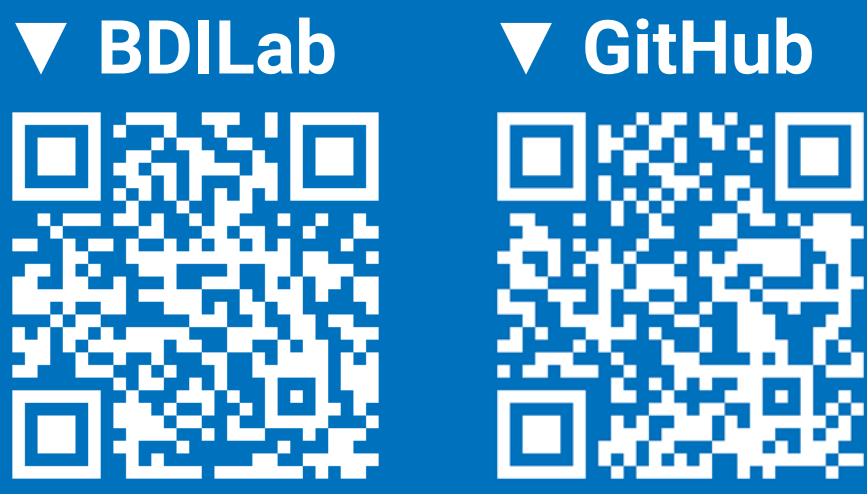


Representation Learning on Hyper-Relational and Numeric Knowledge Graphs with Transformers



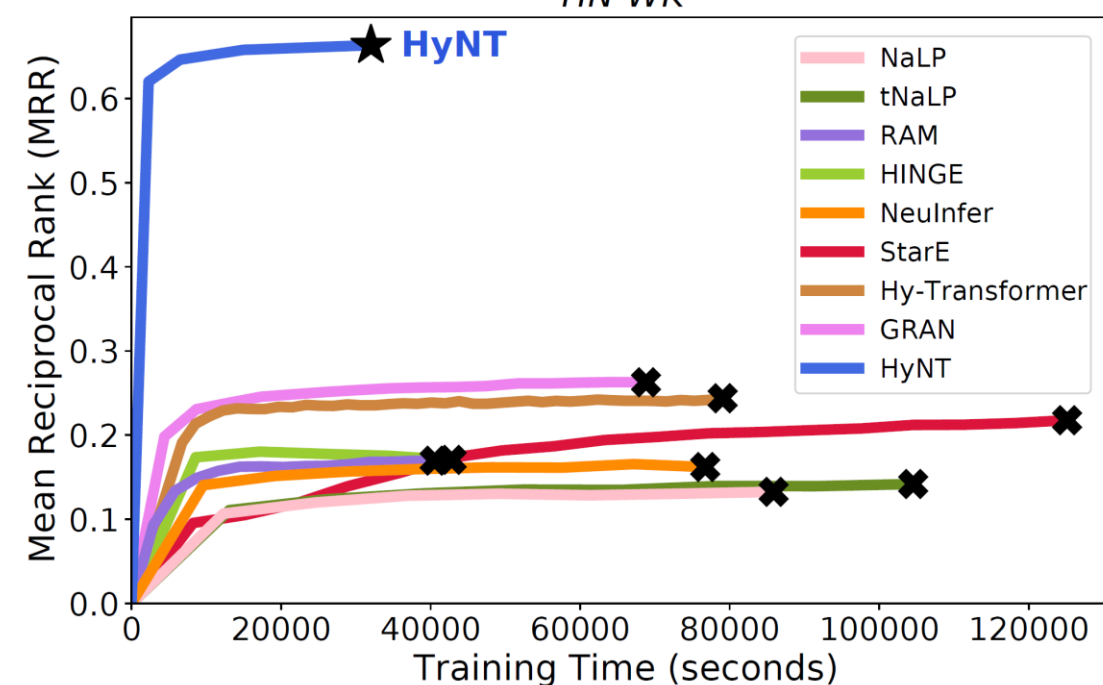
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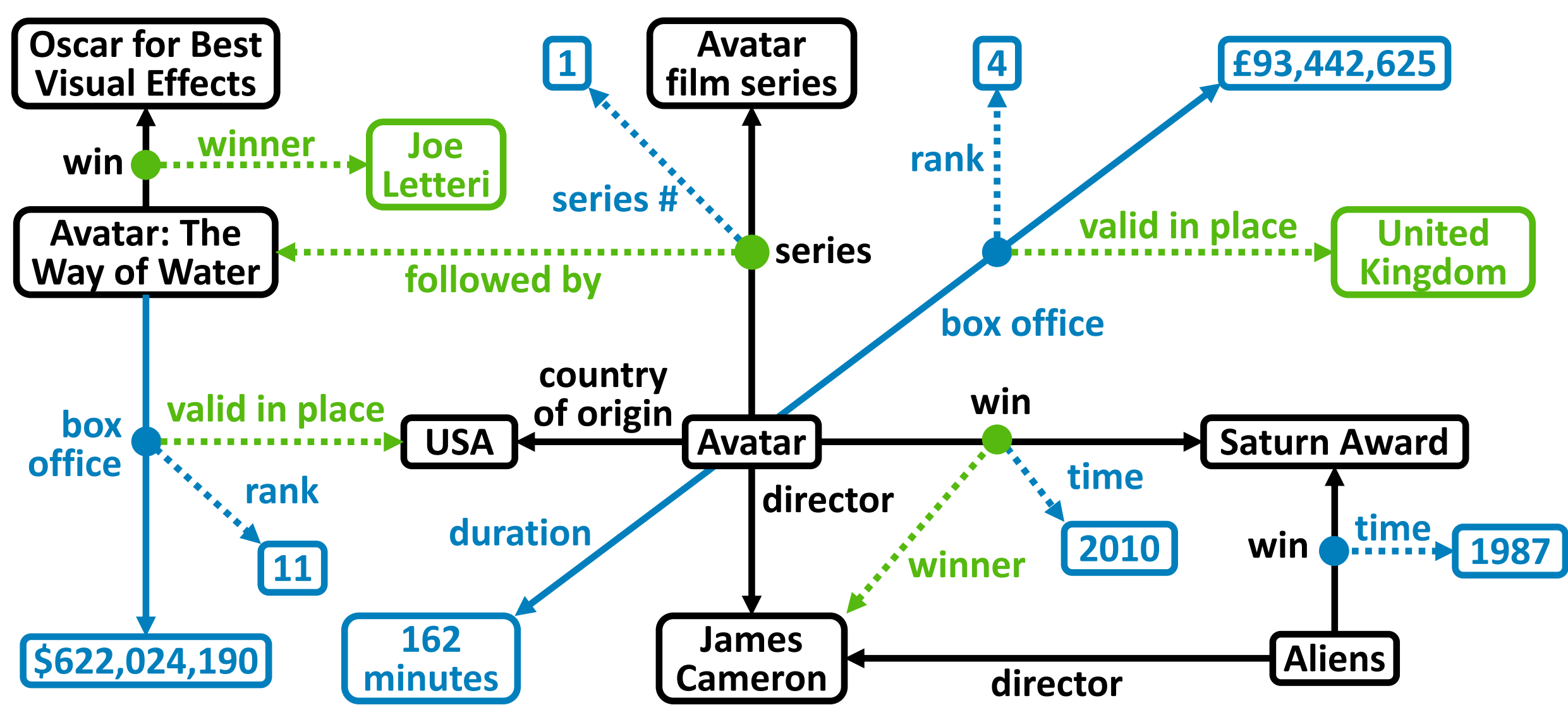
Main Contributions

- Define **Hyper-relational and Numeric Knowledge Graphs (HN-KGs)**
 - Create 4 real-world HN-KG datasets
- Propose **HyNT**, Hyper-relational knowledge graph embedding with **N**umeric literals using **T**ransformers
 - Define a context transformer and a prediction transformer
 - Reduce the cost by learning compact representations of triplets and qualifiers
- HyNT significantly outperforms 12 different state-of-the-art methods for **link prediction**, **numeric value prediction**, and **relation prediction**



Hyper-relational and Numeric Knowledge Graphs (HN-KGs)

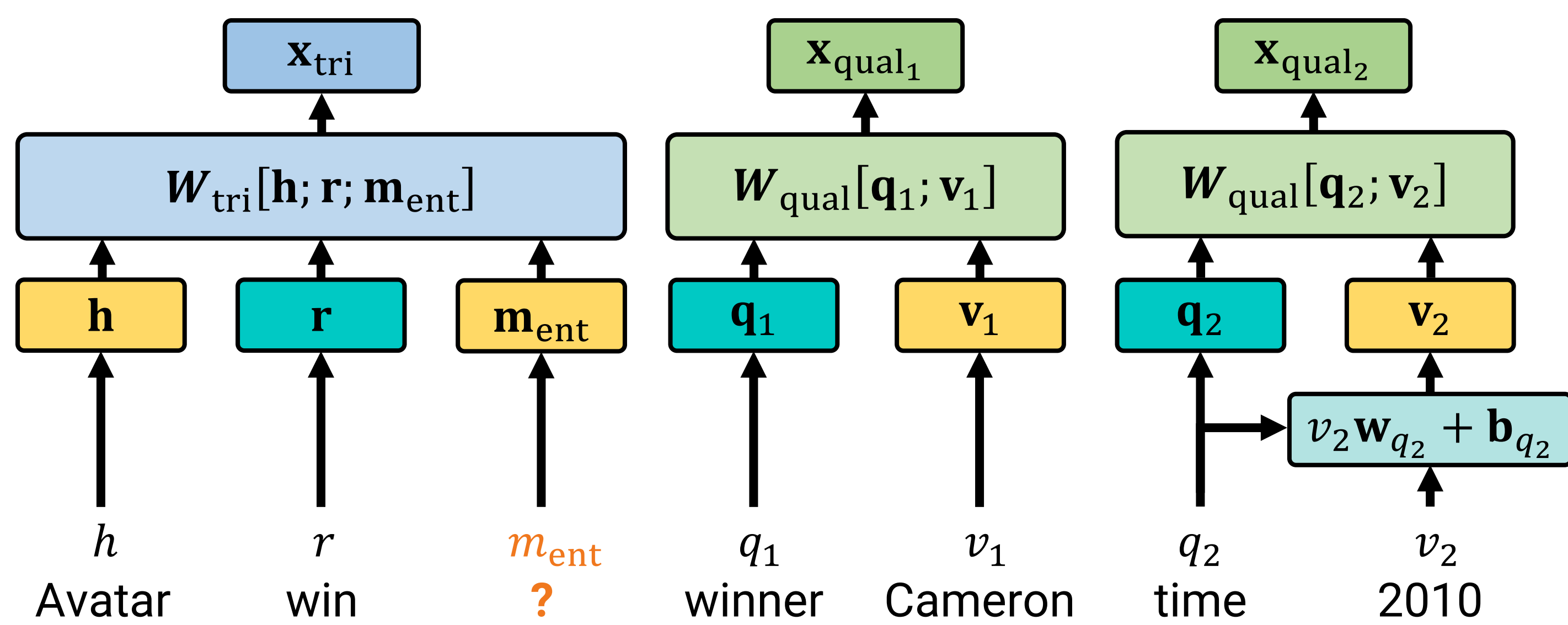
- Hyper-relational Knowledge Graphs**
 - Attach a set of **qualifiers** to a triplet to enrich information
 - Existing methods assume that all entities are **discrete** objects
- Hyper-relational and Numeric Knowledge Graphs**
 - Contain both hyper-relational facts and numeric values



- An example of a hyper-relational fact
 - $((\text{Avatar, win, Saturn_Award}), \{(\text{winner, James_Cameron}), (\text{time, 2010})\})$
 - Primary Triplet: Avatar, win, Saturn_Award
 - Qualifier 1: winner, James_Cameron
 - Qualifier 2: time, 2010
- Predictions on HN-KGs
 - Link Prediction:** Predict a missing **discrete entity**
 - Numeric Value Prediction:** Predict a missing **numeric value**
 - Relation Prediction:** Predict a missing **relation**
 - The missing component can be in either a **primary triplet** or a **qualifier**

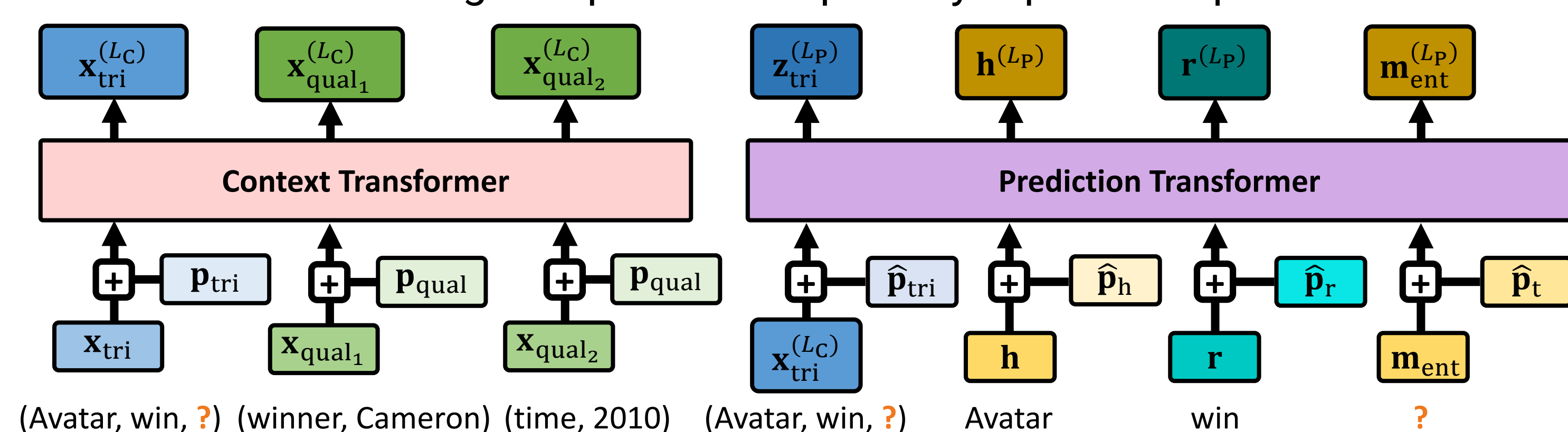
Triplet/Qualifier Encoding

- Convert a triplet/qualifier to a representation vector



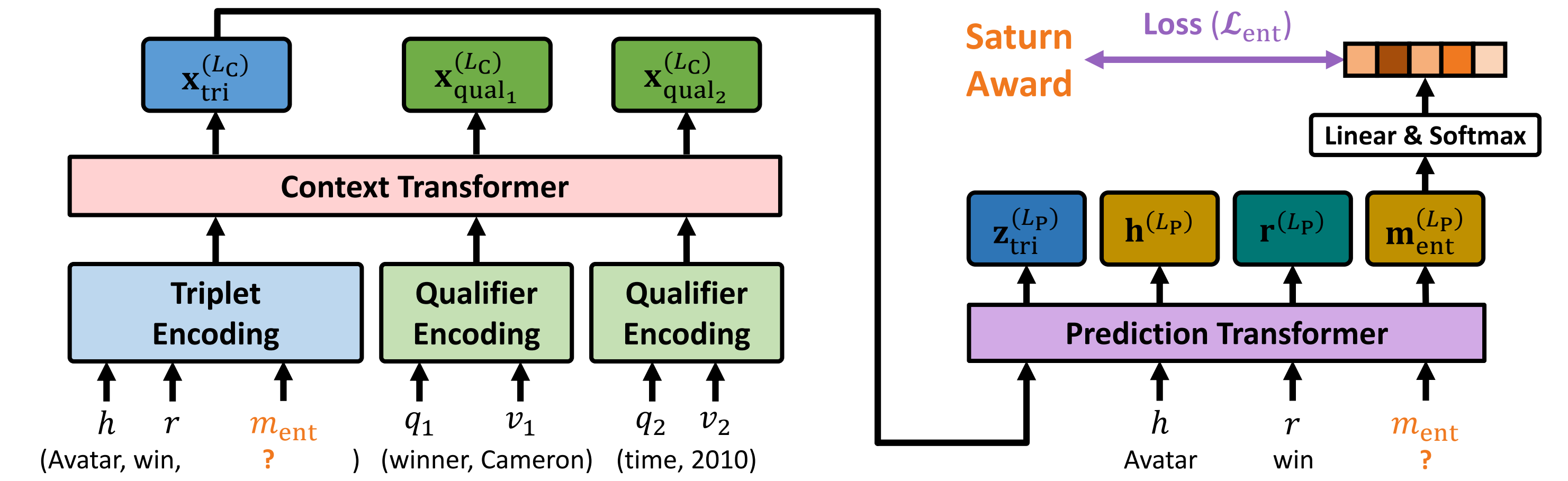
Context & Prediction Transformers

- Context Transformer**
 - Learn the representations of a primary triplet and the qualifiers
- Prediction Transformer**
 - Predict a missing component in a primary triplet or a qualifier

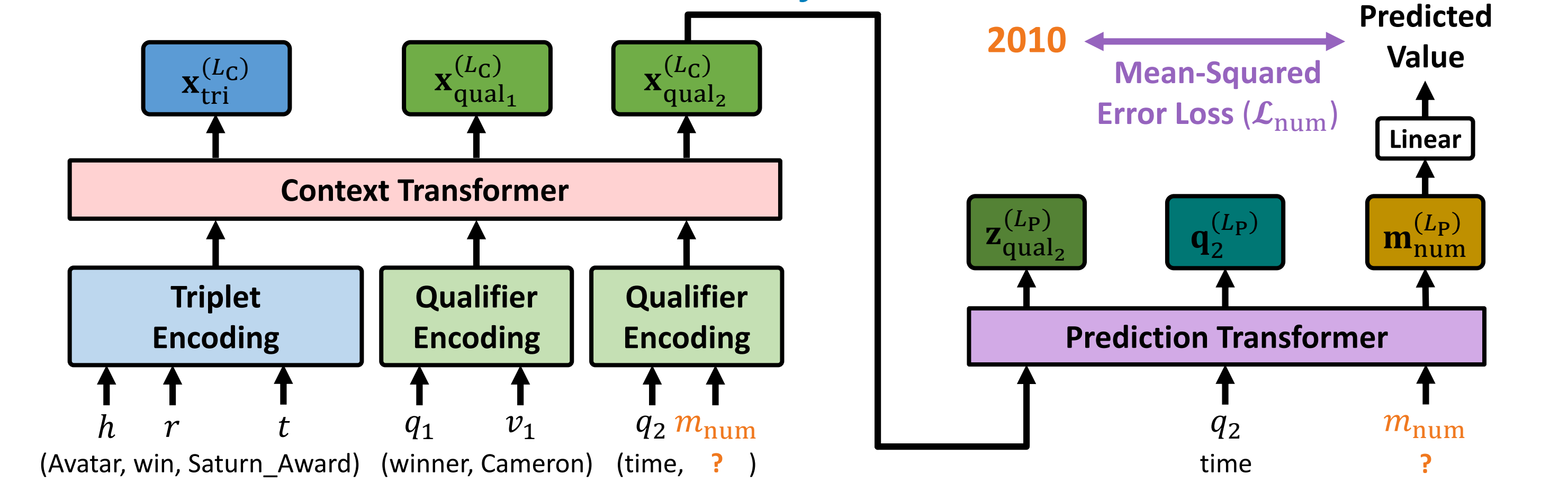


Training & Predictions of HyNT

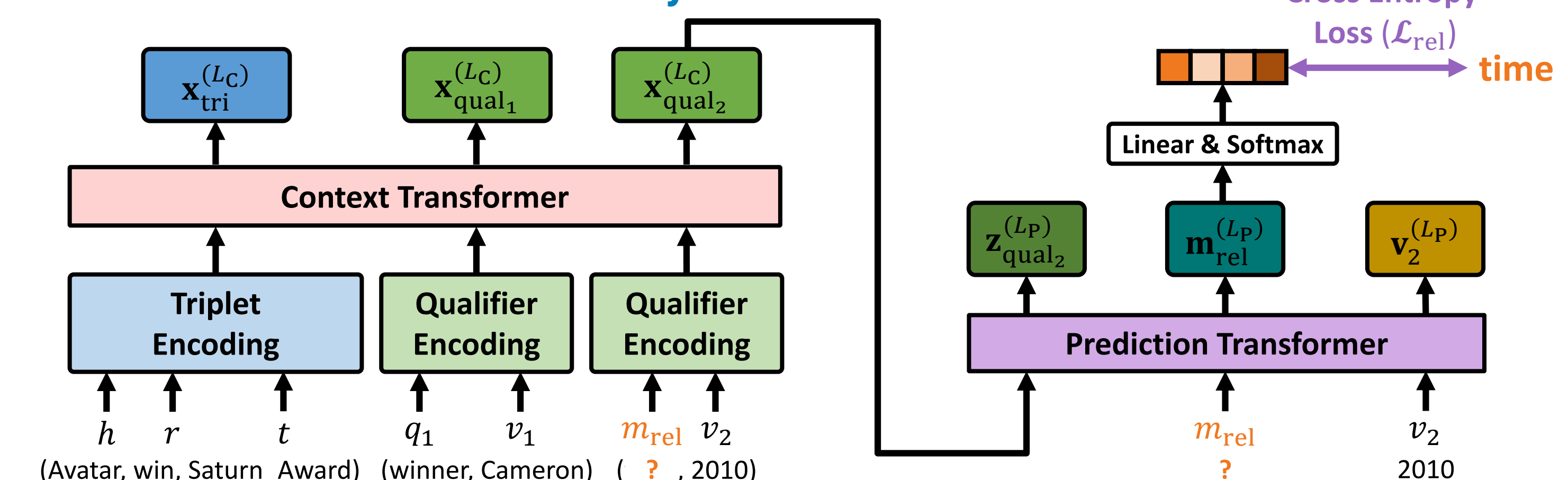
Link Prediction Loss of HyNT



Numeric Value Prediction Loss of HyNT



Relation Prediction Loss of HyNT



Loss of HyNT: $\mathcal{L} := \mathcal{L}_{ent} + \lambda_1 \cdot \mathcal{L}_{rel} + \lambda_2 \cdot \mathcal{L}_{num}$

Experimental Results

- Baseline methods:** TransEA, MT-KGNN, KBLN, LiteralE, NaLP, tNaLP, RAM, HINGE, NeuInfer, StarE, Hy-Transformer, GRAN

Link Prediction Results (MRR, ↑)

| | | HN-WK | HN-YG | HN-FB | HN-FB-S |
|---------|---------------|---------------|---------------|---------------|---------------|
| Primary | Best-baseline | 0.2627 | 0.1951 | 0.2602 | 0.5077 |
| | HyNT | 0.6634 | 0.2718 | 0.6052 | 0.5941 |
| All | Best-baseline | 0.2901 | 0.1951 | - | 0.5873 |
| | HyNT | 0.6680 | 0.2718 | 0.6109 | 0.6365 |

Numeric Value Prediction Results (RMSE, ↓)

| | | HN-WK | HN-YG | HN-FB | HN-FB-S |
|---------|---------------|---------------|---------------|---------------|---------------|
| Primary | Best-baseline | 0.0761 | 0.0778 | 0.0637 | 0.0656 |
| | HyNT | 0.0548 | 0.0706 | 0.0517 | 0.0532 |
| All | Best-baseline | 0.0820 | 0.1123 | - | 0.0627 |
| | HyNT | 0.0405 | 0.0694 | 0.0558 | 0.0499 |

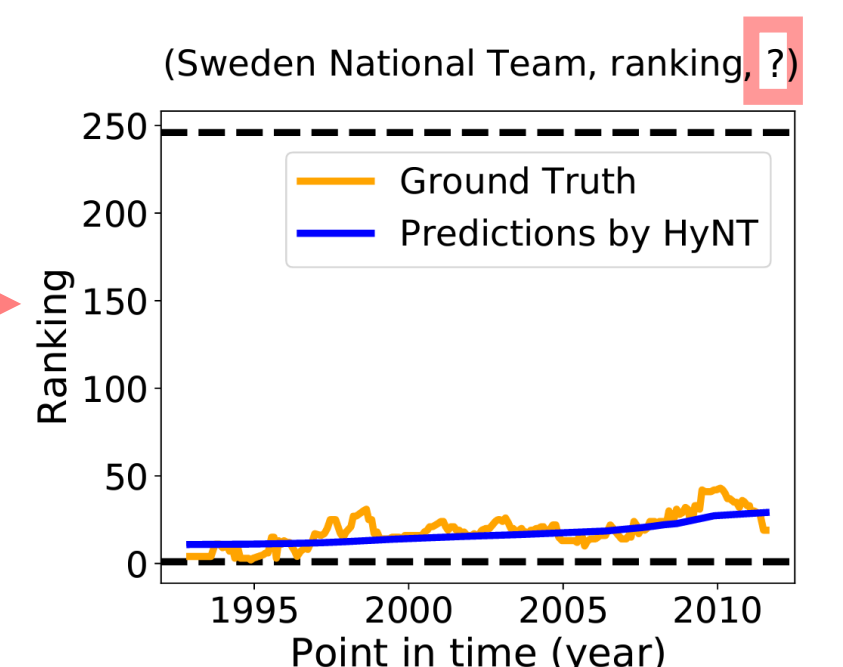
Relation Prediction Results (MRR, ↑)

| | | HN-WK | HN-YG | HN-FB | HN-FB-S |
|---------|---------------|---------------|---------------|---------------|---------------|
| Primary | Best-baseline | 0.9285 | 0.8347 | - | 0.9845 |
| | HyNT | 0.9442 | 0.8797 | 0.9809 | 0.9792 |
| All | Best-baseline | 0.9599 | 0.8548 | - | 0.9918 |
| | HyNT | 0.9688 | 0.8944 | 0.9860 | 0.9890 |

Visualization of Numeric Value Predictions

- Numeric value prediction problems in a particular form

$((\text{Sweden National Team, ranking, ?}), \{(\text{point in time, 1992})\})$
 $((\text{Sweden National Team, ranking, ?}), \{(\text{point in time, 1993})\})$
 $((\text{Sweden National Team, ranking, ?}), \{(\text{point in time, 1994})\})$



Conclusion & Future Work

- Introduce the concept and real-world datasets for **Hyper-relational and Numeric Knowledge Graphs (HN-KGs)**
- Propose **HyNT** to solve **link prediction**, **numeric value prediction**, and **relation prediction** on HN-KGs
- HyNT significantly outperforms 12 different state-of-the-art methods
- Plan to extend HyNT to **inductive learning scenarios** where new entities and relations appear at test time