Extending neurosymbolic AI to infinity and beyond

Lennert De Smet
Promotor: Luc De Raedt

The most impressive AI models can not be trusted

Large language models predict **wrong** answers
and don't provide **trustworthy** explanations

The most impressive AI models can not be trusted

Large language models predict **wrong** answers
and don't provide **trustworthy** explanations

This is fine for simple tasks
but **dangerous** for sensitive applications

We need more expressive and scalable reasoning to make neural models trustworthy

Neurosymbolic AI builds models where
neural predictions are influenced by reasoning

We need more expressive and scalable reasoning to make neural models trustworthy

Neurosymbolic AI builds models where
neural predictions are influenced by reasoning

Expressive and scalable reasoning means
reasoning quickly over finite and infinite spaces

We need more expressive and scalable reasoning to make neural models trustworthy

Neurosymbolic AI builds models where
neural predictions are influenced by reasoning

Expressive and scalable reasoning means
reasoning quickly over finite and infinite spaces

We create expressive neurosymbolic systems
with improved scalability

1. The building blocks needed to express knowledge
2. Approximate probabilistic inference improves scalability
3. Gradient estimation maintains differentiability

1. The building blocks needed to express knowledge
2. Approximate probabilistic inference improves scalability
3. Gradient estimation maintains differentiability

The building blocks needed to express knowledge

Our language is formal mathematical logic
represented using logic programming

The building blocks needed to express knowledge

Our language is formal mathematical logic
represented using logic programming

```
light ~ cat([p_r, p_o, p_g]).
speed ~ normal(μ, σ).
```

Facts express **foundational knowledge**,
which defines current uncertain belief

The building blocks needed to express knowledge

Our language is formal mathematical logic
represented using logic programming

```
light ~ cat([p_r, p_o, p_g]).
speed ~ normal(μ, σ).
```

Facts express **foundational knowledge**,
which defines current uncertain belief

```
safe :-
  light = r, speed < 5.
safe :-
  light = o, speed < 20.
safe :-
  light = g, speed > 10.
```

Rules express **higher-order knowledge**,
which defines constraints that should hold

1. The building blocks needed to express knowledge
2. **Approximate probabilistic inference improves scalability**
3. Gradient estimation maintains differentiability

Approximate probabilistic inference improves scalability

Probability of satisfying a logical property over a neural distribution

$$\mathbb{P}(q) = \int \mathbb{1}_{\omega \vDash q} \; p_{\theta}(\omega) \; d\omega$$

Approximate probabilistic inference improves scalability

Probability of satisfying a logical property over a neural distribution

$$\mathbb{P}(q) = \int \mathbb{1}_{\omega \vDash q}\, p_{\theta}(\omega)\, d\omega$$

We decomposed integration into smaller problems
and use approximate probabilistic inference

1. The building blocks needed to express knowledge
2. Approximate probabilistic inference improves scalability
3. **Gradient estimation maintains differentiability**

Gradient estimation maintains differentiability to optimise neural networks through logic

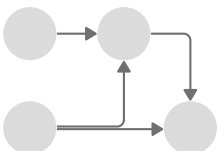
$\approx \nabla_{\boldsymbol{\theta}} \mathbb{P}(\mathrm{q})$

Gradients are needed to improve neural nets
based on the provided expert knowledge

Gradient estimation maintains differentiability to optimise neural networks through logic

$$\approx \nabla_{\boldsymbol{\theta}} \mathbb{P}(\mathrm{q})$$

Gradients are needed to improve neural nets
based on the provided expert knowledge



We decomposed the gradient for lower variability
leading to improved optimisation

1. The building blocks needed to express knowledge
2. Approximate probabilistic inference improves scalability
3. Gradient estimation maintains differentiability

Our developments lead to a framework for expressive and scalable neurosymbolic AI

A framework that…

…can express knowledge
ranging from finite to infinite domains

Our developments lead to a framework for expressive and scalable neurosymbolic AI

A framework that…

…can express knowledge
ranging from finite to infinite domains

Expressivity used in energy grid use case (Vito)

Our developments lead to a framework for expressive and scalable neurosymbolic AI

A framework that…

…can express knowledge
ranging from finite to infinite domains

…scales under certain conditions
but different approaches are necessary

Our developments lead to a framework for expressive and scalable neurosymbolic AI

A framework that…

…can express knowledge
ranging from finite to infinite domains

…scales under certain conditions
but different approaches are necessary

…controls neural networks through optimisation
for tasks like detection and image generation

You can trust LLMs at least a little more in the future because of neurosymbolic AI