ITEM #227 - Motion Trajectory as Time-Series IR: Minimal Differential Primitives for Physical and Biological Movement

Conversation：运动轨迹 Time-Series IR

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DBM-COT ITEM #227 (EN)

Motion Trajectory as Time-Series IR: Minimal Differential Primitives for Physical and Biological Movement

Abstract

This item formalizes the minimal and sufficient raw input representation for modeling physical and biological motion trajectories as Time-Series IR (Information Representation). By decomposing motion into discrete time samples, local geometric direction, and differential changes in position and direction, we establish a coordinate-agnostic, structure-centric IR foundation applicable to aircraft flight, animal locomotion, and other embodied systems. Absolute positions and orientations are explicitly excluded from IR signals and retained only for interpretation and alignment.

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1. Discrete Time Sampling

Given a motion process, we sample the trajectory at fixed or variable time intervals:

```
t[k],  k = 0, 1, 2, …, n
```

The index *k* defines a strictly ordered temporal sequence, serving as the fundamental axis of the Time-Series IR. Continuity is assumed only locally between adjacent samples.

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2. Spatial Observation (Interpretation Layer)

At each time point, the observed spatial position is recorded as:

```
p[k] = (x[k], y[k], z[k])
```

These absolute coordinates **do not directly constitute IR signals**. They serve as raw observations and are retained for visualization, physical grounding, and post-hoc interpretation.

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3. Local Motion Geometry: Directional Normal

At each sampled point, a plane orthogonal to the instantaneous motion direction is defined. Its normal vector represents the local direction of motion:

```
n[k] = (α[k], β[k], γ[k])
```

This normal captures the first-order geometric structure of the trajectory at time *k*, independent of global coordinate frames.

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4. Differential Primitives Between Adjacent Samples

For each adjacent time pair *(k, k+1)*, two and only two differential quantities are extracted as **raw Time-Series IR primitives**:

4.1 Positional Change (Magnitude)

```
Δpos[k] = || p[k+1] - p[k] ||
```

This represents displacement magnitude, corresponding to speed, effort, or kinetic intensity.

4.2 Directional Change (Structure)

```
Δdir[k] = angle( n[k], n[k+1] )
```

This represents turning, curvature, hesitation, or maneuvering behavior.

Together, *(Δpos, Δdir)* form the minimal sufficient IR describing motion dynamics.

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5. Exclusion of Absolute State from IR

For motion trajectory IR:

- Absolute coordinates *(x, y, z)*
- Absolute directions *(α, β, γ)*

must not be treated as IR signals.

They are invariant-breaking, context-dependent, and system-specific. Instead, only *differential changes* carry structural information suitable for metric comparison, clustering, and reasoning.

Absolute values may be retained solely as **explanatory or alignment metadata**.

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6. Relation to Time-Series Structural Intelligence

This representation directly parallels financial Time-Series IR:

Financial Series	Motion Trajectory
Price	Absolute position
Price delta	Δpos
Trend change	Δdir

The IR captures **decision structure**, not raw state.

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7. Scope and Applicability

This primitive IR applies uniformly to:

- Aircraft and UAV flight trajectories
- Animal locomotion and migration
- Human motion and behavior tracking
- Autonomous robotic navigation

Higher-order constructs (curvature, maneuver patterns, intent inference) must be derived **above** this layer, preserving the minimality and purity of the raw IR.

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8. Core Principle

Motion Time-Series IR should encode how movement changes, not where it is.

This principle anchors motion modeling within the broader DBM Structural Intelligence framework.

DBM-COT ITEM #227（中文）

运动轨迹的 Time-Series IR：物理与生物运动的最小差分原语

摘要

本文正式定义了将物理与生物运动轨迹建模为 Time-Series IR（信息表征）的最小且充分的原始输入形式。通过离散时间采样、局部运动几何结构以及位置与方向的差分变化，建立了一套与坐标系无关、以结构为中心的 IR 基础，适用于飞行器、动物运动及其他具身系统。绝对坐标与绝对方向被明确排除在 IR 信号之外，仅作为解释与对齐数据保留。

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1. 离散时间采样

对任意运动过程，在固定或可变时间间隔下采样：

```
t[k],  k = 0, 1, 2, …, n
```

索引 k 构成严格有序的时间序列，是 Time-Series IR 的基本轴线，仅假设相邻采样点之间具有局部连续性。

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2. 空间观测（解释层）

在每个时间点，记录空间位置：

```
p[k] = (x[k], y[k], z[k])
```

这些**绝对坐标不直接作为 IR 信号**，仅作为原始观测数据，用于可视化、物理语义解释与后续对齐。

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3. 局部运动几何：方向法线

在每个采样点，构造一垂直于瞬时运动方向的平面，其法线表示该点的运动方向：

```
n[k] = (α[k], β[k], γ[k])
```

该法线刻画了轨迹在时间 *k* 的一阶几何结构，与全局坐标系无关。

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4. 相邻采样点之间的差分原语

对任意相邻时间点 *(k, k+1)*，仅提取以下**两个差分量**作为 Time-Series IR 的最基本原始输入：

4.1 位置变化（尺度）

```
Δpos[k] = || p[k+1] - p[k] ||
```

表示位移大小，对应速度、能量投入或行为强度。

4.2 方向变化（结构）

```
Δdir[k] = angle( n[k], n[k+1] )
```

表示转向、曲率、犹豫、规避或机动行为。

(Δpos, Δdir) 构成描述运动动力学的**最小充分 IR 对**。

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5. 绝对状态不应进入 IR

在运动轨迹 IR 中：

- 绝对位置 *(x, y, z)*
- 绝对方向 *(α, β, γ)*

不应作为 IR 信号使用。

它们破坏不变性，强依赖上下文与系统设定，仅适合作为**解释数据或对齐元数据**存在。

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6. 与时间序列结构智能的对应关系

该建模方式与金融时间序列 IR 完全同构：

金融时间序列	运动轨迹
价格	绝对位置
价格变动	Δpos
趋势变化	Δdir

IR 关注的是**决策与行为结构**，而非状态本身。

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7. 适用范围

该最小 IR 原语统一适用于：

- 飞行器与无人机轨迹
- 动物运动与迁徙
- 人体行为与动作序列
- 自主机器人导航

更高阶结构（曲率、机动模式、意图推断）必须在此之上派生，而不污染原始 IR 层。

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8. 核心原则

运动的 Time-Series IR 应描述“如何变化”，而非“位于何处”。

该原则是 DBM 结构智能体系中运动建模的基石。
