

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

Chanyoung Chung[†], Jaejun Lee[†], and Joyce Jiyoung Whang^{*}

School of Computing, KAIST

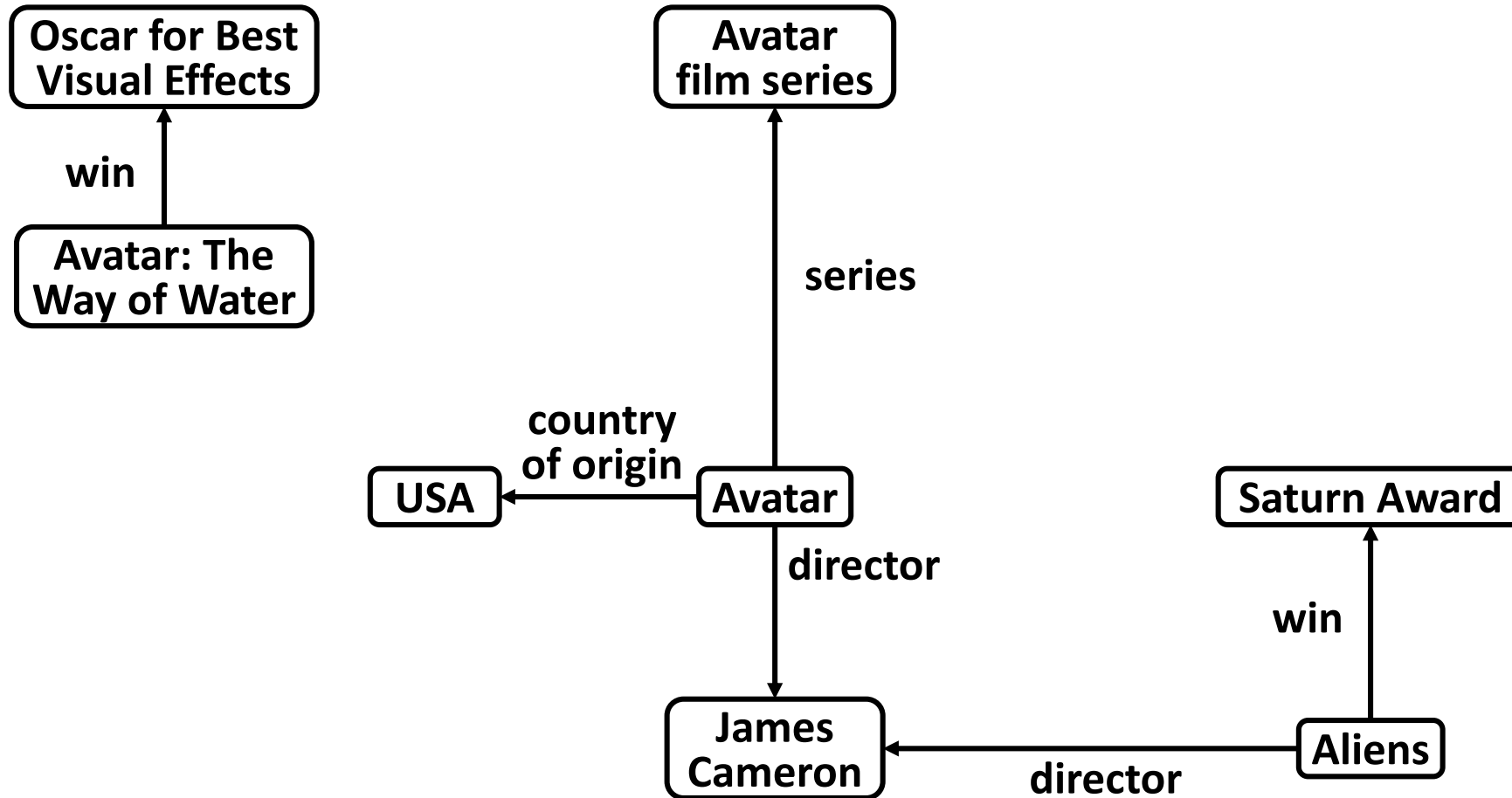
[†] Authors in Alphabetical Order with Equal Contribution

^{*} Corresponding Author

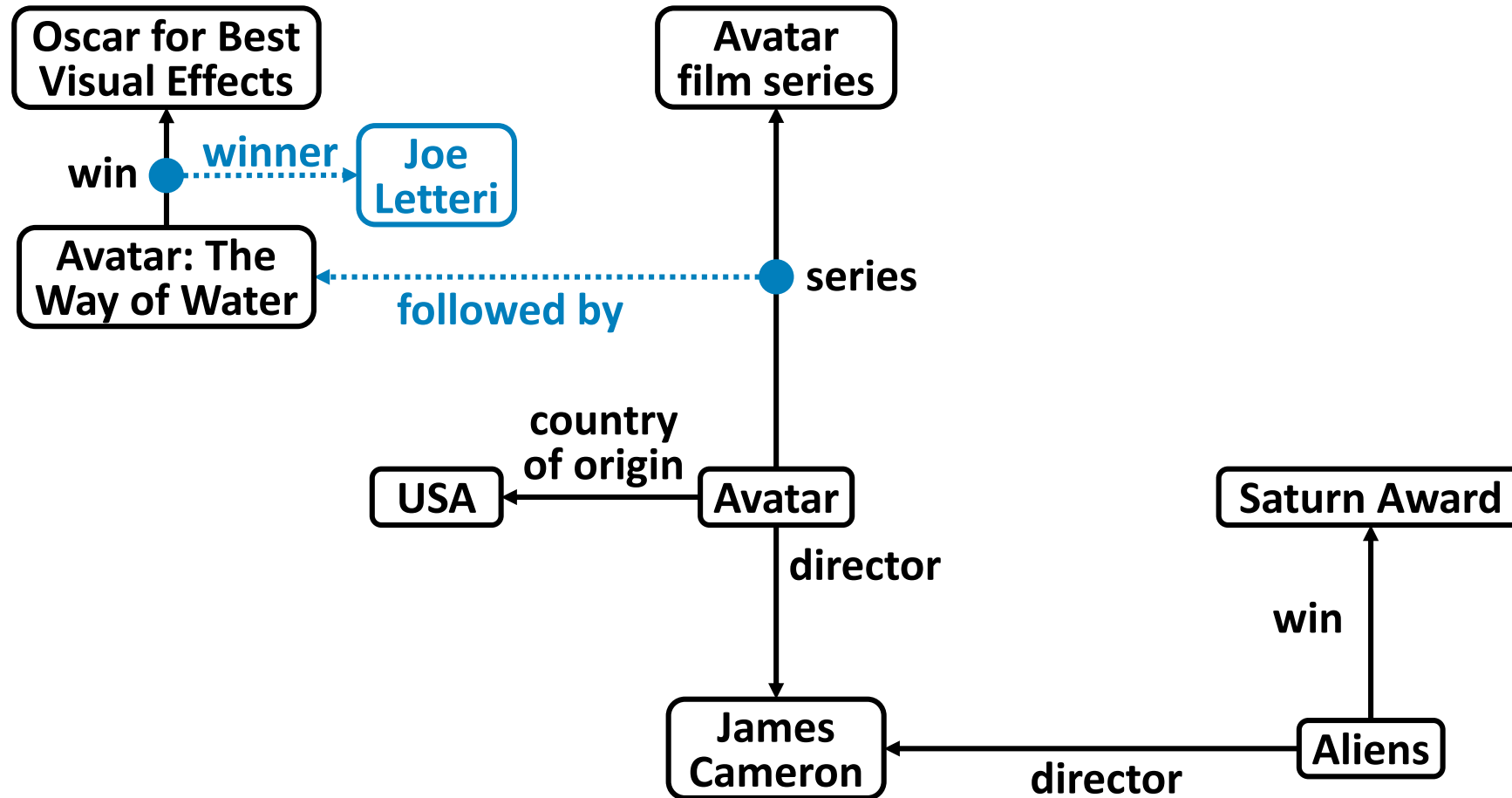
ACM SIGKDD Conference on Knowledge Discovery and Data Mining
(KDD 2023)



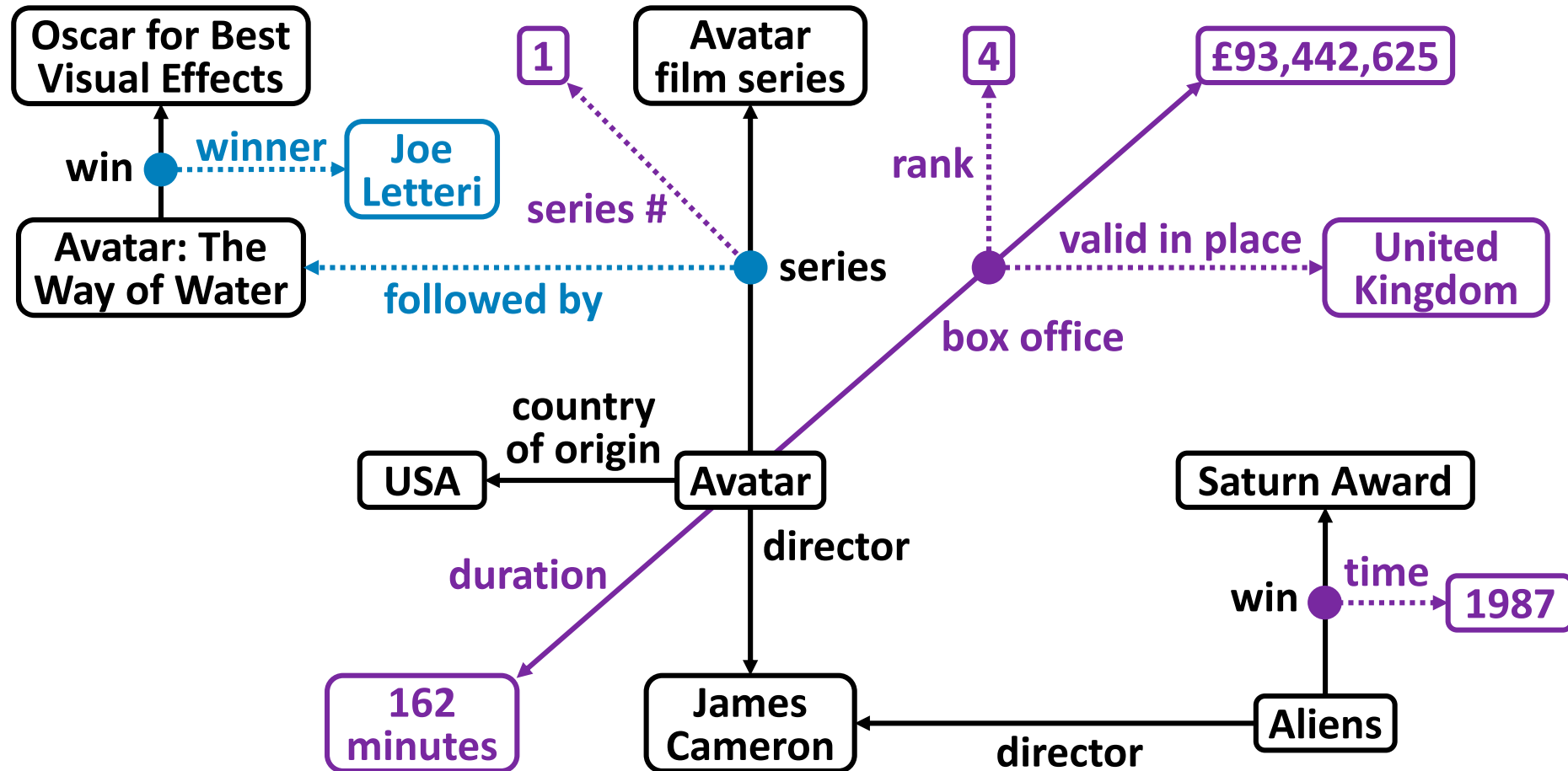
Knowledge Graphs



Hyper-relational Knowledge Graphs



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

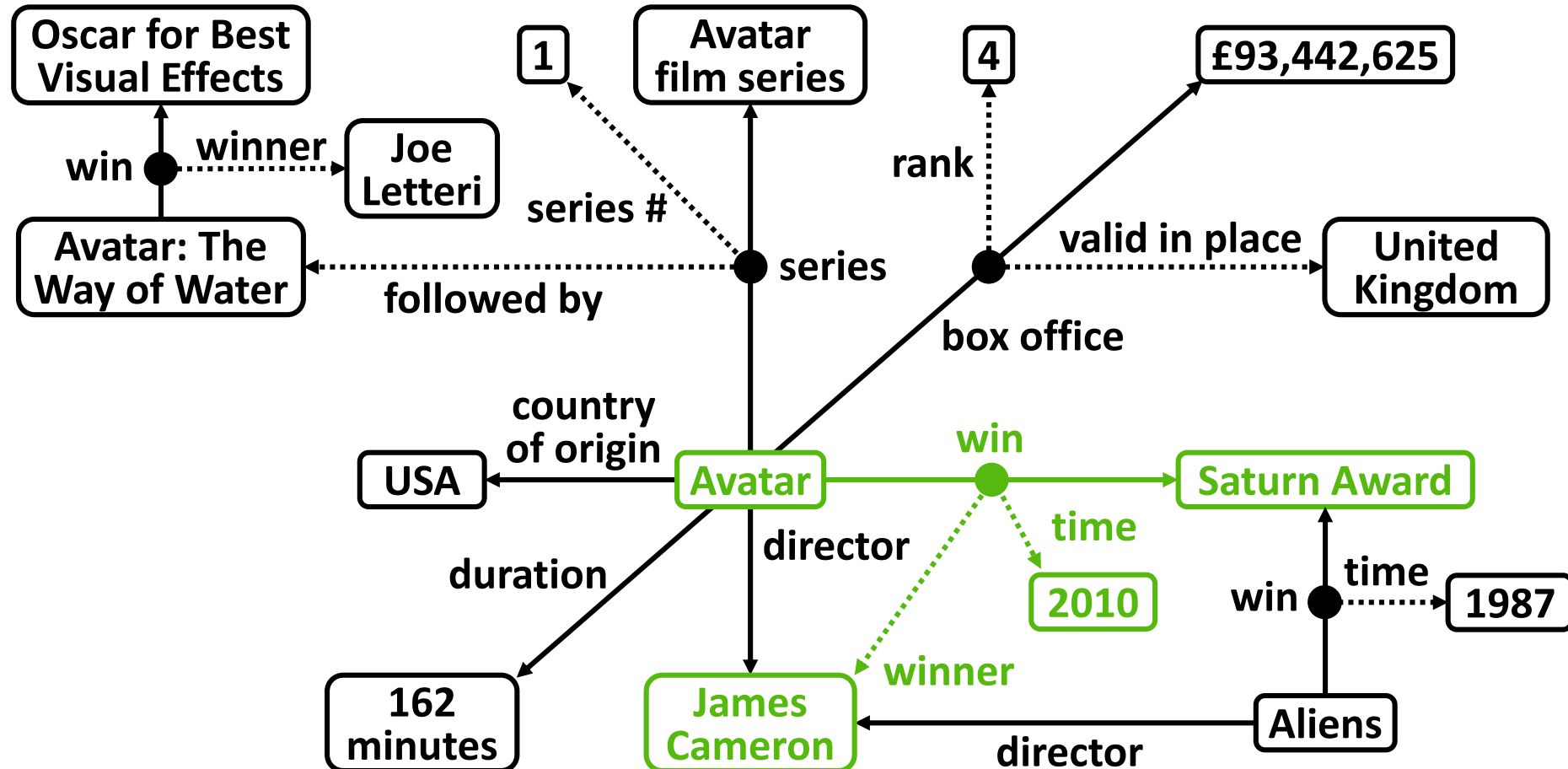


((Avatar, win, Saturn_Award), {(winner, James_Cameron), (time, 2010)})

Primary Triplet

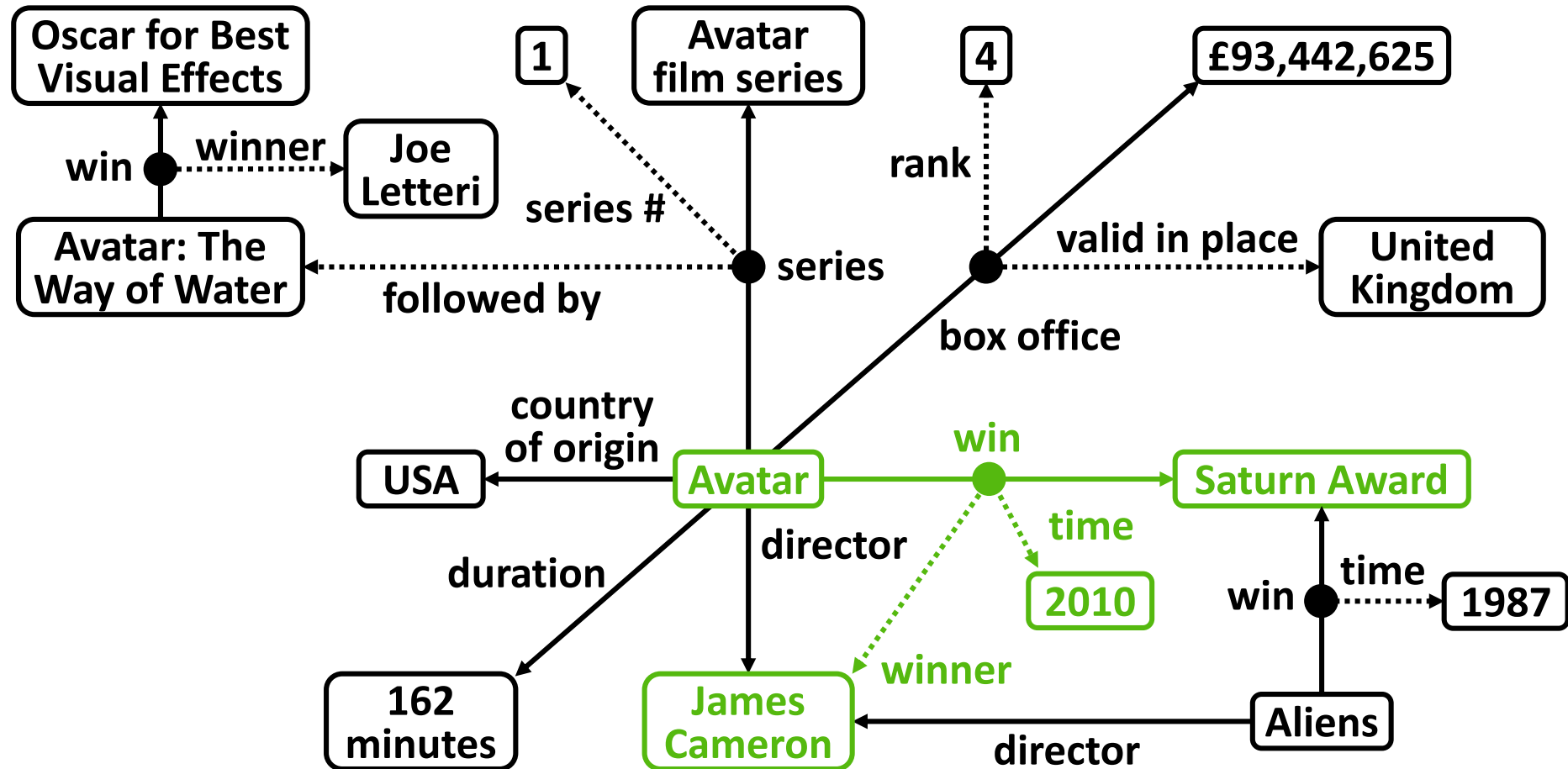
Qualifier 1

Qualifier 2



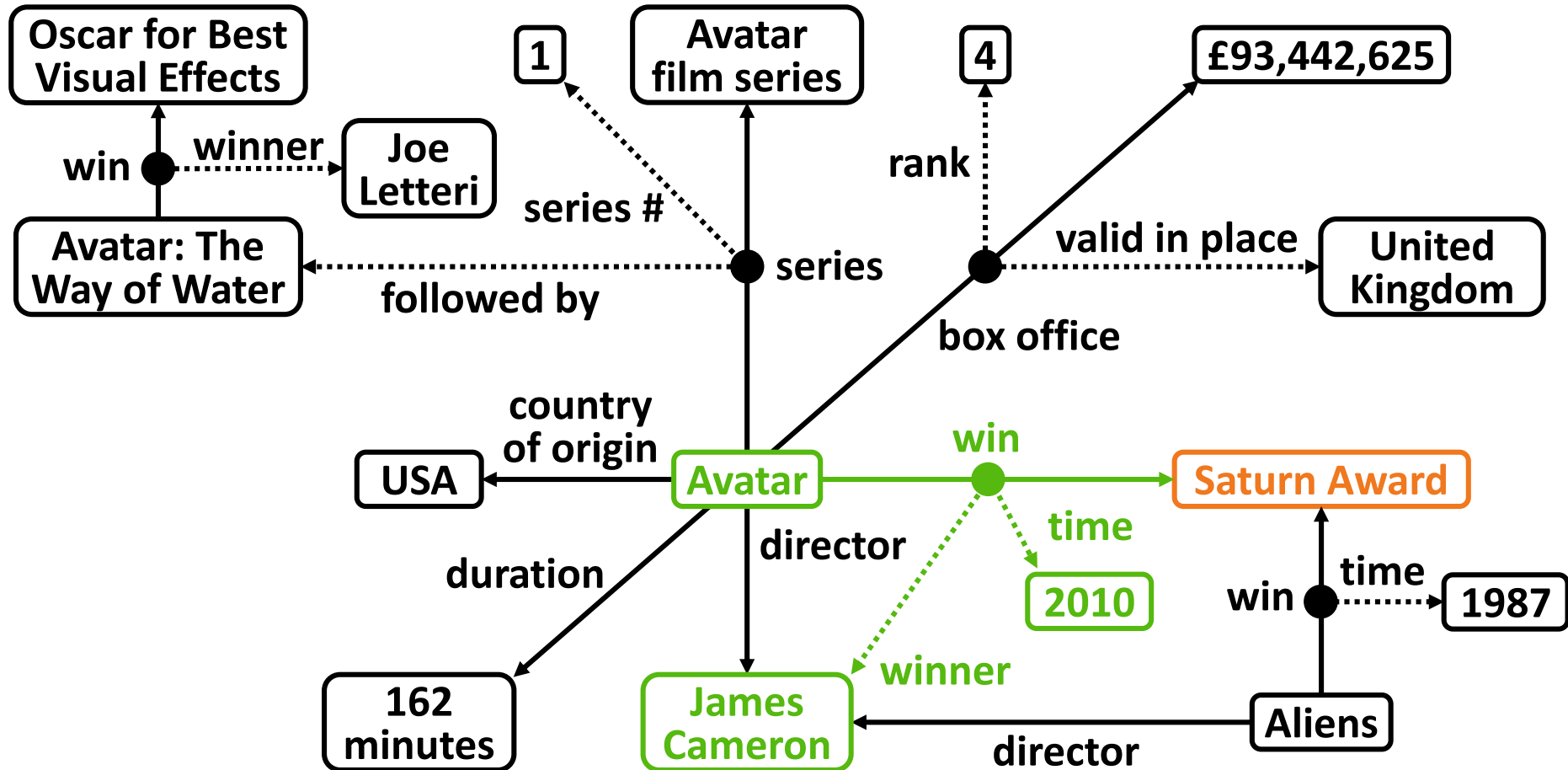
Link Prediction on HN-KGs

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



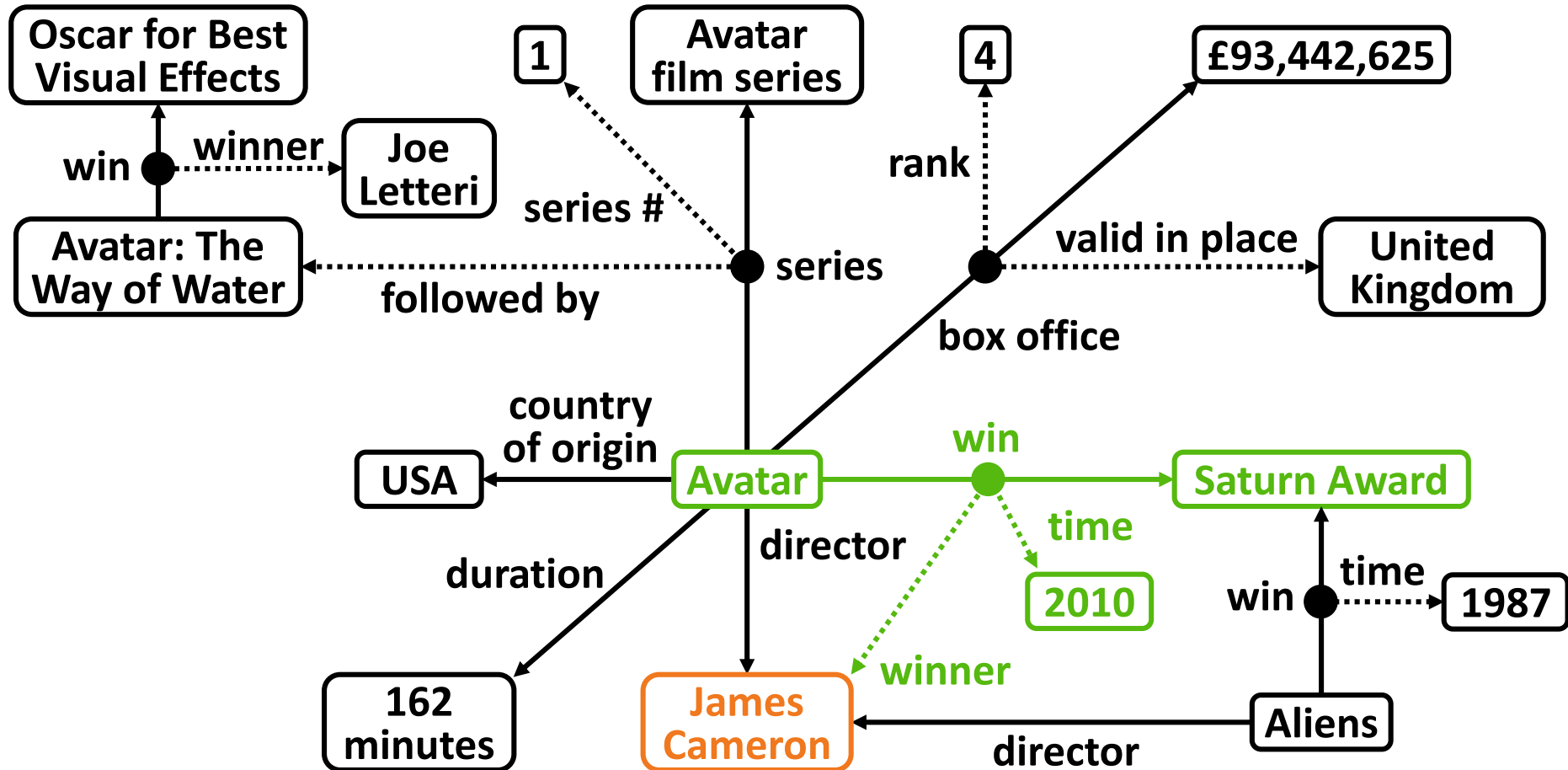
Link Prediction on HN-KGs

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



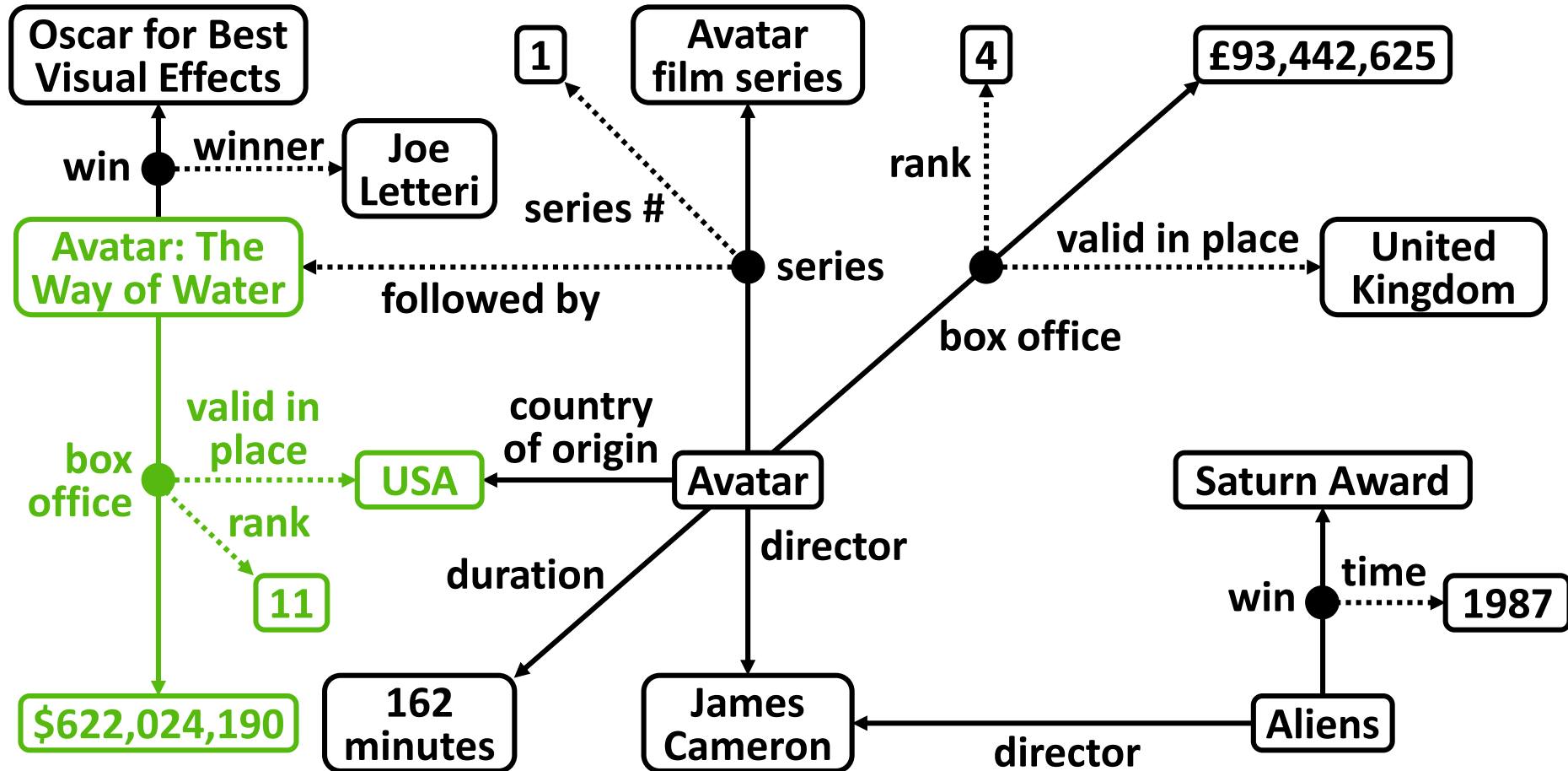
Link Prediction on HN-KGs

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



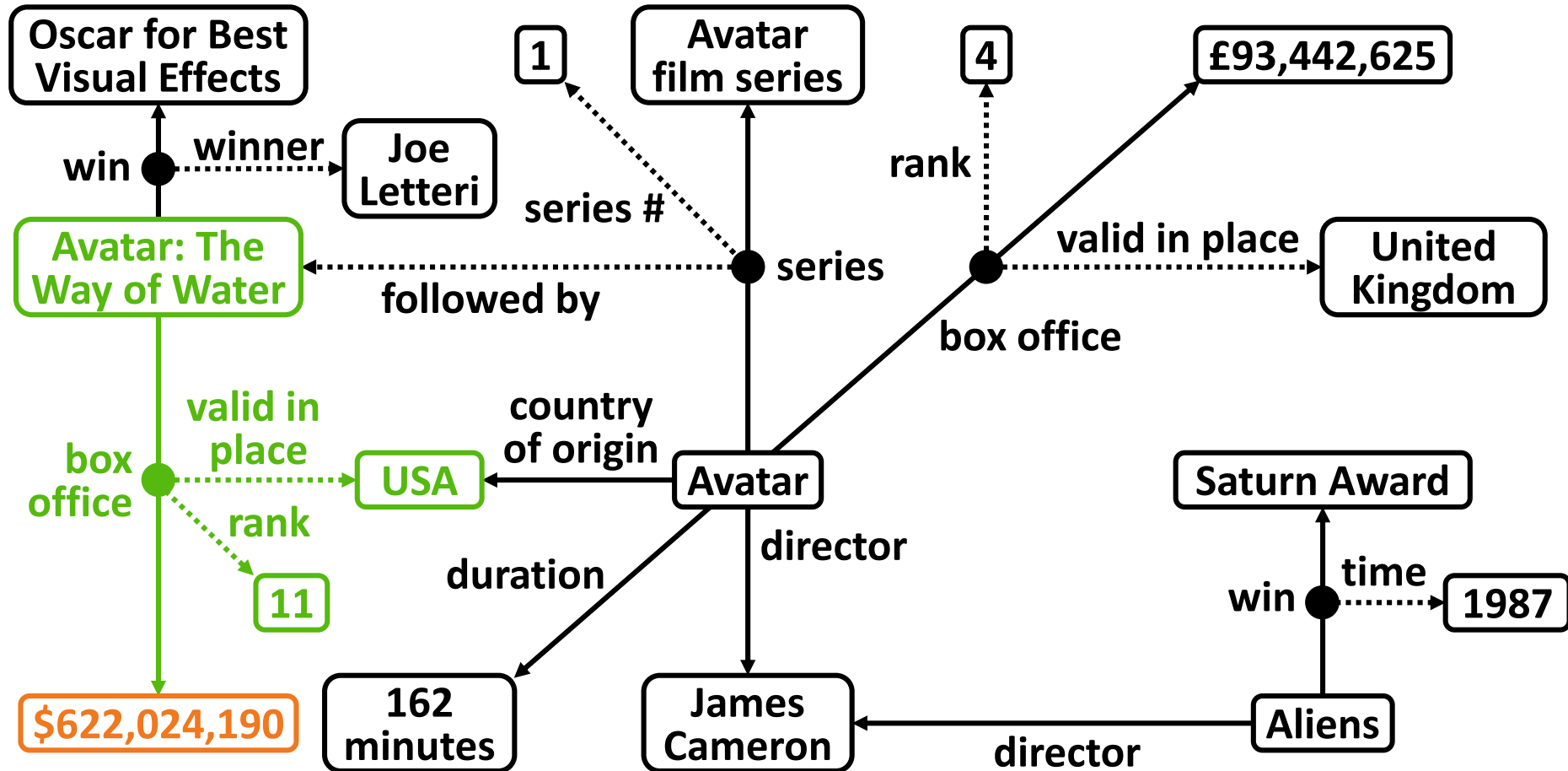
Numeric Value Prediction on HN-KGs

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



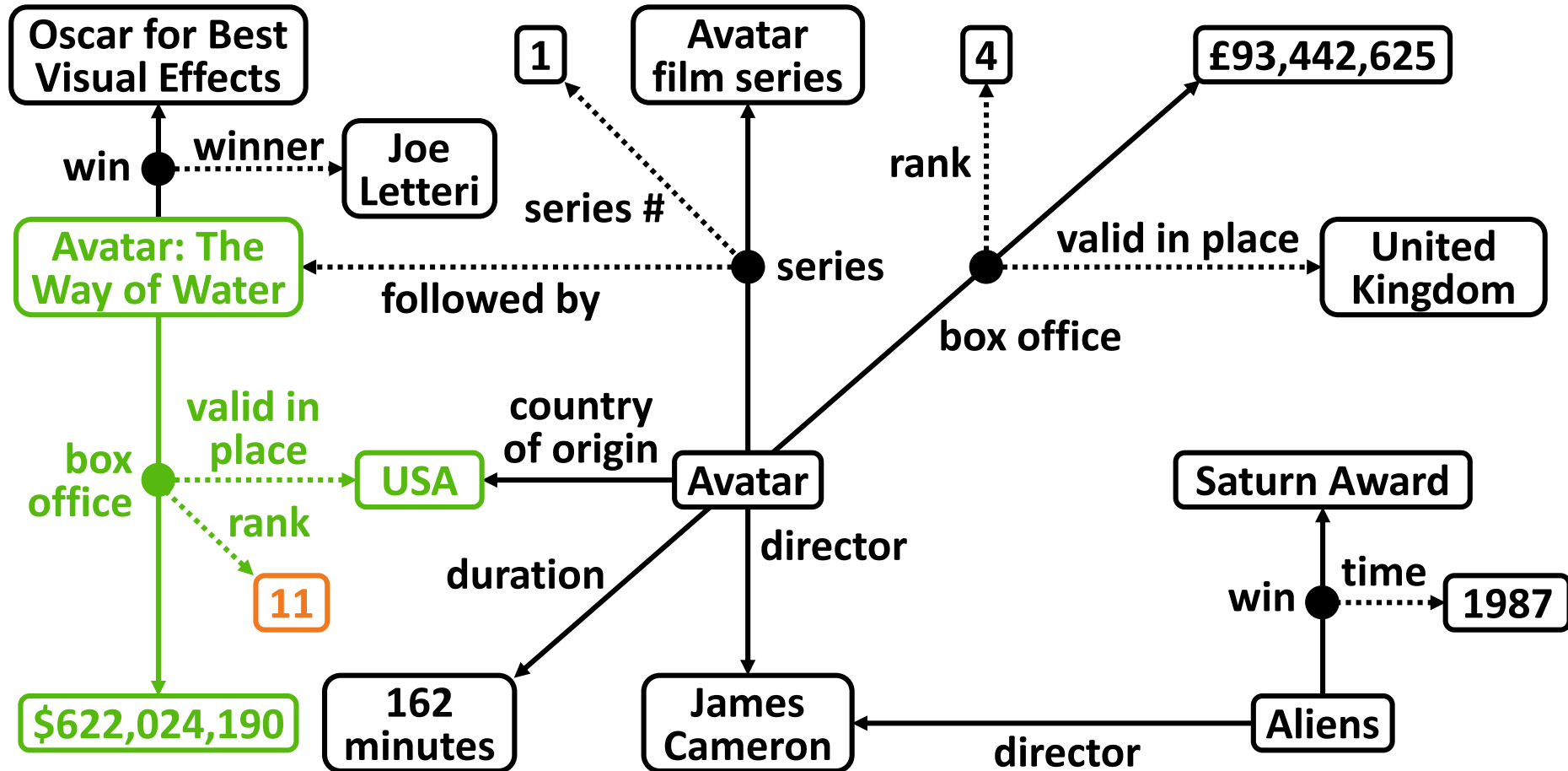
Numeric Value Prediction on HN-KGs

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



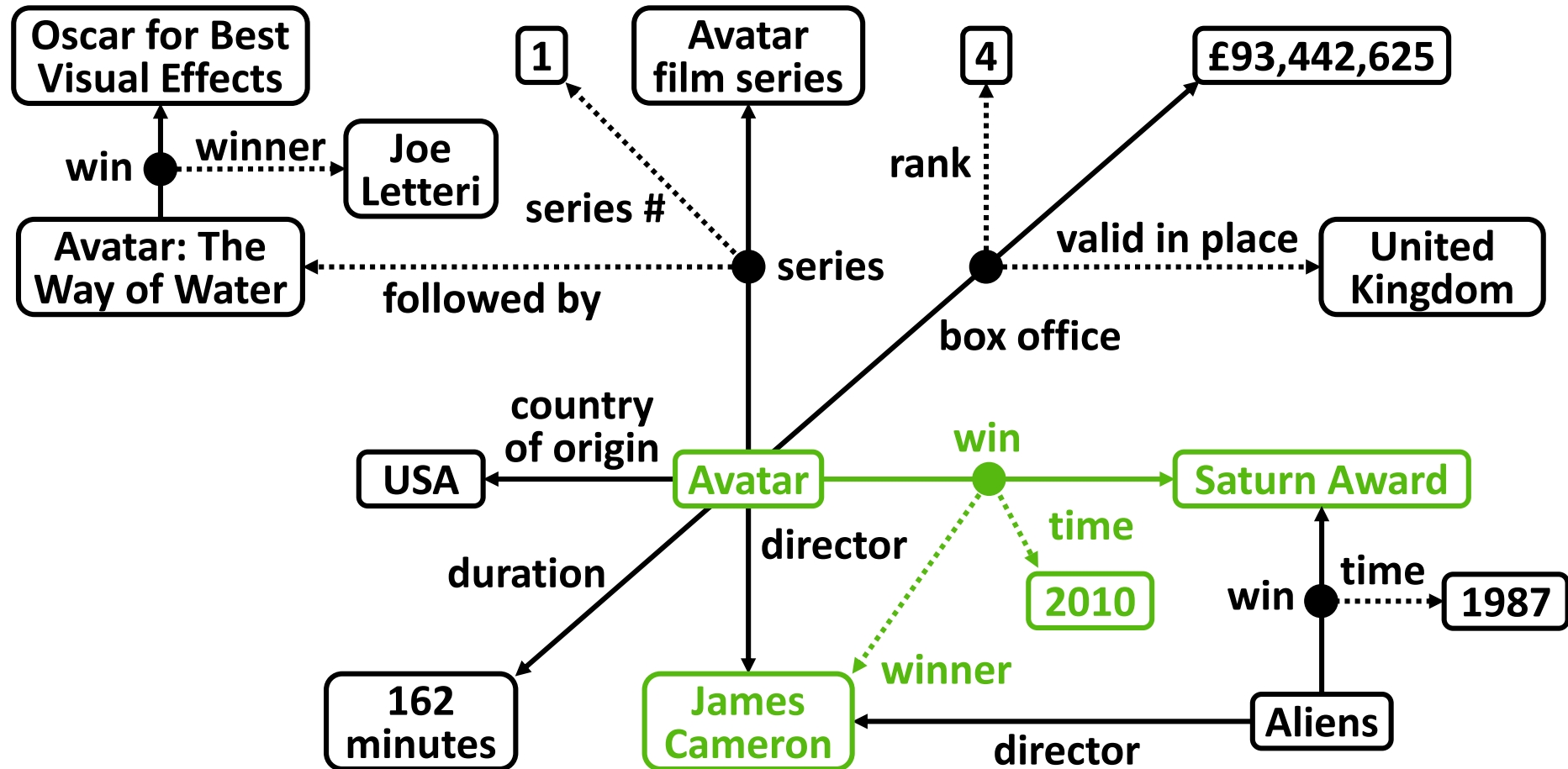
Numeric Value Prediction on HN-KGs

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



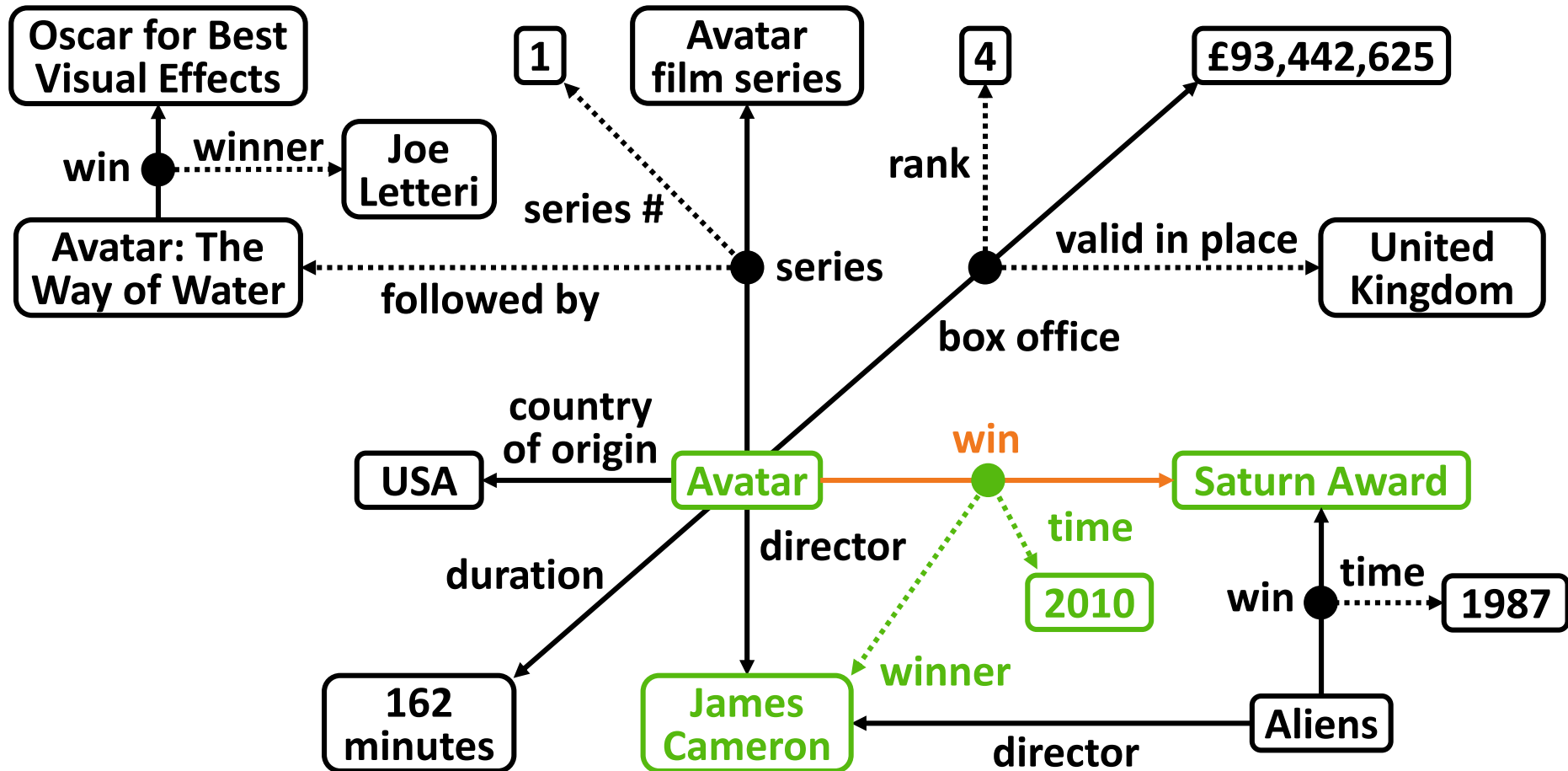
Relation Prediction on HN-KGs

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



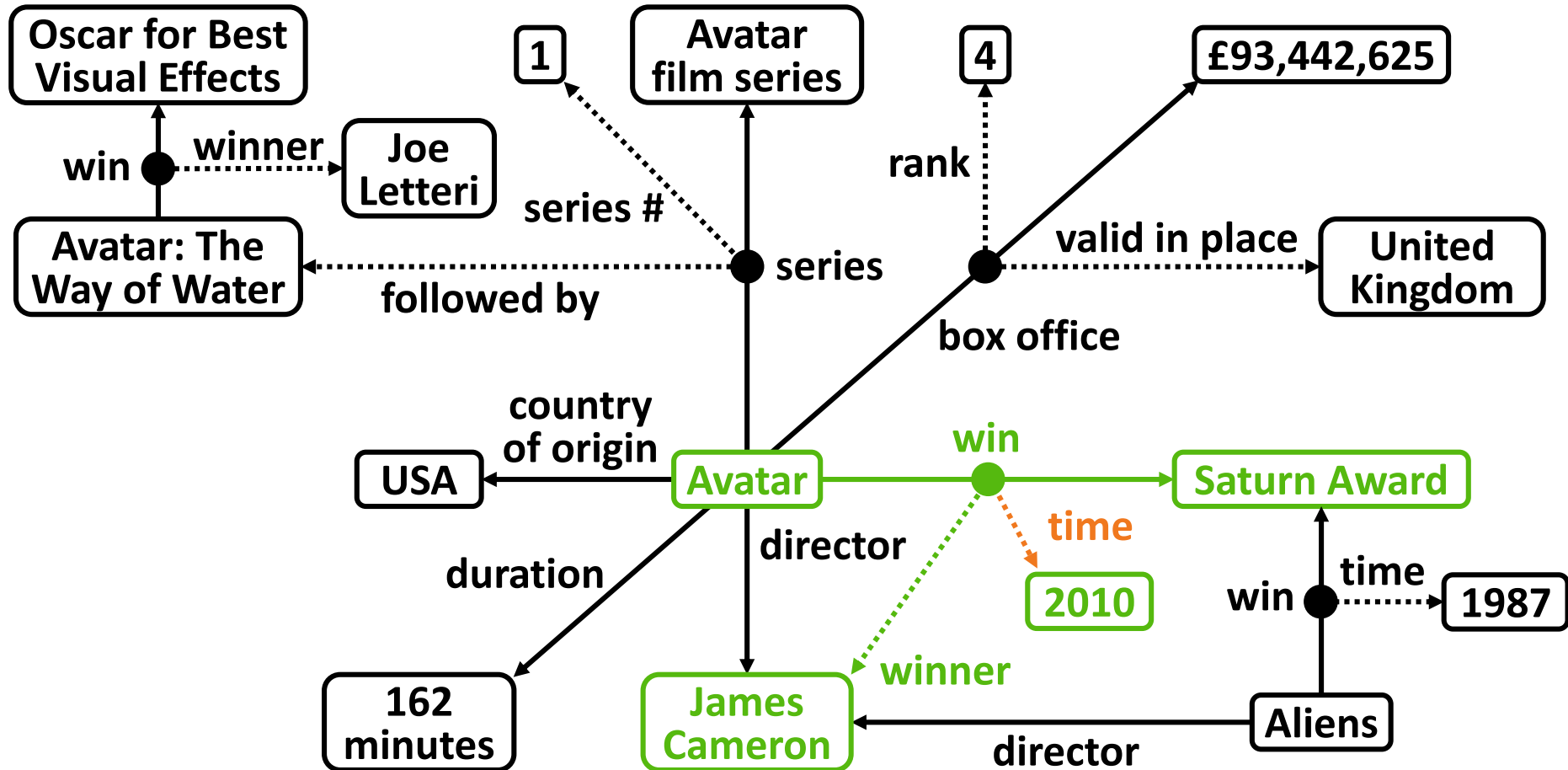
Relation Prediction on HN-KGs

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



Relation Prediction on HN-KGs

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

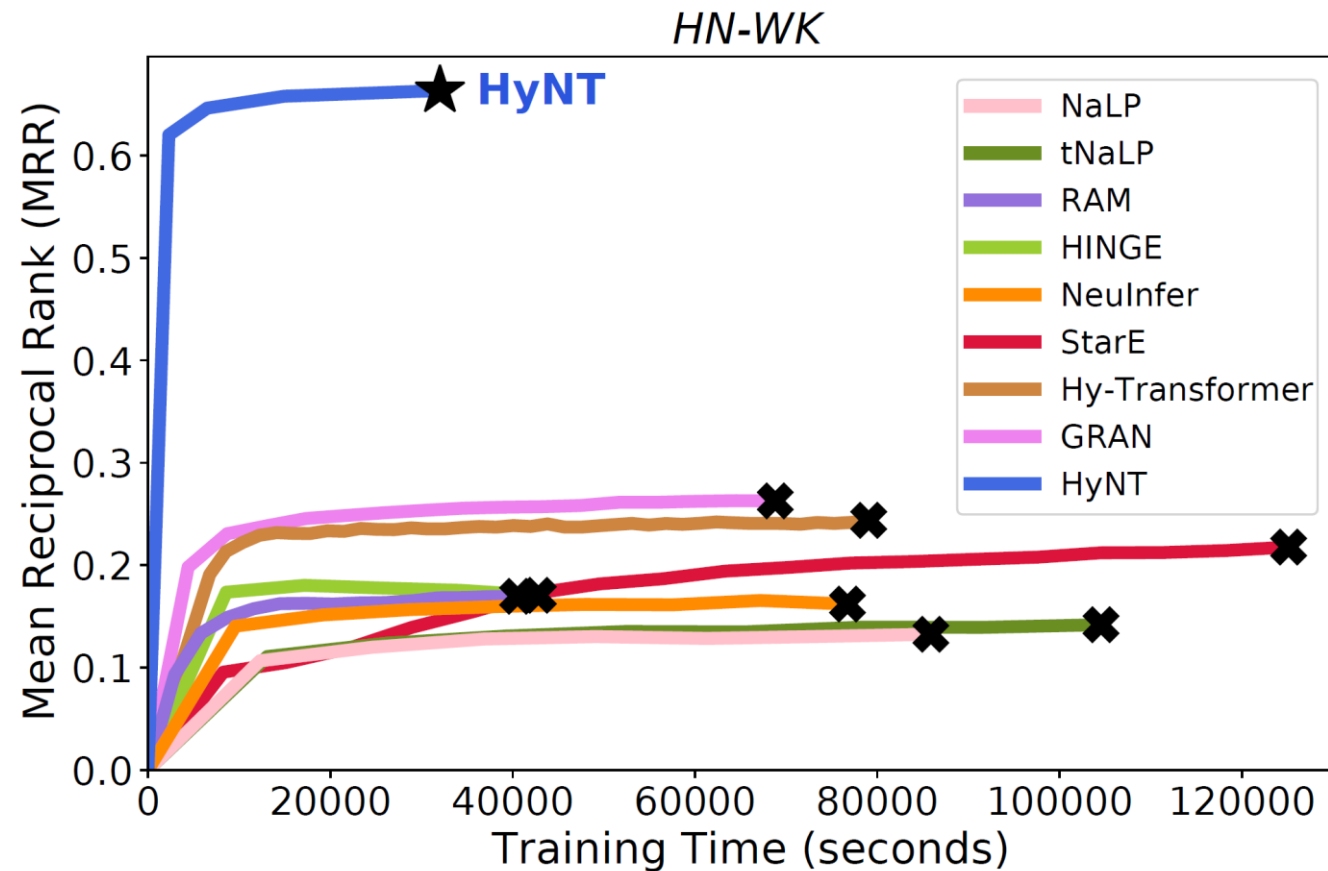


Contributions

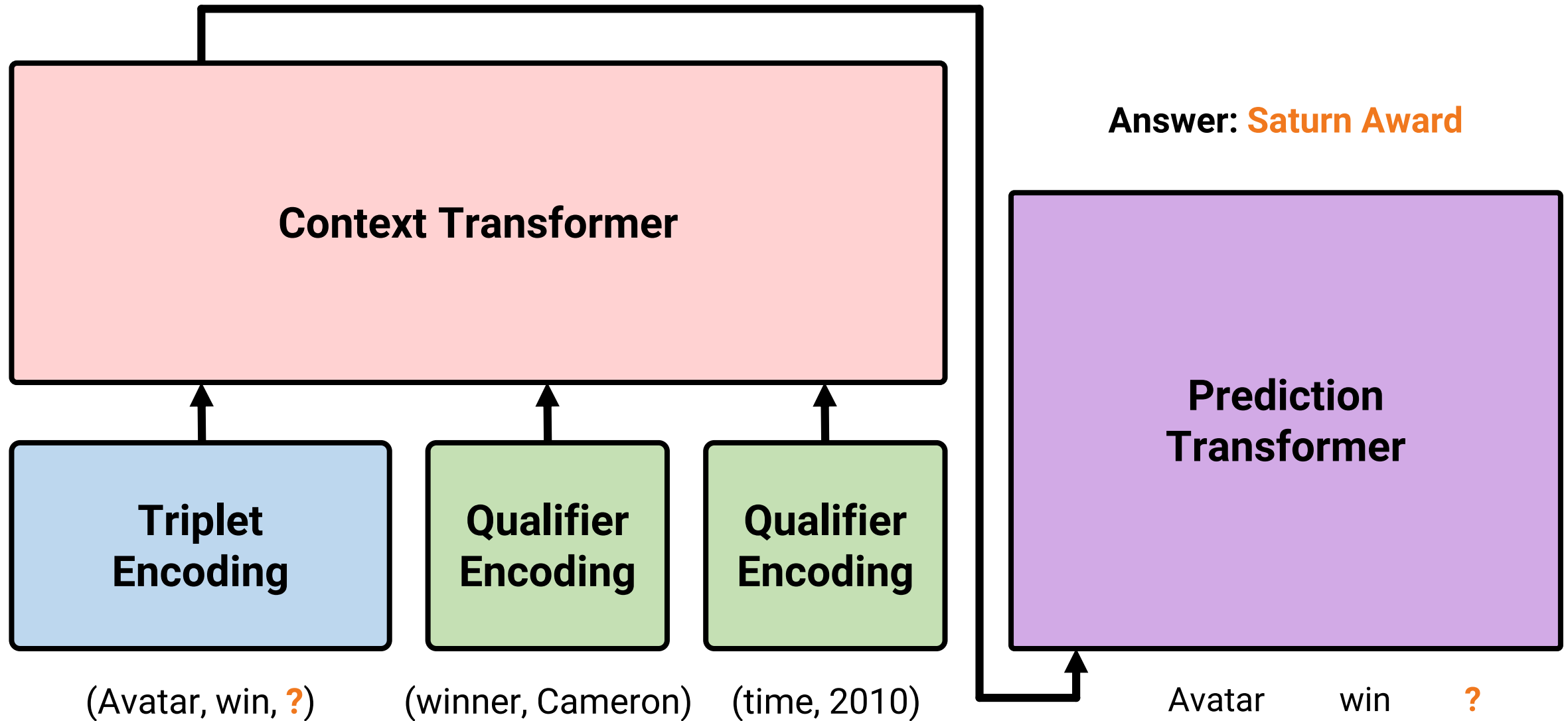
- Define **Hyper-relational and Numeric Knowledge Graphs**
 - Create 4 real-world HN-KG datasets
- Propose **HyNT**, Hyper-relational knowledge graph embedding with **N**umeric literals using **T**ransformers
 - Define a context transformer and a prediction transformer
 - Reduce the cost by learning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

Contributions

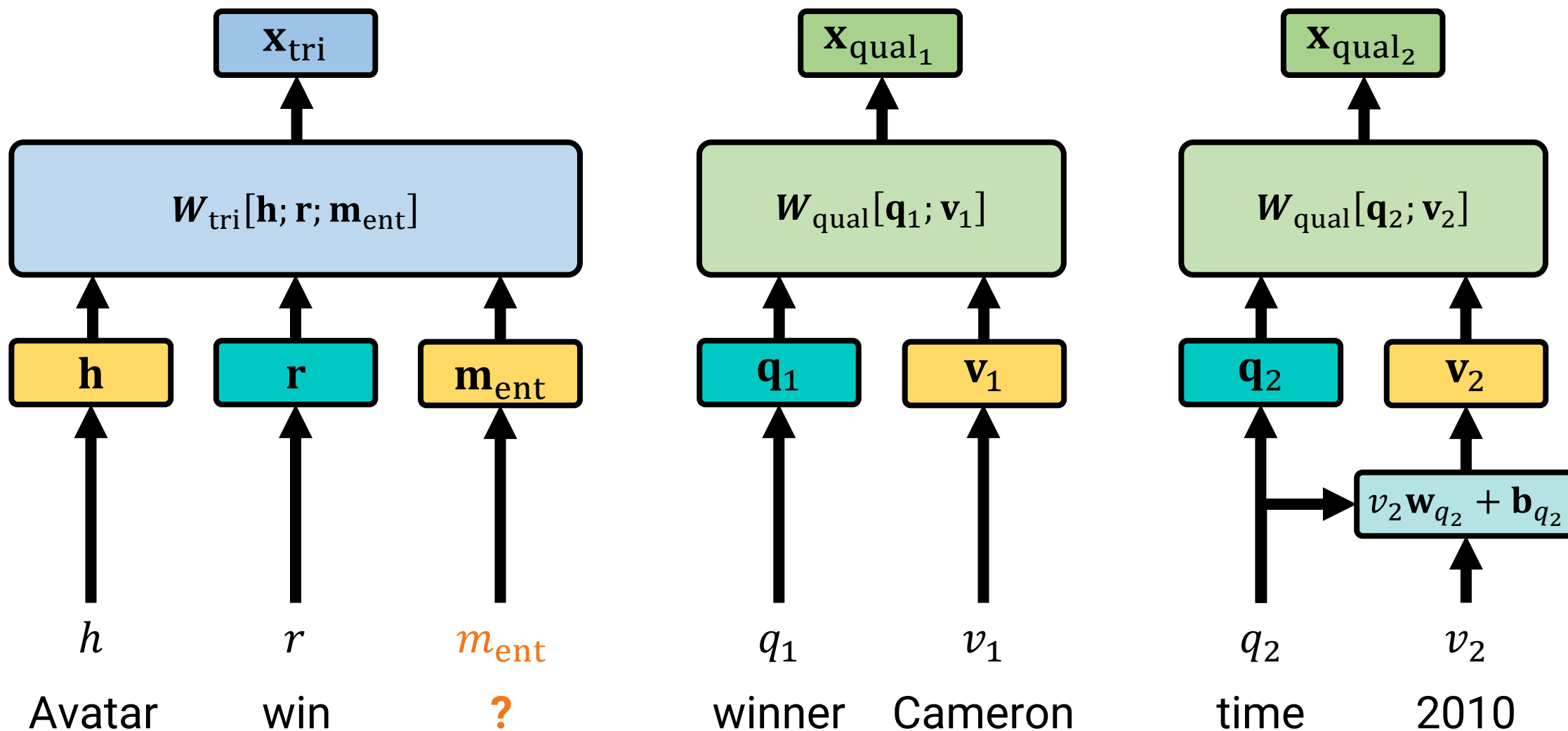
- Link Prediction Performance vs. Training Time



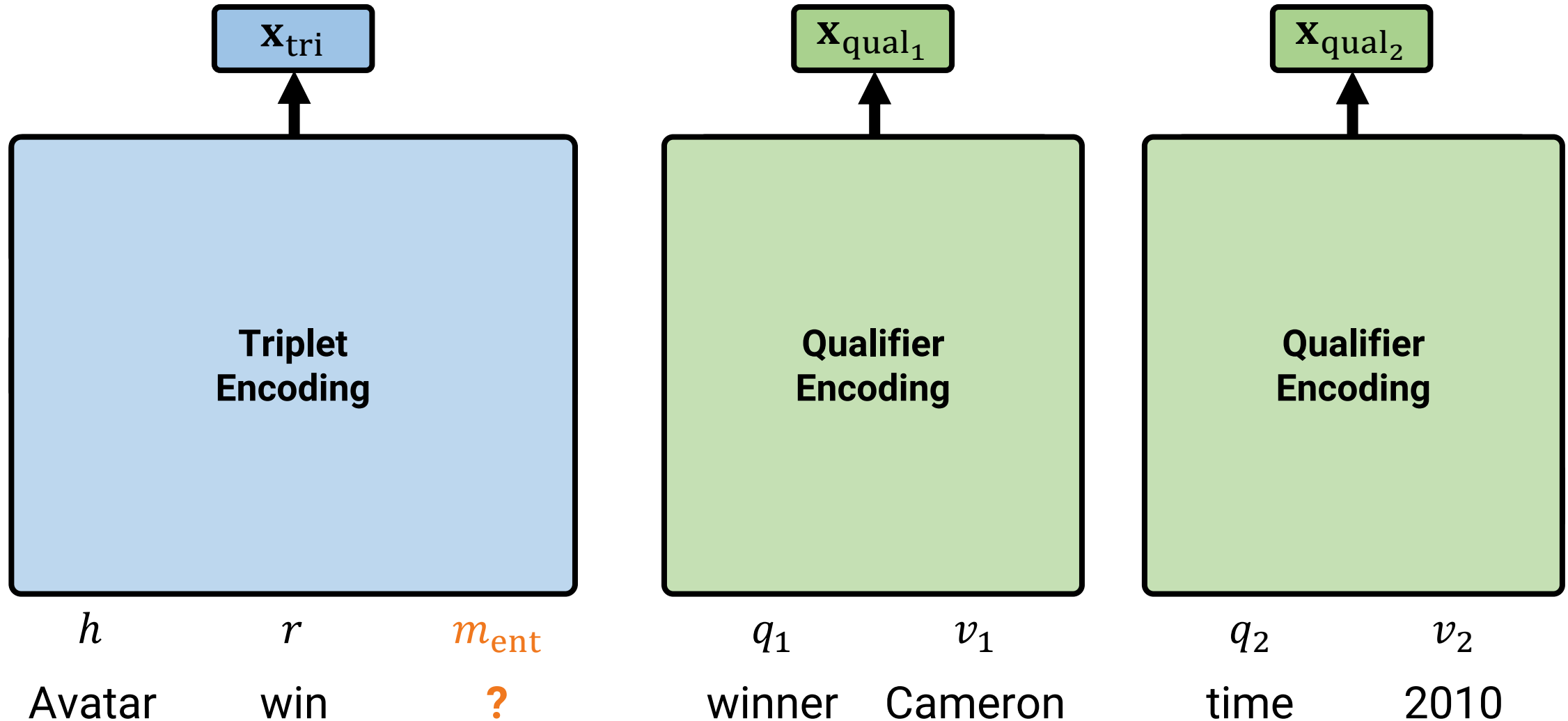
Overview of HyNT



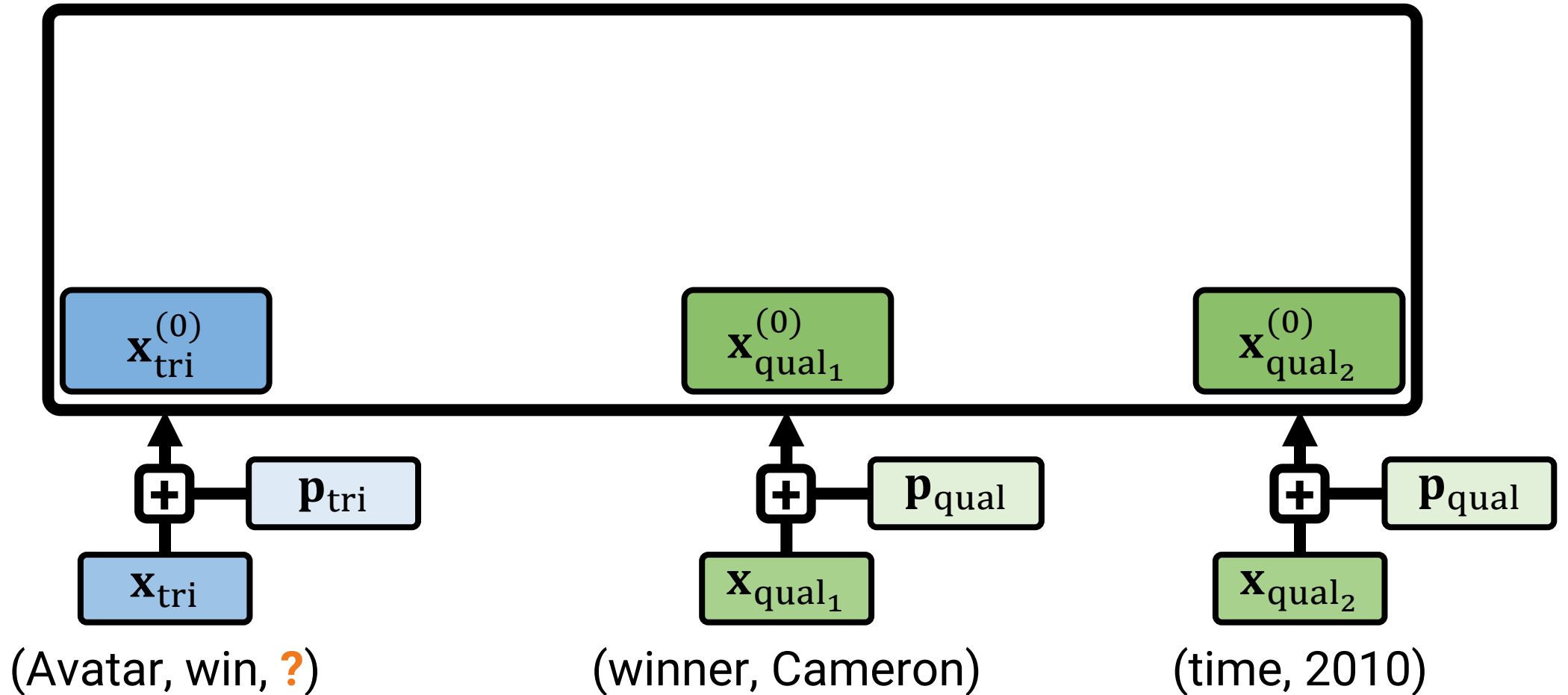
Triplet/Qualifier Encoding



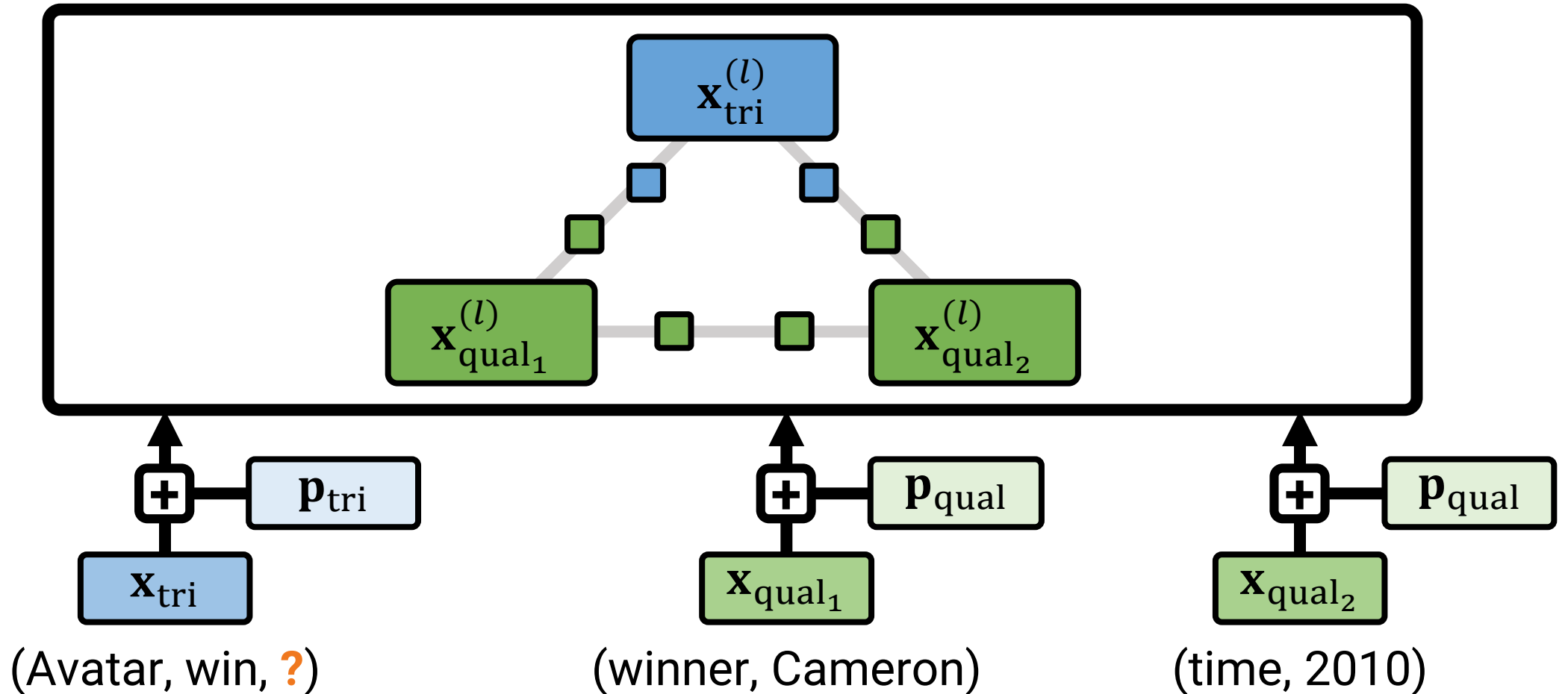
Triplet/Qualifier Encoding



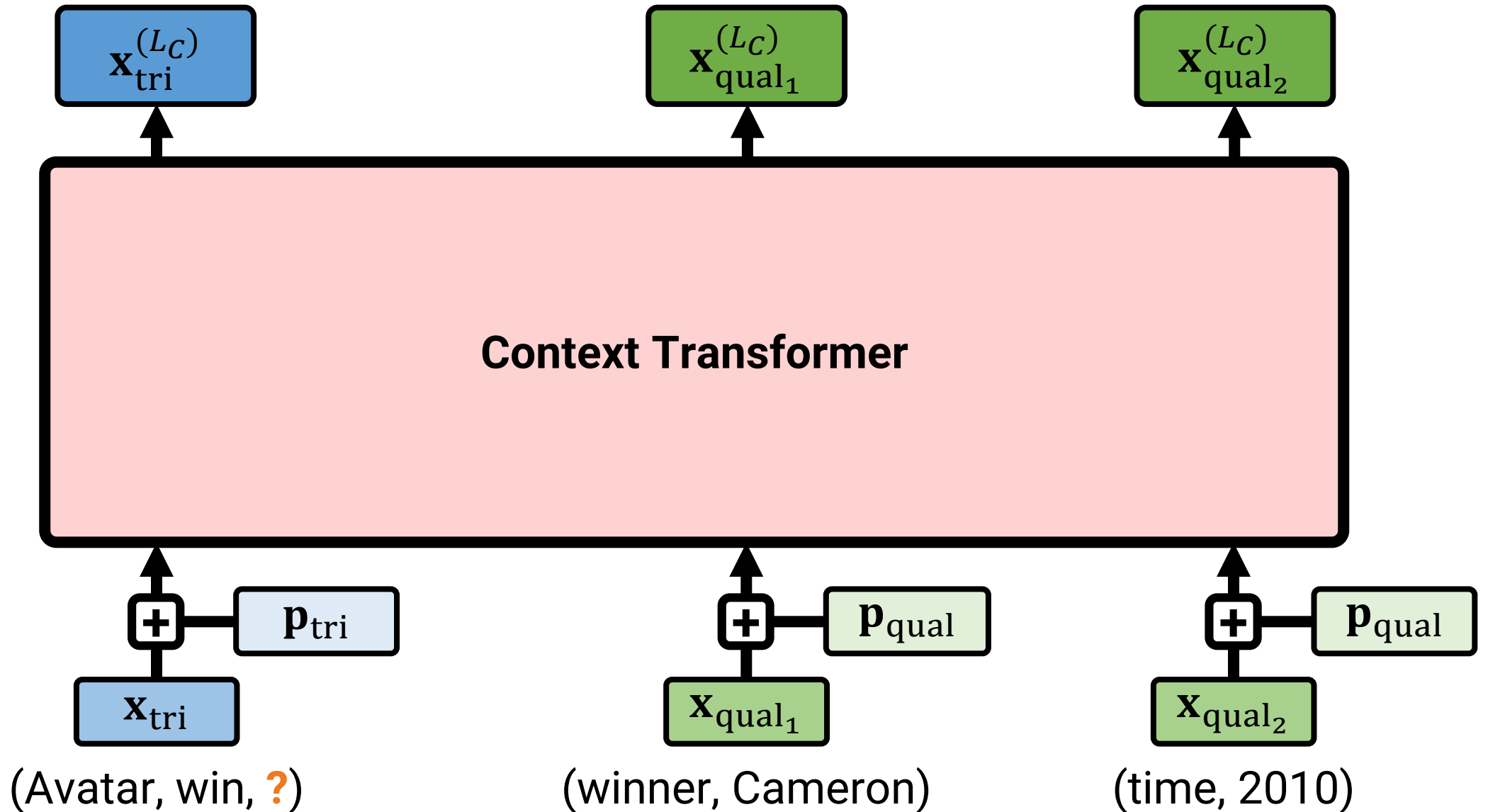
Context Transformer



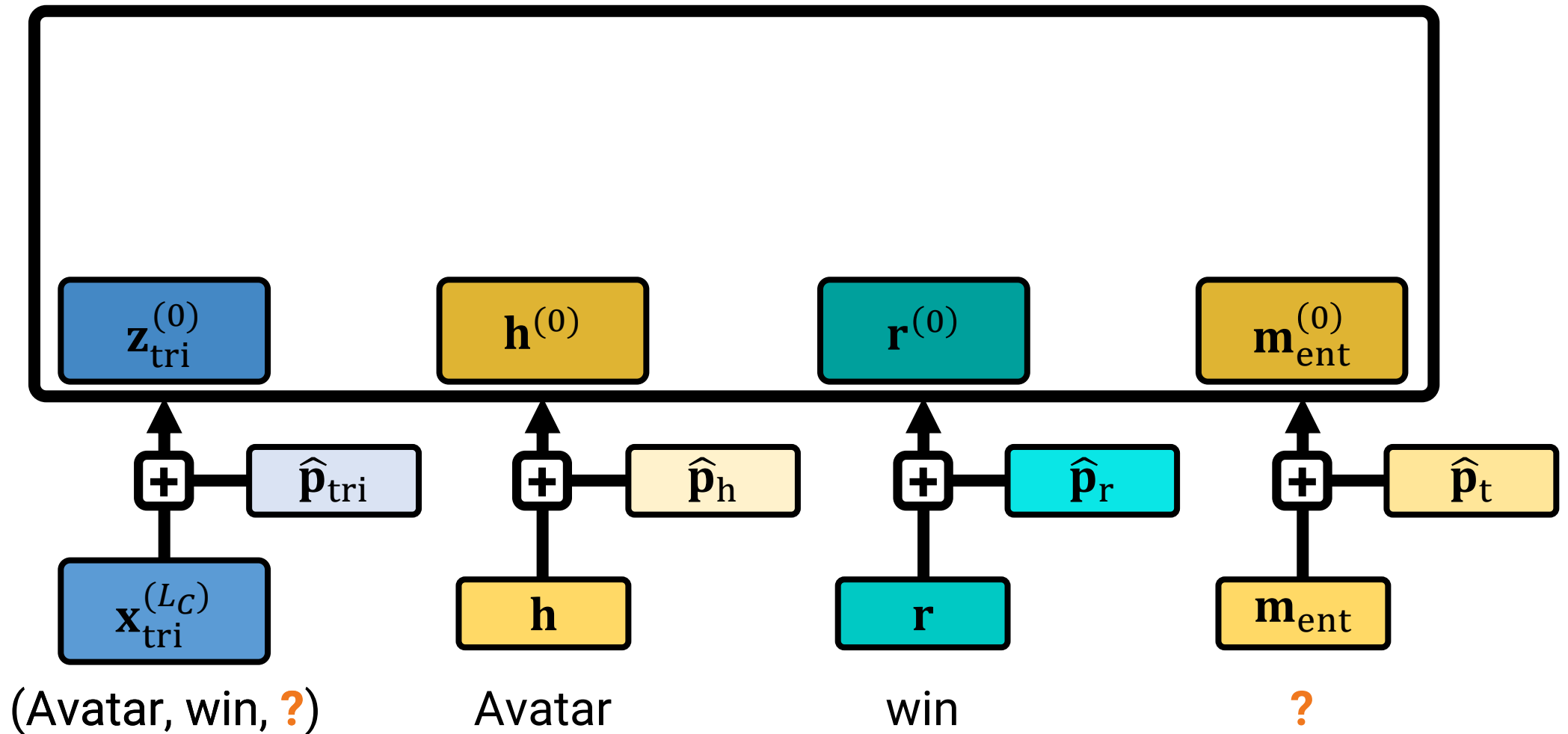
Context Transformer



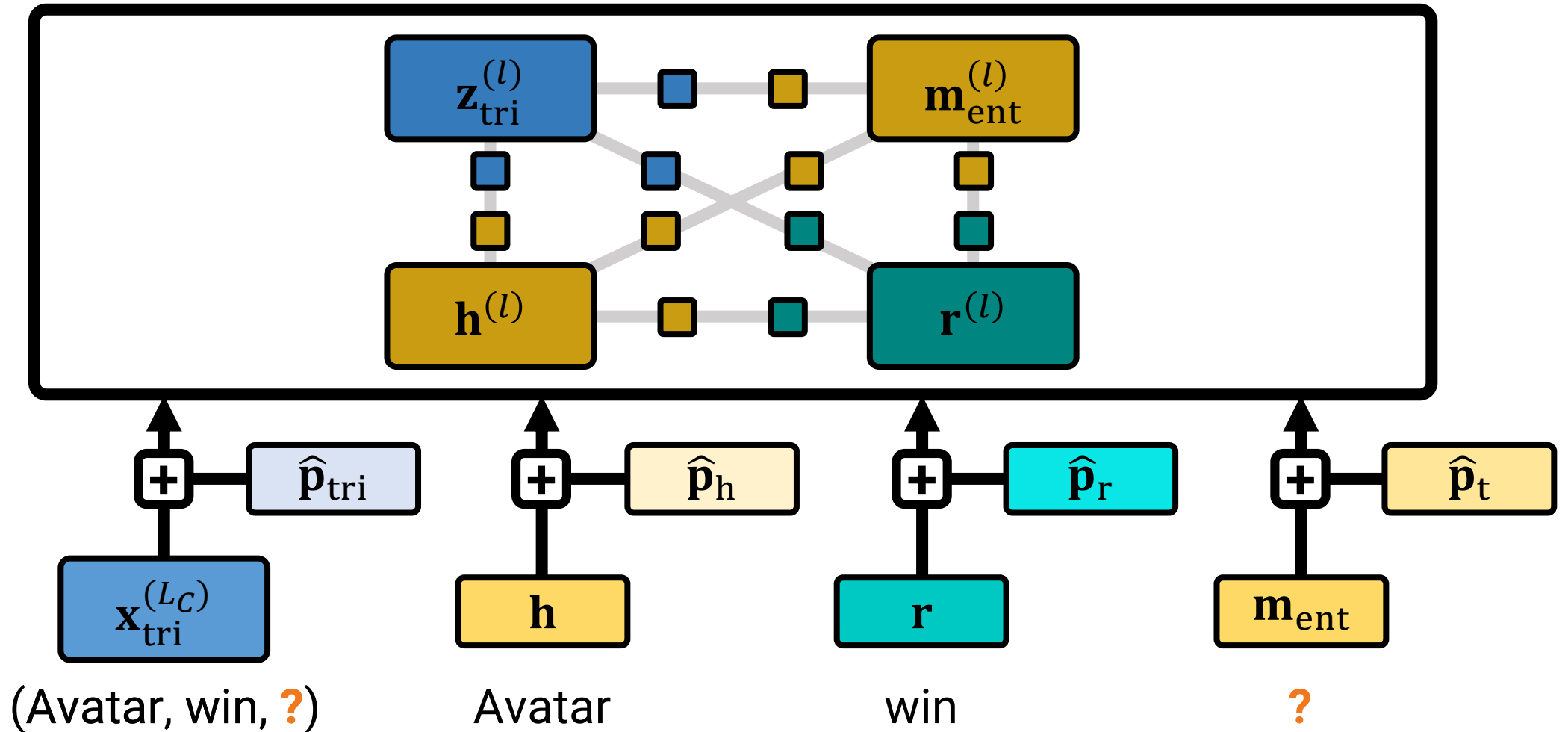
Context Transformer



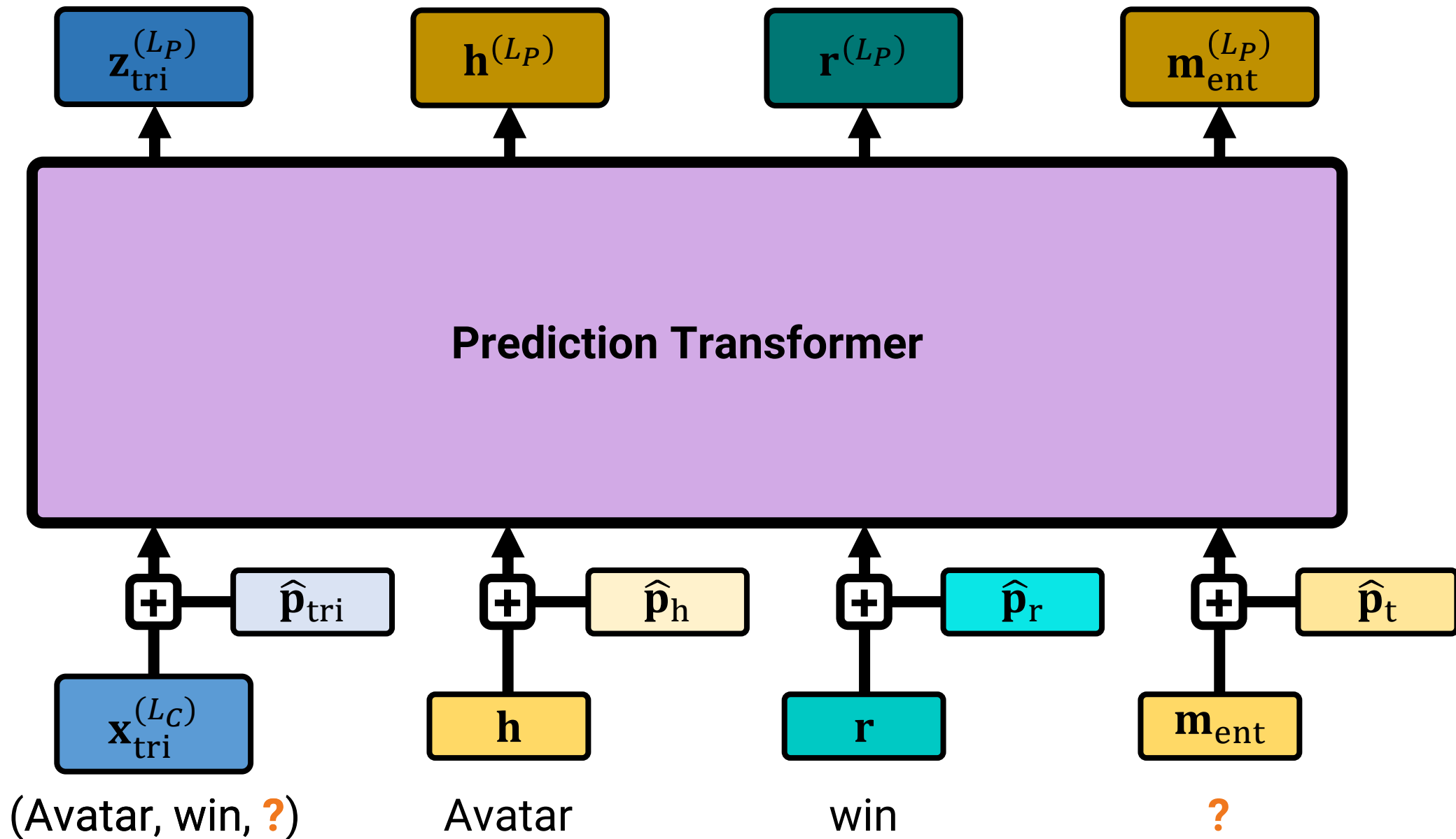
Prediction Transformer



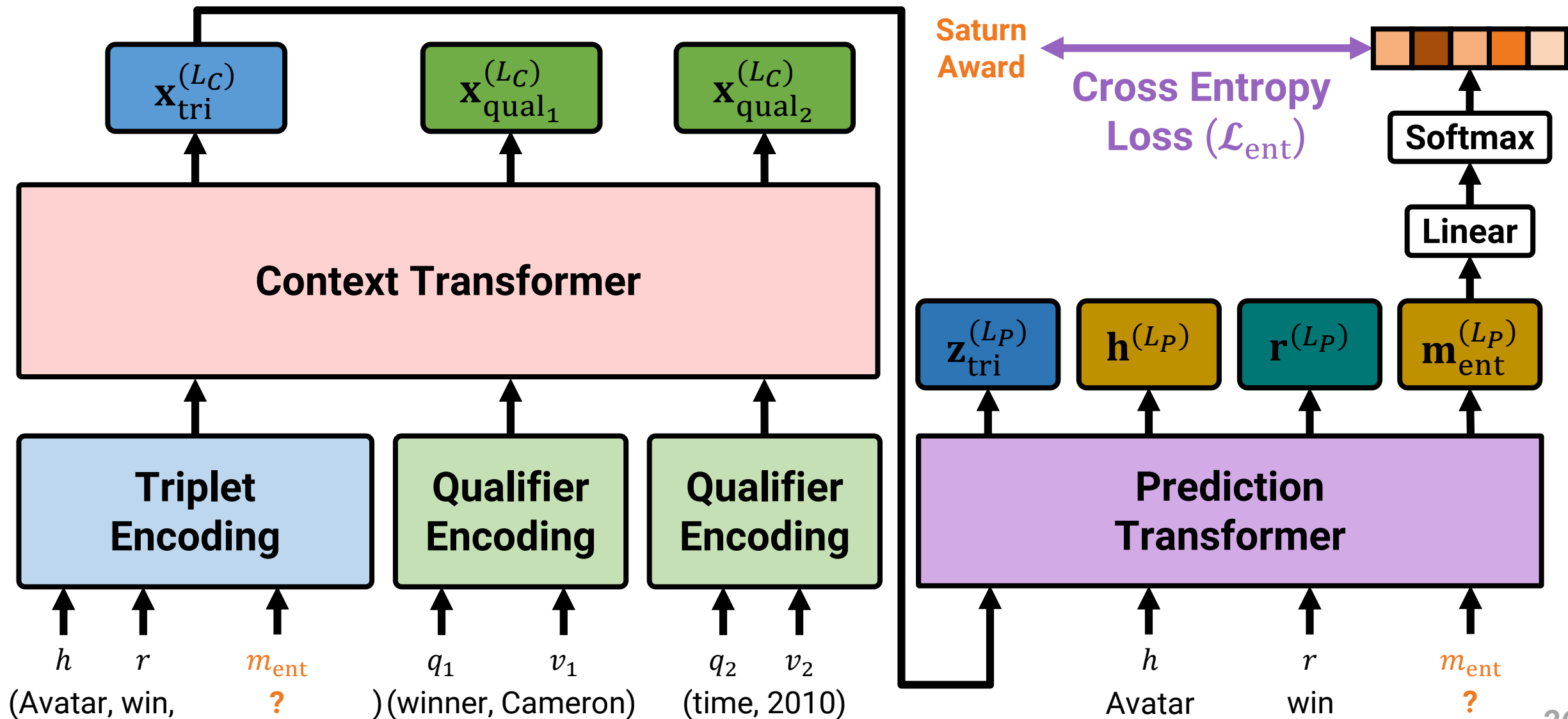
Prediction Transformer



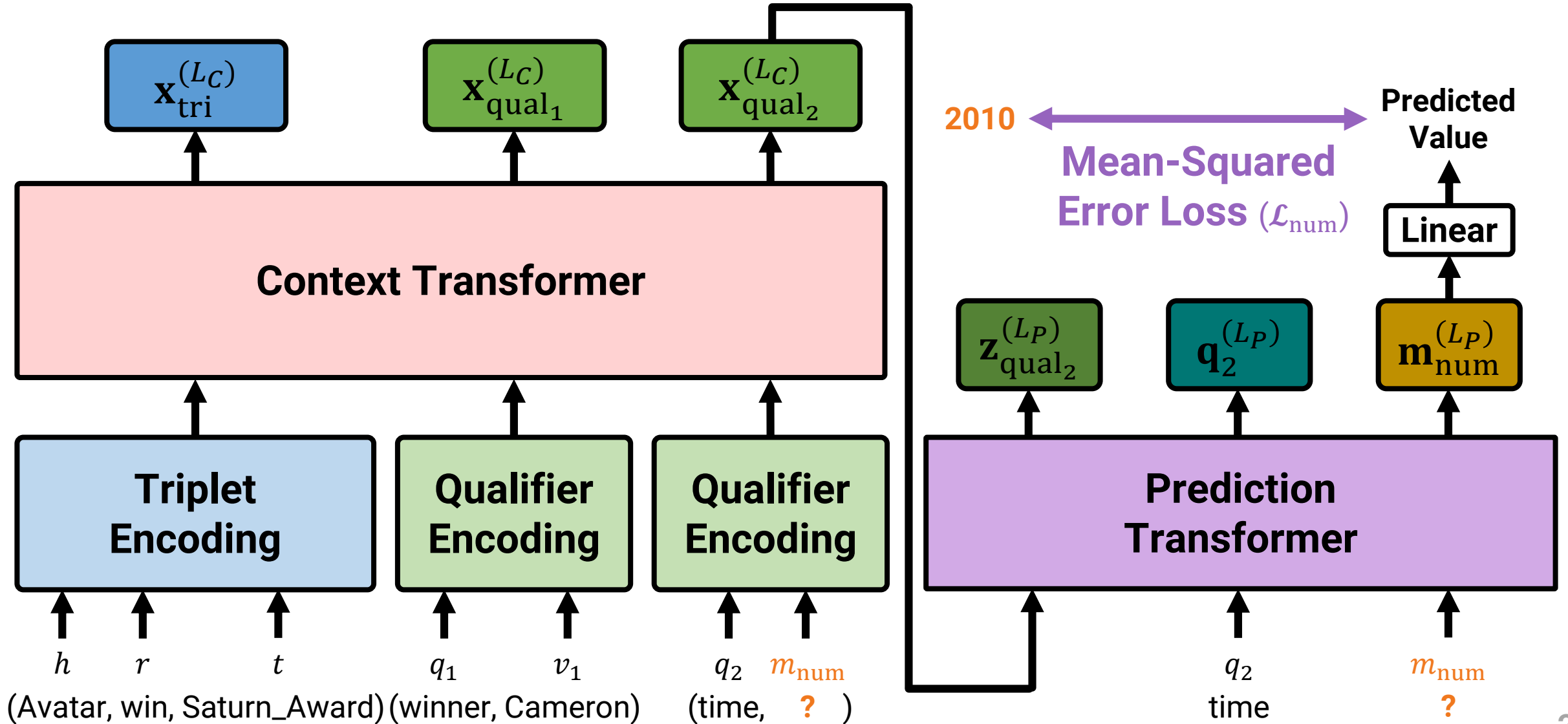
Prediction Transformer



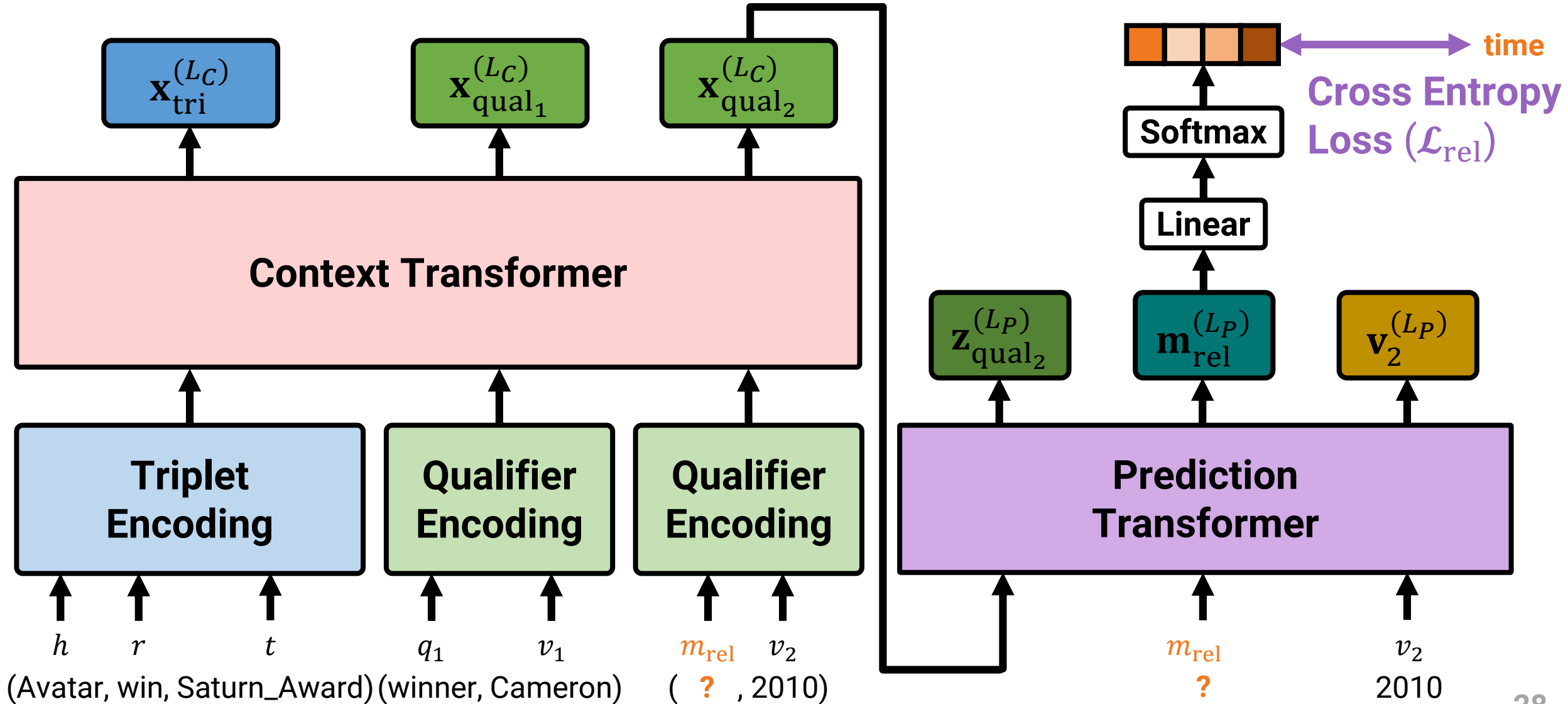
Link Prediction using HyNT



Numeric Value Prediction using HyNT

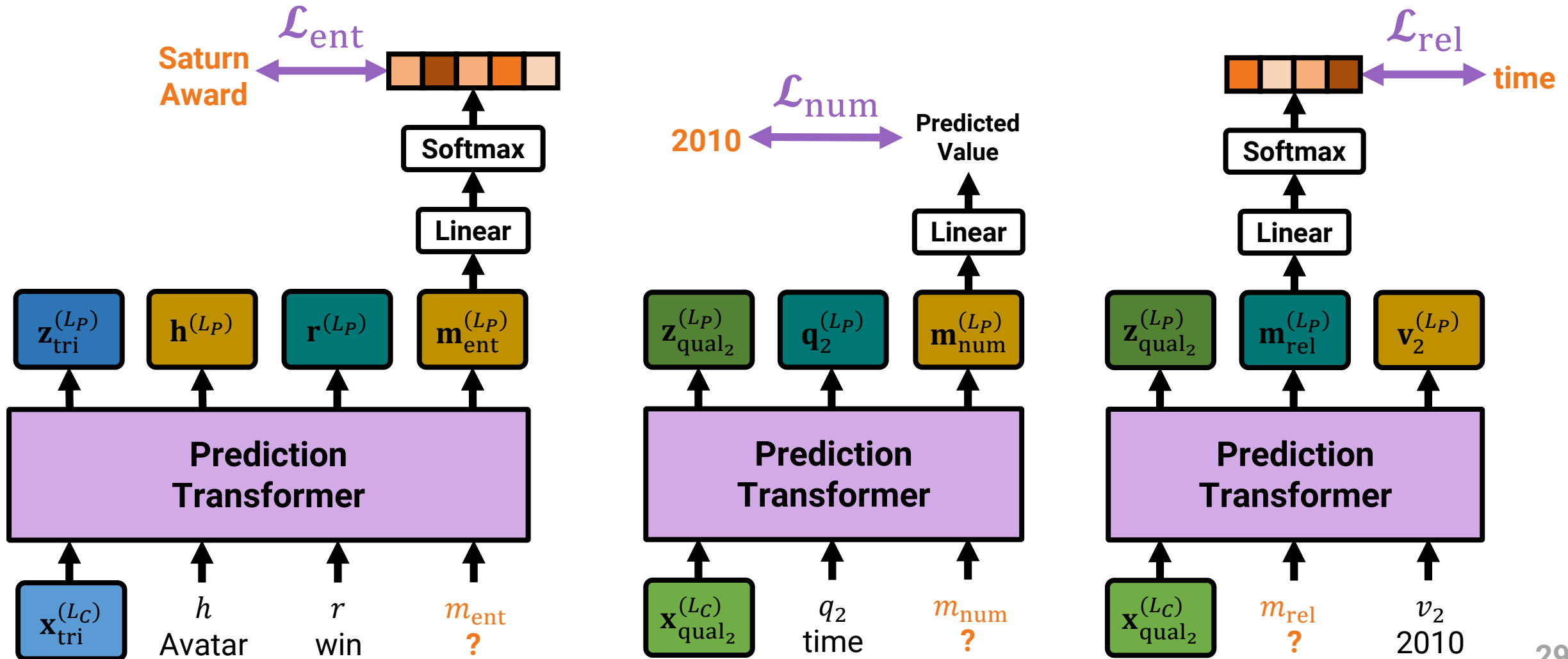


Relation Prediction using HyNT



Loss of HyNT

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

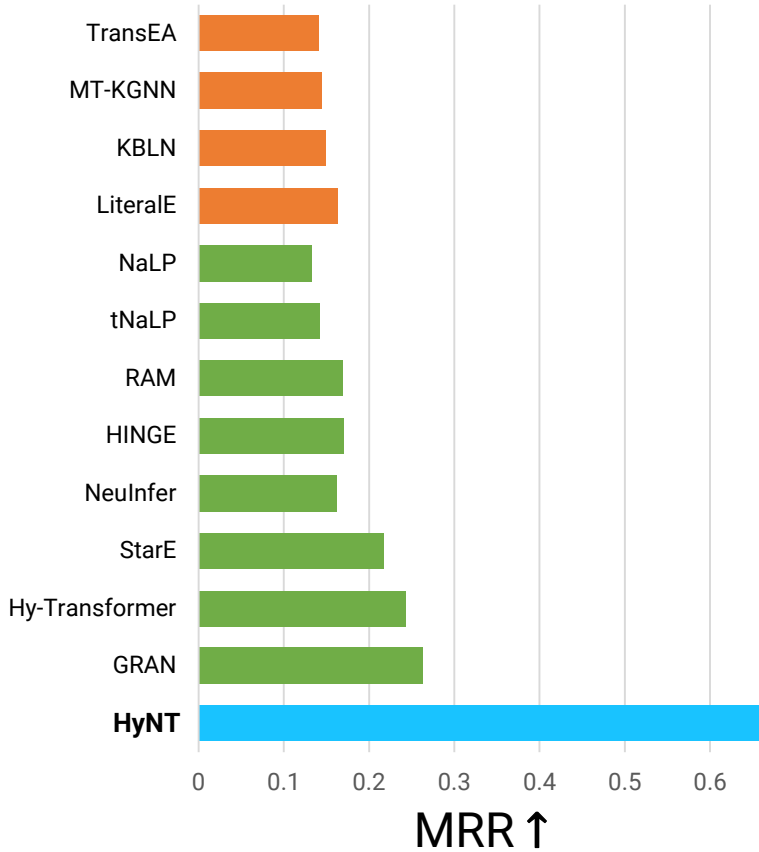


Experimental Results

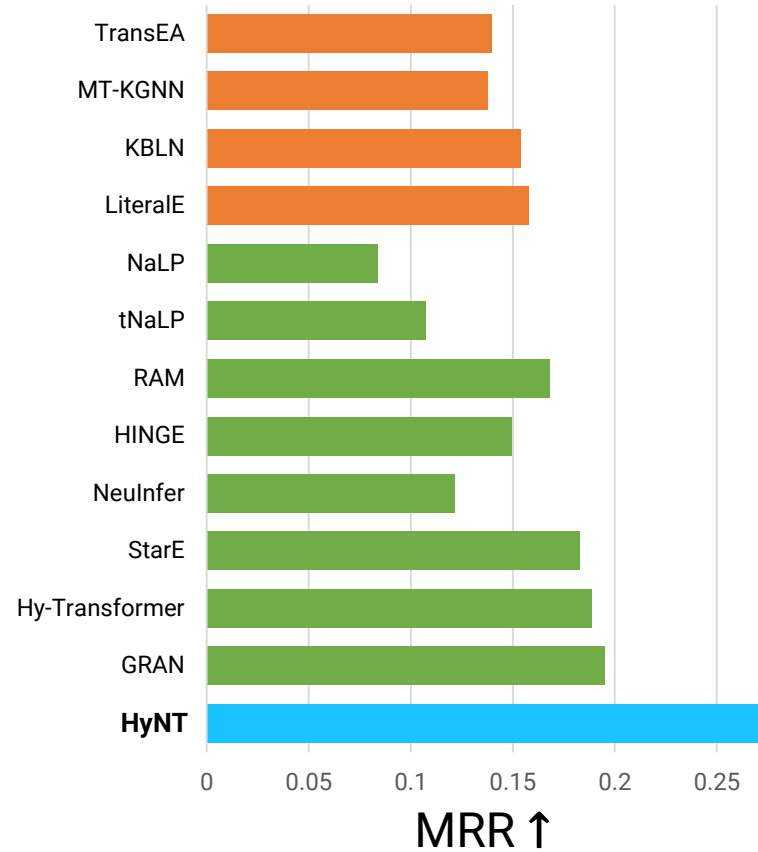
- Datasets
 - Based on Wikidata, YAGO, and Freebase
 - Create **4 Hyper-relational and Numeric Knowledge Graph (HN-KG)** datasets
 - HN-WK, HN-YG, HN-FB, HN-FB-S
- Comparison with **12 baseline methods**
 - Methods for handling numeric literals
 - TransEA, MT-KGNN, KBLN, LiteralE
 - Methods for handling hyper-relational facts
 - NaLP, tNaLP, RAM, HINGE, NeuInfer, StarE, Hy-Transformer, GRAN

Link Prediction Results – Primary

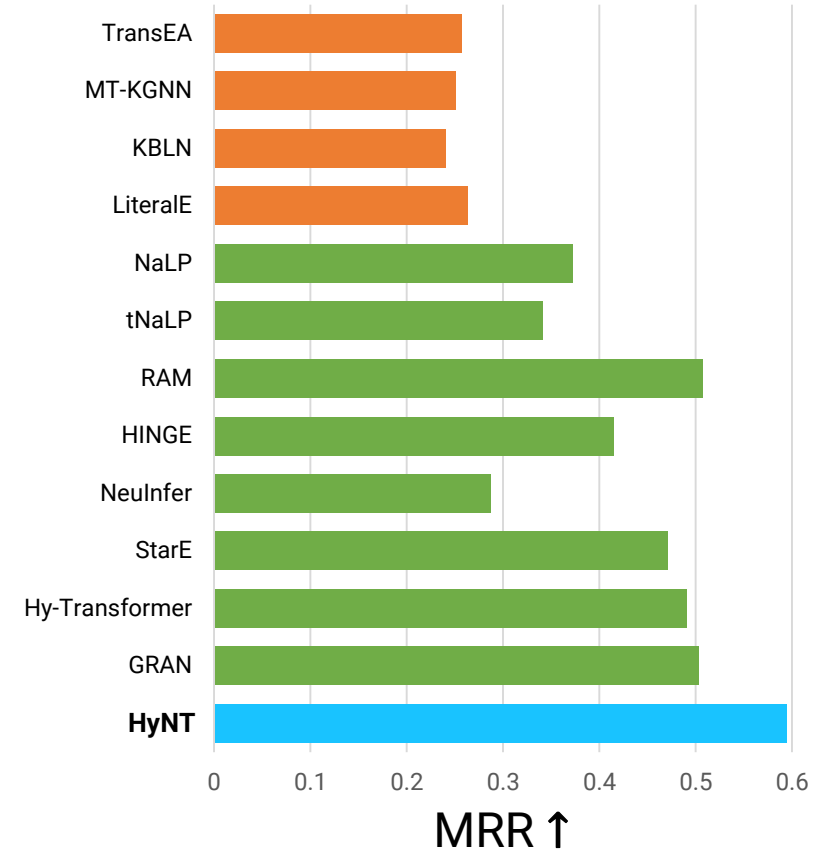
HN-WK



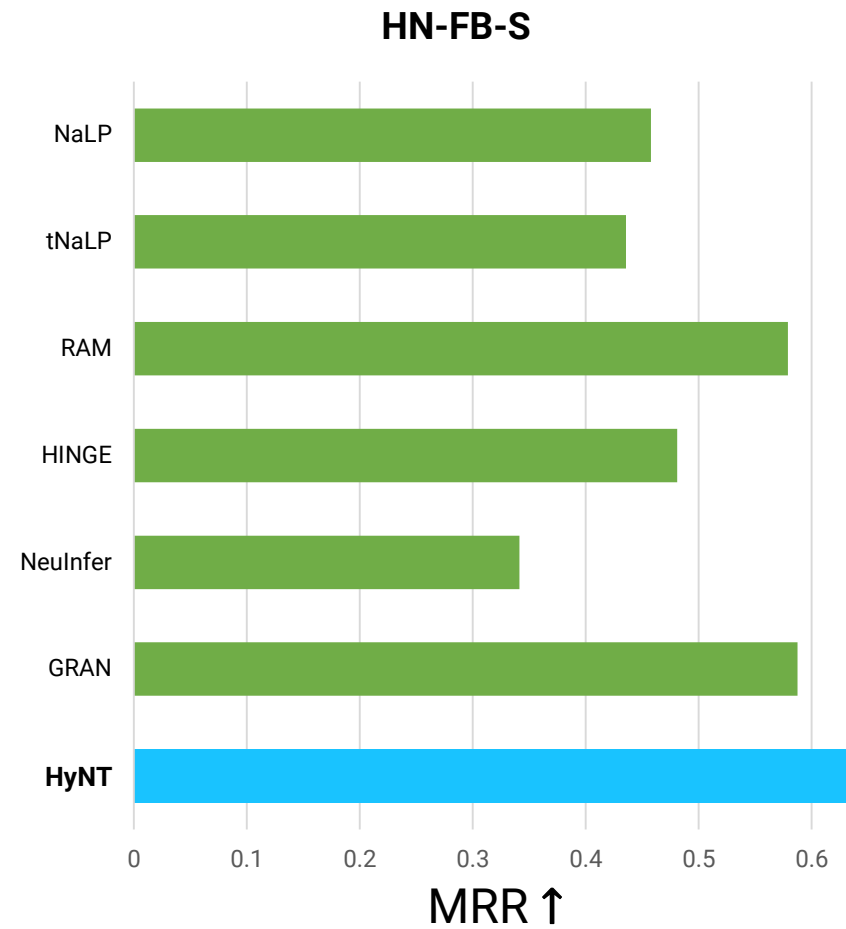
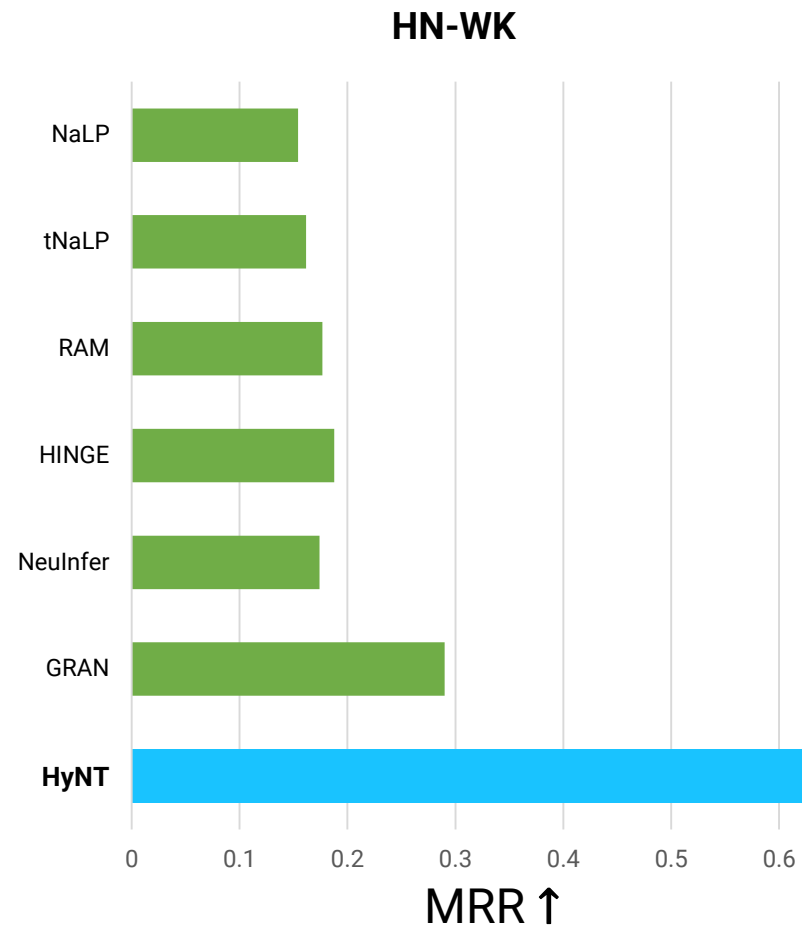
HN-YG



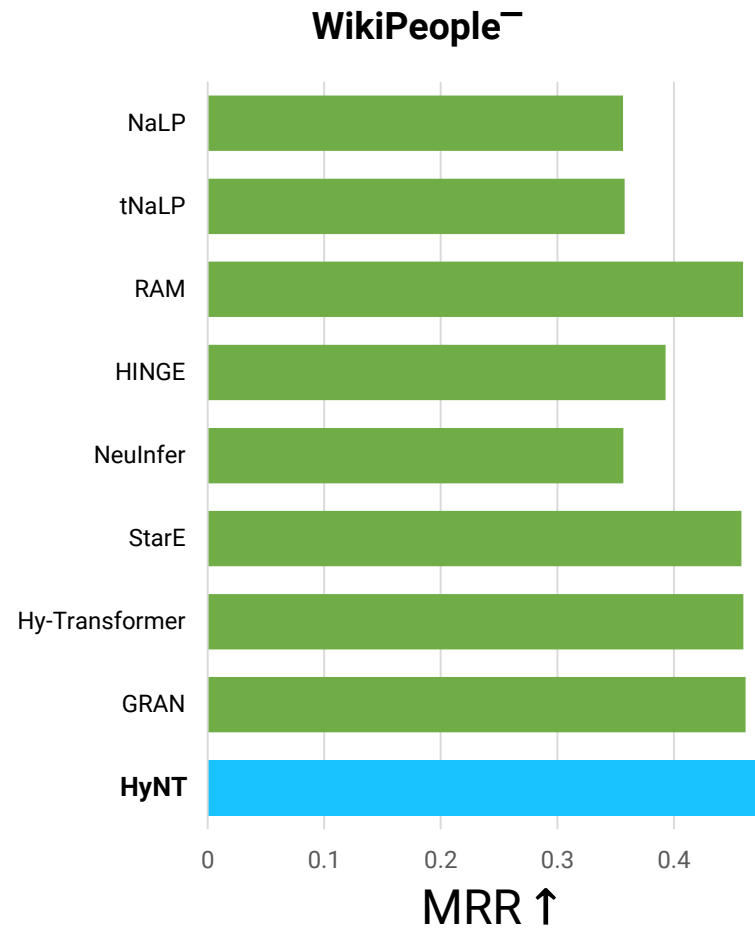
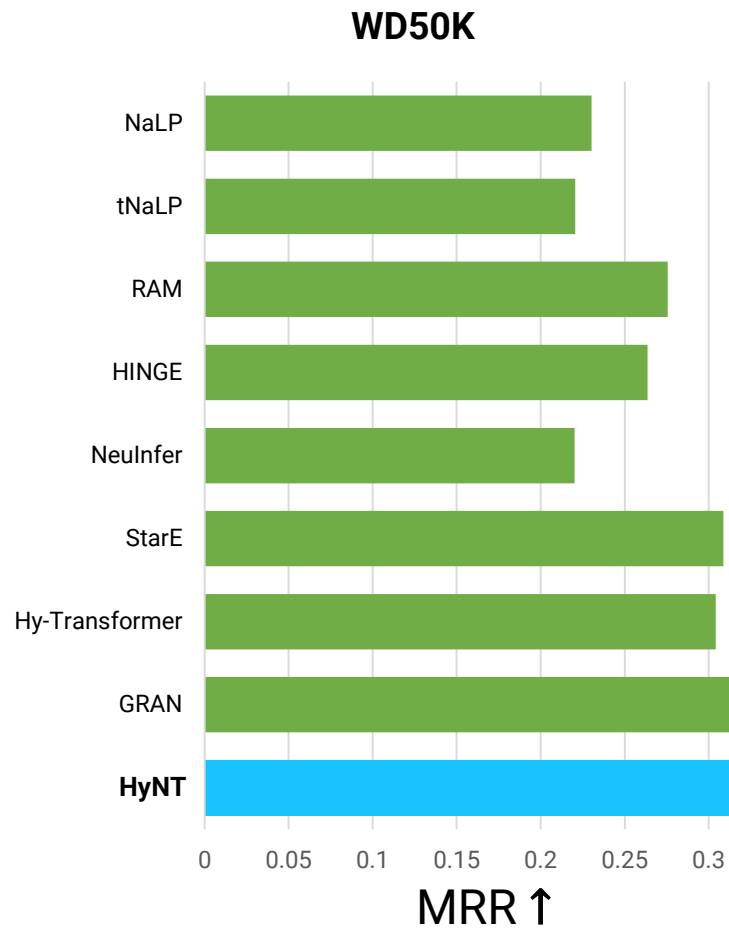
HN-FB-S



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](#))})

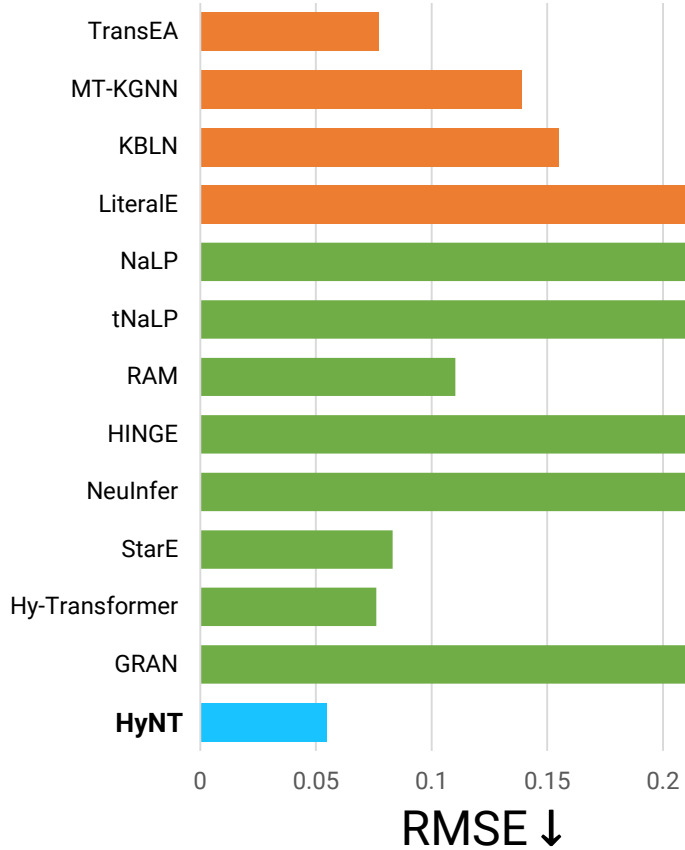
Link Prediction Results of HyNT

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

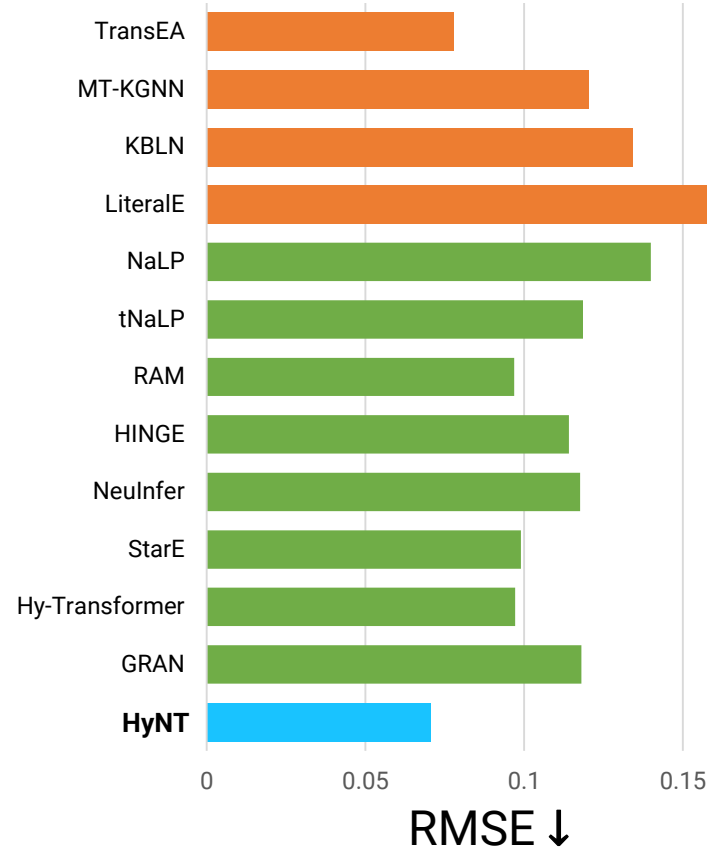
((**Tom_Hanks**, nominated_for, Best_Actor), {(for_work, **Forrest_Gump**), (subject_of, **67th_Oscars**)})

Numeric Value Prediction Results – Primary

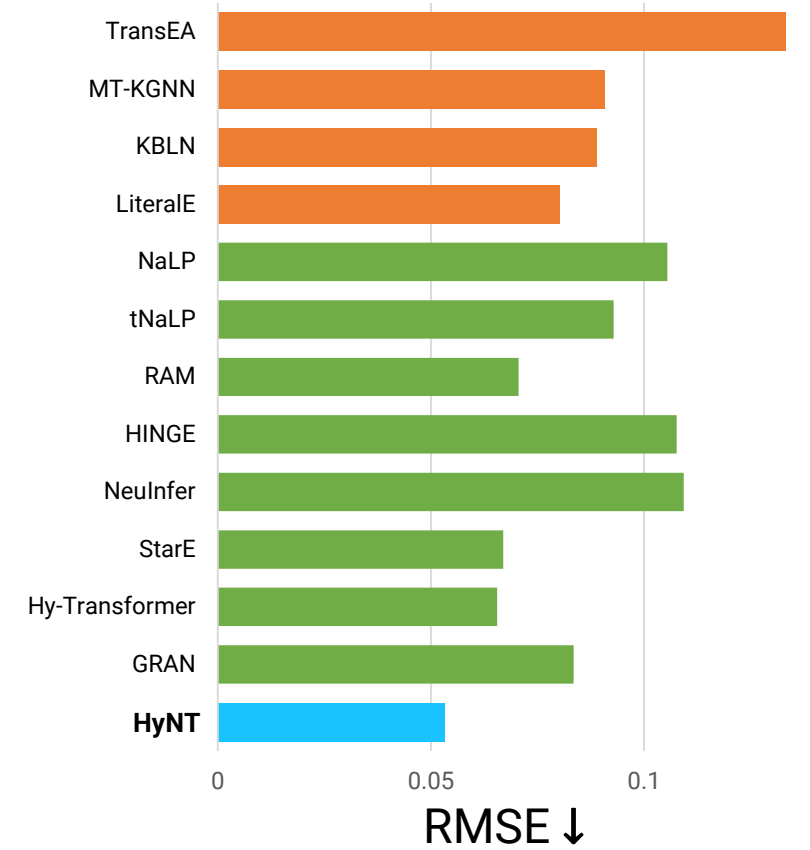
HN-WK



HN-YG

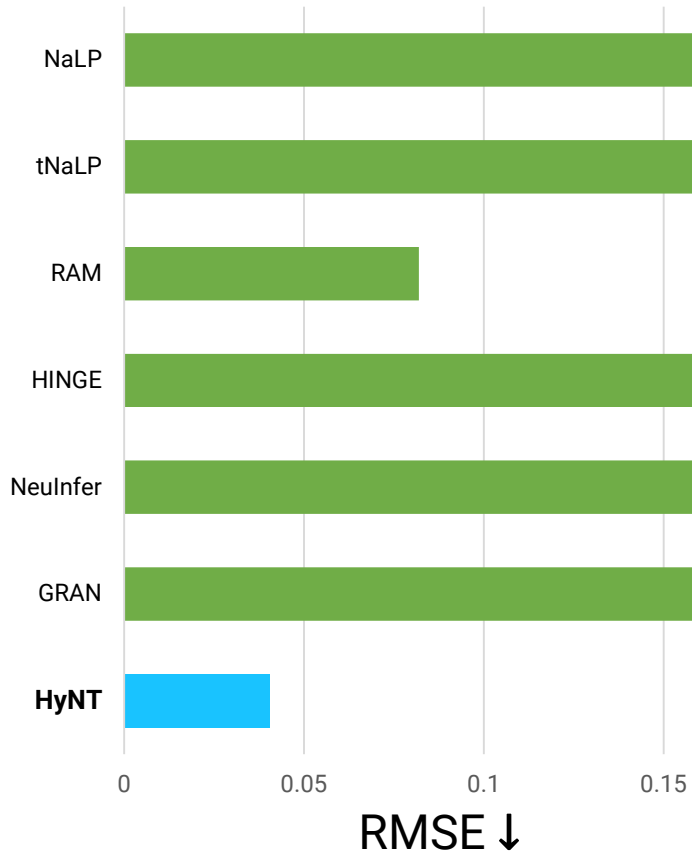


HN-FB-S

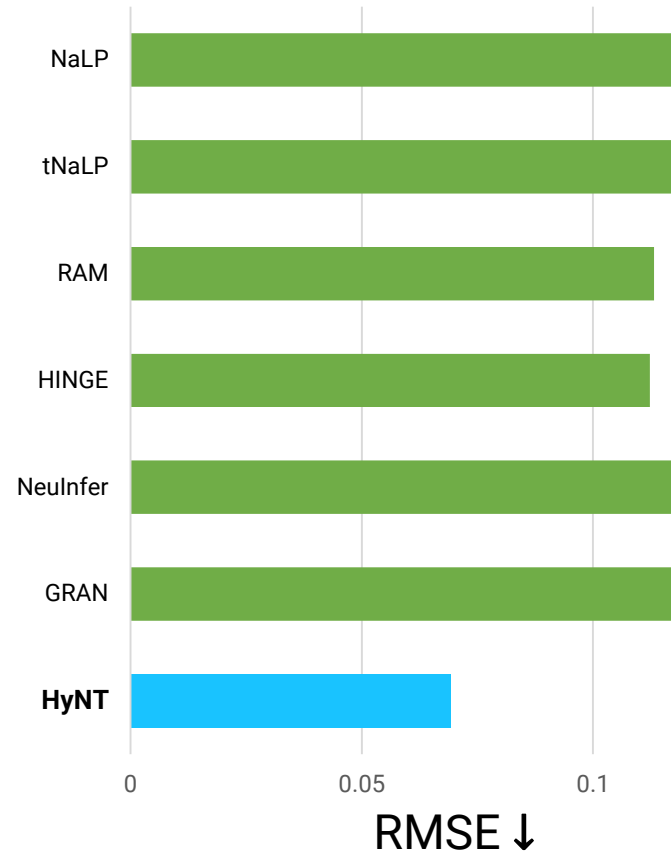


Numeric Value Prediction Results – All

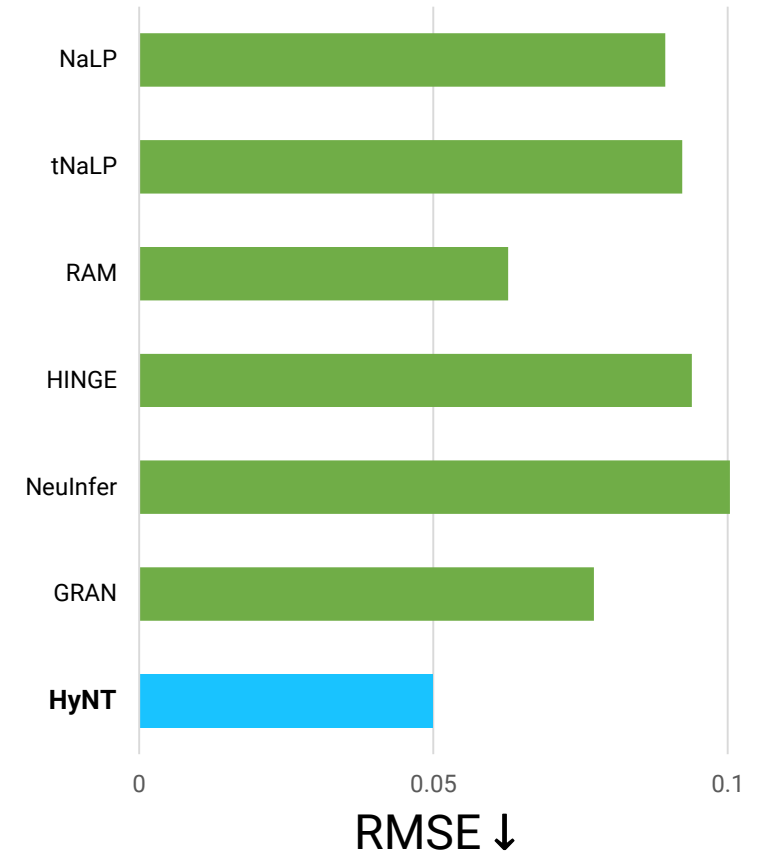
HN-WK



HN-YG

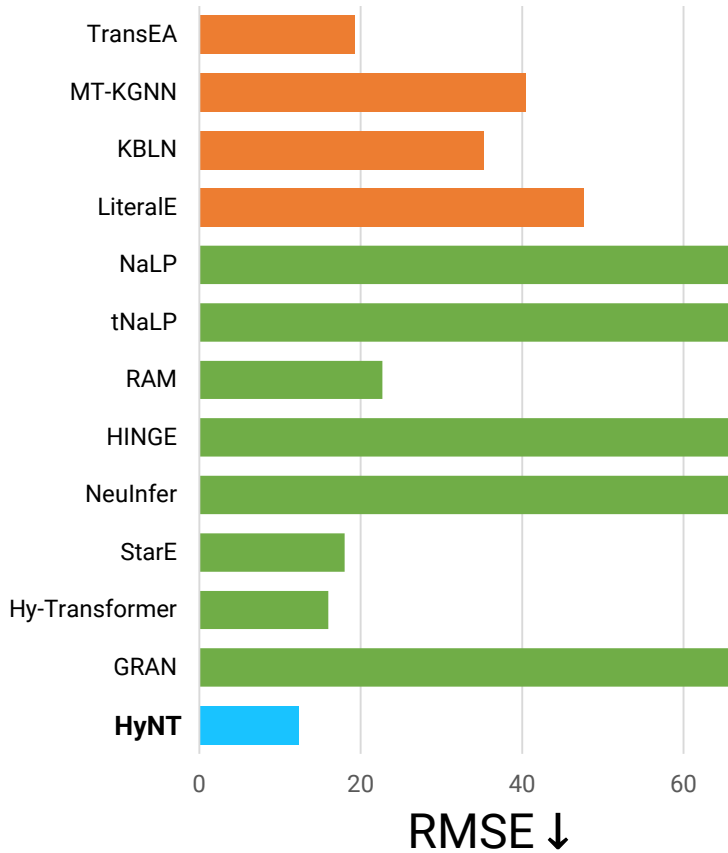


HN-FB-S

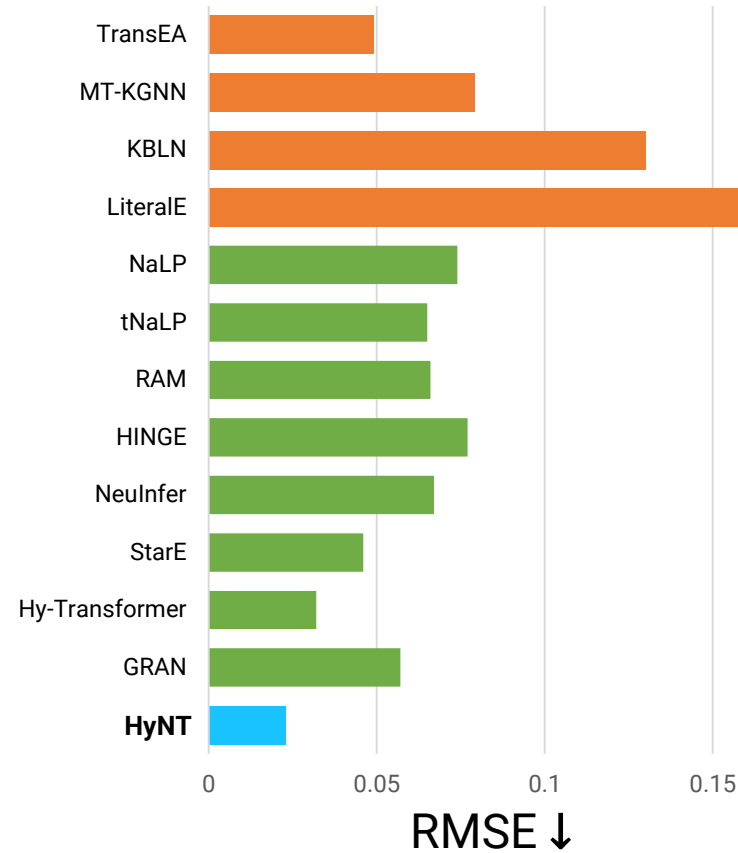


Numeric Value Prediction Results per Attribute Type in HN-WK

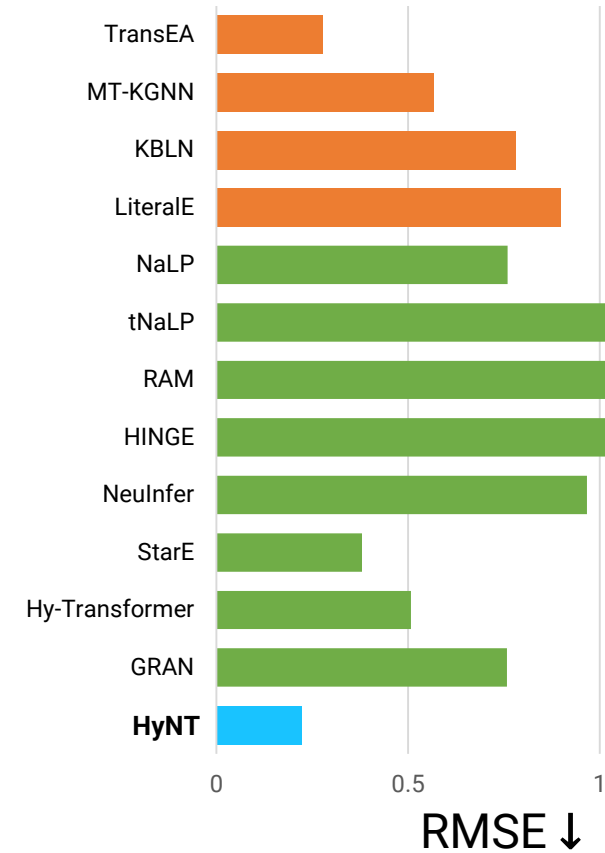
ranking



human development index



fertility rate



Visualization of the Predictions

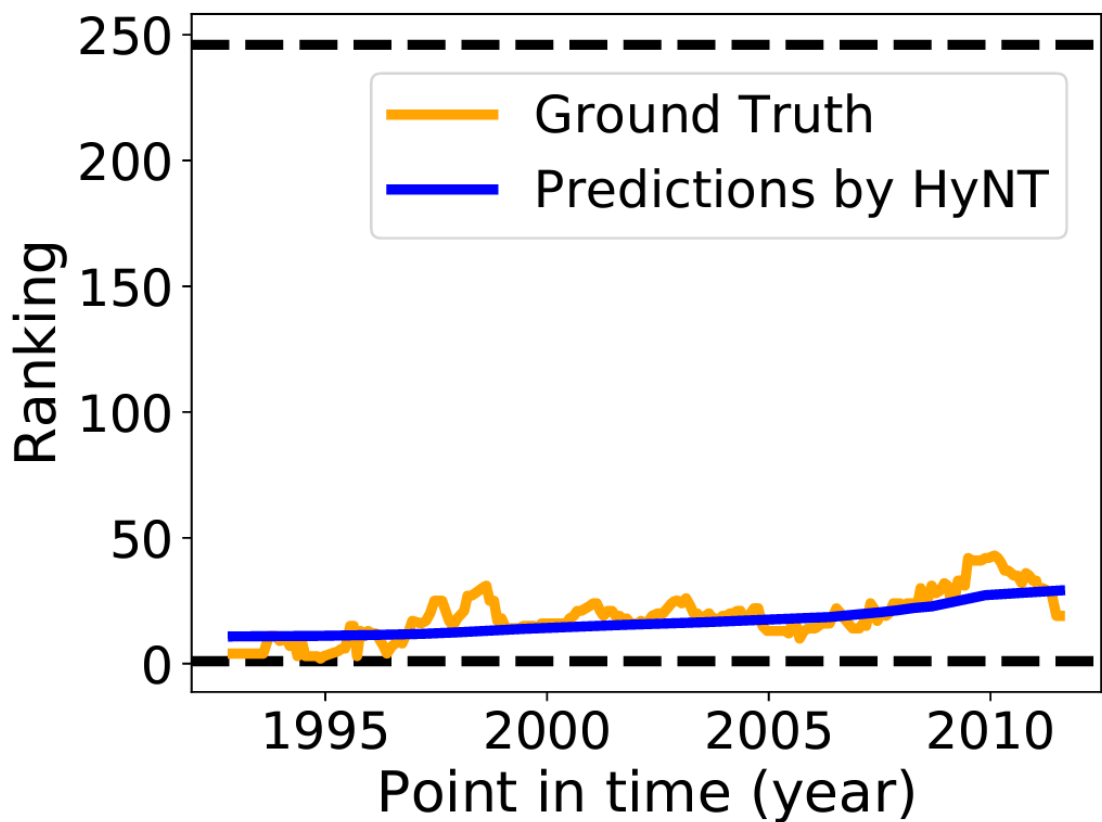
Target Values

((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

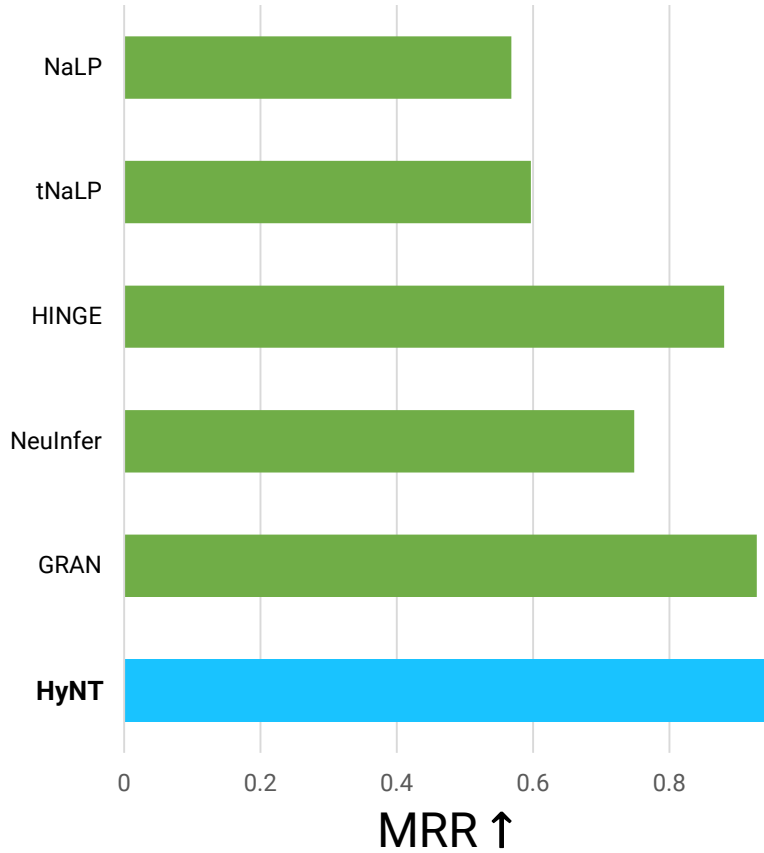
(Sweden National Team, ranking, ?)

Target Values

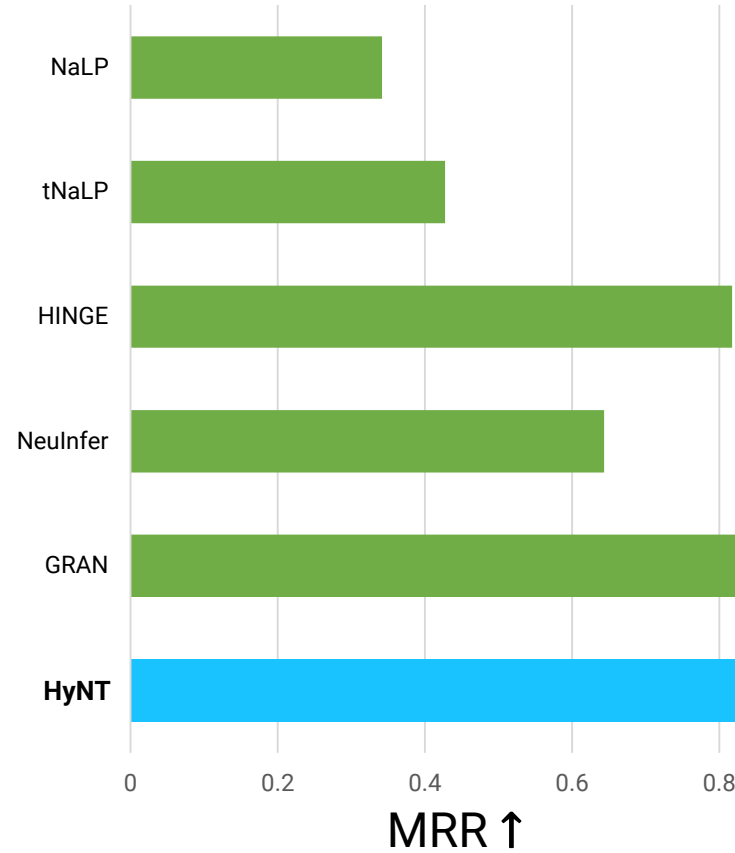


Relation Prediction Results – Primary

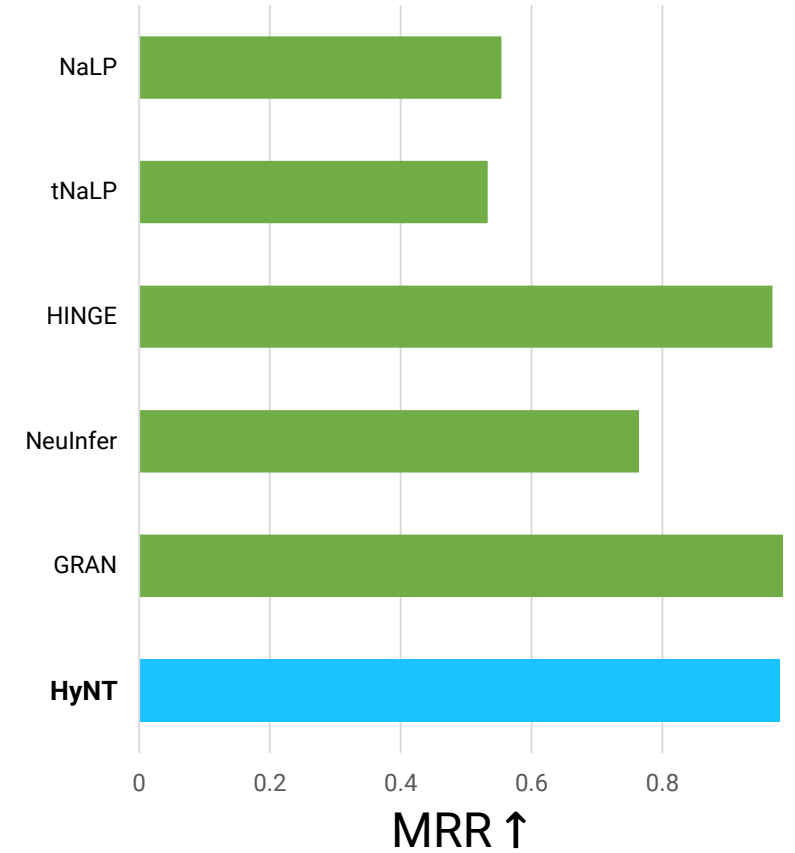
HN-WK



HN-YG

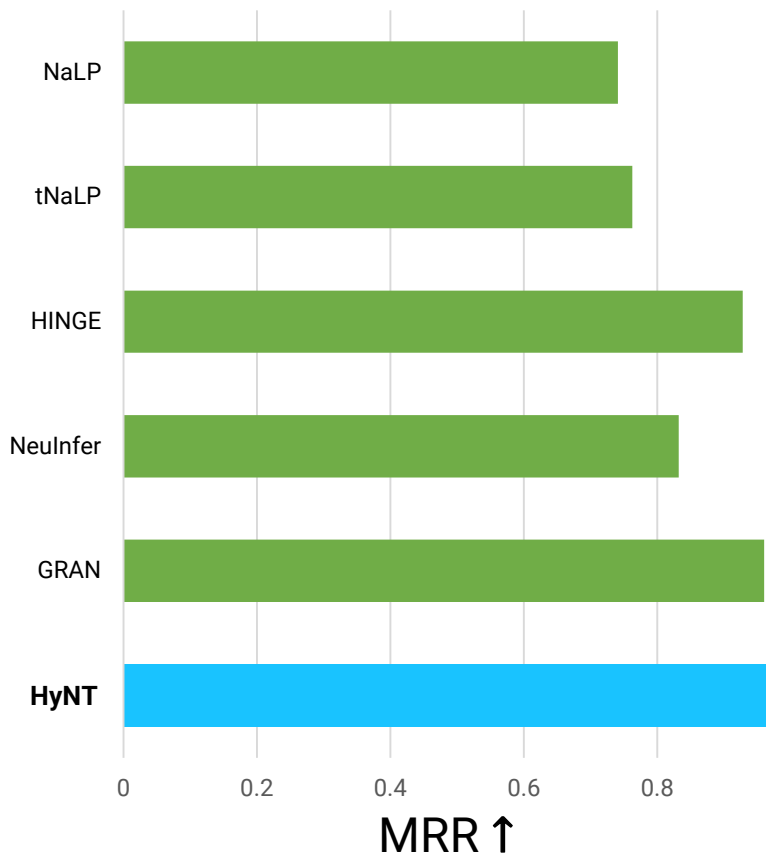


HN-FB-S

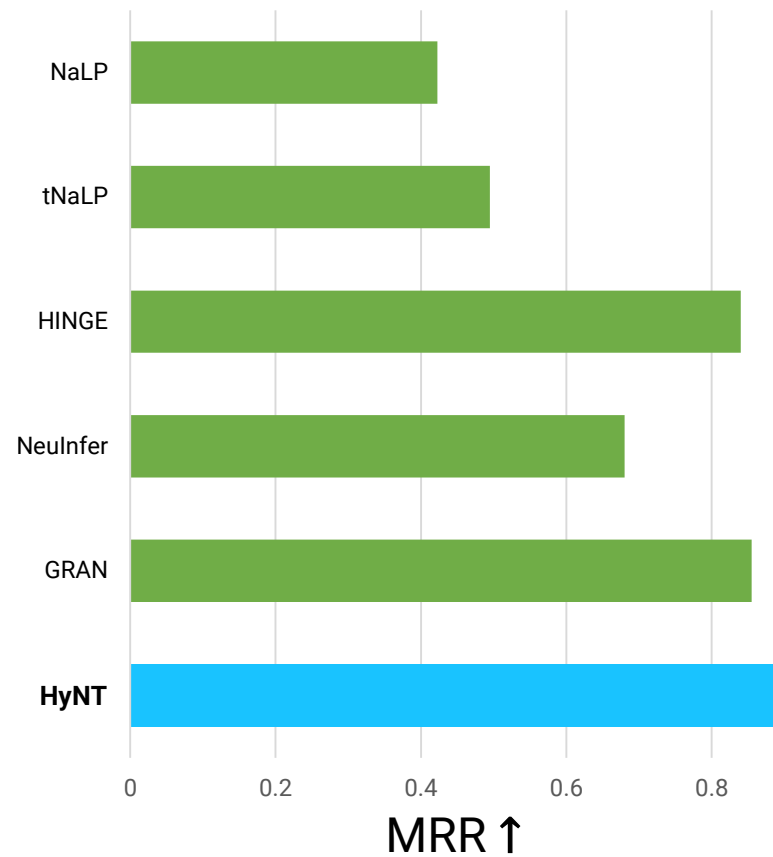


Relation Prediction Results – All

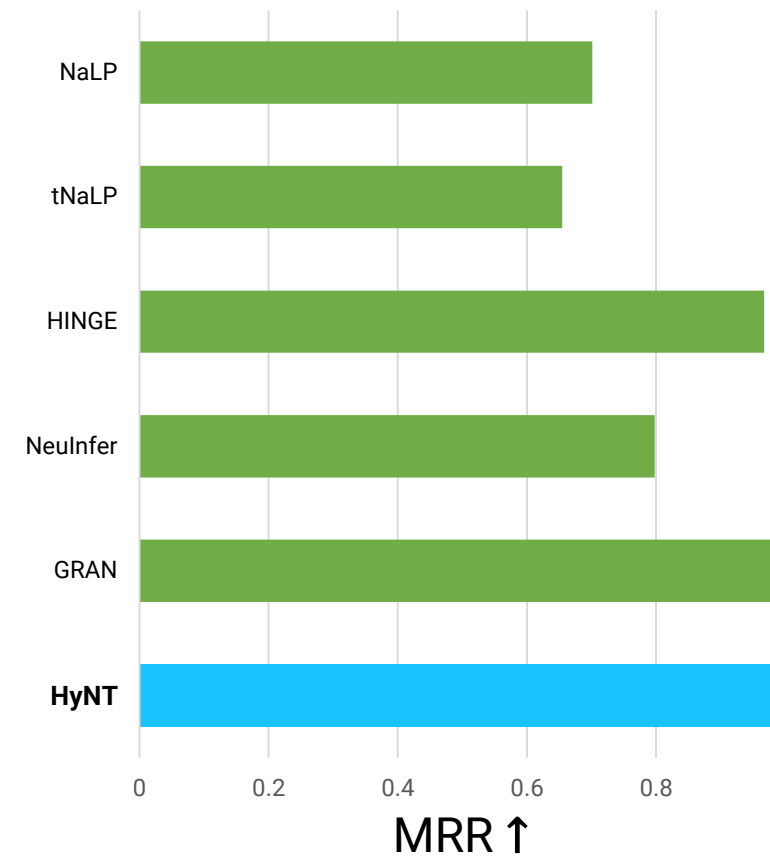
HN-WK



HN-YG



HN-FB-S



Conclusion & Future Work

- Hyper-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

You can find us at:

{chanyoung.chung, jjlee98, jjwhang}@kaist.ac.kr

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



◀ BDI Lab



BDILab

BIG DATA INTELLIGENCE