HyConvE: A Novel Embedding Model for Knowledge Hypergraph Link Prediction with Convolutional Neural Networks

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https://github.com/CarlllWang/HyConvE/tree/master

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Introduction

The knowledge hypergraph link prediction task aims at **predicting missing component** in n-ary facts, where the missing component can be either an entity in the tuple $r(e_1, e_2, ..., ?, ..., e_k)$ or a n-ary relation $?(e_1, e_2, ..., e_k)$.

Tuple	`KidsOf`	(Jeffrey Jordan, Marcus Jordan, Jeffrey Jordan)
	`BestHelper`	(Scottie Pippen, Michael Jordan, 1998)
	`PlayRoleIn`	(Michael Jordan, Scoring Guard, Chicago Bulls)

Introduction

Due to the exponential growth of multi source information, it becomes challenging, even impossible, for the large-scale n-ary knowledge base to be updated in an appropriate way, resulting in incomplete and outdated knowledge hypergraphs.

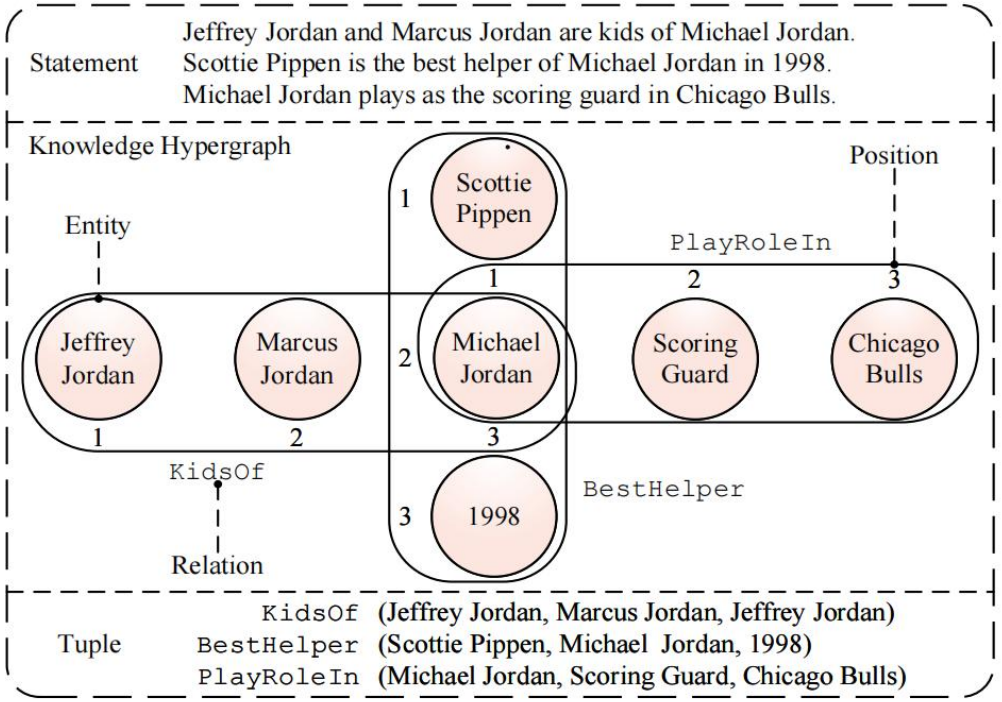


Figure 1: A real-world example of knowledge hypergraph about a set of facts related to *Michael Jordan*, where each tuple is accompanied by different positional information.

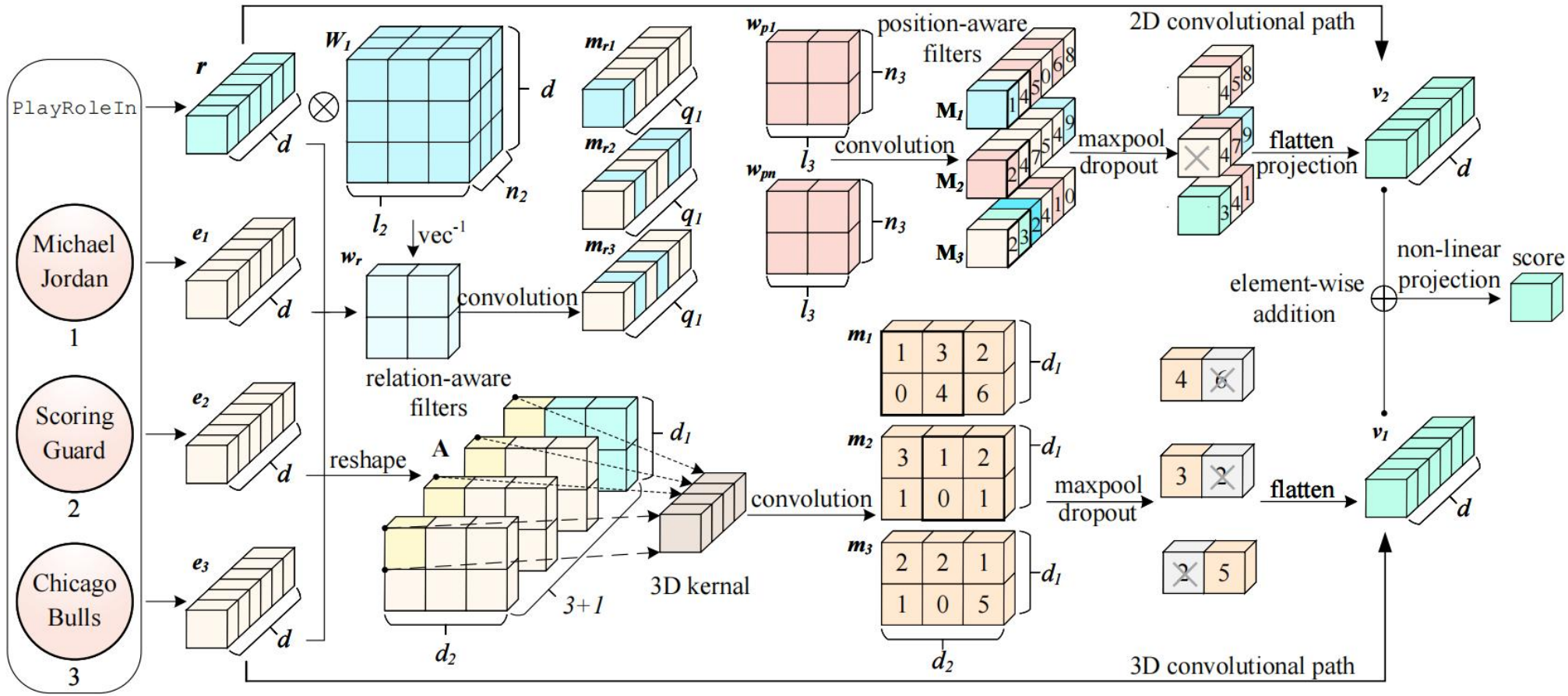
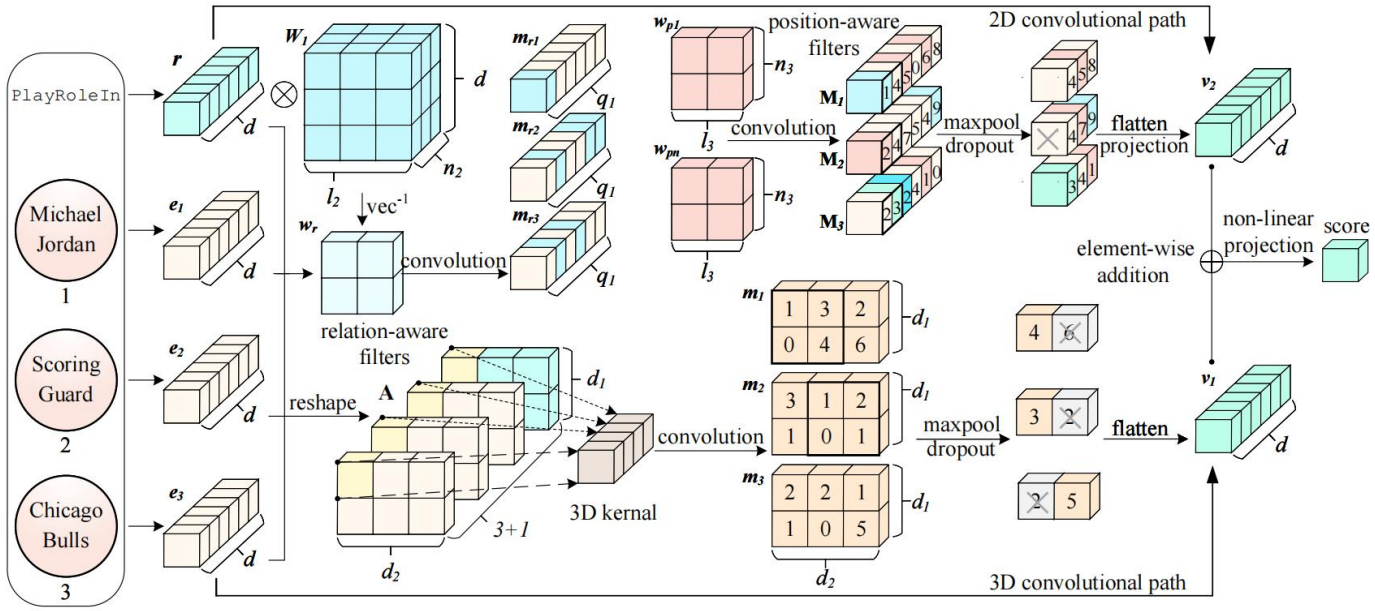


Figure 2: The framework of the HyConvE model.

Method



$$\mathcal{H} = (\mathcal{E}, \mathcal{R}, \mathcal{T}_O) \qquad t = r(e_1, e_2, ..., e_k)$$

$$m_i = \boldsymbol{w_i} * \mathbf{A} + b = \boldsymbol{w} * [\overline{\boldsymbol{r}} \,||\, \overline{\boldsymbol{e_1}}, ..., ||\, \overline{\boldsymbol{e_k}}] + b \qquad (1) \qquad \overline{\boldsymbol{r}} \in \mathbb{R}^{d_1 \times d_2} \qquad \overline{\boldsymbol{e_i}} \in \mathbb{R}^{d_1 \times d_2} \qquad A = [\overline{\boldsymbol{r}} \,||\, \overline{\boldsymbol{e_1}}, ..., ||\, \overline{\boldsymbol{e_k}}] \in \mathbb{R}^{(k+1) \times d_1 \times d_2}$$

$$\boldsymbol{v_1} = \mathbf{maxpool}(\boldsymbol{w} * [\overline{\boldsymbol{r}} \,||\, \overline{\boldsymbol{e_1}}, ..., ||\, \overline{\boldsymbol{e_k}}]) \qquad (2)$$

$$\boldsymbol{w_r} = \mathbf{vec}^{-1}(\boldsymbol{r} \cdot \mathbf{W_1}) \qquad (3) \qquad \mathbf{W_1} \in \mathbb{R}^{d \times l_2 n_2}$$

$$m_{ri} = \boldsymbol{e_i} * \boldsymbol{w_r} = \boldsymbol{e_i} * \mathbf{vec}^{-1}(\boldsymbol{r} \cdot \mathbf{W_1}) \qquad (4)$$

$$m_{ri} \in \mathbb{R}^{q_2 \times n_2} \qquad q_2 = (d - l_2)/s + 1$$

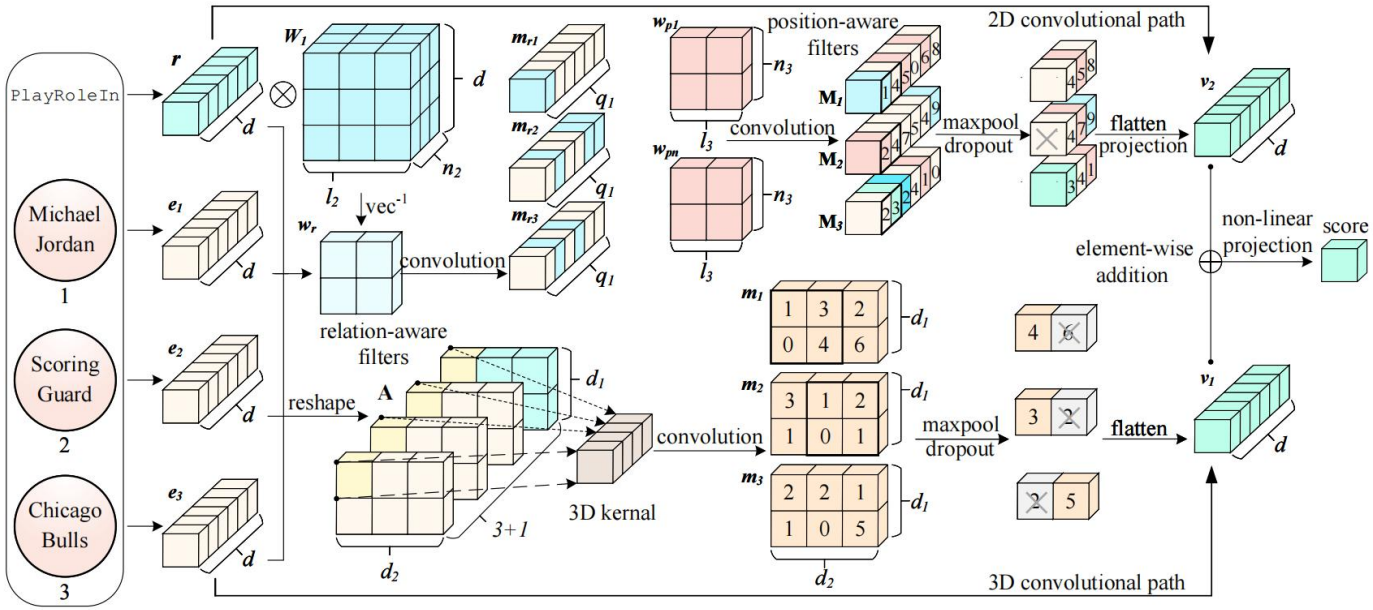
$$\mathbf{M_i} = \left[m_{ri} * \boldsymbol{w_{pi1}} \,||\, m_{ri} * \boldsymbol{w_{pi2}} \,||\, ... \,||\, m_{ri} * \boldsymbol{w_{pin_3}}\right] \qquad (5)$$

$$w_{pi} \in \mathbb{R}^{n_3 \times l_3}$$

$$\boldsymbol{v_2} = \mathbf{maxpool}(\mathbf{vec}([\mathbf{M_i} \,||\, \mathbf{M_2} \,||\, ... \,||\, \mathbf{M_k}]))\mathbf{W_2} \qquad (6)$$

$$\boldsymbol{score} = \mathrm{g}(\boldsymbol{v_1} + \boldsymbol{v_2})\mathbf{W_3} \qquad (7)$$

Method



$$\bigcup_{i=1}^{k} \mathcal{N}_x^{(i)} \equiv \bigcup_{i=1}^{k} \{e_1, \cdots, \bar{e}_i, \cdots, e_k \notin \mathcal{F} | \bar{e}_i \in \mathcal{E}, \bar{e}_i \neq e_i\} \tag{8}$$

$$\mathcal{L} = \sum_{r(e_1,\ldots,e_k) \in \{\mathcal{H} \cup \mathcal{H}'\}} \log(1+\exp(l_{r(e_1,\ldots,e_k)} \cdot f(r(e_1,\ldots,e_k)))) + \phi \tag{9}$$

$$l_{(r,e_1,\ldots,e_k)} = \begin{cases} 1 & \text{for } r(e_1,\ldots,e_k) \in \mathcal{H} \\ -1 & \text{for } r(e_1,\ldots,e_k) \in \mathcal{H}' \end{cases} \tag{10}$$

$$\phi = \lambda(\|\boldsymbol{c}\|_2^2 + \|\boldsymbol{w}\|_2^2 + \|\boldsymbol{p}\|_2^2 + \sum_{i=1}^{k} \|\boldsymbol{e_i}\|_2^2 + \|\boldsymbol{r}\|_2^2 \tag{11}$$

Experiments

Table 1: Dataset Statistics. The size of the train, valid, and test columns represent the number of triples or tuples, respectively. "Arity" denotes the involved arities of relations.

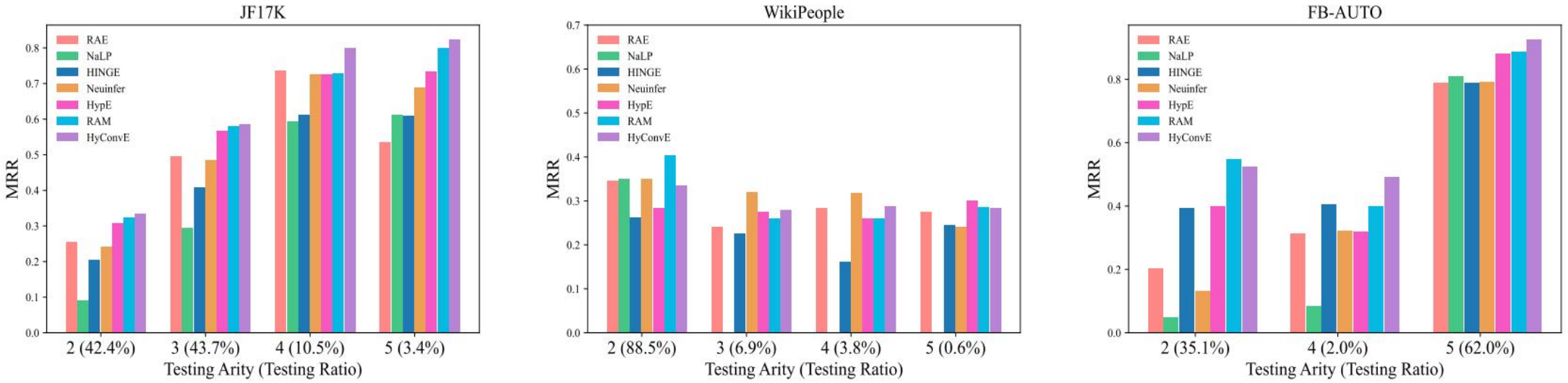
Dataset	$\|\mathcal{E}\|$	$\|\mathcal{R}\|$	Arity	# train	# valid	# test	# arity=2	# arity=3	# arity=4	# arity $\geq$ 5
FB15k-237	14, 541	237	2	272, 115	17, 535	20, 466	310, 116	–	–	–
WN18RR	40, 943	11	2	86, 835	3, 034	3, 134	93, 003	–	–	–
JF17K	29, 177	327	2-6	61, 104	15, 275	24, 568	56, 332	34, 550	9, 509	2, 267
WikiPeople	47, 765	707	2-9	305, 725	38, 223	38, 281	337, 914	25, 820	15, 188	3, 307
FB-AUTO	3, 388	8	2, 4, 5	6, 778	2, 255	2, 180	3, 786	–	125	7, 212
JF17K-3	11, 541	104	3	27, 645	3, 454	3, 455	–	34, 544	–	–
JF17K-4	6, 536	23	4	7, 607	951	951	–	–	9509	–
WikiPeople-3	12, 270	66	3	20, 656	2, 582	2, 582	–	25, 820	–	–
WikiPeople-4	9, 528	50	4	12, 150	1, 519	1, 519	–	–	15188	–

Experiments

Table 2: Results of Link Prediction on Knowledge Hypergraph Datasets. The best results are in boldface and the second best are underlined. Experimental results with "-" are those results that were not presented in the original paper. All experimental results are obtained locally.

Model	JF17K				WikiPeople				FB-AUTO			
	MRR	Hit@1	Hit@3	Hit@10	MRR	Hit@1	Hit@3	Hit@10	MRR	Hit@1	Hit@3	Hit@10
RAE [41]	0.392	0.312	0.433	0.561	0.253	0.118	0.343	0.463	0.703	0.614	0.764	0.854
NaLP [15]	0.310	0.239	0.334	0.450	0.338	0.272	0.362	0.466	0.672	0.611	0.712	0.774
HINGE[28]	0.473	0.397	0.490	0.618	0.333	0.259	0.361	0.477	0.678	0.630	0.706	0.765
NeuInfer [14]	0.451	0.373	0.484	0.604	0.351	0.274	0.381	0.467	0.737	0.700	0.755	0.805
HypE [10]	0.494	0.399	0.532	0.650	0.263	0.127	0.355	0.486	0.804	0.774	0.824	0.856
tNaLP+ [13]	0.449	0.370	0.484	0.598	0.339	0.269	0.369	0.473	0.729	0.645	0.748	0.826
S2S [8]	0.528	0.457	0.570	0.690	**0.364**	0.273	0.402	**0.503**	-	-	-	-
RAM [22]	0.539	0.463	0.572	0.690	0.363	0.271	**0.405**	0.500	0.830	0.803	0.851	0.876
HyConvE (ours)	**0.590**	**0.478**	**0.610**	**0.729**	0.362	**0.275**	0.388	0.501	**0.847**	**0.820**	**0.872**	**0.901**

Experiments



(a) JF17K (b) WikiPeople (c) FB-AUTO

Figure 3: Breakdown performance across relations with different arities. x-axis identifies the relation arity and the ratio of testing samples. 6-ary relational facts and beyond are few and unreliable, thus not reported.

Experiments

Table 3: Results on fixed arity datasets. The best results are in boldface and the second best are underlined.

Model	JF17K-3			JF17K-4			WikiPeople-3			WikiPeople-4		
	MRR	Hit@1	Hit@10	MRR	Hit@1	Hit@10	MRR	Hit@1	Hit@10	MRR	Hit@1	Hit@10
RAE [41]	0.505	0.430	0.644	0.707	0.636	0.835	0.239	0.168	0.379	0.150	0.080	0.273
NaLP [15]	0.515	0.431	0.679	0.719	0.673	0.805	0.301	0.226	0.445	0.342	0.237	0.540
n-CP [21]	0.669	0.613	0.801	0.754	0.701	0.855	0.313	0.237	0.476	0.253	0.163	0.432
n-tucker [21]	0.727	0.664	0.852	0.786	0.723	0.851	0.315	0.236	0.478	0.335	0.225	0.536
GETD [21]	0.725	0.660	0.858	0.822	0.761	0.924	**0.363**	**0.272**	**0.545**	0.346	0.229	0.542
RAM [22]	0.578	0.505	0.722	0.743	0.701	0.845	0.254	0.190	0.383	0.226	0.161	0.367
HyConvE (ours)	**0.729**	**0.670**	**0.861**	**0.827**	**0.770**	**0.931**	0.318	0.240	0.482	**0.386**	**0.271**	**0.607**

Experiments

Table 4: Results of Link Prediction on Knowledge Graph Datasets. The best results are in boldface and the second best are underlined. Experimental results with "-" are those results that were not presented in the original paper. All experimental results are obtained locally.

Model	FB15k-237			WN18RR			JF17K			WikiPeople			FB-AUTO		
	MRR	Hit@1	Hit@10	MRR	Hit@1	Hit@10	MRR	Hit@1	Hit@10	MRR	Hit@1	Hit@10	MRR	Hit@1	Hit@10
TransE [5]	0.294	-	0.561	0.226	-	0.501	0.276	0.167	0.495	0.312	0.146	0.574	0.313	0.132	0.562
DistMult[28]	0.241	0.155	0.419	0.431	0.390	0.490	0.228	0.144	0.411	0.275	0.193	0.388	0.494	0.444	0.566
ComplEx [14]	0.253	0.158	0.428	0.440	0.411	0.512	0.308	0.219	0.498	0.326	0.232	0.461	0.487	0.442	0.568
HypE [10]	0.240	0.160	0.400	0.363	0.332	0.473	-	-	-	-	-	-	-	-	-
S2S [8]	**0.348**	**0.256**	**0.540**	**0.498**	**0.455**	**0.577**	-	-	-	-	-	-	-	-	-
RAM [22]	-	-	-	-	-	-	0.324	0.232	0.515	**0.408**	**0.313**	**0.568**	0.489	0.444	**0.576**
HyConvE (ours)	0.339	0.212	0.458	0.461	0.432	0.534	**0.338**	**0.246**	**0.525**	0.388	0.281	0.556	**0.493**	**0.445**	0.572

Experiments

Table 5: Results of ablation study. The best results are in boldface. HyConvE-path1-only means to use only the 3D path of HyConvE when conducting experiments and HyConvE-path2-only means the other.

Model	JF17K				WikiPeople				FB-AUTO			
	MRR	Hit@1	Hit@3	Hit@10	MRR	Hit@1	Hit@3	Hit@10	MRR	Hit@1	Hit@3	Hit@10
HyConvE-path1-only	0.528	0.457	0.570	0.690	0.323	0.227	0.344	0.478	0.831	0.796	0.851	0.899
HyConvE-path2-only	0.102	0.054	0.094	0.168	0.072	0.048	0.094	0.172	0.145	0.082	0.164	0.212
HyConvE (ours)	**0.590**	**0.478**	**0.610**	**0.729**	**0.352**	**0.275**	**0.388**	**0.501**	**0.847**	**0.820**	**0.872**	**0.901**

Thank you!