dPASP

Differentiable Probabilistic Answer Set Programming For Neurosymbolic Learning and Reasoning

Renato Lui Geh, Jonas Gonçalves, Igor Cataneo Silveira, Denis Deratani Mauá, Fabio Gagliardi Cozman

University of São Paulo

{renatolg,jonasrlg,igorcs,ddm}@ime.usp.br, fgcozman@usp.br

GitHub

Learn dPASP!

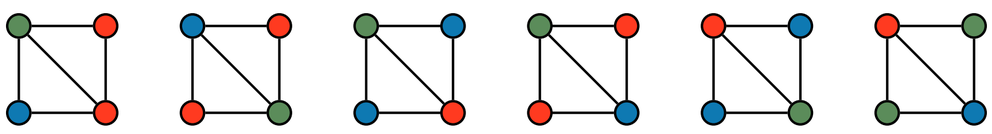
Answer Set Programming

is a powerful declarative language to describe **NP-hard combinatorial problems**

Example: 3-coloring a 4-node graph

```
% graph has 4 nodes
node(1). node(2). node(3). node(4).
% and the following edges
edge(1,2). edge(2,3). edge(3,4). edge(1,4). edge(1,3).
% graph is undirected
edge(X,Y) :- edge(Y,X).
% adjacent nodes must be colored differently
:- not conflict(X,Y), edge(X,Y), color(X,C), color(Y,C).
% a node must have at least 1 of 3 colors
color(X,red); color(X,blue); color(X,green) :- node(X).
```

Stable models:



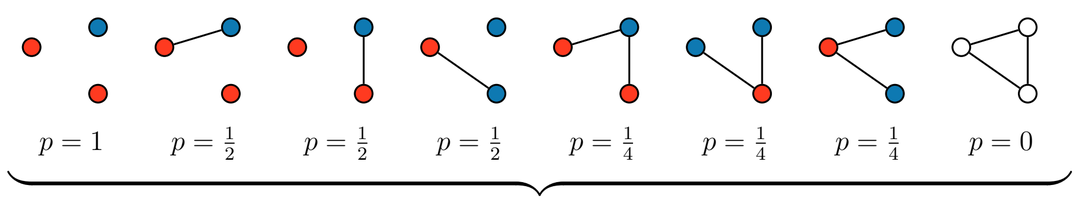
Probabilistic Answer Set Programming

extends ASP with independent **probabilistic choices** to encode uncertain knowledge

Example: 2-colorability of random graph

```
% graph has 3 nodes
node(1).  node(2).  node(3).
% prob. 0.5 of having an (undirected) edge between two nodes
0.5::edge(X,Y) :- node(X), node(Y), X < Y.
edge(X,Y) :- edge(Y,X).
% conflict if neighbors have same color
conflict :- edge(X,Y), color(X,C), color(Y,C).
% a node must have at least 1 of 2 colors
color(X,red); color(X,blue) :- node(X).
% a graph is colorable if it has no conflicts
colorable :- not conflict.
% what is the prob. of a random graph being colorable ℙ(c)?
#query colorable.
```

Probabilities and stable models:



Semantics

tells us **how to interpret** programs both **logically** and **probabilistically**

Example: the barber paradox

```
% barber shaves every villager who does not shave themselves
shaves(X, Y) :- barber(X), villager(Y), not shaves(Y, Y).
villager(a). barber(b). 0.5::villager(b).
% does the barber shave themselves?
#query shaves(b, b).
```

Which **semantics** does dPASP support?

Logic semantics

- ▷ STABLE
- ▷ L-STABLE
- ▷ PARTIAL
- ▷ SMPROBLOG

Probabilistic semantics

- ▷ CREDAL
- ▷ MAX-ENT

Neural Answer Set Programming

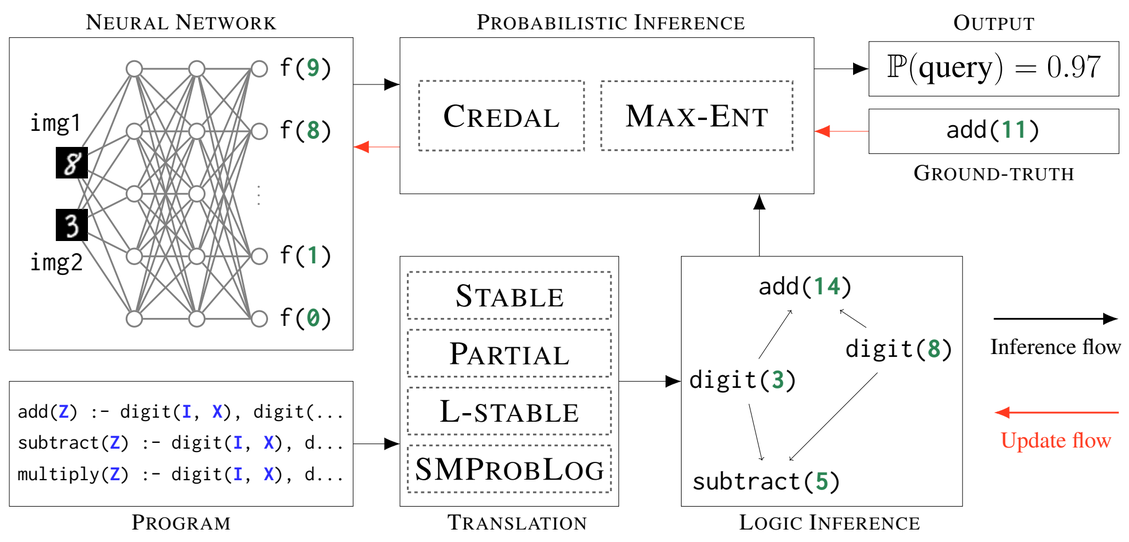
associates probability annotation with the output of neural classifiers

Example: Parsing arithmetic expressions, e.g.

$$\texttt{X} + \texttt{Y} = f(\boxed{8}) + f(\boxed{3}) = ?$$

```
% neural rule
?::digit(Image, {0..9}) :- data(Image).
% data loaders -- interact with Python code
data(img1) ~ test(@mnist_test), train(@mnist_train).
data(img2) ~ test(@mnist_test), train(@mnist_train).
% prob. answer set program
add(Z) :- digit(I, X), digit(J, Y), Z = X + Y.
subtract(Z) :- digit(I, X), digit(J, Y), Z = X - Y.
multiply(Z) :- digit(I, X), digit(J, Y), Z = X * Y.
% learn the program end-to-end and pass learning parameters
#learn @mnist_sum, lr = 1., niters = 5, ..., batch = 1000.
% inference: what is the probability of X + Y = 14 given X = 8?
#query add(11) | digit(img1, 8).
```

How does dPASP **work**?



Experiments

How much **faster** is dPASP on the MNIST Add?