Querying Factorized Probabilistic Triple Databases

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Outline

1. Introduction and Motivation
   - Knowledge Bases are Triple Stores
   - Exploiting Uncertainty in KBs

2. Constructing Probabilistic Knowledge Bases with the RESCAL Tensor-Factorization

3. Complex Querying of Factorized Probabilistic Knowledge Base Representations

Knowledge Bases are Triple Stores

- Represents facts of the world in a machine readable form

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SUBJECT **PREDICATE** **OBJECT**

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- Machine Readable
- Utilize Background Knowledge in Applications
- Provide Additional Information (Search)

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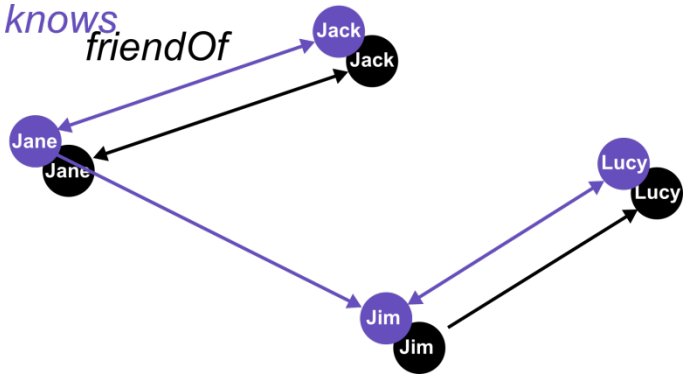
- Many False Facts
- Incomplete
- Only few attempts to represent triple-uncertainty

Benefits of Exploiting Uncertainty in Knowledge Bases

Deterministic Database

Subject	Object
Jack	Jane
Jane	Jim
Jim	Lucy

Subject	Object
Jack	Jane
Jim	Lucy



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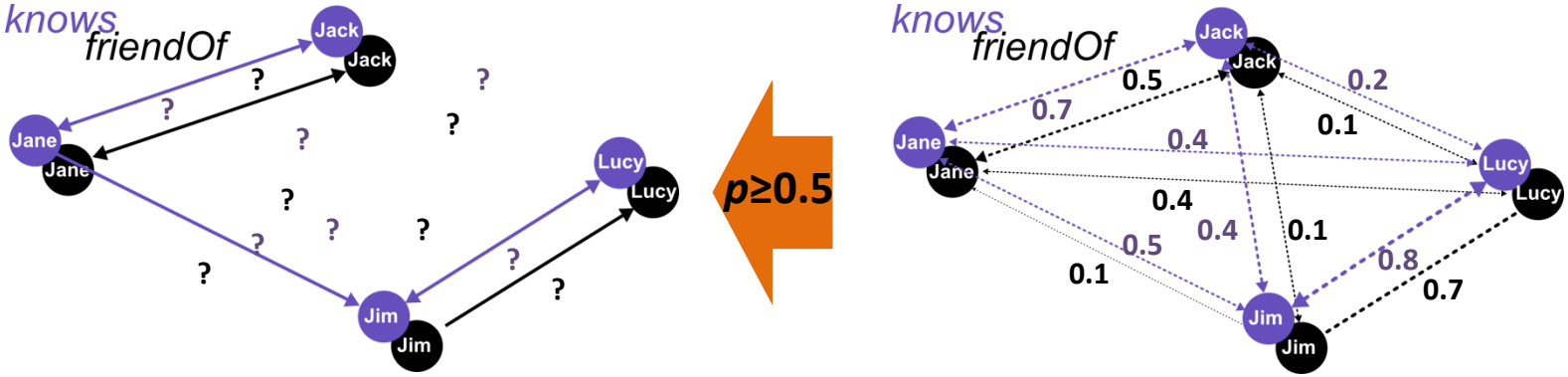

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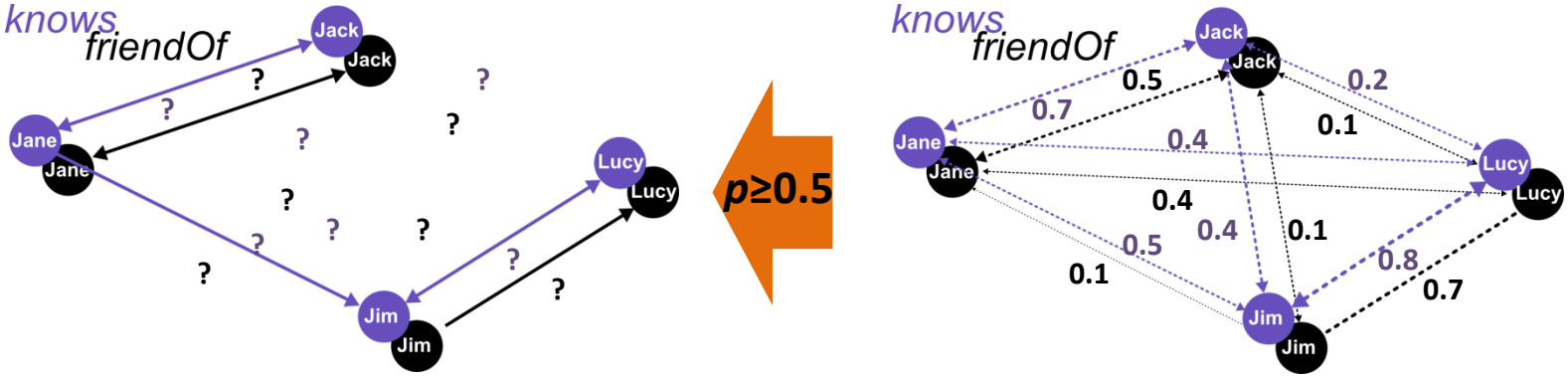

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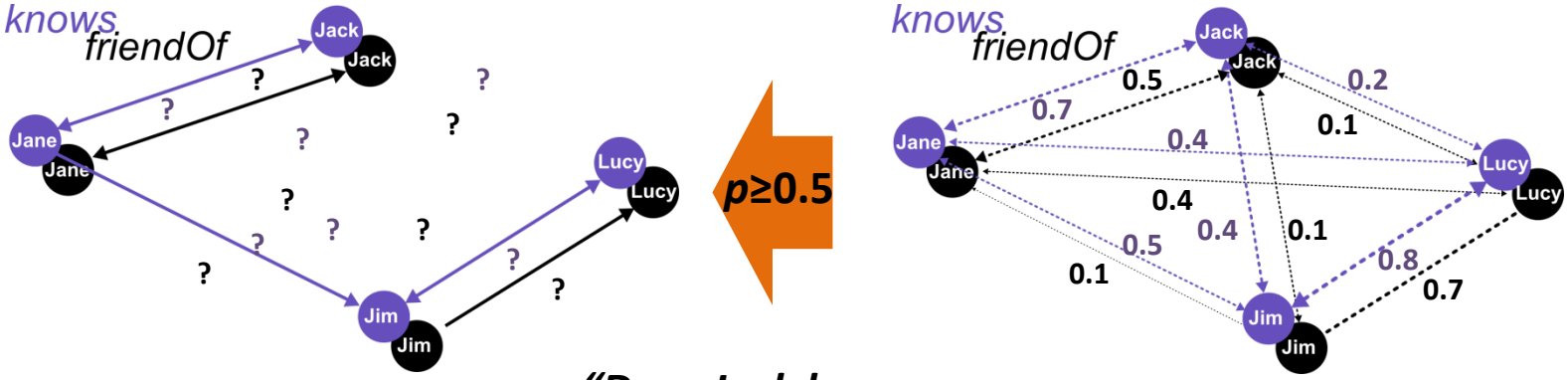

"Does Jack know someone who is a friend of Lucy?"

$$Q :- \exists y.\, knows(\text{'Jack'}, y),\ friendOf(y, \text{'Lucy'})$$

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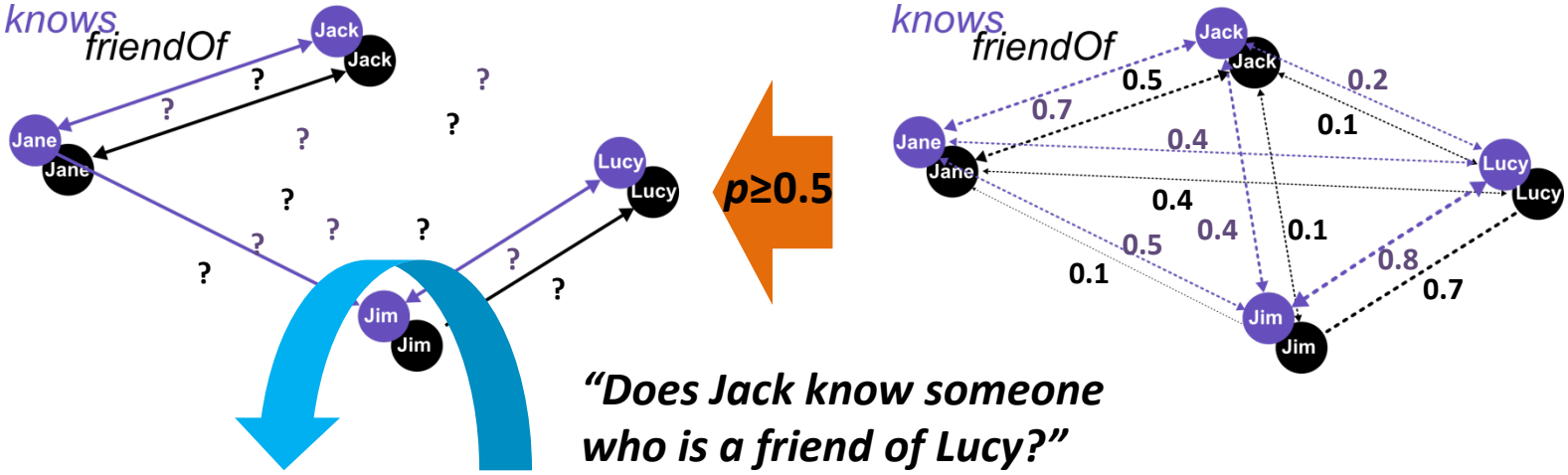

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"No, Jack does not know such a person."

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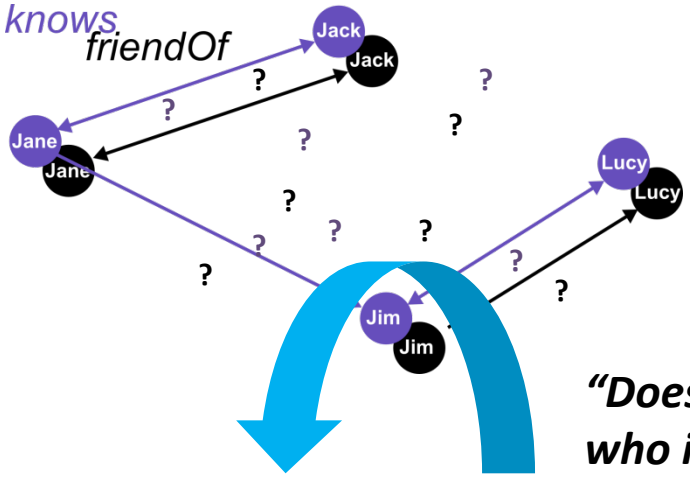

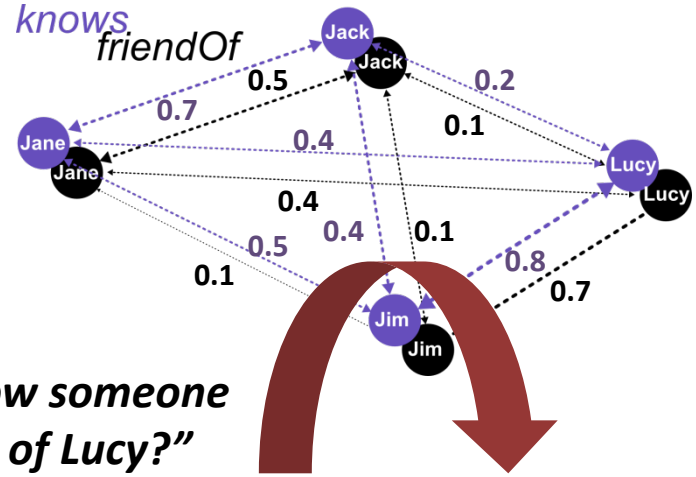

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**Considering that a person knows and is a friend of itself*

Challenges when Exploiting Uncertainty in Knowledge Bases

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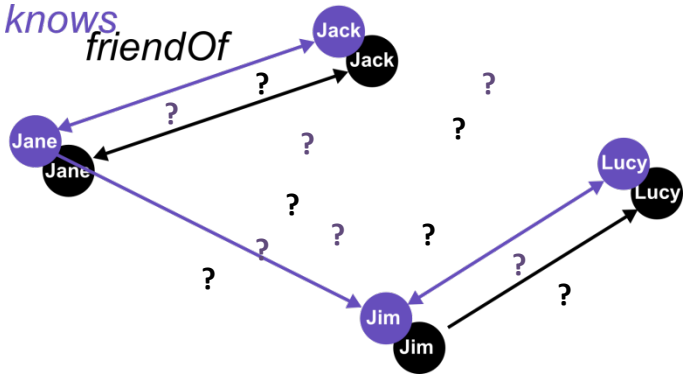

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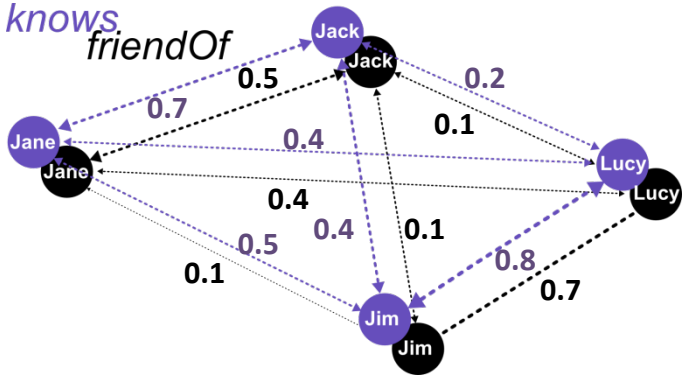

Reintroducing Uncertainty

- Can be **intractable** for larger KBs
  - Millions of Entities
  - Thousands of Relation Types
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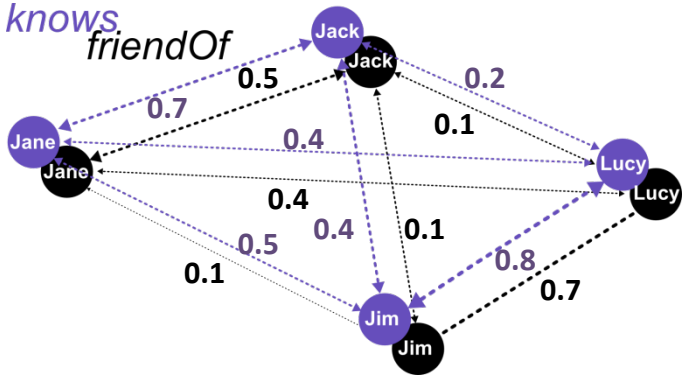

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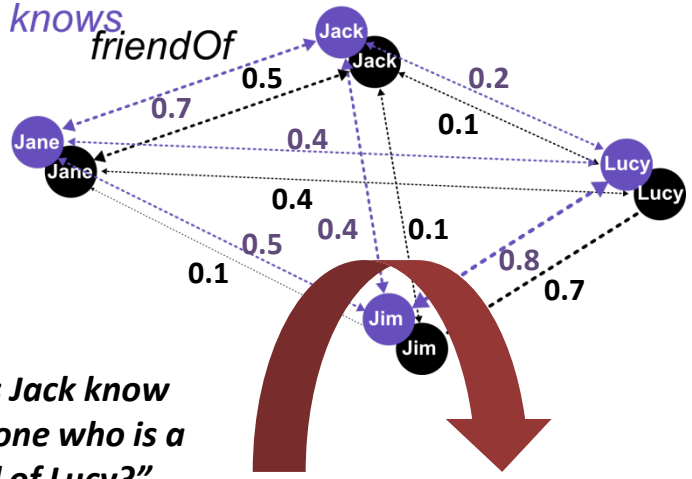

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Complex Querying

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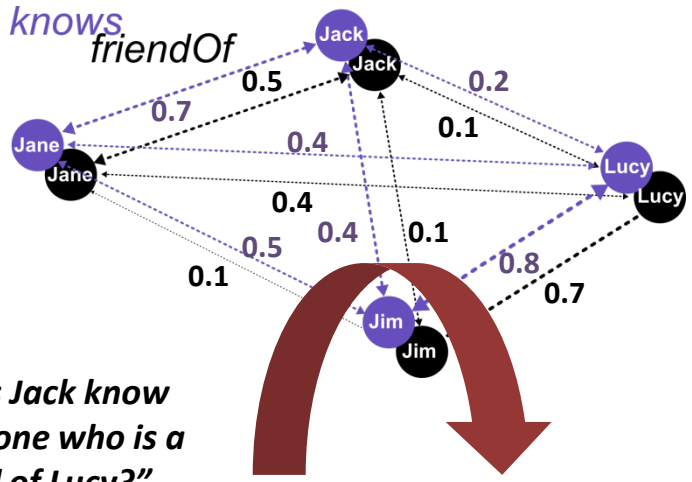

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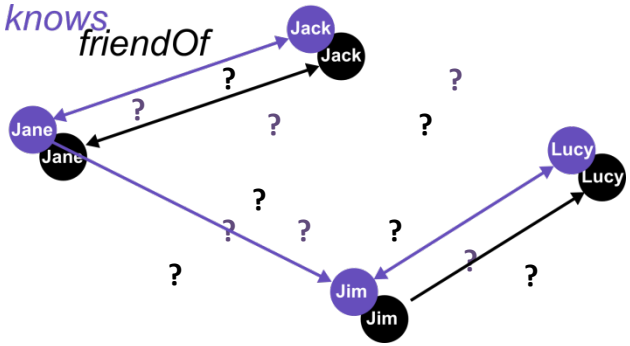
Probabilistic KB Construction with RESCAL



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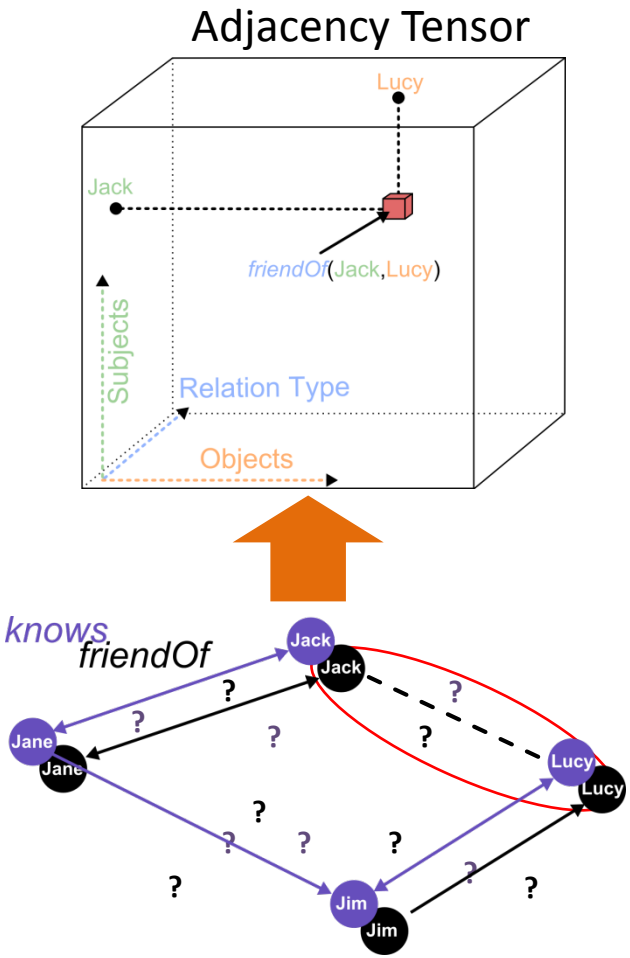

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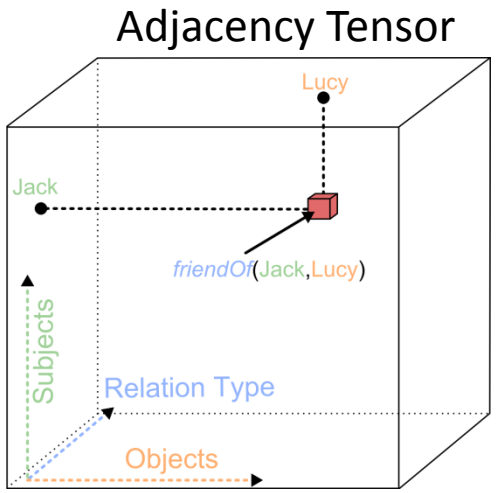

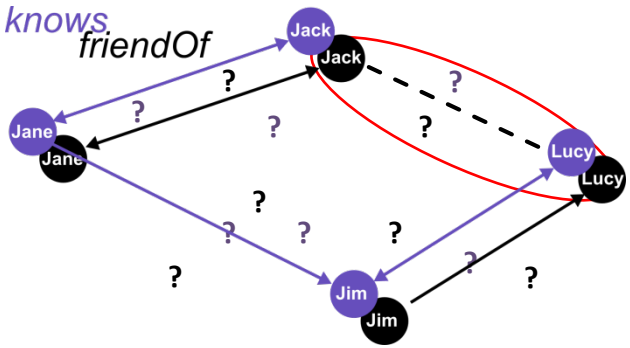

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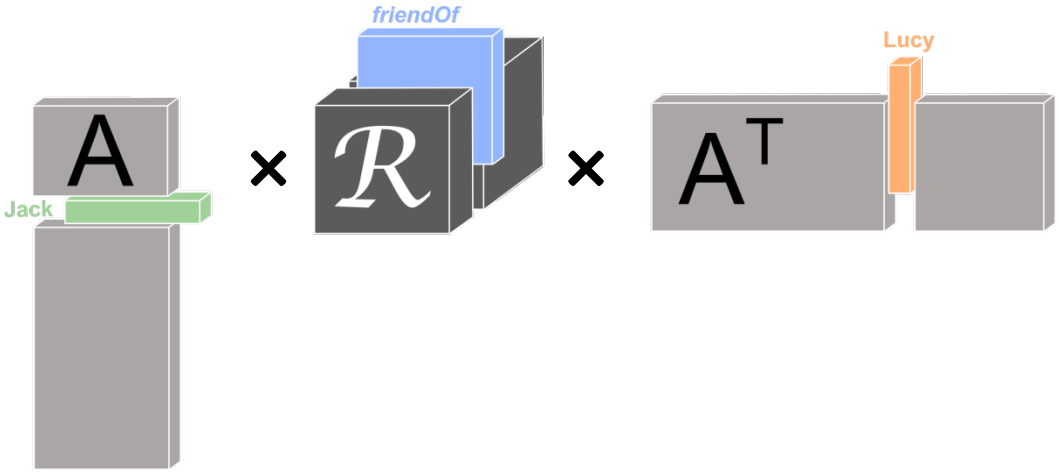

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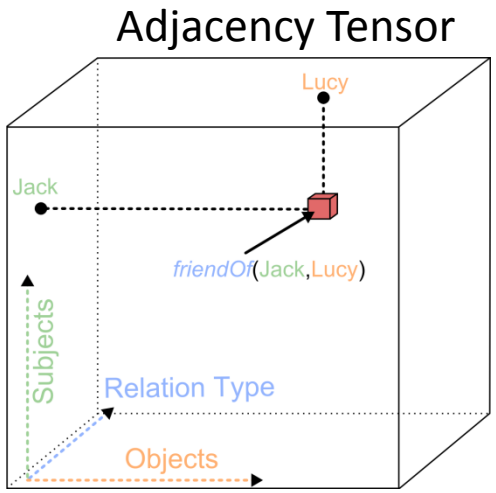

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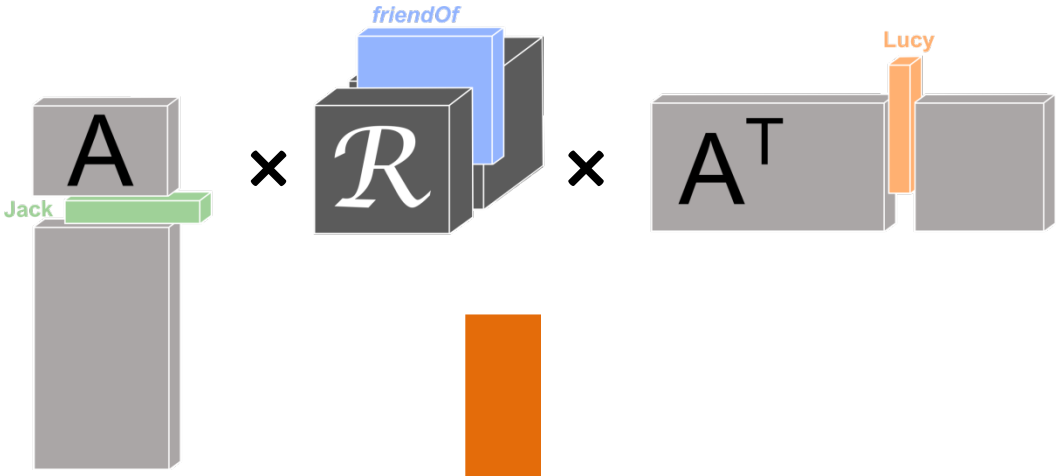

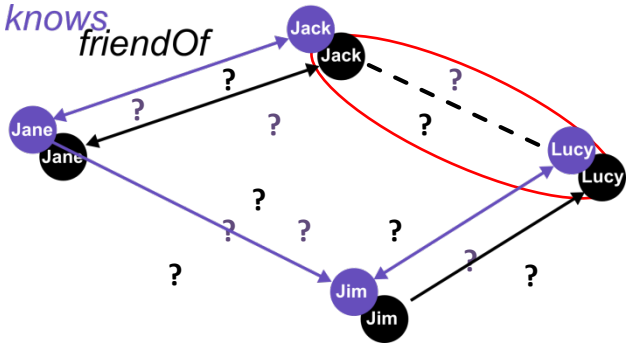

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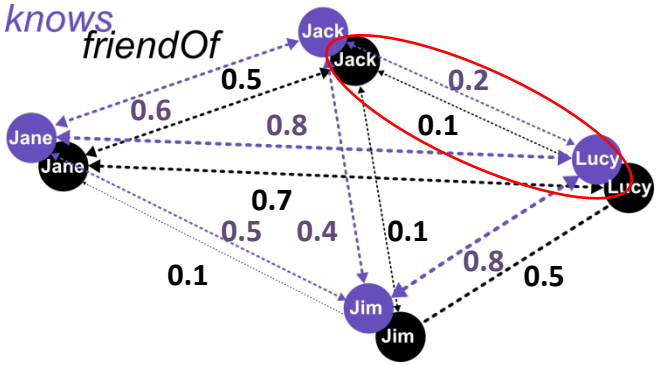

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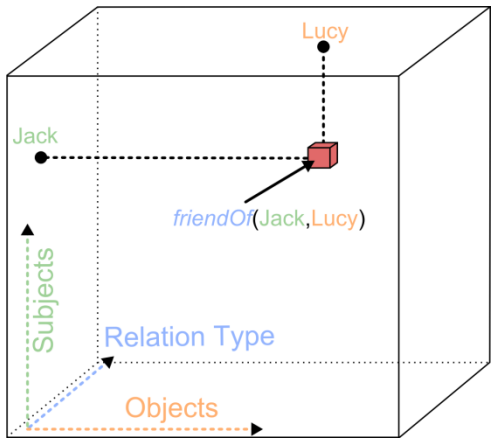

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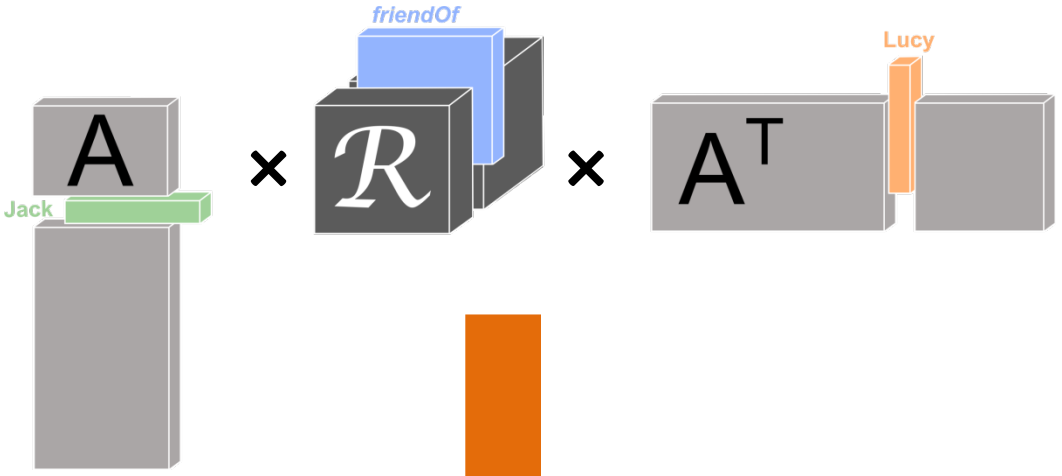

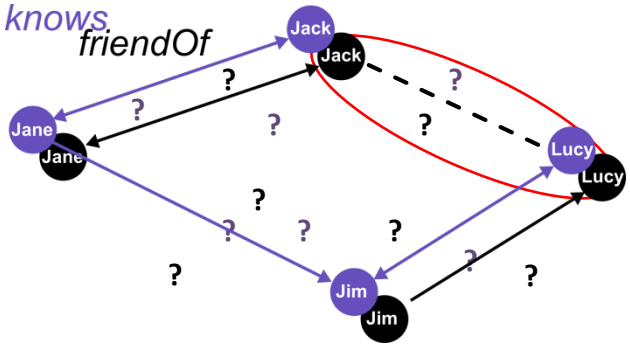

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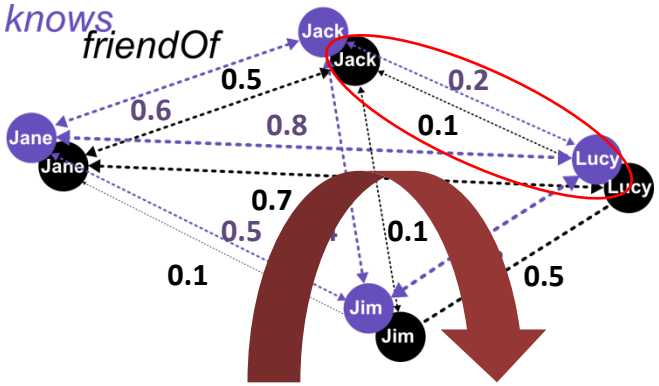

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Query a triple:
„Is Jack a friend of Lucy?“

„Jack might be a friend of Lucy with a probability of 0.1 %“

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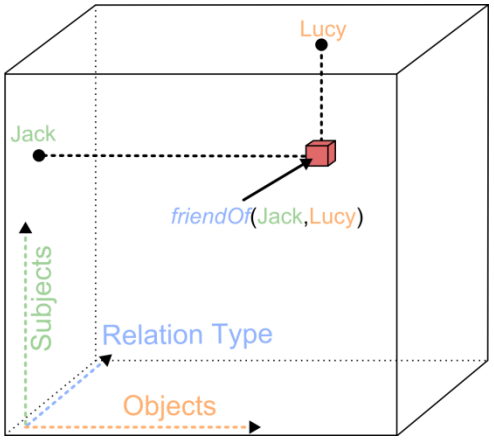

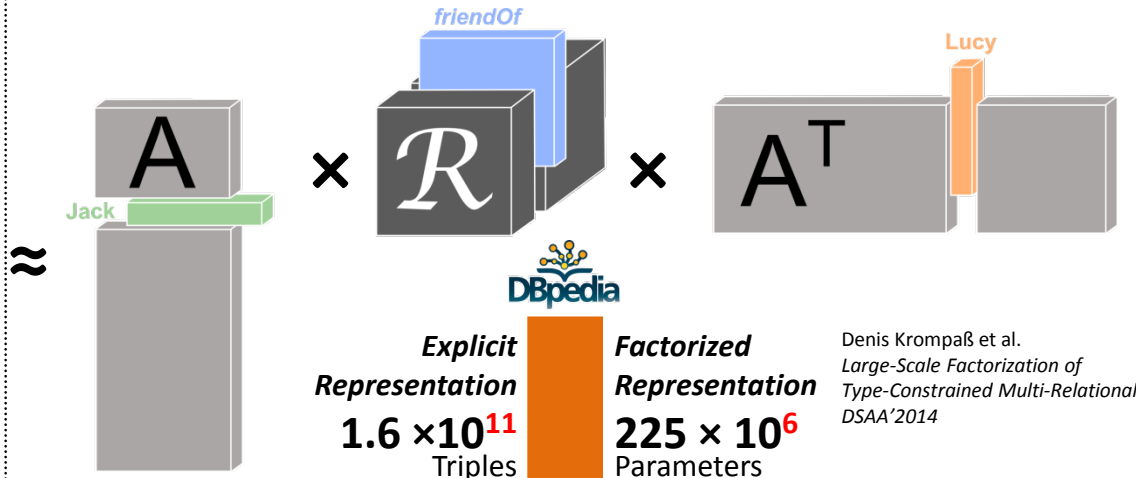

Denis Krompaß et al.
Large-Scale Factorization of Type-Constrained Multi-Relational Data.
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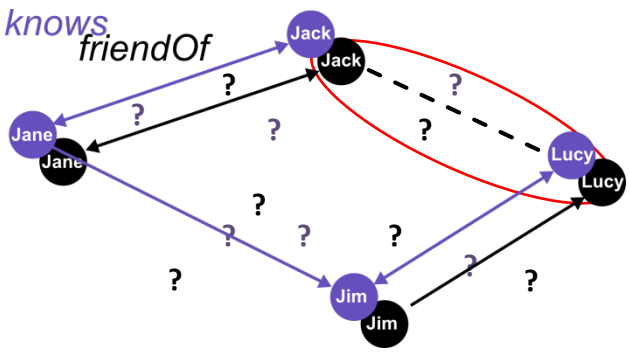

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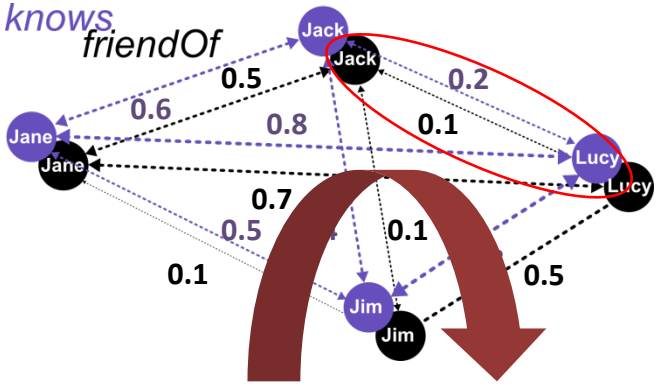

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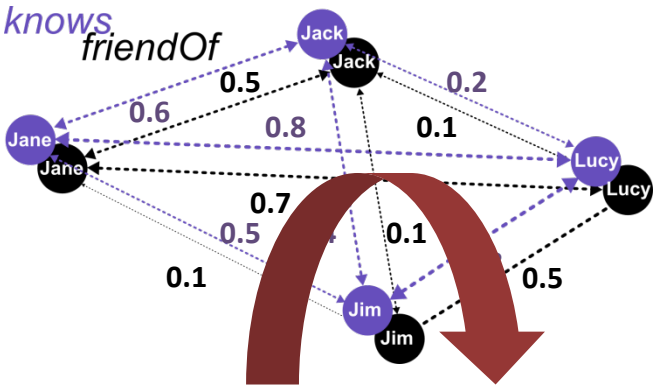
Complex Querying: Pure Extensional Query Evaluation on Factorized PKBs



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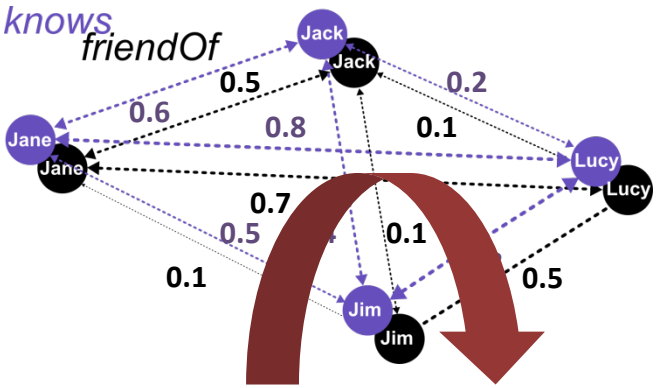

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$$P(Q) = 1 - \prod_{a \in ADom} 1 - P(knows(\text{'Jack'}, a))P(\ friendOf\,(a, \text{'Lucy'}))$$

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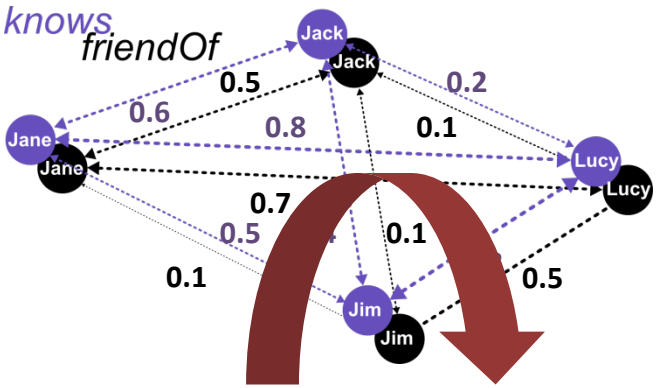

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"Does Jack know a soccer player?"

$Q :- \exists y. \exists z. (knows(\text{'Jack'}, y), soccer(y, z))$

$$P(Q) = 1 - \prod_{a \in ADom} 1 - P(knows(\text{'Jack'}, a)) \left[1 - \prod_{b \in ADom} 1 - P(soccer(a, \text{b})) \right]$$

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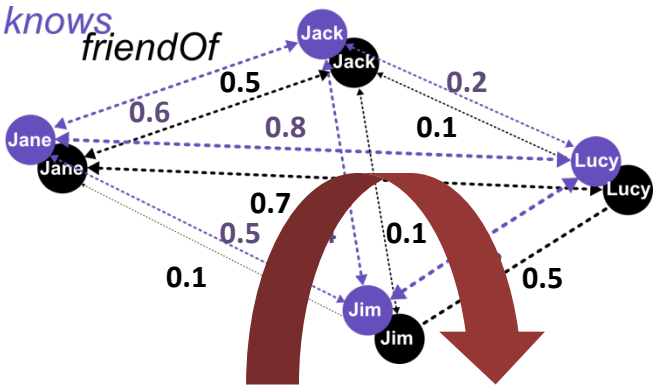

- For each existential quantifier $\exists x.$ the ***independent-project*** rule has to be applied
  - ➢ **Nested loops**

"Does Jack know someone who is a friend of Lucy?"

$$Q :- \exists y.\, knows(\text{'Jack'}, y),\ friendOf\,(y, \text{'Lucy'})$$

$$P(Q) = 1 - \prod_{a \in ADom} 1 - P(knows(\text{'Jack'}, a))P(\ friendOf\,(a, \text{'Lucy'}))$$

"Does Jack know a soccer player?"

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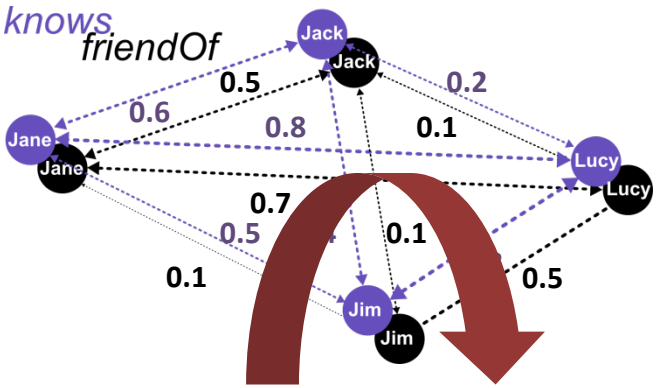
Complex Querying: Pure Extensional Query Evaluation on Factorized PKBs



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Complexity scales already **cubic** in the size of the database if we ask the query **for all persons** in the database

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Querying DBpedia-Music

(44345 Entities, 7 Relations)

- ***„What songs or albums from the Pop-Rock genre are from musical artists that have/had a contract with Atlantic Records?“***

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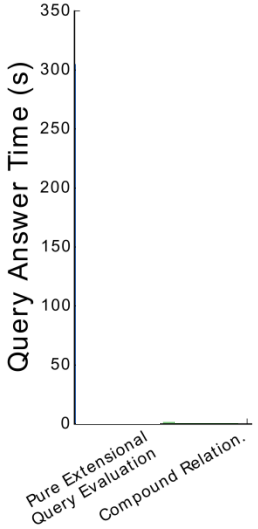

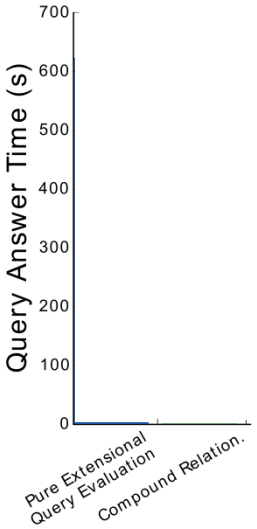

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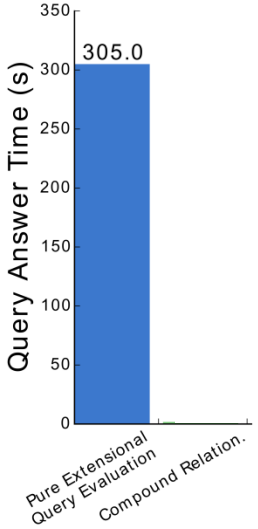

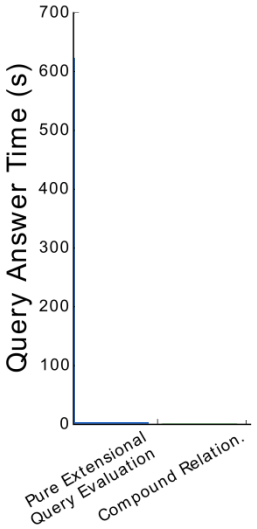

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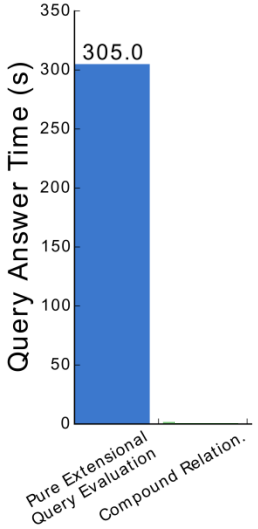

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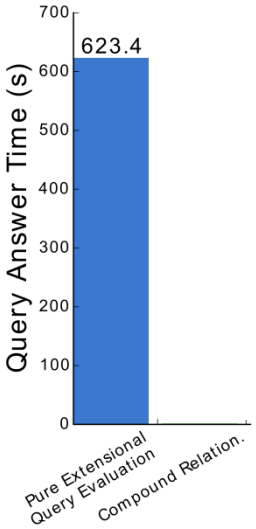

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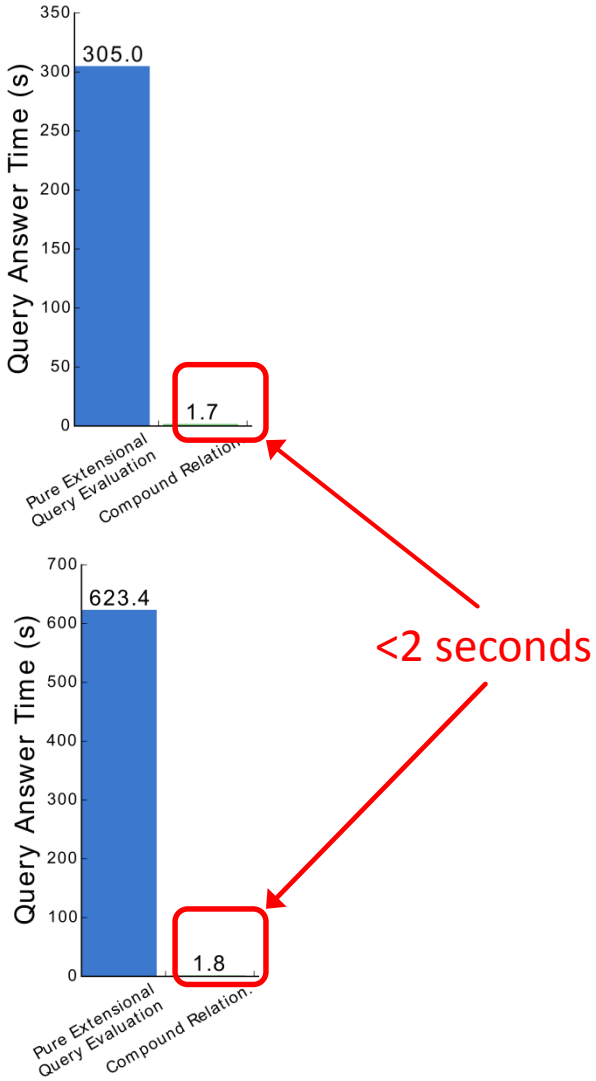

Avoiding Independent-Project

"Does Jack know a soccer player?"

$Q :- \exists y.\exists z.(knows(\text{'Jack'}, y), soccer(y, z))$

$$P(Q) = 1 - \prod_{a \in ADom} 1 - P(knows(\text{'Jack'}, a)) \left[1 - \prod_{b \in ADom} 1 - P(soccer(a, \text{b})) \right]$$

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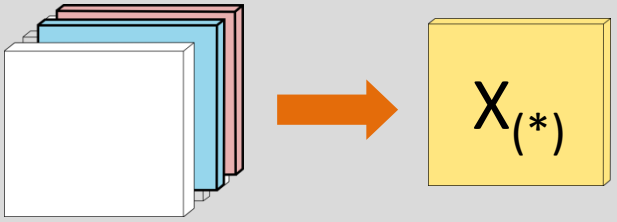
1. Construct deterministic compound relation $X_{(*)}$

Initial Deterministic KB

knows(), *soccer()*

knowsSoccerPlayerOf()



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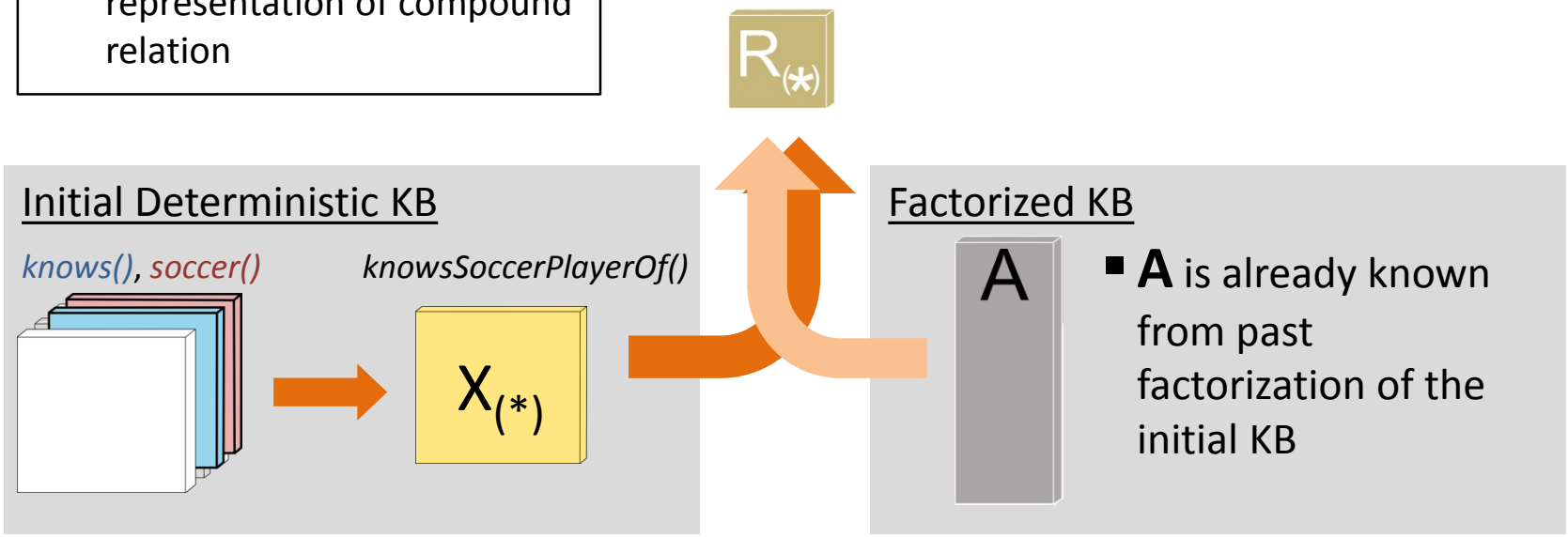
1. Construct deterministic compound relation $X_{(*)}$
2. Approximate latent representation of compound relation



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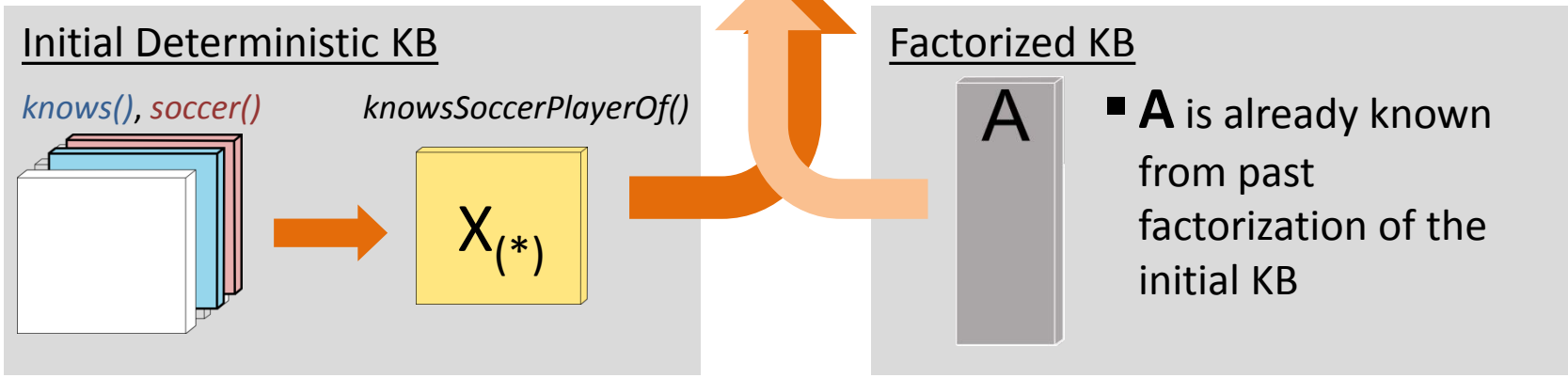
$$R_{(*)} = (A^T A \otimes A^T A + \lambda I)^{-1} (A \otimes A)^T X_{(*)}$$

$$R_{(*)} = V(S * U^T X_{(*)} U) V^T \quad | A = UDV^T$$



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$$P(Q) \approx 1 - \prod_{b \in ADom} 1 - P(knowsSoccerPlayerOf('\text{Jack}', b))$$

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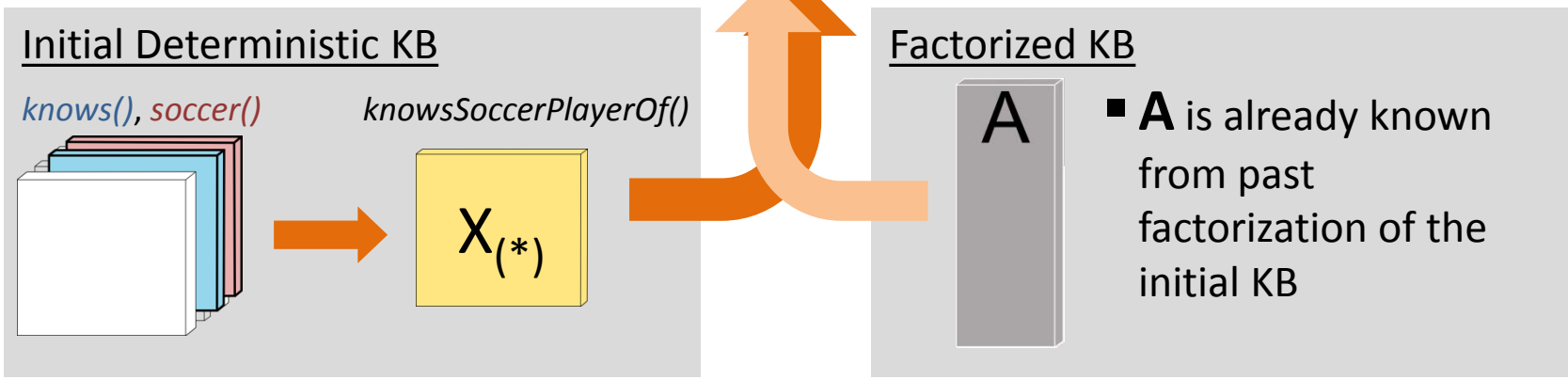

Querying DBpedia-Music

(44345 Entities, 7 Relations)

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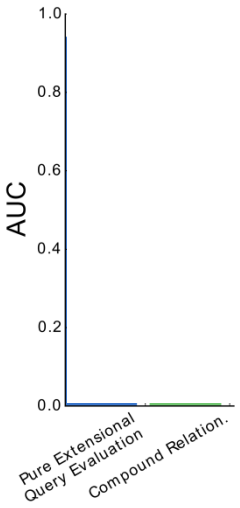

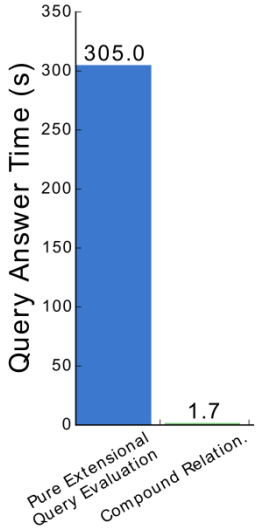

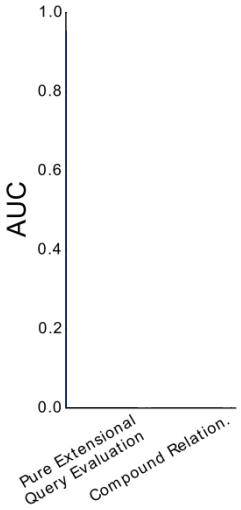

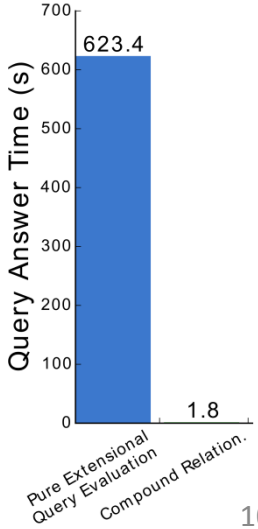

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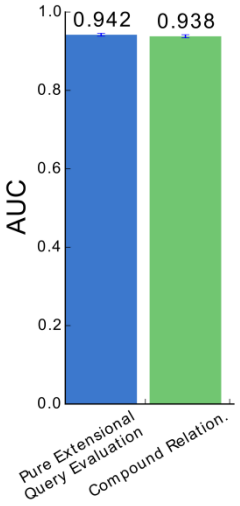

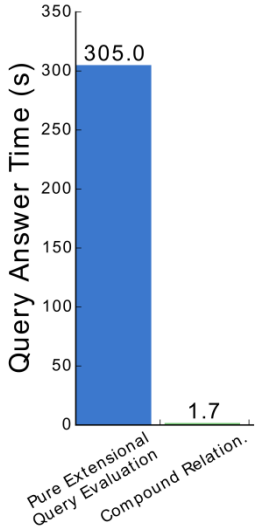

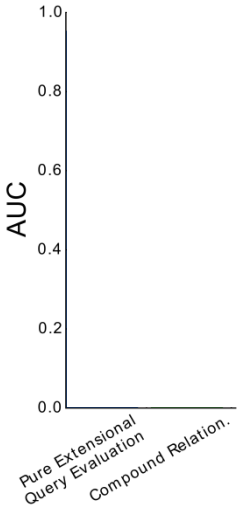

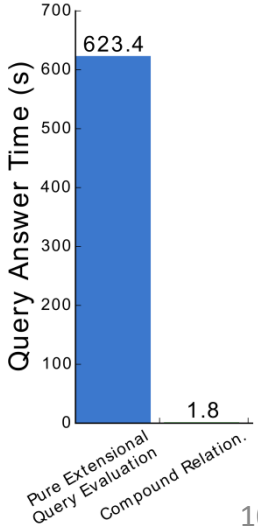

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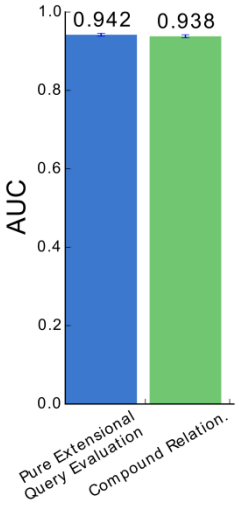

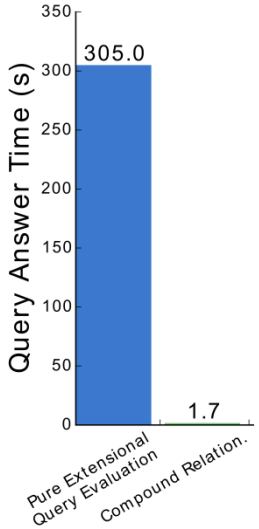

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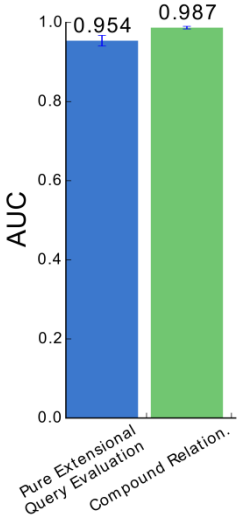

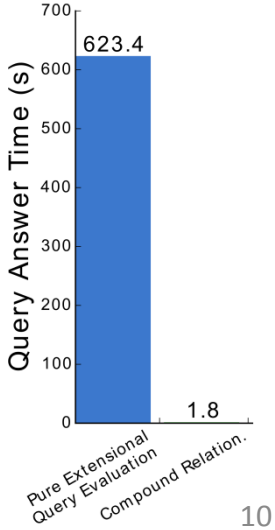

Querying DBpedia-Music

(44345 Entities, 7 Relations)

- ***„Which musical artists from the Hip-Hop music genre are associated with musical artists that have/had a contract with Interscope Records and are involved in an album whose first letter is a 'T'?"***

$$
\begin{aligned}
Q_3(x) :- \; & genre(x, \text{'Hip\_Hop\_Music'}), \\
& \exists y(associatedMusicalArtist(x, y), recordLabel(y, \text{'Interscope\_Records'})), \\
& \exists z.\exists t.(musicalArtist(z, x), album(z, \{\text{'AlbumT.*'}\}))
\end{aligned}
$$

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Pure Extensional Query Evaluation

Processing not finished after **6 hours**!

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Pure Extensional Query Evaluation	Exploiting Approximated Compound-Relations
Processing not finished after **6 hours**!	**3.6 seconds** AUC: 0.985

Summary

- Uncertainty can be reintroduced into deterministic representations of Knowledge Bases with RESCAL
- The factorized Representation can be exploited for complex querying
- Extensional query evaluation can be significantly accelerated by exploiting the RESCAL model (Compound Relations)

Questions ?

http://www.dbs.ifi.lmu.de/~krompass/

Denis.Krompass@campus.lmu.de