

# Time is Not a Label: Continuous Phase Rotation for Temporal Knowledge Graphs and Agentic Memory

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## Contributions

- (1) We formalise the **static–dynamic dilemma**: discrete timestamps treat all relations alike, so conflicts cannot be resolved without burying static knowledge.
- (2) **Geometric shadowing**: time is a continuous phase rotation in complex space, so obsolete facts rotate out of phase. Memory stays append-only, with no LLM call per write.
- (3) A **Semantic Speed Gate** learns each relation’s volatility from its text embedding and transfers zero-shot to unseen relations and domains.

**72.6**

MRR on ICEWS05-15,  
state of the art in TKG completion

**3.3×**

answer accuracy on MultiTQ  
(Acc@5 0.112 → 0.366 over HippoRAG)

**+0.8**

MRR on largely static DMR-MSc:  
no degradation on non-temporal memory

## 1 Motivation: The Static–Dynamic Dilemma

Graph-based agentic memories store time as *discrete metadata*. When facts conflict, e.g. (US, president, Obama) vs. (US, president, Trump), current systems fall back on one of three workarounds:

| Workaround              | Limitation                                                                              |
|-------------------------|-----------------------------------------------------------------------------------------|
| Destructive overwriting | ✗ permanently loses historical context                                                  |
| LLM arbitration         | ✗ one LLM call per ingestion; infeasible for millions of facts                          |
| Recency sorting         | ✗ buries static facts: (Obama, born_in, Hawaii) ranks below fresher, irrelevant entries |

A timestamp records *when* a fact was observed, but not *whether the relation is permanent or transient*. Memory needs to know **which relations change**.

## 2 Method: RoMEM

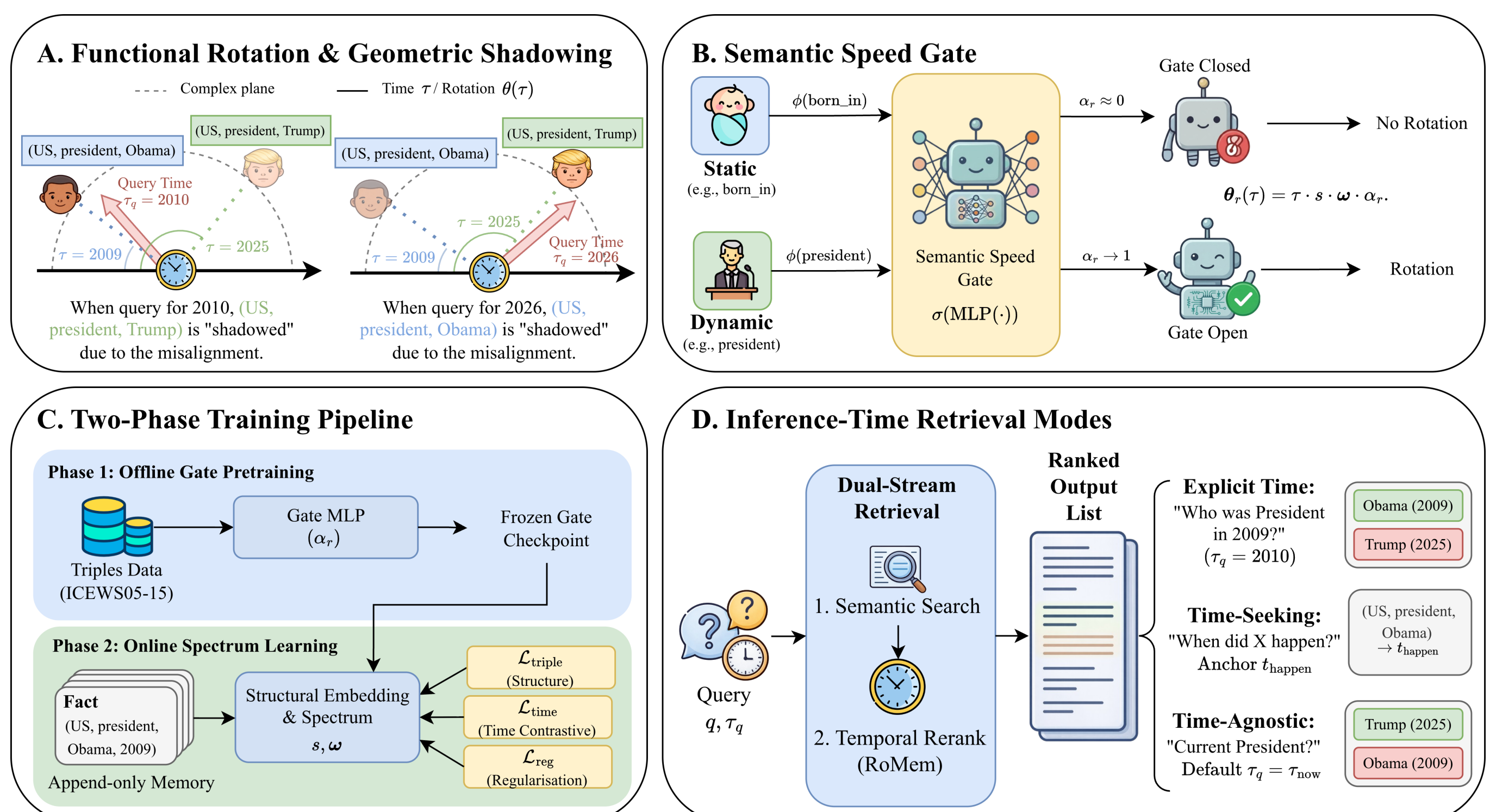


Figure 1. Overview: (A) functional rotation and geometric shadowing; (B) Semantic Speed Gate; (C) two-phase training; (D) inference-time retrieval.

### Functional rotation

Entities and relations live in  $\mathbb{C}^d$ . A continuous time  $\tau$  rotates each entity by a relation-specific angle:

$$\theta_r(\tau) = s \cdot \alpha_r \cdot \tau \cdot \omega, \quad \text{Rot}(\mathbf{e}, \theta) = \mathbf{e} \odot e^{i\theta}$$

with global scale  $s$  and learnable frequencies  $\omega$  (ChronoR-style bilinear scoring  $s_{kge}$ ). Rotation preserves the modulus, so a wrong time moves a fact *out of phase* instead of shrinking it, and unseen timestamps can be scored directly.

### Semantic Speed Gate

A small MLP maps the relation’s text embedding to a rotation speed,  $\alpha_r = \sigma(\text{MLP}(\phi(r))) \in (0, 1)$ . Static relations (born\_in) get  $\alpha_r \approx 0$  and never rotate; dynamic ones (president\_of) get  $\alpha_r \rightarrow 1$ . As  $\alpha_r$  is read from the text embedding  $\phi(r)$ , paraphrases (*married to*, *wedded to*) share one speed.

### Two-phase training

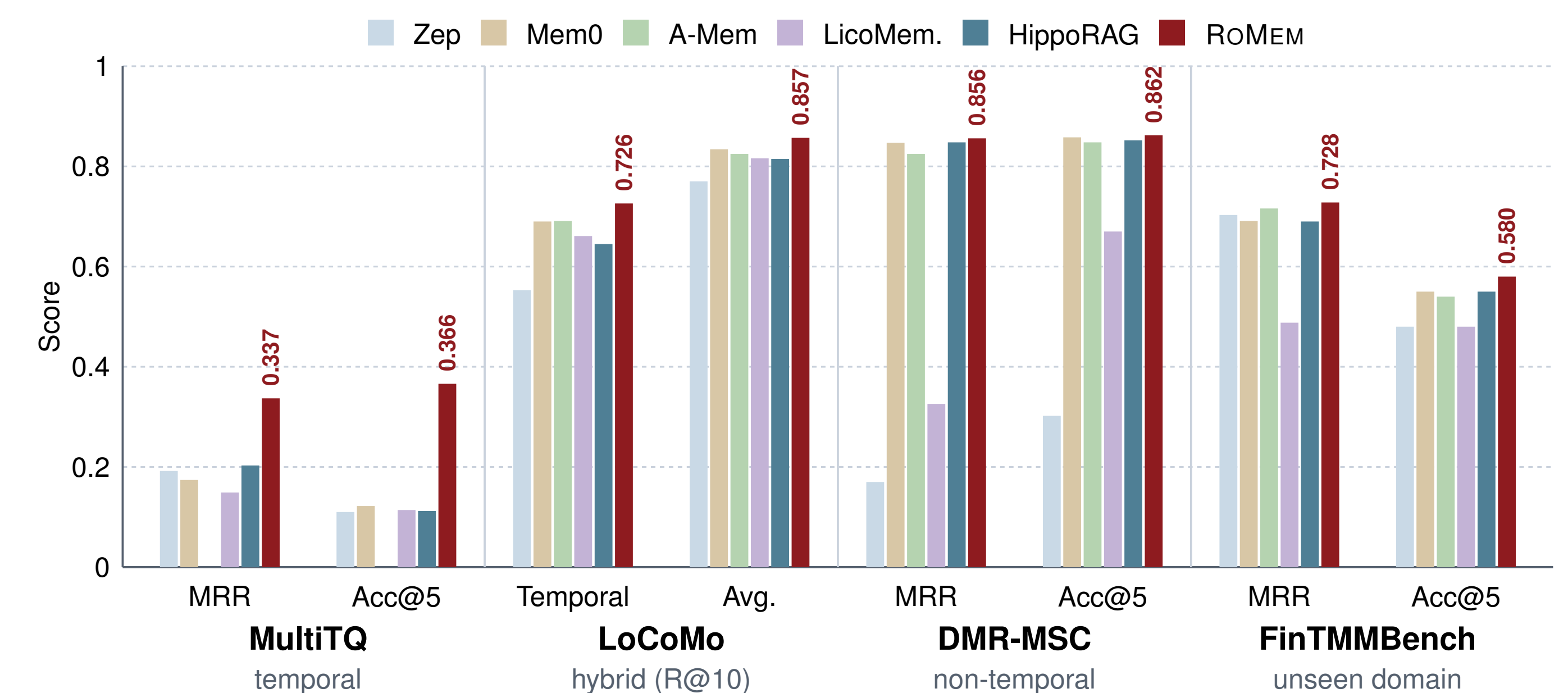
**Phase 1**: pretrain the gate offline on temporal transitions from ICEWS05-15 with  $p_{\text{change}} = 1 - e^{-\alpha_r \lambda \Delta t}$  and a BCE loss; no static/dynamic labels. **Phase 2**: freeze the gate; learn  $(s, \omega)$  and embeddings on the target graph with  $\mathcal{L}_{\text{triple}} + \lambda_t \mathcal{L}_{\text{time}} + \mathcal{L}_{\text{reg}}$ .

### Retrieval

RoMEM reranks HippoRAG’s candidates with  $S_{\text{final}} = S_{\text{sem}}(1 + \alpha_g S_{kge})$ , so time only amplifies facts that are already on topic. At query time  $\tau_q$ , the temporally valid fact is in phase and **shadows** obsolete ones without deleting them. Setting  $\tau_q$  in the past restores historical facts; with no time in the query,  $\tau_q = \tau_{\text{now}}$ .

## 3 Results: Agentic Memory

**Benchmarks**: MultiTQ (temporal reasoning), LoCoMo (hybrid), DMR-MSc (largely non-temporal), FinTMMBench (unseen financial domain). **Baselines**: Zep, Mem0, A-Mem, LicoMem, HippoRAG. Graphs built with GPT-5-mini + text-embedding-3-small. RoMEM reranks the same candidates as HippoRAG, so their gap isolates temporal reranking.



■ **Temporal (MultiTQ)**: MRR 0.203 → **0.337**, Acc@5 0.112 → **0.366** over HippoRAG; LLaMA-3.1-70B + BGE-M3 shows the same trend (Acc@5 0.122 → 0.312).

■ **Non-temporal (DMR-MSc)**: performance preserved (MRR 0.848 → 0.856).

■ **Unseen domain (FinTMMBench)**: the frozen gate transfers from geopolitics to finance (MRR 0.690 → 0.728).

## 4 Results: TKG Completion & Ablation

ICEWS05-15 (filtered)

| Method        | MRR         | H@1         | H@3         | H@10        |
|---------------|-------------|-------------|-------------|-------------|
| TComplEx      | 66.5        | 58.3        | 71.6        | 81.1        |
| ChronoR       | 68.4        | 61.1        | 73.0        | 82.1        |
| TCompoundE    | 69.2        | 61.2        | 74.3        | 83.7        |
| TimeGate      | 69.2        | 61.3        | 74.5        | 83.7        |
| 3DG-TE        | 69.4        | 61.4        | 74.7        | <b>84.1</b> |
| RoMEM-ChronoR | <b>72.6</b> | <b>66.8</b> | <b>75.9</b> | <b>83.7</b> |

Ablation (MultiTQ)

| Variant                         | MRR         | Acc@5       |
|---------------------------------|-------------|-------------|
| Full RoMEM                      | <b>.337</b> | <b>.366</b> |
| w/o $\mathcal{L}_{\text{time}}$ | .325        | .340        |
| w/o speed gate                  | .104        | .100        |
| discrete time                   | .045        | .040        |

Functional time improves the ChronoR backbone by **+4.2 MRR** (DistMult: +16.5). Removing the gate (**−69% MRR**) or using discrete timestamps (**−87%**) collapses temporal retrieval: volatility must be per-relation, and time must be continuous.

## 5 Geometric Shadowing in Practice

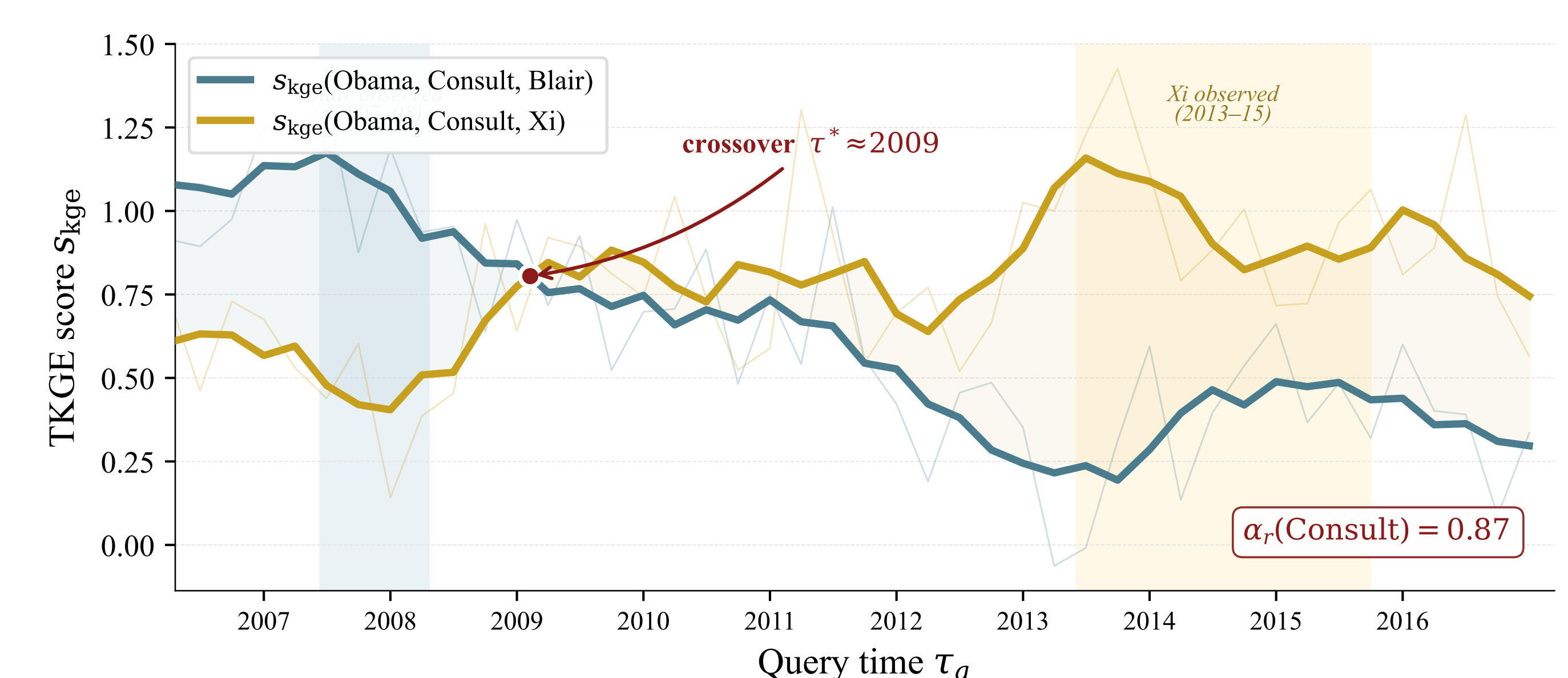


Figure 2. TKGE scores for (Obama, Consult, ?) on ICEWS05-15 as the query time  $\tau_q$  moves ( $\alpha_{\text{Consult}} = 0.87$ ). Xi overtakes Blair around 2009: the obsolete fact is outranked, not deleted.

## 6 Conclusion

Time should not be a label attached to a fact. Modelling it as a **continuous rotation** with a **learned per-relation speed** resolves temporal conflicts geometrically, in an append-only memory: **state of the art** on ICEWS05-15, large gains on temporal agentic memory, no loss on static memory, and zero-shot transfer to finance.

