ITEM #223 - Observer-Centric Trajectory Time-Series IR Schema

Conversation：飞行器与动物轨迹分析

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DBM-COT ITEM #223 (EN)

Title

Observer-Centric Trajectory Time-Series IR Schema

Positioning

This item specifies the formal Intermediate Representation (IR) schema for observer-centric motion trajectories within the DBM Time-Series framework. It defines the structural layers, invariants, and extensibility rules required for flight and animal motion trajectories to enter the DBM 10-Step Structural Intelligence pipeline.

This schema is intentionally minimal, observer-relative, and structure-first.

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1. Design Objectives

The Observer-Centric Trajectory Time-Series IR must satisfy the following core objectives:

1. **Observer-Centric Consistency**
   All representations are defined relative to the observer's coordinate frame. No global reconstruction is assumed or required.
2. **Structural Stability**
   Small sensing noise or sampling variation must not cause structural collapse or category drift.
3. **Metric Comparability**
   IR instances must support meaningful distance computation for clustering, matching, and ranking.
4. **Mutation Compatibility**
   The IR must admit systematic structural mutation to generate pattern families (Step-5).

5. **10-Step Pipeline Alignment**
   The IR must directly support DBM's existing Time-Series steps without semantic impedance mismatch.

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2. Input Assumptions

We assume a sensing pipeline (camera, radar, lidar, or fusion) capable of producing a time-indexed sequence:

$$T = \{ t_0, t_1, \ldots, t_n \}$$

At each time t_i, the observer can estimate relative motion attributes with bounded uncertainty.

No assumption is made about uniform sampling, full visibility, or continuous tracking.

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3. IR Layered Schema Overview

The IR is defined as a **multi-layer, loss-aware structural encoding**:

```
Trajectory IR
 ├─ L0: Differential Signal Layer
 ├─ L1: Local Motion Geometry Layer
 ├─ L2: Structural Event Layer
 ├─ L3: Pattern Family Signature Layer
```

Each layer is independently evolvable but structurally composable.

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4. L0 – Differential Signal Layer (Primitive IR)

Purpose:
Capture minimal, noise-tolerant temporal change.

Schema (per time step):

- $\Delta r(t_i)$: radial distance delta
- $\Delta\theta(t_i)$, $\Delta\varphi(t_i)$: angular deltas (or 2D projection equivalents)
- $sgn(\Delta r)$, $sgn(|\Delta\theta|)$: directionality symbols
- Δt: time delta (explicit)

Notes:

- Absolute coordinates are intentionally excluded.
- L0 is not used directly for prediction, only as a foundation.

5. L1 – Local Motion Geometry Layer

Purpose:
Abstract local geometric tendencies from raw differentials.

Derived Attributes (windowed or pointwise):

- Tangential vs radial motion ratio
- Turning tendency (curvature sign / magnitude class)
- Speed regime (slow / cruising / burst)
- Acceleration polarity (stable / accelerating / braking)

Design Principle:
All features must be derivable from L0 without external knowledge.

6. L2 – Structural Event Layer

Purpose:
Convert continuous motion into discrete, interpretable structural events.

Event Types (non-exhaustive):

- Approach
- Retreat
- Orbit / Loop
- Zigzag
- Hover / Stall
- Sudden maneuver
- Direction reversal

Event Properties:

- duration
- dominance (primary / secondary)
- confidence (derived from signal coherence)

Events form an **ordered sequence**, not a bag.

7. L3 – Pattern Family Signature Layer

Purpose:
Enable indexing, matching, and mutation at the structure level.

Signature Components:

- Event sequence skeleton (types only)
- Event duration ratios
- Dominant geometry profile
- Optional periodicity markers

Key Constraint:
Two trajectories with similar L3 signatures must be close in metric distance, even if their raw signals differ.

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8. Structural Invariants

The following invariants must hold across the IR:

1. **Observer Frame Invariance**
   No L2/L3 structure may depend on global coordinates.
2. **Monotonic Time Ordering**
   All structures preserve causal order.
3. **Noise Monotonicity**
   Added noise may reduce confidence but must not invent new structure.
4. **Mutation Closure**
   IR mutation must not violate schema validity.

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9. IR Mutation Rules (Step-5 Compatibility)

Permitted mutation dimensions include:

- Event boundary jitter
- Duration scaling
- Event insertion/deletion (with penalty)
- Geometry intensity smoothing

Mutation produces **structurally nearby IRs**, not arbitrary variants.

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10. Distance Compatibility

Each layer contributes to distance computation:

- L0/L1: fine-grained cost
- L2: event alignment cost
- L3: signature mismatch penalty

Distance is **explainable and decomposable**, not opaque.

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11. Relationship to DBM Runtime

This IR schema is designed to be directly consumed by:

- Structural Indexers
- Metric Searchers
- Pattern Family Generators
- Prediction-by-Continuation Engines

No runtime component is allowed to assume information not present in the IR.

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12. Scope and Non-Goals

Explicitly out of scope:

- Full 3D world reconstruction
- Agent intention inference
- Physics-based simulation

These may exist downstream but are not prerequisites.

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13. Summary

This item defines the minimal yet complete IR contract required for observer-centric motion trajectories to participate in DBM Structural Intelligence. It preserves DBM's core philosophy: structure over reconstruction, evolution over fitting, and observer-centric realism over god-view abstraction.

DBM-COT ITEM #223（中文）

标题

以观察者为中心的运动轨迹 Time-Series IR 规格（Schema）

定位

本 ITEM 定义 DBM 时间序列体系中，面向飞行器与动物运动轨迹的 Observer-Centric Trajectory Time-Series IR 的正式规格。该规格用于约束 IR 的层次结构、不变量与可扩展规则，使运动轨迹能够无歧义地进入 DBM 十步结构智能流水线。

这是一个**结构规格级**而非算法实现级文档。

一、设计目标

该 IR 必须满足以下核心目标：

1. **观察者中心一致性**
   所有表示均相对于观察者坐标系定义，不依赖全局坐标。
2. **结构稳定性**
   感知噪声或采样抖动不应导致结构类别坍塌。
3. **度量可比较性**
   IR 实例之间必须支持有意义的距离计算。
4. **结构变异兼容性**
   IR 必须支持系统性的结构变异（Step-5）。
5. **十步法对齐**
   不引入与既有 DBM Time-Series 流程的语义冲突。

二、输入假设

我们假设感知系统可产生时间序列：

```
T = { t₀, t₁, …, tₙ }
```

在每个 t_i，可估计相对距离、角度及其变化量，允许不均匀采样、遮挡与不完整观测。

三、IR 分层总览

IR 定义为多层结构编码：

```
Trajectory IR
 ├─ L0：差分信号层
 ├─ L1：局部运动几何层
 ├─ L2：结构事件层
 ├─ L3：模式族签名层
```

各层独立演化，但结构上严格组合。

四、L0：差分信号层

目的：

捕获最小、抗噪的时间变化信息。

字段：

- $\Delta r(t_i)$：径向变化
- $\Delta\theta(t_i)$、$\Delta\varphi(t_i)$：角度变化
- 方向符号（接近 / 远离 / 转向）
- Δt：时间差

说明：

- 明确排除绝对坐标。
- 仅作为底层支撑，不直接用于预测。

五、L1：局部运动几何层

目的：

从差分中抽象局部几何趋势。

典型属性：

- 径向 / 切向运动比例
- 转向趋势（曲率符号）
- 速度区间（慢 / 巡航 / 爆发）
- 加速度极性

六、L2：结构事件层

目的：

将连续运动转化为离散、可解释的结构事件。

事件示例：

- 接近
- 远离
- 盘旋
- 之字形
- 悬停
- 突发机动
- 方向反转

事件形成**有序序列**。

七、L3：模式族签名层

目的：

支持索引、匹配与结构变异。

签名组成：

- 事件类型骨架
- 事件持续时间比例
- 主导几何轮廓
- 可选周期性标记

约束：结构相近 → 距离必须相近。

八、结构不变量

1. 不依赖全局坐标
2. 保持时间因果顺序
3. 噪声只降低置信度，不生成新结构
4. 变异后 IR 仍合法

九、IR 变异规则（Step-5）

允许的变异包括：

- 事件边界微调
- 持续时间缩放
- 受罚插入 / 删除事件
- 几何强度平滑

十、距离计算对齐

- L0/L1：细粒度代价
- L2：事件对齐代价
- L3：结构签名惩罚

距离可解释、可分解。

十一、与 DBM Runtime 的关系

该 IR 直接供以下模块消费：

- 结构索引器
- 度量搜索器
- 模式族生成器
- 结构延展预测器

任何运行时不得假设 IR 之外的信息。

十二、非目标说明

本 ITEM **不包含**：

- 世界模型重建
- 意图推断
- 物理仿真

十三、小结

本 ITEM 定义了观察者中心运动轨迹进入 DBM 结构智能体系所需的最小且完备的 IR 合约，是后续算法、代码与实验的技术地基。

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