Current and Future Trends of Neural Knowledge Graph Representation and Reasoning

Monireh Ebrahimi

Aaron Eberhart

Pascal Hitzler

Data Semantics Laboratory (DaSe Lab)

Kansas State University

http://www.daselab.org

Bassem Makni

Arizona State University

Federico Bianchi

Bocconi University

Deductive Reasoning

- Formal logic
- Deductive inference – mathematically defined
- For many logics, deductive inference is algorithmizeable
- Sometimes decideable, sometimes semi-decideable

- Reasoning algorithms are highly complex and often non-trivial.
- Most interesting logics are NP-complete or worse.

Logic is the Calculus of Computer Science.

$$\forall x \forall y (A(x,y) \rightarrow B(x,x)) \wedge (B(x,y) \rightarrow C(x,y)) \models \exists z (A(z,z) \wedge C(z,z))$$

Reasoning as Classification

- Given a set of logical formulas (a theory).
- Any formula expressible over the same language is either
  - a logical consequence or
  - not a logical consequence.
- This can be understood as a classification problem for machine learning.
- It turns out to be a really hard machine learning problem.

Knowledge Materialization

- Given a set of logical formulas (a theory).
- Produce all logical consequences under certain constraints.
- Without the qualifier this is in general not possible as the set of all logical consequences is infinite.
- So we have to constrain to consequences of, e.g., a certain syntactic form. For relatively simple logics, this is often reasonably possible.

Deep Deductive Reasoners

- We trained deep learning systems to do deductive reasoning.

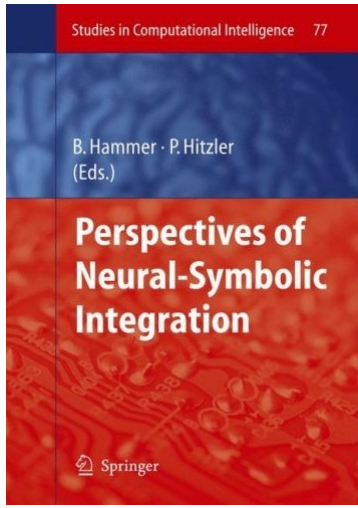
- Why is this interesting?
  - For dealing with noisy data (where symbolic reasoners do very poorly).
  - For speed, as symbolic algorithms are of very high complexity.
  - Out of principle because we want to learn about the capabilities of deep learning for complicated cognitive tasks.

  - To perhaps begin to understand how our (neural) brains can learn to do highly symbolic tasks like formal logical reasoning, or in more generality, mathematics.
    A fundamental quest in Cognitive Science.

Some Background

Workshop Series on Neural-Symbolic Learning and Reasoning, Since 2005.
http://neural-symbolic.org/

Barbara Hammer and Pascal Hitzler (eds), Perspectives of Neural-Symbolic Integration, Springer, 2007

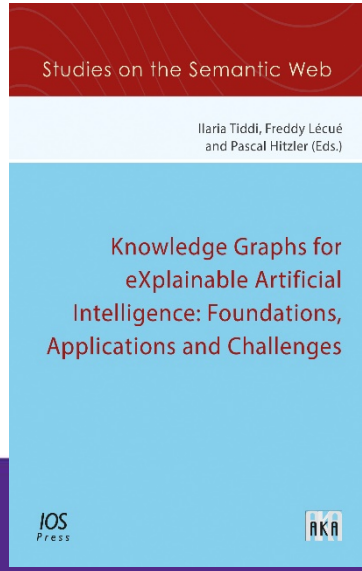


Neural-Symbolic Learning and Reasoning: A Survey and Interpretation

Tarek R. Besold, Artur d'Avila Garcez, Sebastian Bader, Howard Bowman, Pedro Domingos, Pascal Hitzler, Kai-Uwe Kuehnberger, Luis C. Lamb, Daniel Lowd, Priscila Machado Vieira Lima, Leo de Penning, Gadi Pinkas, Hoifung Poon, Gerson Zaverucha

https://arxiv.org/abs/1711.03902 (2017)

Ilaria Tiddi, Freddy Lecue, Pascal Hitzler (eds.), Knowledge Graphs for eXplainable Artificial Intelligence: Foundations, Applications and Challenges. Studies on the Semantic Web Vol. 47, IOS Press, 2020.



Schedule

Openning Session by *Pascal Hitzler:* **Agenda & Neuro-Symbolic Integration: Deduvtive Reasoners**

Talk 1 by *Bassem Makni:* **Deep learning for noise-tolerant RDFS reasoning**

Talk 2 by *Monireh Ebrahimi:* **Neuro-Symbolic Deductive Reasoning for Cross-Knowledge Graph Entailment**

Talk 3 by *Federico Bianchi:* **Complementing Logical Reasoning with Sub-symbolic Commonsense**Talk 3 Video

Talk 4 by *Aaron Eberhart:* **Completion Reasoning Emulation for the Description Logic EL+**

Thanks!

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Tarek R. Besold, Artur d'Avila Garcez, Sebastian Bader, Howard Bowman, Pedro Domingos, Pascal Hitzler, Kai-Uwe Kuehnberger, Luis C. Lamb, Daniel Lowd, Priscila Machado Vieira Lima, Leo de Penning, Gadi Pinkas, Hoifung Poon, Gerson Zaverucha, Neural-Symbolic Learning and Reasoning: A Survey and Interpretation. https://arxiv.org/abs/1711.03902 (2017)

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Bassem Makni, James Hendler, Deep learning for noise-tolerant RDFS reasoning. Semantic Web 10(5): 823-862 (2019)

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Ilaria Tiddi, Freddy Lecue, Pascal Hitzler (eds.), Knowledge Graphs for eXplainable Artificial Intelligence: Foundations, Applications and Challenges. Studies on the Semantic Web Vol. 47, IOS Press/AKA Verlag, 2020.

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