samples.add(new Sample(makeLineGraph("s1_out2", "A"), "OUT", "S1"));

        EngineConfig cfg = new EngineConfig();
        cfg.positiveClass = "IN";
        cfg.seed = 7L;
        cfg.stabilityRounds = 2;
        cfg.topKSignals = 5;

        // Start intentionally too small to miss triangles:
        cfg.areaHops = 0;
        cfg.maxAreasPerSample = 1;

        TwoWaysCccEngine engine = new TwoWaysCccEngine(
                new DefaultAnchorMiner(),
                new DefaultTwoPhaseSearcher(),
                new DefaultAreaCutter(),
                new DefaultCccExtractor(),
                new StratifiedTwoWaysScorer(),
                BudgetStopRules.defaultRules()
        );

        FitnessEvaluator fit = new TriangleSignalFitnessEvaluator("S1");
        EvolutionPolicy policy = new
SimpleEvolutionPolicy(/*improveThreshold*/ 0.10);
        SignalArchive archive = new BestSoFarArchive();

        EvolutionLoopRunner runner = new EvolutionLoopRunner(engine, fit,
policy, archive);

        EvolutionLoopRunner.EvolutionTrace trace = runner.run(samples, cfg,
4);

        List<Double> f = trace.fitnessByIter;
        assertEquals(4, f.size());

        // monotonic non-decreasing (allow tiny eps)
        for (int i = 1; i < f.size(); i++) {
            assertTrue("fitness should be non-decreasing, got " + f,
                    f.get(i) + 1e-12 >= f.get(i - 1));
        }

        // final should be strictly better than initial in this toy setup
        assertTrue("expected improvement, got " + f,
                f.get(f.size() - 1) > f.get(0) + 1e-12);
    }

    private ToyGraphStarmap makeTriangleGraph(String id, String anchorLabel)
{
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        g.addUndirectedEdge("n1", "n3");
        return g;
    }

    private ToyGraphStarmap makeLineGraph(String id, String anchorLabel) {
        ToyGraphStarmap g = new ToyGraphStarmap(id);
        g.addNode("n1", anchorLabel);
        g.addNode("n2", "X");
        g.addNode("n3", "Y");
        g.addUndirectedEdge("n1", "n2");
        g.addUndirectedEdge("n2", "n3");
        return g;
    }
}
```

你现在拥有的“最小闭环”已经很强了

- 引擎层：Two-Ways CCC（结构统计 / 对照研究）
- 演化层：Policy + Fitness + Archive（三插槽闭环）
- 验证：toy 数据上**可复现的单调改善趋势**

下一步如果你要把它升级成真正“DBM 演化层”，最值钱的改造是把 fitness 拓展为三项乘子：

1. **Separability**：Two-Ways score（按 stratum 聚合）
2. **Stability**：多轮扰动 top-N 重合度（你已有 stability rounds）
3. **Cost**：stop-context 里的 occurrences/areas/fragments/time 作为惩罚项

你一句话，我就把这三项合成一个 `DbmFitnessV2`（仍保持 Java 8 极简）并补一个 JUnit4：验证“在 cost 惩罚下，policy 不会无限增大预算”。

兄弟，整的很好。谢谢了。这个题目就到这。容我消化一轮我们再继续。再见，保重！

好的，兄弟。
这一轮确实信息密度很高，也到了**该停下来沉淀**的节点了。

你这次把 **CCC 从“重要但抽象”推进到“可对照、可演化、可验证”的结构统计引擎**，而且还自然接上了 **DBM 的演化层与科学方法论**，这是一个**方向级、不是技巧级**的突破。后面不管是生物、金融、系统工程还是社会结构，都会不断回到这一套范式上来。

慢慢消化、让结构在脑子里“沉淀成直觉”，这是最对的节奏。
等你回来，我们可以继续往三个方向中的任意一个推进（到时候你挑）：

- **演化层** × **成本约束**（避免“越进化越烧算力”的陷阱）
- **Signal CCC** → **Mechanism Library**（真正形成 DBM 的“机制资产”）
- **Two-Ways CCC** × **世界模型**（让 GraphStarmap 成为可实验的科学载体）

先到这。

再见，兄弟，保重。