Natural Language Processing

Neural semantic parsing

Slides adapted from Richard Socher, Chris Manning, Ofir Press
Plan

- Sequence to sequence models
- Attention
- Pointer networks
- Weak supervision
Sequence to sequence
## Conditional generation

<table>
<thead>
<tr>
<th><strong>Input X</strong></th>
<th><strong>Output Y (Text)</strong></th>
<th><strong>Task</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Structured Data</td>
<td>NL Description</td>
<td>NL Generation</td>
</tr>
<tr>
<td>English</td>
<td>Japanese</td>
<td>Translation</td>
</tr>
<tr>
<td>Document</td>
<td>Short Description</td>
<td>Summarization</td>
</tr>
<tr>
<td>Utterance</td>
<td>Response</td>
<td>Response Generation</td>
</tr>
<tr>
<td>Image</td>
<td>Text</td>
<td>Image Captioning</td>
</tr>
<tr>
<td>Speech</td>
<td>Transcript</td>
<td>Speech Recognition</td>
</tr>
</tbody>
</table>

Slide credit: Graham Neubig
Sequence to sequence

How tall is Lebron James?
HeightOf.LebronJames

[How, tall, is, Lebron, James, ?]
[HeightOf, ., LebronJames]

How tall is Lebron James?
¿Que tan alto es Lebron James?
High level

- We will build a differentiable function that maps a natural language statement $x$ to a logical form $y$ (or translation, or summary, or answer to a question…)

- We will define a loss (often cross entropy) that tells us how good is our prediction w.r.t the ground truth

- We will search for parameters that minimize the loss over the training set with SGD.

- We will compute gradients with auto-differentiation packages
Applications

- Machine translation
- Semantic parsing
- Question answering
- Summarization
- Dialogue
- ...
Sequence to sequence

[How, tall, is, Lebron, James, ?]

[HeightOf, ., LebronJames]
Recurrent neural networks

Input: \( w_1, \ldots, w_{t-1}, w_t, w_{t+1}, \ldots, w_T \), \( w_i \in \mathbb{R}^\nu \)

Model: \( x_t = W^{(e)} \cdot w_t \), \( W^{(e)} \in \mathbb{R}^{d \times \nu} \)

\[ h_t = \sigma(W^{(hh)} \cdot h_{t-1} + W^{(hx)} \cdot x_t), W^{(hh)} \in \mathbb{R}^{D_h \times D_h}, W^{(hx)} \in \mathbb{R}^{D_h \times d} \]

\( \hat{y}_t = \text{softmax}(W^{(s)} \cdot h_t) \), \( W^{(s)} \in \mathbb{R}^{\nu \times D_h} \)
Encoder

An RNN without the output layer

How tall is Lebron James?
Decoder (v1.0)

An RNN without the input layer

HeightOf (0.7) . (0.99)
WeightOf (0.2) LebronJames(0.001)

? ?
Seq2seq (v1.0)

Encoder:
\[ h_0^e = 0, h_t^e = \text{RNN}_e(h_{t-1}^e, x_t) \]

Decoder:
\[ h_0^d = \text{RNN}_d(h_{|x|}^e), h_t^d = \text{RNN}_d(h_{t-1}^d) \]
\[ y_t = \text{softmax}(W^{(s)} h_t^d) \]

Model:
\[ p(y \mid x) = \prod_{t} p(y_t \mid y_1, \ldots, y_{t-1}, x) = \prod_{t} p(y_t \mid h_t^d) \]

Training is finding parameters that minimize cross entropy over tokens:
\[ \sum_{i} \log p_{\theta}(y^{(i)} \mid x^{(i)}) \]
Seq2seq (v1.0)

- Training is done with SGD on top of standard auto-diff packages
- At training time decoding is done as many steps as the training example (with a stopping symbol)
- At test time we output the argmax token of every time step and stop when we output the stopping symbol.
Seq2seq (v2.0)

WeightOf (0.7)
HeightOf (0.2)
...
LebronJames (0.001)
...
LebronJames (0.9)
...

<s> HeightOf .
Seq2seq (v2.0)

Encoder:
\[ h_0^e = 0, h_t^e = \text{RNN}_e(h_{t-1}^e, x_t) \]

Decoder:
\[ h_t^d = \text{RNN}_d(h_{t-1}^d, h_{|x|}^e, y_{t-1}) \]
\[ y_t = \text{softmax}(W^{(s)} h_t^d) \]

Model:
\[ p(y \mid x) = \prod_t p(y_t \mid y_1, \ldots, y_{t-1}, x) = \prod_t p(y_t \mid h_t^d) \]

Training is finding parameters that minimize cross entropy over tokens:
\[ \sum_i \log p_\theta(y^{(i)} \mid x^{(i)}) \]
Bidirectional encoder

How tall is Lebron James?
Bidirectional encoder

Encoder:
\[ h_0^f = 0, \quad h_t^f = \text{RNN}_f(h_{t-1}, x_t) \]
\[ h_{|x|}^b = 0, \quad h_t^b = \text{RNN}_b(h_{t+1}, x_t) \]

Decoder:
\[ h_t^d = \text{RNN}_d(h_{t-1}^d, h_{|x|}^f, h_0^b, y_{t-1}) \]

An extremely successful model (state-of-the-art), when using more sophisticated cells (LSTMs, GRUs).
Stacked RNNs

- For encoder or decoder

How tall is Lebron James?
Stacked RNN

- For stacked RNN, we need to have an output to each state, usually the hidden state itself is used as the input to the next layer.

- Empirically stacking RNNs is often better than just increasing the dimensionality.

- For example, Google’s NMT system uses 8 layers at both encoding and decoding time.
Efficiency

• RNNs are not very efficient in terms of parallelization

• You can not compute $h_t$ before computing $h_{t-1}$ (compared to bag of words or convolutional neural networks)

• This becomes a problem for tasks where one needs to read long documents (summarization).

• Today we have the transformer architecture that can replace the RNN encoder
Beam search

• At test time, decoding is greedy - we output the symbol that has highest probability. **Not** guaranteed to produce the highest probability sequence.

• Improved substantially with a small beam.

• At decoding step $t$, we consider $K$ most probable sequence prefixes, and compute all possible continuations, score them, and keep the top-$K$.

• Burden shift from search to learning again.

HeightOf (0.7)
WeightOf (0.2)
Advantages of seq2seq

- Simplicity
- Distributed representations of words and phrases
- Better use of context (history) at encoding and decoding time
- Neural networks seem to be very good at generating text (for MT, summarization, QA, etc.)
Summary

• Sequence to sequence models map a sequence of symbols to another sequence of symbols - very common in NLP!

• LSTMs and GRUs allow this to work for long sequences (~100 steps)

• Results in state-of-the-art performance in many cases

• But not always! Attention!
Attention
The problem

What if the source is very long? “
how tall is the NBA player that has won the most NBA titles before he reached the age of 28?”

This is fixed size!

[How, tall, is, …]

Encoder  Vector  Decoder

[HeightOf, ., …]
Attention

Treat source representations as memory

How tall is Lebron James?

Decide what to read from memory when decoding
Alignment

• What are the important words when we decide on the next symbol at decoding time?

• Alignments are heavily used in traditional MT

[HeightOf, ., LebronJames]

[How, tall, is, Lebron, James, ?]

• We will learn to perform the alignment as we decode
Learning alignment in MT

Replace a fixed vector with a time-variable vector

**Intuition:** before generating a word we softly align to the relevant words in the source!
Attention

To compute $c_t$:

$$\forall i, s_i = \text{score}(h_{d}^{t-1}, h_{e}^{i})$$

$$\alpha = \text{softmax}(s)$$
Attention

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Attention

To compute $c_t$: 

$\forall i, s_i = \text{score}(h_d^{t-1}, h_e^i)$

$\alpha = \text{softmax}(s)$

4 2 3 1

heightOf

tall Lebron James ? <s> HeightOf
Attention

To compute $c_t$:

$\forall i, s_i = \text{score}(h_{d-1}^t, h_e^i)$

$\alpha = \text{softmax}(s)$

soft alignment!
Attention

To compute $c_t$:

$$c_t = \sum_i \alpha_i h^i_e$$
Attention

To compute $c_t$:

$$c_t = \sum_i \alpha_i h^i_e$$
Attention

To compute $c_t$:

$$\forall i, s_i = \text{score}(h_{d}^{t-1}, h_{e}^{i})$$

$$\alpha = \text{softmax}(s)$$

soft alignment!
(b) what’s first class fare round trip from ci0 to ci1

(c) what is the earliest flight from ci0 to ci1 tomorrow
Attention scoring function

- Options for scoring function:
  - Dot-product
  - Bilinear map
  - Single layer neural net
  - Multiple layer neural net

\[
\text{score}(h_d^{t-1}, h_e) = h_d^{t-1\top} h_e
\]

\[
\text{score}(h_d^{t-1}, h_e) = h_d^{t-1\top} W h_e
\]

\[
\text{score}(h_d^{t-1}, h_e) = v^\top \tanh(W_1 h_d^{t-1} + W_2 h_e)
\]
Semantic parsing

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCISSOR (Ge and Mooney, 2005)</td>
<td>72.3</td>
</tr>
<tr>
<td>KRISP (Kate and Mooney, 2006)</td>
<td>71.7</td>
</tr>
<tr>
<td>WASP (Wong and Mooney, 2006)</td>
<td>74.8</td>
</tr>
<tr>
<td>λ-WASP (Wong and Mooney, 2007)</td>
<td>86.5</td>
</tr>
<tr>
<td>LNLZ08 (Lu et al., 2008)</td>
<td>81.8</td>
</tr>
<tr>
<td>ZC05 (Zettlemoyer and Collins, 2005)</td>
<td>79.3</td>
</tr>
<tr>
<td>ZC07 (Zettlemoyer and Collins, 2007)</td>
<td>86.1</td>
</tr>
<tr>
<td>UBL (Kwiatkowski et al., 2010)</td>
<td>87.9</td>
</tr>
<tr>
<td>FUBL (Kwiatkowski et al., 2011)</td>
<td>88.6</td>
</tr>
<tr>
<td>KCAZ13 (Kwiatkowski et al., 2013)</td>
<td>89.0</td>
</tr>
<tr>
<td>DCS+L (Liang et al., 2013)</td>
<td>87.9</td>
</tr>
<tr>
<td>TISP (Zhao and Huang, 2015)</td>
<td>88.9</td>
</tr>
<tr>
<td>SEQ2SEQ</td>
<td>84.6</td>
</tr>
<tr>
<td>— attention</td>
<td>72.9</td>
</tr>
<tr>
<td>— argument</td>
<td>68.6</td>
</tr>
<tr>
<td>SEQ2TREE</td>
<td>87.1</td>
</tr>
<tr>
<td>— attention</td>
<td>76.8</td>
</tr>
</tbody>
</table>

Table 3: Evaluation results on GEO. 10-fold cross-validation is used for the systems shown in the top half of the table. The standard split of ZC05 is used for all other systems.

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZC07 (Zettlemoyer and Collins, 2007)</td>
<td>84.6</td>
</tr>
<tr>
<td>UBL (Kwiatkowski et al., 2010)</td>
<td>71.4</td>
</tr>
<tr>
<td>FUBL (Kwiatkowski et al., 2011)</td>
<td>82.8</td>
</tr>
<tr>
<td>GUSP-FULL (Poon, 2013)</td>
<td>74.8</td>
</tr>
<tr>
<td>GUSP++ (Poon, 2013)</td>
<td>83.5</td>
</tr>
<tr>
<td>TISP (Zhao and Huang, 2015)</td>
<td>84.2</td>
</tr>
<tr>
<td>SEQ2SEQ</td>
<td>84.2</td>
</tr>
<tr>
<td>— attention</td>
<td>75.7</td>
</tr>
<tr>
<td>— argument</td>
<td>72.5</td>
</tr>
<tr>
<td>SEQ2TREE</td>
<td>84.6</td>
</tr>
<tr>
<td>— attention</td>
<td>77.5</td>
</tr>
</tbody>
</table>

Table 4: Evaluation results on ATIS.

<table>
<thead>
<tr>
<th>Method</th>
<th>Channel</th>
<th>+Func</th>
<th>F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>retrieval</td>
<td>28.9</td>
<td>20.2</td>
<td>41.7</td>
</tr>
<tr>
<td>phrasal</td>
<td>19.3</td>
<td>11.3</td>
<td>35.3</td>
</tr>
<tr>
<td>sync</td>
<td>18.1</td>
<td>10.6</td>
<td>35.1</td>
</tr>
<tr>
<td>classifier</td>
<td>48.8</td>
<td>35.2</td>
<td>48.4</td>
</tr>
<tr>
<td>posclass</td>
<td>50.0</td>
<td>36.9</td>
<td>49.3</td>
</tr>
<tr>
<td>SEQ2SEQ</td>
<td>54.3</td>
<td>39.2</td>
<td>50.1</td>
</tr>
<tr>
<td>— attention</td>
<td>54.0</td>
<td>37.9</td>
<td>49.8</td>
</tr>
<tr>
<td>— argument</td>
<td>53.9</td>
<td>38.6</td>
<td>49.7</td>
</tr>
<tr>
<td>SEQ2TREE</td>
<td>55.2</td>
<td>40.1</td>
<td>50.4</td>
</tr>
<tr>
<td>— attention</td>
<td>54.3</td>
<td>38.2</td>
<td>50.0</td>
</tr>
</tbody>
</table>

(a) Omit non-English.

<table>
<thead>
<tr>
<th>Method</th>
<th>Channel</th>
<th>+Func</th>
<th>F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>retrieval</td>
<td>36.8</td>
<td>25.4</td>
<td>49.0</td>
</tr>
<tr>
<td>phrasal</td>
<td>27.8</td>
<td>16.4</td>
<td>39.9</td>
</tr>
<tr>
<td>sync</td>
<td>26.7</td>
<td>15.5</td>
<td>37.6</td>
</tr>
<tr>
<td>classifier</td>
<td>64.8</td>
<td>47.2</td>
<td>56.5</td>
</tr>
<tr>
<td>posclass</td>
<td>67.2</td>
<td>50.4</td>
<td>57.7</td>
</tr>
<tr>
<td>SEQ2SEQ</td>
<td>68.8</td>
<td>50.5</td>
<td>60.3</td>
</tr>
<tr>
<td>— attention</td>
<td>68.7</td>
<td>48.9</td>
<td>59.5</td>
</tr>
<tr>
<td>— argument</td>
<td>68.8</td>
<td>50.4</td>
<td>59.7</td>
</tr>
<tr>
<td>SEQ2TREE</td>
<td>69.6</td>
<td>51.4</td>
<td>60.4</td>
</tr>
<tr>
<td>— attention</td>
<td>68.7</td>
<td>49.5</td>
<td>60.2</td>
</tr>
</tbody>
</table>

(b) Omit non-English & unintelligible.

<table>
<thead>
<tr>
<th>Method</th>
<th>Channel</th>
<th>+Func</th>
<th>F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>retrieval</td>
<td>43.3</td>
<td>32.3</td>
<td>56.2</td>
</tr>
<tr>
<td>phrasal</td>
<td>37.2</td>
<td>23.5</td>
<td>45.5</td>
</tr>
<tr>
<td>sync</td>
<td>36.5</td>
<td>24.1</td>
<td>42.8</td>
</tr>
<tr>
<td>classifier</td>
<td>79.3</td>
<td>66.2</td>
<td>65.0</td>
</tr>
<tr>
<td>posclass</td>
<td>81.4</td>
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</tr>
<tr>
<td>SEQ2SEQ</td>
<td>87.8</td>
<td>75.2</td>
<td>73.7</td>
</tr>
<tr>
<td>— attention</td>
<td>88.3</td>
<td>73.8</td>
<td>72.9</td>
</tr>
<tr>
<td>— argument</td>
<td>86.8</td>
<td>74.9</td>
<td>70.8</td>
</tr>
<tr>
<td>SEQ2TREE</td>
<td>89.7</td>
<td>78.4</td>
<td>74.2</td>
</tr>
<tr>
<td>— attention</td>
<td>87.6</td>
<td>74.9</td>
<td>73.5</td>
</tr>
</tbody>
</table>

(c) ≥ 3 turkers agree with gold.

Table 5: Evaluation results on IFTTT.
Machine translation

Attention

No Attention

- ours, no attn (BLEU 13.9)
- ours, local–p attn (BLEU 20.9)
- ours, best system (BLEU 23.0)
- WMT’14 best (BLEU 20.7)
- Jeans et al., 2015 (BLEU 21.6)

BLEU

Sent Lengths
Coverage

• Caption generation

• How do we make sure we cover the source? (also relevant for summarization)
  • Penalize for source patches/words that are not aligned to any target word

\[
\sum_{\text{patch}} \left(1 - \sum_{\text{word}} \alpha_{\text{patch,word}}\right)^2
\]
Attention is all you need

- Attention-based encoders and decoders

Encoder-Decoder Attention

Encoder Self-Attention

MaskedDecoder Self-Attention

[vaswani et al., 2018]

Slide credit: Lukasz Kaiser
Summary

• Attention has enabled getting state-of-the-art performance for transduction scenarios

• Allows to softly align each token in a sequence of text to another sequence
Pointer networks
Problem

• Often at test time you need to translate entities you have never seen

• If we define the target vocabulary with the training set, we will never get it right

• In addition, translation for those entities is often simply copying

How tall is Dreymond Green?
HeightOf.DreymondGreen
Solution 1

- Mask entities
- Translate
- Bring back entities
  - But if there are many entities
  - How do you identify entities?

How tall is \(<e>\)?

\(\text{HeightOf}.<e>\)
Idea

- When we translate a sentence, the probability of a word increases once we see it.
  - $P(\text{“pokemen”})$ is low
  - $P(\text{“pokemon”} \mid \text{“the pokemon company”})$ is high
- Let’s allow outputting either words from a fixed target vocabulary or any word from the source sentence
Regular model

\[ p(y_t = w \mid x, y_1, \ldots, y_{t-1}) \propto \exp(U_w h_t) \]

HeightOf [3]
WeightOf [-1]
NumAssists [40]
( [9]
) [5.8]
. [3.7]
and [13]

Copying model

\[ p(y_t = w \mid x, y_1, \ldots, y_{t-1}) \propto \exp(U_w h_t) \]
\[ p(y_t = x_i \mid x, y_1, \ldots, y_{t-1}) \propto \exp(s_{ti}) \]

How tall is Dreymond Green?

- HeightOf [3]
- WeightOf [-1]
- NumAssists [40]
  - [9]
  - [5.8]
  - [3.7]
  and [13]
- How [5]
- tall [1]
- is [-2]
- Dreymond [100]
- Green [100]
- ? [0]
Copying model

• Need to marginalize over the words since there could be repetitions

• At training this means that the true distribution is uniform over all correct tokens

• At test time we choose the highest probability token, but marginalize over the same instances of a token
Slight improvement

\[
\begin{align*}
  p(y_t = w \mid x, y_1, \ldots, y_{t-1}) &\propto \exp(U_w h_t) \\
  p(y_t = x_i \mid x, y_1, \ldots, y_{t-1}) &\propto \exp(s_{ti})
\end{align*}
\]

- These scores need to be calibrated
- We can just interpolate two distributions after normalization

\[
\begin{align*}
p_{\text{vocab}}(y_t \mid x, y_1, \ldots, y_{t-1}) &= \text{softmax}(U h_t) \\
p_{\text{copy}}(y_t \mid x, y_1, \ldots, y_{t-1}) &= \text{softmax}(s_t) \\
p(y_t \mid x, y_1, \ldots, y_{t-1}) &= p_{\text{gen}} \cdot p_{\text{vocab}} + (1 - p_{\text{gen}}) \cdot p_{\text{copy}} \\
p_{\text{gen}} &= \sigma(w_1^\top h_t + w_2^\top c_t + w_3^\top y_{t-1})
\end{align*}
\]
Illustration

See et al., 2016
Summary

• Neural network for semantic parsing are based on sequence to sequence models

• These models are useful also for summarization, dialogue, question answering, paraphrasing, and other transduction tasks

• Attention added memory to circumvent the constant representation problem

• Pointer networks help in handling new words at test time

• Together you can often get models that are comparable to state-of-the-art without a grammar
Weak supervision
Weak supervision

• We have assumed that we have as input pairs of natural language and logical form

• In practice those are hard to collect and we usually have \((\text{language}, \text{denotation})\) pairs

<table>
<thead>
<tr>
<th>Heavy supervision</th>
<th>Light supervision</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>How tall is Lebron James?</em></td>
<td></td>
</tr>
<tr>
<td>HeightOf.LebronJames</td>
<td></td>
</tr>
<tr>
<td><em>What is Steph Curry’s daughter called?</em></td>
<td></td>
</tr>
<tr>
<td>ChildrenOf.StephCurry (\cap) Gender.Female</td>
<td></td>
</tr>
<tr>
<td><em>Youngest player of the Cavaliers</em></td>
<td></td>
</tr>
<tr>
<td>(\text{arg min}(\text{PlayerOf.Cavaliers, BirthDateOf}))</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td><em>How tall is Lebron James?</em></td>
</tr>
<tr>
<td>203cm</td>
<td></td>
</tr>
<tr>
<td><em>What is Steph Curry’s daughter called?</em></td>
<td></td>
</tr>
<tr>
<td>Riley Curry</td>
<td></td>
</tr>
<tr>
<td><em>Youngest player of the Cavaliers</em></td>
<td></td>
</tr>
<tr>
<td>Kyrie Irving</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>
The problem

- In sequence to sequence we trained end-to-end with SGD, minimizing the cross entropy loss of every token.
- Here we don’t have tokens.
- **Suggestion**: generate the program token by token, execute, and minimize cross entropy over denotations.
- **Problem**: The loss is not a differentiable function of the input because we don’t input gold tokens.

\[
\text{softmax} \quad \text{WeightOf (0.7)} \quad \text{HeightOf (0.2)} \quad \text{argmax} \quad \text{WeightOf}
\]

\[t \quad \rightarrow \quad \text{softmax} \quad \text{WeightOf (0.7)} \quad \text{HeightOf (0.2)} \quad \text{argmax} \quad \text{WeightOf} \quad t+1\]
Markov Decision Process

• Sequence of states, actions and rewards
  • $s_0, s_1, s_2, \ldots, s_T$ from a set $S$
  • $a_0, a_1, a_2, \ldots, a_T$ from a set $A$
    • Let’s assume a deterministic transition function $f:S\times A\rightarrow S$
  • $r_0, r_1, r_2, \ldots, r_T$ given by a reward function $r(s, a)$
• We want a policy $\pi(a \mid s)$ providing a distribution over actions that will maximize future reward
Seq2seq as MDP

- \( s_t: h_t \)
- \( a_t \) is in \( A(s_t) \)
  - Either all symbols in the target vocabulary
  - All \textbf{valid} symbols if we check grammaticality
- \( r_t \) is zero in all steps except the last. Then, it is 1 if execution results in a correct answer and 0 otherwise.

\[ \text{tall} \rightarrow \text{Lebron} \rightarrow \text{James} \rightarrow ? \rightarrow <s> \rightarrow \text{HeightOf} \]

Liang et al, 2017, Guu et al., 2017
Seq2seq as MDP: policy

\[ p(z \mid x) = \prod_{t} p(z_t \mid x, z_0, \ldots, z_{t-1}) \]
\[ = \prod_{t} p(a_t \mid x, a_0, \ldots, a_{t-1}) \]
\[ = \prod_{t} \pi(a_t \mid s_t) \]
\[ \pi(a_t \mid s_t) = \text{softmax}(W^{(s)} h_t) \]
Seq2seq as MDP: policy

\[
p(z \mid x) = \prod_t p(z_t \mid x, z_0, \ldots, z_{t-1}) \\
= \prod_t p(a_t \mid x, a_0, \ldots, a_{t-1}) \\
= \prod_t \pi(a_t \mid s_t) \\
\rho(a_t \mid s_t) = \text{softmax}(W^{(s)} h_t)
\]
Option 1: Maximum marginal likelihood

• Our data is language-dentation pairs \((x,y)\)

• We obtain \(y\) by constructing a logical form \(z\)

• We can use maximum marginal likelihood by interleaving search and learning:
  
  • Search to get candidate logical forms
  
  • Learn from these candidates
Maximum marginal likelihood

- $z$ is independent of $x$ conditioned on $y$

$$p_\theta(y \mid x) = \sum_z p_\theta(z \mid x) \cdot p(y \mid z)$$

$$= \sum_z p_\theta(z \mid x) R(z) = E_{p_\theta(z \mid x)}[R(z)]$$

$$\mathcal{L}_{MML}(\theta) = \log \prod_{(x, y)} p_\theta(y \mid x) = \log \prod_{(x, y)} E_{p_\theta(z \mid x)}[R(z)]$$

$$= \sum_{(x, y)} \log \sum_z p_\theta(z \mid x) \cdot R(z)$$
Gradient of MML

- Gradient has similar form to what we have seen in the past, except that we are not in a log-linear model. Let’s assume a binary reward:

\[
\nabla_{\theta} \log \sum_z p_\theta(z \mid x) \cdot R(z) = \sum_z \frac{p_\theta(z \mid x)R(z)\nabla \log p_\theta(z \mid x)}{\sum'_{z'} p_\theta(z' \mid x) \cdot R(z')} \\
= \sum_z p(z \mid x, R(z) = 1)\nabla \log p_\theta(z \mid x)
\]

- Compute the gradient of the log probability for every logical form, and weight the gradient using the reward.
Computing the gradient

- We can not enumerate all of the logical forms
- Instead we perform beam search as usual and get a beam $Z$ containing $K$ logical forms.
- We imagine that this beam is the entire set of possible logical forms
  \[
  \sum_{z \in Z} p(z \mid x, R(z) = 1) \nabla \log p_\theta(z \mid x)
  \]
- For every $z$ we can compute the gradient of $\log p(z \mid x)$ since this is now the usual seq2seq setup.
Option 2: policy gradient

• We would like to simply maximize our expected reward

\[ E_{p_\theta(z|x)}[R(z)] = \sum_z p_\theta(z \mid x)R(z) \]

\[ \mathcal{L}_{RL}(\theta) = \sum_{(x,y)} \sum_z p_\theta(z \mid x)R(z) = \sum_{(x,y)} E_{p_\theta(z|x)}[R(z)] \]

\[ \nabla \mathcal{L}_{RL}(\theta) = \sum_{(x,y)} \sum_z p_\theta(z \mid x)R(z) \nabla \log p_\theta(z \mid x) \]

\[ = \sum_{(x,y)} E_{p_\theta(z|x)}[R(z) \nabla \log p_\theta(z \mid x)] \]

• Weight the gradient by the product of the reward and the model probability
Computing the gradient

- Again, we can not sum over all logical forms

- But the gradient for every example is an expectation over a distribution we can sample from!

- So we can sample many logical forms, compute the gradient and sum them weighted by the product of the model probability and reward

- Again, for every sample this is regular seq2seq and we can compute an approximate gradient
Some differences

• Using MML with beam search is a biased estimator and has less exploration - we only observe the approximate top-K logical forms.

• Using RL could be harder to train. If we have a correct logical form $z^*$ that has low probability at the beginning of training, then the contribution to the gradient would be very smaller and it would be hard to bootstrap.
Summary

• Training with a seq2seq model with weak supervision is problematic because the loss function is not a differentiable function of the input

• We saw both MML and RL approaches for getting around that

• In both we find a set of logical forms, compute the gradient for them like in supervised learning, and weight them in some way to form a final gradient

• This let’s us train with SGD

• It is still often hard to train