Neuro-Symbolic Agents: Reason, Act, and Learn Faithfully in the Complex World

TECHNISCHE UNIVERSITÄT DARMSTADT

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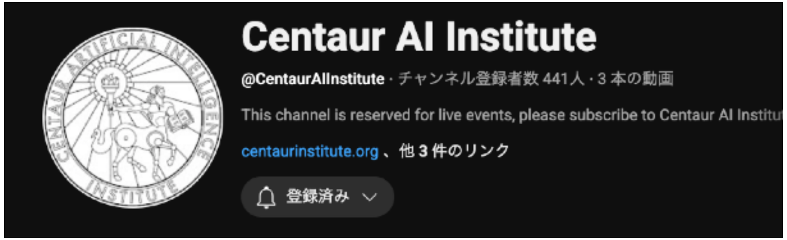
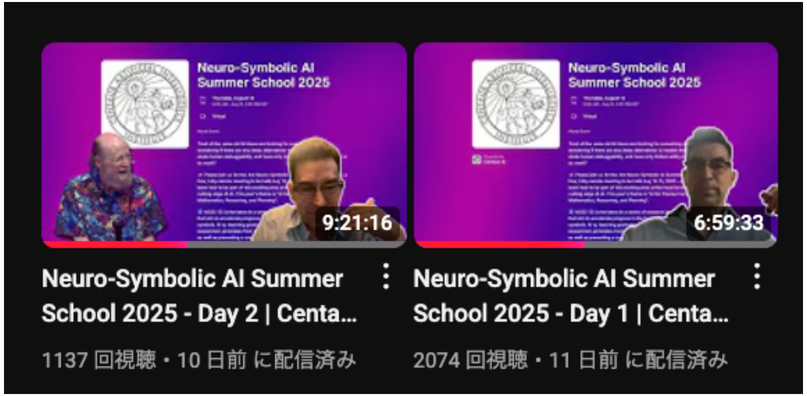
August 26, 2025

Neuro-Symbolic AI Summer School

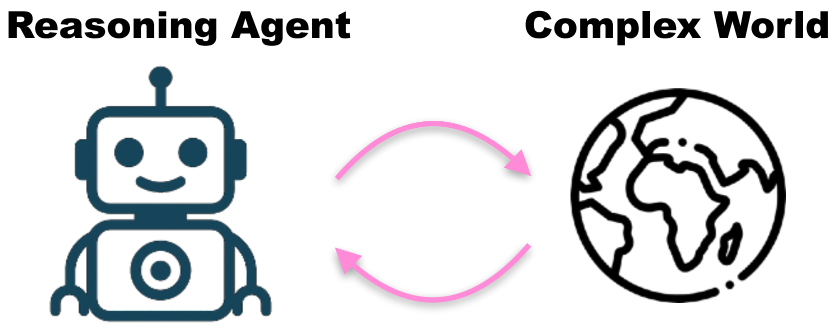




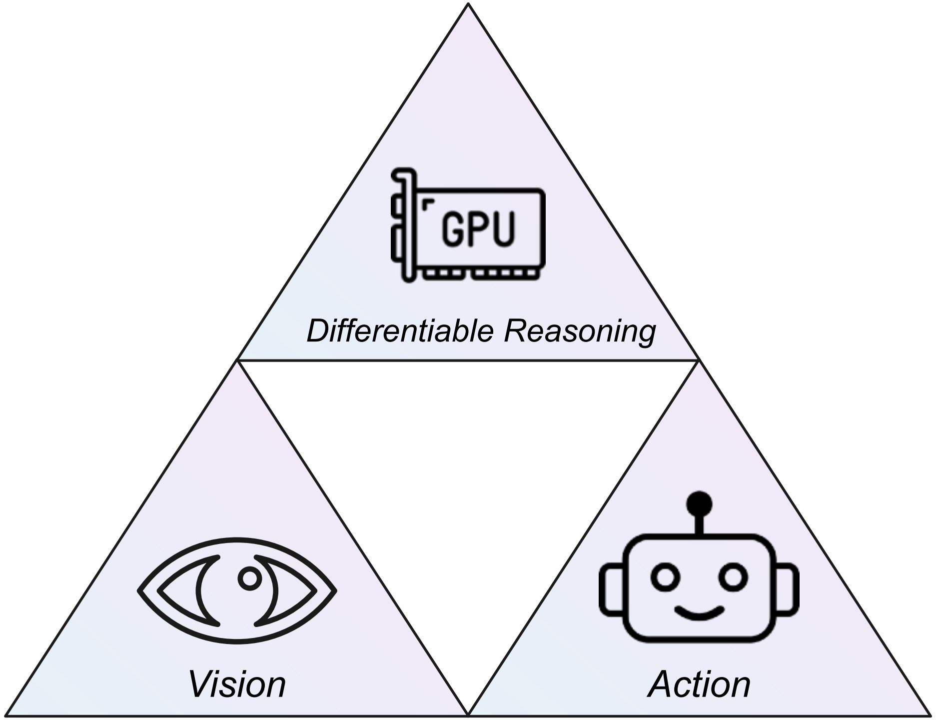
Outline

My research goal:

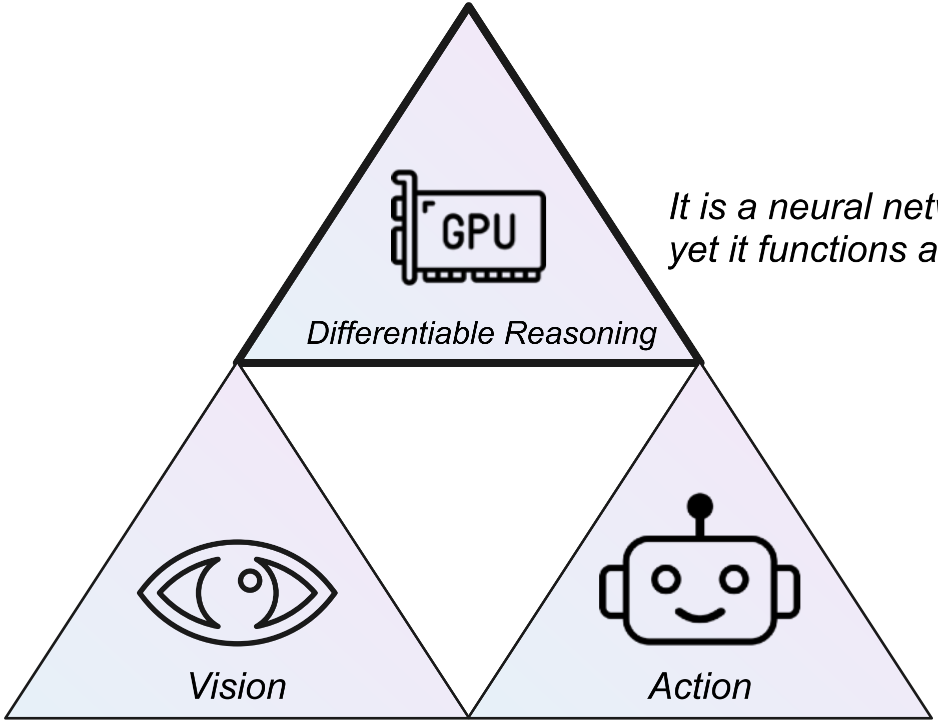
An intelligent agent that can:
- *perform **faithful reasoning** on noisy observations*
- ***act effectively** interacting with complex environments*
- ***learn efficiently** from less data*



Research Overview



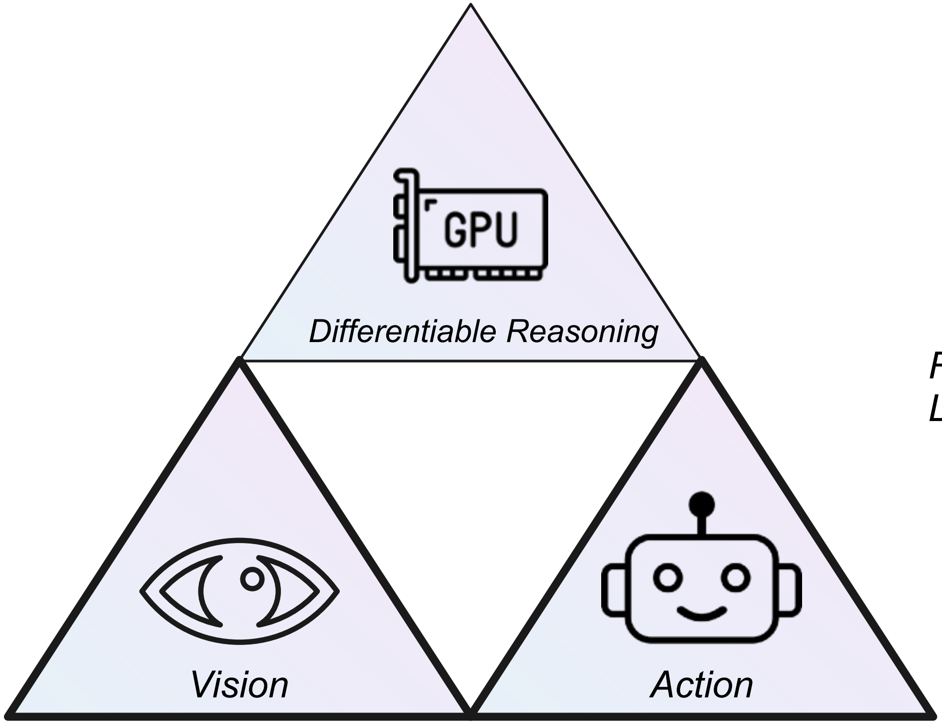
Research Overview



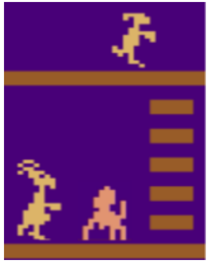
It is a neural network,
yet it functions as a logical reasoner.

Research Overview

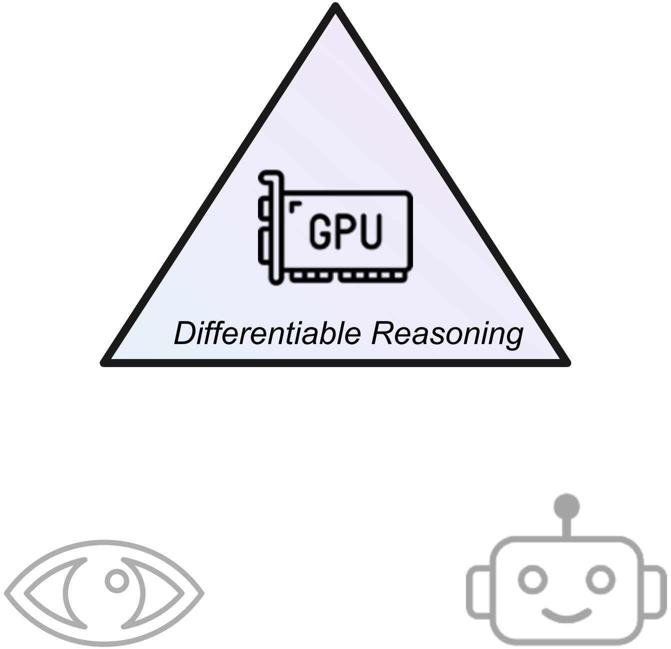
Segment objects with complex prompts



Reasoning to act,
Learning from experiences



Research Overview



Logical Reasoning... Differentiably?

Input:

```
∀x (human(x) → mortal(x))

human(socrates).
```

Logical Reasoning... Differentiably?

Input:

```
∀x (human(x) → mortal(x))

human(socrates).
```

Output:

```
mortal(socrates).
```

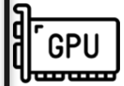
Logical Reasoning... Differentiably?

Input:

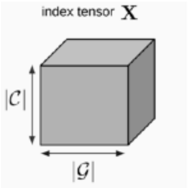
```
∀x (human(x) → mortal(x))

human(socrates).
```

✅ gradient-based learning

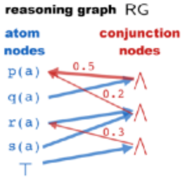
✅ scalable GPU inference



Tensor Encoding [1,2]



GNN Encoding [3]



Output:

```
mortal(socrates).
```

[1] Evans, Grefenstette: Learning Explanatory Rules from Noisy Data. *JAIR* 2018
[2] Shindo, Pfanschilling, Dhami, Kersting: αILP: Thinking Visual Scenes as Differentiable Logic Programs. *Mach. Learn. 2023*
[3] Shindo, Pfanschilling, Dhami, Kersting: Learning Differentiable Logic Programs for Abstract Visual Reasoning. *Mach. Learn.* 2024

Perception + Differentiable Reasoning

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Raw Input

Image

Text

[1] Evans, Grefenstette: Learning Explanatory Rules from Noisy Data. *JAIR* 2018
[2] Shindo, Pfanschilling, Dhami, Kersting: αILP: Thinking Visual Scenes as Differentiable Logic Programs. *Mach. Learn. 2023*
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Perception + Differentiable Reasoning

Raw Input

Image

Text

perception

Input

`0.5: human(socrates)`

[1] Evans, Grefenstette: Learning Explanatory Rules from Noisy Data. *JAIR* 2018
[2] Shindo, Pfanschilling, Dhami, Kersting: αILP: Thinking Visual Scenes as Differentiable Logic Programs. *Mach. Learn. 2023*
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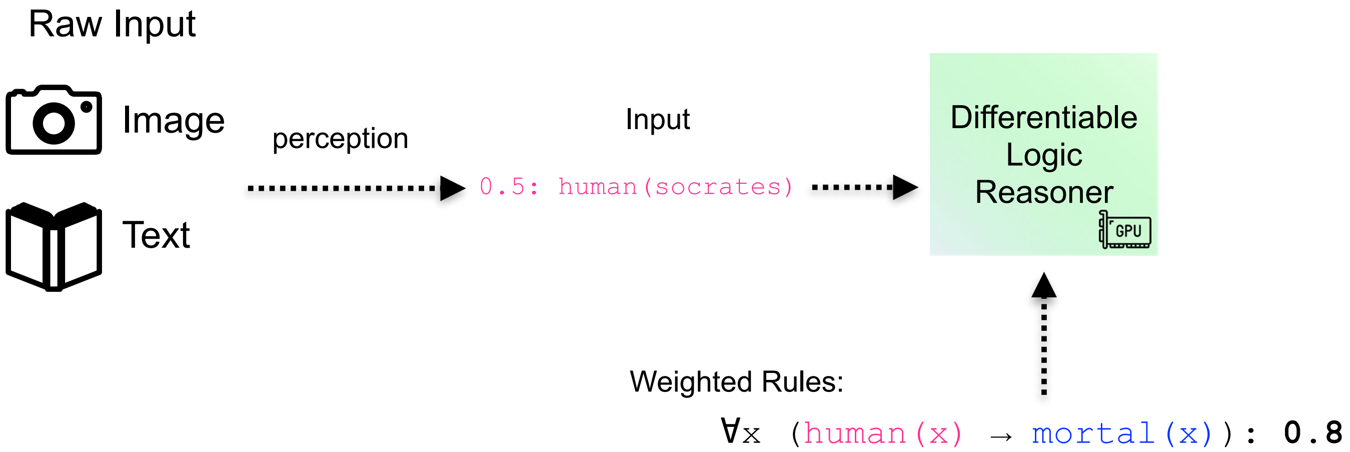
Perception + Differentiable Reasoning



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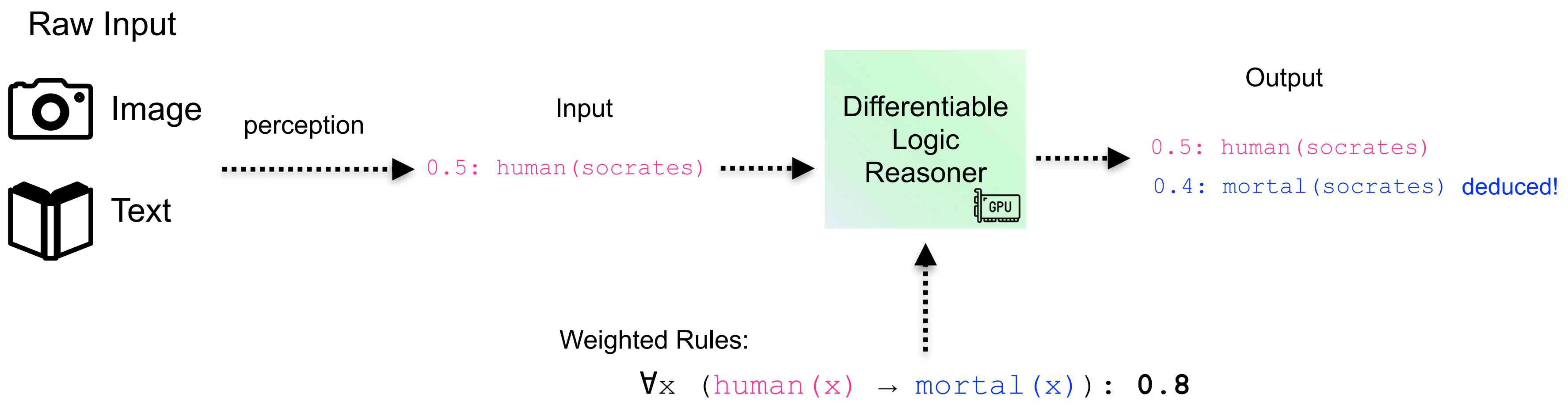
Perception + Differentiable Reasoning



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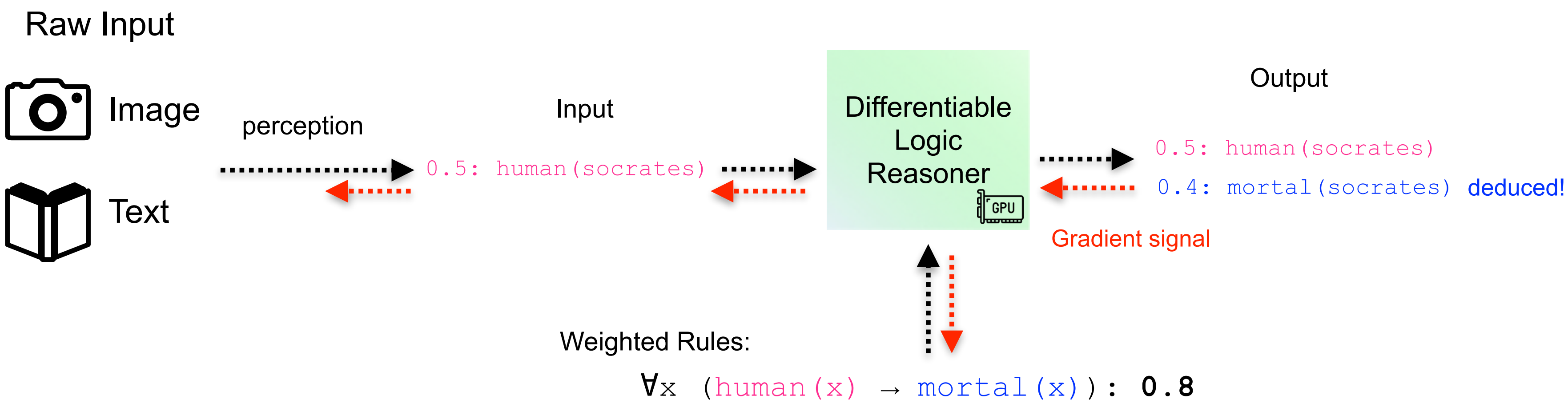
Perception + Differentiable Reasoning



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Research Overview

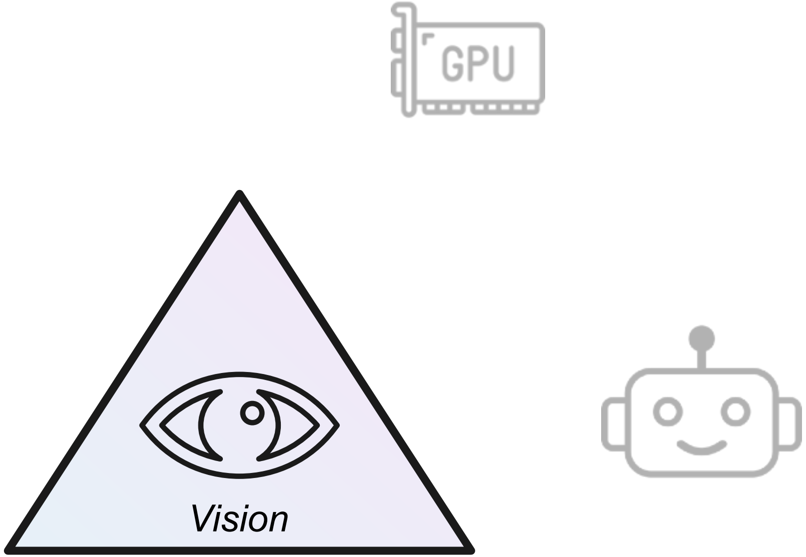

Image Segmentation with Complex Textual Prompts

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Visual Input

Deictic Prompt

"An object that is on the boat, and that is holding an umbrella."

Shindo, Brack, Sudhakaran, Dhami, Kersting: DeiSAM: Segment Anything with Deictic Prompting. NeurIPS 2024

Image Segmentation with Complex Textual Prompts

TECHNISCHE UNIVERSITÄT DARMSTADT

Visual Input

Segmentation Output

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Image Segmentation with Complex Textual Prompts

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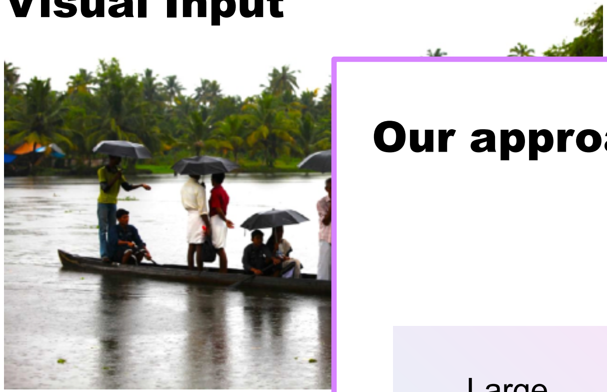
Image Segmentation with Complex Textual Prompts

Visual Input



Segmentation Output

Our approach

Large Language Models

Deictic Promp

“An object that
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Image Segmentation with Complex Textual Prompts

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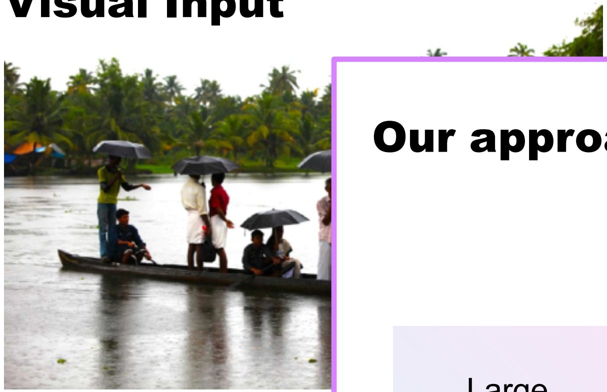
Visual Input



Segmentation Output

Our approach

Large Language Models → Differentiable Logic Reasoner

Deictic Prompt

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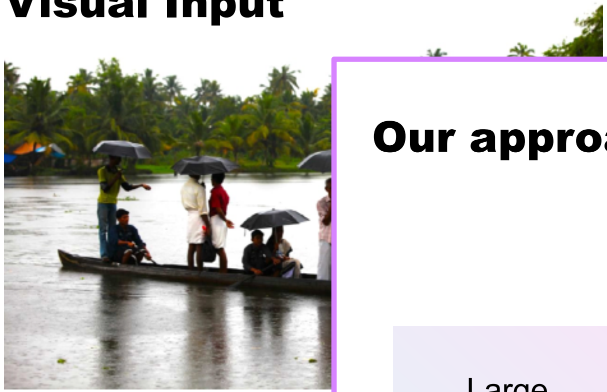

Segmentation Output

Our approach

Differentiable Logic Reasoner

Large Language Models

Large Segmentation Models

Deictic Promp

"An object that is on the boat,
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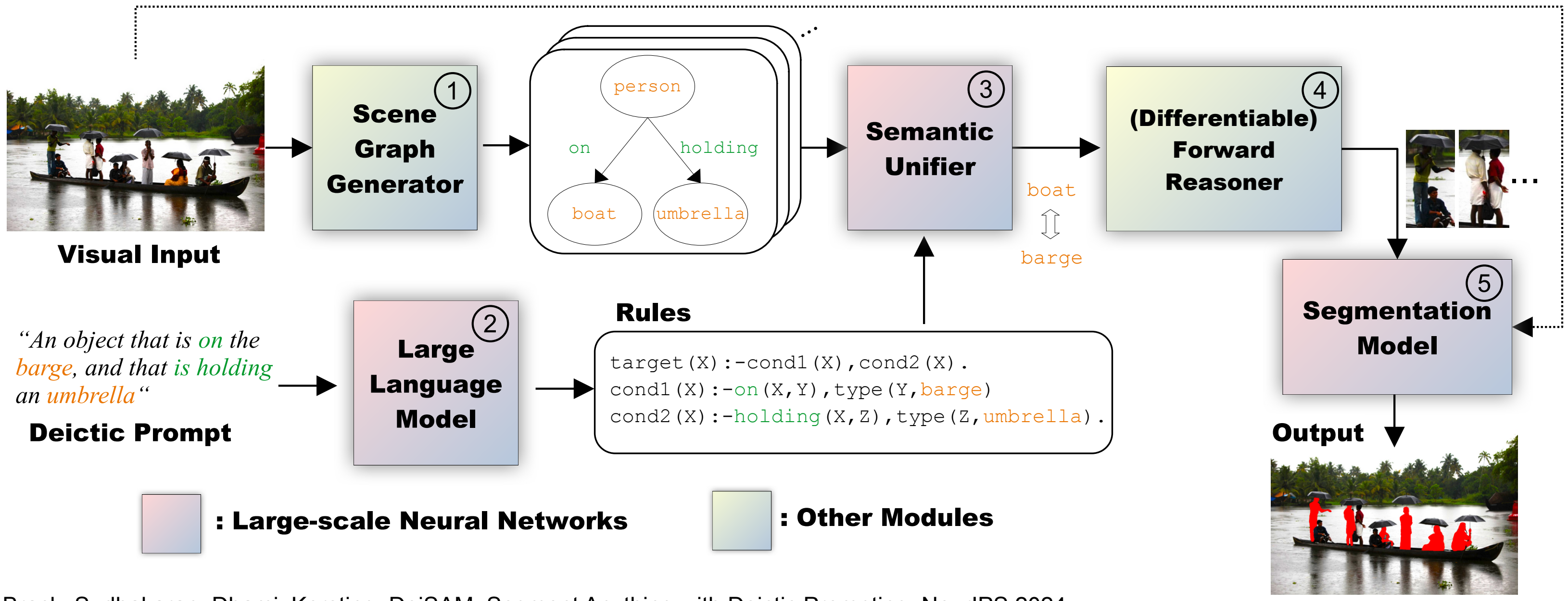
DeiSAM: Large-scale NNs + Differentiable Reasoners

Deictic **S**egment **A**nything **M**odel

Key Idea: **Large-scale Neural Networks** + **Differentiable Reasoners**



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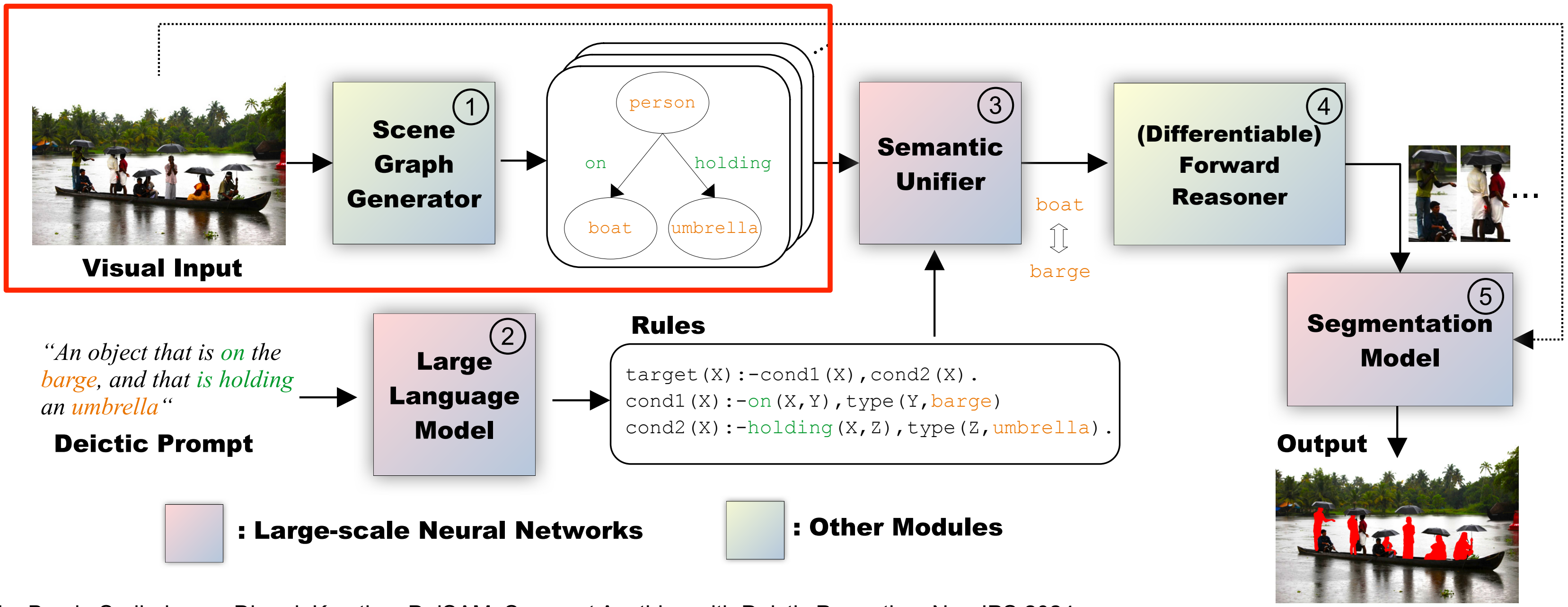
DeiSAM: Large-scale NNs + Differentiable Reasoners

Generate scene graphs from visual input

Image → Scene Graphs



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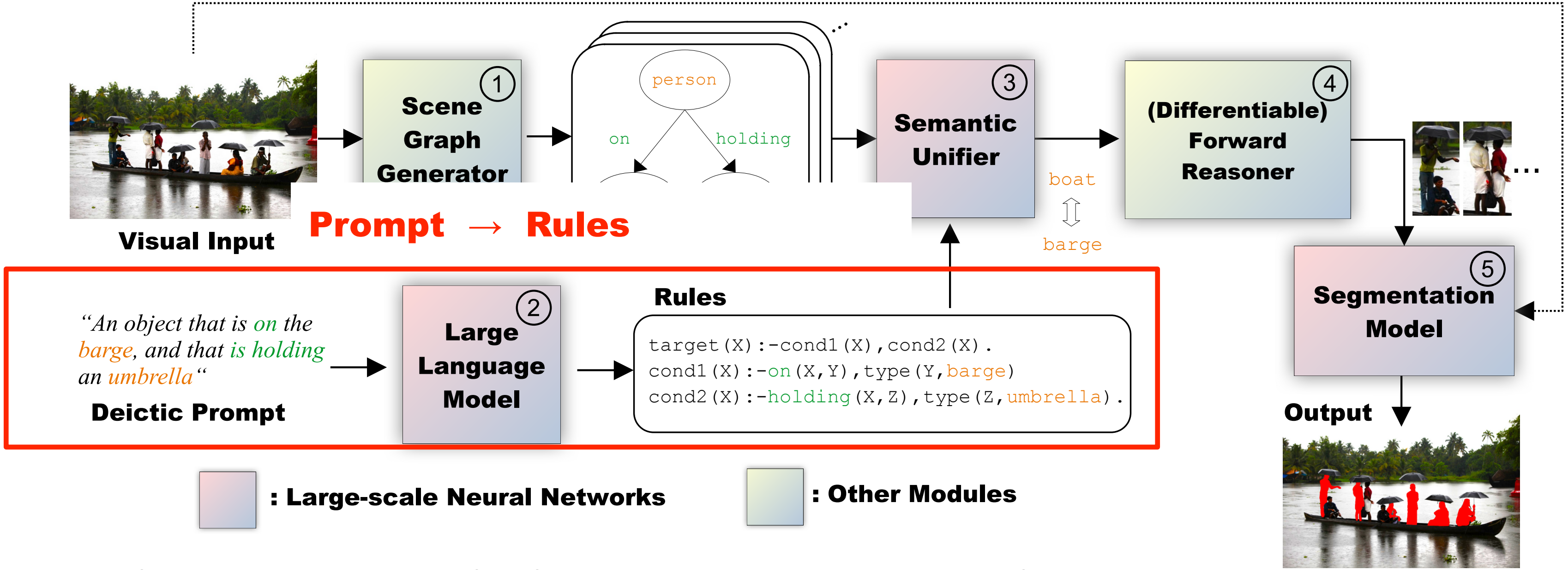
DeiSAM: Large-scale NNs + Differentiable Reasoners

Generate rules from deictic prompt

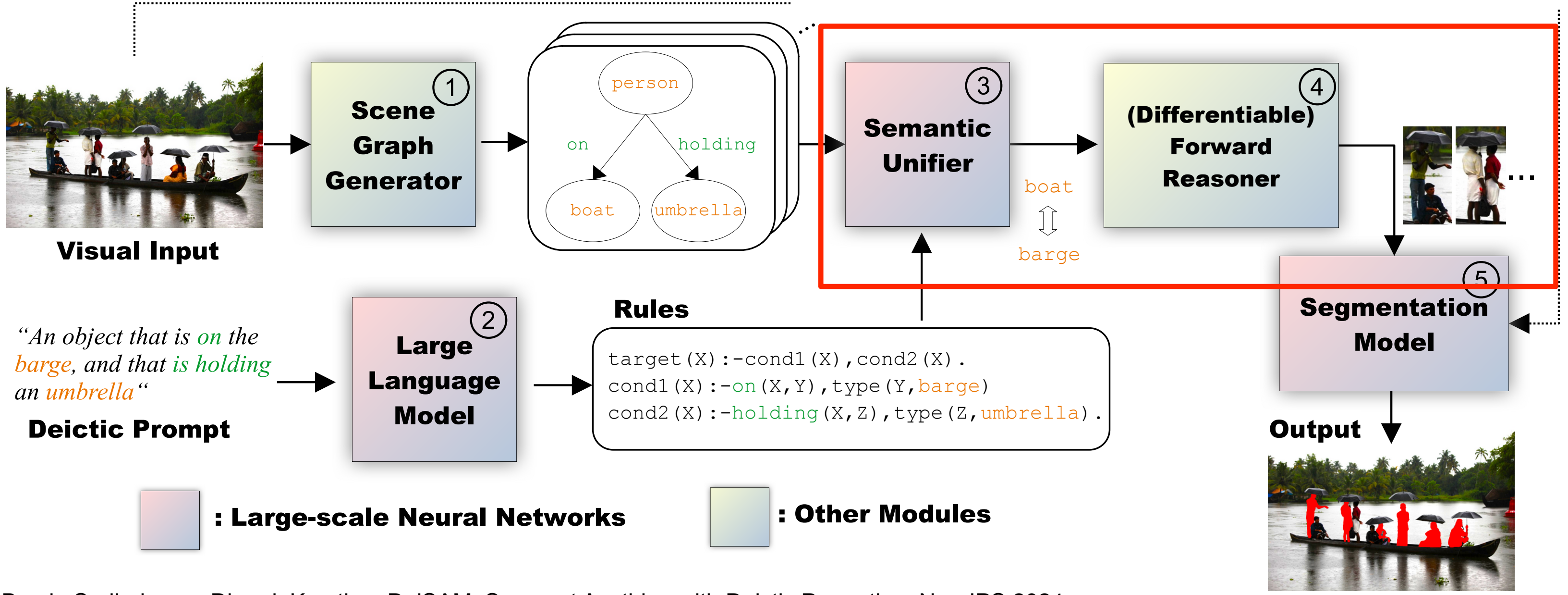


Shindo, Brack, Sudhakaran, Dhami, Kersting: DeiSAM: Segment Anything with Deictic Prompting. NeurIPS 2024

DeiSAM: Large-scale NNs + Differentiable Reasoners

Identify objects by (differentiable) forward reasoning
- compute logical entailment given scene graphs and rules

Scene Graphs, Rules → Target Objects



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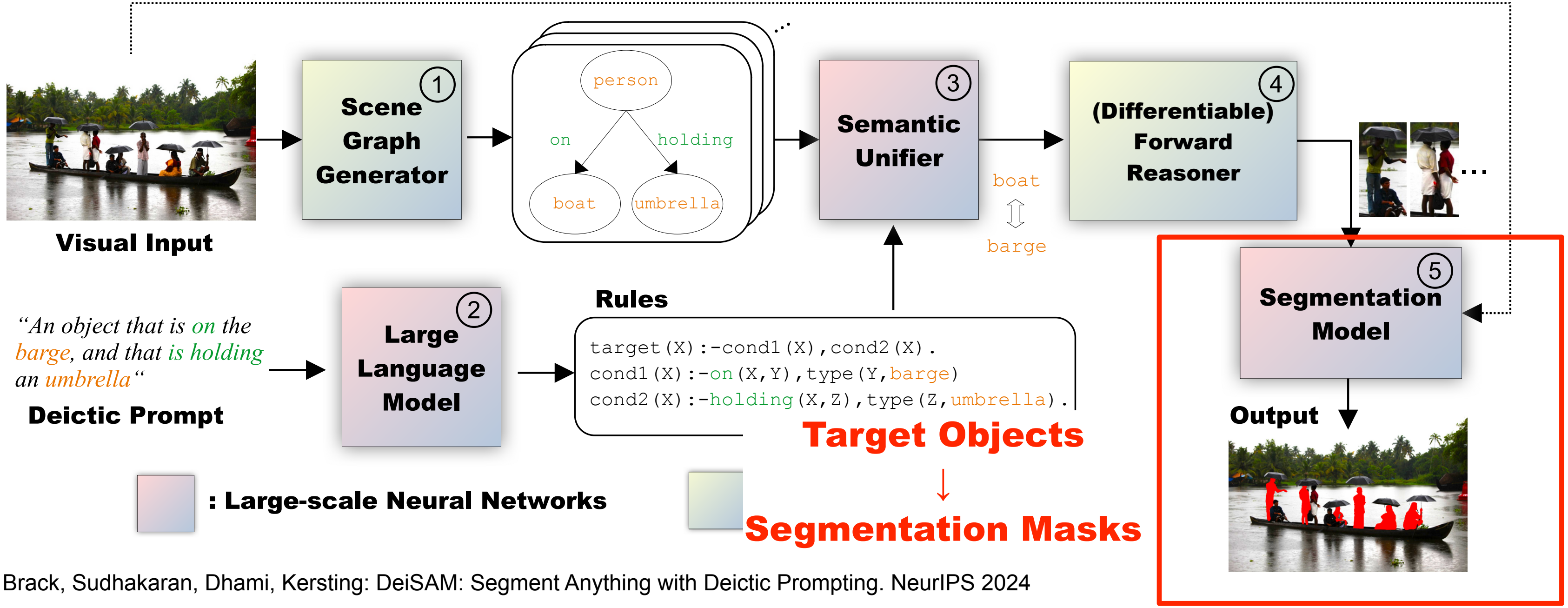
DeiSAM: Large-scale NNs + Differentiable Reasoners

Segment objects by Segment Anything Model (SAM)



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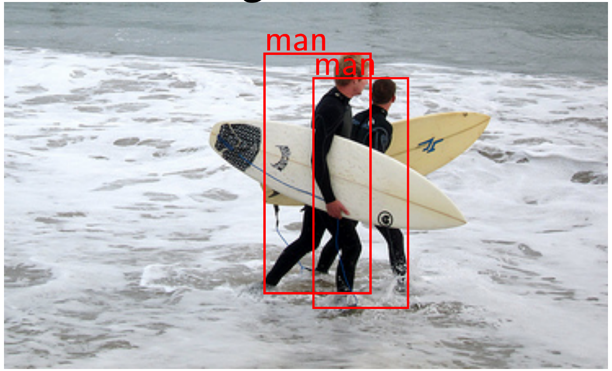
DeiVG Dataset

'An object that is wearing a wet suit'



Complexity 1 (DeiVG1)

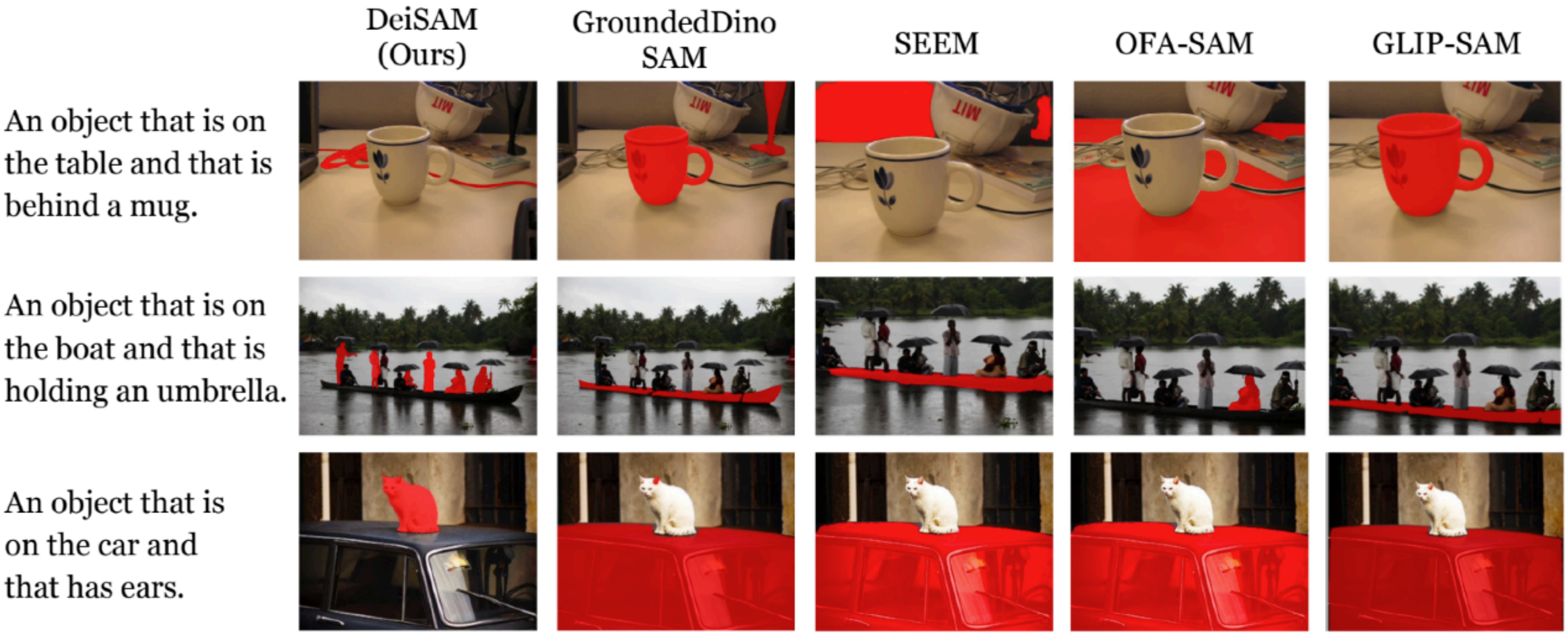
'An object that has a handle and that is on a bench'

Complexity 2 (DeiVG2)

- 10k pairs of visual scene and deictic prompt
- Generated from Visual Genome dataset

Shindo, Brack, Sudhakaran, Dhami, Kersting: DeiSAM: Segment Anything with Deictic Prompting. NeurIPS 2024

Results



Shindo, Brack, Sudhakaran, Dhami, Kersting: DeiSAM: Segment Anything with Deictic Prompting. NeurIPS 2024

Results

Method	Mean Average Precision (%) ↑ val	testA	testB
LISA	67.55	74.86	63.03
GroundedSAM	55.09	66.21	44.21
DeiSAM	**71.72**	**77.29**	**64.98**

Comparison on RefCOCO+

"**kid** wearing navy shirt"

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Results

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Comparison on RefCOCO+

"**kid** wearing navy shirt"

Method	Mean Average Precision (%) ↑ val	testA	testB
LISA	44.92	47.60	43.23
GroundedSAM	30.06	31.75	28.12
DeiSAM	**71.56**	**79.51**	**66.43**

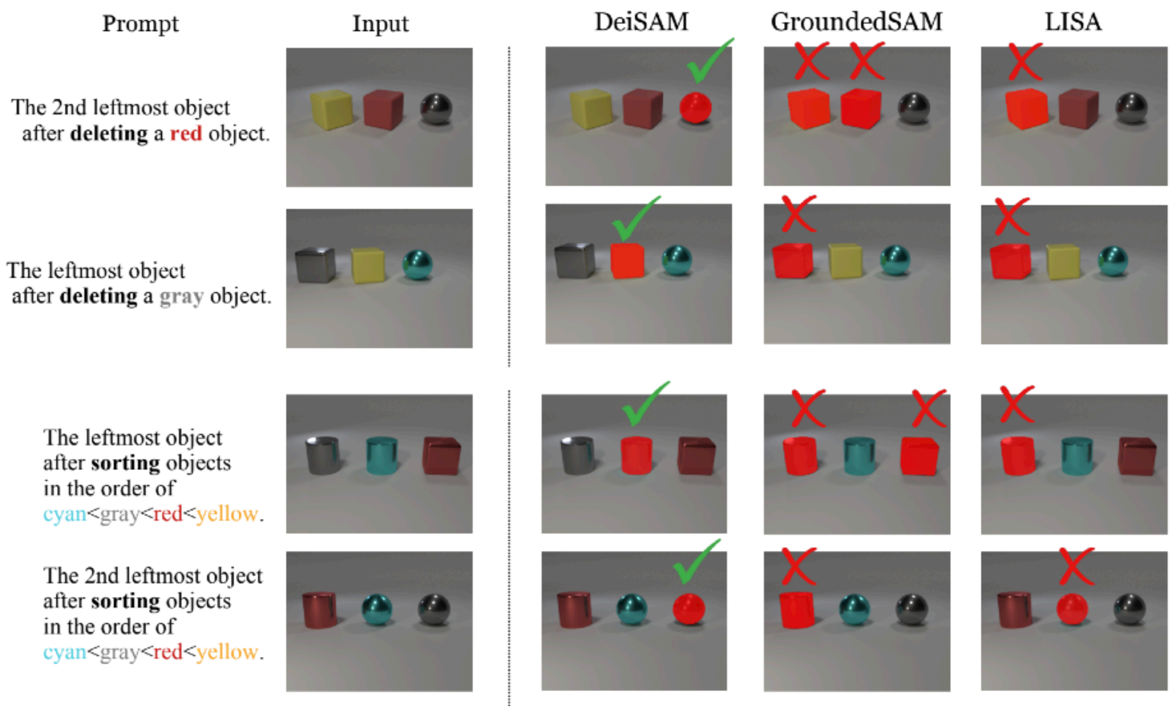
Comparison on DeiRefCOCO+

"**an object** that is wearing navy shirt".

Large neural models fail on the abstract prompts!

Shindo, Brack, Sudhakaran, Dhami, Kersting: DeiSAM: Segment Anything with Deictic Prompting. NeurIPS 2024

Results



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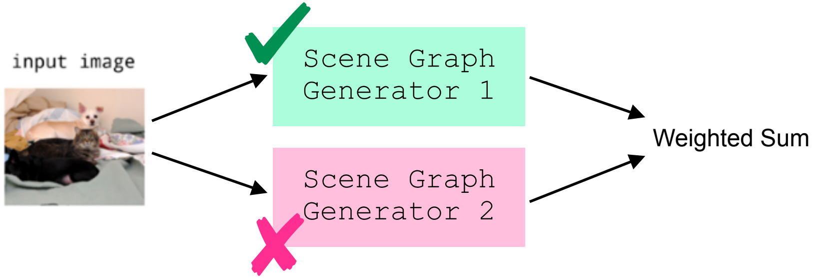
Results

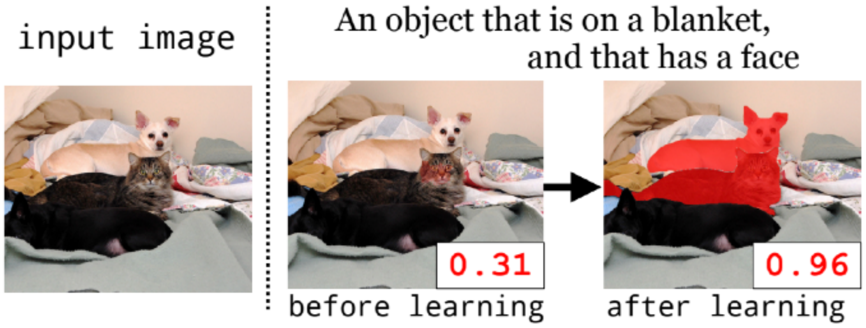



```
% Program 2
targetSgg(X,SG):-cond1(X,SG),cond2(X,SG).
cond1(X,SG):-hasSgg(X,Y,SG),typeSgg(Y,hair,SG).
cond2(X,SG):-onSgg(X,Y,SG),onSgg(Y,surfboard,SG).
% Compose weighted mixtures.
w_1: target(X):-targetSgg(X,sgg1).
w_2: target(X):-targetSgg(X,sgg2).
```

Listing 2: A program for SGG learning.

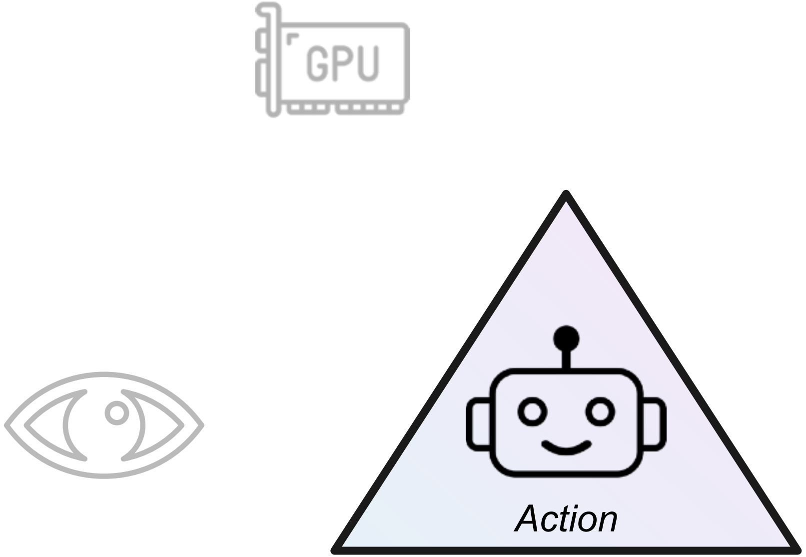
Table 5: **End-to-end training improves DeiSAM.** Mean Average Precision on the test split of the task of learning SGGs. DeiSAM-VETO uses a trained VETO model (Sudhakaran et al., 2023), DeiSAM-Mixture (naive) uses a mixture of a trained VETO model and VG scene graphs with randomly initialized rule weights, DeiSAM-Mixture* uses the resulted mixture model after the weight learning.

	mAP (%) ↑	
Method	DeiVG_1	DeiVG_2
DeiSAM-VETO	6.64	15.92
DeiSAM-Mixture (naive)	37.61	59.81
DeiSAM-Mixture*	**64.44**	**86.57**



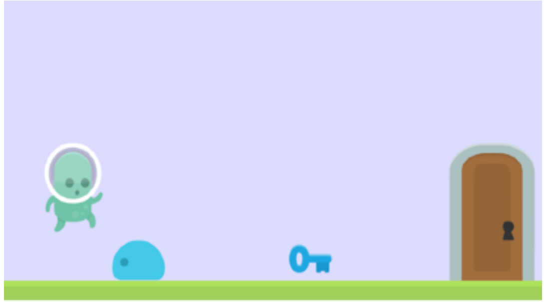
Shindo, Brack, Sudhakaran, Dhami, Kersting: DeiSAM: Segment Anything with Deictic Prompting. NeurIPS 2024

Research Overview



Fully (Differentiable) Logic Agent

NUDGE: Neurally gUided Differentiable loGic policiEs



0.8: jump:- closeby(agent, enemy).

Delfosse*, Shindo*, Dhami, Kersting: Interpretable and Explainable Logical Policies via Neurally Guided Symbolic Abstraction. NeurIPS 2023

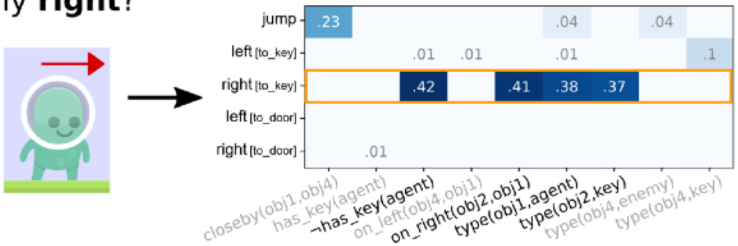
NUDGE is Interpretable and Explainable

Learned Policy

```
0.57:jump:-closeby(agent,enemy).
0.32:left[to_key]:- ¬has_key(agent),on_right(agent,key)
0.30:left[to_door]:- has_key(agent),on_left(door,agent).
0.29:right[to_key]:-¬has_key(agent),on_left(agent,key).
0.56:right[to_door]:-has_key(agent),on_left(agent,door)
```

Explanation for action

Why **right**?



"Because the agent does not have the key and the key is on its right."

Delfosse*, Shindo*, Dhami, Kersting: Interpretable and Explainable Logical Policies via Neurally Guided Symbolic Abstraction. NeurIPS 2023

Are „Neural“ or „Logical“ Policies Enough?

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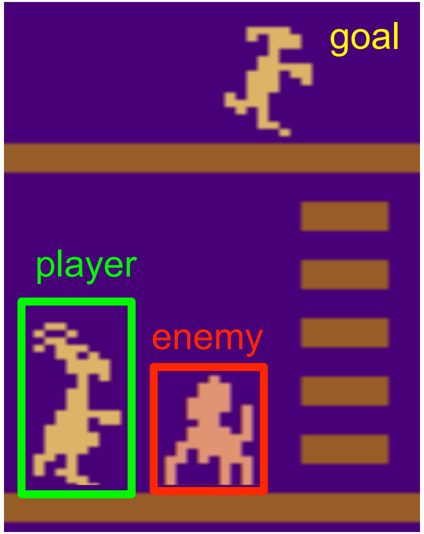
Generated by ChatGPT4o

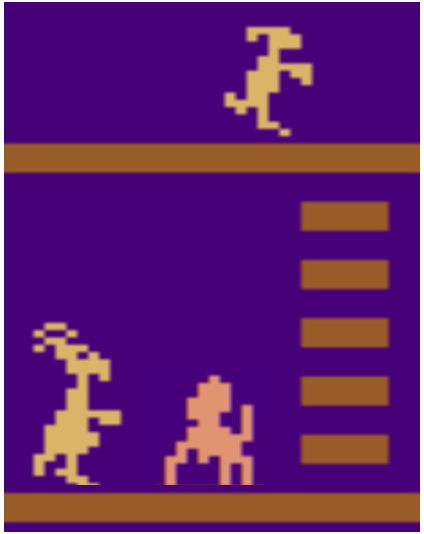
Hybrid Neuro-Symbolic Policies?

Input State

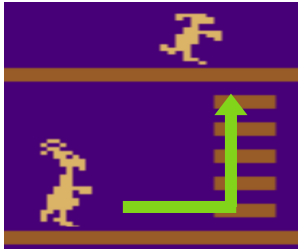


Hybrid Neuro-Symbolic Policies?

Input State



High-level Reasoning

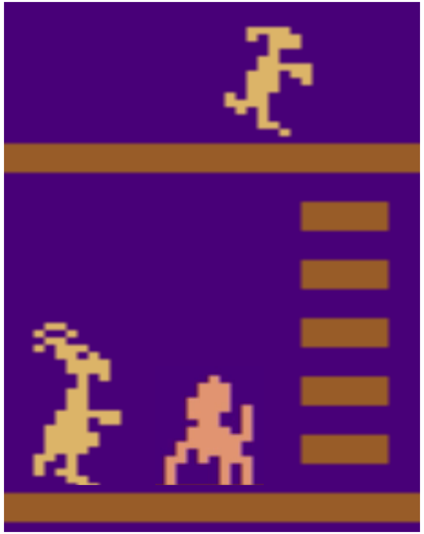


Reach to the goal

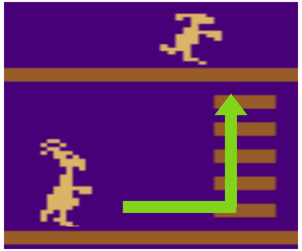
- Object-centric state
- Reasoning and Planning

Hybrid Neuro-Symbolic Policies?

Input State



High-level Reasoning



Reach to the goal

- Object-centric state
- Reasoning and Planning

Low-level Reaction

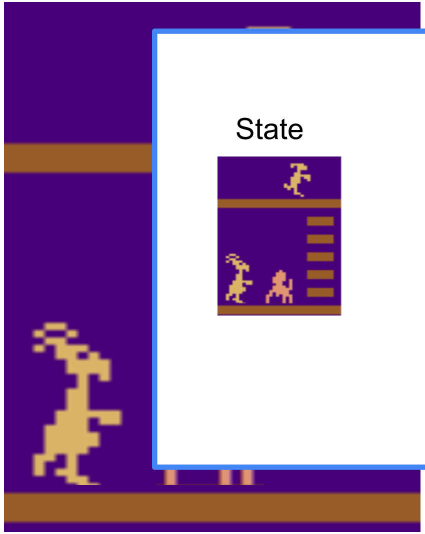
Punch the enemy

- Pixel-based state
- Intuitive Action

Hybrid Neuro-Symbolic Policies?

High-level Reasoning

Input State



Reach to the goal

State

state

Planning

my

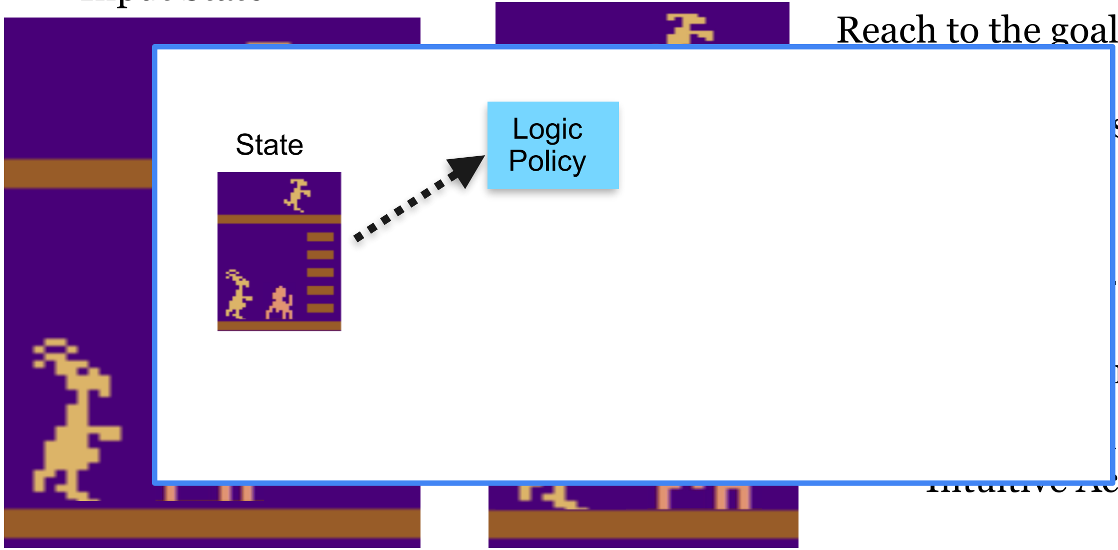
state

tion

Hybrid Neuro-Symbolic Policies?

High-level Reasoning

Input State



Reach to the goal

state

Planning

my

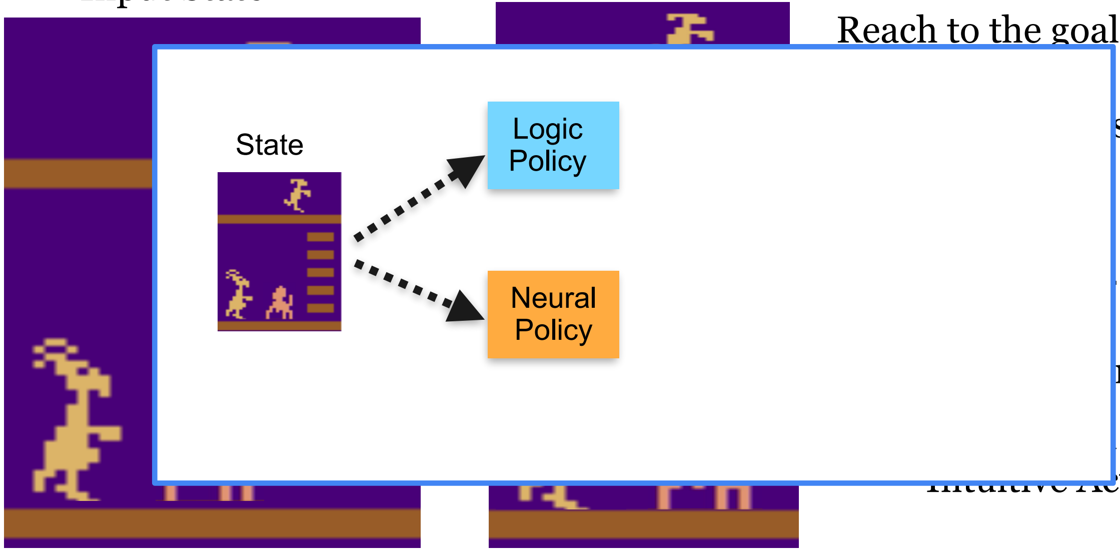
state

tion

Hybrid Neuro-Symbolic Policies?

Input State

High-level Reasoning



Reach to the goal

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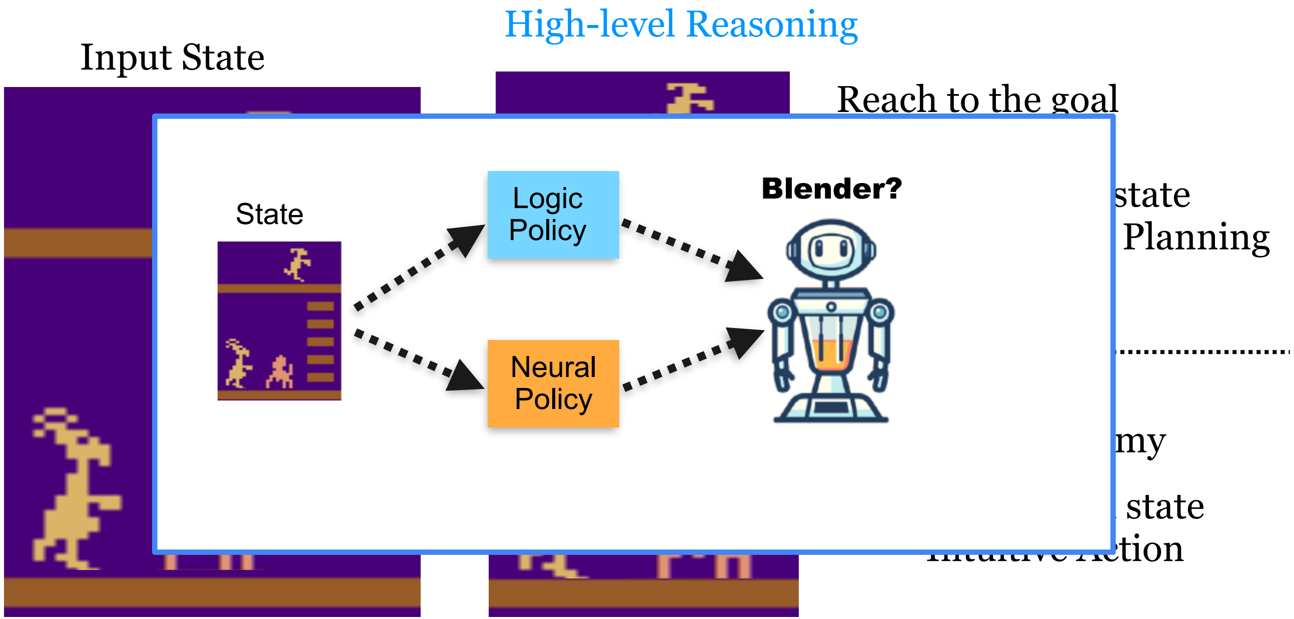
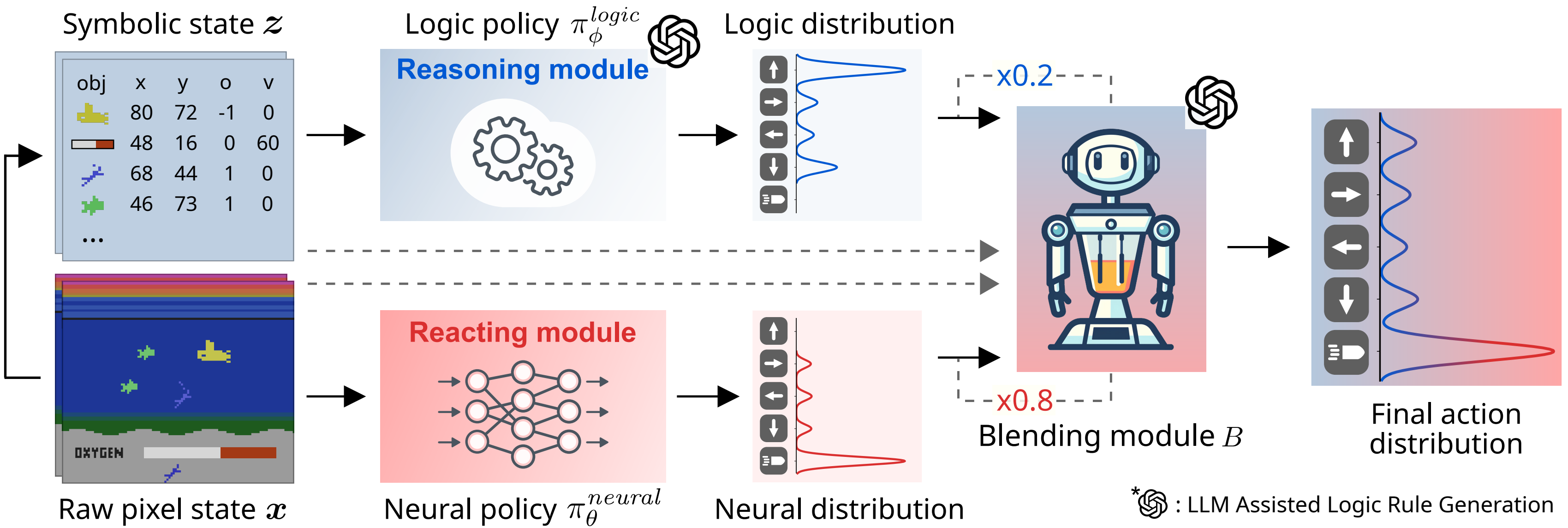
Hybrid Neuro-Symbolic Policies?



BlendRL: A Framework for Merging Symbolic and Neural Policy Learning

```
[R1] 0.73: up(X):-is_empty(Oxygen).
[R2] 0.42: up(X):-above(Diver,Agent).
[R3] 0.31: left(X):-left_of(Diver,Agent).
```

Listing 1: Exemplary action rules for *Seaquest*.



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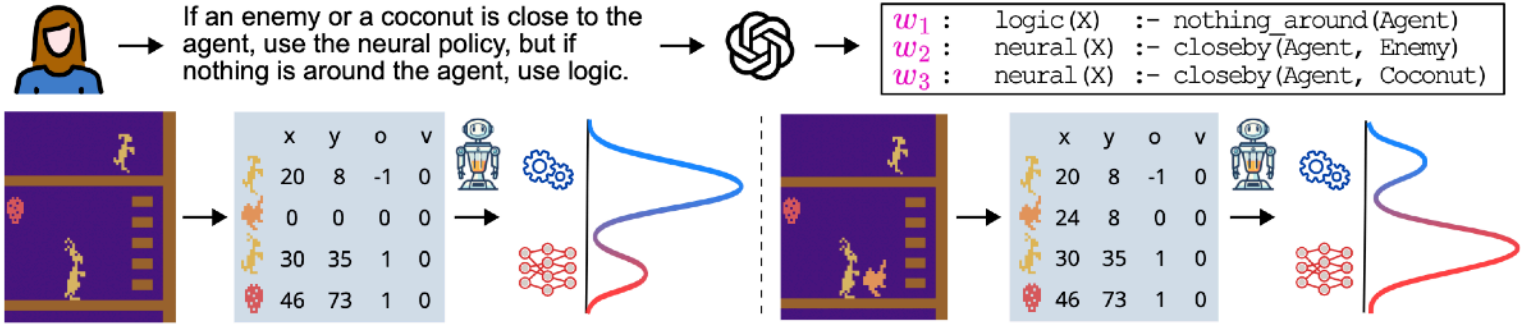

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Neural PPO

suboptimal policy!

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Thank you for your attention.
Happy to answer any questions!

TECHNISCHE UNIVERSITÄT DARMSTADT

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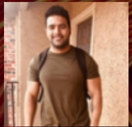
Quentin Delfosse	Viktor Pfanschilling	Manuel Brack	Gopika Sudhakaran	Devendra Singh Dhami	Patrick Schramowski	Kristian Kersting
						

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