The Goldilocks Principle

Reading Children’s Books with Explicit Memory Representations

Felix Hill, Antoine Bordes, Sumit Chopra & Jason Weston
Context is needed to understand language

“What the heck should I do?”

“What would you like to do?”
"Bears are bad news. Go through the secret passage in the fireplace."

"So I’m hidden under the covers, but there’s someone at the door.

It looks like bears.

What the heck should I do?"
Children’s Book Test
1. Mr. Cropper was opposed to our hiring you.
2. Not, of course, that he had any personal objection to you, but he is set against female teachers, and when a Cropper is set there is nothing on earth can change him.
3. He says female teachers can't keep order.
4. He's started in with a spite at you on general principles, and the boys know it.
5. They know he'll back them up in secret, no matter what they do, just to prove his opinions.
6. Cropper is sly and slippery, and it is hard to corner him. ''
7. ``Are the boys big?''
8. queried Esther anxiously.
9. ``Yes.
10. Thirteen and fourteen and big for their age.
11. You can't whip 'em -- that is the trouble.
12. A man might, but they'd twist you around their fingers.
13. You'll have your hands full, I'm afraid.
14. But maybe they'll behave all right after all. ''
15. Mr. Baxter privately had no hope that they would, but Esther hoped for the best.
16. She could not believe that Mr. Cropper would carry his prejudices into a personal application.
17. This conviction was strengthened when he overtook her walking from school the next day and drove her home.
18. He was a big, handsome man with a very suave, polite manner.
19. He asked interestedly about her school and her work, hoped she was getting on well, and said he had two young rascals of his own to send soon.
20. Esther felt relieved.
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She thought that Mr. ______ had exaggerated matters a little.
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Query

She thought that Mr. _______ had exaggerated matters a little.

Candidates

Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite
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Candidates
10, multiple choice
Baxter, Cropper Esther, course, fingers, manner, objection, opinion, right, spite,
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Query
She thought that Mr. ______ had exaggerated matters a little.

Candidates
Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite

Answer
Baxter
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3 He says female teachers can’t keep order.
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**Candidates**

Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite

**Answer**

Baxter
# Children’s Book Test

<table>
<thead>
<tr>
<th></th>
<th>Books</th>
<th>Questions</th>
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<tr>
<td>Train</td>
<td>98</td>
<td>670,000</td>
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<tr>
<td>Validation</td>
<td>5</td>
<td>8,000</td>
</tr>
<tr>
<td>Test</td>
<td>5</td>
<td>10,000</td>
</tr>
</tbody>
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Prepositions

She thought that Mr Baxter had exaggerated the story ____ the train.

a on in about under as for to below eats
She thought that Mr Baxter had exaggerated the story on the train.

Prepositions

She thought that Mr Baxter had exaggerated the story ____ the train.

a  on  in  about  under  as  for  to  below  eats

Verbs

She thought that Mr Baxter had _____ the story on the train

heard  run  exaggerated  eats  is  rush  fly  have  had  fallen
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Verbs
She thought that Mr Baxter had _____ the story on the train

heard run exaggerated eats is rush fly have had fallen

Common Nouns
She thought that Mr Baxter had exaggerated the _____ on the train

ball rock train food paper story hell pen floor head

Named Entities
She thought that Mr _____ had exaggerated the story on the train

Baxter Cropper Esther John course finger manner objection spite paper
CBT: Importance-weighted evaluation

More training data
Easier
Less informative

More informative
More important?

1
2
3
4
What does the CBT add?

MSR Sentence Completion Challenge (Zweig & Burges 2011)

- Context
- Different word types
- More questions and more candidates
What does the CBT add?

**MSR Sentence Completion Challenge (Zweig & Burges 2011)**
- Context
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**MCTest (Richardson et al. 2013)**
- Many training examples
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**MSR Sentence Completion Challenge (Zweig & Burges 2011)**

- Context
- Different word types
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- Many training examples
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**CNN and Daily Mail QA Dataset (Hermann et al. 2015)**

- Different word types
- Can integrate world knowledge (entities not anonymised)
- Complementary to CBT - see later
Can humans do the CBT?
She thought that Mr. ______ had exaggerated matters a little.

Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

Baxter
15 Mr. Baxter privately had no hope that they would, but Esther hoped for the best.
16 She could not believe that Mr. Cropper would carry his prejudices into a personal application.
17 This conviction was strengthened when he overtook her walking from school the next day and drove her home.
18 He was a big, handsome man with a very suave, polite manner.
19 He asked interestedly about her school and her work, hoped she was getting on well, and said he had two young rascals of his own to send soon.
20 Esther felt relieved.

: She thought that Mr. ______ had exaggerated matters a little.

: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

: Baxter
What about machines?
Mr. Cropper was opposed to our hiring you.

1 Not, of course, that he had any personal objection to you, but he is set against female teachers, and when a Cropper is set there is nothing on earth can change him.

2 He says female teachers can't keep order.

3 He's started in with a spite at you on general principles, and the boys know it.

4 They know he'll back them up in secret, no matter what they do, just to prove his opinions.

5 Cropper is sly and slippery, and it is hard to corner him."

6 "Are the boys big?"

7 "queried Esther anxiously."

8 "Yes."

9 Thirteen and fourteen and big for their age.

10 You can't whip 'em -- that is the trouble.

11 A man might, but they'd twist you around their fingers.

12 You'll have your hands full, I'm afraid.

13 But maybe they'll behave all right after all."

14 Mr. Baxter privately had no hope that they would, but Esther hoped for the best.

15 She could not believe that Mr. Cropper would carry his prejudices into a personal application.

16 This conviction was strengthened when he overtook her walking from school the next day and drove her home.

17 He was a big, handsome man with a very suave, polite manner.

18 He asked interestingly about her school and her work, hoped she was getting on well, and said he had two young rascals of his own to send soon.

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Q: She thought that Mr. ______ had exaggerated matters a little.

C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

a: Baxter
Memory Networks for machine reading

S: 1 Mr. Cropper was opposed to our hiring you.
2 Not, of course, that he had any personal objection to you, but he is set
against female teachers, and when a Cropper is set against something
he is set against it.
3 He says female teachers can't keep order.
4 He's started in with a spite at you on general grounds.
5 They know he'll back them up in secret, no matter what
his opinions.
6 Cropper is sly and slippery, and it is hard to
7 "Are the boys big?"
8 queried Esther anxiously.
9 "Yes."
10 Thirteen and fourteen and big for their age.
11 You can't whip 'em--that is the trouble.
12 A man might, but they'd twist you around their
13 You'll have your hands full, I'm afraid.
14 But maybe they'll behave all right after all.
15 Mr. Baxter privately had no hope that they would
16 She could not believe that Mr. Cropper would care.
17 This conviction was strengthened when he overtook her walking from school the
next day and drove her home.
18 He was a big, handsome man with a very suave, polite manner.
19 He asked interestingly about her school and her work, hoped she was getting on
well, and said he had two young rascals of his own to send soon.
20 Esther felt relieved.

Q: She thought that Mr. ______ had exaggerated matters a little.
C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.
A: Baxter
explicit memory representations

S: 1 Mr. Cropper was opposed to our hiring you .
  2 Not , of course , that he had any personal objection to you — but he is set
    against female teachers , and when a Cropper is set against something
    he never changes his mind .
  3 He says female teachers can't keep order .
  4 He 's started in with a spite at you on general principle.
  5 They know he 'll back them up in secret , no matter what his opinions .
  6 Cropper is sly and slippery , and it is hard to
    catch him.
  7 " Are the boys big ? "
  8 queried Esther anxiously.
  9 " Yes .
 10 Thirteen and fourteen and big for their age .
 11 You can't whip 'em -- that is the trouble .
 12 A man might , but they 'd twist you around their fingers .
 13 You 'll have your hands full , I 'm afraid .
 14 But maybe they 'll behave all right , after all .
 15 Mr. Baxter privately had no hope that they would.
 16 She could not believe that Mr. Cropper would care .
 17 This conviction was strengthened when he overtook her walking from school the
    next day and drove her home .
 18 He was a big , handsome man with a very suave , polite manner .
 19 He asked interestedly about her school and her work , hoping she was getting on
    well , and said he had two young rascals of his own to send soon .
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Q: She thought that Mr. ______ had exaggerated matters a little .

C: Baxter , Cropper , Esther , course , fingers , manner , objection , opinion , right , spite .

a: Baxter
Memory Networks for machine reading

S: Mr. Cropper was opposed to our hiring you.
1  He was a big, handsome man with a very suave, polite manner.
2  Not, of course, that he saw any personal objection to you—but he is set
3  against female teachers, and when Mr. Cropper is set
4  to change him.
5  He says female teachers can't keep order.
6  It's started in with a spite at you on general principles.
7  They know he'll back them up in secret, no matter what his opinions.
8  Cropper is sly and slippery, and it is hard to check him.
9  "Are the boys big?"
10  "Yes."
11  Thirteen and fourteen and big for their age.
12  You can't whip 'em— that is the trouble.
13  A man might, but they 'd twist you around their fingers.
14  You 'l1 have your hands full, I 'm afraid.
15  But maybe they 'l1 behave all right. After all.
16  She could not believe that Mr. Cropper would carry
17  personal application.
18  This conviction was strengthened when he overtook her walking from school the
19  next day and drove her home.
20  He asked interestingly about her school and her work, hoped she was getting on
21  well, and said he had two young rascals of his own to send soon.
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C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.
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   2 Not, of course, that he had any personal objection to you, but he is set
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      he'll change him.
   3 He says female teachers can't keep order.
   4 He's started in with a spite at you on general principles.
   5 They know he'll back them up in secret, no matter what he says.
   6 Cropper is sly and slippery, and it is hard to
      7 "Are the boys big?"
   8 queried Esther anxiously.
   9 "Yes.
   10 Thirteen and fourteen and big for their age.
   11 You can't whip 'em -- that is the trouble.
   12 A man might, but they 'd twist you around their fingers.
   13 You 'll have your hands full, I'm afraid.
   14 But maybe they 'll behave all right after all.
   15 Mr. Baxter privately had no hope that they would
      ever be the best.
   16 She could not believe that Mr. Cropper would carry
      her personal application.
   17 This conviction was strengthened when he overtook her walking from school the
      next day and drove her home.
   18 He was a big, handsome man with a very suave, polite manner.
   19 He asked interestedly about her school and her work, hoped she was getting on
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for machine reading

S: 1 Mr. Cropper was opposed to our hiring you.
    2 Not, of course, that he had any personal objection to you... but he is set
    3 against female teachers, and when a Cropper is set against something
    4 he says female teachers can't keep order.
    5 They know he'll back them up in secret, no matter what his opinions.
    6 Cropper is sly and slippery, and it is hard to get him to give
    7 ``Are the boys big?''
    8 queried Esther anxiously.
    9 ``Yes.
   10 Thirteen and fourteen and big for their age.
   11 You can't whip 'em -- that is the trouble.
   12 A man might, but they 'd twist you around their
   13 You 'll have your hands full, I 'm afraid.
   14 But maybe they 'll behave all right after all.
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   17 This conviction was strengthened when he overtook her walking from school the
   18 next day and drove her home.
   19 He was a big, handsome man with a very suave, polite manner.
   20 He asked ... well, and said he had two young rascals of his own to send soon.
   20 Baxter felt relieved.

Q: She thought that Mr. ______ had exaggerated matters a little.
C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.
A: Baxter
Memory Networks for machine reading

S: Mr. Cropper was opposed to our hiring you.
2 Not, of course, that he had any personal objection to you, but he is set
against female teachers, and when a Cropper is set it is very hard to
change him.
3 He says female teachers can't keep order.
4 He's started in with a spite at you on general principles, as
his opinions.
5 They know he'll back them up in secret, no matter
how foolish his opinions.
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7 "Are the boys big?"
8 queried Esther anxiously.
9 "Yes."
10 Thirteen and fourteen and big for their age.
11 You can't whip 'em -- that is the trouble.
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13 You'll have your hands full, I'm afraid.
14 But maybe they'll behave all right after all.
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16 She could not believe that Mr. Cropper would carry
personal application.
17 This conviction was strengthened when he overtook her walking from school the
next day and drove her home.
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19 He asked interestingly about her school and her work, hoped she was getting on
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C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.
A: Baxter
Memory Networks for machine reading

S: 1 Mr. Cropper was opposed to our hiring you.
  2 Not, of course, that he had any personal objection to you, but he is set
    against female teachers, and when a Cropper is set against anything
    he usually sees that it is changed.
  3 He says female teachers can't keep order.
  4 He's started in with a spite at you on general principles.
  5 They know he'll back them up in secret, no matter how many
    you tell him his opinions.
  6 Cropper is sly and slippery, and it is hard to
    7 "Are the boys big?"
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    9 "Yes."
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    next day and drove her home.
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       well, and said he had two young rascals of his own to send soon.
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C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

a: Baxter
Three ways to represent text in memory
1: Lexical Memory

S: 1 Mr. Cropper was opposed to our hiring you.
2 Not, of course, that he had any personal objection to you, but he is set
3 He says female teachers ca n't keep order.
4 He 's started in with a spite at you on general principles, it.
5 They know he 'll back them up in secret, no matter how
6 Cropper is sly and slippery, and it is hard to
7 " Are the boys big? "
8 queried Esther anxiously.
9 " Yes.
10 Thirteen and fourteen and big for their age.
11 You ca n't whip 'em -- that is the trouble.
12 A man might, but they 'd twist you around their
13 You 'll have your hands full, I 'm afraid.
14 But maybe they 'll behave all right after all.
15 Mr. Baxter privately had no hope that they would
16 best.
17 She could not believe that Mr. Cropper would take
18 personal application.
19 This conviction was strengthened when he overtook her walking from school the
20 next day and drove her home.
21 He was a big, handsome man, with a very suave, polite manner.
22 He asked interestingly about her school and her work, hoped she was getting on
23 well, and said he had two young rascals of his own to send soon.
24 Esther felt relieved.

Q: She thought that Mr. ______ had exaggerated matters a little.
C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.
A: Baxter
2: Window Memory

S: 1 Mr. Cropper was opposed to our hiring you.
   2 Not, of course, that he had any personal objection to you, but he is set
      against female teachers, and when a Cropper is set against anything, he
      will not change.
   3 He says female teachers can’t keep order.
   4 He’s started in with a spite at you on general principles.
   5 They know he’ll back them up in secret, no matter how much they
      don’t like it.
   6 Cropper is sly and slippery, and it is hard to get a hold of his opinions.
   7 "Are the boys big?"
   8 queried Esther anxiously.
   9 "Yes.
   10 Thirteen and fourteen and big for their age.
   11 You can’t whip ‘em — that is the trouble.
   12 A man might, but they’d twist you around their fingers.
   13 You’ll have your hands full, I’m afraid.
   14 But maybe they’ll behave all right after all.
   15 Mr. Baxter privately had no hope that they would.
   16 She could not believe that Mr. Cropper would carry such a
      personal application.
   17 This conviction was strengthened when he overtook her walking from school the
      next day and drove her home.
   18 He was a big, handsome man with a very suave, polite manner.
   19 He asked interestedly about her school and her work, hoped she was getting on
      well, and said he had two young rascals of his own to send soon.
   20 Esther felt relieved.

Q: She thought that Mr. ________ had exaggerated matters a little.
C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.
A: Baxter
3: Sentence Memory

S: Mr. Cropper was opposed to our hiring you. He says female teachers can't keep order. Cropper is sly and slippery, and it is hard to get him to change his opinions. Cropper is sly and slippery, and it is hard to get him to change his opinions. Are the boys big? "Yes.

10 Thirteen and fourteen and big for their age.

You can't whip 'em -- that is the trouble. A man might, but they'd twist you around their fingers. You'll have your hands full, I'm afraid. But maybe they'll behave all right after all. Mr. Baxter privately had no hope that they would. She could not believe that Mr. Cropper would carry out his personal application. This conviction was strengthened when he overtook her walking from school the next day and drove her home. He was a big, handsome man with a very suave, polite manner.

19 He asked interestedly about her school and her work, hoped she was getting on well, and said he had two young rascals of his own to send soon.

Esther felt relieved.

Q: She thought that Mr. ______ had exaggerated matters a little.

C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

a: Baxter
Self-supervision for memory retrieval

embedding matrix

memory & query representations (addressing)

softmax distribution

‘correct’ memory (heuristic)

backpropagate
Choose the memory* with the correct answer in it

S: 1 Mr. Cropper was opposed to our hiring you.
   2 Not, of course, that he had any personal objection to you, but he is set
      against female teachers, and when a Cropper is set there is nothing on earth
can change him.
   3 He says female teachers can’t keep order.
   4 He ’s started in with a spite at you on general principles, and the boys know
      it.
   5 They know he ’ll back them up in secret, no matter what they do, just to prove
      his opinions.
   6 Cropper is sly and slippery, and it is hard to corner him.”
   7 “Are the boys big?”
   8 queried Esther anxiously.
   9 “Yes.
   10 Thirteen and fourteen and big for their age.
   11 You can’t whip ’em—- that is the trouble.
   12 A man might, but they ’d twist you around their fingers.
   13 You ’ll have your hands full, I’m afraid.
   14 But maybe they ’ll behave all right after all.”
   15 Mr. Baxter privately had no hope that they would, but Esther hoped for the
      best.
   16 She could not believe that Mr. Cropper would carry his prejudices into a
      personal application.
   17 This conviction was strengthened when he overtook her walking from school the
      next day and drove her home.
   18 He was a big, handsome man with a very suave, polite manner.
   19 He asked interestedly about her school and her work, hoped she was getting on
      well, and said he had two young rascals of his own to send soon.
   20 Esther felt relieved.

Q: She thought that Mr. ______ had exaggerated matters a little.

C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

a: Baxter
Results
Prepositions
Verbs
Common Nouns
Named Entities

LSTM (query)
LSTM (context + query)
MemNN (sentence memory + PE)

human performance
human performance

LSTM (query)
LSTM (context + query)
MemNN (sentence memory + PE)
MemNN (window memory)
MemNN (window memory + self-sup)

30 50 70 90

Prepositions  Verbs  Common Nouns  Named Entities

human performance
These memories are just right!
DeepMind reading comprehension benchmark

Document:

Gov. @entity0 has long made it clear that he holds sharp disdain for @entity3. In fact, he finds it so unappealing, he’d rather drown himself than serve in @entity6. Speaking at the @entity12 @entity11 conference on saturday, the second term @entity8 governor emphasized that he never plans on running for office in @entity12 again. Most think @entity6 is worst in their lifetime "the only job left for me to run for is @entity17, and let me just say this: I would rather die than be in the @entity17. Okay? I would be bored to death," @entity0, who’s considering a 2016 presidential bid, said to laughs from the audience. "Can you imagine me bangin’ around that chamber with 99 other people? Asking for a motion on the amendment in the subcommittee? Forget it. It would be over, everybody. You’d watch me just walk out and walk right into the @entity31 and drown. That’d be it." @entity0 says again he’d love to run the @entity35 @entity0 gets compassionate as he eyes 2016

Question:

Gov. @placeholder says he’s not running for office again in @entity12.

Answer: @entity0

Anonymisation table:

<table>
<thead>
<tr>
<th>@entity0</th>
<th>Chris Christie</th>
<th>@entity12</th>
<th>New Jersey</th>
</tr>
</thead>
<tbody>
<tr>
<td>@entity3</td>
<td>Washington</td>
<td>@entity17</td>
<td>U.S. Senate</td>
</tr>
<tr>
<td>@entity6</td>
<td>Congress</td>
<td>@entity31</td>
<td>Potomac River</td>
</tr>
<tr>
<td>@entity8</td>
<td>Republican</td>
<td>@entity35</td>
<td>Mets</td>
</tr>
<tr>
<td>@entity11</td>
<td>NAACP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DeepMind reading comprehension benchmark

- CNN Test Set
- Deep LSTM (context + query)
- Contextual LSTM ("Attentive Reader")
- Contextual LSTM ("Impatient Reader")
- MemNN (window memory)
- MemNN (window memory + self-sup)
- MemNN (window memory + self-sup + ensemble)
- MemNN (window memory + self-sup + ensemble + exclude query repeats)

Graph:
- Y-axis labeling: 50, 55, 60, 65, 70
- X-axis labeling: CNN Test Set
- Bar: Deep LSTM (context + query)
DeepMind reading comprehension benchmark

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Diagram:
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Conclusions

For language understanding:

• Context matters, not used enough

• Evaluations should distinguish frequent and semantic words (unlike e.g. perplexity)

• The CBT is a useful new resource for both
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https://research.facebook.com
Any questions?

Thanks
Antoine Bordes
Sumit Chopra
Jason Weston

Facebook AI Research
sparse sentence representation

embedding matrix

\[ A \]

\[ V^+ \]

distributed memory representation

\[ \phi(s_i) \]

\[ c_i = A\phi(s_i) \]

\[ m_i = B\phi(s_i) \]
sparse query representation

\[ q = A \phi(q) \]
memory representations
(content)

\[ m_i \ldots m_n \]

softmax distribution

\[ \alpha_i = \frac{e^{q \cdot c_i}}{\sum_j e^{q \cdot c_j}} \]

output memory

\[ m_{O_1} = \sum_i \alpha_i m_i \]
Machine comprehension with the CBT

For language understanding:

• Context matters, not used enough

• Evaluations should distinguish frequent and semantic words (unlike e.g. perplexity)

• The CBT is a useful new resource for both
distributed query representation

q

memory representations (addressing)

\[ c_1 \ldots c_n \]

softmax distribution

\[ \alpha_i = \frac{e^{q \cdot c_i}}{\sum_j e^{q \cdot c_j}} \]
\[ m_{O_1} = \sum_i \alpha_i m_i \]
\[ q' = Hq + m_{O_1} \]
\[ \hat{a} = \text{softmax}(Uq') \]
Other details

- Temporal Encoding of memory position

\[ c_i = A \phi(s_i) \rightarrow c_i = A \phi(s_i) + T_A(i) \]

- Position Encoding (PE) of words in window and sentence memories

\[ c_i = A \phi(s_i) \rightarrow c_i = \sum_j l_j \odot A x_{ij} \]