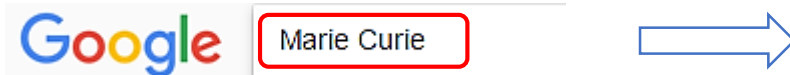





# Convolutional Neural Network for Knowledge Graph Completion

Shao Mingguang

# Knowledge Graph



Knowledge Graph (KGs) provide **structured information** of **entities** and **relations**, generally encoded in the form of **directed multi-relation graphs**.



More images

## Marie Curie

French-Polish physicist

Marie Skłodowska Curie was a Polish and naturalized-French physicist and chemist who conducted pioneering research on radioactivity.  
[Wikipedia](#)

**Born:** November 7, 1867, Warsaw, Poland  
**Died:** July 4, 1934, Sancellemoz  
**Spouse:** [Pierre Curie](#) (m. 1895–1906)  
**Discovered:** [Radium](#), [Polonium](#)  
**Awards:** [Nobel Prize in Physics](#), [Nobel Prize in Chemistry](#), [MORE](#) ▾


Quotes View 7+ more

*"Have no fear of perfection; you'll never reach it." "Nothing in life is to be feared; it is only to be understood."*


*Be less curious about people and more curious about ideas.*

*One never notices what has been done; one can only see what remains to be done.*


People also search for View 15+ more




Stephen Hawking




Pierre Curie



Albert Einstein



Antoine Henri



Irène Joliot— ..

# Application of Knowledge Graph

A large number of KGs has been created, including **Freebase**, **WordNet**, **YAGO** and **Google Knowledge Graph**.

provides general facts about the word

Groups words into synonyms and provides lexical relations



**Watson**, 一个面向认知商业的平台

Watson 是一个通过自然语言处理和机器学习, 从非结构化数据中揭示洞察的技术平台。

2011年, Watson 在美国最受欢迎的智力问答电视节目《危险边缘》(Jeopardy)中亮相, 一举打败了人类智力竞赛冠军。如今, Watson 已经发展为一个商业化、基于云的认知系统, 应用到各行各业中, 逐渐让我们的生活变得更好。

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认知计算如何帮助医疗保健行业进行转型

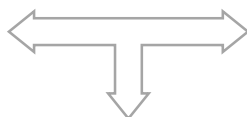
**颠覆银行业**  
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**零售行业的认知未来**  
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**Watson 物联网**  
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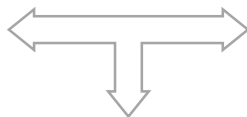


Corpus



*Leonard Nimoy was an actor who played the character Spock in the science-fiction movie Star Trek.*

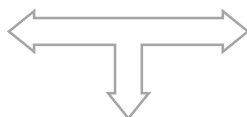
NLP: Entity recognition  
Relation recognition



*Leonard Nimoy* was an *actor* who  
*played the character Spock* in the  
*science-fiction* movie *Star Trek*.

Triple: (head, relation, tail)

Note: Only store true facts



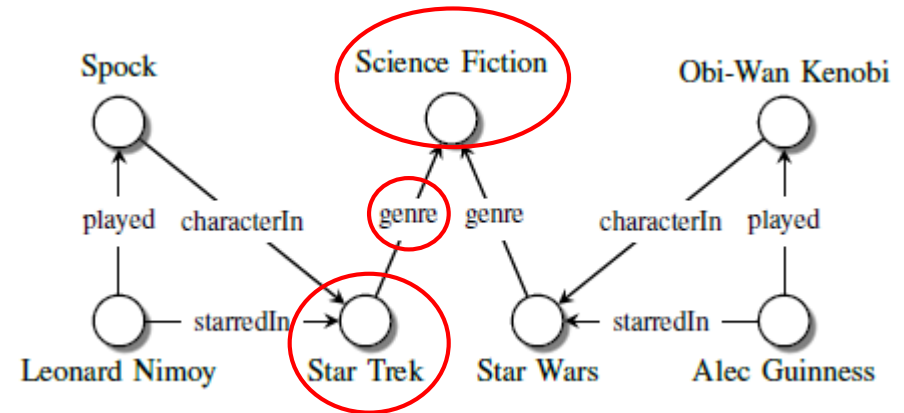
(LeonardNimoy,	profession,	Actor)
(LeonardNimoy,	starredIn,	StarTrek)
(LeonardNimoy,	played,	Spock)
(Spock,	characterIn,	StarTrek)
(StarTrek,	genre,	ScienceFiction)

Is that enough?

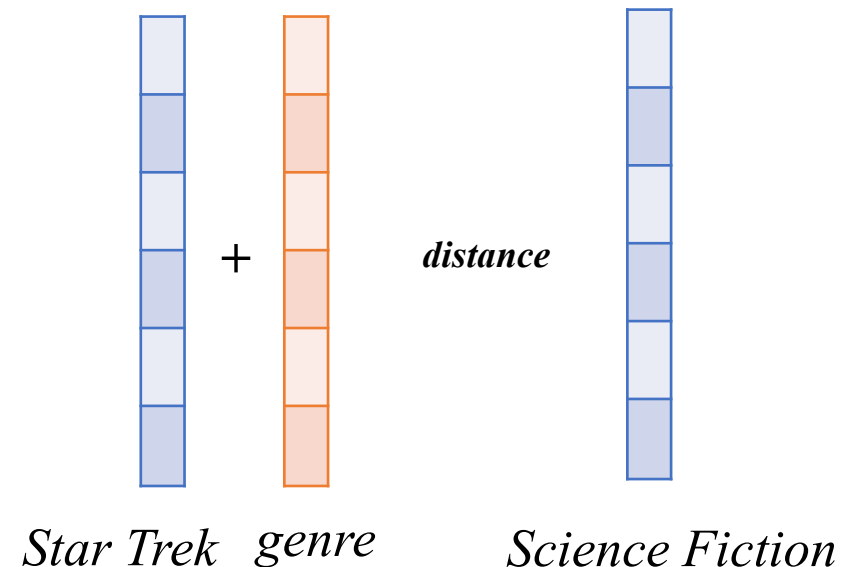
# Knowledge Graph Construction

Problem: We can't use **triple** for calculations.

For example, calculate **distance** between *Star Trek + genre* and *Science Fiction*



**Embedding** to Vector Space



# Knowledge Graph Completion

Another Problem: **Incomplete knowledge**

Existing Knowledge Graphs are often missing many facts.

**Knowledge graph completion(KGC)** aims at filling in incomplete triples like  $(h,r,?)$ ,  $(?,r,t)$  or  $(h,?,t)$ .

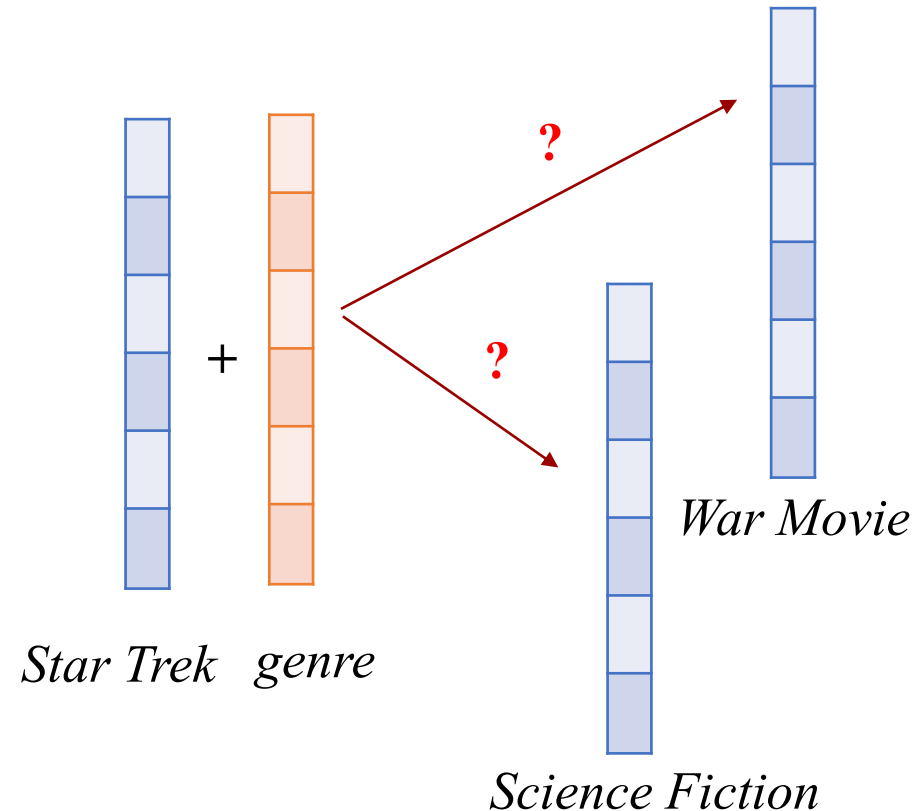


**KGC MODEL**

*(Leonard Nimoy ,profession ,? )*

*(Leonard Nimony ,?, StarTrek)*

*(Star Trek, genre,?)*



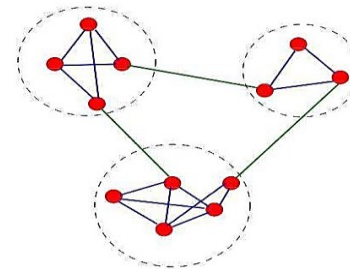
# Different types of KGC models

Markov Random Fields

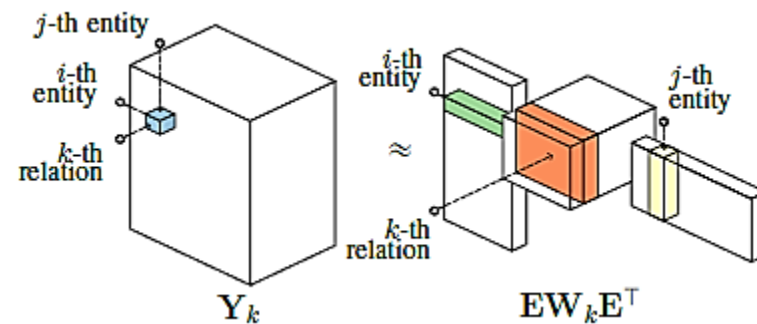
$$F_1 : (x, \text{parentOf}, z) \wedge (y, \text{parentOf}, z) \Rightarrow (x, \text{marriedTo}, y)$$

$$F_2 : (x, \text{marriedTo}, y) \Rightarrow \neg(y, \text{parentOf}, x)$$

Graph Features Models



Embedding models





## KGC Model

---

Three key points of a KGC Model: score function, negative sampling, training methods(loss function)

**SCORE FUNCTION:** the probability of the existence of  $(h, r, t)$

**TransE:** A. Bordes . Translating Embeddings for Modeling Multi-relation Data

Score function:

$$\Pr(h, t, r) = \exp(-\|h + r - t\|_2^2)$$

**HoLE:** Maximilian Nickel. Holographic Embedding of Knowledge Graphs

**RESCAL:** A Three-Way Model for Collective Learning on Multi-Relation Data

Score function:

$$\Pr(h, t, r) = \exp(r^T (h \otimes t))$$

**ProjE:** Baoxu Shi. ProjE: Embedding Projection for Knowledge Graph Completion

Score function:

$$\Pr(h, r) = \exp(W^e f(D_e h + D_r r + b_e) + b_p)$$



## KGC Model

**NEGATIVE SAMPLING:** generate negative relation instance for training from  $p$ ,  $p$  can be replaced by a  $(0,1)$  binomial distribution.

$$(h, r, t) \rightarrow (h', r, t) \quad (h, r', t) \quad (h, r, t')$$

### LOSS FUNCTION:

Pair-wise:

$$L = \sum_{(h,r,t) \in S} \sum_{(h',r,t') \in S'} \max(0, f_r(h, t) + \gamma - f_r(h', t'))$$

Point-wise:

$$\max_{\Theta} \sum_{i \in \{i | y_i = 1\}} \log(g(\eta_i)) + \sum_{i \in \{j | y_j = -1\}} \log(1 - g(\eta_j)) + \lambda \|\Theta\|_2^2 \quad \eta_i = \mathbf{t}^\top (\mathbf{h} \circ \mathbf{r})$$

List-wise:

$$\max_{\Theta} \log\left(\prod_{i=1}^m g(\eta_i)\right) + \lambda \|\Theta\|_2^2 \quad \eta_i = \mathbf{t}^\top (\mathbf{h} \circ \mathbf{r})$$

**Details:** List approach to learning to rank - Theory and Algorithm

## Details of Embedding

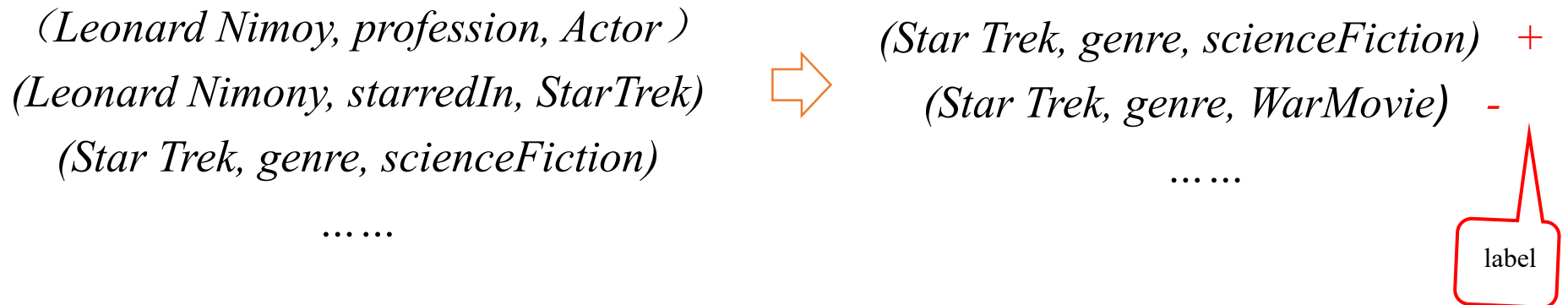
<i>Leonard Nimoy</i>	0	<i>profession</i>	0	<i>(Leonard Nimoy, profession, Actor)</i>
<i>Star Trek</i>	1	<i>starred in</i>	1	<i>(Leonard Nimony, starredIn, StarTrek)</i>
<i>Science Fiction</i>	2	<i>genre</i>	2	<i>(Star Trek, genre, scienceFiction)</i>
.....		.....		.....

List of entities and index

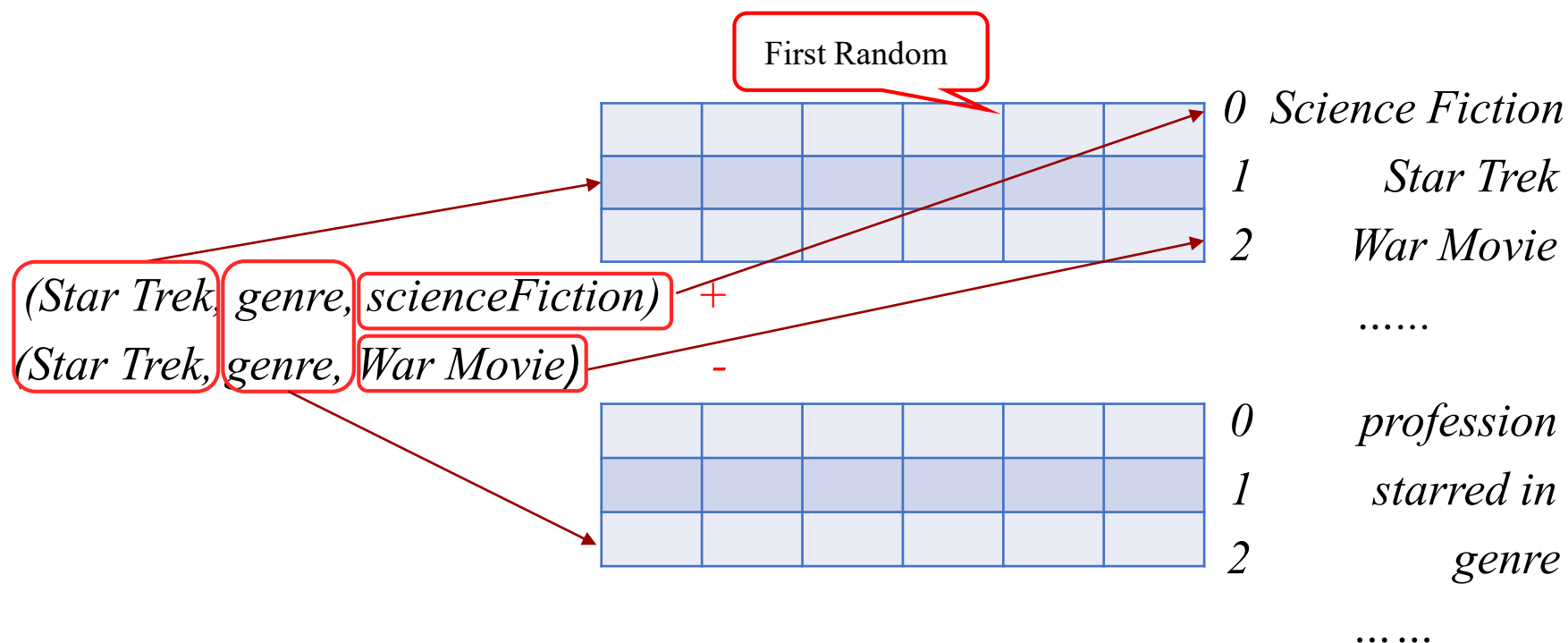
List of relations and index

List of triples(golden triple)

## Generate negative instance

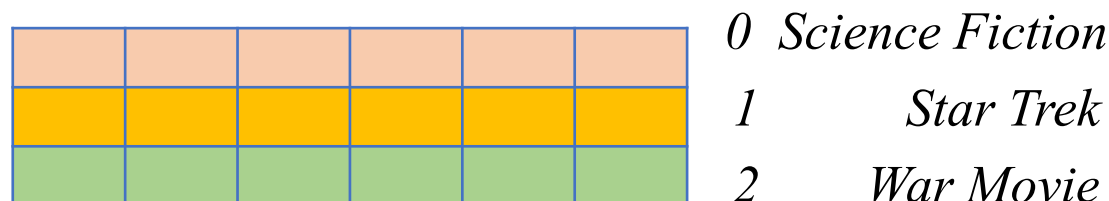


# Details of Embedding

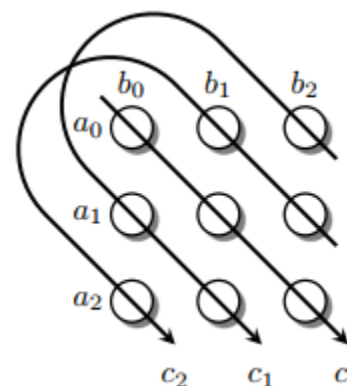
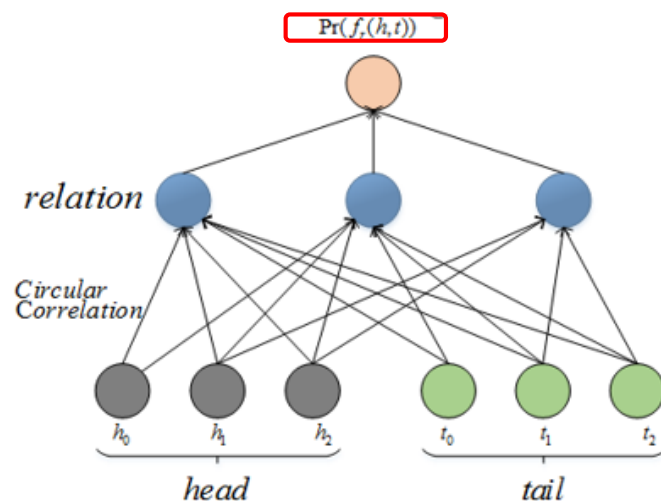


$$\min L = \sum_{(h,r,t) \in S} \sum_{(h',r,t') \in S'} \max(0, f_r(h,t) + \gamma - f_r(h',t'))$$

Then, update  $h, t$  and  $r$



# MODEL: RESCAL



$$c = a \star b$$

$$c_0 = a_0 b_0 + a_1 b_1 + a_2 b_2$$

$$c_1 = a_0 b_2 + a_1 b_0 + a_2 b_1$$

$$c_2 = a_0 b_1 + a_1 b_2 + a_2 b_0$$

**HoLE:** Maximilian Nickel. Holographic Embedding of Knowledge Graphs

**RESCAL:** A Three-Way Model for Collective Learning on Multi-Relation Data

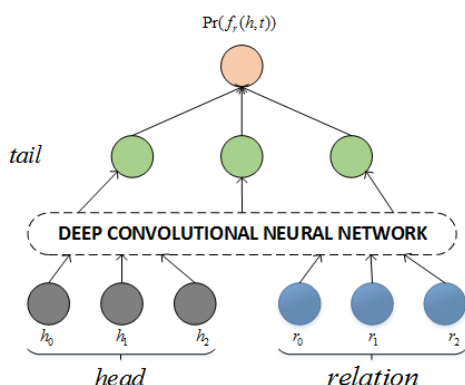
Score function:

$$\Pr(h, t, r) = f(r^T (h \otimes t))$$

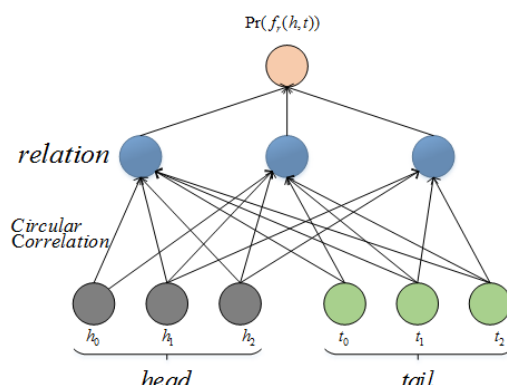
$$L = \sum_{(h, r, t) \in S} \sum_{(h', r, t') \in S'} \max(0, f_r(h, t) + \gamma - f_r(h', t'))$$

# OUR MODEL: CNN-MODEL

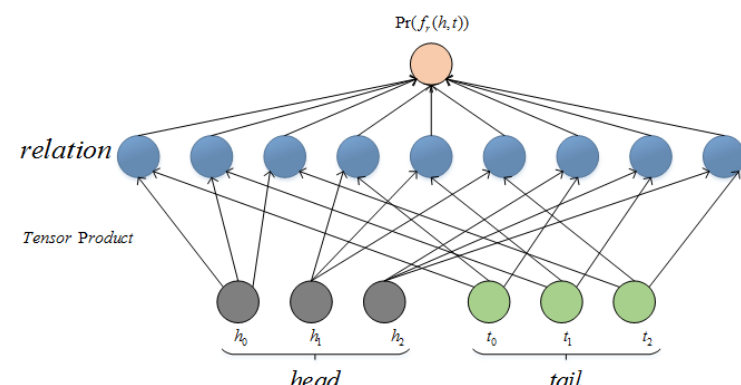
We first introduce deep neural network and CNN to KGC:



Learned by CNN



hand-crafted



**HoIE**: Maximilian Nickel. Holographic Embedding of Knowledge Graphs

**RESAL**: A Three-Way Model for Collective Learning on Multi-Relation Data

Score function:

$$\Pr(h, t, r) = f(r^T (h \otimes t))$$

Another training method: classification based model:

$$\max_{\Theta} \log\left(\prod_{i=1}^m g(-y_i \eta_i)\right) + \lambda \|\Theta\|_2^2 \quad \eta_i = \mathbf{t}^\top (\mathbf{h} \circ \mathbf{r})$$

$$\min_{\Theta} \sum_{i=1}^m \log(1 + \exp(-y_i \eta_i)) + \lambda \|\Theta\|_2^2$$

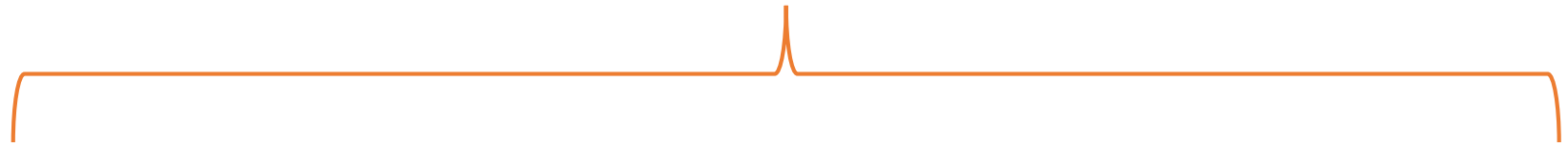
- **Mean Rank:** measures the average of rank of correct entities or relations
- **Hits@k:** measures the proportion of valid entities/reactions ranked in top k

The “filter” setting protocol remove all instances that appear in the knowledge graph base before ranking.

NOTE: Higher Hits@k or lower mean rank indicates better entity prediction performance.



## FUTURE WORK



### Negative sampling

- Random
- Corrupted
- LCWA
- PU learning

### Score function

- Hand-crafted
- CNN-based

### Training method

- pairwise
- pointwise
- List-wise
- classification

### Reasoning

- Reinforcement learning



谢谢各位老师指导！