2020全国知识图谱与语义计算大会

China Conference on Knowledge Graph and Semantic Computing

南昌 – 2020年11月

基于深度学习的知识图谱实体对齐

王志春

北京师范大学人工智能学院

2020年11月15日

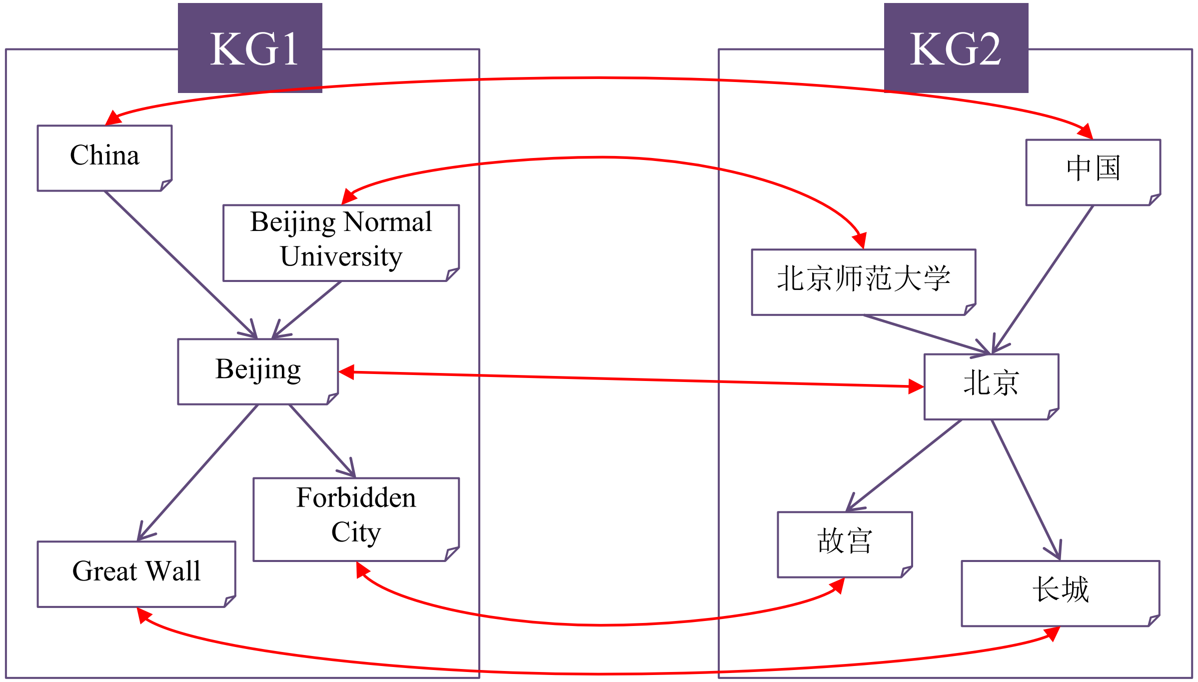
知识图谱

- 知识图谱(Knowledge Graph)以结构化的形式描述客观世界中概念、实体及其关系
- 大规模的知识图谱被构建和应用于多个领域
  - 语义检索、智能问答、实体链接、阅读理解……

KnowItAll
DBpedia
WordNet
BabelNet
ZHISHI.me
ProBase
yago select knowledge
Google Knowledge Graph
CN-DBpedia
NELL
WIKIDATA
Freebase™
XLORE 中英文跨语言百科知识图谱

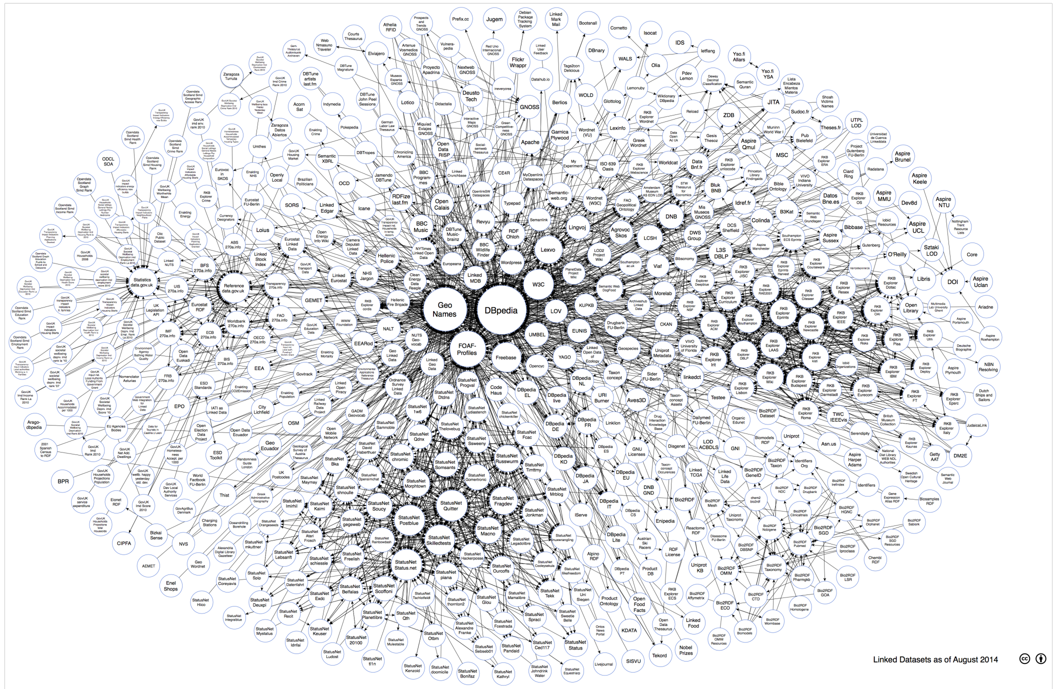
知识图谱实体对齐

- 实体对齐 (entity alignment)， 是判断不同知识图谱中的两个实体是否指向真实世界同一对象的过程。



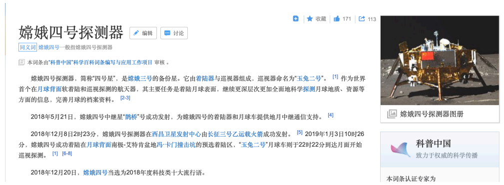
实体对齐应用场景

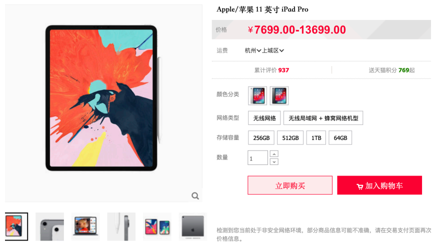
知识图谱互联



图片出自https://lod-cloud.net/versions/2014-08-30/lod-cloud.png

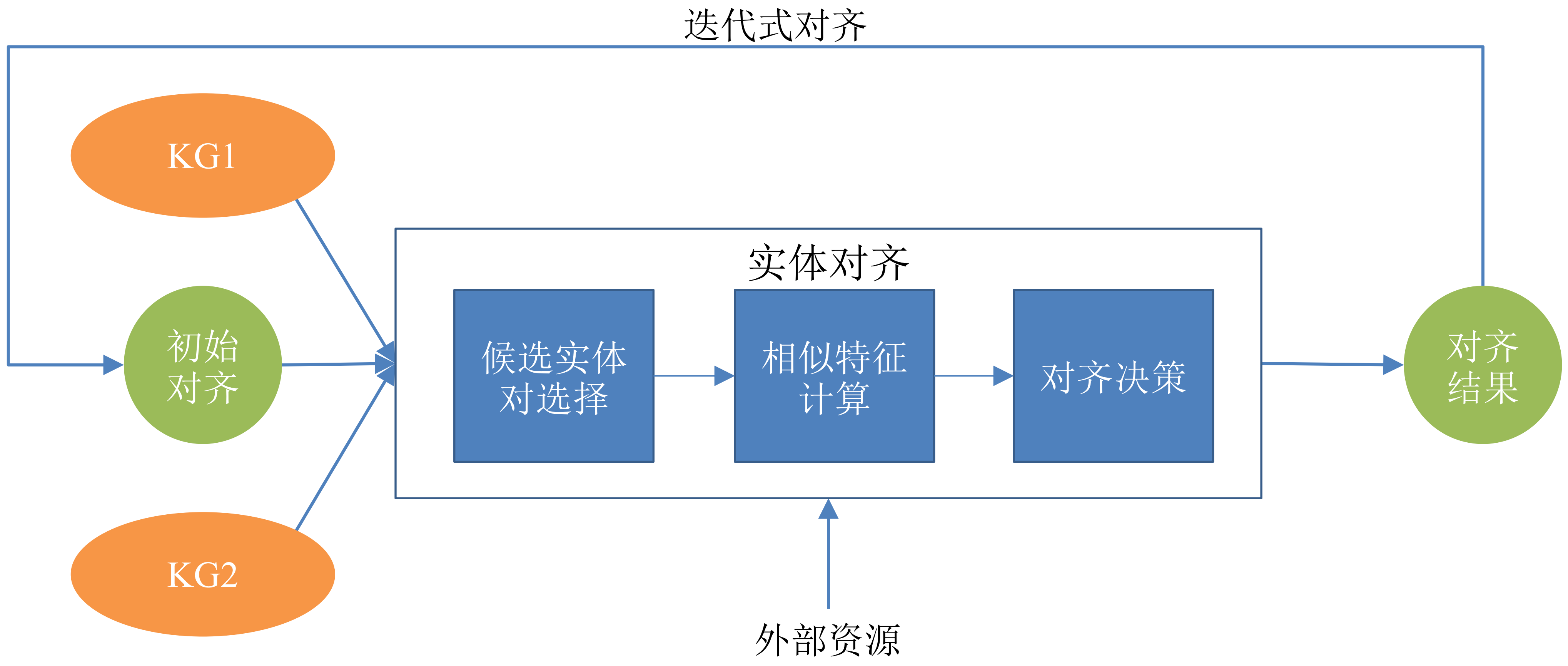
知识集成





基于相似度特征的实体对齐

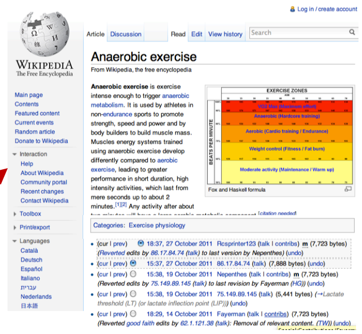
- 实体对齐的基本假设：（1）等价实体具有相似的属性（2）等价实体具有相似的邻接实体
- 实体对齐的基本框架：



基于相似度特征的实体对齐

输入

维基百科



百度百科

相似度特征计算

- 基于链出的相似度

$$f_{out} = \frac{2 \cdot |\{(a',b')|(a',b') \in EL, a' \in O(a_{i_1}), b' \in O(b_{i_2})\}|}{|O(a_{i_1})| + |O(b_{i_2})|}$$

- 基于链入的相似度

$$f_{in} = \frac{2 \cdot |\{(a',b')|(a',b') \in EL, a' \in I(a_{i_1}), b' \in I(b_{i_2})\}|}{|I(a_{i_1})| + |I(b_{i_2})|}$$

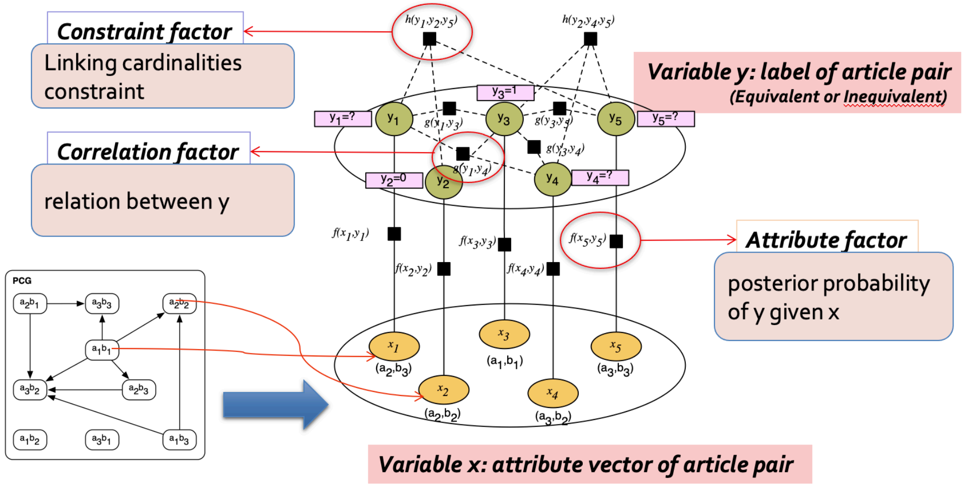
- 基于分类的相似度

$$f_{cate} = \frac{2 \cdot |\{(c,c')|(c,c') \in EC, c \in C(a_{i_1}), c' \in C(b_{i_2})\}|}{|C(a_{i_1})| + |C(b_{i_2})|}$$

- 基于作者的相似度

$$f_{auth} = \frac{1}{|U(a_{i_1})| \cdot |U(b_{i_2})|} \sum_{u_1 \in U(a_{i_1})} \sum_{u_2 \in U(b_{i_2})} s(u_1, u_2)$$

对齐决策（分类）



[1] Wang, Z., Li, J., Wang, Z., & Tang, J. (2012). Cross-lingual knowledge linking across wiki knowledge bases. *WWW*.

RDF数据集实体对齐工具

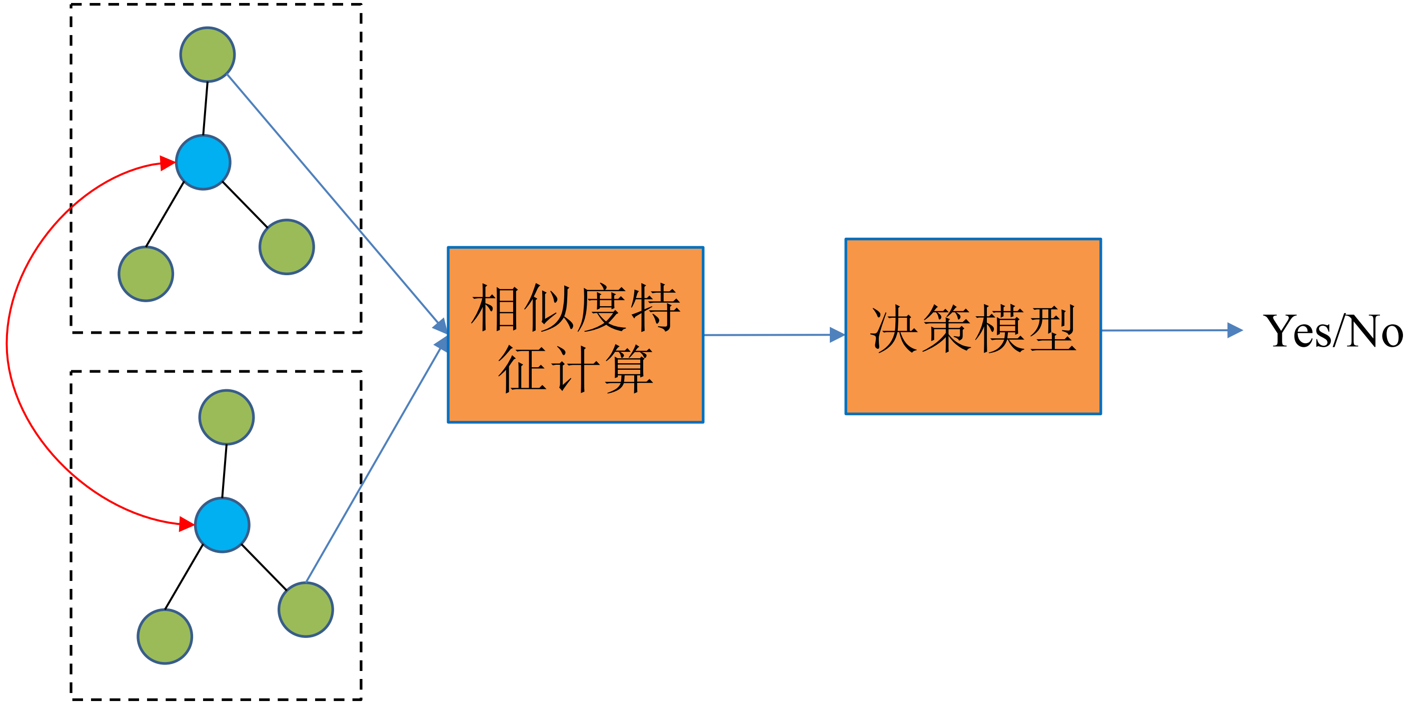
		RiMOM	AgreementMaker	CODI	LogMap	SERIMI	Zhishi.links	SLINT+
	Data Input	RDF, OWL	SPARQL	RDF, OWL	RDF, OWL	SPARQL	RDF	RDF
	Supported linktypes	`owl:sameAs`	`owl:sameAs`	`owl:sameAs`	`owl:sameAs`	`owl:sameAs`	`owl:sameAs`	`owl:sameAs`
	Configuration	adaptive	manual	manual	manual	adaptive	manual	adaptive
	- matcher combination	weighted average	weighted combination	weighted average	weighted average	-	weighted combination	weighted average
候选实体对选择	Runtime optimization							
候选实体对选择	- Blocking	-	-	-	-	-	-	-
候选实体对选择	- Filtering	indexing	indexing	-	indexing	-	indexing	indexing
相似度特征计算方法	String similarity measures	✓	✓	✓	✓	✓	✓	✓
相似度特征计算方法	Further similarity measures	-	-	-	-	-	geographical coordinates	inverted disparity
相似度特征计算方法	Structure matcher	-	semantic similarity	iterative anchor-based mapping generation	iterative anchor-based mapping generation	-	semantic similarity	-
	Use of							
	- external dictionaries	?*	?*	-	?*	-	-	-
	- existing mappings	-	-	-	-	-	-	-
	Post-processing	-	-	Coherence checks	Inconsistency repair	-	-	-
	Parallel processing	-	-	-	-	-	MapReduce	-
	GUI/web interface/API	- / - / -	✓/ ? / -	- / - / -	✓/ ✓/ -	- / - / -	- / - / -	- / - / -
	Download Tool/Source	✓/ -	-[1] / -	✓/ ✓	✓/ ✓	✓/ ✓	✓/ -	✓/ -
	Open Source project	-	-	✓	✓	✓	-	-

[2] Nentwig M, Hartung M, Ngonga Ngomo AC, Rahm E. A survey of current link discovery frameworks. Semantic Web. 2017 Jan 1;8(3):419-36.

深度学习方法的引入

■基于相似度特征的方法

- 对齐结果依赖于人工设计的特征
- 不同的对齐任务需要不同的特征



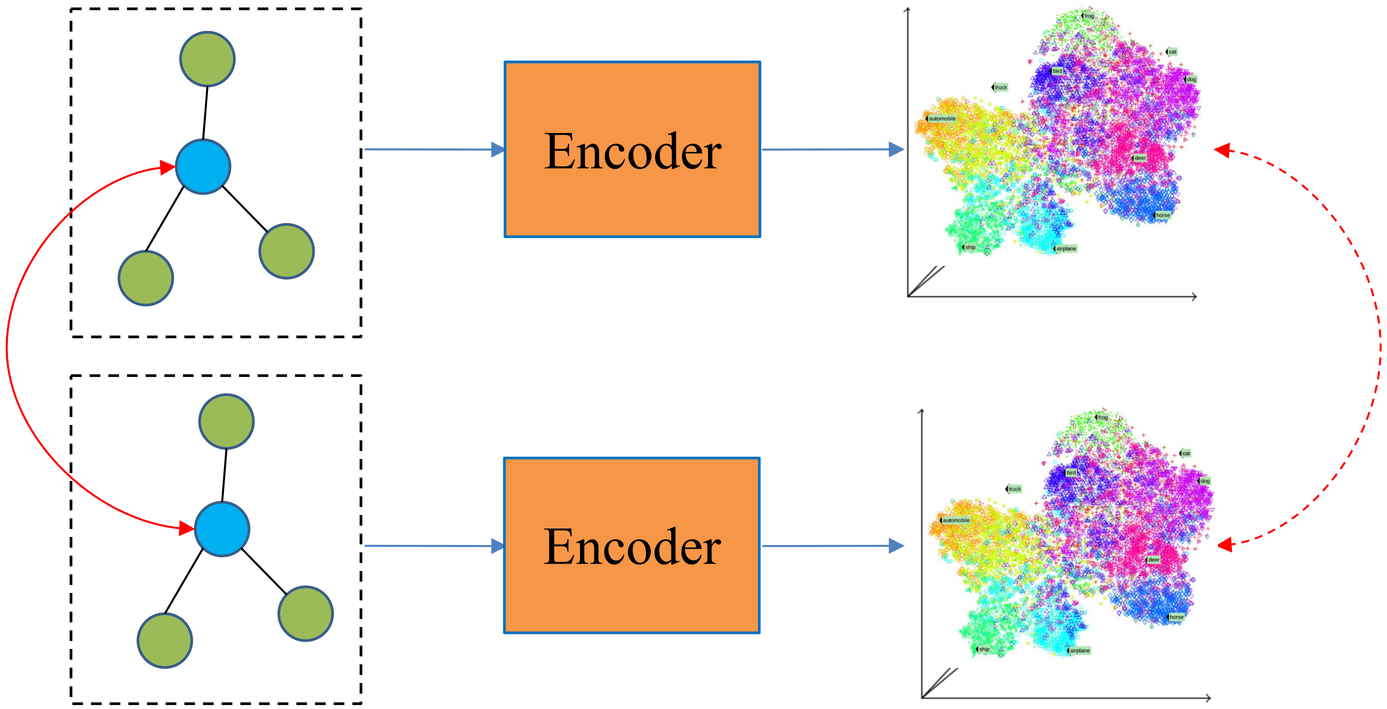
深度学习方法的引入

■基于相似度特征的方法

- 对齐结果依赖于人工设计的特征
- 不同的对齐任务需要不同的特征

■基于深度学习的方法

- 利用表示学习、神经网络模型自动获取隐式特征
- 在隐式向量空间计算实体相似度



知识图谱分布式表示

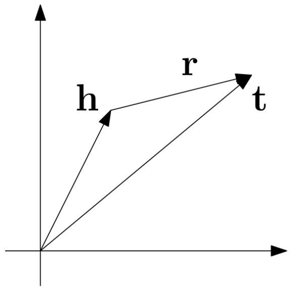
■在隐式向量空间对知识图谱中的实体及关系进行表示、建模与学习

- 实体：表示为向量
- 关系：表示为向量或矩阵

■分布式表示的应用

- 链接预测
- 三元组分类

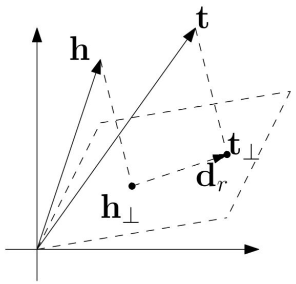
TransE



Score function:

f(h, r, t) = D(h + r, t)

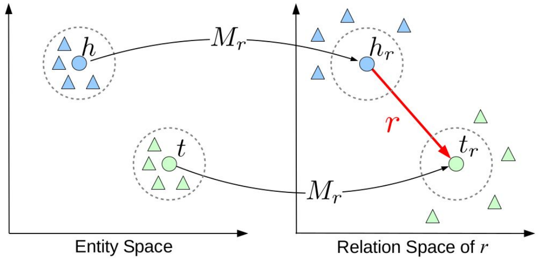
TransH



Score function:

f(h, r, t) = D($h_\perp$ + d_r, $t_\perp$)

TransR



Score function:

f(h, r, t) = D(h_r + r , t_r)

[3] Bordes A, Usunier N, Garcia-Duran A, Weston J, Yakhnenko O. Translating embeddings for modeling multi-relational data. InAdvances in neural information processing systems 2013 (pp. 2787-2795).
[4] Wang Z, Zhang J, Feng J, Chen Z. Knowledge Graph Embedding by Translating on Hyperplanes. InAAAI 2014 Jul 27 (Vol. 14, pp. 1112-1119).
[5] Lin Y, Liu Z, Sun M, Liu Y, Zhu X. Learning entity and relation embeddings for knowledge graph completion. InAAAI 2015 Jan 25 (Vol. 15, pp. 2181-2187).

MTransE：面向跨语言实体对齐的表示学习模型

- *Knowledge model*

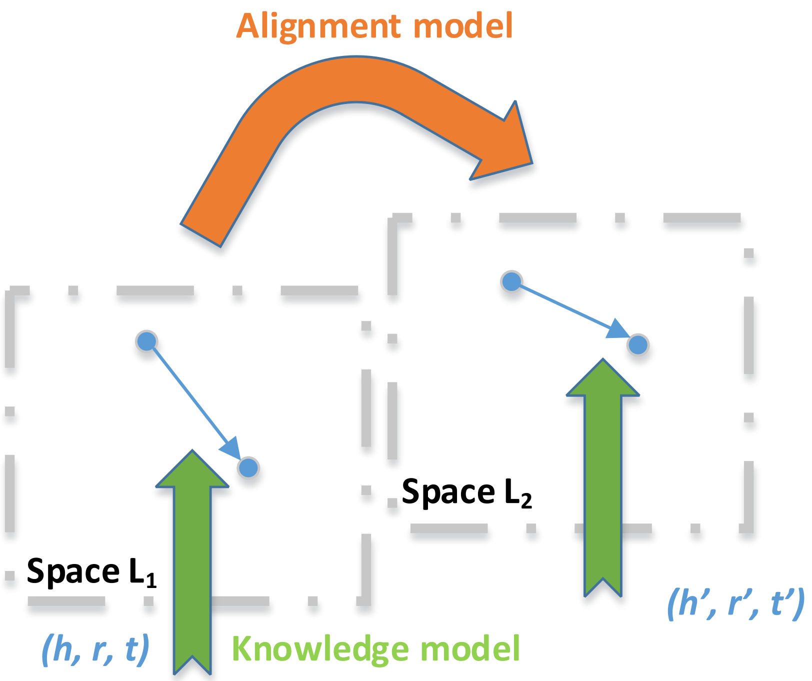
$$S_K = \sum_{L \in \{L_i, L_j\}} \sum_{T \in G_L} ||\mathbf{h} + \mathbf{r} - \mathbf{t}||$$

- *Alignment model*

$$S_A = \sum_{(T,T') \in \delta(L_i, L_j)} S_a(T, T')$$

All aligned triples

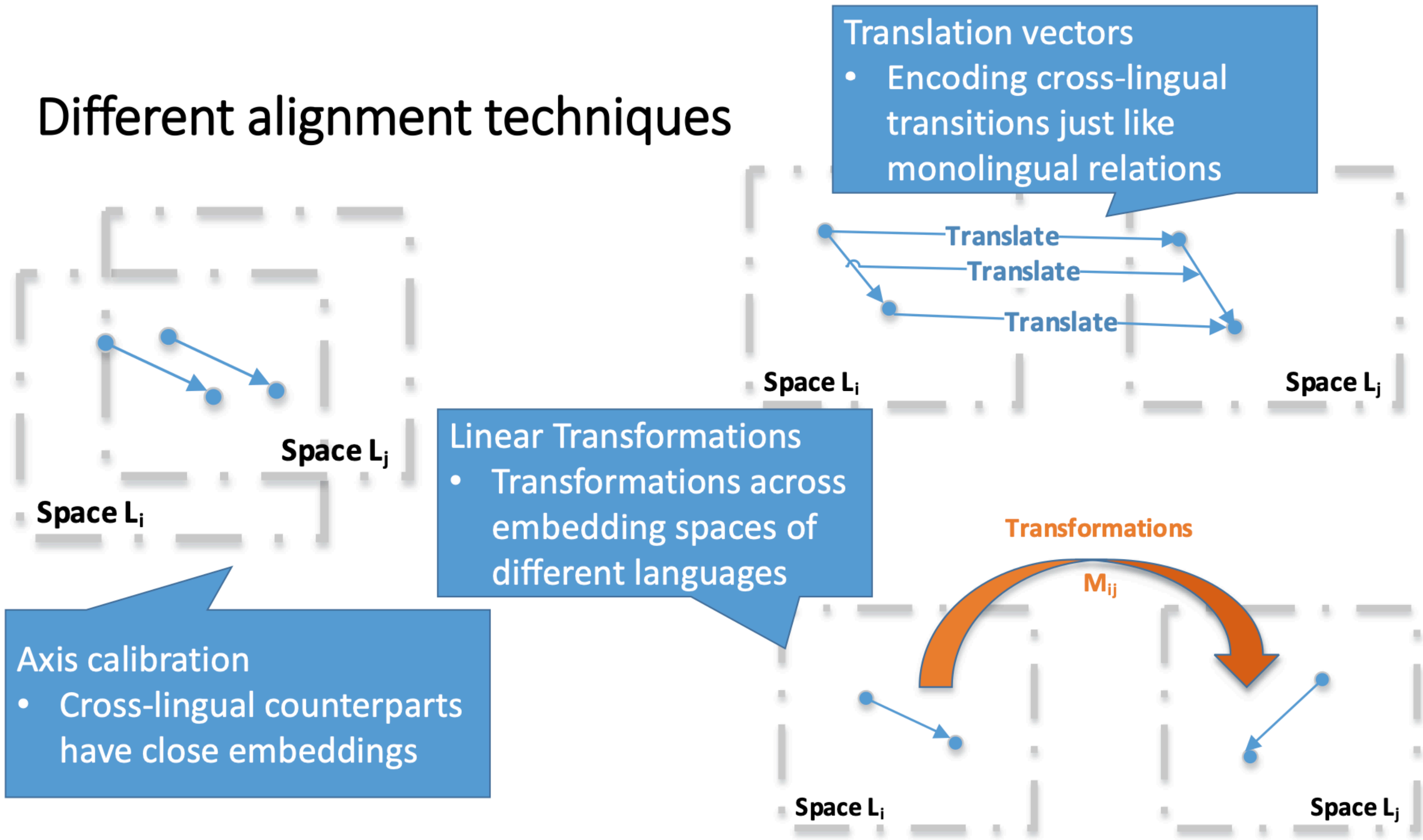
- *Objective of learning*
  - Minimizing $J(\theta) = S_K + \alpha S_A$



http://yellowstone.cs.ucla.edu/~muhao/slides/mtranse_slides_short.pdf

[6] Muhao Chen, Yingtao Tian, Mohan Yang, and Carlo Zaniolo. Multilingual knowledge graph embeddings for cross-lingual knowledge alignment. In Proceedings of the 26th International Joint Conference on Artificial Intelligence, pages 1511–1517, 2017.

MTransE：面向跨语言实体对齐的表示学习模型

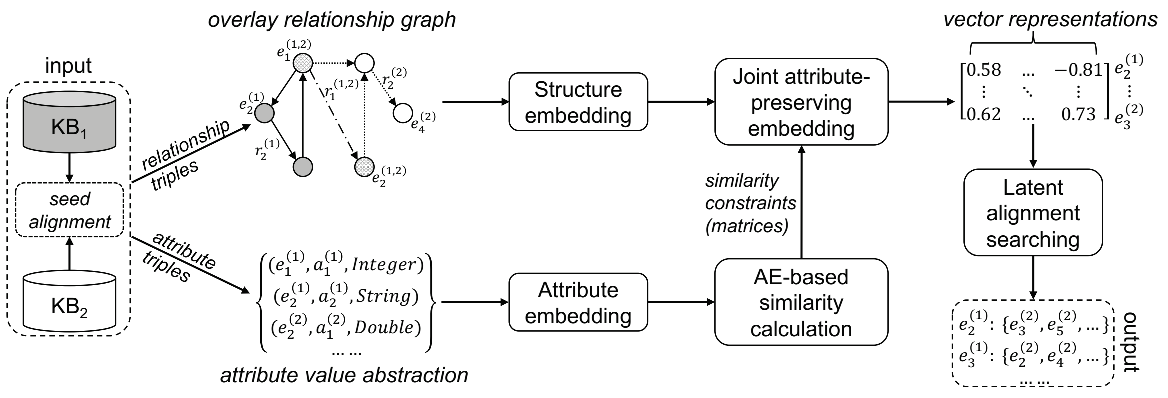


http://yellowstone.cs.ucla.edu/~muhao/slides/mtranse_slides_short.pdf

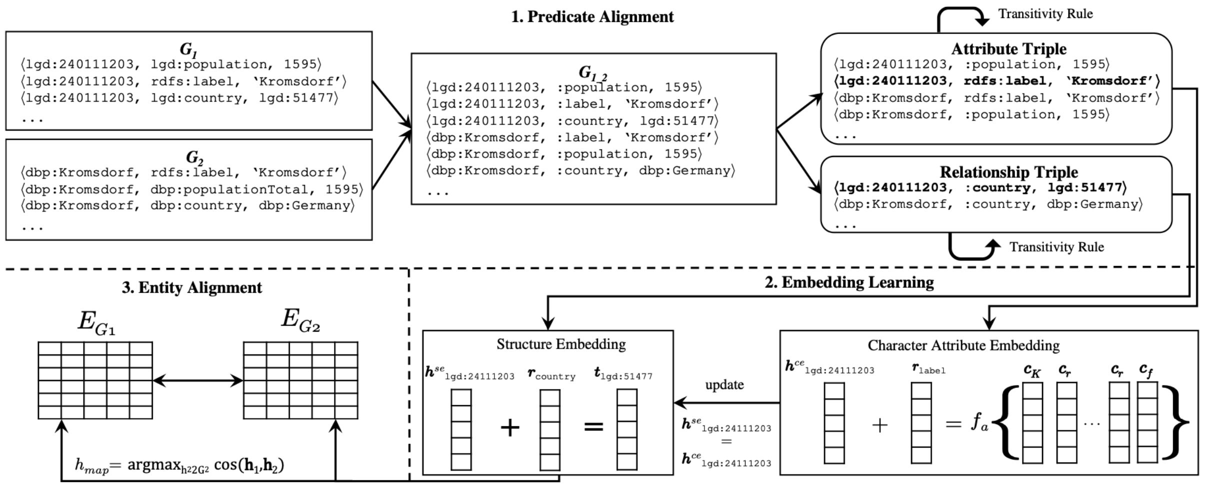
[6] Muhao Chen, Yingtao Tian, Mohan Yang, and Carlo Zaniolo. Multilingual knowledge graph embeddings for cross-lingual knowledge alignment. In Proceedings of the 26th International Joint Conference on Artificial Intelligence, pages 1511–1517, 2017.

基于TransE模型的实体对齐

■实体属性和实体关系相结合：JAPE[7]、AttrE[8]



JAPE[7]



AttrE[8]

- 使用skip-gram模型对属性类型进行表示学习
- 结构信息、属性信息联合Embedding

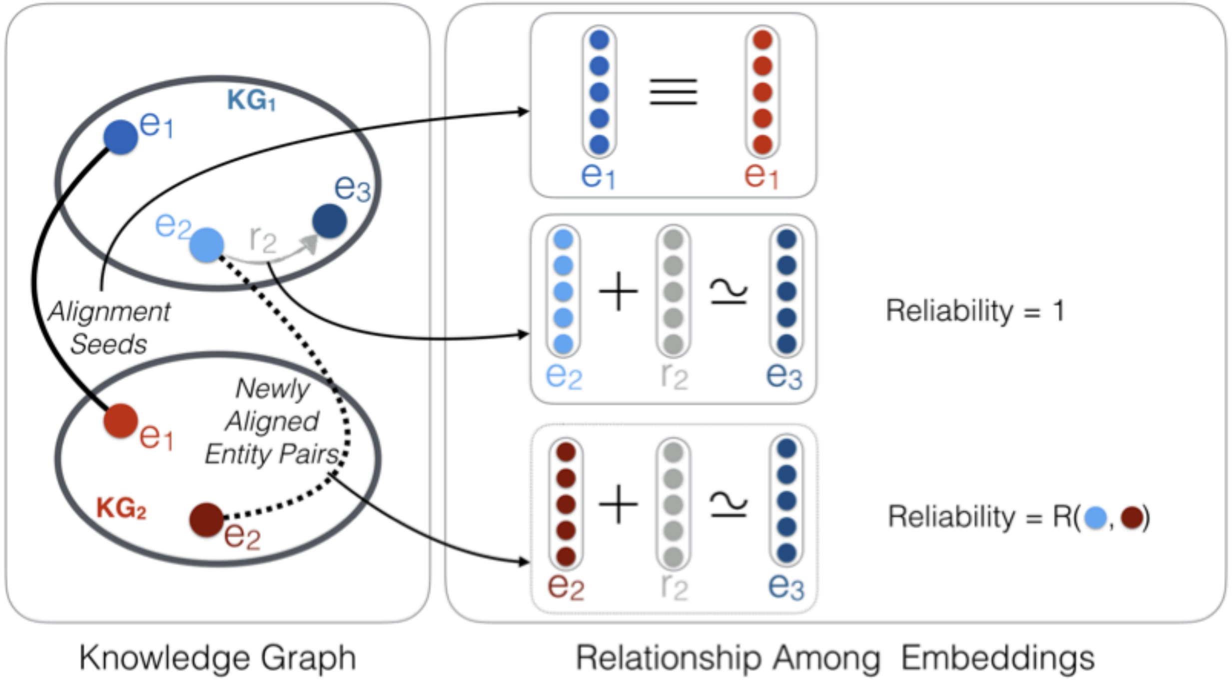
- 对属性值进行字符Embdding的组合
- <实体,属性,属性值>按照TransE评分函数进行评分

[7] Zequn Sun, Wei Hu, and Chengkai Li. Cross-lingual entity alignment via joint attribute-preserving embedding. In International Semantic Web Conference, pages 628–644. Springer, 2017.

[8] Bayu D. Trsedya, Jianzhong Qi, Rui Zhang. Entity Alignment between Knowledge Graphs Using Attribute Embeddings. AAAI 2019

基于TransE模型的实体对齐

■迭代式实体对齐：IPTransE[9]、BootEA[10]



IPTransE[9]

使用新发现的等价实体更新实体的向量表示

[9] Hao Zhu, Ruobing Xie, Zhiyuan Liu, and Maosong Sun. Iterative entity alignment via joint knowledge embeddings. In Proceedings of the 26th International Joint Conference on Artificial Intelligence, pages 4258–4264. AAAI Press, 2017.

[10] Sun Z, Hu W, Zhang Q, Qu Y. Bootstrapping Entity Alignment with Knowledge Graph Embedding. InIJCAI 2018 (pp. 4396-4402).

基于TransE模型的实体对齐

■实体对齐结果评价

- 数据集：
  - DBP15k
  - DWY100k

Datasets		# Entities	# Relations	# Attributes
DBP_{ZH-EN}	Chinese	66,469	2,830	8,113
	English	98,125	2,317	7,173
DBP_{JA-EN}	Japanese	65,744	2,043	5,882
	English	95,680	2,096	6,066
DBP_{FR-EN}	French	66,858	1,379	4,547
	English	105,889	2,209	6,422
DBP-WD	DBpedia	100,000	330	351
	Wikidata	100,000	220	729
DBP-YG	DBpedia	100,000	302	334
	YAGO3	100,000	31	23

DBP15k

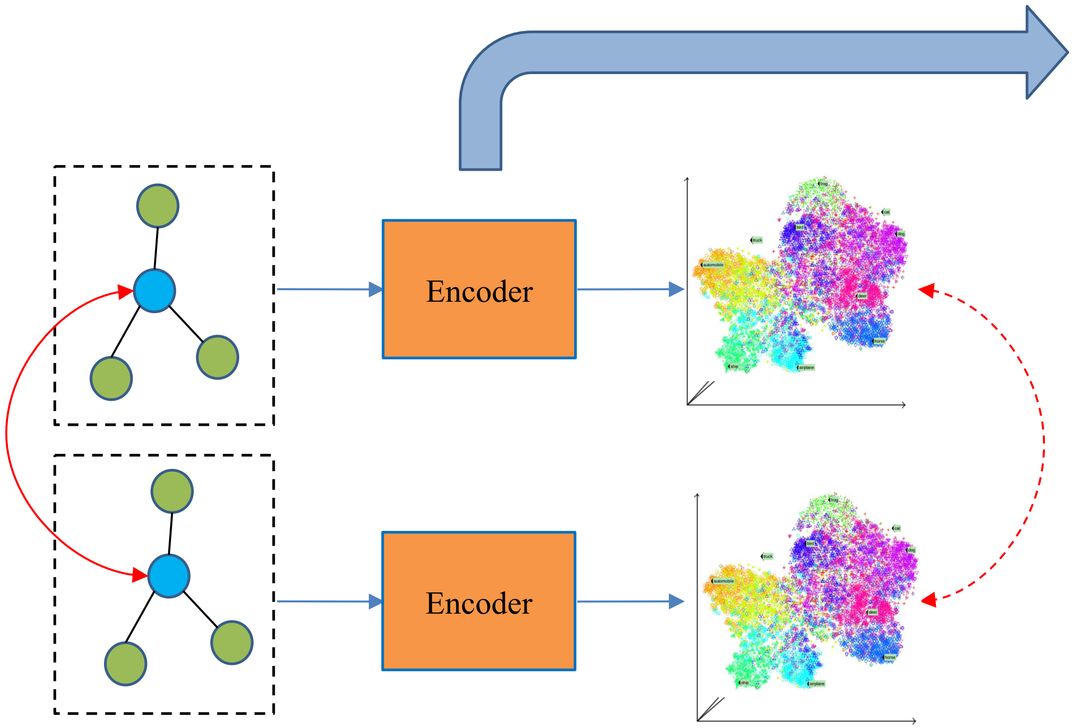
Approaches	DBP_{ZH-EN}			DBP_{JA-EN}			DBP_{FR-EN}		
	Hits@1	Hits@10	MRR	Hits@1	Hits@10	MRR	Hits@1	Hits@10	MRR
MTransE	30.83	61.41	0.364*	27.86	57.45	0.349*	24.41	55.55	0.335*
IPTransE	40.59	73.47	0.516	36.69	69.26	0.474	33.30	68.54	0.451
JAPE	41.18	74.46	0.490*	36.25	68.50	0.476*	32.39	66.68	0.430*
AlignE	47.18	79.19	0.581	44.76	78.89	0.563	48.12	82.43	0.599
BootEA	**62.94**	**84.75**	**0.703**	**62.23**	**85.39**	**0.701**	**65.30**	**87.44**	**0.731**

DWY100k

Approaches	DBP-WD			DBP-YG		
	Hits@1	Hits@10	MRR	Hits@1	Hits@10	MRR
MTransE	28.12	51.95	0.363	25.15	49.29	0.334
IPTransE	34.85	63.84	0.447	29.74	55.76	0.386
JAPE	31.84	58.88	0.411	23.57	48.41	0.320
AlignE	56.55	82.70	0.655	63.29	84.76	0.707
BootEA	**74.79**	**89.84**	**0.801**	**76.10**	**89.44**	**0.808**

[9] Sun Z, Hu W, Zhang Q, Qu Y. Bootstrapping Entity Alignment with Knowledge Graph Embedding. InIJCAI 2018 (pp. 4396-4402).

基于深度学习的实体对齐



Translational Models (e.g. TransE)

- MTransE (Chen et al., 2017)
- IPTransE (Zhu et al., 2017)
- JAPE (Sun et al., 2017),
- AttrE (Trsedya et al., 2019)
- MultiKE (Zhang et al., 2019)

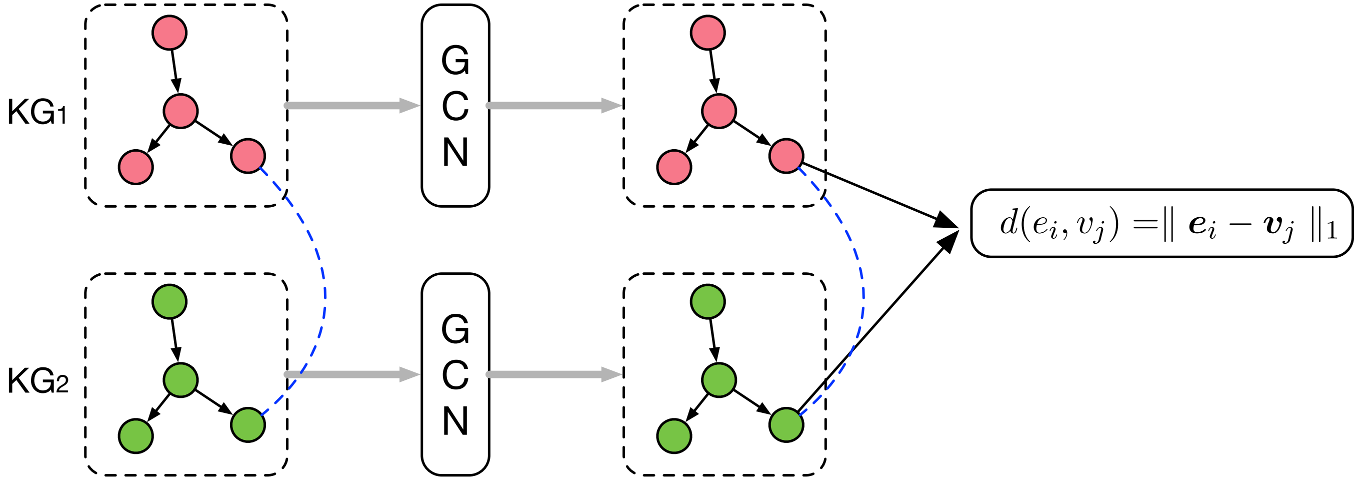
基于TransE实体对齐模型的特点

- 同时对知识图谱内部的实体关系和跨知识图谱的对齐关系进行建模
- 模型损失 = a*知识模型损失 + b*对齐模型损失，难以平衡

GCN-Align：基于图卷积神经网络的实体对齐

■基于图卷积神经网络的实体对齐模型

- 直接面向对齐任务学习实体的向量表示
- 使用图卷积神经网络作为特征编码器



模型目标函数 $$\mathcal{L} = \sum_{(e,v)\in S} \sum_{(e',v')\in S'_{(e,v)}} [d(e,v) + \gamma - d(e',v')]_+$$

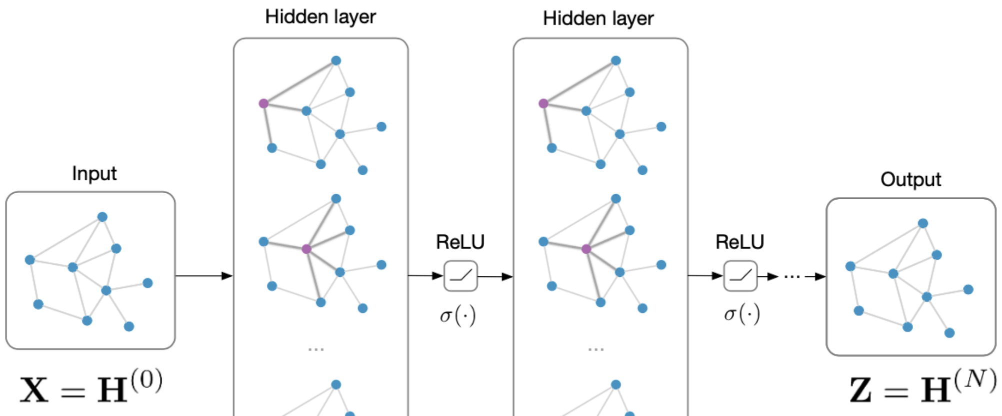
[11] Wang, Z., Lv, Q., Lan, X. and Zhang, Y., 2018. Cross-lingual Knowledge Graph Alignment via Graph Convolutional Networks. In *Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing* (pp. 349-357).

图卷积神经网络（GCN）

$$\mathbf{h}_i^{(l+1)} = \sigma\left(\mathbf{h}_i^{(l)}\mathbf{W}_0^{(l)} + \sum_{j\in\mathcal{N}_i}\frac{1}{c_{ij}}\mathbf{h}_j^{(l)}\mathbf{W}_1^{(l)}\right)$$

$\mathcal{N}_i$: neighbor indices

c_{ij} : norm. constant (per edge)



$$\mathbf{H}^{(l+1)} = \sigma\left(\hat{\mathbf{A}}\mathbf{H}^{(l)}\mathbf{W}^{(l)}\right)$$

[12] Kipf, T., & Welling, M. (2017). Semi-Supervised Classification with Graph Convolutional Networks.ICLR

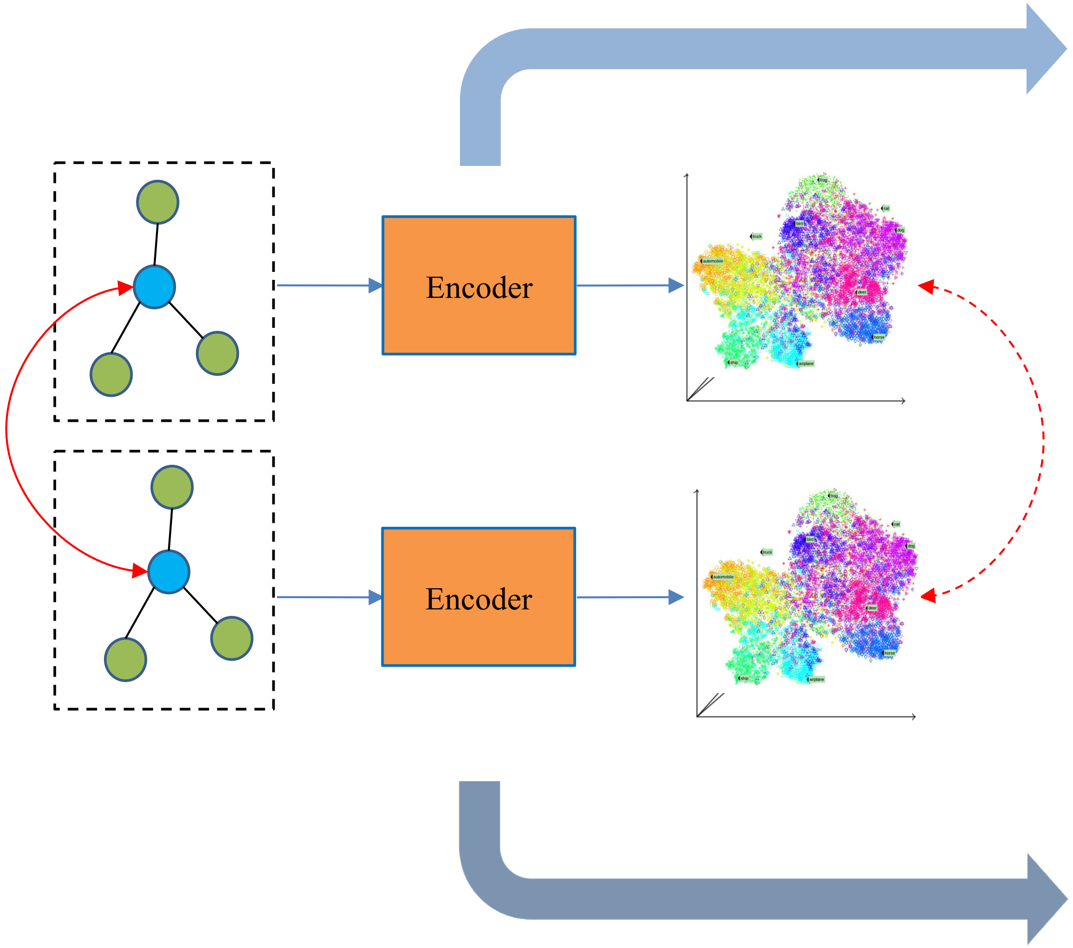
GCN-Align：基于图卷积神经网络的实体对齐

- GCN-Align V.S. MTransE 、JAPE、JE、

DBP15K		*FR → EN*			*EN → FR*			*JA → EN*			*EN → JA*		
		Hits@1	Hits@10	Hits@50	Hits@1	Hits@10	Hits@50	Hits@1	Hits@10	Hits@50	Hits@1	Hits@10	Hits@50
JE		15.38	38.84	56.50	14.61	37.25	54.01	18.92	39.97	54.24	17.80	38.44	52.48
MTransE		24.41	55.55	74.41	21.26	50.60	69.93	27.86	57.45	75.94	23.72	49.92	67.93
JAPE	SE w/o neg.	29.55	62.18	79.36	25.40	56.55	74.96	33.10	63.90	80.80	29.71	56.28	73.84
	SE	29.63	64.55	81.90	26.55	60.30	78.71	34.27	66.39	83.61	31.40	60.80	78.51
	SE + AE	32.39	66.68	83.19	32.97	65.91	82.38	36.25	68.50	85.35	38.37	67.27	82.65
JAPE′	SE w/o neg.	28.23	60.99	78.47	24.68	55.25	74.19	28.90	60.61	80.03	25.34	53.36	71.94
	SE	27.58	62.03	79.98	24.93	58.95	77.79	29.35	63.31	82.76	26.37	57.35	76.87
	SE + AE	30.21	65.81	82.57	31.42	63.86	80.95	31.06	64.11	81.57	32.45	62.21	79.08
GCN	SE	36.51	73.42	85.93	36.08	72.37	85.44	38.21	72.49	82.69	36.90	68.50	79.51
	SE + AE	**37.29**	**74.49**	**86.73**	**36.77**	**73.06**	**86.39**	**39.91**	**74.46**	**86.10**	**38.42**	**71.81**	**83.72**

[11] Wang, Z., Lv, Q., Lan, X. and Zhang, Y., 2018. Cross-lingual Knowledge Graph Alignment via Graph Convolutional Networks. In *Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing* (pp. 349-357).

基于深度学习的实体对齐



Translational Models (e.g. TransE)

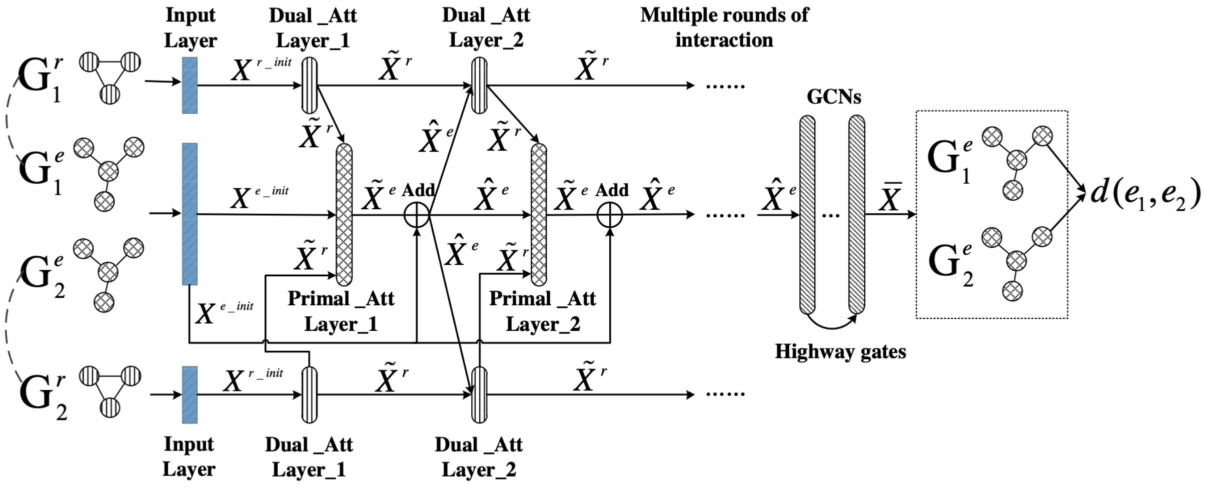
- MTransE (Chen et al., 2017)
- IPTransE (Zhu et al., 2017)
- JAPE (Sun et al., 2017),
- AttrEAttrE (Trsedya et al., 2019)
- MultiKE (Zhang et al., 2019)

GNNs

- GCN-Align (Wang et al., 2018)
- RDGCN (Wu et al., 2019)
- AVR-GCN (Ye et al., 2019)
- AttrGNN (Liu et al., 2020)
- NMN (Wu et al., 2020)
- AliNet (Sun et al., 2020)

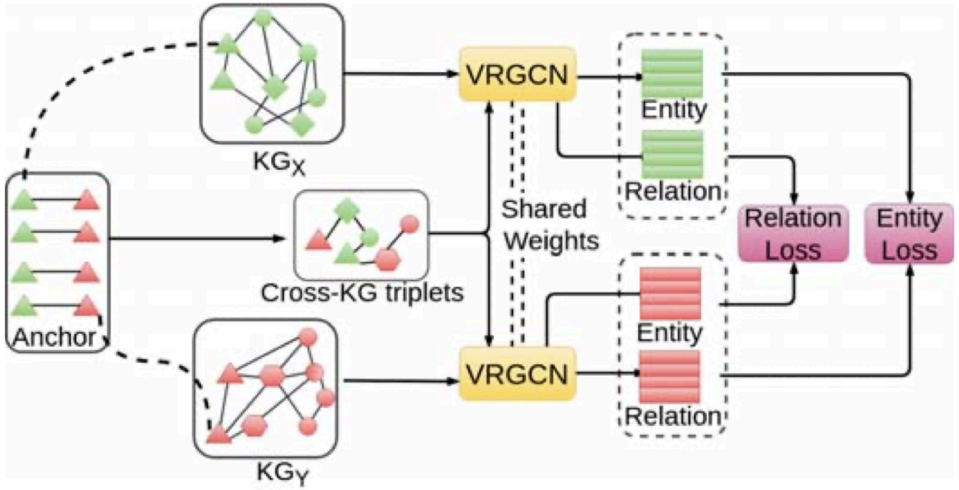
基于GNNs的实体对齐

■考虑关系类型在特征聚合中的作用



RDGCN[13]

- 构建关系图，基于实体向量计算关系向量
- 将关系向量应用于实体特征的聚合



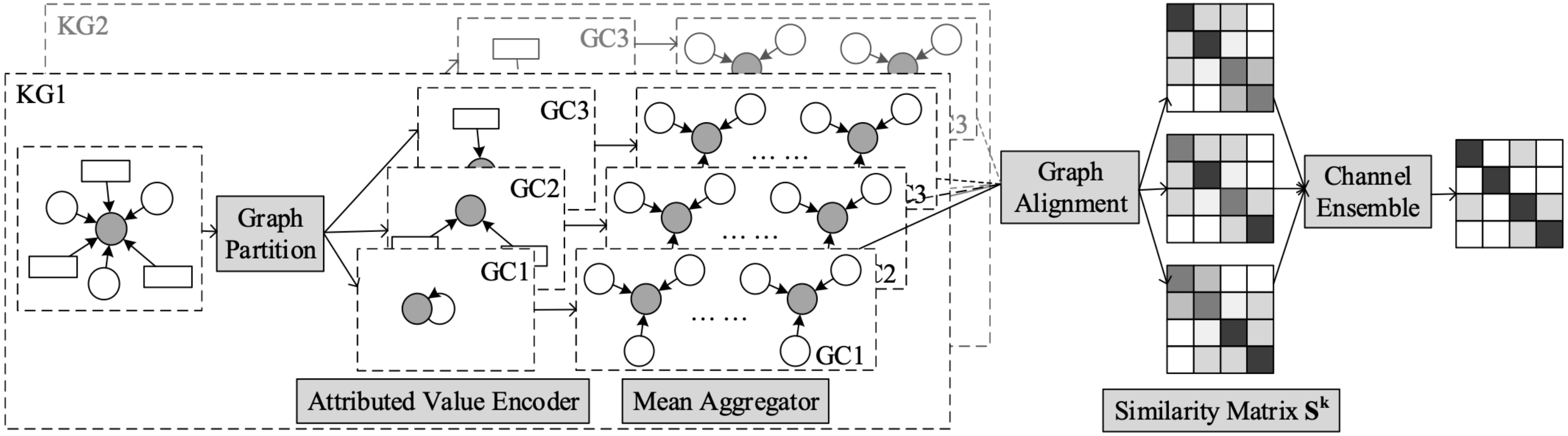
AVR-GCN[14]

- 同时学习实体和关系的向量
- GCN卷积操作同时应用于实体和关系

[13] Yuting Wu, Xiao Liu, Yansong Feng, Zheng Wang, Rui Yan, Dongyan Zhao. Relation-Aware Entity Alignment for Heterogeneous Knowledge Graphs. IJCAI 2019.
[14] Rui Ye, Xin Li, Yujie Fang, Hongyu Zang, Mingzhong Wang. A Vectorized Relational Graph Convolutional Network for Multi-Relational Network Alignment. IJCAI 2019

基于GNNs的实体对齐

■实体属性和实体关系相结合



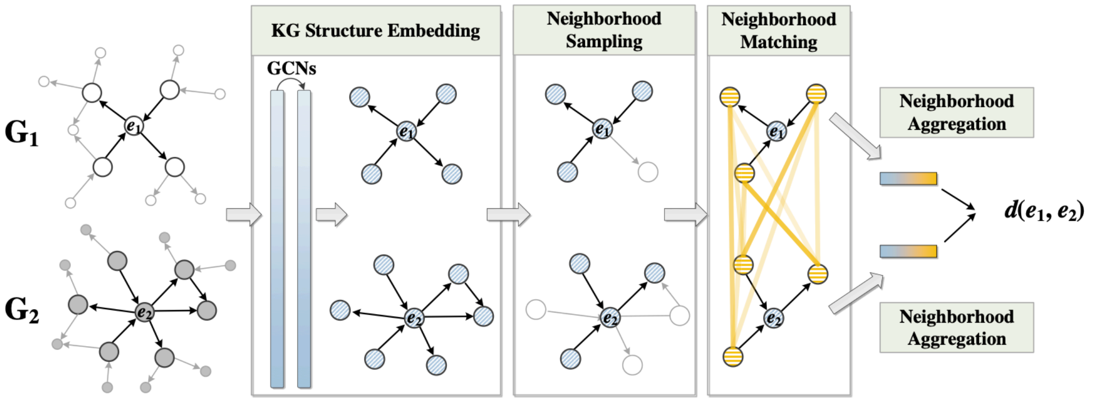
AttrGNN[15]

- 按照实体的属性将知识图谱划分为四个子图（实体名、文字属性、数值属性、无属性）
- 四个GNN通道获取实体的向量表示，文字属性和数值属性采用BERT编码

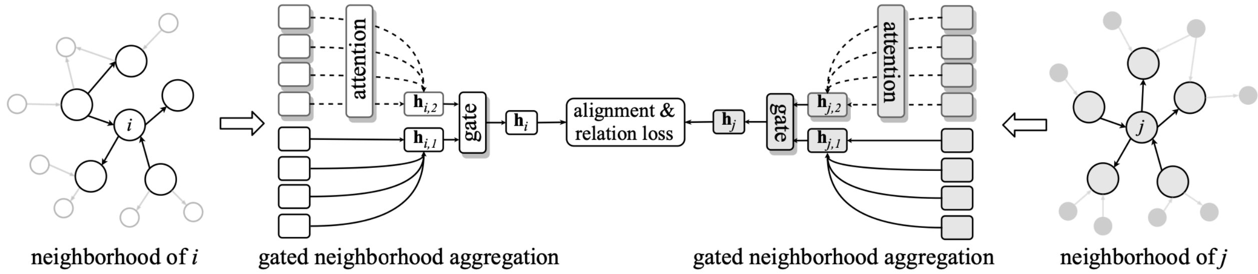
[15]Zhiyuan Liu, Yixin Cao, Liangming Pan, Juanzi Li, Zhiyuan Liu, Tat-Seng Chua. Exploring and Evaluating Attributes, Values, and Structures for Entity Alignment. EMNLP 2020

基于GNNs的实体对齐

■改进邻域特征聚集方法



NMN[16]

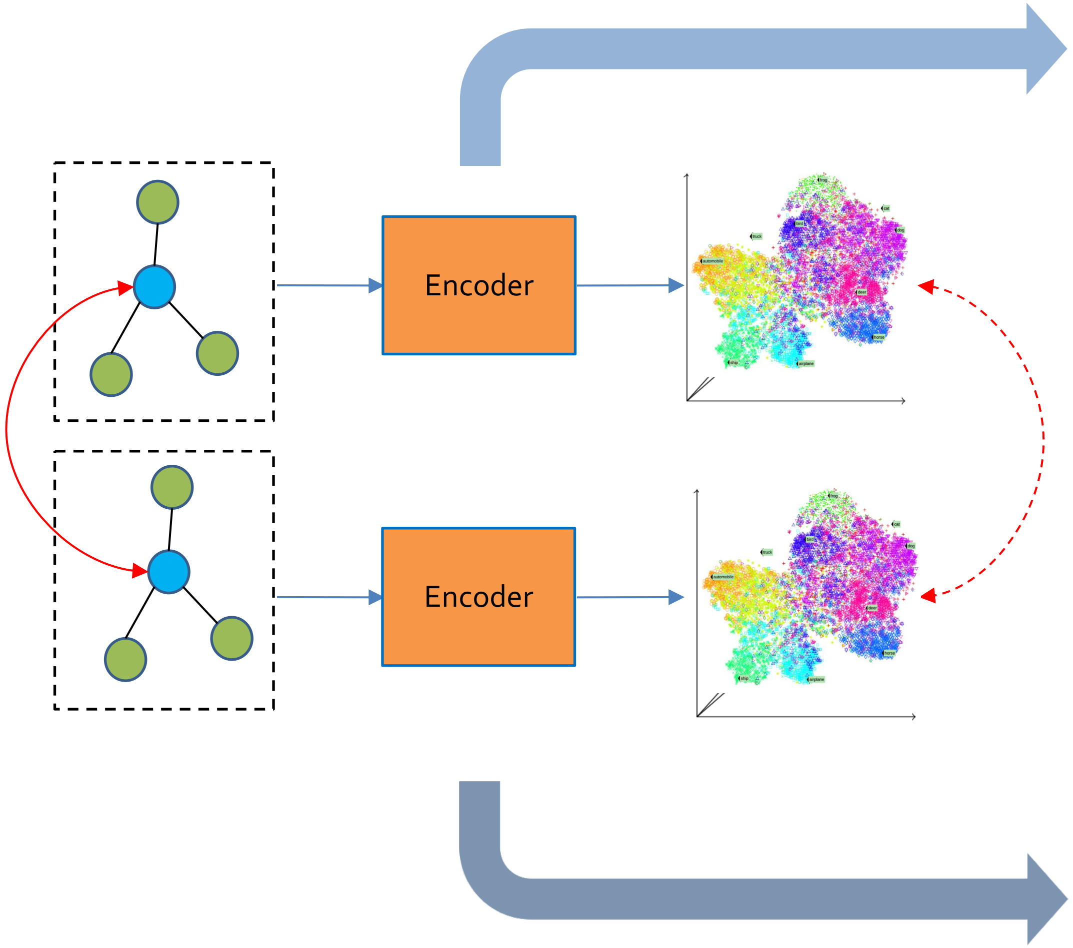


AliNet[17]

[16] Yuting Wu, Xiao Liu, Yansong Feng, Zheng Wang, Dongyan Zhao. Neighborhood Matching Network for Entity Alignment. ACL 2020

[17] Zequn Sun, Chengming Wang, Wei Hu, Muhao Chen, Jian Dai, Wei Zhang, Yuzhong Qu. Knowledge Graph Alignment Network with Gated Multi-hop Neighborhood Aggregation. AAAI 2020

基于深度学习的实体对齐



Translational Models (e.g. TransE)

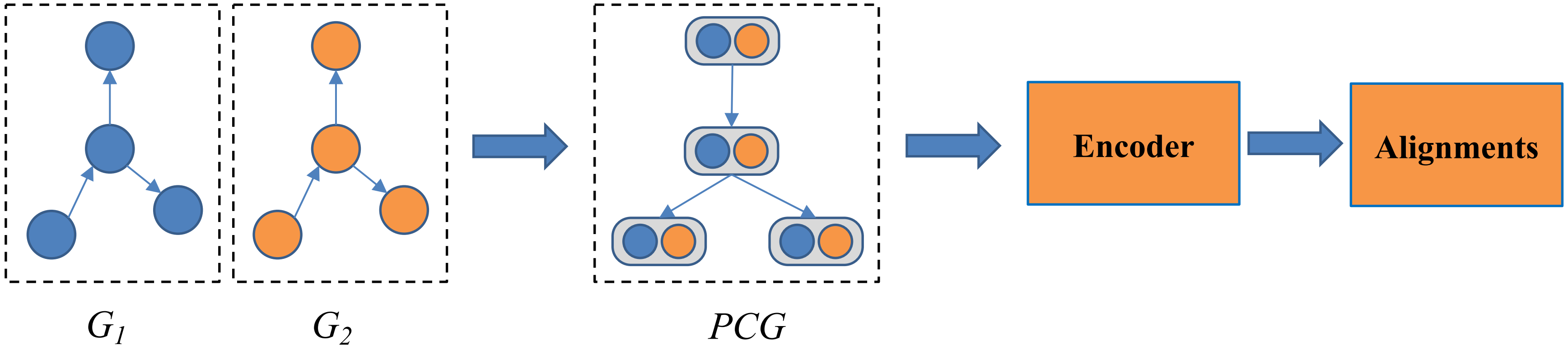
- MTransE (Chen et al., 2017)
- IPTransE (Zhu et al., 2017)
- JAPE (Sun et al., 2017),
- AttrEAttrE (Trsedya et al., 2019)
- MultiKE (Zhang et al., 2019)

GNNs

- GCN-Align (Wang et al., 2018)
- RDGCN (Wu et al., 2019)
- AVR-GCN (Ye et al., 2019)
- AttrGNN (Liu et al., 2020)
- NMN (Wu et al., 2020)
- AliNet (Sun et al., 2020)

基于“实体对”表示学习的对齐方法

- 生成知识图谱的成对连接图（Pair-wise connectivity graph， PCG），将实体对（Entity-pair）作为对象进行特征的学习
- 基于实体对的特征判断其是否有等价关系



[18] Zhichun Wang, Jinjian Yang, Xiaoju Ye. Knowledge Graph Alignment with Entity-Pair Embedding. EMNLP 2020

基于“实体对”表示学习的对齐方法

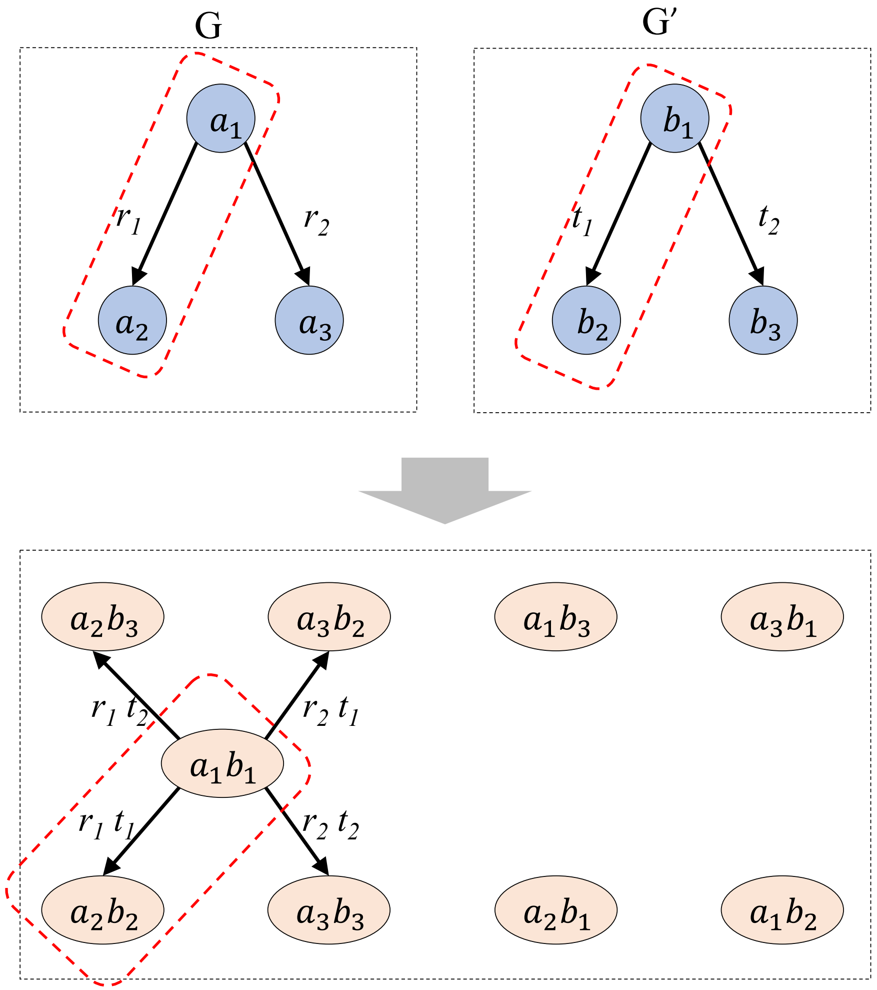
- 生成PCG
  - PCG中的节点为实体对（两个来自不同知识图谱的实体）
  - PCG中的边通过以下规则建立：

KGs to be aligned

$$G=(E,R,A,L,T)$$
$$G'=(E',R',A',L',T')$$

Rule for generating PCG

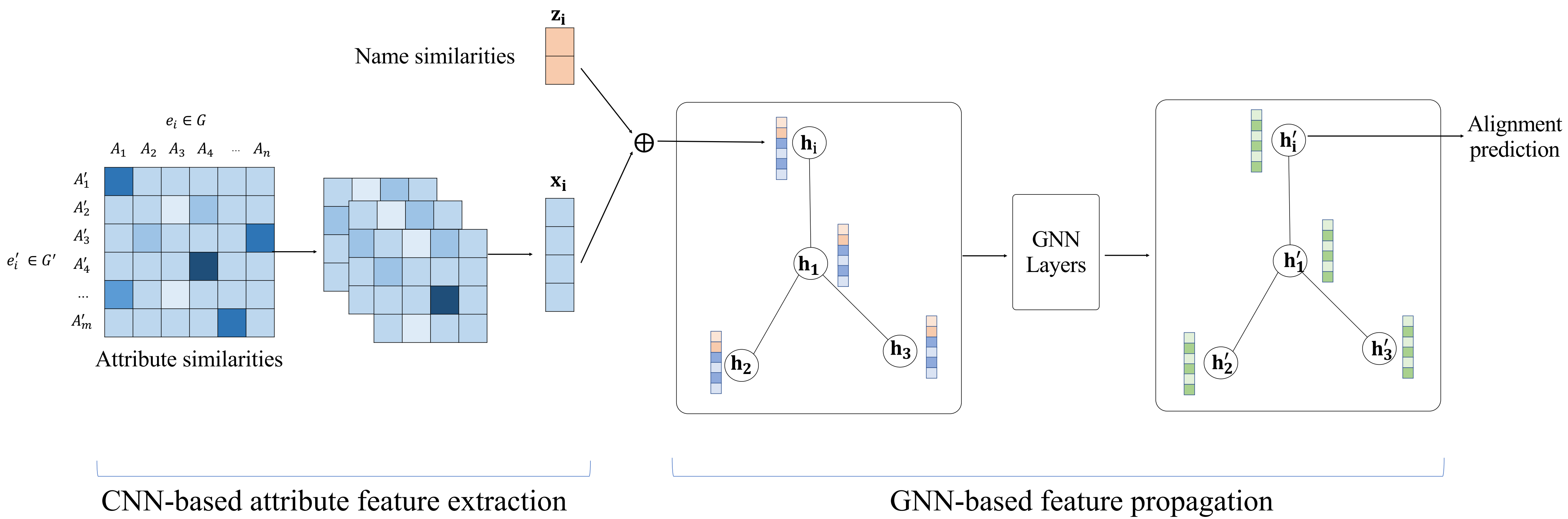
$$\langle a,r,b\rangle \in T \wedge \langle a',r',b'\rangle \in T'$$
$$\Longleftrightarrow \langle (a,a'),(r,r'),(b,b')\rangle \in \mathcal{T}$$



PCG of G and G′

[18] Zhichun Wang, Jinjian Yang, Xiaoju Ye. Knowledge Graph Alignment with Entity-Pair Embedding. EMNLP 2020

基于“实体对”表示学习的对齐方法



- 实体对名称相似度特征
- 基于卷积神经网络的属性相似度特征提取
- 基于图神经网络的特征传递

[18] Zhichun Wang, Jinjian Yang, Xiaoju Ye. Knowledge Graph Alignment with Entity-Pair Embedding. EMNLP 2020

基于“实体对”表示学习的对齐方法

实验结果

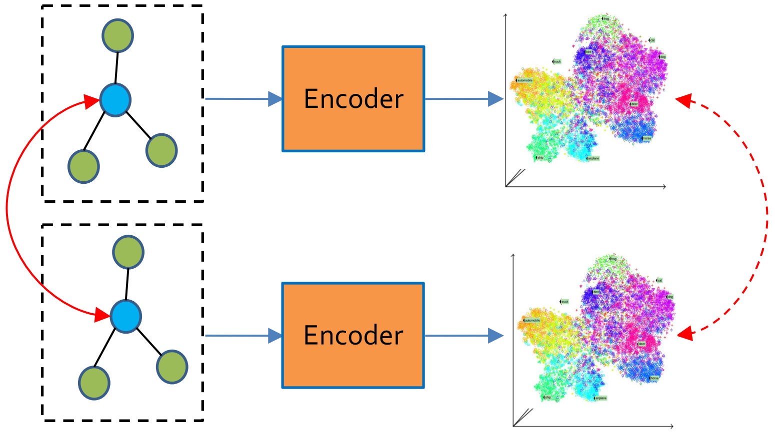
Approaches	DBP_{ZH-EN}			DBP_{JA-EN}			DBP_{FR-EN}			DBP – WD			DBP – YG		
	H@1	H@10	MRR	H@1	H@10	MRR	H@1	H@10	MRR	H@1	H@10	MRR	H@1	H@10	MRR
MTransE	0.308	0.614	0.364	0.279	0.575	0.349	0.244	0.556	0.335	0.281	0.520	0.363	0.252	0.493	0.334
IPTransE	0.406	0.735	0.516	0.367	0.693	0.474	0.333	0.685	0.451	0.349	0.638	0.447	0.297	0.558	0.386
BootEA	0.629	0.848	0.703	0.622	0.854	0.701	0.653	0.874	0.731	0.748	0.898	0.801	0.761	0.894	0.808
MuGNN	0.494	0.844	0.611	0.501	0.857	0.621	0.495	0.870	0.621	0.616	0.897	0.714	0.741	0.937	0.810
RDGCN	0.708	0.846	0.746	0.767	0.895	0.812	0.886	0.957	0.911	-	-	-	-	-	-
AliNet	0.539	0.826	0.628	0.549	0.831	0.645	0.552	0.852	0.657	0.690	0.908	0.766	0.786	0.943	0.841
NAEA	0.650	0.867	0.720	0.641	0.872	0.718	0.673	0.894	0.752	0.767	0.917	0.817	0.778	0.912	0.821
JAPE	0.412	0.745	0.490	0.363	0.685	0.476	0.324	0.667	0.430	0.318	0.589	0.411	0.236	0.484	0.320
GCN-Align	0.413	0.744	0.549	0.399	0.745	0.546	0.375	0.745	0.532	0.506	0.772	0.600	0.597	0.838	0.682
MultiKE	-	-	-	-	-	-	-	-	-	0.914	0.951	0.928	0.880	0.953	0.906
CEA	0.787	-	-	0.863	-	-	**0.972**	-	-	**0.998**	-	-	**0.999**	-	-
CNN	0.612	0.840	0.694	0.569	0.820	0.657	0.777	0.930	0.833	0.840	0.986	0.897	0.780	0.975	0.854
CNN+GAT	0.726	0.916	0.803	0.764	0.936	0.836	0.758	0.960	0.839	0.945	0.967	0.955	0.980	0.999	0.988
EPEA	**0.885**	**0.953**	**0.911**	**0.924**	**0.969**	**0.942**	0.955	**0.986**	**0.967**	0.975	**0.981**	**0.977**	**1.000**	**1.000**	**1.000**

[18] Zhichun Wang, Jinjian Yang, Xiaoju Ye. Knowledge Graph Alignment with Entity-Pair Embedding. EMNLP 2020

总结

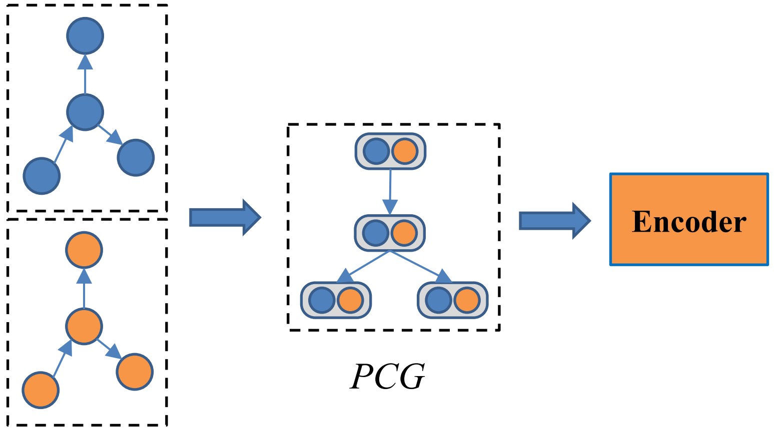
■现有的工作

- TransE模型 **V.S** GNNs模型
- 结构信息 **V.S**. 结构信息+属性信息
- 实体Embedding **V.S** 实体对Embedding



■存在的挑战

- 如何处理大规模的知识图谱实体对齐
- 如何处理非对称的实体对齐
- 如何在种子结果较少、或没有种子结果情况下进行实体对齐



参考文献

- [1] Wang, Z., Li, J., Wang, Z., & Tang, J. (2012). Cross-lingual knowledge linking across wiki knowledge bases. WWW.
- [2] Nentwig M, Hartung M, Ngonga Ngomo AC, Rahm E. A survey of current link discovery frameworks. Semantic Web. 2017 Jan 1;8(3):419-36.
- [3] Bordes A, Usunier N, Garcia-Duran A, Weston J, Yakhnenko O. Translating embeddings for modeling multi-relational data. InAdvances in neural information processing systems 2013 (pp. 2787-2795).
- [4] Wang Z, Zhang J, Feng J, Chen Z. Knowledge Graph Embedding by Translating on Hyperplanes. InAAAI 2014 Jul 27 (Vol. 14, pp. 1112-1119).
- [5] Lin Y, Liu Z, Sun M, Liu Y, Zhu X. Learning entity and relation embeddings for knowledge graph completion. InAAAI 2015 Jan 25 (Vol. 15, pp. 2181-2187).
- [6] Muhao Chen, Yingtao Tian, Mohan Yang, and Carlo Zaniolo. Multilingual knowledge graph embeddings for cross-lingual knowledge alignment. In Proceedings of the 26th International Joint Conference on Artificial Intelligence, pages 1511–1517, 2017.
- [7] Zequn Sun, Wei Hu, and Chengkai Li. Cross-lingual entity alignment via joint attribute-preserving embedding. In International Semantic Web Conference, pages 628–644. Springer, 2017.
- [8] Hao Zhu, Ruobing Xie, Zhiyuan Liu, and Maosong Sun. Iterative entity alignment via joint knowledge embeddings. In Proceedings of the 26th International Joint Conference on Artificial Intelligence, pages 4258–4264. AAAI Press, 2017.
- [9] Sun Z, Hu W, Zhang Q, Qu Y. Bootstrapping Entity Alignment with Knowledge Graph Embedding. InIJCAI 2018 (pp. 4396-4402).
- [10] Bayu D. Trsedya, Jianzhong Qi, Rui Zhang. Entity Alignment between Knowledge Graphs Using Attribute Embeddings. AAAI 2019

- [9] Sun Z, Hu W, Zhang Q, Qu Y. Bootstrapping Entity Alignment with Knowledge Graph Embedding. InIJCAI 2018 (pp. 4396-4402).

- [11] Wang, Z., Lv, Q., Lan, X. and Zhang, Y., 2018. Cross-lingual Knowledge Graph Alignment via Graph Convolutional Networks. In Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing (pp. 349-357).
- [12] Kipf, T., & Welling, M. (2017). Semi-Supervised Classification with Graph Convolutional Networks.ICLR
- [13] Yuting Wu, Xiao Liu, Yansong Feng, Zheng Wang, Rui Yan, Dongyan Zhao. Relation-Aware Entity Alignment for Heterogeneous Knowledge Graphs. IJCAI 2019.
- [14] Rui Ye, Xin Li, Yujie Fang, Hongyu Zang, Mingzhong Wang. A Vectorized Relational Graph Convolutional Network for Multi-Relational Network Alignment. IJCAI 2019
- [15]Zhiyuan Liu, Yixin Cao, Liangming Pan, Juanzi Li, Zhiyuan Liu, Tat-Seng Chua. Exploring and Evaluating Attributes, Values, and Structures for Entity Alignment. EMNLP 2020
- [16] Yuting Wu, Xiao Liu, Yansong Feng, Zheng Wang, Dongyan Zhao. Neighborhood Matching Network for Entity Alignment. ACL 2020
- [17] Zequn Sun, Chengming Wang, Wei Hu, Muhao Chen, Jian Dai, Wei Zhang, Yuzhong Qu. Knowledge Graph Alignment Network with Gated Multi-hop Neighborhood Aggregation. AAAI 2020
- [18] Zhichun Wang, Jinjian Yang, Xiaoju Ye. Knowledge Graph Alignment with Entity-Pair Embedding. EMNLP 2020

谢谢！