Neural Module Networks

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Visual question answering

What color is the necktie?

yellow
Is there a red shape above a circle?

yes
Neural module networks

Is there a red shape above a circle?

- red
- exists
- above

$\rightarrow$ true
Neural module networks

Is there a red shape above a circle?

red  \(\mapsto\)  red
exists  \(\mapsto\)  true
above  \(\mapsto\)  above

exists  \(\mapsto\)  true
above  \(\mapsto\)  above
Neural module networks

Is there a red shape above a circle?

- red
- exists
- above

exists \rightarrow true
above \rightarrow true
red \rightarrow true

Yes
Nearest neighbors

Structured neural models


Probabilistic formal semantics / predicate learning

- [Beltagy et al. 2013, Lewis & Steedman 2013, Malinowski & Fritz 2014]
Representing meaning

Is there a red shape above a circle?
Representing meaning

Is there a red shape above a circle?
Attentions encode meaning

Is there a red shape above a circle?
Attention transformations encode meaning

Is there a red shape above a circle?
Set transformations encode meaning

Is there a red shape above a circle?
Sentence meanings are computations

Is there a red shape above a circle?

- exists
  - and
    - red
    - above
  - circle
Sentence meanings are computations

Is there a red shape above a circle?
Compositions of vector functions are neural nets
Is there a red shape above a circle?

- **red** \(\mapsto\) \[\text{red shape}\]
- **exists** \(\mapsto\) \[\text{true}\]
- **above** \(\mapsto\) \[\text{true}\]
Is there a red shape above a circle?

- **red**
- **exists**
- **above**

**yes**
Is there a red shape above a circle?

red \iff \exists \text{red above circle} \implies \text{true}
The [find] module
The [find] module
The [find] module

![Diagram of the find module with various shapes and colors.]
The [find] module
The [find] module
The [find] module
The [find] module
The [find] module
The `[describe]` module

```
red
```

color

```
\[\text{Diagram of color examples}\]
```

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The [describe] module

necktie

what
The [describe] module

- red
- color
The [describe] module
The [describe] module

red

color
Is there a red shape above a circle?

red ⇔ true
exists ⇔ true
above ⇔ true

yes
Where do layouts come from?

*Is there a red shape above a circle?*

[Reddy et al. 2016]
Learning

Is there a red shape above a circle?  
yes

e.xists and red above circle

What color is the shape right of a circle?  
blue

color right_of circle
Is there a red shape above a circle?  What color is the shape right of a circle?
Is there a red shape above a circle? Yes

What color is the shape right of a circle? Blue
Is there a red shape above a circle?  

What color is the shape right of a circle?
Extreme parameter tying
Learning with fixed layouts is easy!

$$\arg\max_W \sum p(\text{yes} | \text{answer}, \text{data}; W)$$

(where every root module outputs a distribution over answers and $W$ is the set of all module parameters)
Learning module behaviors

Module specialization is driven entirely by context!
Experiments
Experiments: VQA dataset

What color is the necktie?  yellow

What is in the sheep’s ear?  tag

[Antol et al. 2015]
Experiments: VQA dataset

- Zhou (2015): 55.9
- Noh (2015): 57.4
Experiments: VQA dataset

Zhou (2015): 55.9
Noh (2015): 57.4
Yang (2015): 58.9
Ours: 59.4
Experiments: VQA dataset

What color is she wearing? white
Experiments: VQA Dataset

What color is she wearing?

white
What is in the sheep’s ear?
Experiments: VQA Dataset

What is in the sheep's ear?
What is in the sheep’s ear?
Experiments: SHAPES dataset

Is there a red shape above a circle? yes

Is a green shape above left of a red shape? no

c.f. [Xu and Saenko, 2016]
Experiments: SHAPES dataset

- Zhou: 65.3
- Yang: 76.5
- Ours: 90.6
Experiments: SHAPES dataset

find[red] → combine[and] → exists → yes

find[circle] → relate[above]
Neural module networks

Is there a red shape above a circle?

red \iff \exists \text{red above exists} \land 53

yes
Neural module networks

Linguistic structure dynamically generates model structure

Combines advantages of:

• Representation learning (like a neural net)
• Compositionality (like a semantic parser)
thank you

Download our code at http://github.com/jacobandreas/nmn2