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

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ACM SIGKDD Conference on Knowledge Discovery and Data Mining (KDD 2023)

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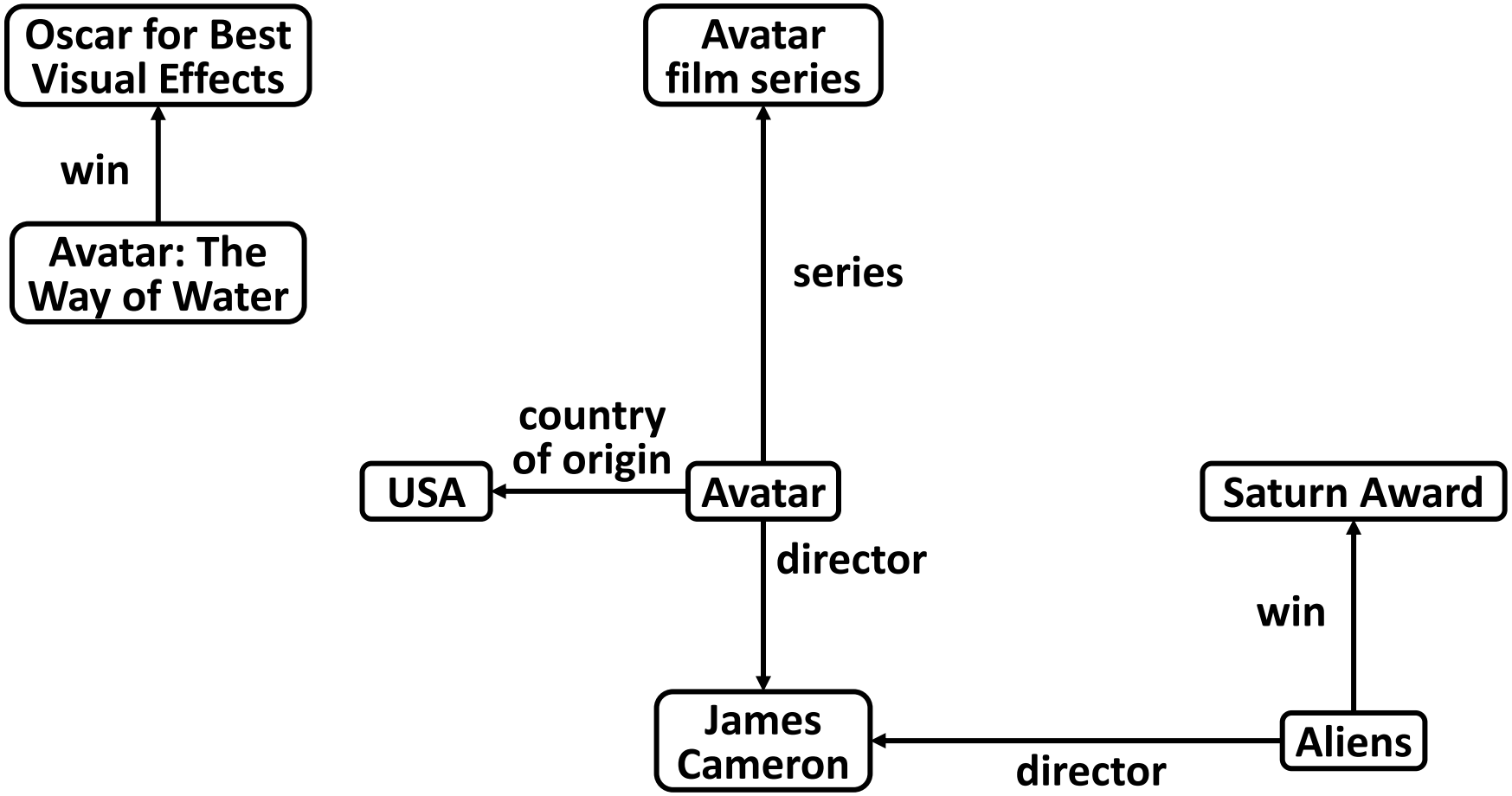
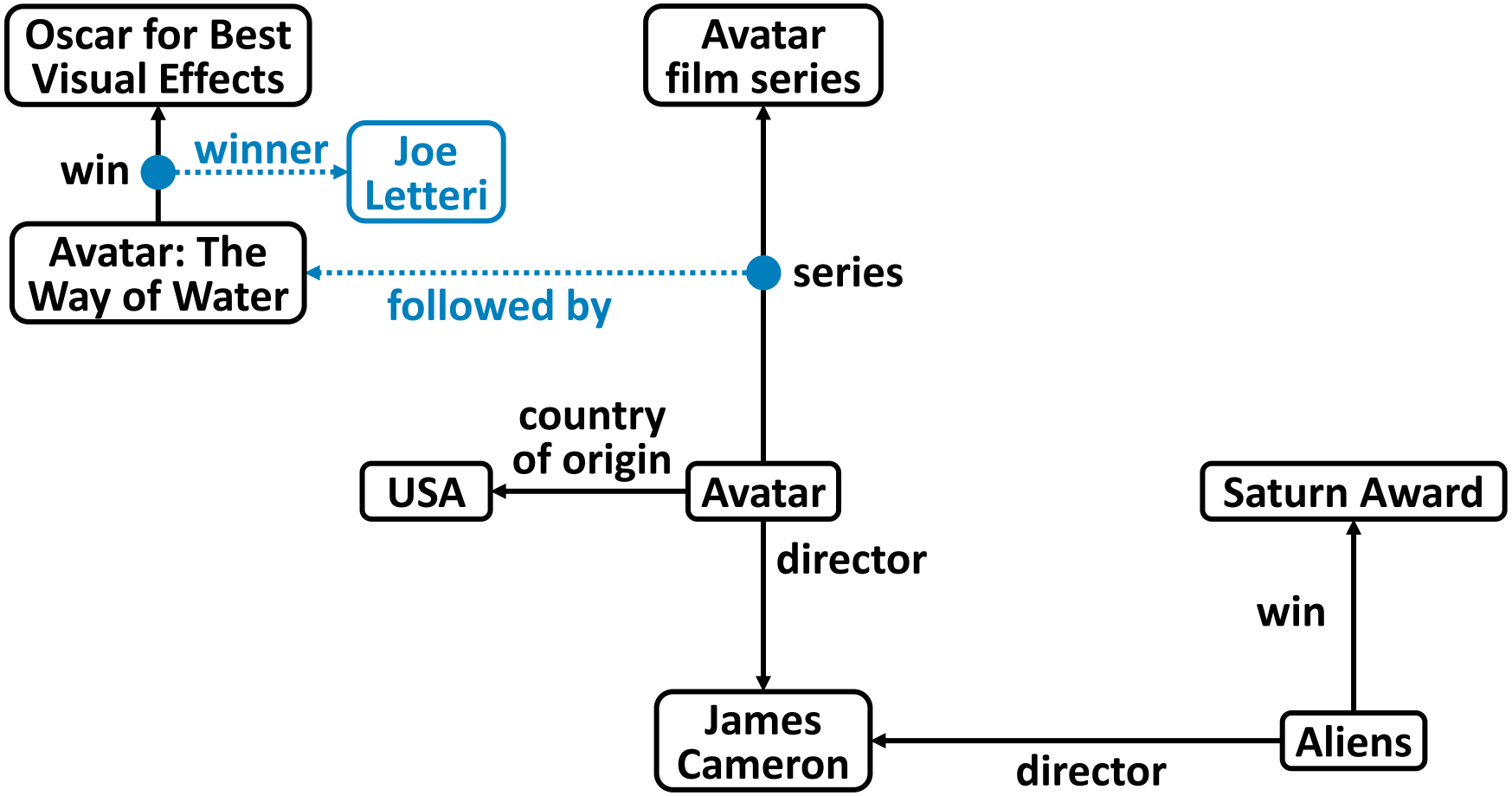
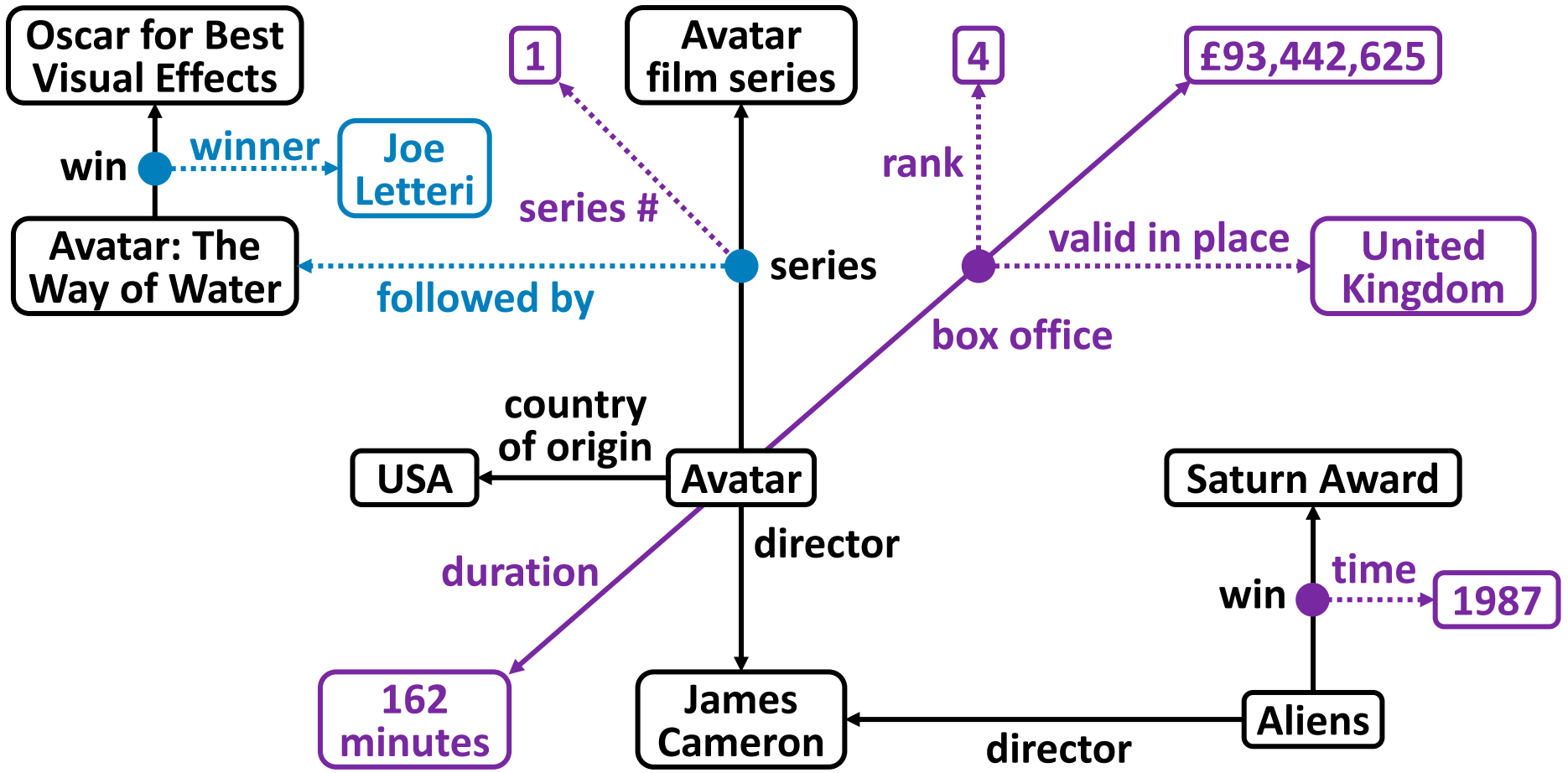
Knowledge Graphs



Hyper-relational Knowledge Graphs

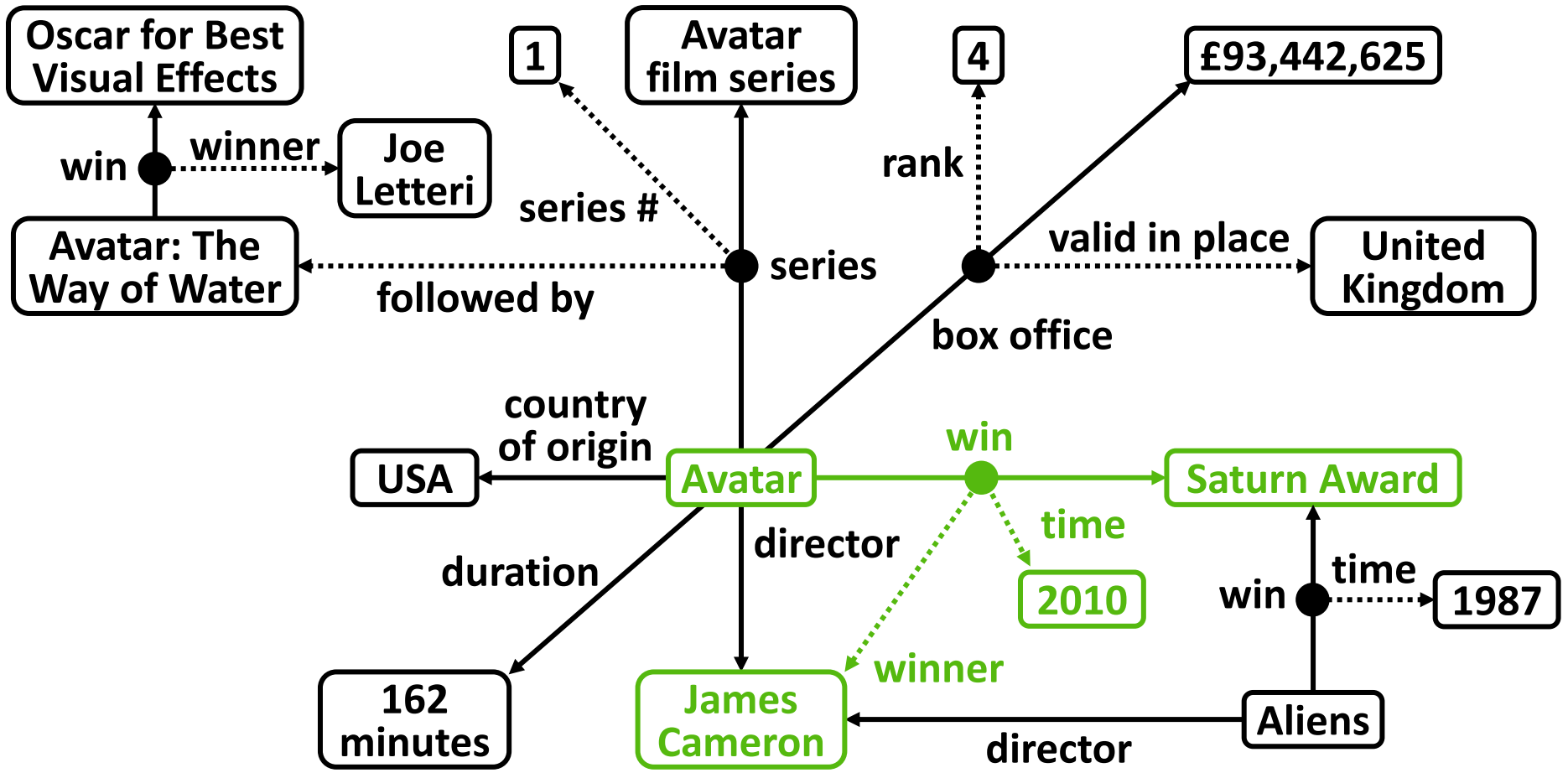


Hyper-relational and Numeric Knowledge Graphs (HN-KGs)



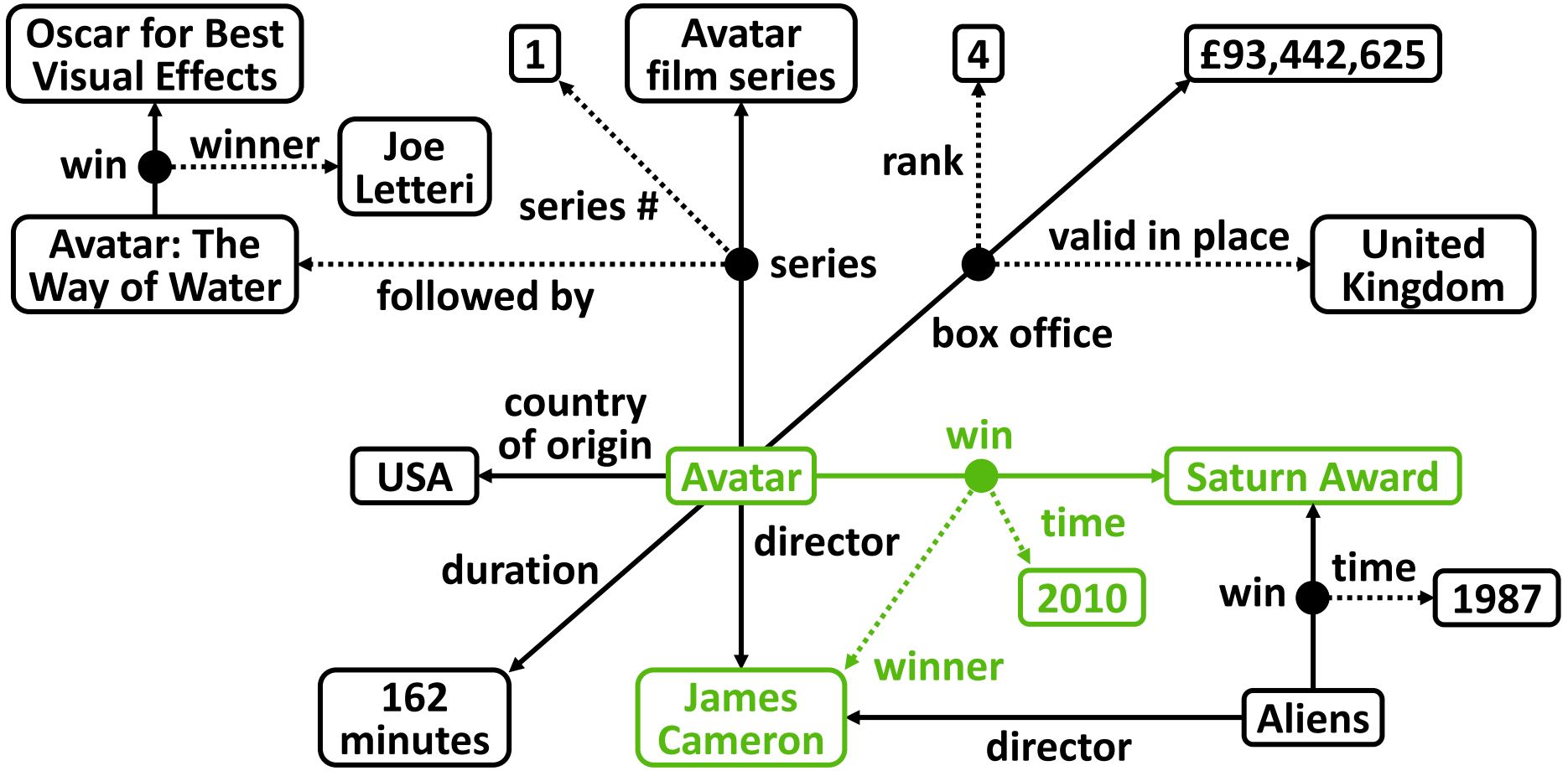
((Avatar, win, Saturn_Award), {(winner, James_Cameron), (time, 2010)})

Primary Triplet | Qualifier 1 | Qualifier 2



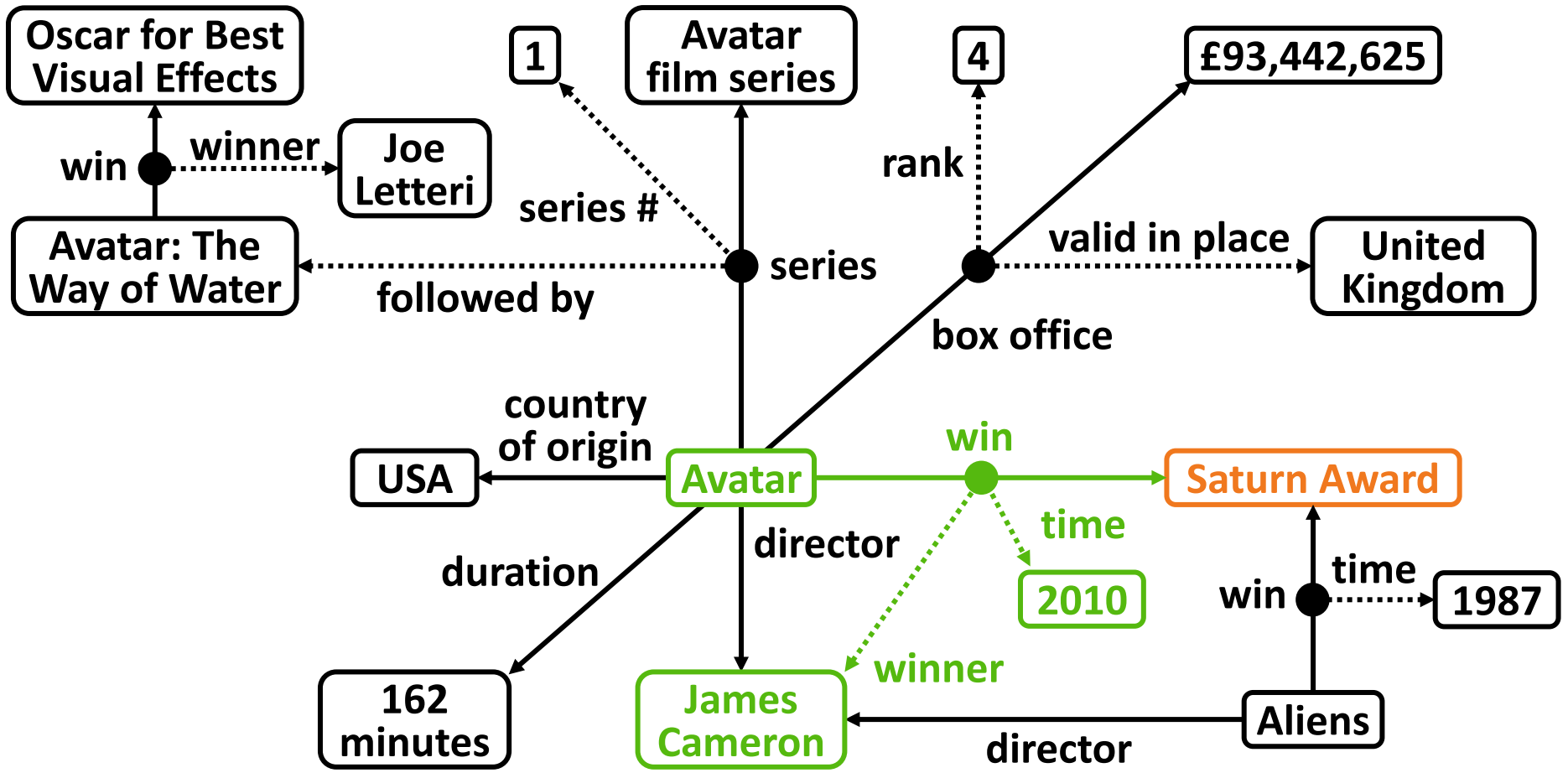
Link Prediction on HN-KGs

((Avatar, win, Saturn_Award), {(winner, James_Cameron), (time, 2010)})



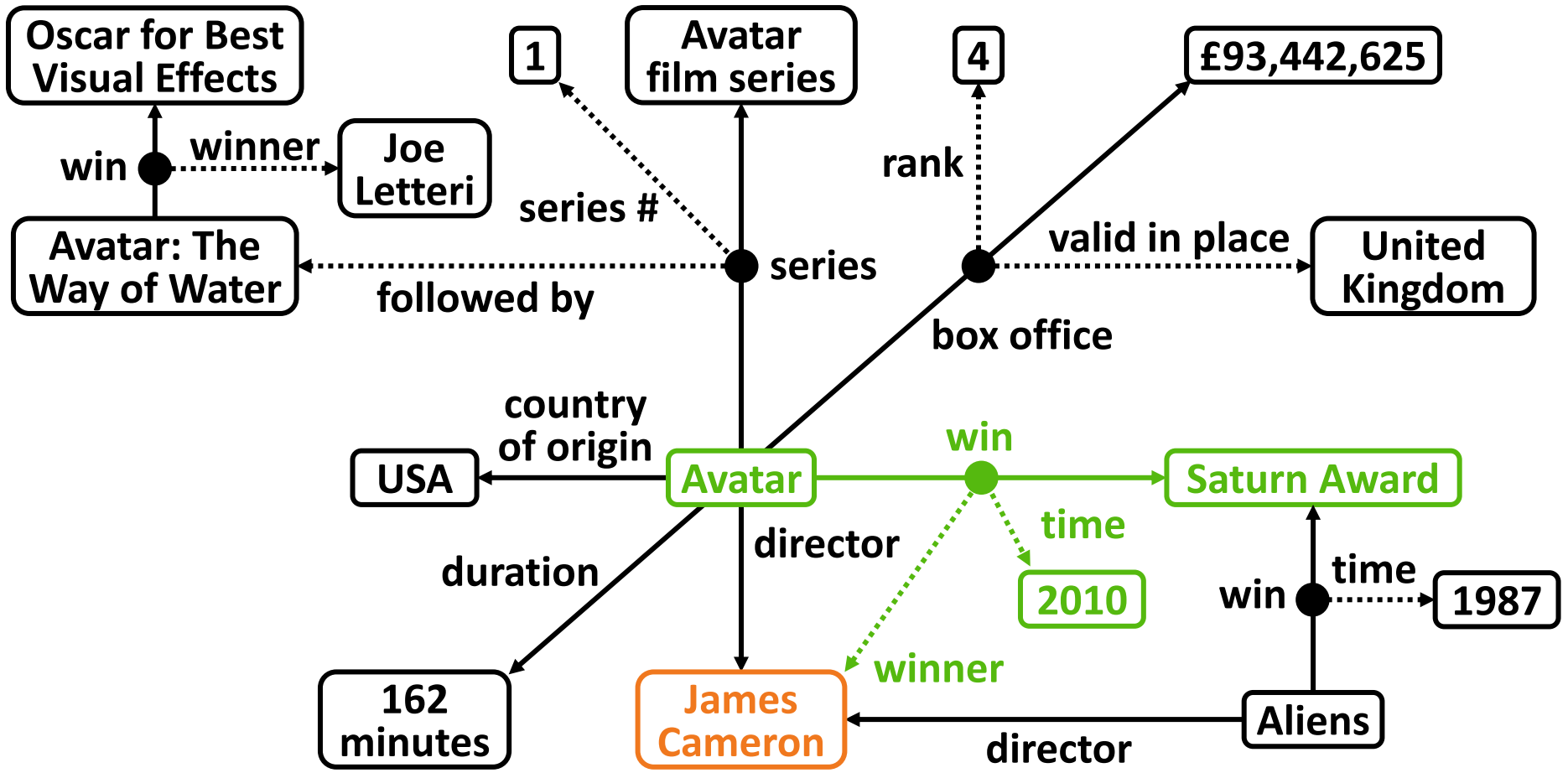
Link Prediction on HN-KGs

((Avatar, win, ?), {(winner, James_Cameron), (time, 2010)})



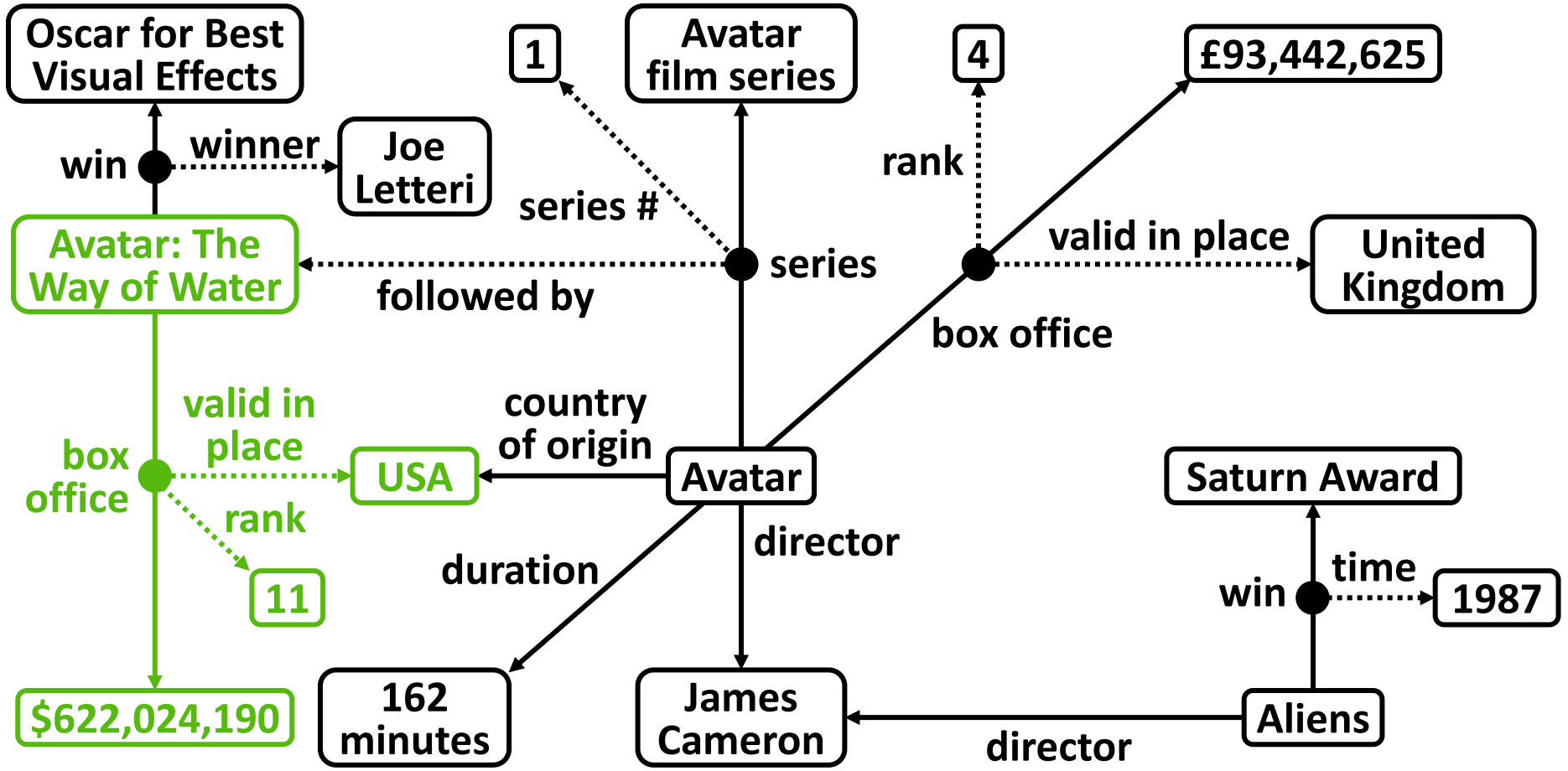
Link Prediction on HN-KGs

((Avatar, win, Saturn_Award), {(winner, ?), (time, 2010)})



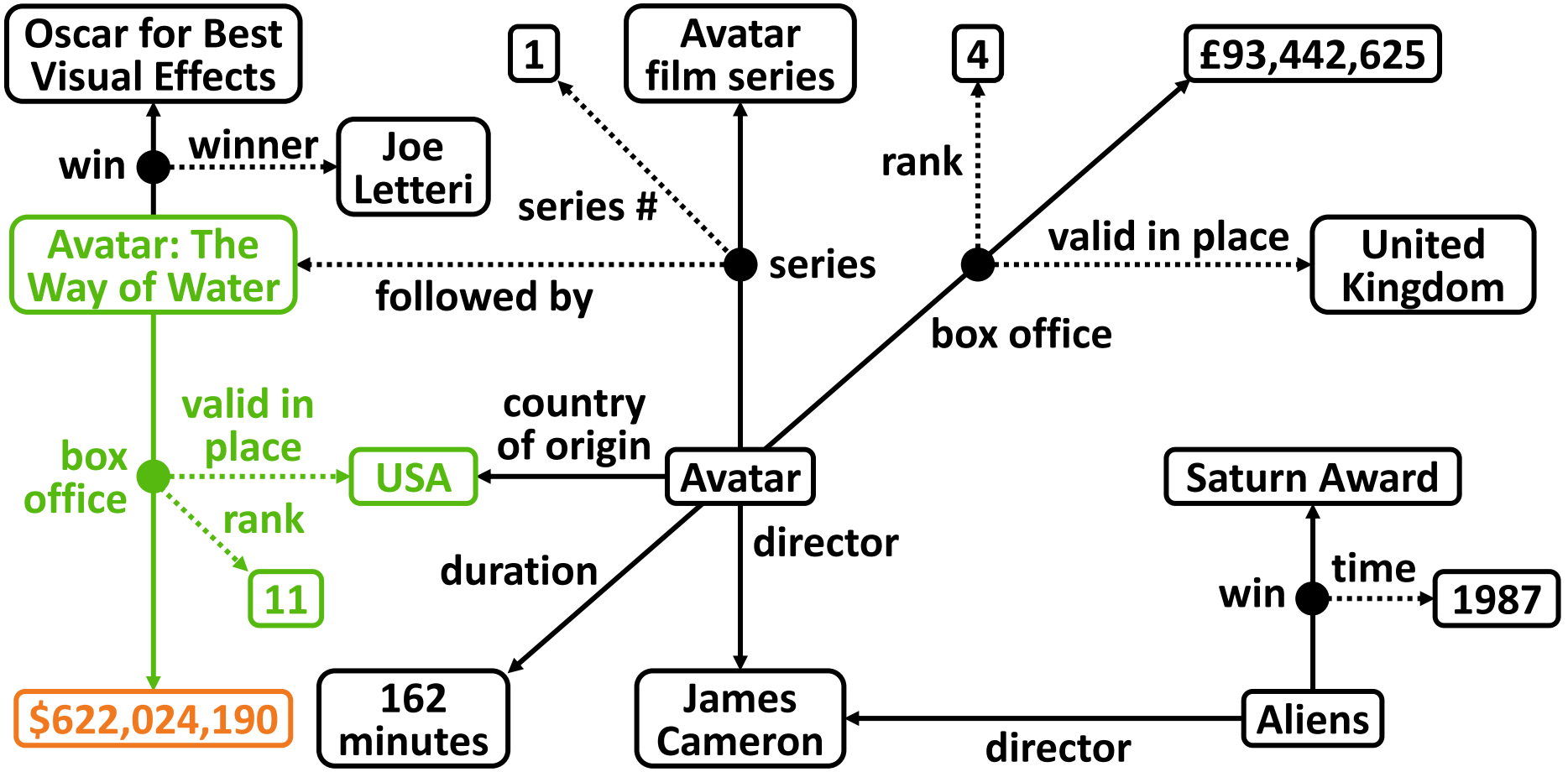
Numeric Value Prediction on HN-KGs

((Avatar:The_Way_of_Water, box_office, $622,024,190), {(rank, 11), (valid_in_place, USA)})



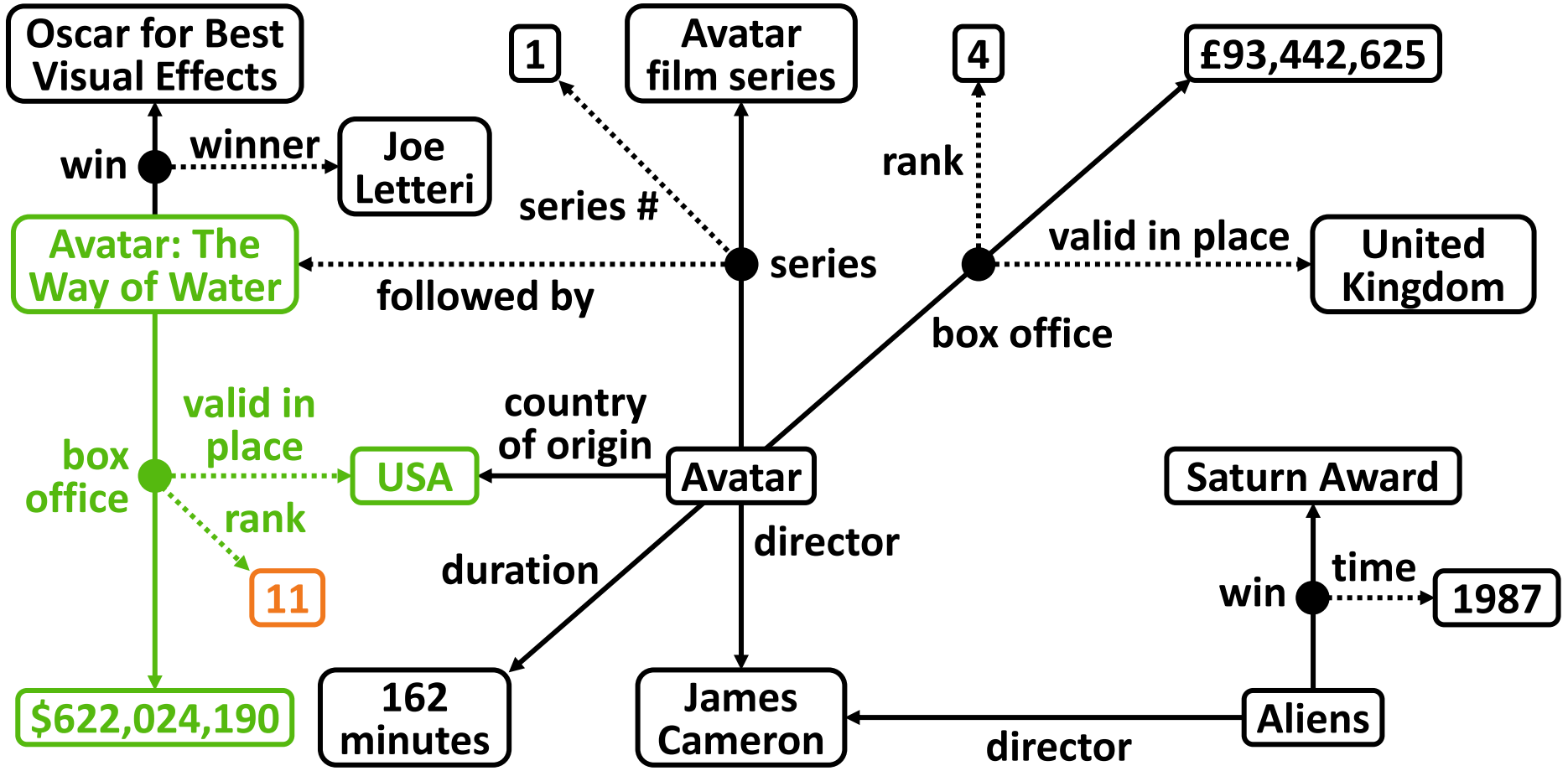
Numeric Value Prediction on HN-KGs

((Avatar:The_Way_of_Water, box_office, ?), {(rank, 11), (valid_in_place, USA)})



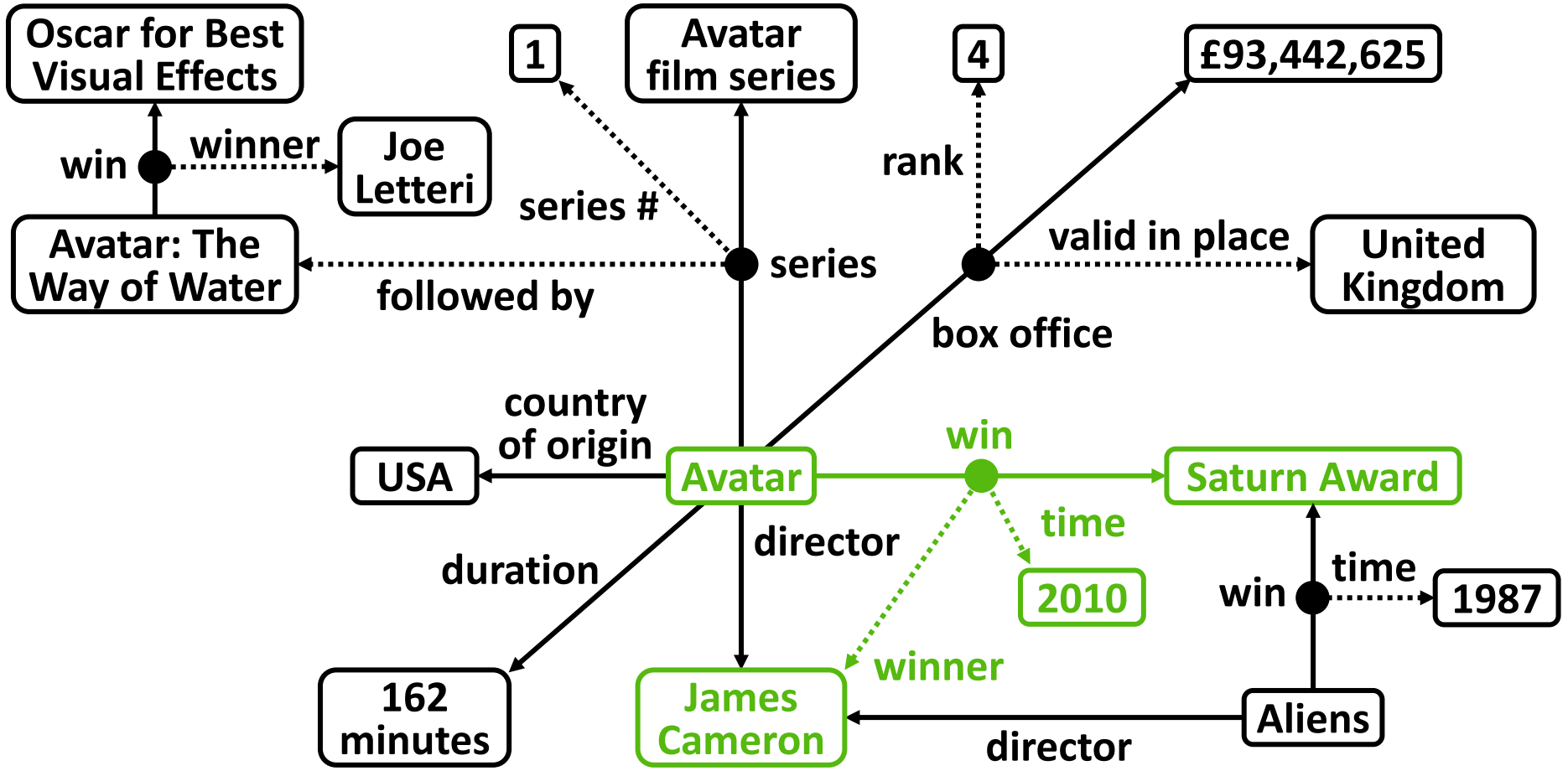
Numeric Value Prediction on HN-KGs

((Avatar:The_Way_of_Water, box_office, $622,024,190), {(rank, ?), (valid_in_place, USA)})



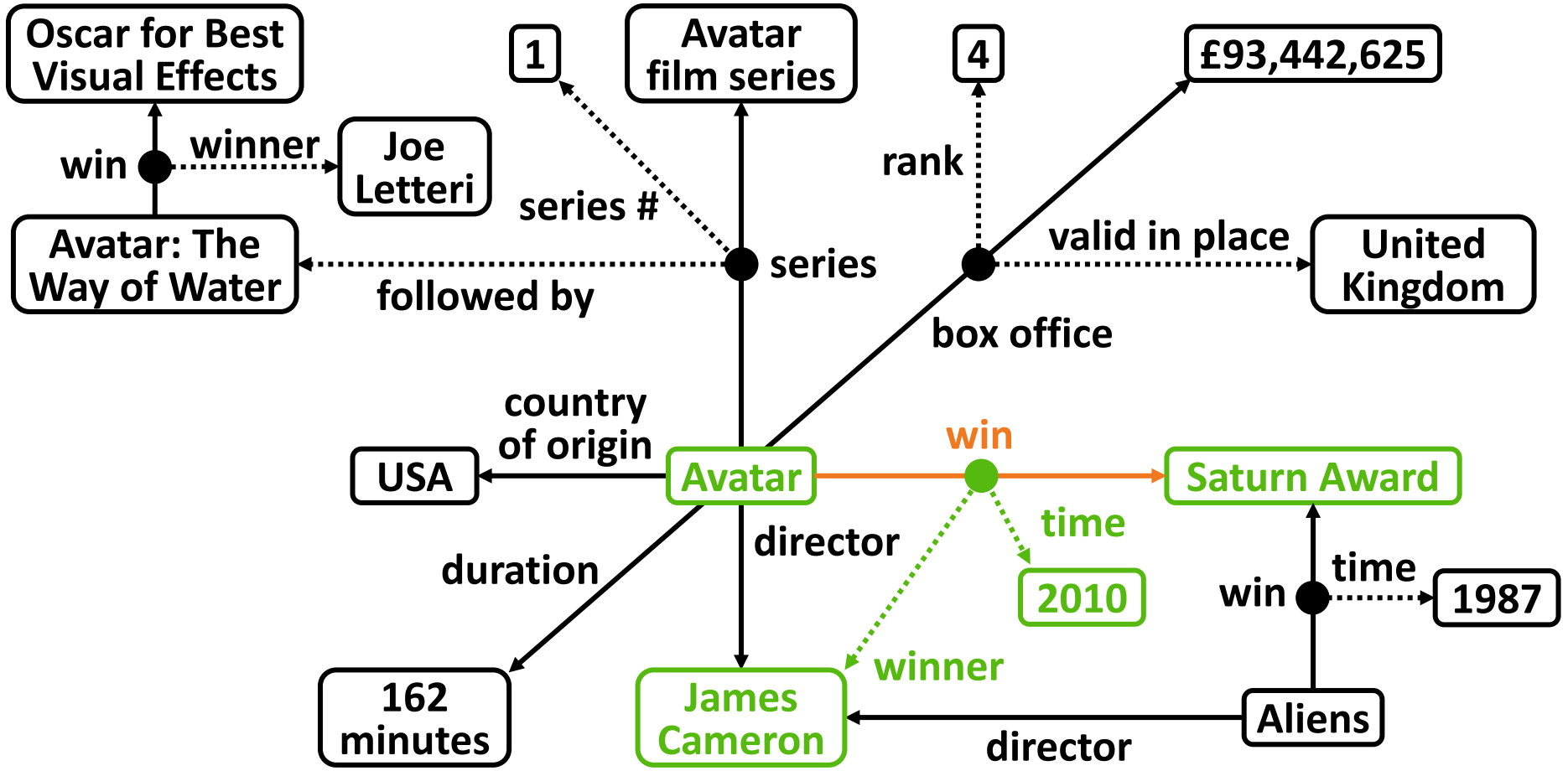
Relation Prediction on HN-KGs

((Avatar, win, Saturn_Award), {(winner, James_Cameron), (time, 2010)})



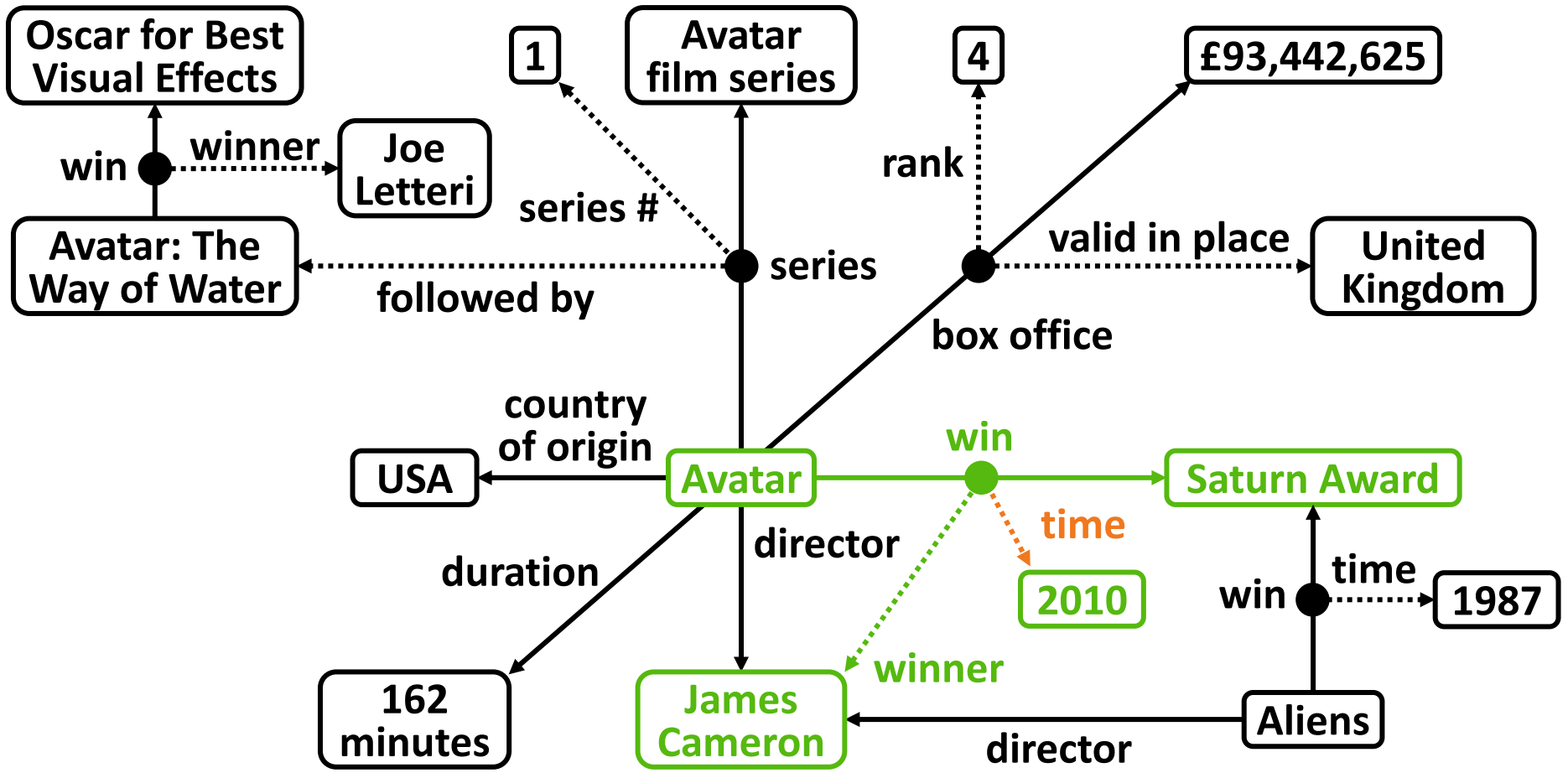
Relation Prediction on HN-KGs

((Avatar, ? , Saturn_Award), {(winner, James_Cameron), (time, 2010)})



Relation Prediction on HN-KGs

((Avatar, win, Saturn_Award), {(winner, James_Cameron), (? , 2010)})

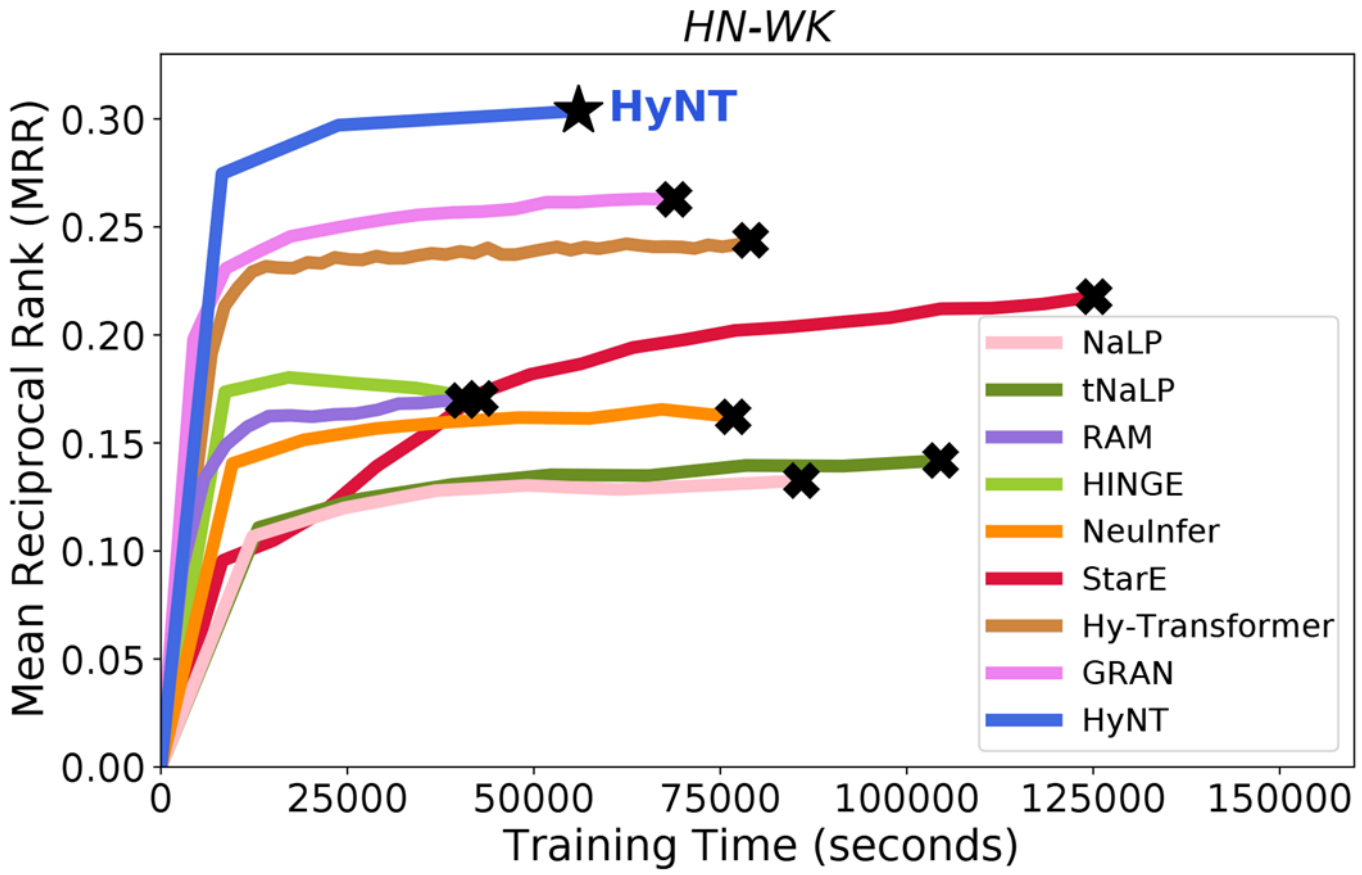


Contributions

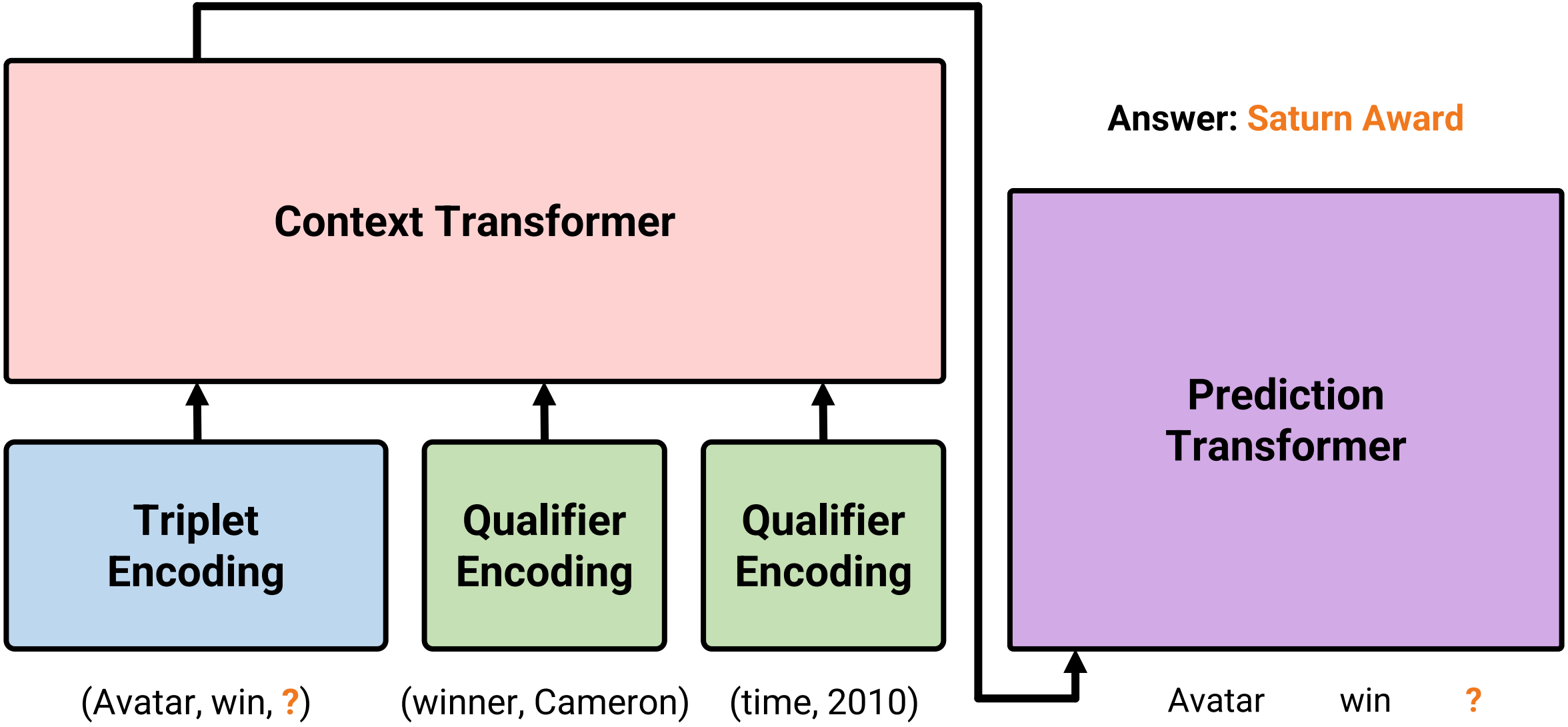
- Define **Hyper-relational and Numeric Knowledge Graphs**
  - Create 4 real-world HN-KG datasets
- Propose **HyNT**, **Hy**per-relational knowledge graph embedding with **N**umeric literals using **T**ransformers
  - Define a context transformer and a prediction transformer
  - Reduce the cost by learning 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**

Contributions

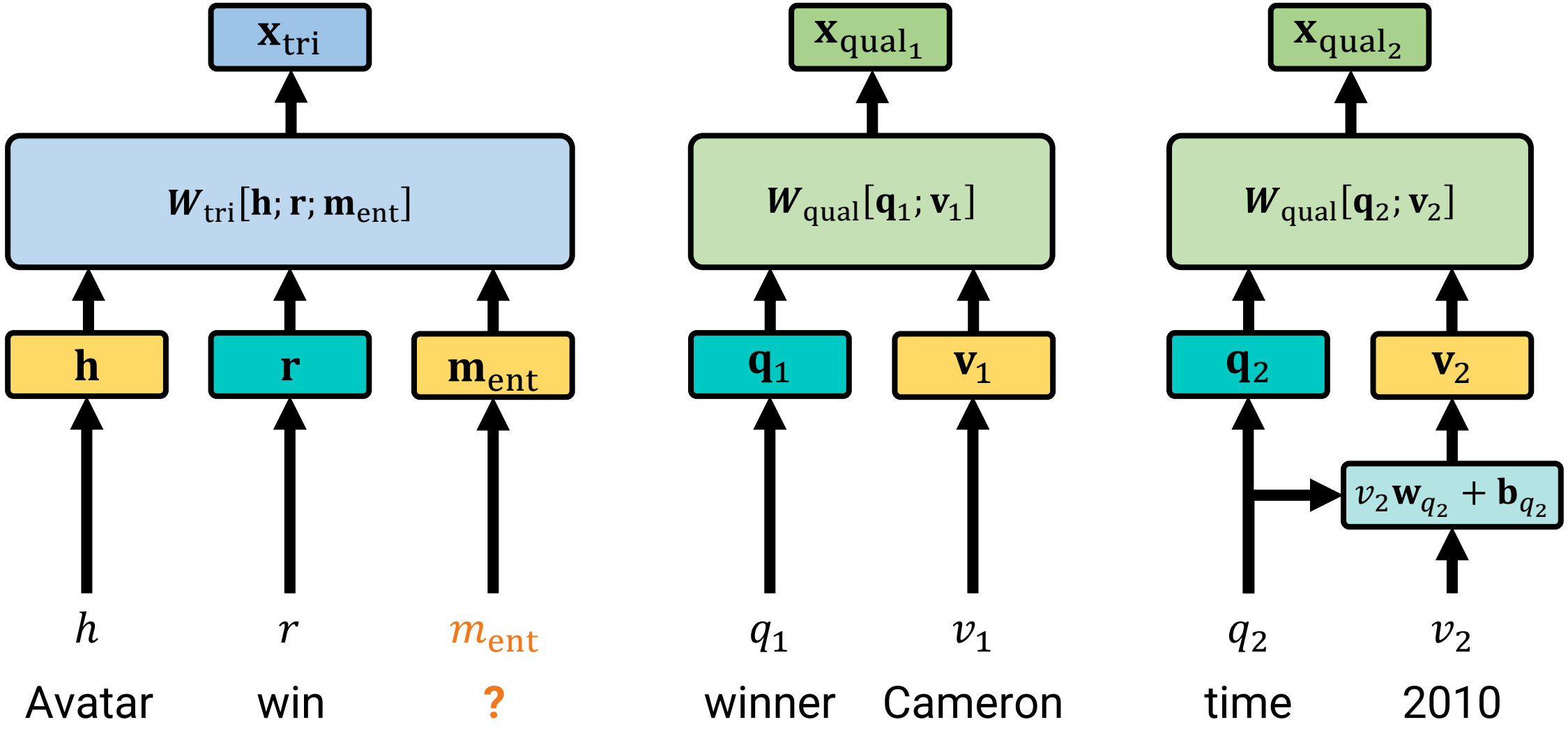
- Link Prediction Performance vs. Training Time



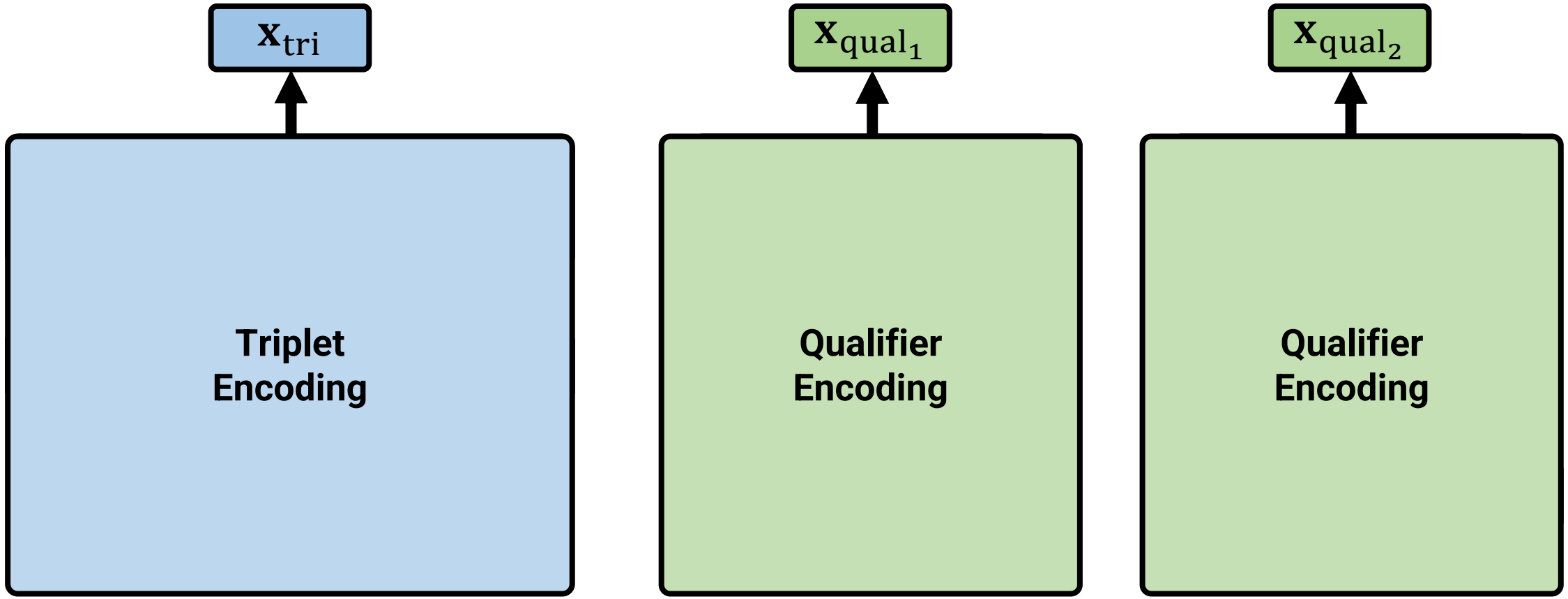
Overview of HyNT



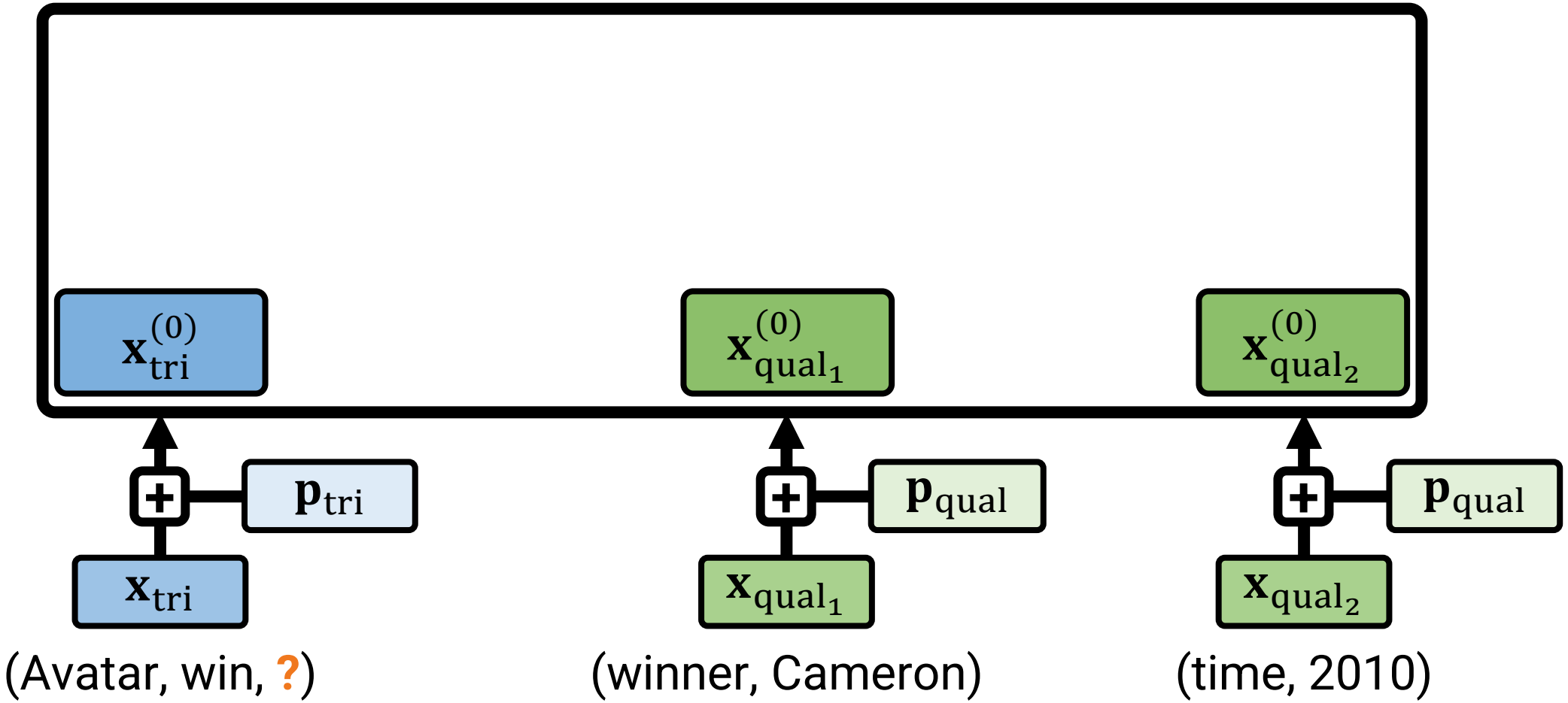
Triplet/Qualifier Encoding



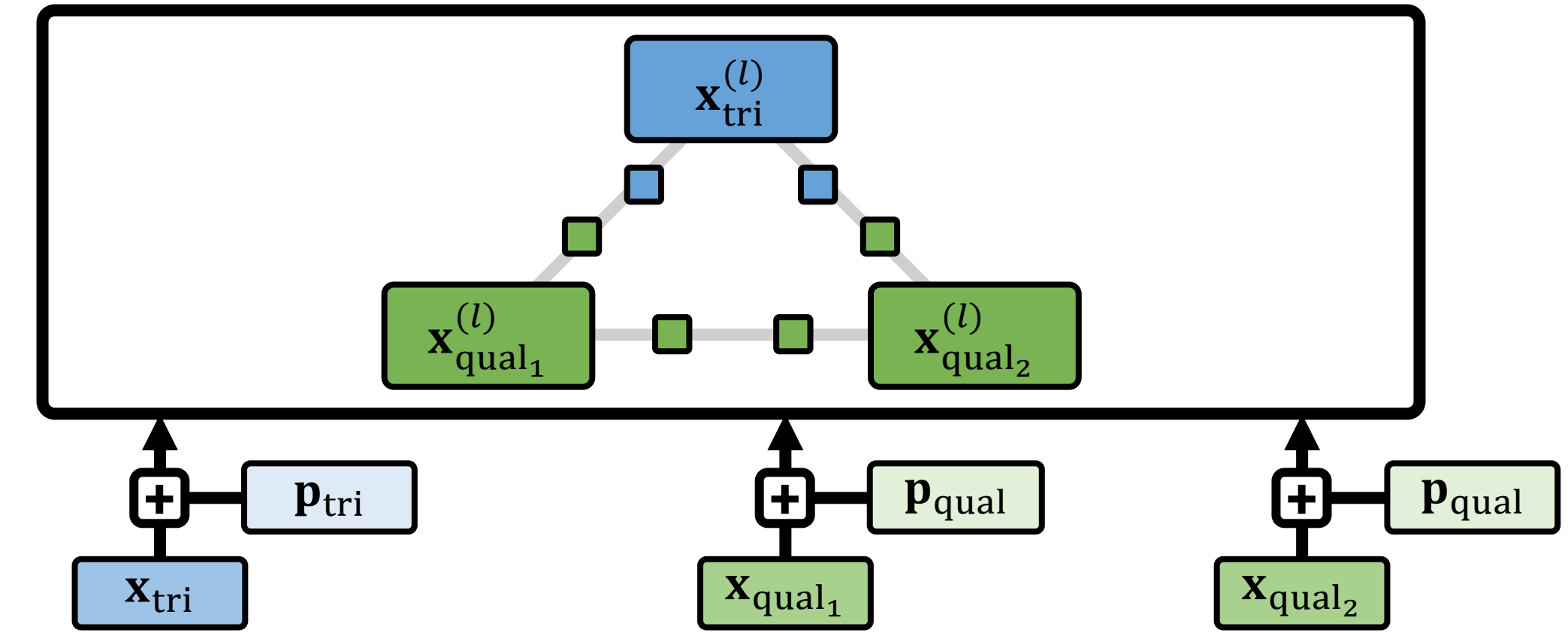
Triplet/Qualifier Encoding



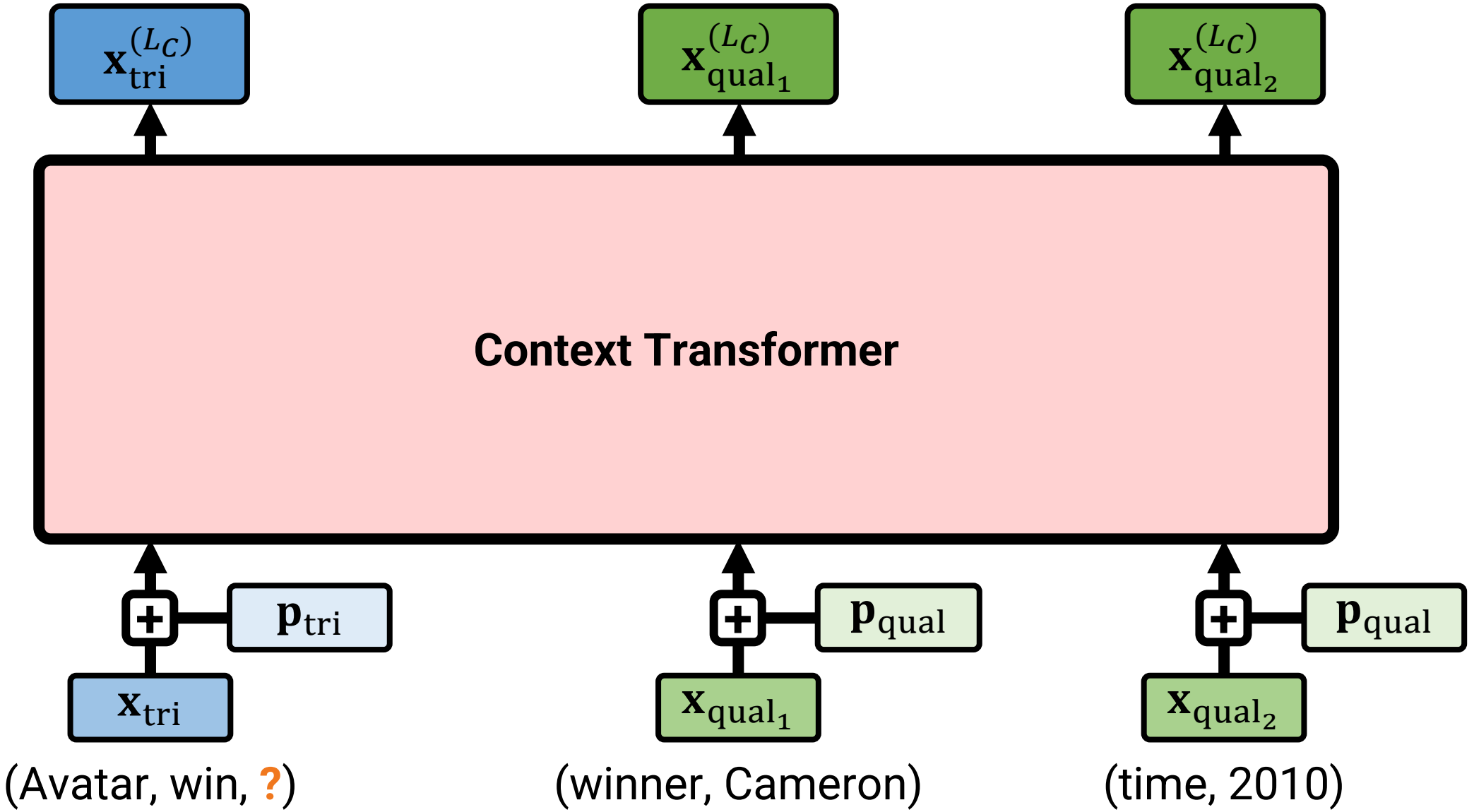
Context Transformer



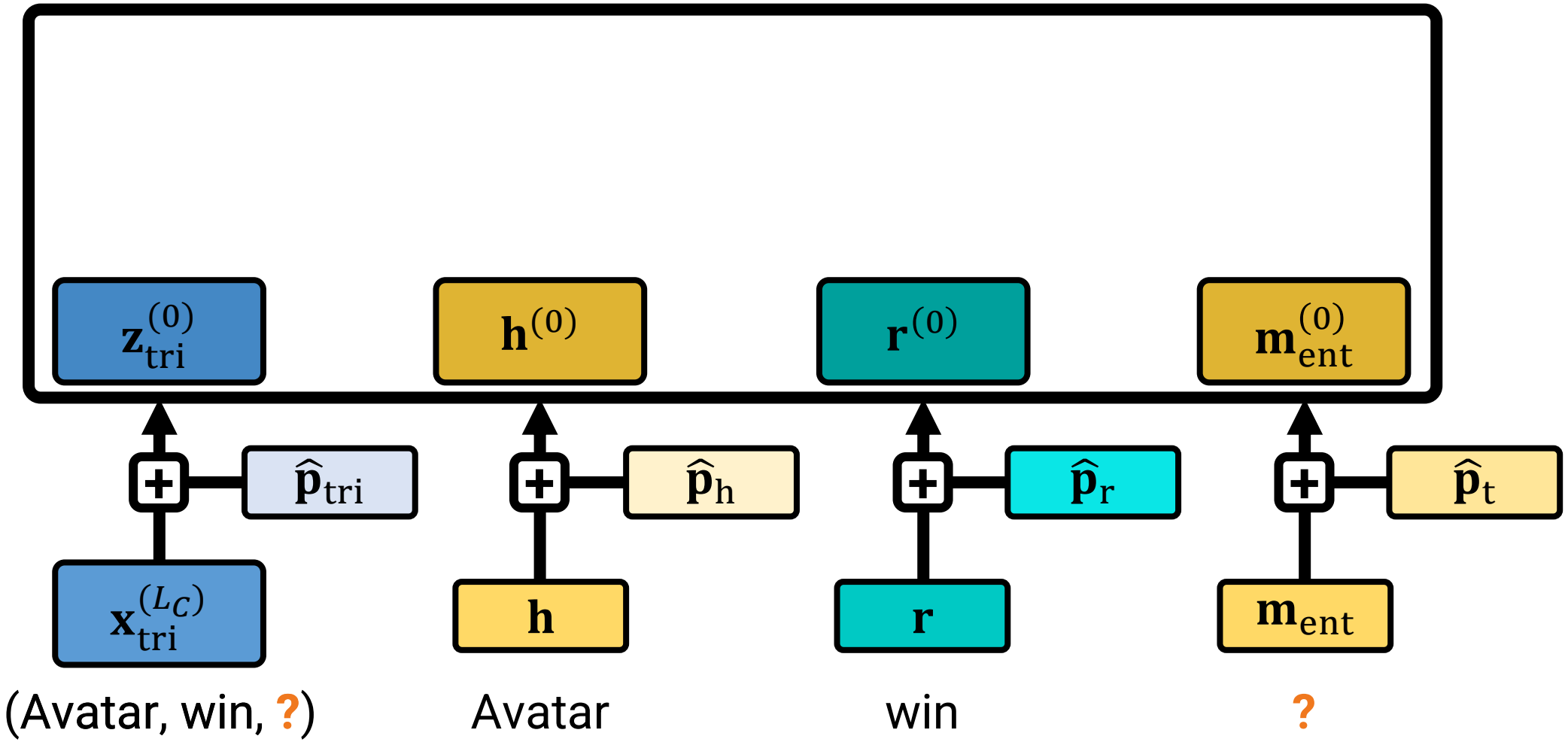
Context Transformer



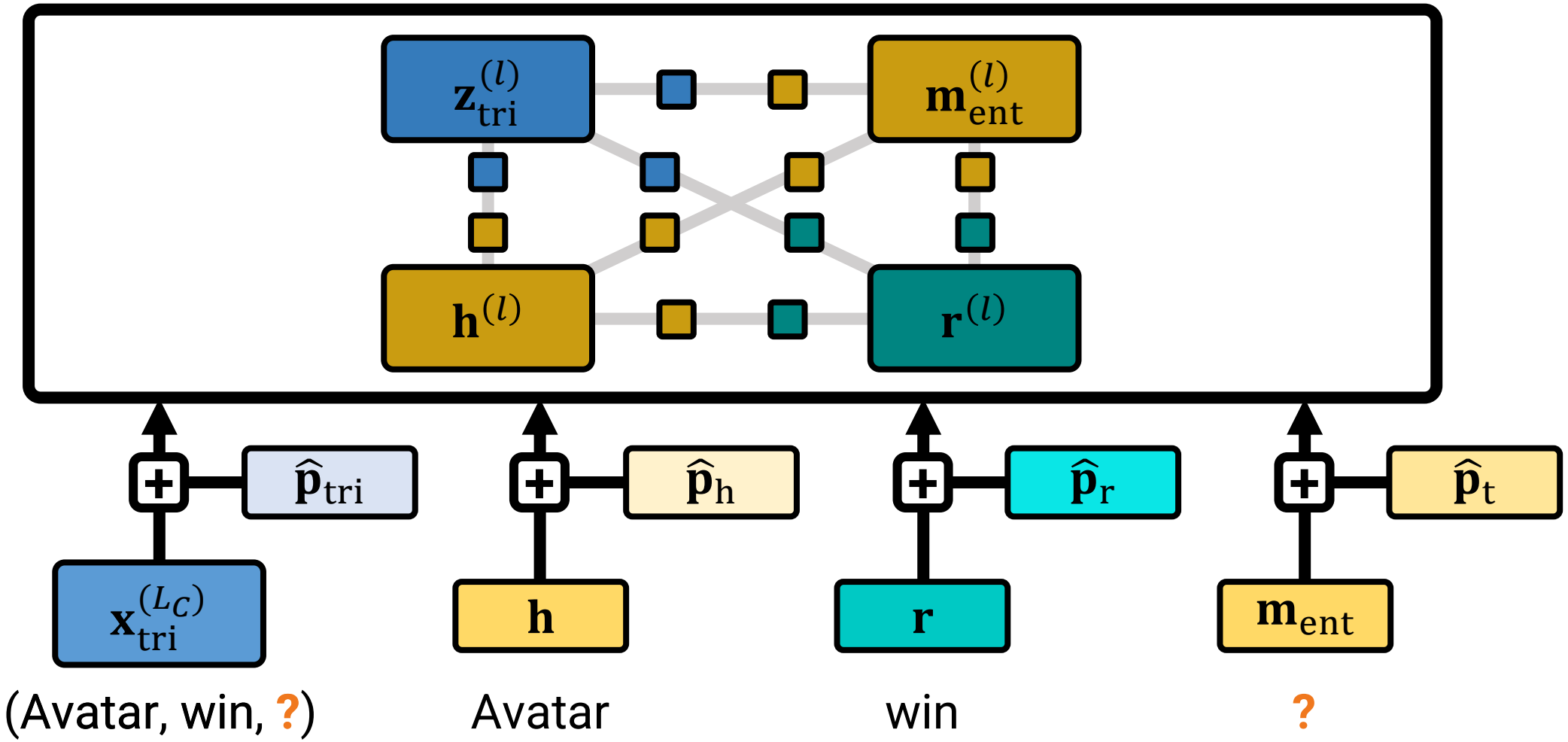
Context Transformer



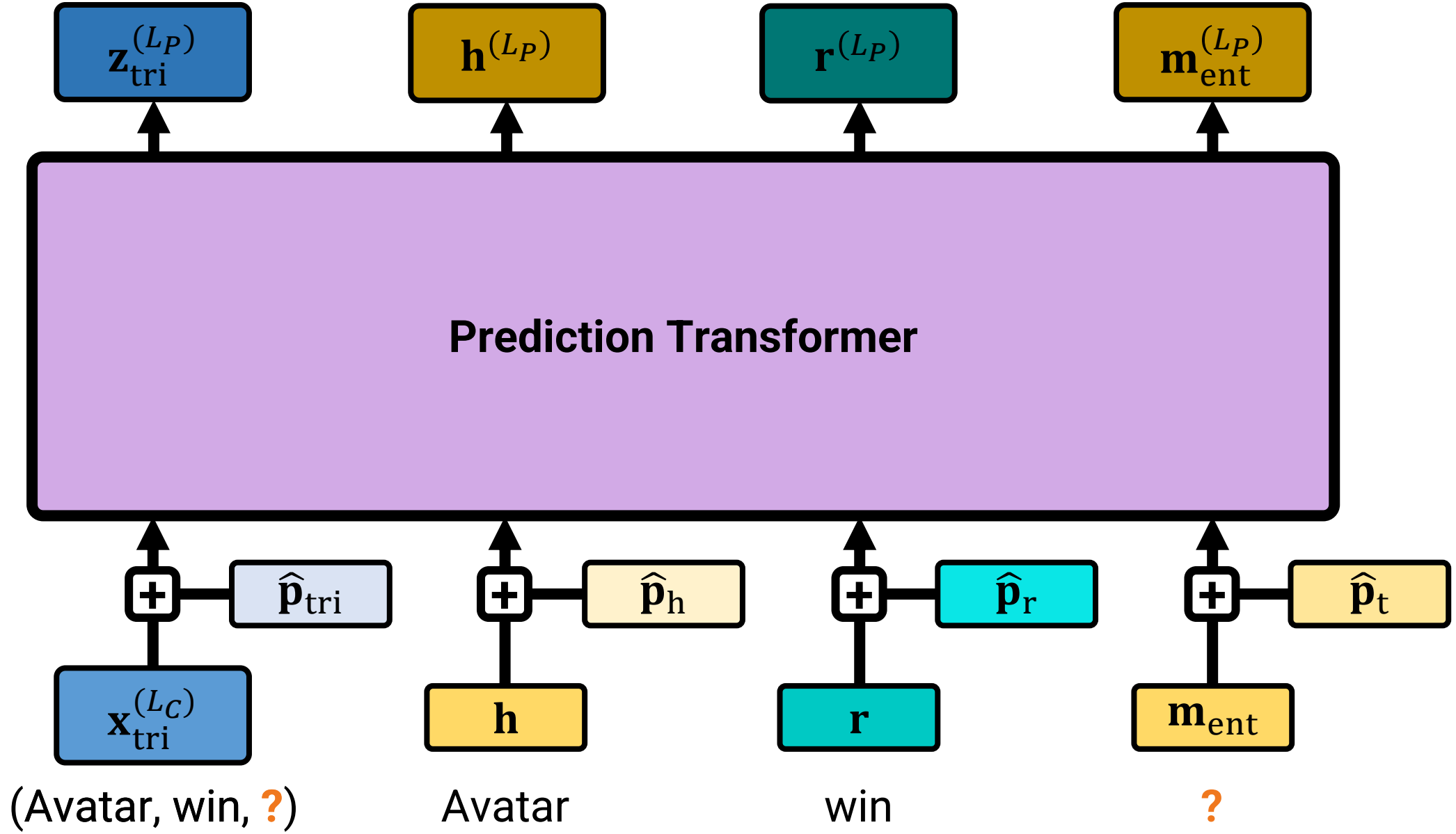
Prediction Transformer



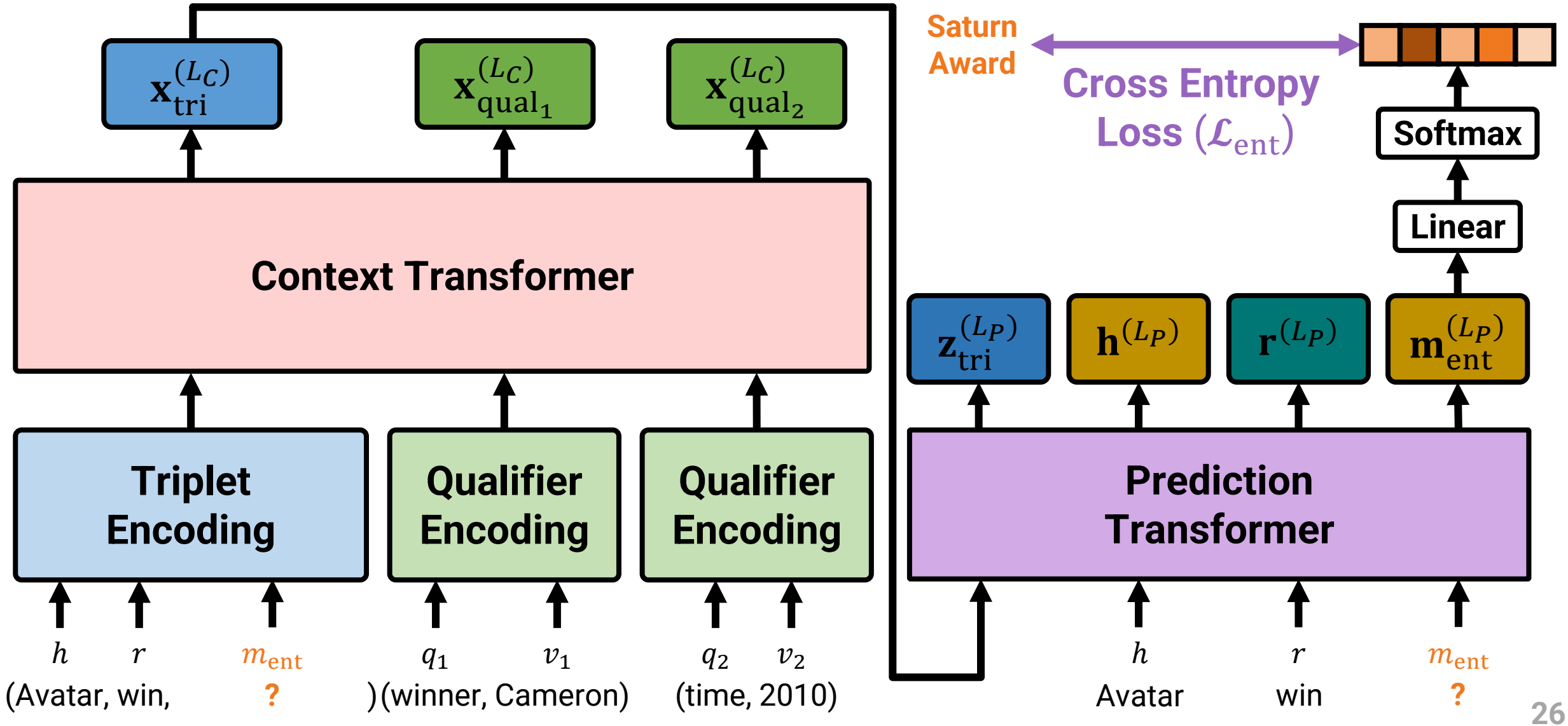
Prediction Transformer



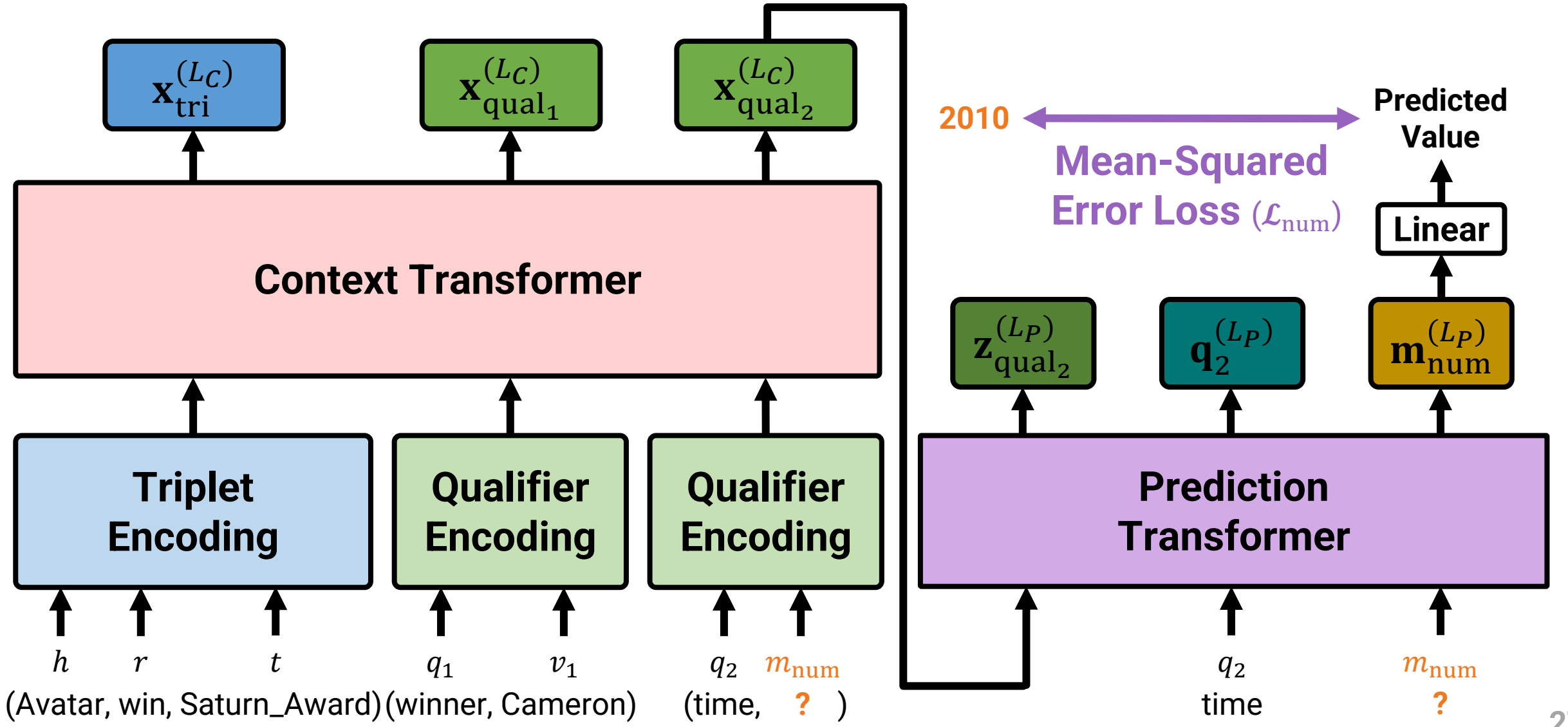
Prediction Transformer



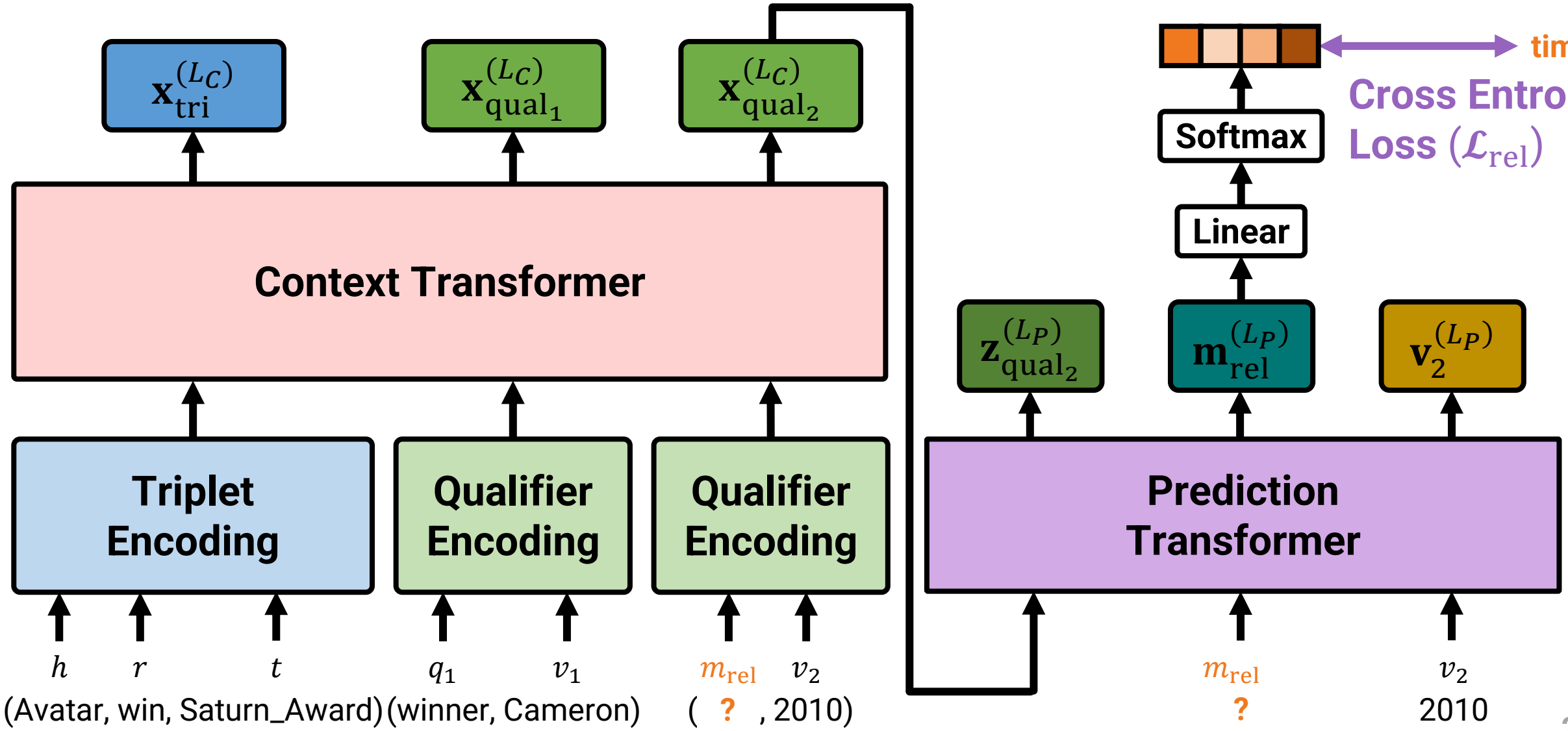
Link Prediction using HyNT



Numeric Value Prediction using HyNT

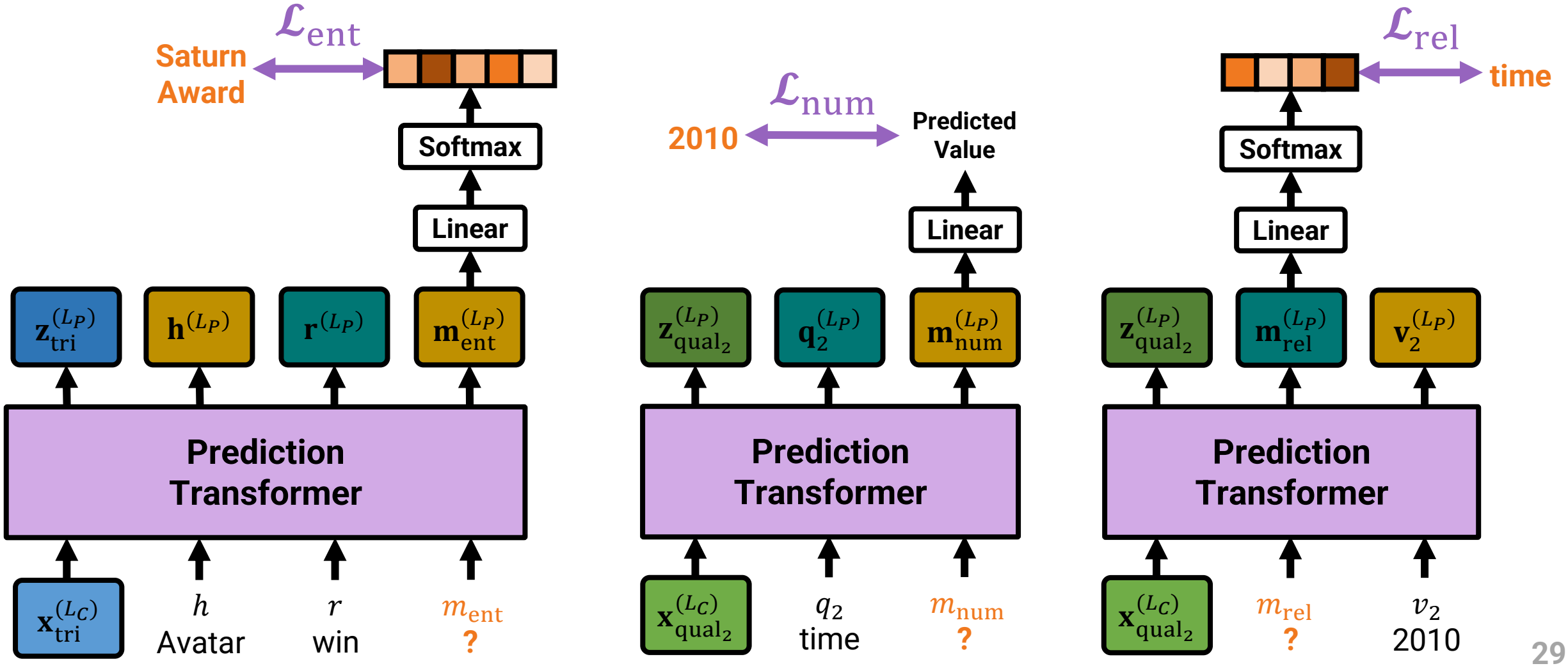


Relation Prediction using HyNT



Loss of HyNT

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

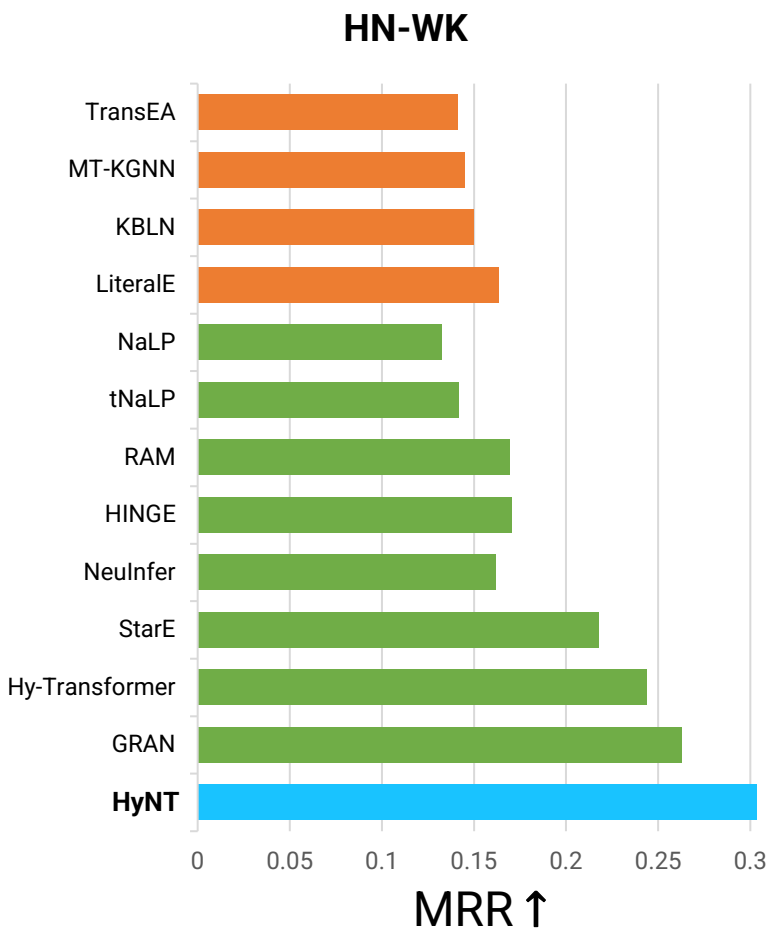


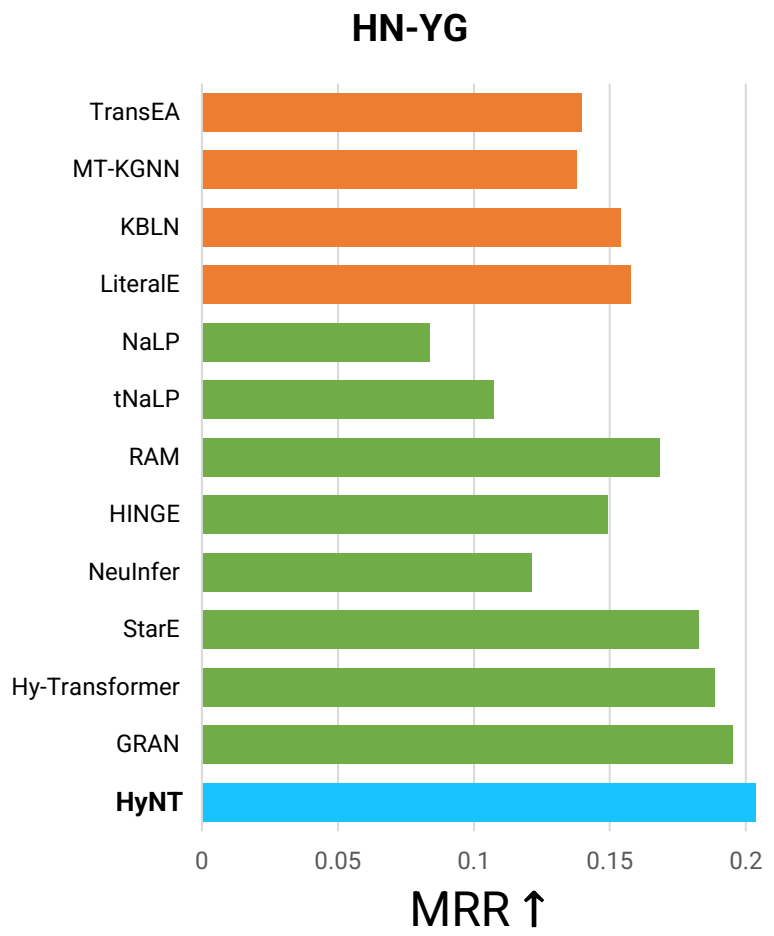
Experimental Results

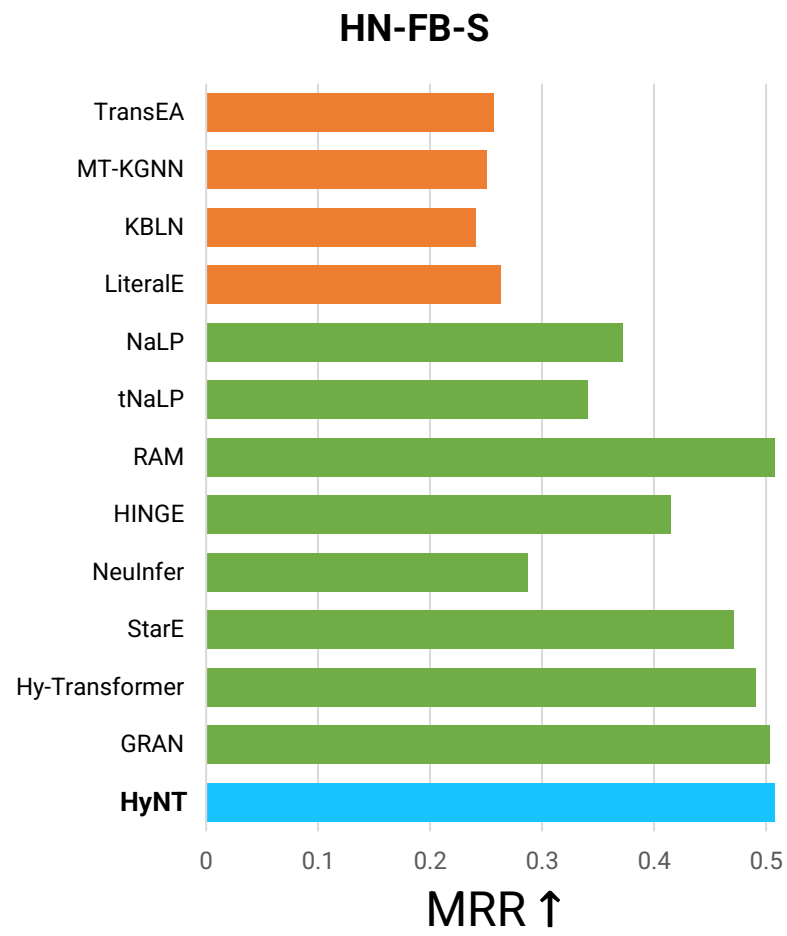
- Datasets
  - Based on Wikidata, YAGO, and Freebase
  - Create **4 Hyper-relational and Numeric Knowledge Graph (HN-KG)** datasets
    - HN-WK, HN-YG, HN-FB, HN-FB-S

- Comparison with **12 baseline methods**
  - Methods for handling numeric literals
    - TransEA, MT-KGNN, KBLN, LiteralE
  - Methods for handling hyper-relational facts
    - NaLP, tNaLP, RAM, HINGE, NeuInfer, StarE, Hy-Transformer, GRAN

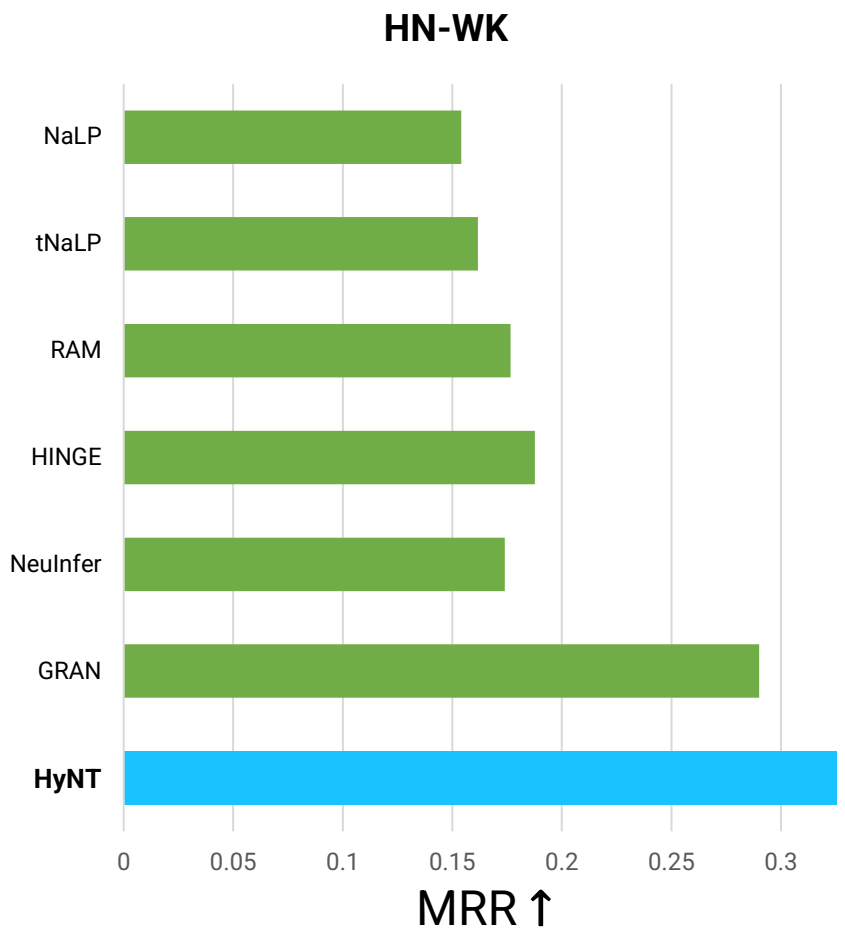
Link Prediction Results – Primary

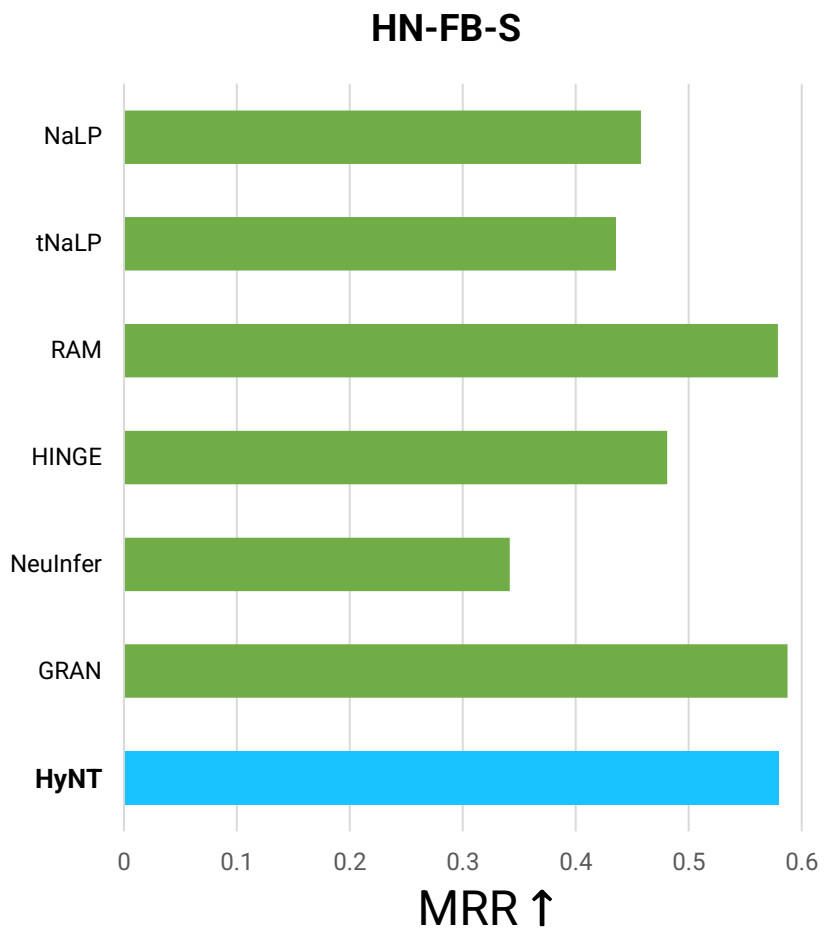




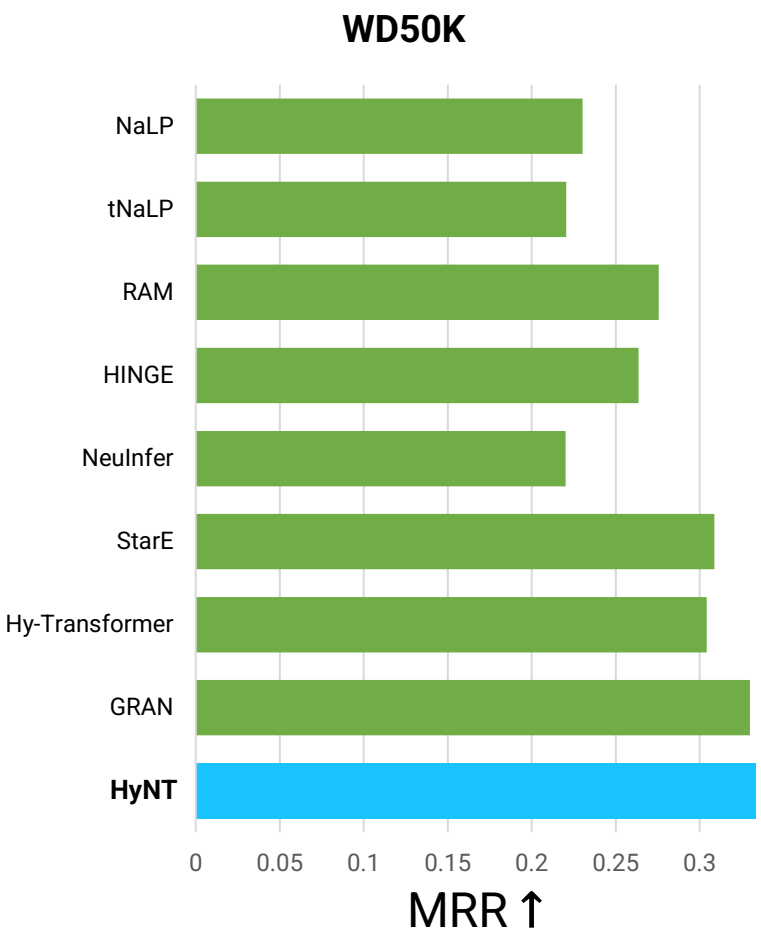


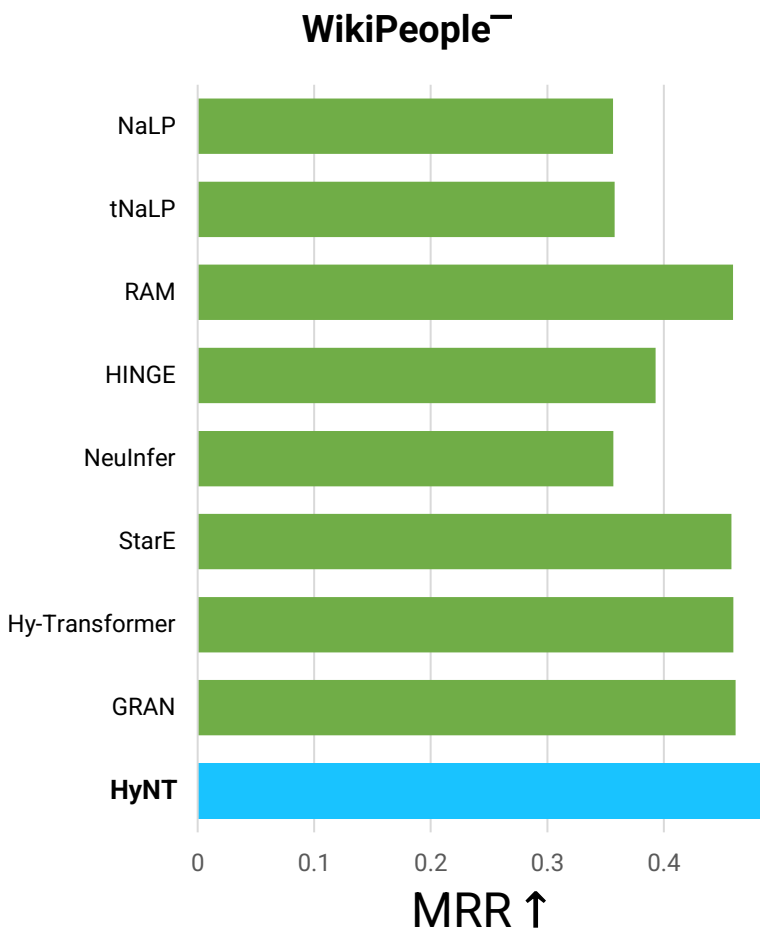
Link Prediction Results – All





Link Prediction Results – Primary (Benchmark Datasets)





Link Prediction Results of HyNT

((? , nominated_for, Best_Actor), {(for_work, Moneyball), (subject_of, 84th_Oscars)})

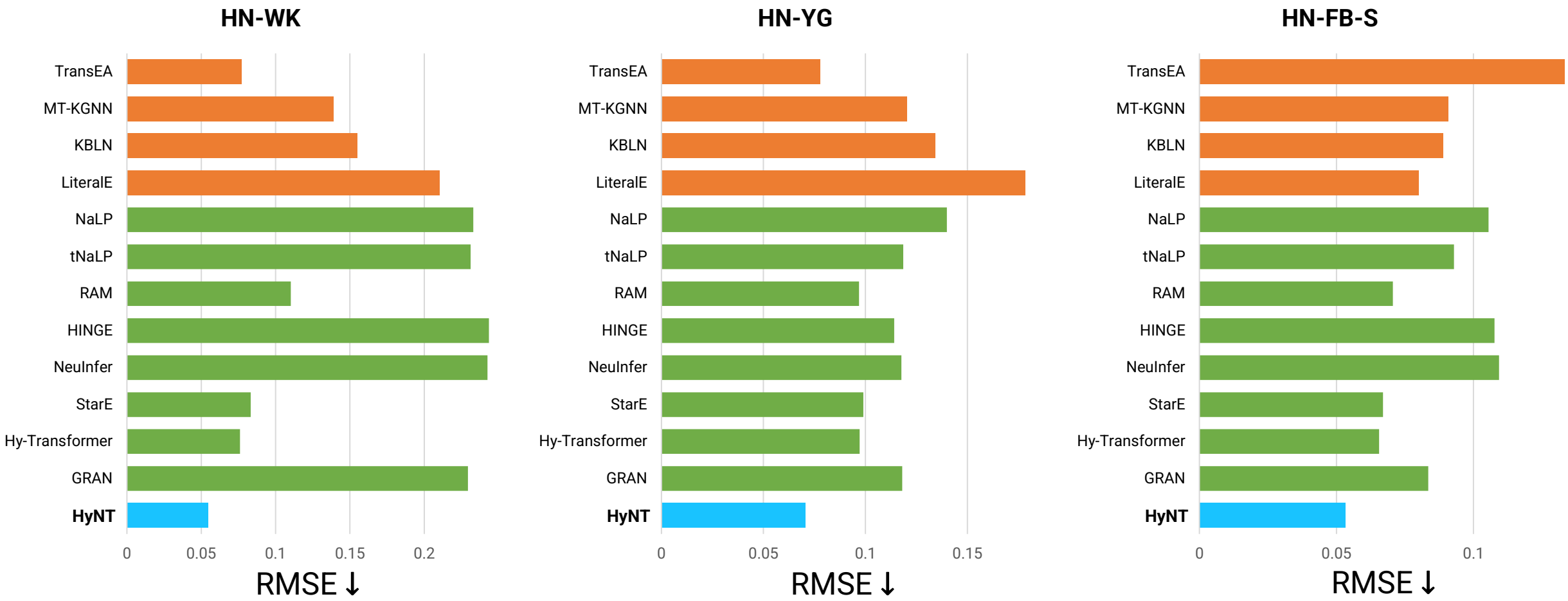
((? , nominated_for, Best_Actor), {(for_work, Forrest_Gump), (subject_of, 67th_Oscars)})

Link Prediction Results of HyNT

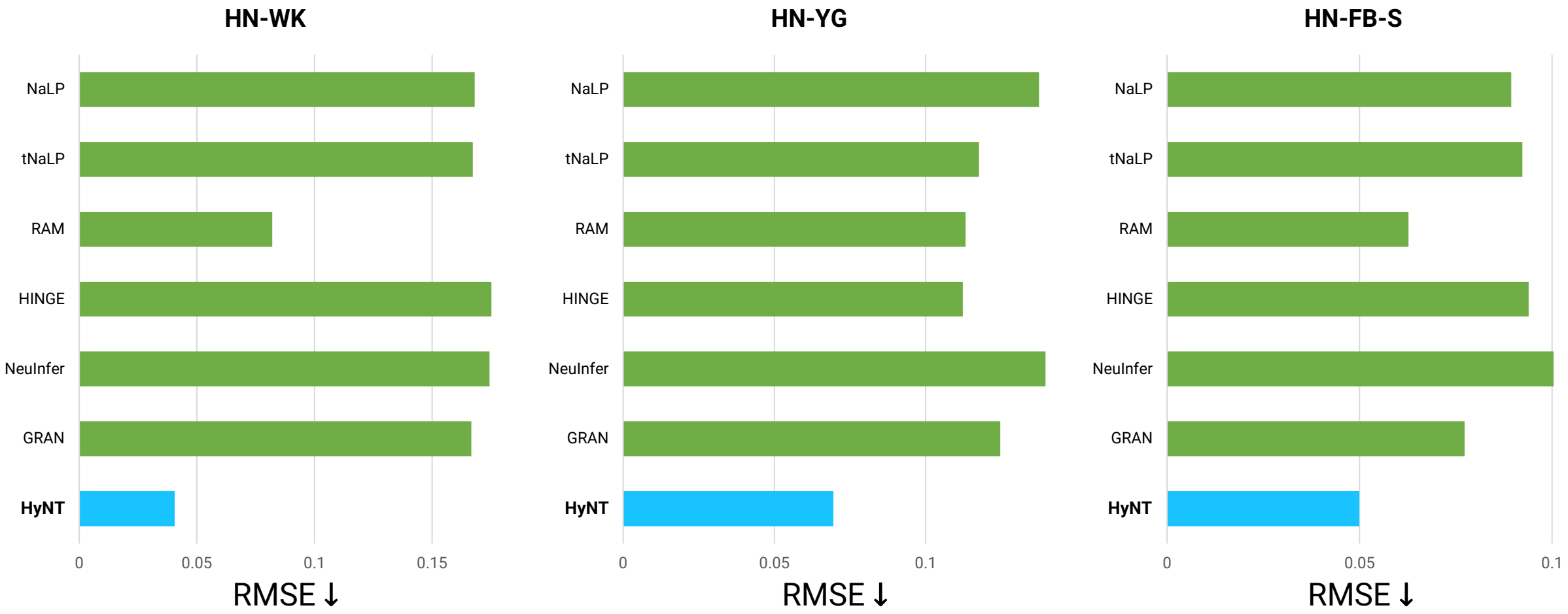
((**Brad_Pitt**, nominated_for, Best_Actor), {(for_work, Moneyball), (subject_of, 84th_Oscars)})

((**Tom_Hanks**, nominated_for, Best_Actor), {(for_work, Forrest_Gump), (subject_of, 67th_Oscars)})

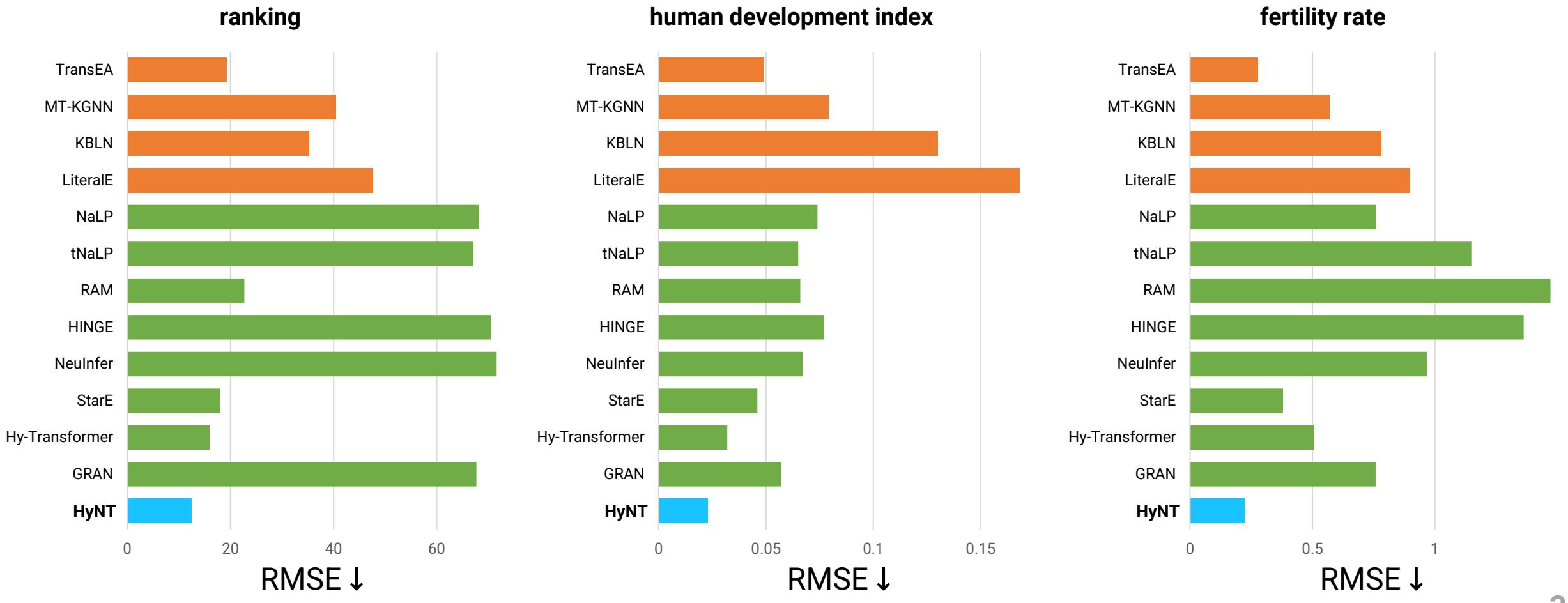
Numeric Value Prediction Results – Primary



Numeric Value Prediction Results – All



Numeric Value Prediction Results per Attribute Type in HN-WK

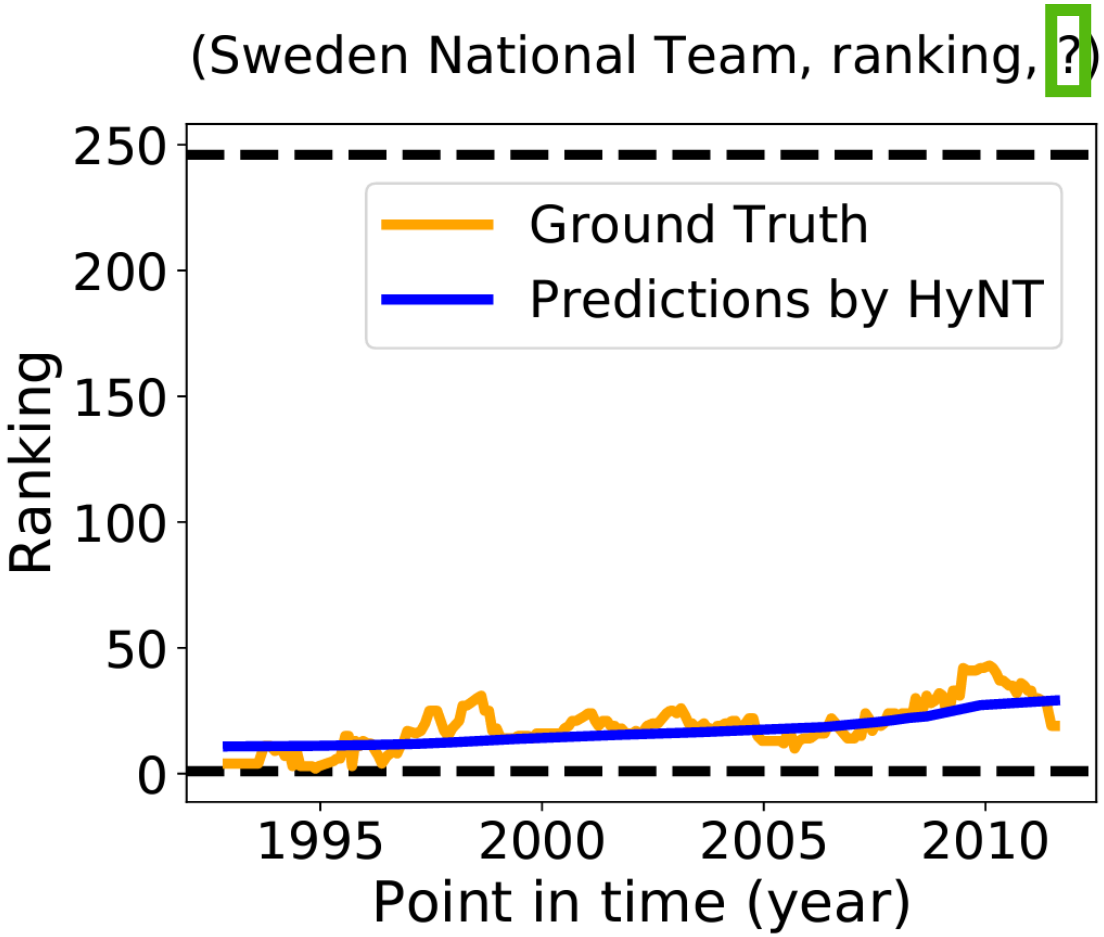


Visualization of the Predictions

Target Values

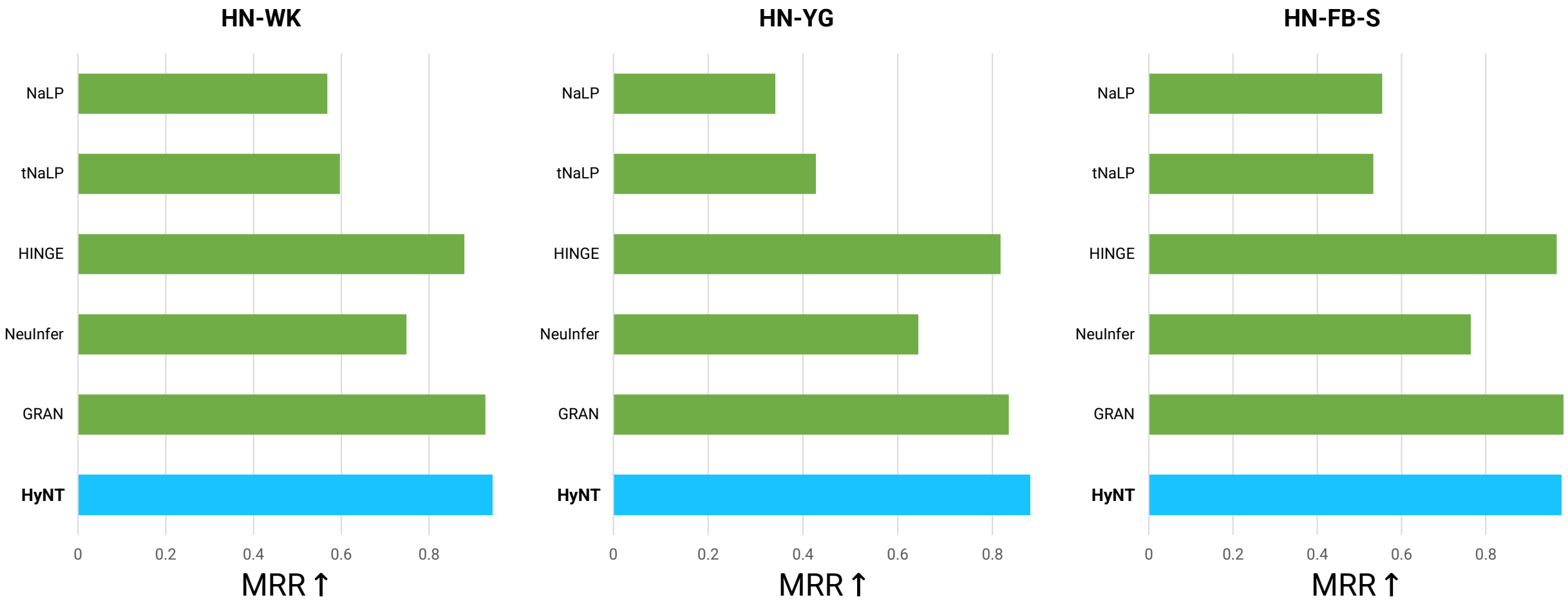
((Sweden National team, ranking, ?), {(point in time, 1995)})
((Sweden National team, ranking, ?), {(point in time, 1996)})
((Sweden National team, ranking, ?), {(point in time, 1997)})
⋮

Visualization of the Predictions

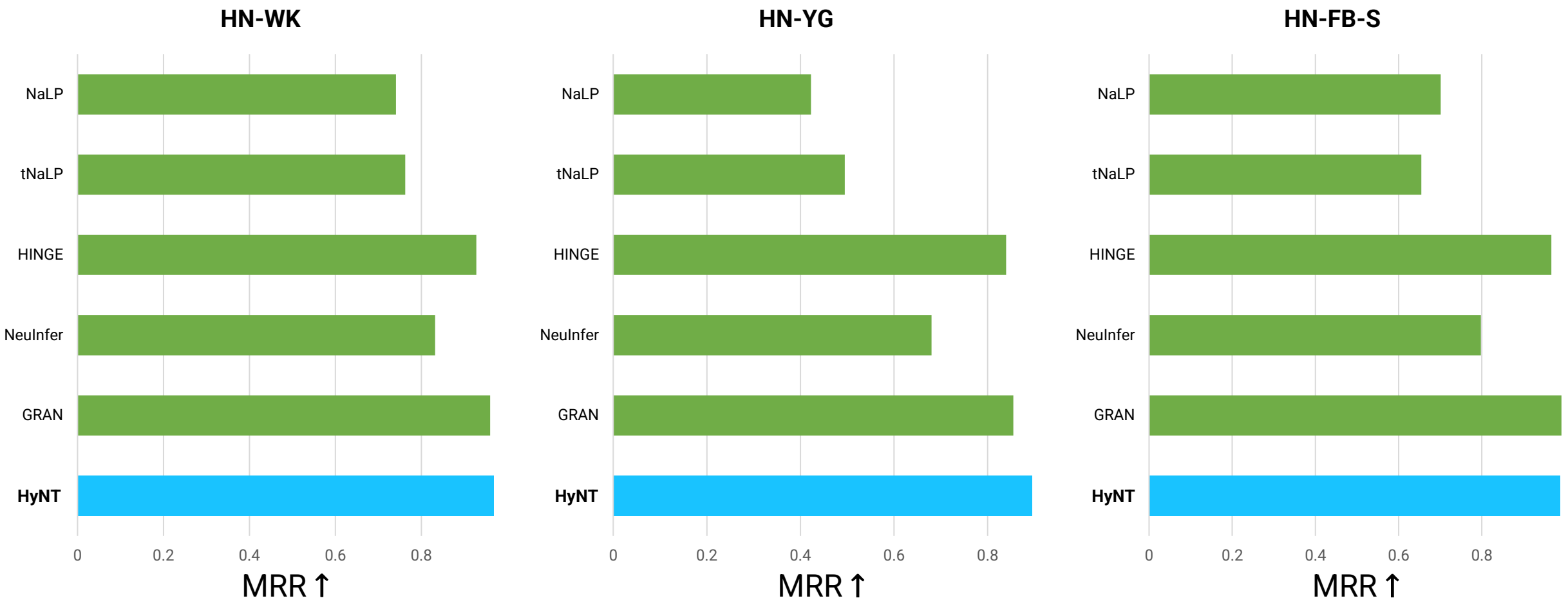


Target Values

Relation Prediction Results – Primary



Relation Prediction Results – All



Conclusion & Future Work

- **H**yper-relational and **N**umeric **K**nowledge **G**raphs **(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
- Extend HyNT to **inductive learning scenarios**
  - New entities and relations appear at test time

Our datasets and codes are available at:

https://github.com/bdi-lab/HyNT

◀ GitHub

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https://bdi-lab.kaist.ac.kr

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