

DeepProbLog: Neural Probabilistic Logic Programming

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Real-life problems involve two important aspects.

Sub-symbolic perception



Reasoning with knowledge under uncertainty

Stop in front of a red light	P(light = red) = 0.9
Obey the speed limit	P(obj1 = car) = 0.8
Be in the correct lane	P(obj1 turn right) = 0.7

Deep Learning Probabilistic logic program ProbLog = ProbLog + neural predicate

The neural predicate



- Classifier defines a probability distribution over its output
- Uncertainty in the prediction
- Neural predicate: output = probabilistic choices in program
- No changes needed in the ProbLog inference or its semantics
- ProbLog can natively calculate the gradient

Perception





Perception





Reasoning





Related work

Related work	DeepProbLog
Logic is made less expressive	Full expressivity is retained
Logic is pushed into the neural part	Clean separation
Fuzzy logic	Probabilistic logic
Language semantics is unclear	Clear semantics

- Neural-symbolic integration (Garcez)
- Logical constraints as a regularizer (Xu, Diligenti, ...)
- Differentiable logical framework (Rocktäschel and Riedel, Evans and Grefenstette)
- Differentiable interpreters (Graves, Bosnjak)

• ...

Example task: MNIST addition

35041+921=?

- Only labeled sums, not single digits
- Train using only neural networks? Not suited!
- DeepProbLog can solve this:
 - Neural predicate
 - From pixels to distribution over digits
 - NN trained from scratch
 - Logic:
 - Combine predictions into larger numbers
 - Perform addition

Unknown distribution









Conclusion

DeepProbLog: Neural Probabilistic Logic Programming

- Integration of DL and PLP
- Probabilistic
- Clean semantics, clear separation
- Retain power of both worlds
- Power of ProbLog

Code is available at:

https://bitbucket.org/problog/deepproblog

Poster #118 DEPARTMENT OF COMPUTER SCIENCE **KU LEUVEN** DeepProbLog: Neural Probabilistic Logic Programming Robin Manhaeve1, Sebastijan Dumančić1, Angelika Kimmig2, "Thomas Demeester3, 'Luc De Raedt' ¹KU Leuven, ²Cardiff University, ³ Ghent University - imec, ³Joint last authors probin.manhaeve@cs.kuleuven.be Integrating reasoning and perception Integrating low-level perception with high-level reasoning is one of the oldest. and ver aProbLog: ProbLog + Semirings most active open challenges in AI. Gradient semiring: elements of the form $(p, \frac{\partial p}{\partial n})$ Low-level perception is typically handled by deep learning. $(a_1, d_2) \oplus (b_1, b_2) = (a_1 + b_1, d_2 + b_2)$ $L(f) = (p, \vec{0})$ High-level reasoning is typically addressed using (probabilistic) logical representations $(a_1, \vec{a_2}) \otimes (b_1, \vec{b_2}) = (a_1 b_1, b_1 \vec{a_2} + a_1 \vec{b_2})$ $L(f_i) = (p_i, \mathbf{e}_i)$ for $t(p_i) :: f_i$ with learnable p_i and inference $L(\neg f) = (1 - p, -\nabla p)$ with $L(f) = (p, \nabla p)$ Joining the full flexibility of high-level probabilistic reasoning with the representation flip(coini). flip(coin2). nm(m_side.C_(beads.talls)):sside(C_X) ((0.5):result(0.5):tblue. beads :- flip(X), side(X,beads). wim :- beads. wim :- beads. wim :- beads. power of deep neural networks is still an open problem Instead of integrating reasoning capabilities into a complex neural network architectur we proceed the other way round DeepProbLog is a probabilistic logic programming language incorporating deep learning It contains expressive probabilistic-logical modeling and reasoning It encapsulates general-purpose neural networks It can be trained end-to-end on examples Our approach has: The expressiveness and strengths of both worlds A clean separation between both side T1: addition(13,15,8): Classify the sum of pair of MNIST digits A clear semantics T2: addition([[],[],[],[],63): Classify the sum of two multi-digit numbe DeepProbLog Prolog: ProbLog + Probabilities (Probabilistic) facts 0.1::burglary. 0.2::ea 5000 10000 15000 20000 25000 T3, T4, T5: Learning to perform addition, sorting and WAP problems[1 Sorting (T4): Training length Addition (T3): training length DeepProbl og: Probl og + Neural predicates Neural Annotated Disjunction (nAD): $nn(m_q, \vec{t}, \vec{u}) :: q(\vec{t}, u_1); ...; q(\vec{t}, u_n) := b_1, ..., b_m.$ aining length on T4 -Evaluates a neural network m_n on input it 24 on GPU 24 on CPU DeepProbLog on CPU It defines a probability distribution over up up T5: Accuracy = 96 - 97% T6: A task in which we model a probabilistic game in which Neural networks are trained from scratch to recognize colours and heads / tail Classify the sum of pairs of MNIST images. e.g. 3 + 5 = The input is coins (MNIST images), noisy RGB triplets and the outcome Encode the background knowledge of the sum Probabilistic parameters need to be trained jointly with the neural networks We show that DeepProbLog can achieve all this jointly, achieving 100% accurac Define the neural predicate for classifying the digits nn(m digit, X, [0, ..., 9]) :: digit(X, 0); ...; digit(X, 9) Define the addition Conclusion addition(X,Y,Z):-digit(X,X2),digit(Y,Y2),ZisX2+Y2.We introduce a framework where neural networks and probabilistic logic programmin are integrated in a way that exploits the full expressiveness and strengths of both worlds The neural predicate evaluates the neural network This was accomplished by extending an existing probabilistic logic programming I . ; 0.2 :: digit(2,2) ; 0.8 :: digit((2,3) ; ... guage. ProbLog, with neural predicates ... ; 0.7 :: digit(3,5) ; 0.3 :: digit(3,6) ; We evaluated it on experiments that demonstrate combined symbolic and sub-symbolic easoning and learning, program induction, and probabilistic logic programming. uerv(addition(E. M.X) addition(3, 5,7):0.14 addition(3,5,8):0.62 addition(3,5,9):0.24 Matko Bošnjak, Tim Rocktäschel, and Sebastian Riedel. Programming with a differentiable forth interpreter In Proceedings of the 34th International Conference on Machine Learning, volume 70, pages 547–556, 2017 KU Leuven Department of Computer Science Celestijnenlaan 200A box 2402 $\widehat{\blacksquare}$ fwo DTAI GHENT 3001 Leuven Belgium