Learning to compose neural networks for question answering

Jacob Andreas, Marcus Rohrbach, Trevor Darrell, Dan Klein
Grounded question answering

What color is the necktie? yellow
What rivers are in South Carolina?

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</table>
Is there a red shape above a circle?

Yes
Neural nets learn lexical groundings

Is there a red shape above a circle? yes

[Iyyer et al. 2014, Bordes et al. 2014, Yang et al. 2015, Malinowski et al., 2015]
Semantic parsers learn composition

Is there a red shape above a circle? Yes

Neural module networks learn both!

Is there a red shape above a circle?

yes
Neural module networks

Is there a red shape above a circle?

- **red** \(\mapsto\) red
- **exists** \(\mapsto\) true
- **above** \(\mapsto\) above
Neural module networks

Is there a red shape above a circle?

- red
- exists
- above

→ True
Is there a red shape above a circle?

red \iff \exists \text{true}

above \iff \text{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?
Sets encode meaning

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

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

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

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

Is there a red shape above a circle?
Computations are built from set functions
Modules can be manually specified...

- \( \text{shapes.where(}.color == \text{“red”}) \)
- \( d => d.nonEmpty ? true : false \)
- \( d => d.map(\_.neighborAbove) \)

[Liang et al. 2011]
...or learned as classifiers...

\[
x \mapsto \text{sign}(a^T \phi(x))
\]

\[
x \mapsto \text{sign}(b^T \phi(x))
\]

\[
x \mapsto \text{sign}(c^T \phi(x))
\]

[Krishnamurthy & Kollar 2013]
...or relaxed to real-valued vectors
...or relaxed to real-valued vectors
Composing vector functions

- red: exists $\rightarrow$ true
- exists: above $\rightarrow$ true
- above: red $\rightarrow$ true

exists $\land$ red $\rightarrow$ circle
Composing vector functions

- red
- exists
- above

\rightarrow

- red
- exists
- above
- true

exists
and
red
above
circle
Composing vector functions

- **red** $\mapsto$ [Diagram of red shape]
- **exists** $\mapsto$ [Diagram of exists block]
- **above** $\mapsto$ [Diagram of above block]

- **exists** $\quad$ and $\quad$ **red** above **circle**

27
Compositions of vector functions are neural nets
Compositions of vector functions are neural nets

red $\mapsto$ true
exists $\mapsto$ true
above $\mapsto$ true
exists and red above circle
Is there a red shape above a circle?

- red
- exists
- above
- true
- yes
Is there a red shape above a circle?

red → true
exists → true
above → true

yes
Is there a red shape above a circle?

- red
- exists
- above

→ true

→ yes
Is there a red shape above a circle?

- **exists** \(\mapsto\) true
- **red** \(\mapsto\) red above circle

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

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<td>true</td>
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Anatomy of a module
Anatomy of a module

red

color

![Diagram showing the anatomy of a module with a color node and a red node]
What modules do we need?

*Is there a red shape above a circle?*

*What color is the triangle?*

*Who is running in the grass?*

*What cities are south of San Diego?*
A module for predicates

- Is there a red shape above a circle?
- What color is the triangle?
- Who is running in the grass?
- What cities are south of San Diego?
A module for relations

Is there a red shape above a circle?

What color is the triangle?

Who is running in the grass?

What cities are south of San Diego?
A module for quantifiers

- [exists] → true

Is there a red shape above a circle?

What color is the triangle?

Who is running in the grass?

What cities are south of San Diego?
A module for attributes

Is there a red shape above a circle?

What color is the triangle?

Who is running in the grass?

What cities are south of San Diego?
A module for logic

[describe]

[find]  [relate]  [exists]

Is there a red shape above a circle?

What color is the triangle?

Who is running in the grass?

What cities are south of San Diego?
Module inventory

Is there a red shape above a circle?

What color is the triangle?

Who is running in the grass?

What cities are south of San Diego?
The [find] module

red
The [find] module

[Xu et al. 2015]
The [find] module

- Columbia: 0.9
- Cooper: 0.1
- Myrtle Beach: 0.8

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The [find] module
The [find] module
The [find] module
The [find] module
The [find] module
The [find] module
The [describe] module

red

color
The [describe] module

necktie

what
The `[describe]` module

- **red**

**color**
The [describe] module

- red

- color
The [describe] module

red

color
Is there a red shape above a circle?

red \rightarrow \text{exists} \rightarrow true

yes

Outline
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?
Is there a red shape above a circle?  

What color is the shape right of a circle?
Parameter tying

Is there a red shape above a circle?

What color is the shape right of a circle?
Extreme parameter tying

- exists and red above circle
- color right_of circle
- exists and above circle
- above red left_of circle
- shape right_of square
Learning with fixed layouts is easy!

\[
\arg \max_W \sum p(\text{yes} \mid \text{ }, \text{ } ; W)
\]

(where every root module outputs a distribution over answers and $W$ is the set of all module parameters)
Maximum likelihood estimation
Module specialization is driven entirely by context

“Lexicon learning” is a continuous optimization problem
Is there a red shape above a circle?

- red
- exists
- above

exists and red above circle

yes
Where do layouts come from?

Is there a red shape above a circle?

[Reddy et al. 2016]
Where do layouts come from?

*Is there a red shape above a circle?*

Diagram: 
```
be
  ↓
shape
  ↓
red  above
  ↓
circle
```
Where do layouts come from?

Is there a red shape above a circle?
Where do layouts come from?

*Is there a red shape above a circle?*
Where do layouts come from?

Is there a red shape above a circle?
Where do layouts come from?

Is there a red shape above a circle?
Choosing among layouts

Is there a red shape above a circle?
Learning to choose layouts

Is there a red shape above a circle?
Learning with unknown layouts uses RL

Is there a red shape above a circle?

[Williams 1992]
Experiments

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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: SHAPES dataset

- *Zhou: 65.3
- *Yang: 76.5
- Ours: 90.6
Experiments: VQA dataset

What color is she wearing?

- color
- wear
- white
Experiments: VQA Dataset

What color is she wearing?

- color
- wear

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: GeoQA dataset

#### What are some beaches in Florida?

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- **Daytona Beach**

#### Is Key Largo an island?

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<td>city</td>
<td>no</td>
</tr>
<tr>
<td>Daytona Beach</td>
<td>city</td>
<td>yes</td>
</tr>
<tr>
<td>Everglades</td>
<td>park</td>
<td>no</td>
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- **Yes**

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[Krishnamurthy & Kollar 2013]
Experiments: GeoQA dataset

[Kwiatkowski et al. 2010, Krishnamurthy & Kollár 2013]
Experiments: GeoQA dataset

[Kwiatkowski et al. 2010, Krishnamurthy & Kollar 2013]
Experiments: GeoQA dataset

Is Key Largo an island?

.exists
.and
.Key Largo island

yes
What are some beaches in Florida?

Beach in Florida exists and (wrong parse)
Experiments: GeoQA dataset

What beach city is there in Florida?

(and)

beach city in Florida

{} (wrong module behavior)
Neural module networks

Is there a red shape above a circle?

red
exists
above

true

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