Neural-Symbolic Models for Logical Queries on Knowledge Graphs

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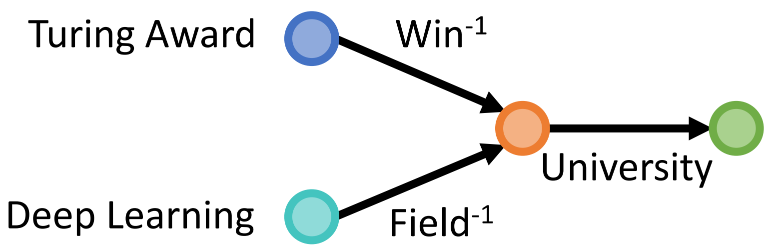
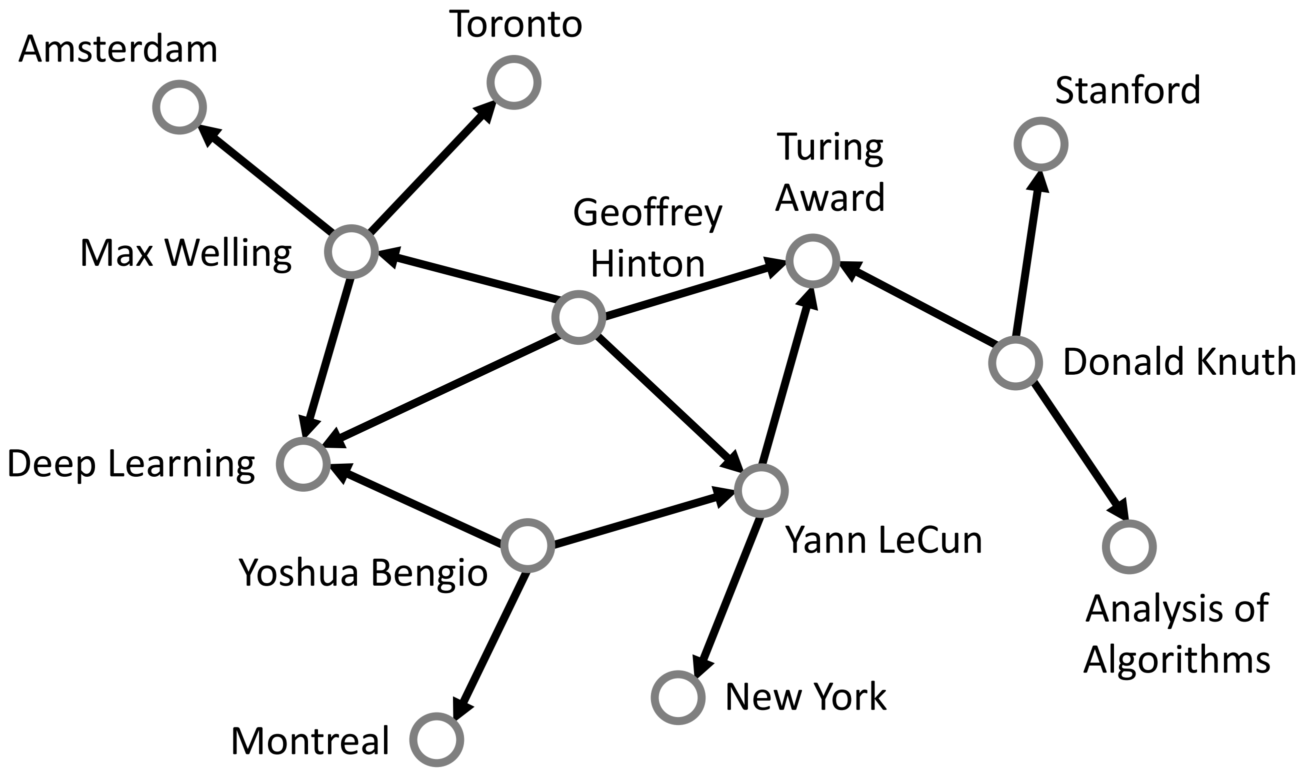
First-Order Logic Queries

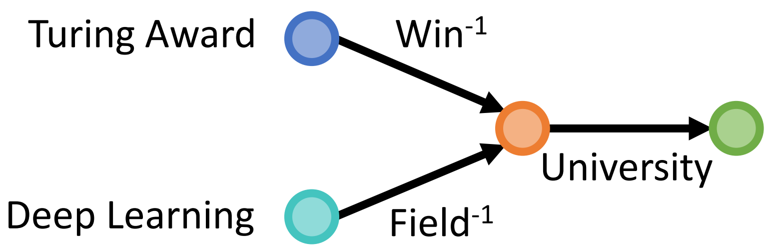
Which universities do the Turing Award winners of deep learning work in?

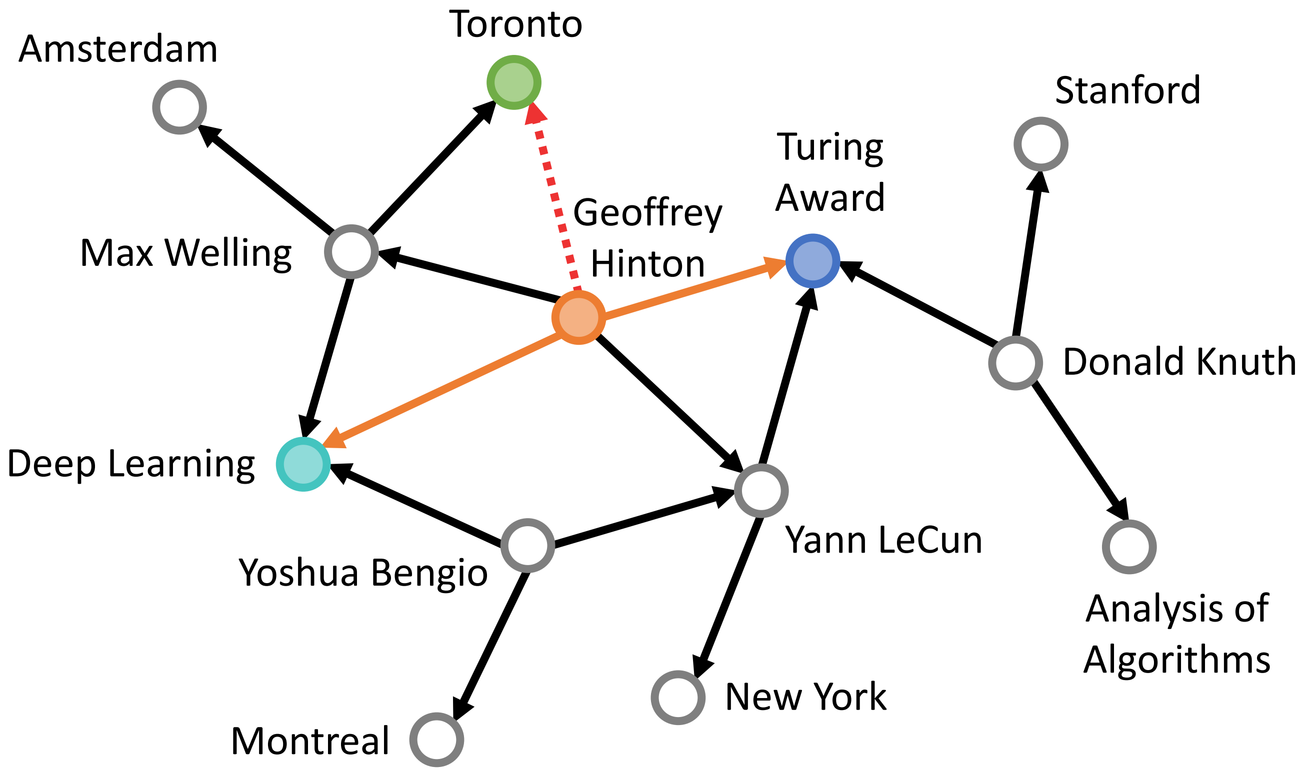




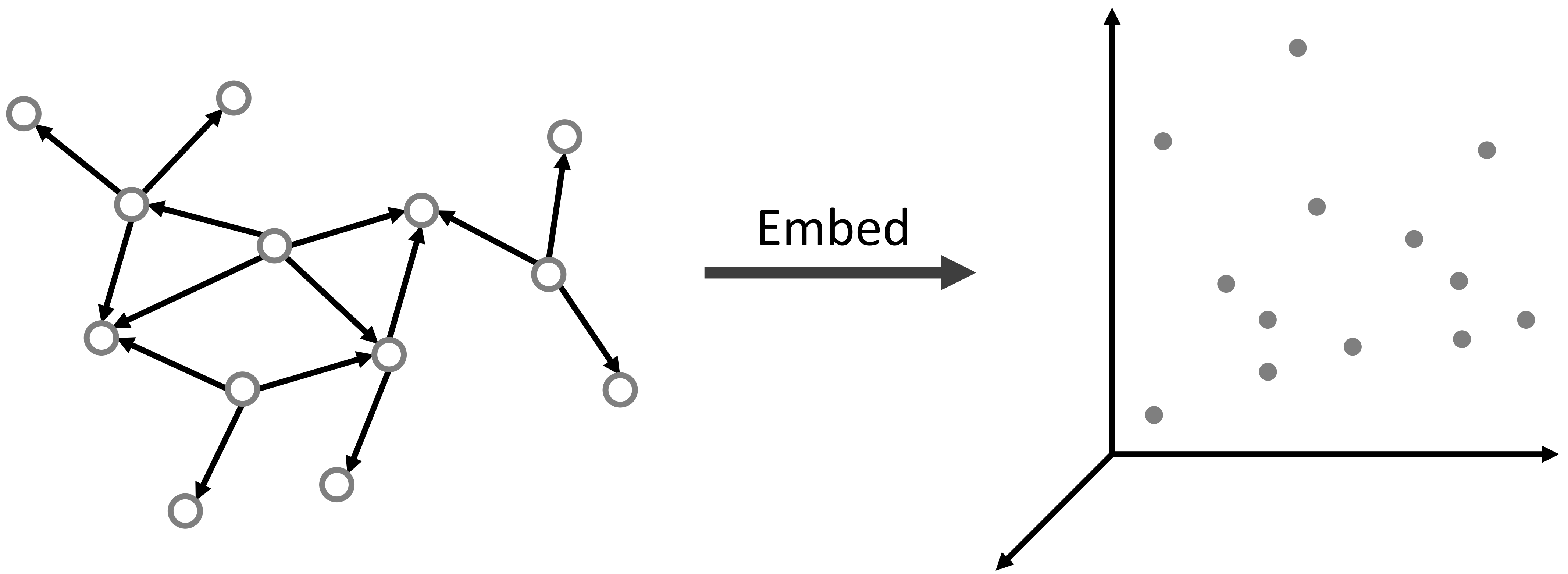
Symbolic Methods

Can't deal with missing links



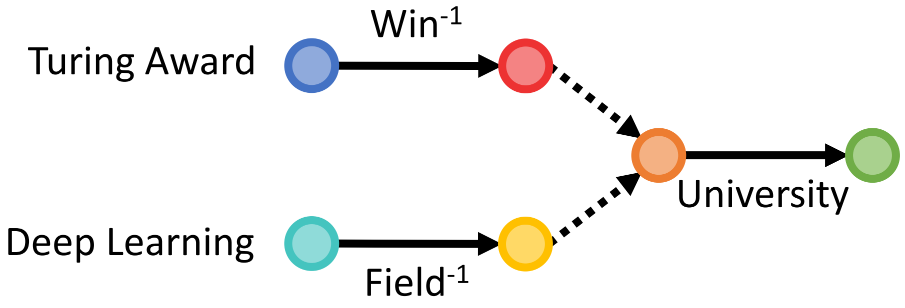


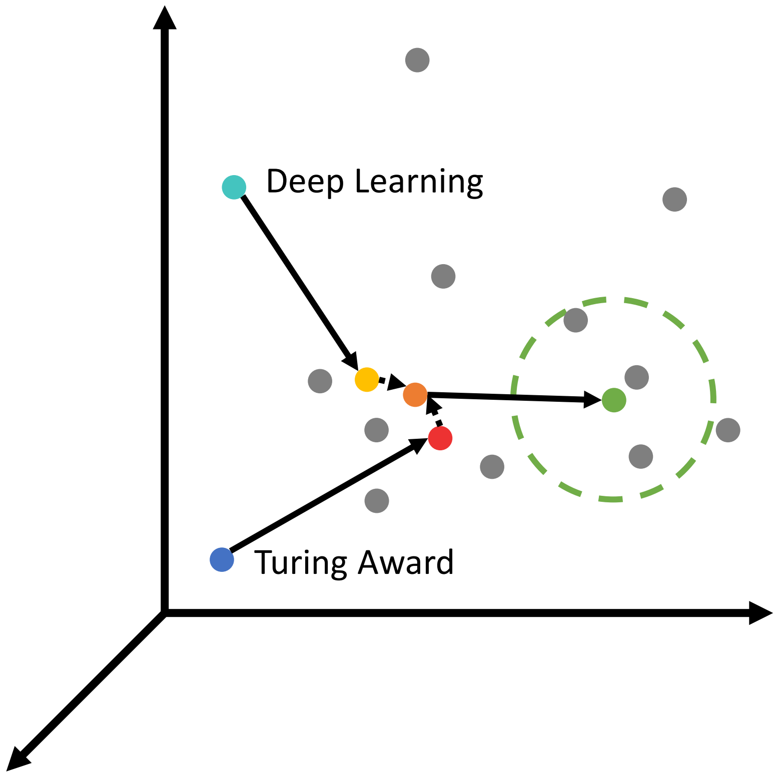
Neural Methods



Neural Methods

Can't interpret intermediate variables





Goal

Can we answer logical queries on **incomplete** knowledge graphs, with **interpretability** for intermediate variables?

Graph Neural Network - Query Executor (GNN-QE)

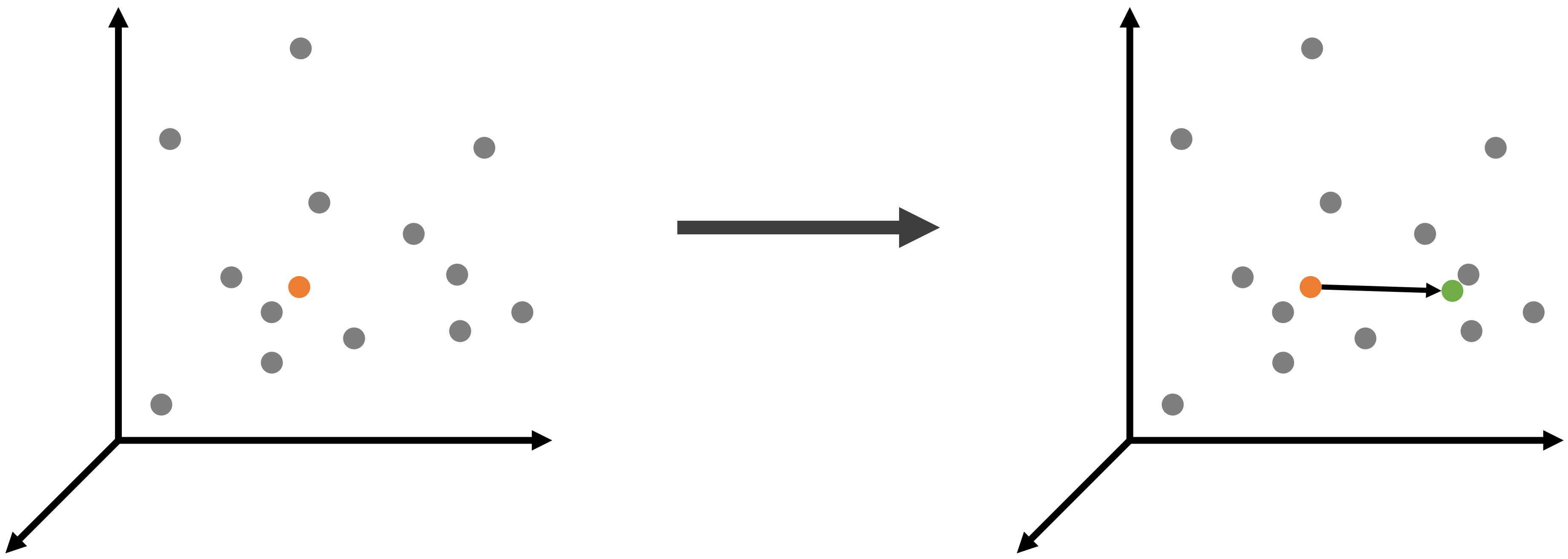
Neural + **Symbolic**

Symbolic: Decompose a logical query as operations over fuzzy sets

Neural: Learn relation projection operation with a graph neural network

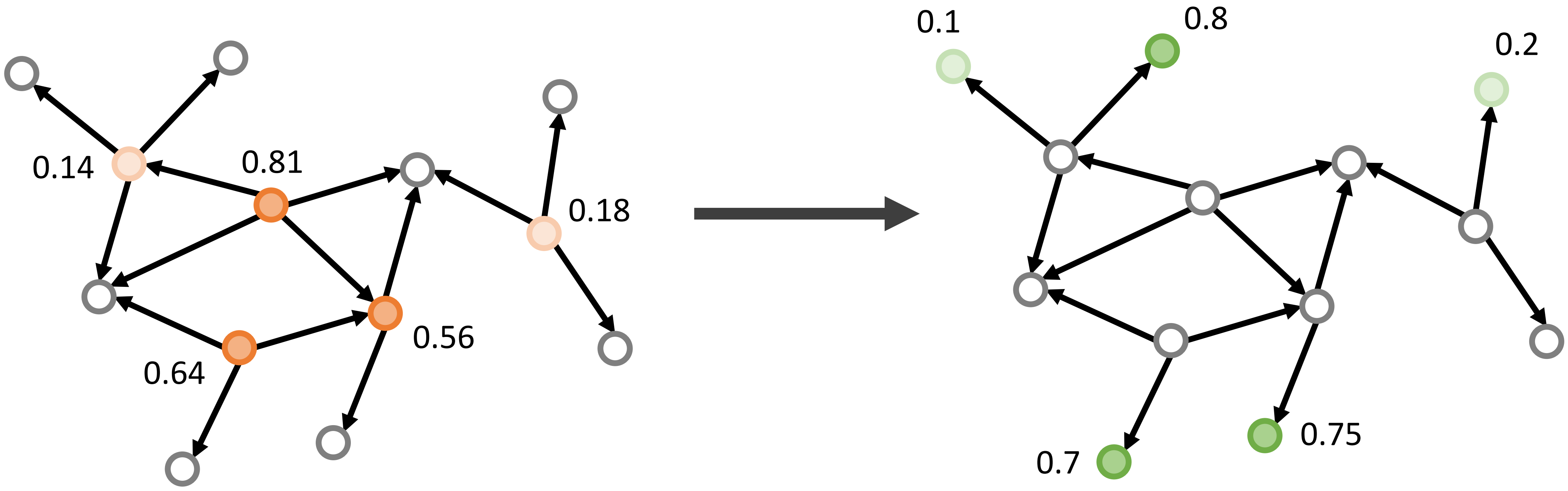
Operations over Embeddings

$$y = University(x)$$



Operations over Fuzzy Sets

$$\boldsymbol{y} = University(\boldsymbol{x})$$



Four Operations

Relation Projection: $University(\boldsymbol{x})$

Conjunction: $\boldsymbol{x} \wedge \boldsymbol{y}$

Disjunction: $\boldsymbol{x} \vee \boldsymbol{y}$

Negation: $\neg \boldsymbol{x}$

Four Operations

Relation Projection: $University(\boldsymbol{x})$ **GNN**

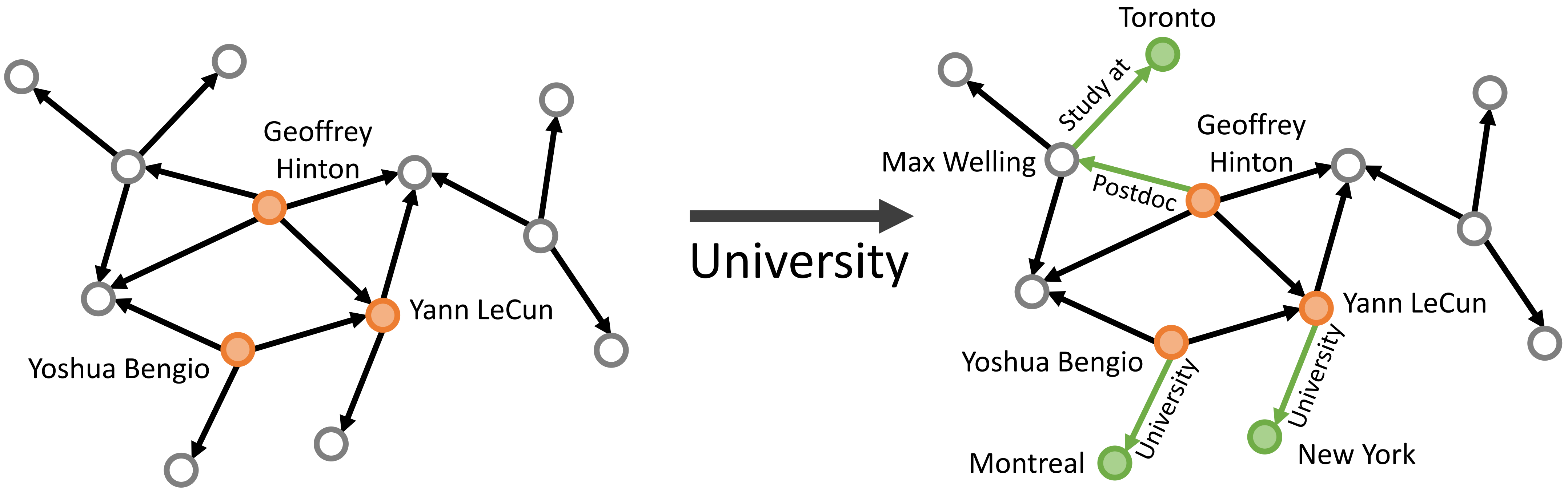
Conjunction: $\boldsymbol{x} \wedge \boldsymbol{y}$

Disjunction: $\boldsymbol{x} \vee \boldsymbol{y}$ **Fuzzy Logic**

Negation: $\neg \boldsymbol{x}$

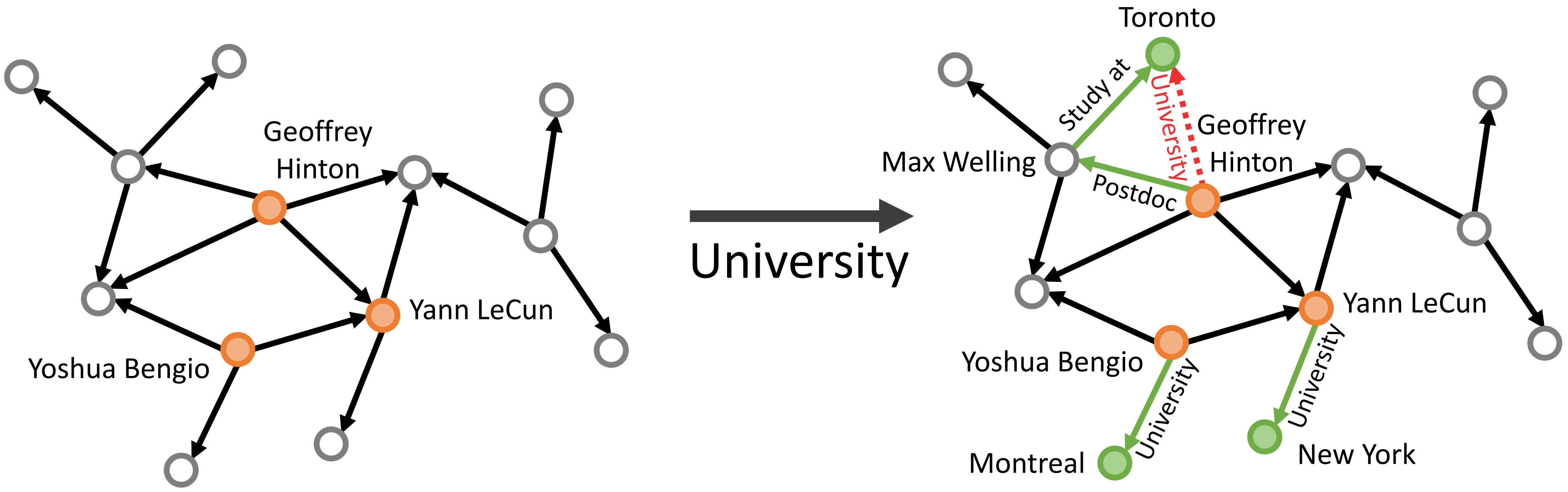
Relation Projection

Propagate with a GNN

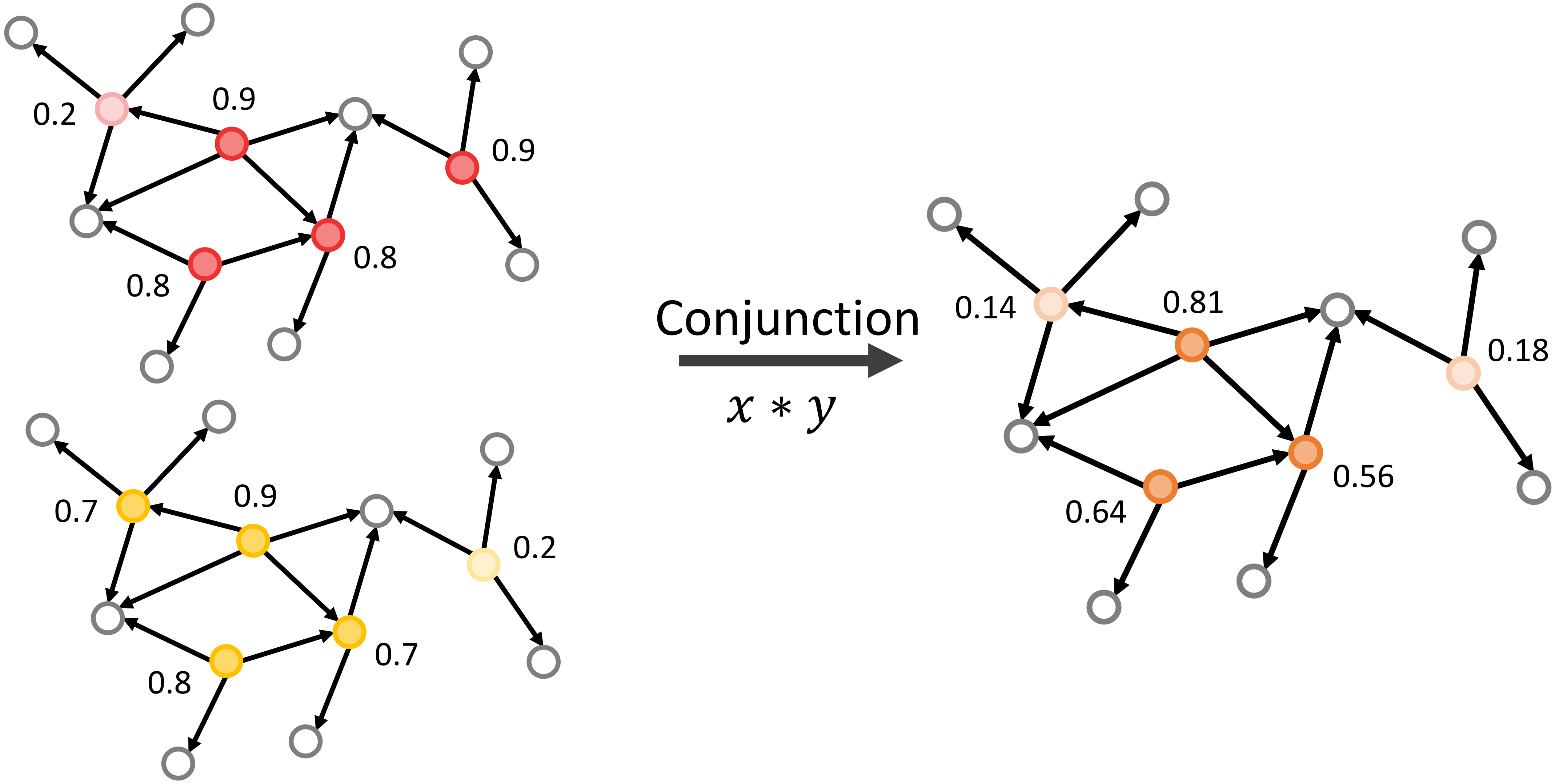


Relation Projection

Can deal with missing links



Fuzzy Logic Operations



Summary

22.3% relative improvement on EPFO queries

95.1% relative improvement on negation queries

Interpret intermediate variables

Predict the number of answers without explicit supervision