Commonsense for Generative Multi-Hop Question Answering Tasks

Lisa Bauer*    Yicheng Wang*    Mohit Bansal
• Reading Comprehension Task (Lisa)
• Reading Comprehension Baseline (Yicheng)
• Commonsense Extraction (Lisa)
• Commonsense Model Integration (Yicheng)
• Results on NarrativeQA & WikiHop (Yicheng)
“What is the connection between Esther and Lady Dedlock?”

“Mother and daughter.”
“Mother and illegitimate child.”
• Motivation
  • Answer spans: 44.05%
  • Outside knowledge required: 42%

• Challenges
  • Intricate event timelines
    “Who leads Mickey back to boxing after the HBO documentary is released?”
  • Large number of characters
    “Why did Sophia go to Russia with Alexei, instead of John?”
  • Complex structure
    “Why did Mickey have reservations about his fight in Atlantic City?”
Baseline Multi-Hop Pointer-Generator

• Success on Multi-Hop Reasoning QA datasets require a model to have:
Baseline Multi-Hop Pointer-Generator

• Success on Multi-Hop Reasoning QA datasets require a model to have:
  • Strong NLU capabilities
Baseline Multi-Hop Pointer-Generator

• Success on Multi-Hop Reasoning QA datasets require a model to have:
  • Strong NLU capabilities
  • Ability to extract disjoint pieces of information
Success on Multi-Hop Reasoning QA datasets require a model to have:

- Strong NLU capabilities
- Ability to extract disjoint pieces of information
- Tools to process long/interconnected context
Success on Multi-Hop Reasoning QA datasets require a model to have:

- Strong NLU capabilities
- Ability to extract disjoint pieces of information
- Tools to process long/interconnected context
- Strong generative modelling capabilities (rare words)
Baseline Multi-Hop Pointer-Generator

Embedding Layer

- Query Embedding:
  - $w^Q_i$
  - $w^Q_m$
- Context Embedding:
  - $w^C_i$
  - $w^C_2$
  - $w^C_n$
Baseline Multi-Hop Pointer-Generator

Embedding Layer

$$w_1^O \quad \vdots \quad w_m^O \quad \text{Query} \quad \text{Embed}$$

Reasoning Layer

$$w_1^C \quad w_2^C \quad \vdots \quad w_n^C \quad \text{Context} \quad \text{Embed}$$
Baseline Multi-Hop Pointer-Generator

Embedding Layer

Query

Reasoning Layer

Context

...
Baseline Multi-Hop Pointer-Generator

Embedding Layer

Query Embedding Layer

Reasoning Layer

Context Embedding Layer

$k$ Reasoning Cells
Baseline Multi-Hop Pointer-Generator

Embedding Layer

$w_1^Q \rightarrow \text{Embed} \rightarrow \text{Reasoning Layer} \rightarrow \ldots \rightarrow \text{Self-Attention Layer}$

Reasoning Layer

$W_l^Q \rightarrow \text{Embed} \rightarrow \ldots \rightarrow \text{Self-Attention} \rightarrow +$

Self-Attention Layer

$k$ Reasoning Cells

Query

Context
Baseline Multi-Hop Pointer-Generator

Embedding Layer

Reasoning Layer

Self-Attention Layer

Decoding Layer

$k$ Reasoning Cells
Baseline Reasoning Cell

Reasoning Layer

Query

Context

Baseline Reasoning Cell

Bi-LSTM

BiDAF

Baseline Reasoning Cell

Bi-LSTM

Query

Context
## Baseline Ablations

<table>
<thead>
<tr>
<th>Model</th>
<th>BLEU-1 (Δ)</th>
<th>BLEU-4 (Δ)</th>
<th>METEOR (Δ)</th>
<th>ROUGE-L (Δ)</th>
<th>CiDER (Δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>42.3 (-)</td>
<td>18.9 (-)</td>
<td>18.3 (-)</td>
<td>44.9 (-)</td>
<td>151.6 (-)</td>
</tr>
<tr>
<td>Single-Hop Baseline</td>
<td>32.5 (-9.8)</td>
<td>11.7 (-7.2)</td>
<td>12.9 (-5.4)</td>
<td>32.4 (-12.5)</td>
<td>95.7 (-55.9)</td>
</tr>
<tr>
<td>Without ELMo</td>
<td>32.8 (-9.5)</td>
<td>12.7 (-6.2)</td>
<td>13.6 (-4.7)</td>
<td>33.7 (-11.2)</td>
<td>103.1 (-48.5)</td>
</tr>
<tr>
<td>Without Self-Attn</td>
<td>37.0 (-5.3)</td>
<td>16.4 (-2.5)</td>
<td>15.6 (-2.7)</td>
<td>38.6 (-6.3)</td>
<td>125.6 (-26.0)</td>
</tr>
</tbody>
</table>
Commonsense Requirements

• Success on Multi-Hop Reasoning QA datasets require a model to have:
  • Strong NLU capabilities
  • Ability to extract disjoint pieces of information
  • Tools to process long/interconnected context
  • Strong generative modelling capabilities (rare words)
Commonsense Requirements

- Success on Multi-Hop Reasoning QA datasets require a model to have:
  - Strong NLU capabilities
  - Ability to extract disjoint pieces of information
  - Tools to process long/interconnected context
  - Strong generative modelling capabilities (rare words)
  - Reason with implicit relations not mentioned in the context
Commonsense Addition

Query

Bi-LSTM

BiDAF

Context

Bi-LSTM

Commonsense Relations

w₁ CS \hspace{2pt} w₂ CS \hspace{2pt} w₃ CS \hspace{2pt} w₄ CS \hspace{2pt} w₅
Types of Commonsense

• Taxonomic

What **physical disorders** do Paul and Charmian have in common?

Paula, like Charmian, is subject to **insomnia**, and Paula, like Charmian, is **unable to bear children**.

Insomnia and the inability to have kids
Types of Commonsense

- **Taxonomic**
  What **physical disorders** do Paul and Charmian have in common?
  Paula, like Charmian, is subject to **insomnia**, and Paula, like Charmian, is **unable to bear children**.
  Insomnia and the inability to have kids

- **Cause/Effect**
  What **position does Anne take** at Summerside School?
  Having recently **received an offer** to be the principal of the Summerside School in the fall, Anne is keeping herself occupied.
  Principal
Types of Commonsense

• **Taxonomic**
  - What **physical disorders** do Paul and Charmian have in common?
    - Paula, like Charmian, is subject to **insomnia**, and Paula, like Charmian, is **unable to bear children**.
    - Insomnia and the inability to have kids

• **Cause/Effect**
  - What **position does Anne take** at Summerside School?
    - Having recently **received an offer** to be the principal of the Summerside School in the fall, Anne is keeping herself occupied.
    - Principal

• **Colloquialisms**
  - Why did Jack take the job?
    - To **make ends meet** and against better judgement, he takes a job as a croupier.
    - Jack took the job **to pay for necessities**.
ConceptNet

• A knowledge graph of semantic relations between concepts
• Has **28 million edges**
• Each edge represents one of 37 types of semantic relationship, e.g., UsedFor, FormOf, CapableOf, etc.

[Speer and Havasi, 2012]
"What is the connection between Esther and Lady Dedlock?"

"Sir Leicester Dedlock and his wife Lady Honoria live on his estate at Chesney Wold."

"..Unknown to Sir Leicester, Lady Dedlock had a lover .. before she married and had a daughter with him."

"..Lady Dedlock believes her daughter is dead. The daughter, Esther, is in fact alive."

"..Esther sees Lady Dedlock at church and talks with her later at Chesney Wold though neither woman recognizes their connection."

"Mother and daughter."

"Mother and illegitimate child."

ConceptNet:
- lady → mother → daughter → child
- multi-hop reasoning

Context:
- church
- wife
- class
- UK
- lord
- historical
- person
Tree Construction

lady

Question concept
Tree Construction

- lady
- church
- wife
- mother
- person

Question concept

Direct Interaction
Tree Construction

- Lady
  - Church
  - Wife
  - Mother
  - Person
    - House
    - Marry
    - Daughter
    - Book
    - Lover
    - Help

Question concept

Direct Interaction

Multi-Hop
Tree Construction

- Lady
  - Church
    - House
      - Child
  - Wife
    - Marry
      - Child
  - Mother
  - Person
  - Book
  - Lover
  - Help

Question concept
Direct Interaction
Multi-Hop
Outside Knowledge
Tree Construction

- **lady**
  - **church**
    - **house**
      - **child**
        - their
  - **wife**
    - **marry**
  - **mother**
    - **daughter**
      - **child**
  - **person**
    - **book**
    - **lover**
    - **help**

**Outside Knowledge**
- *their*

**Multi-Hop**
- *marry*

**Direct Interaction**
- *child*

**Context Grounding**
- *church*
- *mother*
- *book*
- *lover*
- *help*
Initial Node Scoring

Term-Frequency

- lady
  - church: freq=1/1044
  - wife: freq=3/1044
  - mother: freq=1/1044
  - person: freq=1/1044
- house
- marry
- daughter
- book
- lover
- help
- child
- their
Initial Node Scoring

```
<table>
<thead>
<tr>
<th>lady</th>
</tr>
</thead>
<tbody>
<tr>
<td>church</td>
</tr>
<tr>
<td>wife</td>
</tr>
<tr>
<td>mother</td>
</tr>
<tr>
<td>person</td>
</tr>
<tr>
<td>house</td>
</tr>
<tr>
<td>marry</td>
</tr>
<tr>
<td>daughter</td>
</tr>
<tr>
<td>book</td>
</tr>
<tr>
<td>lover</td>
</tr>
<tr>
<td>help</td>
</tr>
</tbody>
</table>

Softmax Normalization

child

their
```
Initial Node Scoring

![Diagram showing the initial node scoring for various words like lady, church, wife, mother, person, house, marry, daughter, book, lover, help, and their, with probabilities for each connection.](image)

Softmax Normalization
Initial Node Scoring

**Softmax Normalization**

0.249

0.499

0.500

0.249

1.0

1.0

1.0

1.0

1.0

1.0

0.499

0.500

0.499

0.500

0.499

Pointwise Mutual Information
Cumulative Node Scoring

- lady
  - mother
    - daughter
    - book
    - lover
    - help
  - person
  - child
Cumulative Node Scoring

- lady
  - mother
    - daughter
      - child
  - person
    - book
    - lover
    - help
Cumulative Node Scoring

1.0 + 0.500 = 1.500
Cumulative Node Scoring

1.0 + 0.500 = 1.500

1.500 + 0.499 \over 2 + 0.249 = 1.249

0.500 + 0.499 \over 2 + 0.249 = 0.744
Cumulative Node Scoring

- lady
  - mother
    - daughter
      - child
    - book
    - lover
  - person
    - help

Scores:
- lady: 0.744
- mother: 1.249
- person: 0.744
- daughter: 1.500
- book: 0.499
- lover: 0.500
- help: 0.499
- child: 1.0
Path Selection

- lady
  - mother
    - daughter 1.500
    - child 1.0
  - person
    - book 0.499
    - lover 0.500
    - help 0.499

Weights: 0.499, 0.744, 0.499, 1.249, 0.500

43
Path Selection

Graph showing relationships between terms: lady, mother, daughter, book, lover, help, and child. The graph illustrates how these terms are connected, with distances and weights indicating the strength of the connections.
Commonsense Incorporation

• Effective incorporation of commonsense information requires:
  • Multihop, selective commonsense incorporation
  • The ability to ignore ‘noisy’ unnecessary commonsense
• This fits in with our modular baseline design
• **Necessary and Optional Information Cell (NOIC)** incorporates optional commonsense information via a gated-attention layer
NOIC Cell

- **Query**
- **Bi-LSTM**
- **BiDAF**

**Context**

**Commonsense Relations**

**NOIC Reasoning Cell**
NOIC Cell

Query

Bi-LSTM

BiDAF

Attention

Context

Commonsense Relations

NOIC Reasoning Cell
NOIC Cell

Query

Bi-LSTM

BiDAF

Bypass

Attention

σ

Context

NOIC Reasoning Cell

Bi-LSTM

Commonsense Relations

w₁ CS, ..., wₗ CS
MHPGM + NOIC

NOIC Reasoning Cell

BiDAF

Bi-LSTM

Attention

Query

Context

Commonsense Relations

Reasoning Layer

Query

Context

Commonsense

Bypass

σ

\( w_1^{CS}, \ldots, w_l^{CS} \)
MHPGM + NOIC

NOIC Reasoning Cell

Context

BiDAF

Bi-LSTM

Query

Bypass

Attention

σ

Commonsense Relations

W₁, W₂, ..., Wₗ

Reasoning Layer

Query

Context

Commonsense
MHPGM + NOIC

NOIC Reasoning Cell

BiDAF

Attention

Σ

Bi-LSTM

Query

Reasoning Layer

Context

Commonsense Relations

\( w_1, w_2, ..., w_l \)

\( c_1, c_2, ..., c_s \)
By visualizing the sigmoid activation value, we can visualize how much commonsense was added into each part of the context during each hop.

Consider the question “What shore does Michael’s corpse wash up on?”

“Maurya has lost her husband, and five of her sons to the sea. As the play begins Nora and Cathleen receive word from the priest that a body, that may be their brother Michael, has washed up on shore in Donegal, the island farthest north of their home Island of Inishmaan. Bartley is planning to sail to Connemara to sell a horse, and ignores Maurya’s pleas to stay. He leaves gracefully. Maurya predicts that by nightfall she will have no living sons, and her daughters chide her for sending Bartley off with an ill word. Maurya goes after Bartley to bless his voyage, and Nora and Cathleen receive clothing from the drowned corpse that confirms it is their brother. Maurya returns home claiming to have seen the ghost of Michael riding behind Bartley and begins lamenting the loss of the men in her family to the sea, after which some villagers bring in the corpse of Bartley, who has fallen off his horse into the sea and drowned. This speech of Maurya’s is famous in Irish drama: (raising her head and speaking as if she did not see the people around her) They re all gone now, and there isn’t anything more the sea can do to me... . I’ll have no call now to be up crying and praying when the wind breaks from the south, and you can hear the surf is in the east, and the surf is in the west, making a great stir with the two noises, and they hitting one on the other. I’ll have no call now to be going down and getting holy water in the dark nights after samhain, and i won't care what way the sea is when the other women will be keening. (to Nora) give me the holy water , Nora: there’s a small sup still on the dresser .”
maurya has lost her husband, and five of her sons to the sea. as the play begins nora and cathleen receive word from the priest that a body, that may be their brother michael, has washed up on shore in donegal, the island farthest north of their home island ofinishmaan. bartley is planning to sail to connemara to sell a horse, and ignores maurya’s pleas to stay. he leaves gracefully. maurya predicts that by nightfall she will have no living sons, and her daughters chide her for sending bartley off with an ill word.

maurya goes after bartley to bless his voyage, and nora and cathleen receive clothing from the drowned corpse that confirms it is their brother. maurya returns home claiming to have seen the ghost of michael riding behind bartley and begins lamenting the loss of the men in her family to the sea, after which some villagers bring in the corpse of bartley, who has fallen off his horse into the sea and drowned. this speech of maurya’s is famous in irish drama: (raising her head and speaking as if she did not see the people around her) they’re all gone now, and there’s not anything more the sea can do to me ... i’ll have no call now to be up crying and praying when the wind breaks from the south, and you can hear the surf is in the east, and the surf is in the west, making a great stir with the two noises, and they hitting one on the other, i’ll have no call now to be going down and getting holy water in the dark nights after samhain, and i won’t care what way the sea is when the other women will be keening. (to nora) give me the holy water, nora; there’s a small sup still on the dresser.
maurya has lost her husband, and five of her sons to the sea. as the play begins nora and cathleen receive word from the priest that a body, that may be their brother michael, has washed up on shore in donegal, the island farthest north of their home island ofinishmaan. bartley is planning to sail to connemara to sell a horse, and ignores maurya's pleas to stay. he leaves gracefully. maurya predicts that by nightfall she will have no living sons, and her daughters chide her for sending bartley off with an ill word. maurya goes after bartley to bless his voyage, and nora and cathleen receive clothing from the drowned corpse that confirms it is their brother. maurya returns home claiming to have seen the ghost of michael riding behind bartley and begins lamenting the loss of the men in her family to the sea, after which some villagers bring in the corpse of bartley, who has fallen off his horse into the sea and drowned. this speech of maurya's is famous in irish drama: (raising her head and speaking as if she did not see the people around her) they're all gone now, and there is n't anything more the sea can do to me .... i'll have no call now to be up crying and praying when the wind breaks from the south, and you can hear the surf is in the east, and the surf is in the west, making a great stir with the two noises, and they hitting one on the other. i'll have no call now to be going down and getting holy water in the dark nights after samhain, and i wo n't care what way the sea is when the other women will be keening. (to nora) give me the holy water, nora; there's a small sup still on the dresser.
maurya has lost her husband, and five of her sons to the sea. as the play begins nora and cathleen receive word from the priest that a body, that may be their brother michael, has washed up on shore in donegal, the island farthest north of their home island ofinishmaan. bartley is planning to sail to connemara to sell a horse, and ignores maurya’s pleas to stay. he leaves gracefully. maurya predicts that by nightfall she will have no living sons, and her daughters chide her for sending bartley off with an ill word. maurya goes after bartley to bless his voyage, and nora and cathleen receive clothing from the drowned corpse that confirms it is their brother. maurya returns home claiming to have seen the ghost of michael riding behind bartley and begins lamenting the loss of the men in her family to the sea, after which some villagers bring in the corpse of bartley, who has fallen off his horse into the sea and drowned. this speech of maurya’s is famous in irish drama: (raising her head and speaking as if she did not see the people around her) they’re all gone now, and there is n’t anything more the sea can do to me…. i’ll have no call now to be up crying and praying when the wind breaks from the south, and you can hear the surf is in the east, and the surf is in the west, making a great stir with the two noises, and they hitting one on the other. i’ll have no call now to be going down and getting holy water in the dark nights after samhain, and i won’t care what way the sea is when the other women will be keening. (to nora) give me the holy water, nora; there’s a small sup still on the dresser.
maurya has lost her husband, and five of her sons to the sea. as the play begins nora and cathleen receive word from the priest that a body, that may be their brother michael, has washed up on shore in donegal, the island farthest north of their home island ofinishmaan. bartley is planning to sail to connemara to sell a horse, and ignores maurya's pleas to stay. he leaves gracefully. maurya predicts that by nightfall she will have no living sons, and her daughters chide her for sending bartley off with an ill word. maurya goes after bartley to bless his voyage, and nora and cathleen receive clothing from the drowned corpse that confirms it is their brother. maurya returns home claiming to have seen the ghost of michael riding behind bartley and begins lamenting the loss of the men in her family to the sea, after which some villagers bring in the corpse of bartley, who has fallen off his horse into the sea and drowned. this speech of maurya's is famous in irish drama: (raising her head and speaking as if she did not see the people around her) they're all gone now, and there is n't anything more the sea can do to me. ... i'll have no call now to be up crying and praying when the wind breaks from the south, and you can hear the surf is in the east, and the surf is in the west, making a great stir with the two noises, and they hiting one on the other. i'll have no call now to be going down and getting holy water in the dark nights after samhain, and i wo n't care what way the sea is when the other women will be keening. (to nora) give me the holy water, nora; there's a small sup still on the dresser.
maurya has lost her husband, and five of her sons to the sea. as the play begins nora and cathleen receive word from the priest that a body, that may be their brother michael, has washed up on shore in donegal, the island farthest north of their home island of inishmaan. bartley is planning to sail to connemara to sell a horse, and ignores maurya’s pleas to stay. he leaves gracefully. maurya predicts that by nightfall she will have no living sons, and her daughters chide her for sending bartley off with an ill word. maurya goes after bartley to bless his voyage, and nora and cathleen receive clothing from the drowned corpse that confirms it is their brother. maurya returns home claiming to have seen the ghost of michael riding behind bartley and begins lamenting the loss of the men in her family to the sea, after which some villagers bring in the corpse of bartley, who has fallen off his horse into the sea and drowned. this speech of maurya’s is famous in irish drama: (raising her head and speaking as if she did not see the people around her) they’re all gone now, and there is n’t anything more the sea can do to me... i’ll have no call now to be up crying and praying when the wind breaks from the south, and you can hear the surf is in the east, and the surf is in the west, making a great stir with the two noises, and they hitting one on the other. i’ll have no call now to be going down and getting holy water in the dark nights after samhain, and i wo n’t care what way the seas is when the other women will be keening. (to nora) give me the holy water, nora; there’s a small sup still on the dresser.
## Results: NarrativeQA

<table>
<thead>
<tr>
<th>Model</th>
<th>BLEU-1</th>
<th>BLEU-4</th>
<th>METEOR</th>
<th>Rouge-L</th>
<th>CIDEr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seq2Seq (Kočiský et al., 2018)</td>
<td>15.89</td>
<td>1.26</td>
<td>4.08</td>
<td>13.15</td>
<td>-</td>
</tr>
<tr>
<td>ASR (Kočiský et al., 2018)</td>
<td>23.20</td>
<td>6.39</td>
<td>7.77</td>
<td>22.26</td>
<td>-</td>
</tr>
<tr>
<td>BiDAF† (Kočiský et al., 2018)</td>
<td>33.72</td>
<td>15.53</td>
<td>15.38</td>
<td>36.30</td>
<td>-</td>
</tr>
<tr>
<td>BiAttn + MRU-LSTM† (Tay et al., 2018)</td>
<td>36.55</td>
<td>19.79</td>
<td>17.87</td>
<td>41.44</td>
<td>-</td>
</tr>
<tr>
<td>MHPGM</td>
<td>40.24</td>
<td>17.40</td>
<td>17.33</td>
<td>41.49</td>
<td>139.23</td>
</tr>
<tr>
<td>MHPGM+ NOIC</td>
<td><strong>43.63</strong></td>
<td><strong>21.07</strong></td>
<td><strong>19.03</strong></td>
<td><strong>44.16</strong></td>
<td><strong>152.98</strong></td>
</tr>
</tbody>
</table>

† indicates span prediction models trained on the Rouge-L retrieval oracle.
## Results: Human Evaluation

<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHPGM+NOIC better</td>
<td>23%</td>
</tr>
<tr>
<td>MHPGM better</td>
<td>15%</td>
</tr>
<tr>
<td>Indistinguishable (Both-good)</td>
<td>41%</td>
</tr>
<tr>
<td>Indistinguishable (Both-bad)</td>
<td>21%</td>
</tr>
</tbody>
</table>

- Fleiss-Kappa between three human annotators = 0.831 (“Almost-perfect agreement” *(Landis and Koch, 1997)*))
## Results: WikiHop

<table>
<thead>
<tr>
<th>Model</th>
<th>Dev (%)</th>
<th>Test (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHPGM</td>
<td>56.7</td>
<td>57.5</td>
</tr>
<tr>
<td>MHPGM+ NOIC</td>
<td>58.2</td>
<td>57.9</td>
</tr>
</tbody>
</table>

- Only 11% of examples need outside knowledge as opposed to 42% on NarrativeQA
- Needs more fact-based commonsense (e.g., Freebase) instead of semantics-based ones (e.g., ConceptNet)
- Future Work: Adding commonsense to new/stronger state-of-the-art 68-70% baseline for WikiHop
## Results: Commonsense Ablation

<table>
<thead>
<tr>
<th>Commonsense</th>
<th>BLEU-1</th>
<th>BLEU-4</th>
<th>METEOR</th>
<th>ROUGE-L</th>
<th>CiDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>42.3</td>
<td>18.9</td>
<td>18.3</td>
<td>44.9</td>
<td>151.6</td>
</tr>
<tr>
<td>NumberBatch</td>
<td>42.6</td>
<td>19.6</td>
<td>18.6</td>
<td>44.4</td>
<td>148.1</td>
</tr>
<tr>
<td>Random Rel.</td>
<td>43.3</td>
<td>19.3</td>
<td>18.6</td>
<td>45.2</td>
<td>151.2</td>
</tr>
<tr>
<td>Single Hop</td>
<td>42.1</td>
<td>19.9</td>
<td>18.2</td>
<td>44.0</td>
<td>148.6</td>
</tr>
<tr>
<td>Grounded Rel.</td>
<td><strong>45.9</strong></td>
<td><strong>21.9</strong></td>
<td><strong>20.7</strong></td>
<td><strong>48.0</strong></td>
<td><strong>166.6</strong></td>
</tr>
</tbody>
</table>

[Speer and Havasi, 2012]
## Results: Commonsense Ablation

<table>
<thead>
<tr>
<th>Commonsense</th>
<th>BLEU-1</th>
<th>BLEU-4</th>
<th>METEOR</th>
<th>ROUGE-L</th>
<th>CiDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>42.3</td>
<td>18.9</td>
<td>18.3</td>
<td>44.9</td>
<td>151.6</td>
</tr>
<tr>
<td>NumberBatch</td>
<td>42.6</td>
<td>19.6</td>
<td>18.6</td>
<td>44.4</td>
<td>148.1</td>
</tr>
<tr>
<td>Random Rel.</td>
<td>43.3</td>
<td>19.3</td>
<td>18.6</td>
<td>45.2</td>
<td>151.2</td>
</tr>
<tr>
<td>Single Hop</td>
<td>42.1</td>
<td>19.9</td>
<td>18.2</td>
<td>44.0</td>
<td>148.6</td>
</tr>
<tr>
<td>Grounded Rel.</td>
<td><strong>45.9</strong></td>
<td><strong>21.9</strong></td>
<td><strong>20.7</strong></td>
<td><strong>48.0</strong></td>
<td><strong>166.6</strong></td>
</tr>
</tbody>
</table>

[Speer and Havasi, 2012]
## Results: Commonsense Ablation

<table>
<thead>
<tr>
<th>Commonsense</th>
<th>BLEU-1</th>
<th>BLEU-4</th>
<th>METEOR</th>
<th>ROUGE-L</th>
<th>CiDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>42.3</td>
<td>18.9</td>
<td>18.3</td>
<td>44.9</td>
<td>151.6</td>
</tr>
<tr>
<td>NumberBatch</td>
<td>42.6</td>
<td>19.6</td>
<td>18.6</td>
<td>44.4</td>
<td>148.1</td>
</tr>
<tr>
<td>Random Rel.</td>
<td>43.3</td>
<td>19.3</td>
<td>18.6</td>
<td>45.2</td>
<td>151.2</td>
</tr>
<tr>
<td>Single Hop</td>
<td>42.1</td>
<td>19.9</td>
<td>18.2</td>
<td>44.0</td>
<td>148.6</td>
</tr>
<tr>
<td>Grounded Rel.</td>
<td><strong>45.9</strong></td>
<td><strong>21.9</strong></td>
<td><strong>20.7</strong></td>
<td><strong>48.0</strong></td>
<td><strong>166.6</strong></td>
</tr>
</tbody>
</table>
### Results: Commonsense Ablation

<table>
<thead>
<tr>
<th>Commonsense</th>
<th>BLEU-1</th>
<th>BLEU-4</th>
<th>METEOR</th>
<th>ROUGE-L</th>
<th>CiDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>42.3</td>
<td>18.9</td>
<td>18.3</td>
<td>44.9</td>
<td>151.6</td>
</tr>
<tr>
<td>NumberBatch</td>
<td>42.6</td>
<td>19.6</td>
<td>18.6</td>
<td>44.4</td>
<td>148.1</td>
</tr>
<tr>
<td>Random Rel.</td>
<td>43.3</td>
<td>19.3</td>
<td>18.6</td>
<td>45.2</td>
<td>151.2</td>
</tr>
<tr>
<td><strong>Single Hop</strong></td>
<td>42.1</td>
<td>19.9</td>
<td>18.2</td>
<td>44.0</td>
<td>148.6</td>
</tr>
<tr>
<td>Grounded Rel.</td>
<td><strong>45.9</strong></td>
<td><strong>21.9</strong></td>
<td><strong>20.7</strong></td>
<td><strong>48.0</strong></td>
<td><strong>166.6</strong></td>
</tr>
</tbody>
</table>

[Speer and Havasi, 2012]
## Results: Commonsense Ablation

<table>
<thead>
<tr>
<th>Commonsense</th>
<th>BLEU-1</th>
<th>BLEU-4</th>
<th>METEOR</th>
<th>ROUGE-L</th>
<th>CiDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>42.3</td>
<td>18.9</td>
<td>18.3</td>
<td>44.9</td>
<td>151.6</td>
</tr>
<tr>
<td>NumberBatch</td>
<td>42.6</td>
<td>19.6</td>
<td>18.6</td>
<td>44.4</td>
<td>148.1</td>
</tr>
<tr>
<td>Random Rel.</td>
<td>43.3</td>
<td>19.3</td>
<td>18.6</td>
<td>45.2</td>
<td>151.2</td>
</tr>
<tr>
<td>Single Hop</td>
<td>42.1</td>
<td>19.9</td>
<td>18.2</td>
<td>44.0</td>
<td>148.6</td>
</tr>
<tr>
<td>Grounded Rel.</td>
<td>45.9</td>
<td>21.9</td>
<td>20.7</td>
<td>48.0</td>
<td>166.6</td>
</tr>
</tbody>
</table>
Results: Commonsense Extraction

<table>
<thead>
<tr>
<th>Commonsense Required</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant CS Extracted</td>
<td>34%</td>
<td>14%</td>
</tr>
<tr>
<td>Irrelevant CS Extracted</td>
<td>16%</td>
<td>36%</td>
</tr>
</tbody>
</table>
Conclusions & Future Work

• In this work, we...
  • Proposed a strong multi-hop baseline for generative QA task
  • Used PMI/TF based filtering algorithm to effectively query large knowledge graphs for relevant subgraphs
  • Effectively incorporated commonsense paths into our multi-hop baseline via multiple hops of selectively gated attention

• In the future, we will...
  • Explore adding different types of commonsense to other domains
  • Explore the possibility of adding graph-based attention to more directly incorporate semantic networks
Thank you for listening!
Questions?

Acknowledgement: DARPA (YFA17-D17AP00022), Google, Bloomberg, NVidia