Neural, Symbolic and Neural-Symbolic Reasoning on Knowledge Graphs
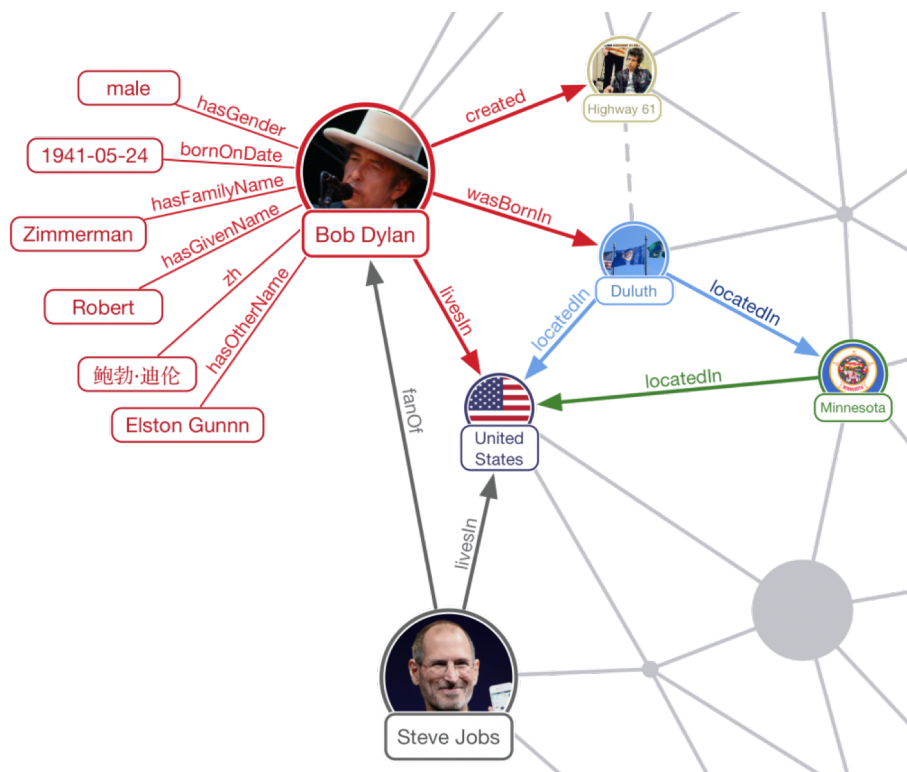
Jing Zhang

School of Information, Renmin University of China

What is Knowledge Graph Reasoning?

Knowledge Graph

➢A set of facts represented as triplets (head entity, relation, tail entity)

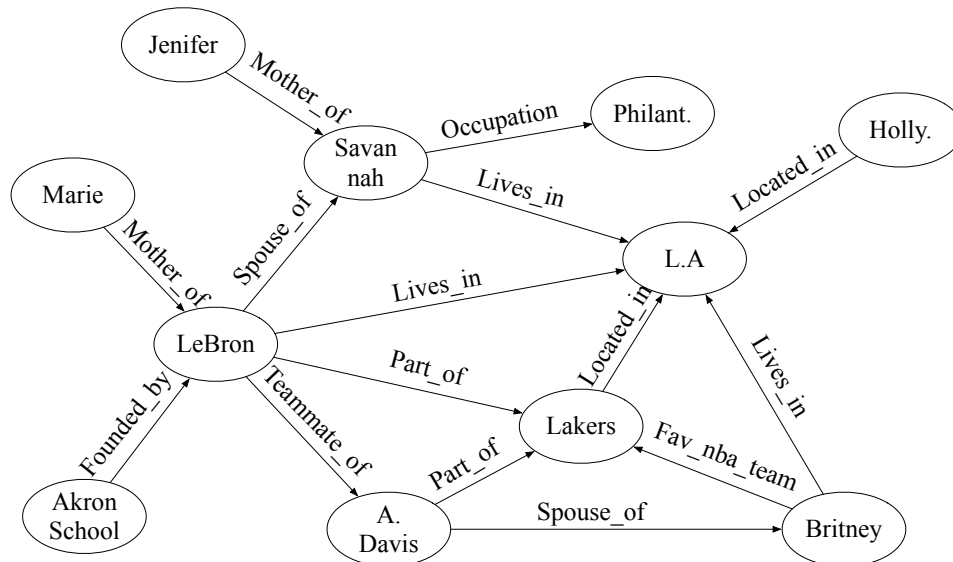# Knowledge Graph Reasoning

➢ Deduce entities on KGs as the answers to the given query.

➢ A query can be a pair of (head entity, query relation) (knowledge graph completion, KGC) or a textural question (knowledge graph question answering, KGQA).

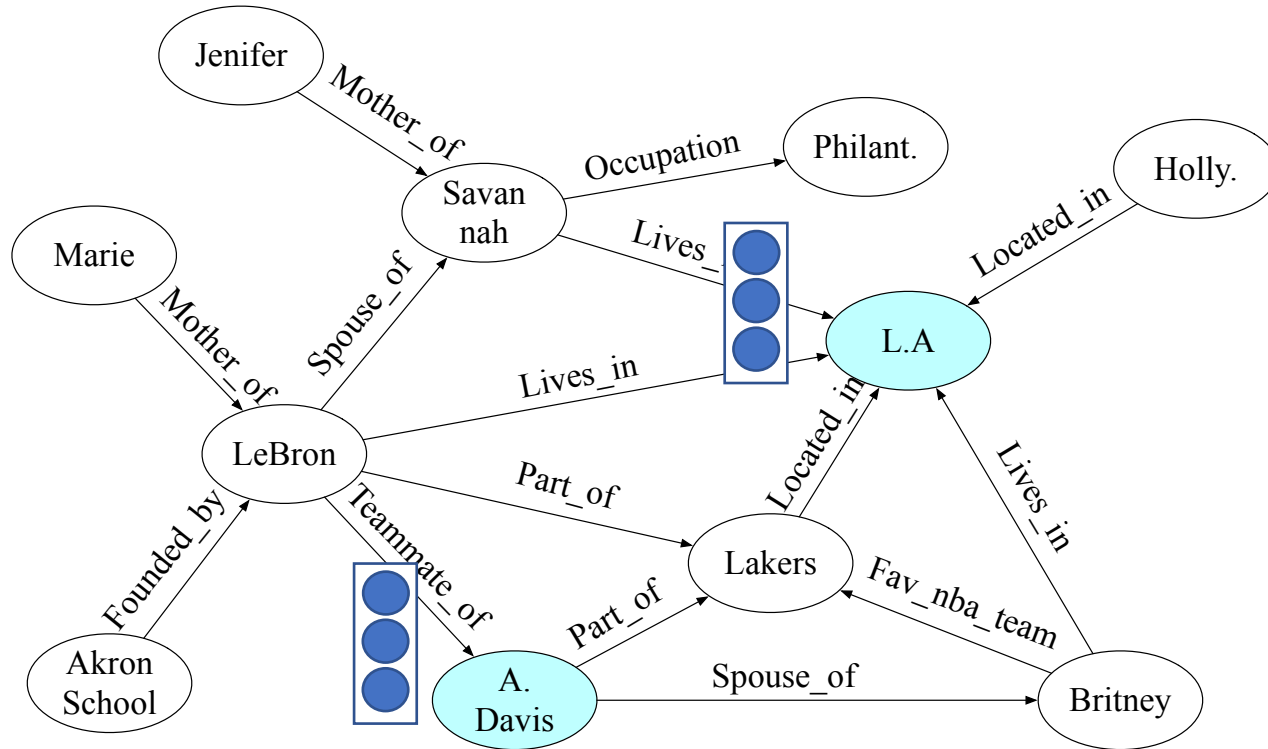Head entity: A. Davis, Query relation: Lives_in
Reasoning result: L.A

Textual question: Where do the spouses of the teammates of Lakers usually live?
Reasoning result: L.A

Neural-based KGC Reasoning

Head entity: A. Davis,   Query relation: Lives_in   Reasoning result: L.A

Neural-based KGQA Reasoning
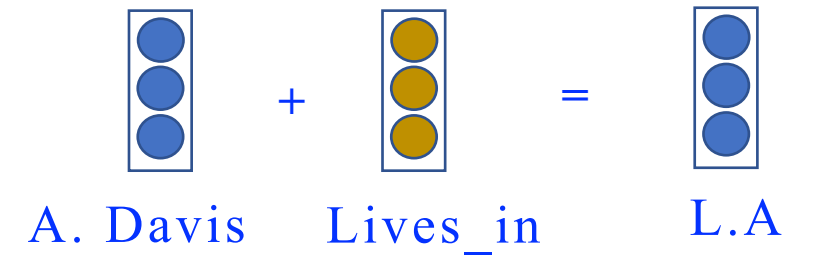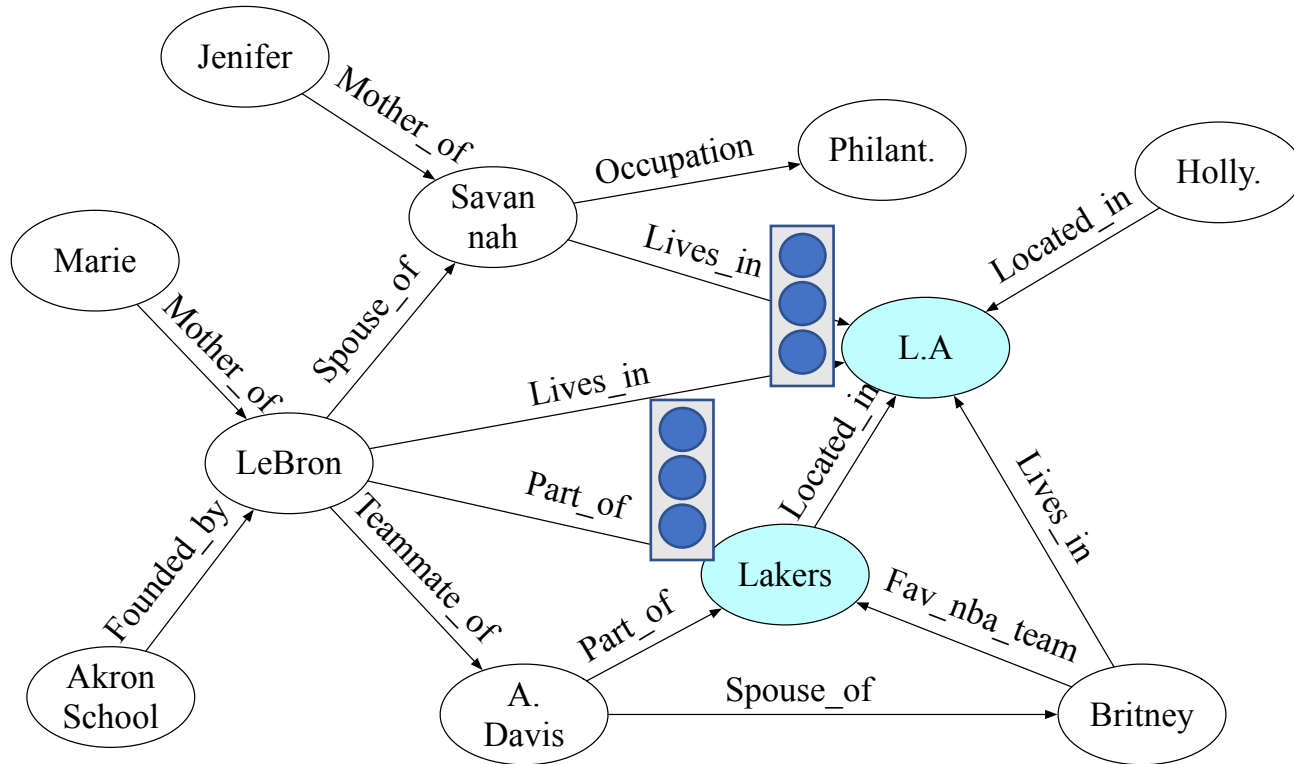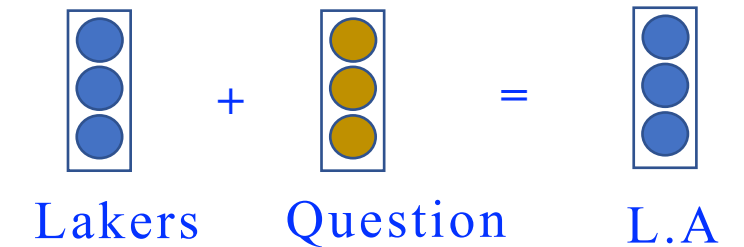

Textual question: Where do the spouses of the teammates of Lakers usually live?
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Symbolic-based KGC Reasoning
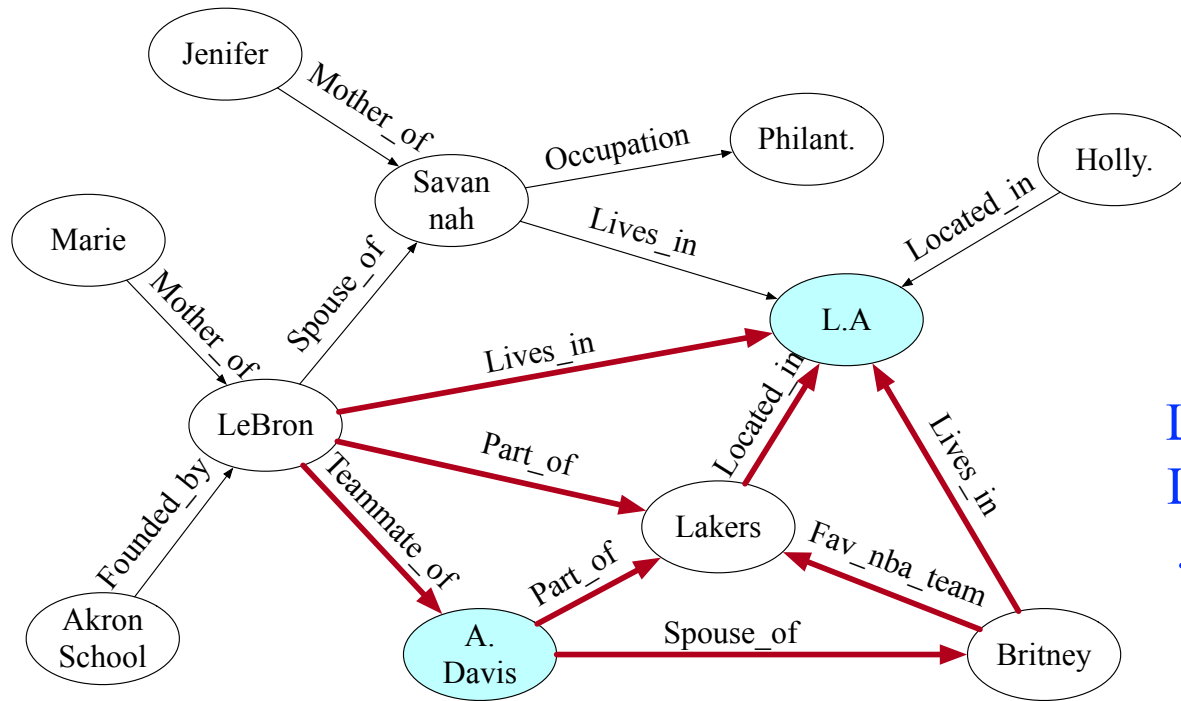
Symbolic-based Reasoning

Lives_in (x,y) ← Part_of(x,z) ∧ Located_in (z,y)
Lives_in (x,y) ← Spouse_of(x,z) ∧ Lives_in (z,y)
…

Head entity: A. Davis, Query relation: Lives_in Reasoning result: L.A

Symbolic-based KGQA Reasoning
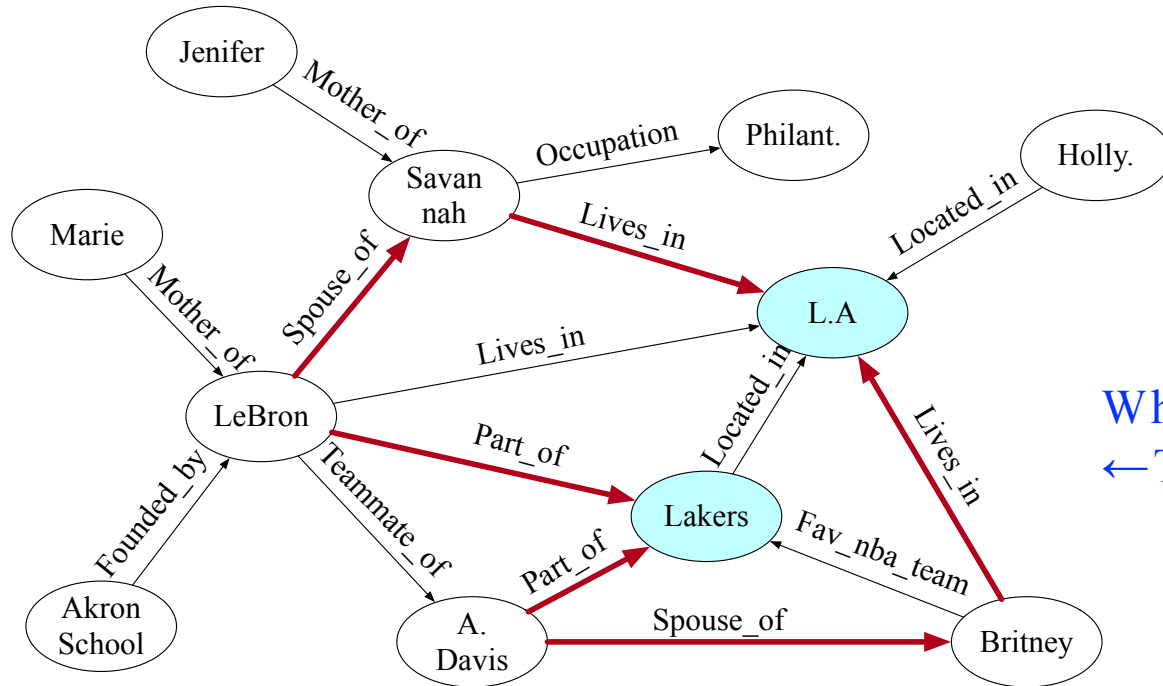
Symbolic-based Reasoning

Where do the spouses of the teammates of x usually live?
←Teammate_of(x,z) ∧ Spouse_of(z,w) ∧ Lives_in (w,y)

Textual question: Where do the spouses of the teammates of Lakers usually live?
Reasoning result: L.A

How to solve Knowledge Graph Completion?

Knowledge Graph Completion

Knowledge Graph Completion

KB embedding

Good generalization,
lack interpretation.

TransE, DisMult, ConvE, R-CGN

KGC

Neural Reasoning

Symbolic Reasoning

Symbolic-enhanced Neural Reasoning

Neural-enhanced Symbolic Reasoning

Path-based

Matrix-based

Knowledge Graph Completion

KGC

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Good generalization,
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TransE, DisMult, ConvE, R-CGN

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Neural-enhanced Symbolic Reasoning

Add new triplets by rules

Lack interpretation

Guo et al. 2018
Want et al., 2019
Niu et al., 2020

Path-based

Matrix-based

Knowledge Graph Completion

KGC

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Good generalization,
lack interpretation.

TransE, DisMult, ConvE, R-CGN

Inductive logic programming

Good interpretation, but intolerant to
the ambiguous and noisy data.

AMIE (Galarraga et al., 2013) bottom up
RARL (Giuseppe, 2020) top down

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Neural Reasoning	Symbolic Reasoning

Symbolic-enhanced Neural Reasoning

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Neural-enhanced Symbolic Reasoning

Extend multi-hop neighbors, NN is to deal with the uncertainty and ambiguity, and also reduce the search space.

Path-based

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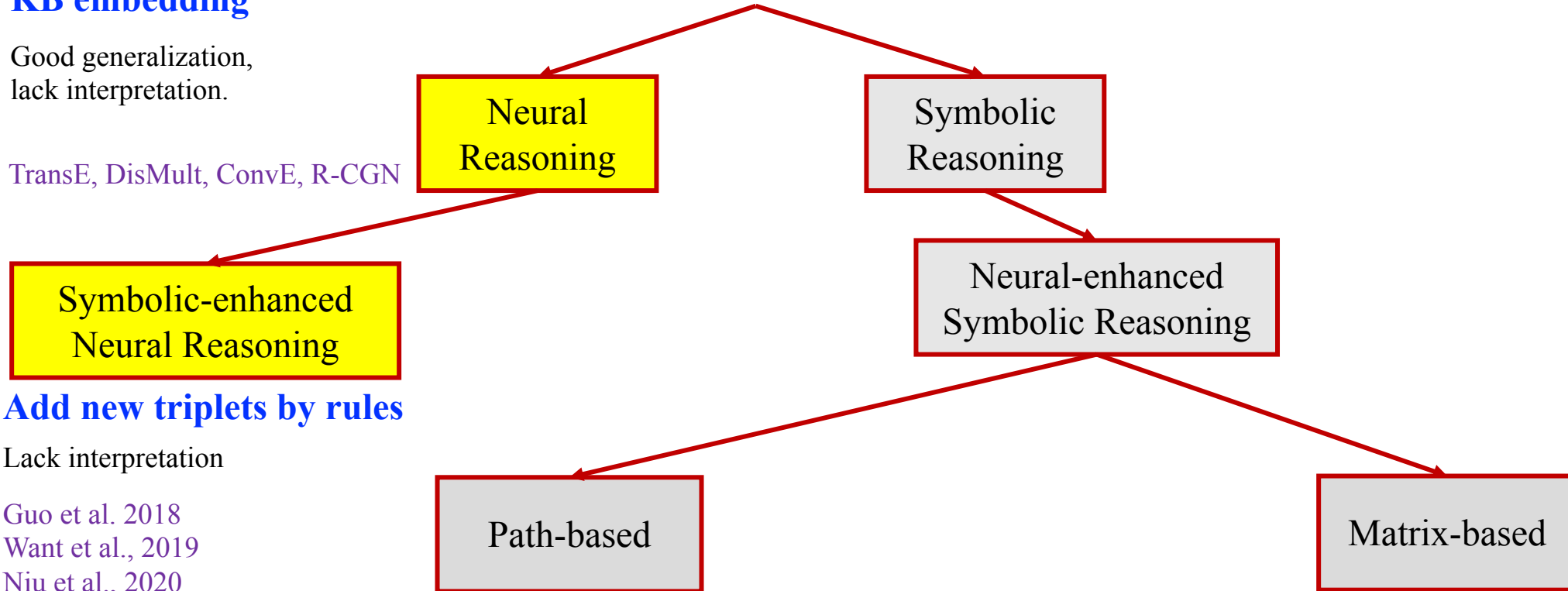
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Extend only one neighbor

DeepPath (Xiong et al. 2011)
MINERVA(Das et al., 2018)

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Neural
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Symbolic
Reasoning

Symbolic-enhanced
Neural Reasoning

Neural-enhanced
Symbolic Reasoning

**Extend multi-hop neighbors,
NN is to deal with the
uncertainty and ambiguity, and
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Add new triplets by rules

Lack interpretation

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Path-based

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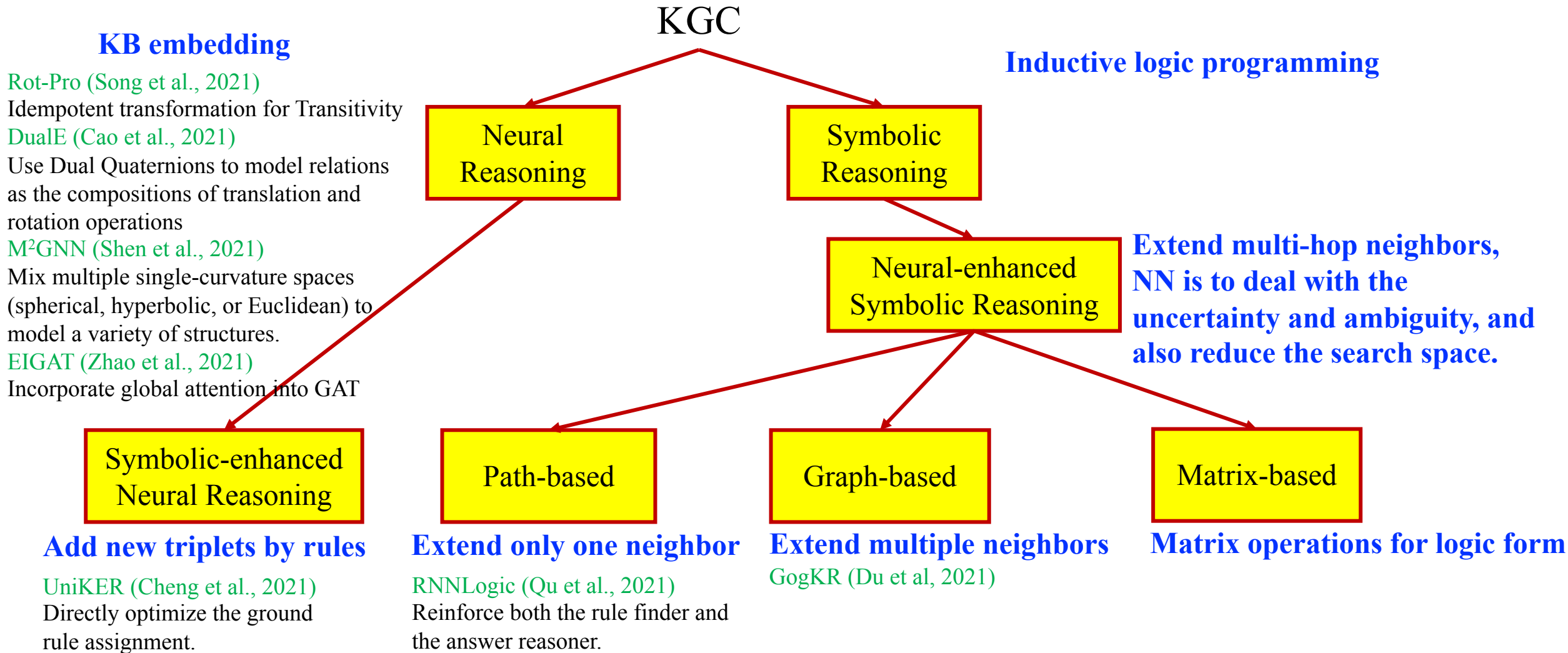
Extend only one neighbor

DeepPath (Xiong et al. 2011)
MINERVA(Das et al., 2018)

Matrix operations for logic form

TensorLog (Cohen et al, 2016)
Neural LP (Yang et al, 2017)
NLIL (Yang, et al, 2020)
Neural-Num-LP (Wang et al, 2020)

Knowledge Graph Completion – 2021 Progress

KGC

KB embedding

Rot-Pro (Song et al., 2021)
Idempotent transformation for Transitivity
DualE (Cao et al., 2021)
Use Dual Quaternions to model relations
as the compositions of translation and
rotation operations
M²GNN (Shen et al., 2021)
Mix multiple single-curvature spaces
(spherical, hyperbolic, or Euclidean) to
model a variety of structures.
EIGAT (Zhao et al., 2021)
Incorporate global attention into GAT

Inductive logic programming

Neural Reasoning

Symbolic Reasoning

Neural-enhanced Symbolic Reasoning

Extend multi-hop neighbors, NN is to deal with the uncertainty and ambiguity, and also reduce the search space.

Symbolic-enhanced Neural Reasoning

Path-based

Graph-based

Matrix-based

Add new triplets by rules

UniKER (Cheng et al., 2021)
Directly optimize the ground
rule assignment.

Extend only one neighbor

RNNLogic (Qu et al., 2021)
Reinforce both the rule finder and
the answer reasoner.

Extend multiple neighbors

GogKR (Du et al, 2021)

Matrix operations for logic form

How to solve Knowledge Graph Question Answering?
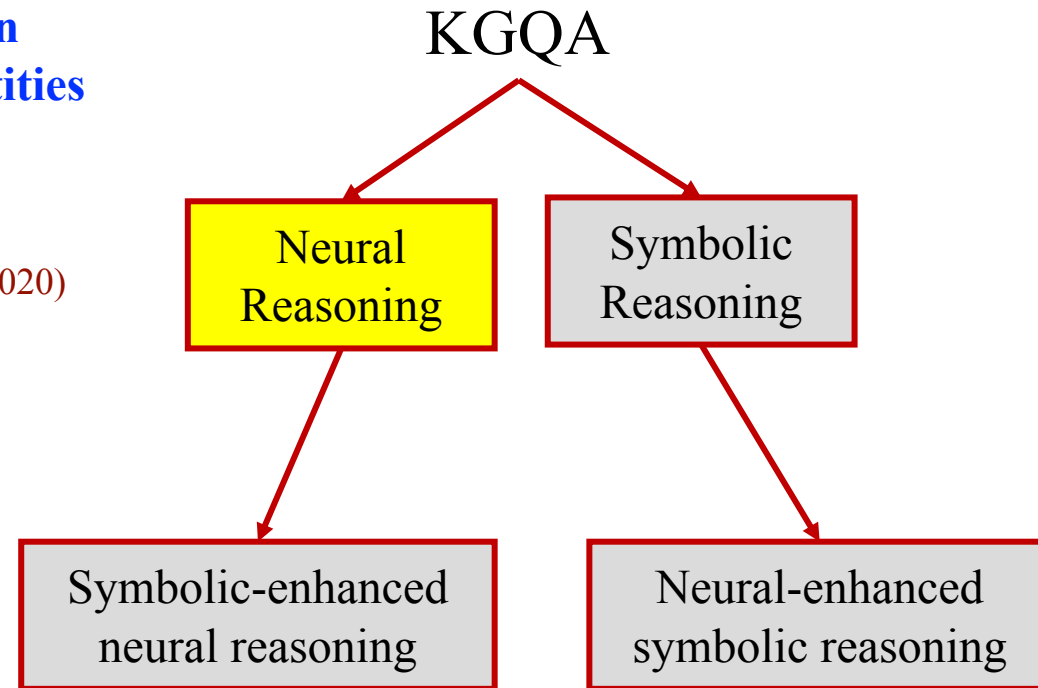
Knowledge Graph Question Answering

Bridge the gap between question and KB's entities

Multi-hop relation

BAMnet (Chen et al. 2019)
EmbedKGQA (Saxena et al., 2020)

KGQA

Neural Reasoning

Symbolic Reasoning

Symbolic-enhanced neural reasoning

Neural-enhanced symbolic reasoning

Question types

Single-relation

Multi-hop relation

Complex-logic

Constraints

Knowledge Graph Question Answering

Bridge the gap between question and KB's entities
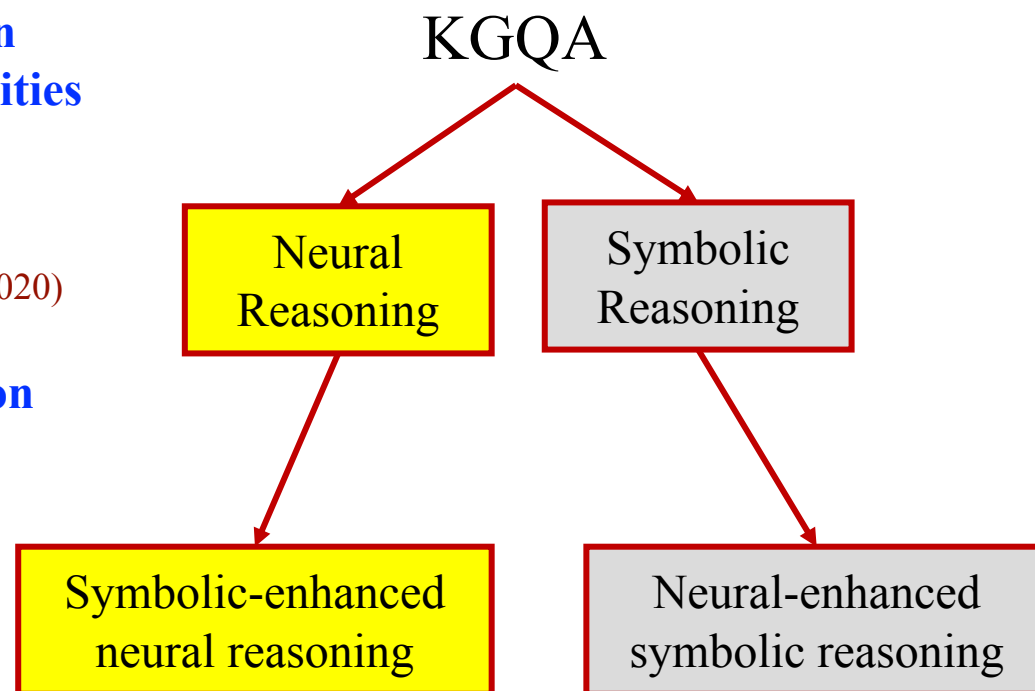
Multi-hop relation

BAMnet (Chen et al. 2019)
EmbedKGQA (Saxena et al., 2020)

Define NN for logic operation
Complex logic

GQE (Hamilton et al., 2018) :
Intersection
Query2Box (Ren et al., 2020) :
Intersection, Union
EMQL (Sun et al, 2020):
Intersection, Union

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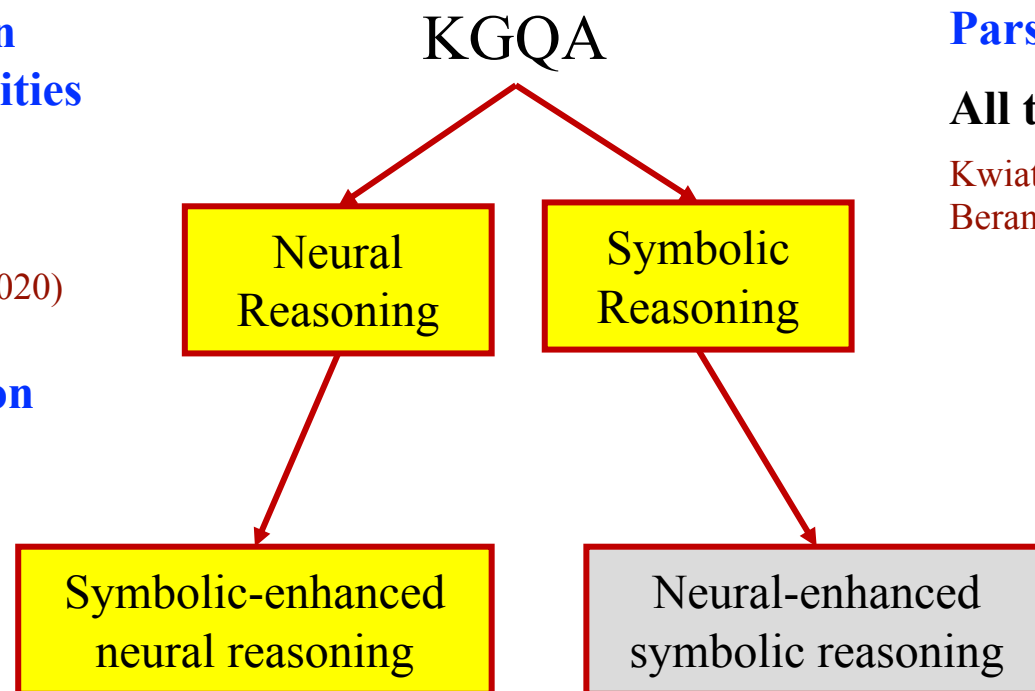GQE (Hamilton et al., 2018) :
Intersection
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KGQA

Parse questions into logic expression

All types

Kwiatkowksi et al. 2010
Berant et al., 2014

Neural Reasoning

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Knowledge Graph Question Answering

Bridge the gap between question and KB's entities

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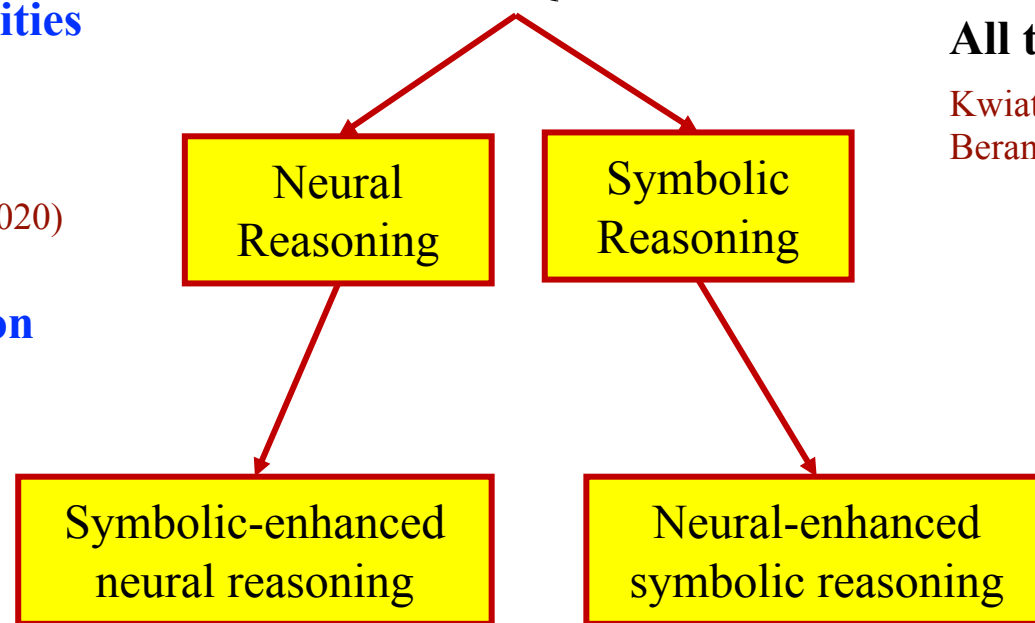EmbedKGQA (Saxena et al., 2020)

Define NN for logic operation
Complex logic

GQE (Hamilton et al., 2018) :
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KGQA

Neural Reasoning

Symbolic Reasoning

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Neural-enhanced symbolic reasoning

Parse questions into logic expression

All types

Kwiatkowksi et al. 2010
Berant et al., 2014

End-to-End

Multi-hop
Path-based
IRN (Zhou et al., 2018)
SRN (Qiu et al., 2020)
Graph-based
Graft-net (Sun et al., 2018)
PullNet (Sun et al., 2019)

Question types

Single-relation

Multi-hop relation

Complex-logic

Constraints

KGQA – 2021 Progress

Bridge the gap between question and KB's entities

Parse questions into logic expression

All types

KGQA

Multi-hop relation

KV-MemNNs (Xu et al., 2021)
Repeated KV match-and-retrieval
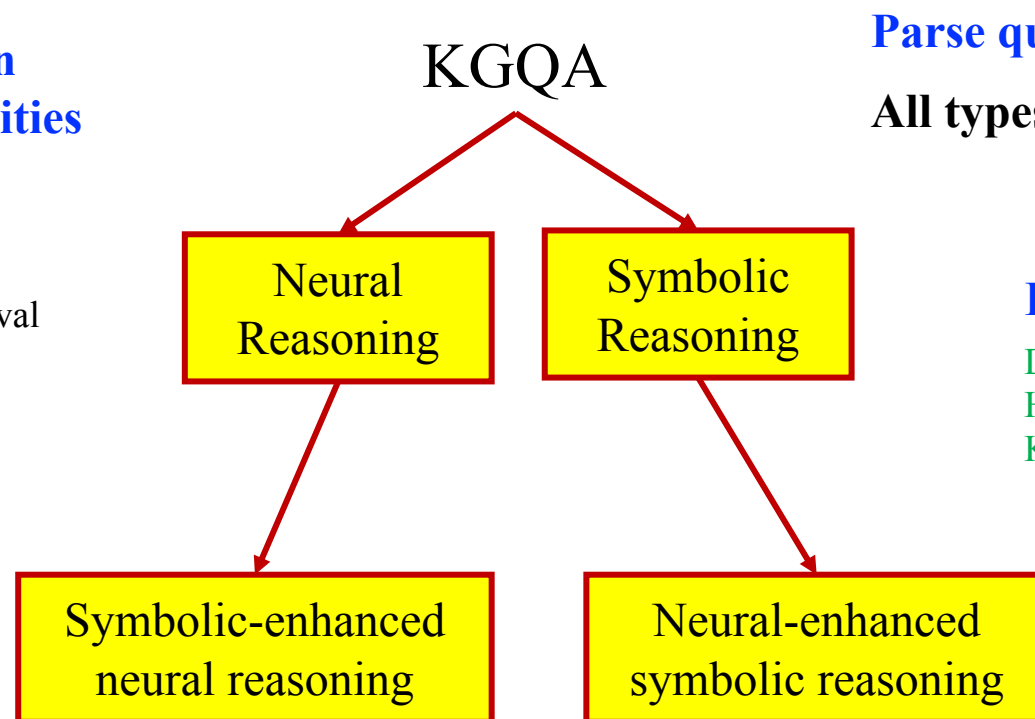Yan et al., 2021
Match question with paths

Neural Reasoning

Symbolic Reasoning

Parse and execute **All types**

Das et al., 2021 Seq2seq
Huang et al., 2021 Seq2seq
Kapanipathi, 2021 AMR->Query Graph ->SPARQL

Symbolic-enhanced neural reasoning

Neural-enhanced symbolic reasoning

Define NN for logic operation

Complex logic

LEGO (Ren et al, 2021),
Sen, 2021
Parse query tree and embedding
update simultaneously

Incorporate AMR

Nassem et al, 2021
Link AMR of question and the relations.

End-to-End

Multi-hop, Constraint

Graph-based
NSM (He et al., 2021)
Enhance the intermediate supervision
NT-NSM (Feng et al., 2021)
Numerical constraint
Qin et al., 2021
first query relation subgraph, then
rank instantiated subgraphs

Future Directions

Complex Questions

➢ Symbolic reasoning

   ➢ Can easily handle complex questions

   ➢ Depend on large annotated question-logic expression pairs.

   ➢ How to automatically generate training data?

➢ Neural reasoning

   ➢ Only question-answer pairs are required.

   ➢ Difficult to address constraints and complex logics.

   ➢ How to identify and express constraints by NN?

Generalization

➢Gu et al., 2021
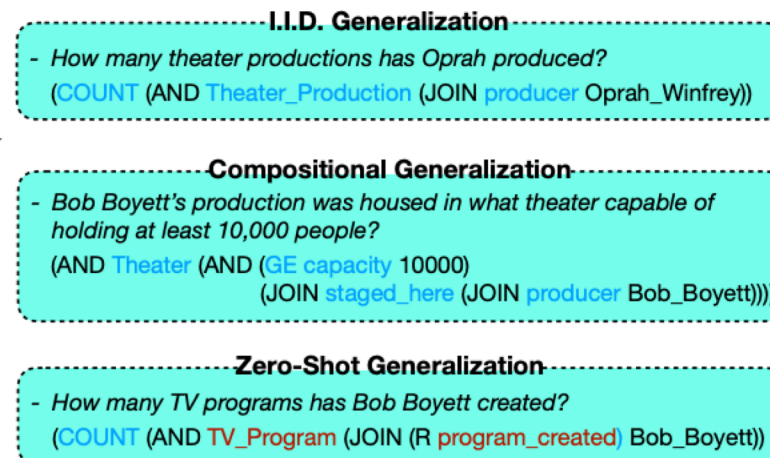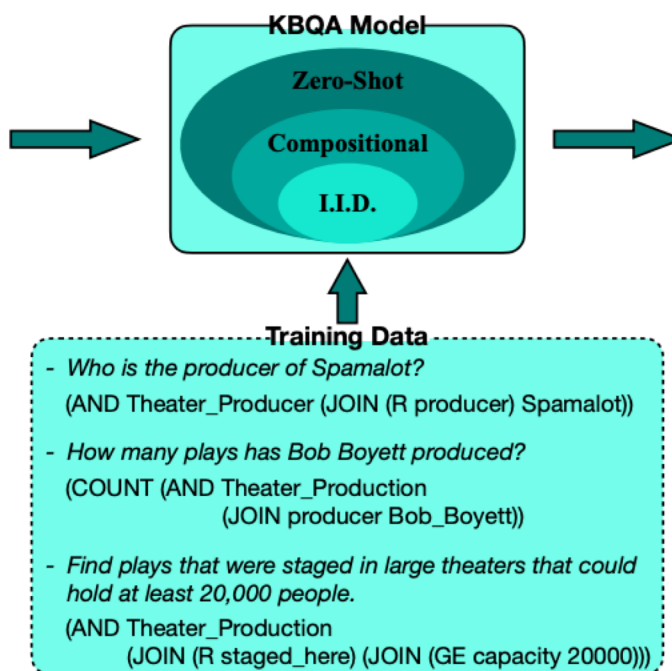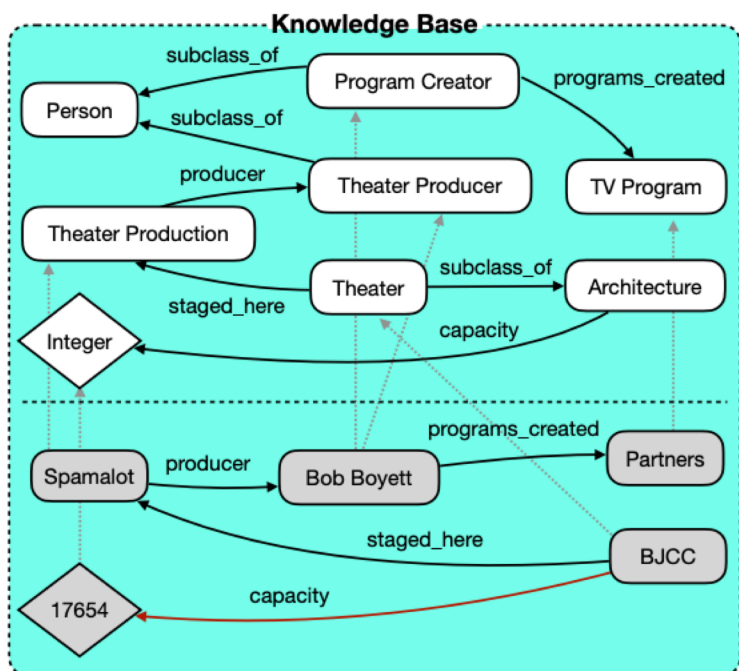
Fuse Text and KB

➤ Build entity-relation-entity from text (Fu 2019, Lu, 2019)

➤ Build entity-text from text (Sun et al., 2018, Sun et al., 2019, Han et al., 2020)

➤ Without building the new edges from text, directly encode text (Xiong et al., 2019)

➤ Unitedly encode text and KG by pre-trained LMs?

Pipeline

➢Oliya et al., 2021

    ➢Incorporate the entity resolution result into the differentiable KB.

➢Srivastava et al. 2021

    ➢Multi-task learning.

    ➢Share BERT encoders across tasks.

        ➢Topic entity identification

        ➢Entity linking

        ➢Relation detection

        ➢Answer reasoning

Temporal Knowledge Graph

➢ (Barack Obama, held position, President of USA, 2008, 2016)

Reasoning	Example Template	Example Question
Simple time	When did {head} hold the position of {tail}	*When did Obama hold the position of President of USA*
Simple entity	Which award did {head} receive in {time}	*Which award did Brad Pitt receive in 2001*
Before/After	Who was the {tail} {type} {head}	*Who was the President of USA before Obama*
First/Last	When did {head} play their {adj} game	*When did Messi play their first game*
Time join	Who held the position of {tail} during {event}	*Who held the position of President of USA during WWII*

➢ Saxena et al., 2021

   ➢ A temporal KBQA dataset, Revised EmbedKGQA (temporal KG embeding)

➢ Li et al., 2021

   ➢ Temporal KBC

Conversational KBQA

Q1: What novel has the character named Nick Carraway?	
R1: The Great Gatsby	
Q2: Where is Jay Gatsby born?	The Great Gatsby
R2: North Dakota	
Q3: What is the name of the author?	The Great Gatsby
R3: F. Scott Fitzgerald	
Q4: What's his first novel?	F. Scott Fitzgerald
R4: This Side of Paradise	
Q5: Who was his child?	F. Scott Fitzgerald
R5: Frances Scott Fitzgerald	

➢ Solve the transitions of focal entities

➢ Dataset: Complex sequential question answering (CSQA), ConvQuestions (5 turn dialog)

➢ Marion et al., 2021

➢ Lan et al., 2021

2021 References of KGC

[Song, 2021]Tengwei Song, Jie Luo, and Lei Huang. Rot-Pro: Modeling Transitivity by Projection in Knowledge Graph Embedding. In NIPS'2021.

[Cao, 2021] Zongsheng Cao, Qianqian Xu, et al. Dual Quaternion Knowledge Graph Embeddings. In AAAI'2021.

[Wang, 2021] Shen Wang, Xiaokai Wei, et al. Mixed-Curvature Multi-Relational Graph Neural Network for Knowledge Graph Completion. In WWW'2021.

[Zhao, 2021] Yu Zhao, Han Zhou, et al. Incorporating Global Information in Local Attention for Knowledge Representation Learning.

[Qu, 2021] Meng Qu, Junkun Chen, et al. RNNLogic: Learning Logic Rules for Reasoning on Knowledge Graphs. In ICLR'2021.

[Cheng, 2021] Kewei Cheng, Ziqing Wang, et al. UniKER: A Unified Framework for Combining Embedding and Definite Horn Rule Reasoning for Knowledge Graph Inference. In EMNLP'2021.

2021 References of KGQA

[Das, 2021] Rajarshi Das, Manzil Zaheer, et al. Case-based Reasoning for Natural Language Queries over Knowledge Bases. In EMNLP'2021.

[Yan, 2021] Yuanmeng Yan, Rumei Li, et al. Large-Scale Relation Learning for Question Answering over Knowledge Bases with Pre-trained Language Models. In EMNLP'2021.

[Qin, 2021] Kechen Qin, Cheng Li, et al. Improving Query Graph Generation for Complex Question Answering over Knowledge Base. In EMNLP'2021.

[Huang, 2021] Xin Huang, Jung-jae Kim et al. Unseen Entity Handling in Complex Question Answering over Knowledge Base via Language Generation. In EMNLP'2021.

[Sen, 2021] Priyanka Sen, Amir Saffari, et al. Expanding End-to-End Question Answering on Differentiable Knowledge Graphs with Intersection.In EMNLP'2021

[Oliya, 2021] Armin Oliya, Amir Saffari, et al. End-to-End Entity Resolution and Question Answering Using Differentiable Knowledge Graphs. In EMNLP'2021.

[Naseem, 2021] Tahira Nassem, Srinivas Ravishankar, et al. A Semantics-aware Transformer Model of Relation Linking for Knowledge Base Question Answering. In ACL'2021.

[Kapanipathi, 2021] Pavan Kapanipathi , Ibrahim Abdelaziz, et al. Leveraging Abstract Meaning Representation for Knowledge Base Question Answering. ACL'2021

[Srivastava, 2021] Saurabh Srivastava, Mayur Patidar et al. Complex Question Answering on knowledge graphs using machine translation and multi-task learning. EACL'2021.

[Gu, 2021] Yu Gu, Sue Kase, et al. Beyond I.I.D.: Three Levels of Generalization for Question Answering on Knowledge Bases. WWW'2021.

[Saxena, 2021] Apoorv Saxena, Soumen Chakrabarti, et al. Question Answering Over Temporal Knowledge Graphs. In ACL'2021.

[Li, 2021] Zixuan Li, Xiaolong Jin, et al. Search from History and Reason for Future: Two-stage Reasoning on Temporal Knowledge Graphs. In ACL'2021.

[Sun, 2021] Haitian Sun, Pat Verga, et al. Reasoning Over Virtual Knowledge Bases With Open Predicate Relations. In ICML'2021.

[Marion, 2021] Pierre Marion, Paweł Krzysztof Nowak et al. Structured Context and High-Coverage Grammar for Conversational Question Answering over Knowledge Graphs. In EMNLP'2021.

[Lan, 2021] Yunshi Lan and Jing Jiang. Modeling Transitions of Focal Entities for Conversational Knowledge Base Question Answering. In ACL'2021.

[Feng, 2021] Yu Feng, Jing Zhang, et al. A Pretraining Numerical Reasoning Model for Ordinal Constrained Question Answering on Knowledge Base. In Findings of EMNLP'2021.

[He, 2021] Gaole He, Yunshi Lan, et al. Improving Multi-hop Knowledge Base Question Answering by Learning Intermediate Supervision Signals. In WSDM'2021

Thank You