TransINT: Embedding Implication Rules in Knowledge Graphs with Isomorphic Intersections of Linear Subspaces

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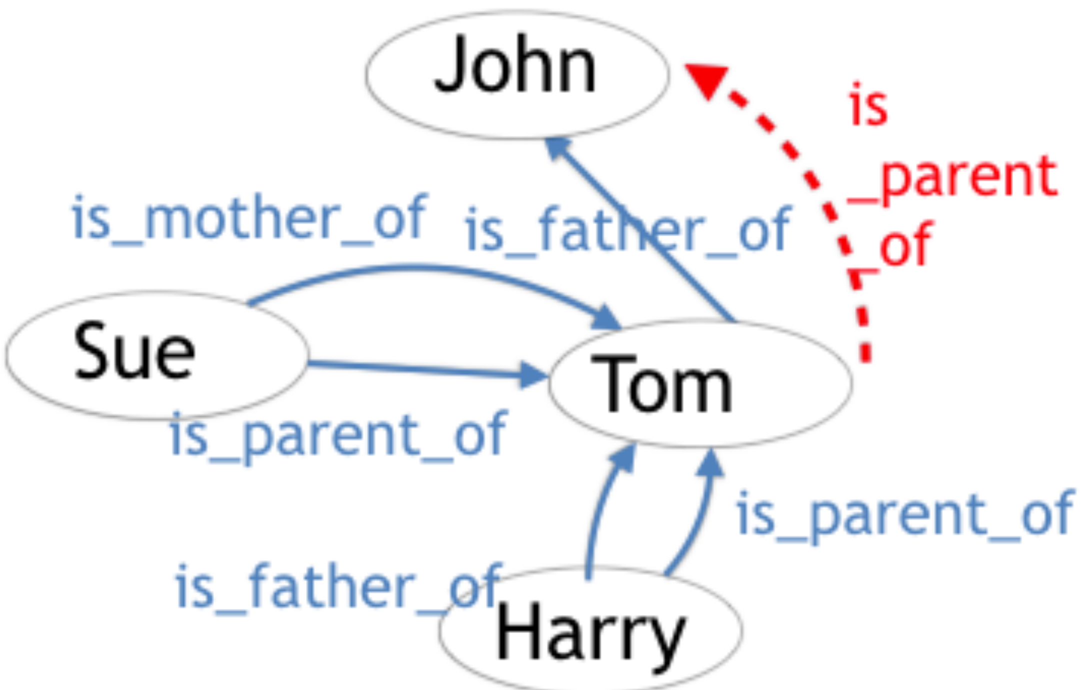
Knowledge Graph Embeddings



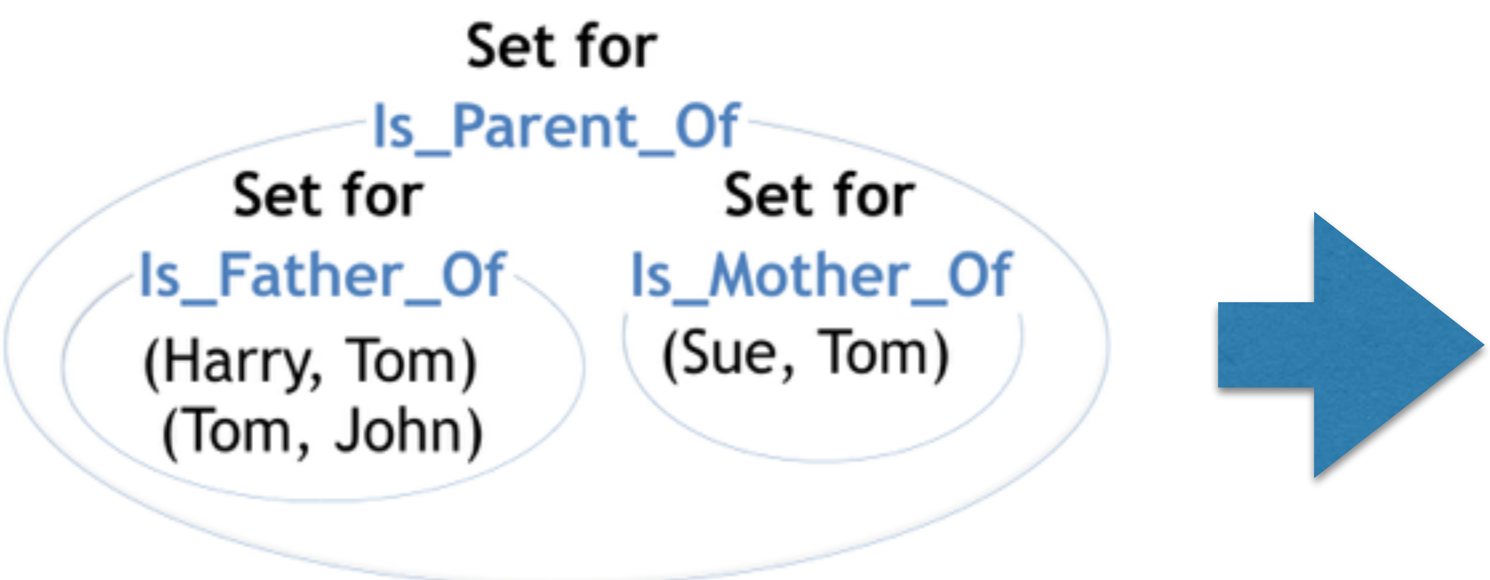
A Knowledge Graph

Ex) Implication Rule:
Is_Father_Of -> Is_Parent_Of

Can we impose
Implication Rule in KG Embedding?

Problem Statement

- Relation as sets of ordered pairs of entities
- Given rules or hierarchy



In R^d ?

Knowledge Graph

Embeddings in R^d

Goal: $(R_i \subset R_j) \quad \text{iff} \quad (r_i' s \text{ relation space} \subset r_j' s \text{ relation space})$

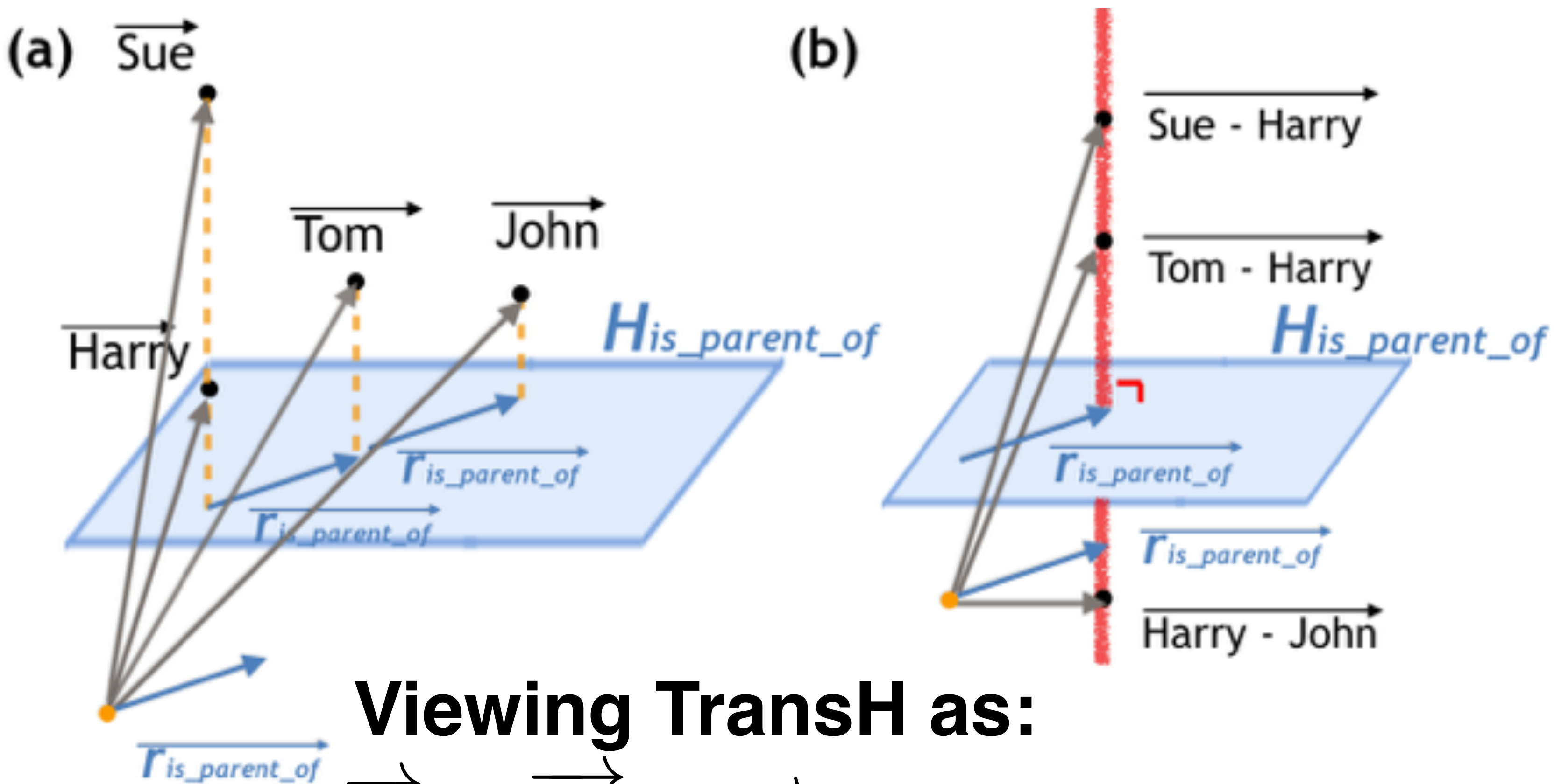
or equivalently,

$(r_i \Rightarrow r_j) \quad \text{iff} \quad (r_i\text{'s relation space} \subset r_j\text{'s relation space})$

TransH

Given (h, r, t) -> $\overrightarrow{h}, \overrightarrow{t}, \overrightarrow{r}, H_r$

A Different Perspective on TransH



Viewing TransH as:

(a): $\overrightarrow{t_\perp} - \overrightarrow{h_\perp} \approx \overrightarrow{r}$

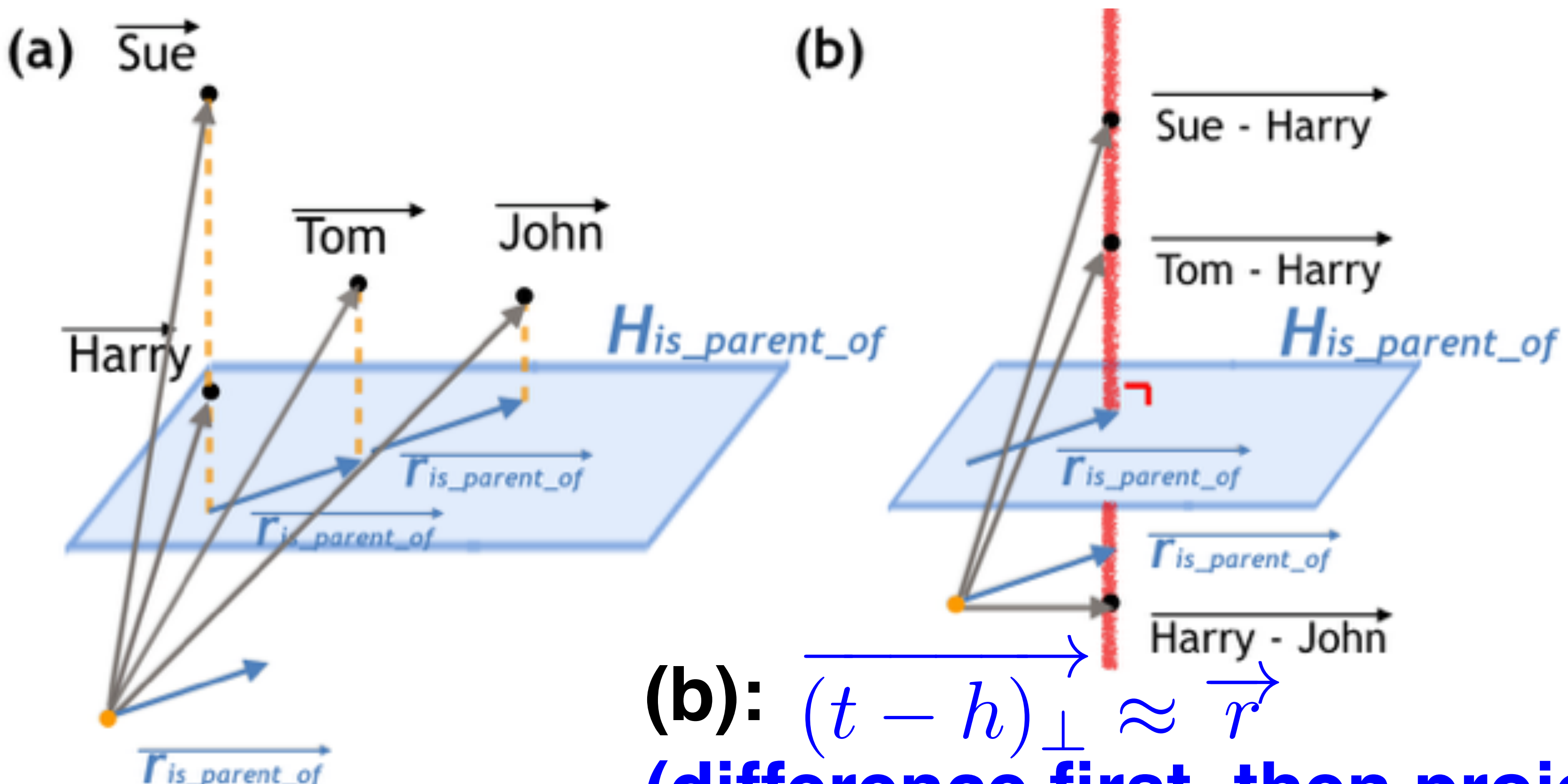
(projection first, then difference)

(b): $\overrightarrow{(t-h)_\perp} \approx \overrightarrow{r}$

(difference first, then projection)

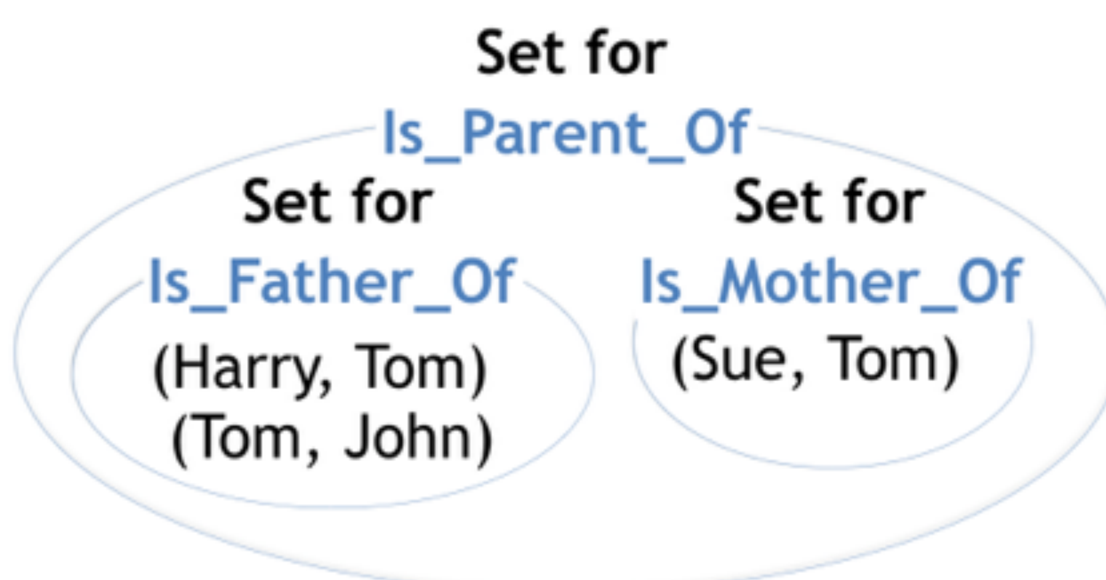
Red Line: The space where $\overrightarrow{t-h}$ of all (h,t)'s tied by *is_parent_of* can exist.
= <u>Relation Space</u> of *is_parent_of*

Methods



(b): $\overrightarrow{(t-h)_{\perp}} \approx \overrightarrow{r}$

(difference first, then projection)



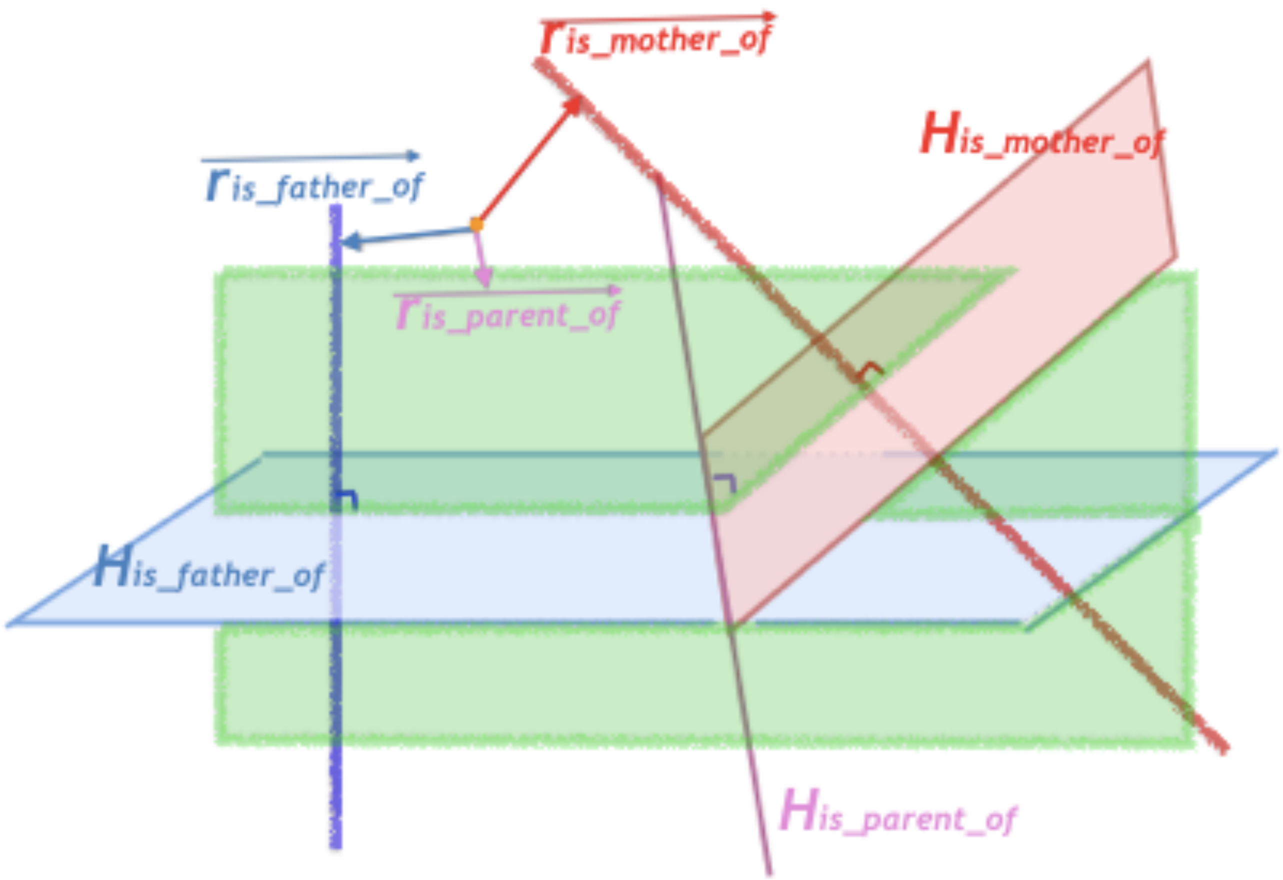
Methods

1. Intersection Constraint: $H_i \subset H_j$

2. Projection Constraint: Projection of $\overrightarrow{r_j}$ onto H_i is $\overrightarrow{r_i}$.

Or equivalently

$P_i \overrightarrow{r_j} = \overrightarrow{r_i}$ where P_i is projection matrix onto H_i .



rel.space(*is_father_of*),
rel.space(*is_mother_of*)
⊂ rel.space(*is_parent_of*)

Green hyperplane = relation space of *is_parent_of*
Blue, red lines: relation space of *is_father_of, is_mother_of*

Results - Link Prediction

Link Prediction: predict ? in (h, r, ?)

ex) (Harry, is_father_of, ?)

Table 1: Results for Link Prediction on FB122. *: For KALE, we report the best performance by any of KALE-PRE, KALE-Joint, KALE-TRIP (3 variants of KALE proposed by Guo et al. [2016]).

	Raw					Filtered				
	MRR	MED	Hits N%			MRR	MED	Hits N%		
			3	5	10			3	5	10
TransE	0.262	10.0	33.6	42.5	50.0	0.480	2.0	58.9	64.2	70.2
TransH	0.249	12.0	31.9	40.7	48.6	0.460	3.0	53.7	59.1	66.0
TransR	0.261	15.0	28.9	37.4	45.9	0.523	2.0	59.9	65.2	71.8
KALE*	0.294	9.0	36.9	44.8	51.9	0.523	2.0	61.7	66.4	72.8
TransINT^G	**0.339**	**6.0**	**40.1**	**49.1**	**54.6**	**0.655**	**1.0**	**70.4**	**75.1**	**78.7**
TransINT^{NG}	0.323	8.0	38.3	46.6	53.8	0.620	1.0	70.1	74.1	78.3

Table 2: Results for Link Prediction on NELL sport/ location.

	Sport					Location				
	MRR		Hits N%			MRR		Hits N%		
	Filtered	Raw	1	3	10	Filtered	Raw	1	3	10
Logical Inference	-	-	28.8	-	-	-	-	27.0	-	-
SimplE	0.230	0.174	18.4	23.4	32.4	0.190	0.189	13.0	21.0	31.5
SimplE+	0.404	0.337	33.9	44.0	50.8	0.440	0.434	43.0	44.0	45.0
TransINT^G	**0.450**	0.361	**37.6**	**50.2**	**56.2**	**0.550**	**0.535**	**51.2**	**56.8**	**61.1**
TransINT^{NG}	0.431	**0.362**	36.7	48.7	52.1	0.536	0.534	51.1	53.3	59.0

Results - Triple Classification

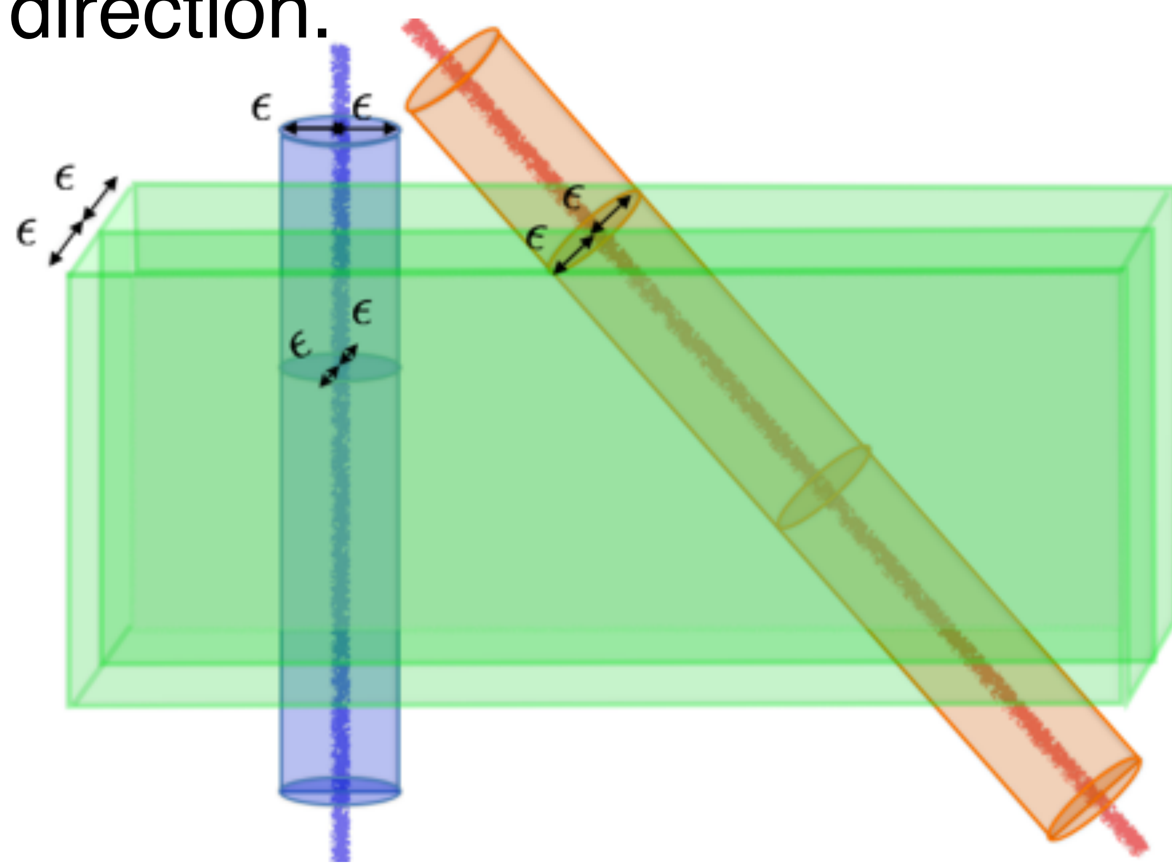
Triple Classification: predict (h, r, t) valid/ invalid

Table 3: Results for Triple Classification on FB122, in Mean Average Precision (MAP).

TransE	**TransH**	**TransR**	**KALE***	**TransINT^G**	**TransINT^{NG}**
0.634	0.641	0.619	0.677	**0.781** (0.839/ 0.752)	**0.743** (0.709/ 0.761)

Margin-aware geometry

Margin-aware Geometry (Fig. (d)): If weaker objective required (i.e. $\overrightarrow{(t-h)_{\perp}} - \overrightarrow{r} < \epsilon$), relation spaces (now with thickness 2ϵ) still included in the same direction.



rel.space(*is_father_of*),
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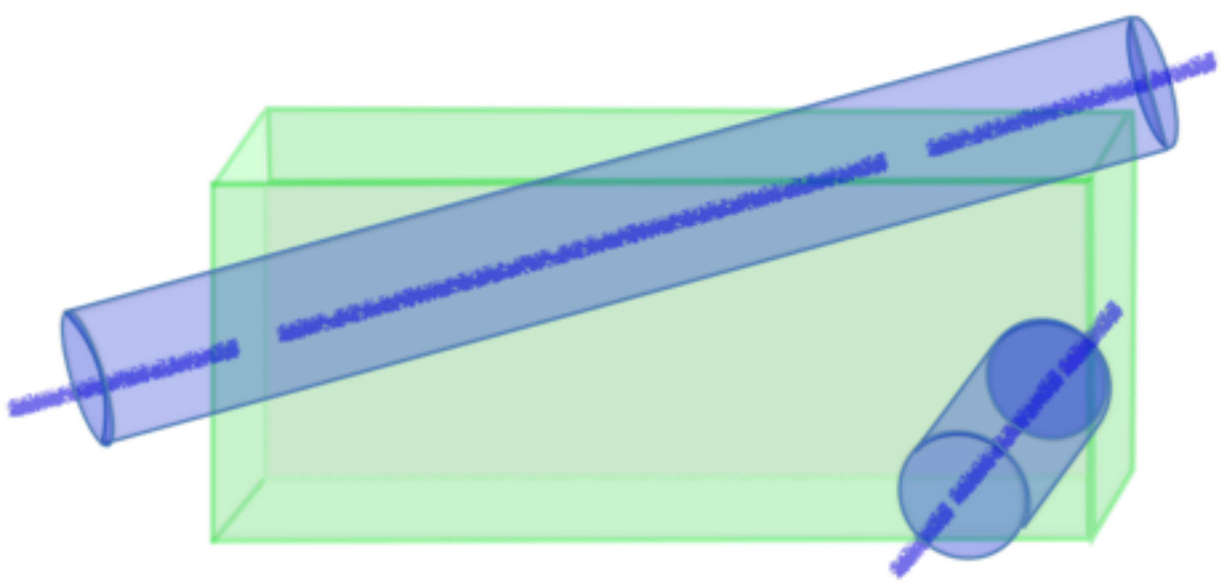
Green hyperrectangle = rel. space of *is_parent_of*
Blue, red cylinders: rel. space of *is_father_of, is_mother_of*

Semantic Relatedness/ Rule Mining



▲ Relation Spaces over-lapping with different angles

Angle:
Metric of similarity between embedded objects
Ex) Word2vec, Visual Semantics

Between two relation spaces, the closer the angle
⇳
the more overlap in area

Table 4: Examples of relations' angles and *imb* with respect to /people/person/place_of_birth

		Relation	Anlge	*imb*
Not Disjoint	Relatedness	/people/person/nationality	22.7	1.18
	Implication	/people/person/place_lived/location*	46.7	3.77
Disjoint		/people/cause_of_death/people	76.6	n/a
		/sports/sports_team/colors	83.5	n/a