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

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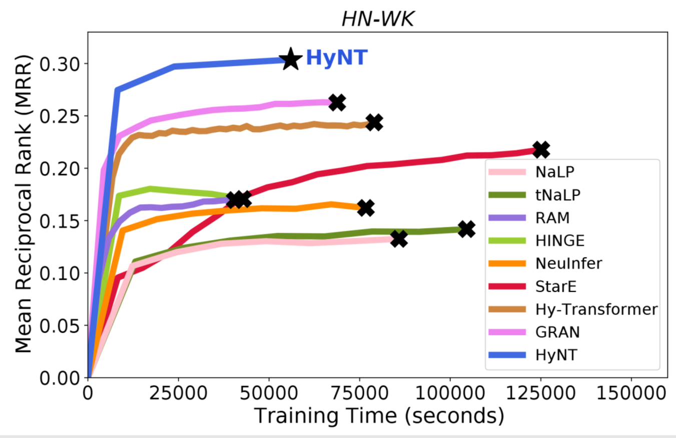
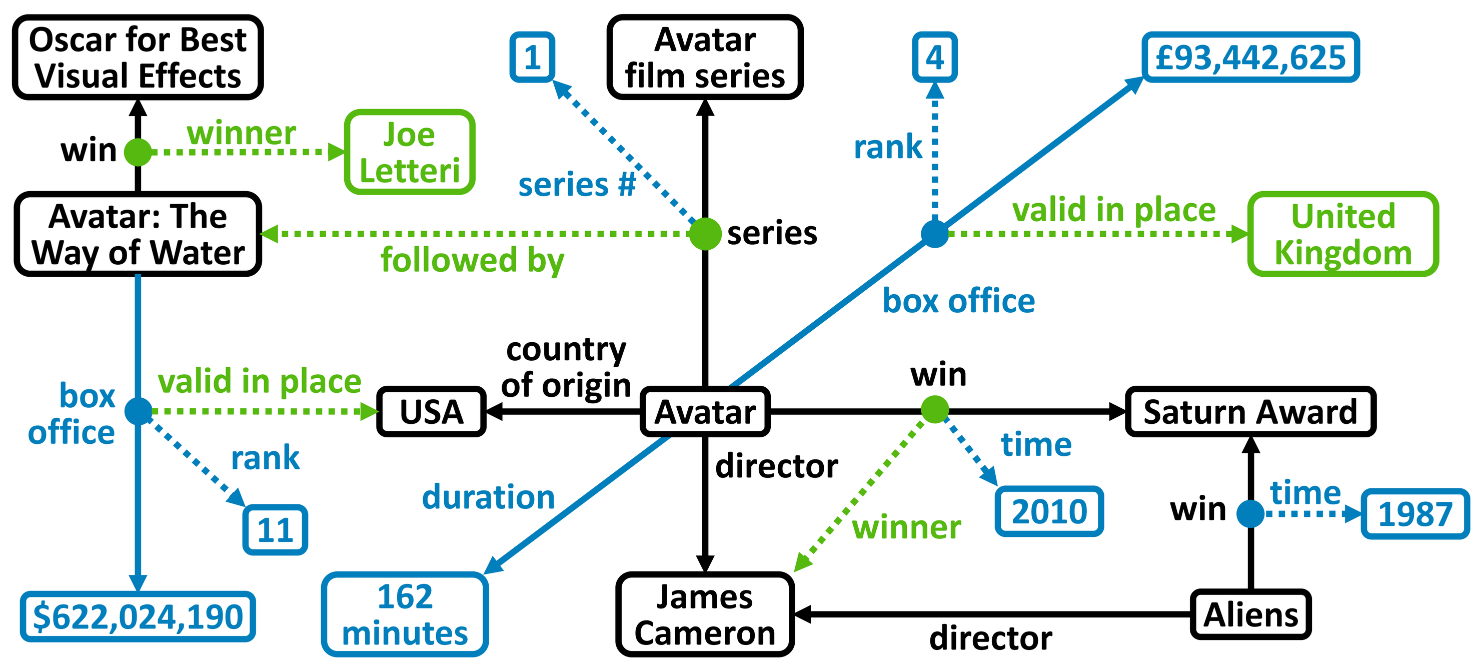
## Main Contributions

- Define **Hyper-relational and Numeric Knowledge Graphs** (**HN-KGs**)
  - Create 4 real-world HN-KG datasets
- Propose **HyNT**, **Hy**per-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)

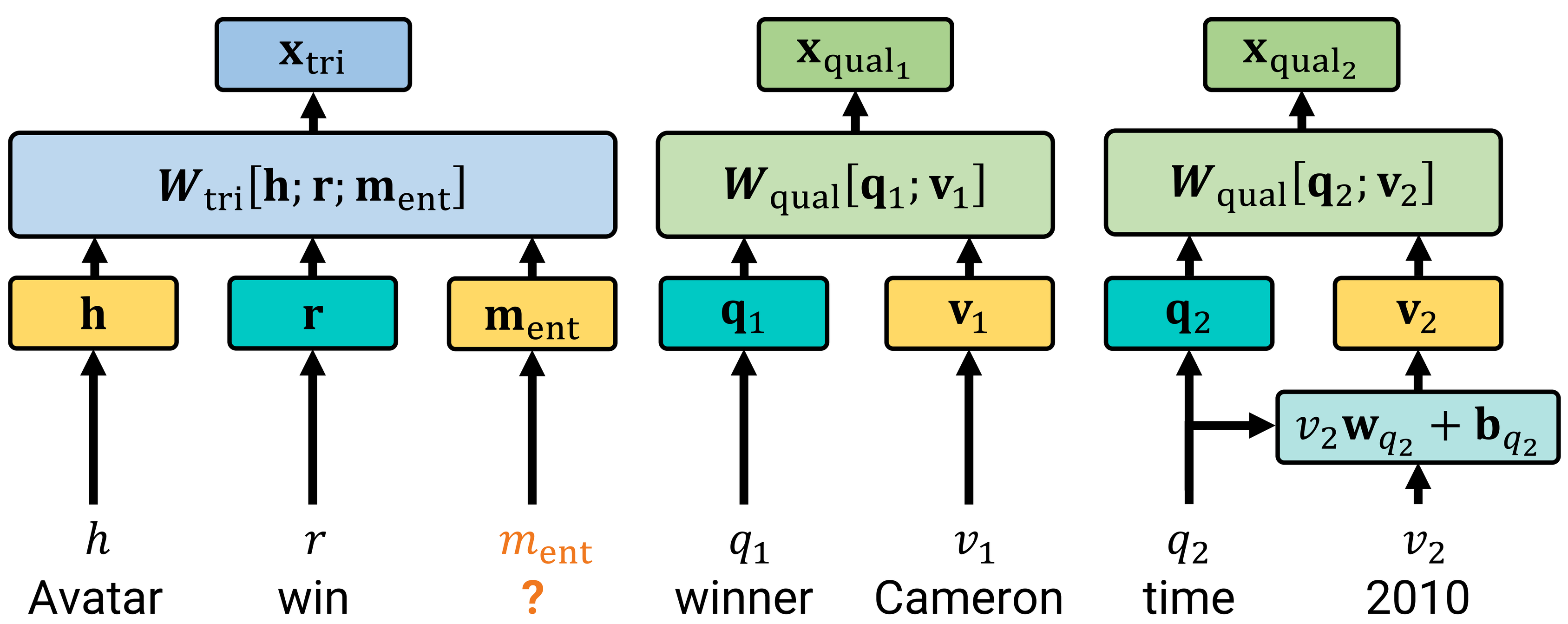
- **Hyper-relational Knowledge Graphs**
  - Attach a set of **qualifiers** to a triplet to enrich information
  - Existing methods assume that all entities are **discrete** objects
- **Hyper-relational and Numeric Knowledge Graphs**
  - Contain both hyper-relational facts and numeric values




- An example of a hyper-relational fact
  - ((**Avatar**, **win**, **Saturn_Award**), {(**winner**, **James_Cameron**), (**time**, **2010**)})
    Primary Triplet — Qualifier 1 — Qualifier 2
- 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**

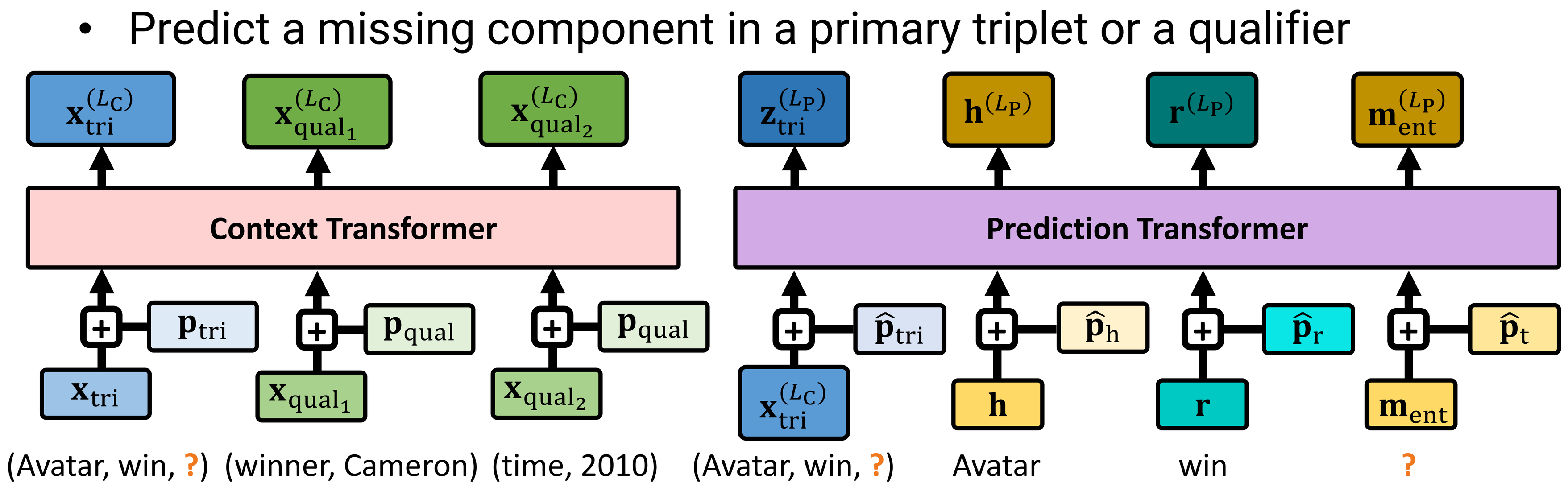
## Triplet/Qualifier Encoding

- Convert a triplet/qualifier to a representation vector



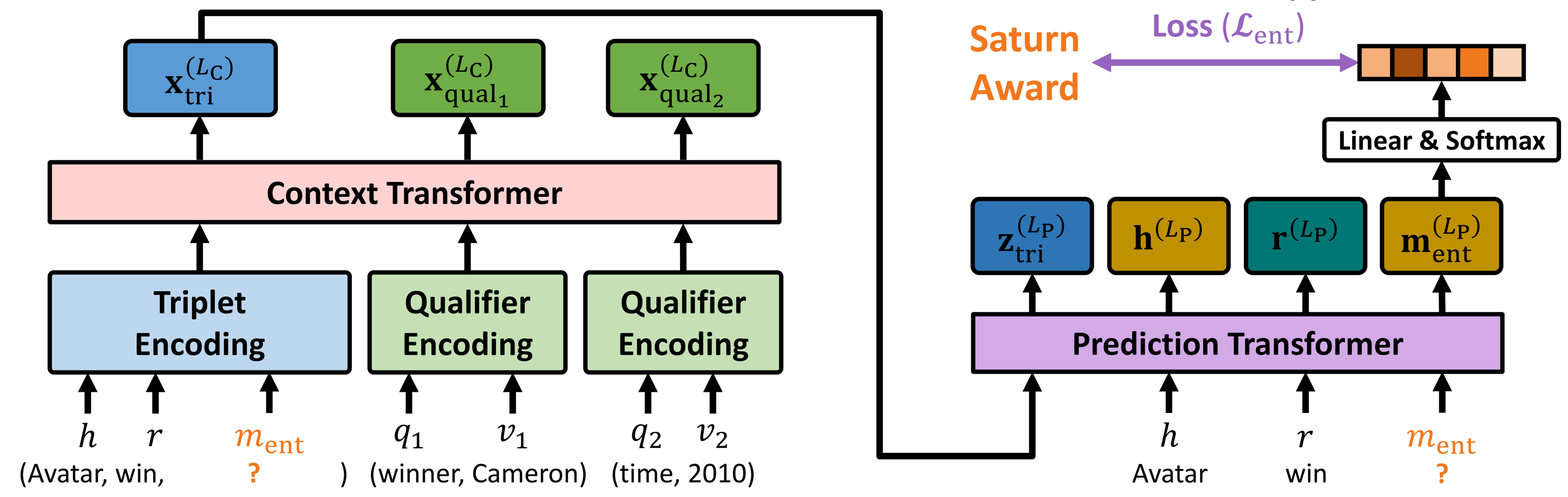

## Context & Prediction Transformers

- **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

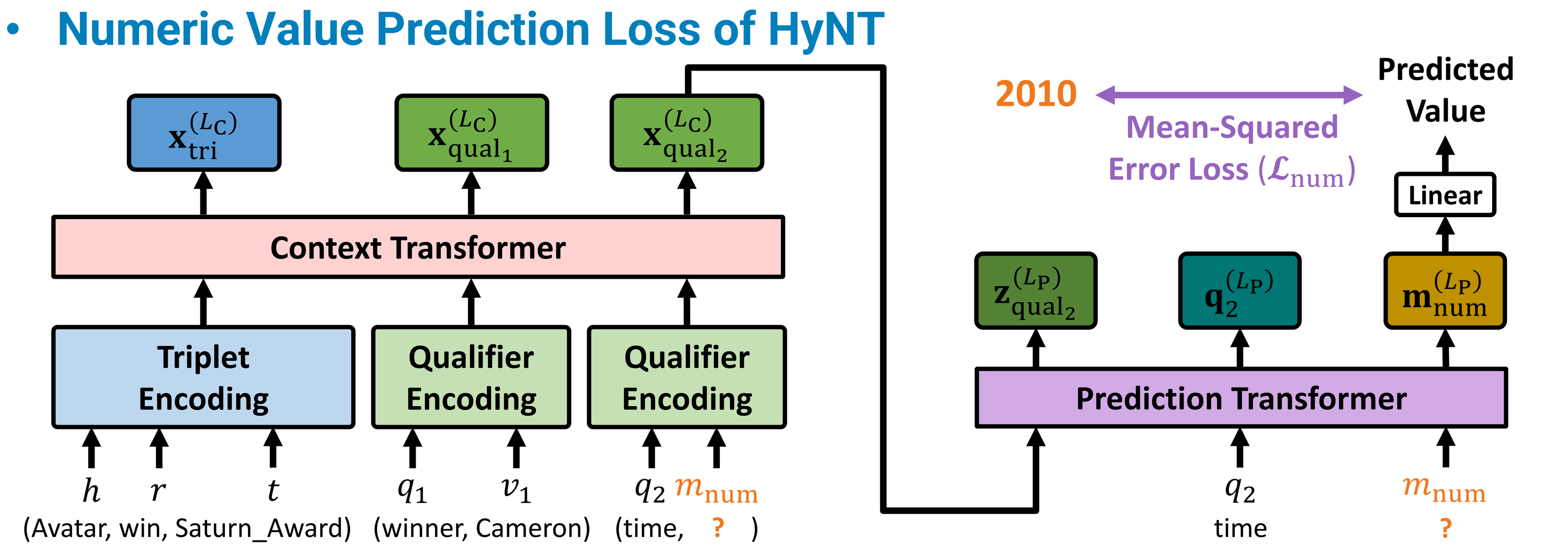



## Training & Predictions of HyNT

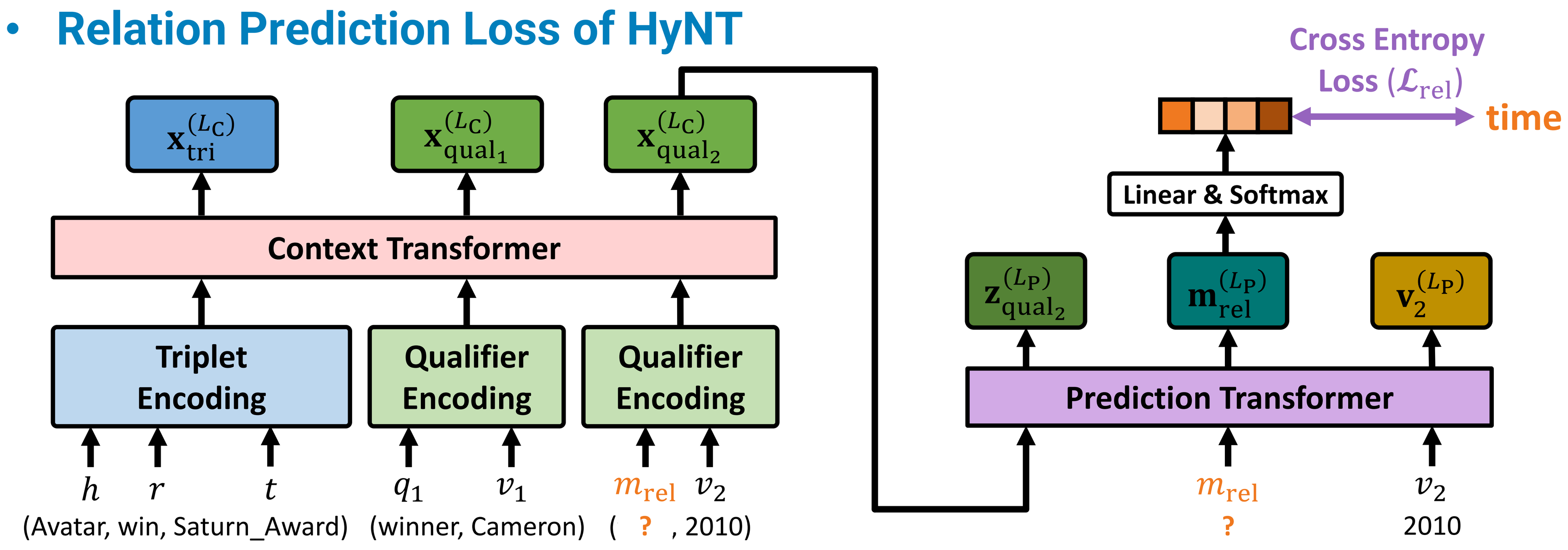
- **Link Prediction Loss of HyNT**




- **Numeric Value Prediction Loss of HyNT**




- **Relation Prediction Loss of HyNT**




- **Loss of HyNT**: $\mathcal{L} \coloneqq \mathcal{L}_{\text{ent}} + \lambda_1 \cdot \mathcal{L}_{\text{rel}} + \lambda_2 \cdot \mathcal{L}_{\text{num}}$

## 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 | **0.3037** | **0.2035** | **0.4544** | **0.5079** |
| All | Best-baseline | 0.2901 | 0.1951 | - | **0.5873** |
| | HyNT | **0.3254** | **0.2035** | **0.5022** | 0.5796 |

- **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** |

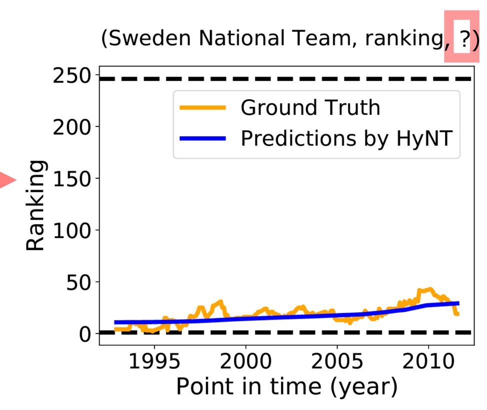
- **Relation Prediction Results (MRR, ↑)**

| | | HN-WK | HN-YG | HN-FB | HN-FB-S |
|---|---|---|---|---|---|
| Primary | Best-baseline | 0.9285 | 0.8347 | - | **0.9845** |
| | HyNT | **0.9474** | **0.8797** | **0.9809** | 0.9815 |
| All | Best-baseline | 0.9599 | 0.8548 | - | **0.9918** |
| | HyNT | **0.9706** | **0.8944** | **0.9860** | 0.9902 |

- **Visualization of Numeric Value Predictions**
  - Numeric value prediction problems in a particular form

Target Values

((Sweden National Team, ranking, ?), {(point in time, 1992)})
((Sweden National Team, ranking, ?), {(point in time, 1993)})
((Sweden National Team, ranking, ?), {(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