

# The Goldilocks Principle

Reading Children's Books  
with Explicit Memory Representations

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Facebook AI Research



# Context is needed to understand language



“ What the heck should I do? ”



“ What would you like to do? ”



# Context is needed to understand language



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

It looks like bears.

What the heck should I do? ”



“ Bears are bad news. Go through the secret passage in the fireplace ”



# Children's Book Test



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**Context**  
20 consecutive  
sentences

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Context

**Query**  
21st sentence  
with  
missing word

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

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Answer

Baxter

also in context

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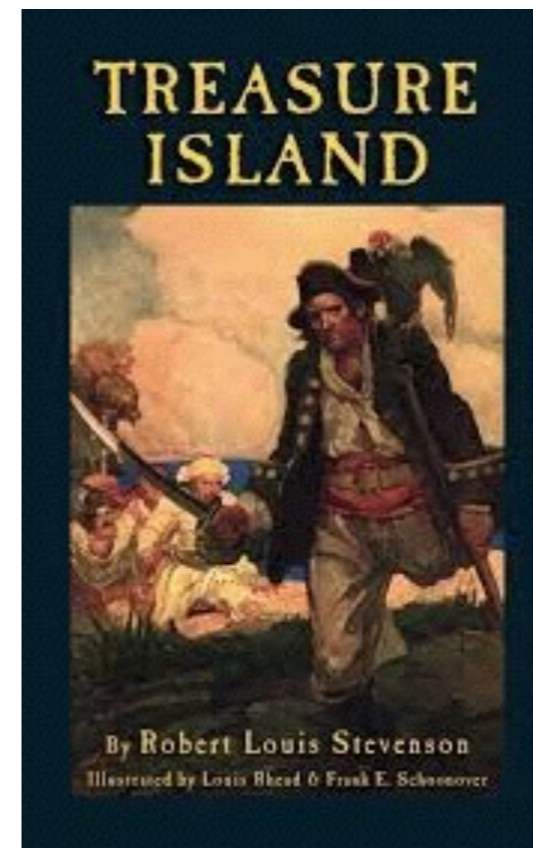
Answer

**Baxter**

also in context

# Children's Book Test

	Books	Questions
Train	98	670,000
Validation	5	8,000
Test	5	10,000



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## Prepositions

She thought that Mr Baxter had exaggerated the story \_\_\_\_ the train.

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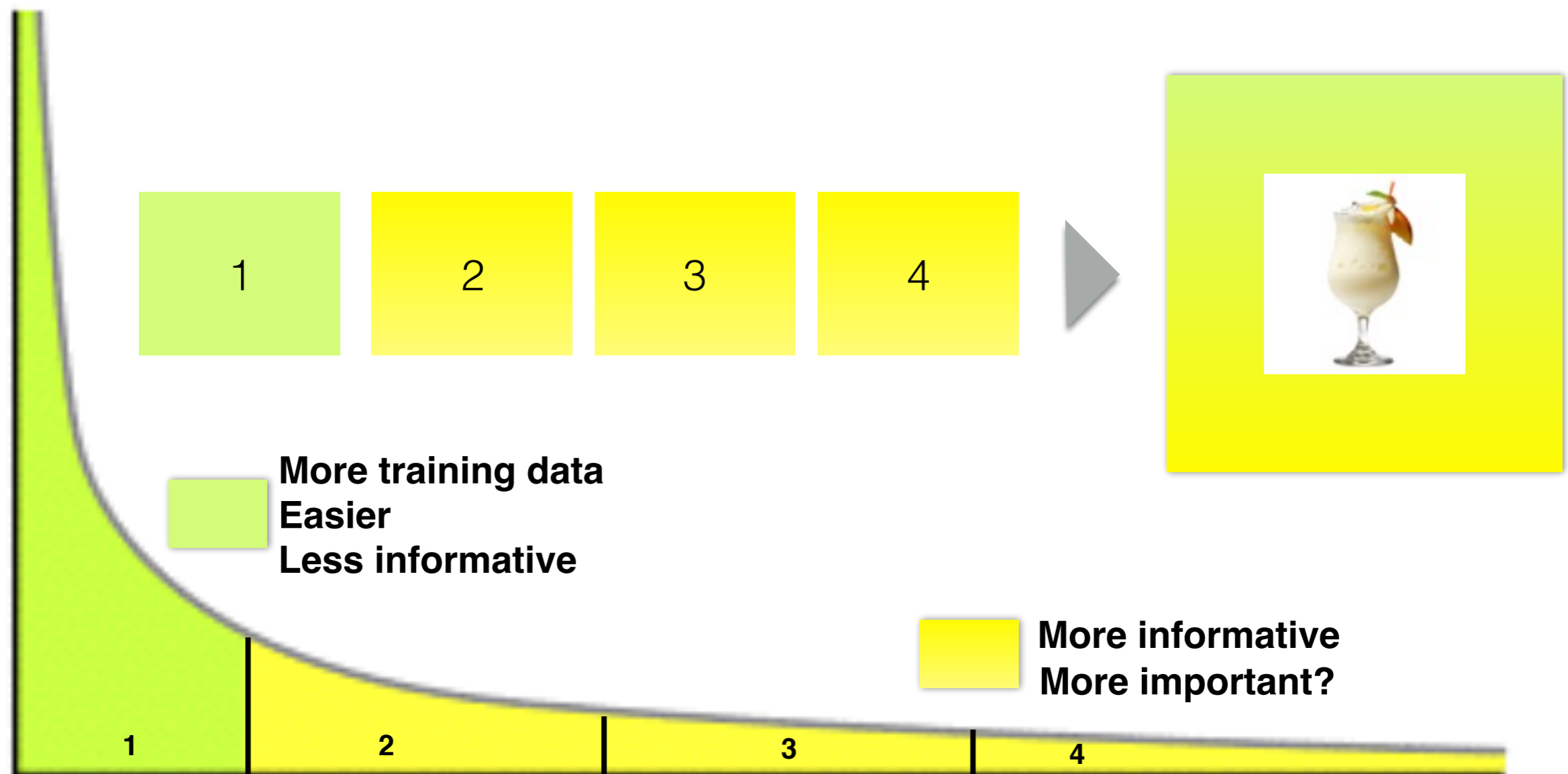
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## Named Entities

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



# What does the CBT add?

## **MSR Sentence Completion Challenge (Zweig & Burges 2011)**

- Context
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- More questions and more candidates

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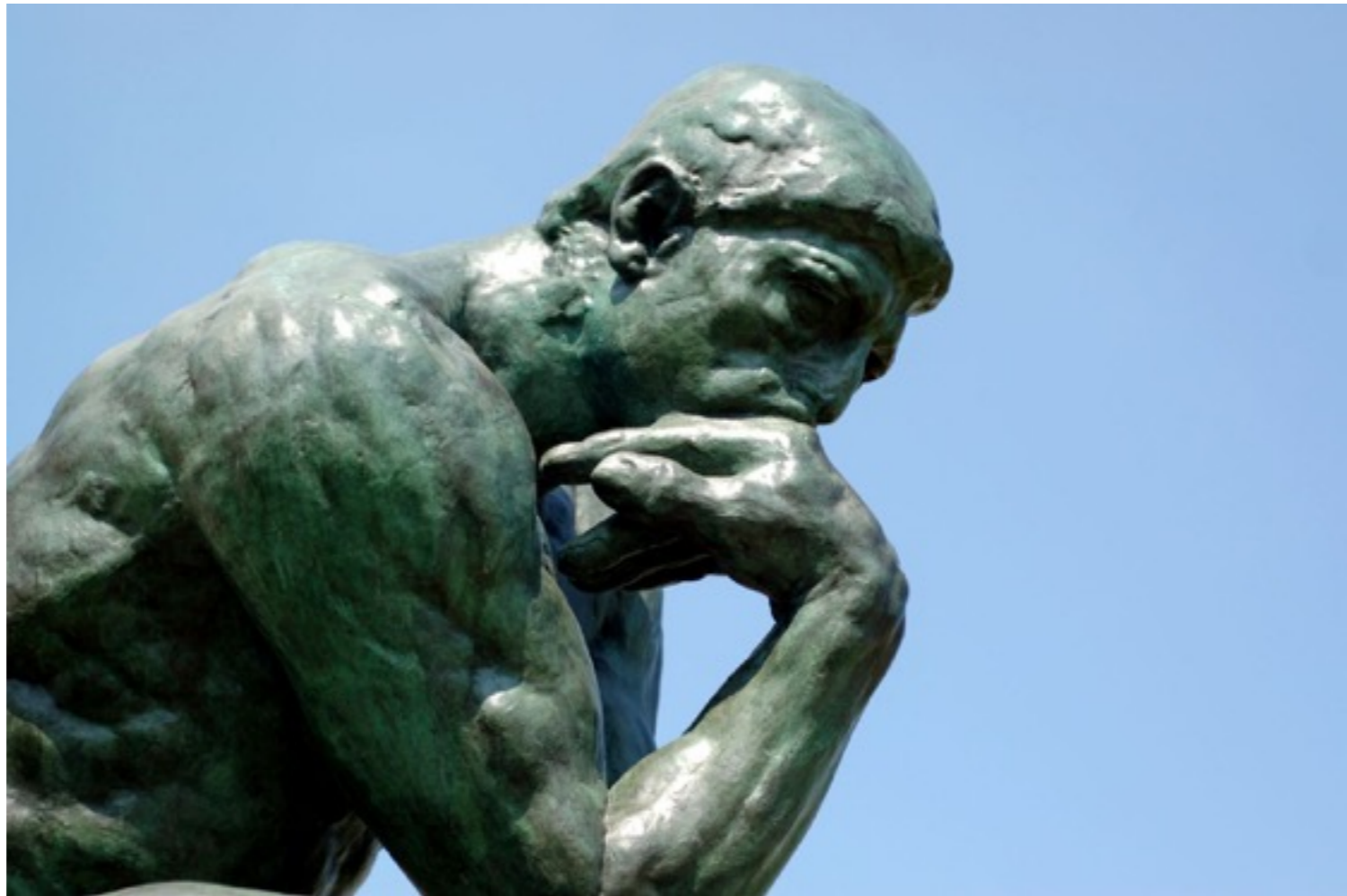
## **MCTest (Richardson et al. 2013)**

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## **CNN and Daily Mail QA Dataset (Hermann et al. 2015)**

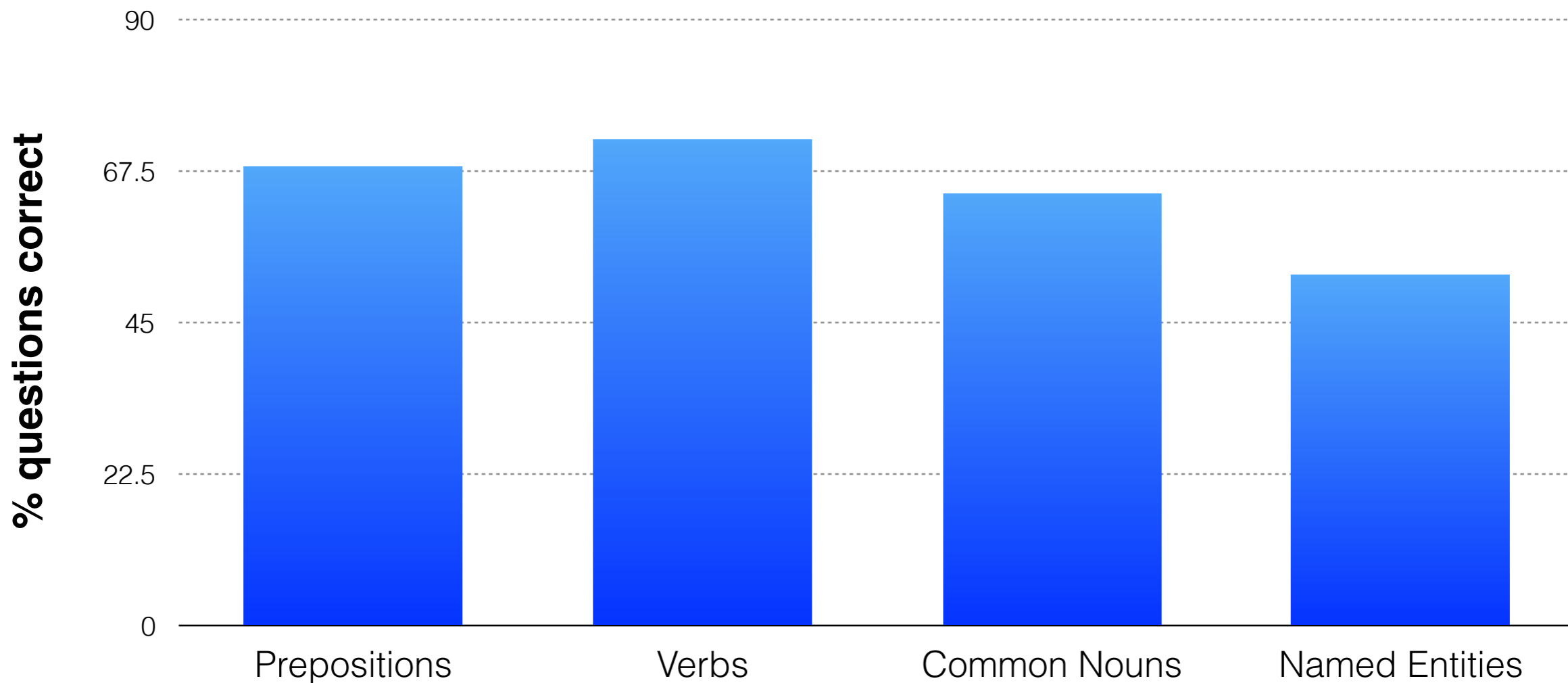
- Different word types
- Can integrate world knowledge (entities not anonymised)
- Complementary to CBT - see later

# Can humans do the CBT?



# Query only

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



Query

+

Context

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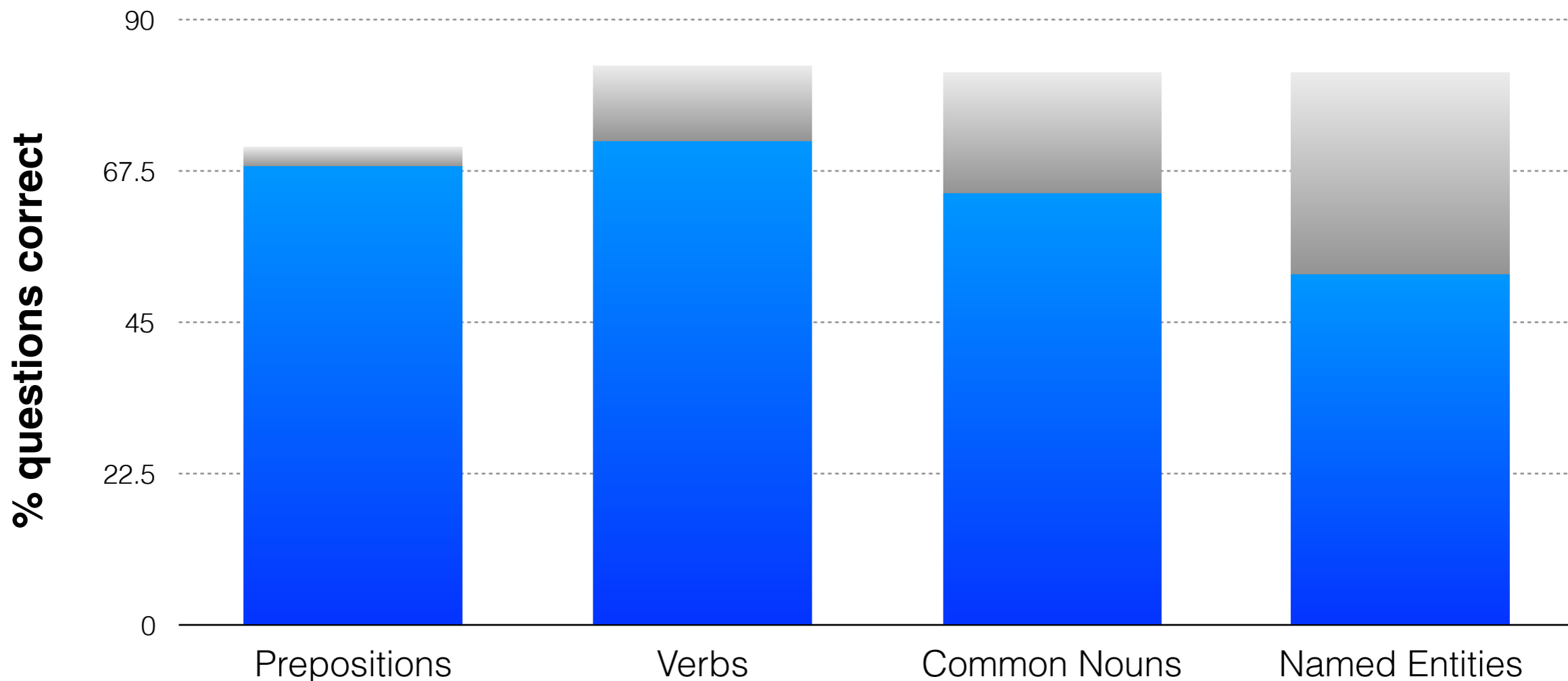
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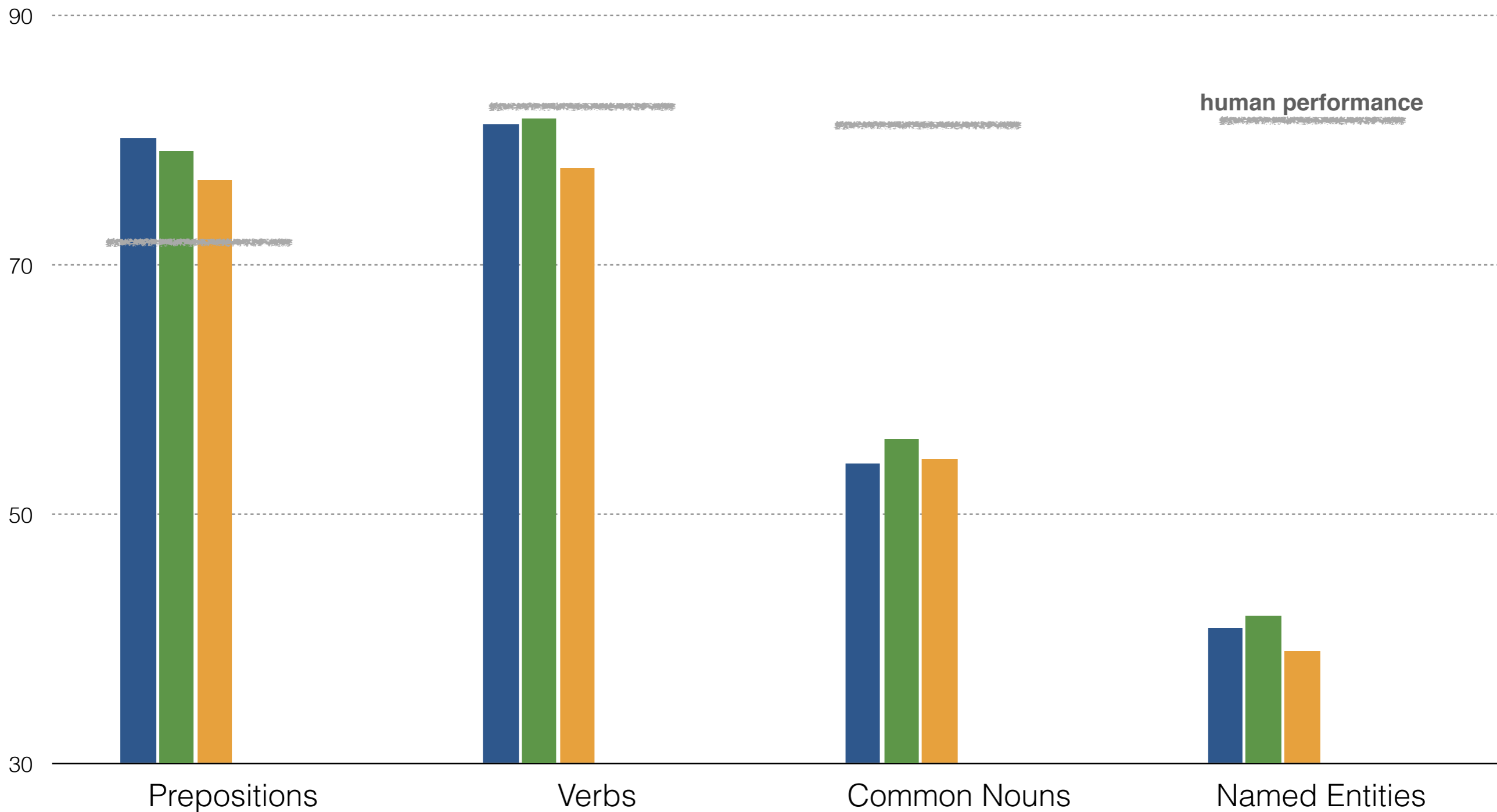
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What about machines?



■ LSTM (query)

■ n-gram LM + KneserNey

■ LSTM (context + query)

human performance

# *Memory Networks*

## for machine reading

Weston et al. 2015  
Sukhbaatar et al. 2015

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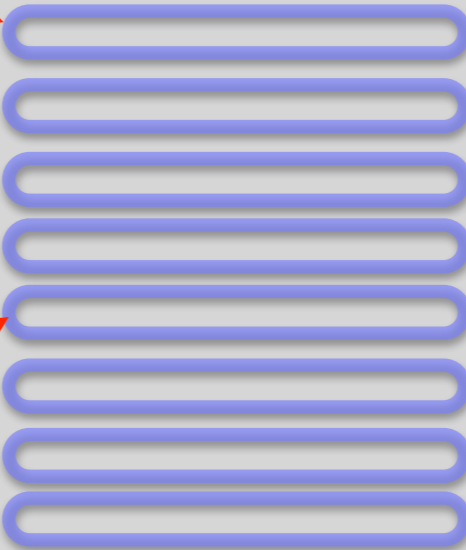
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explicit memory  
representations



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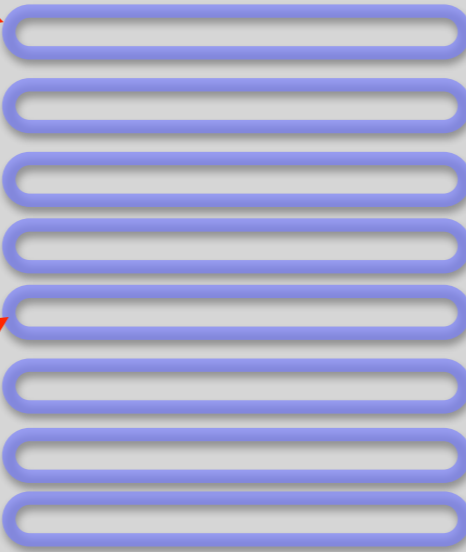
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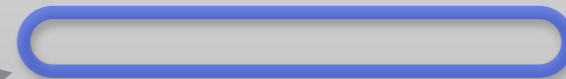
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explicit memory  
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query representation



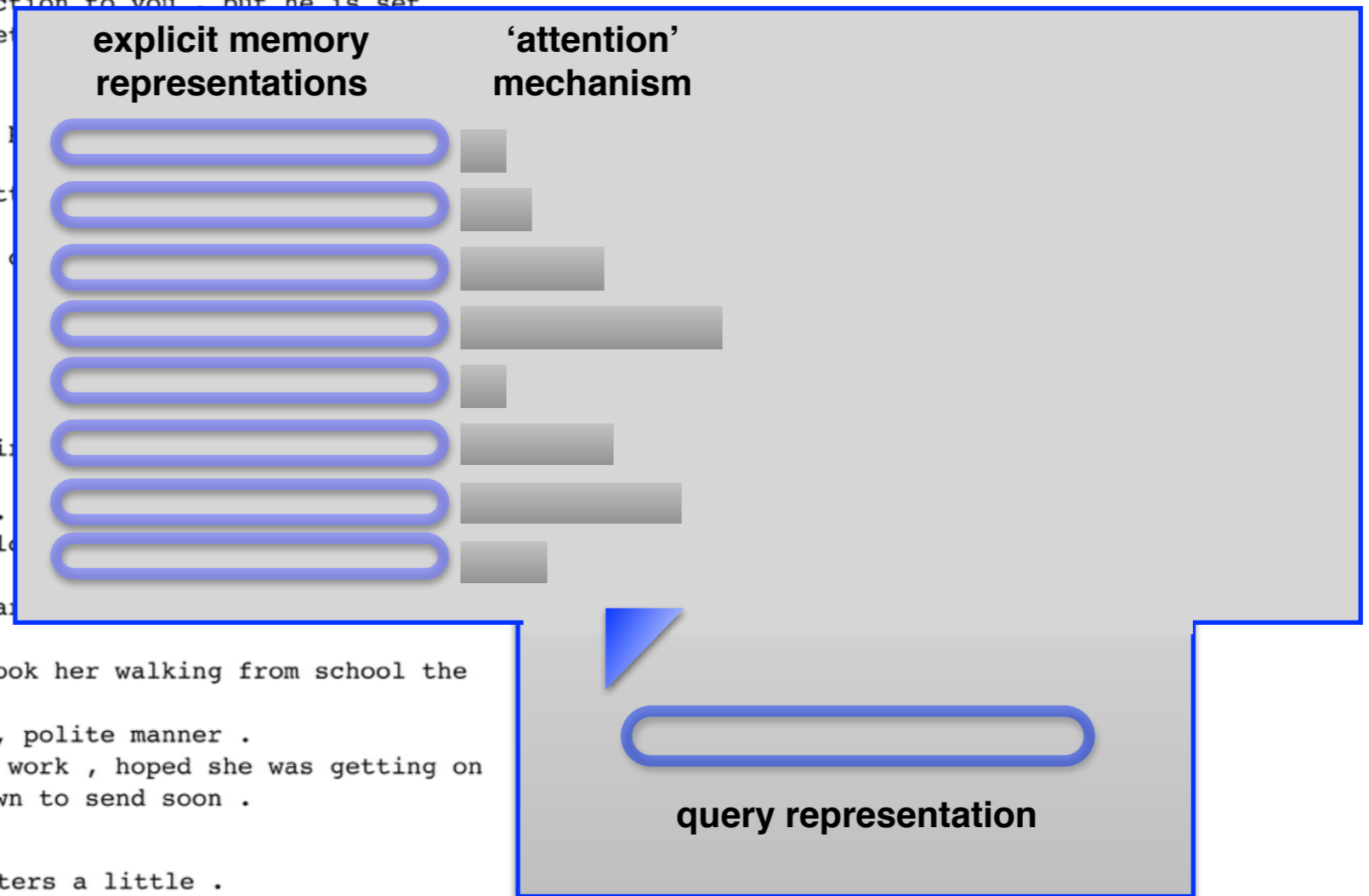
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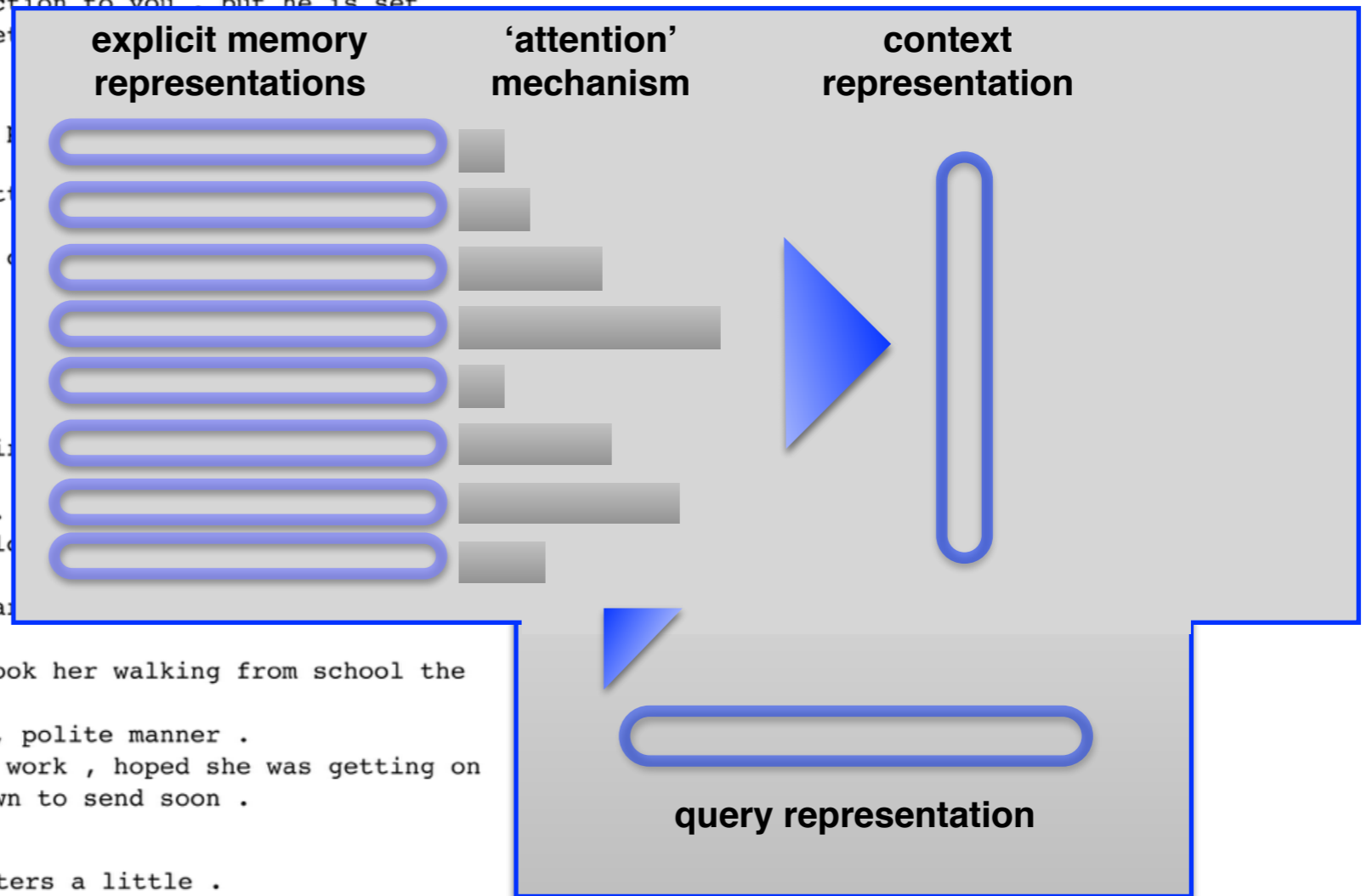
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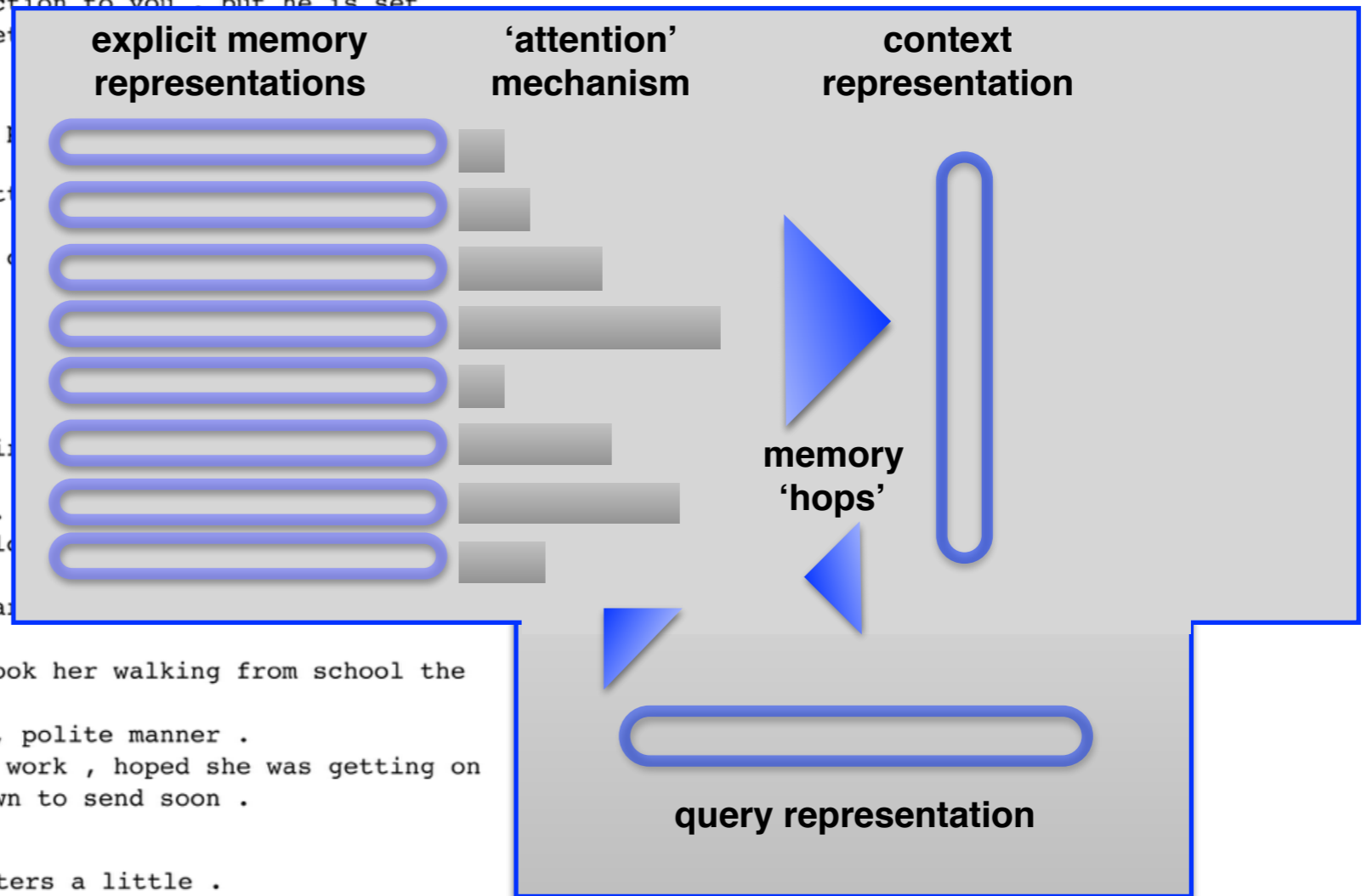
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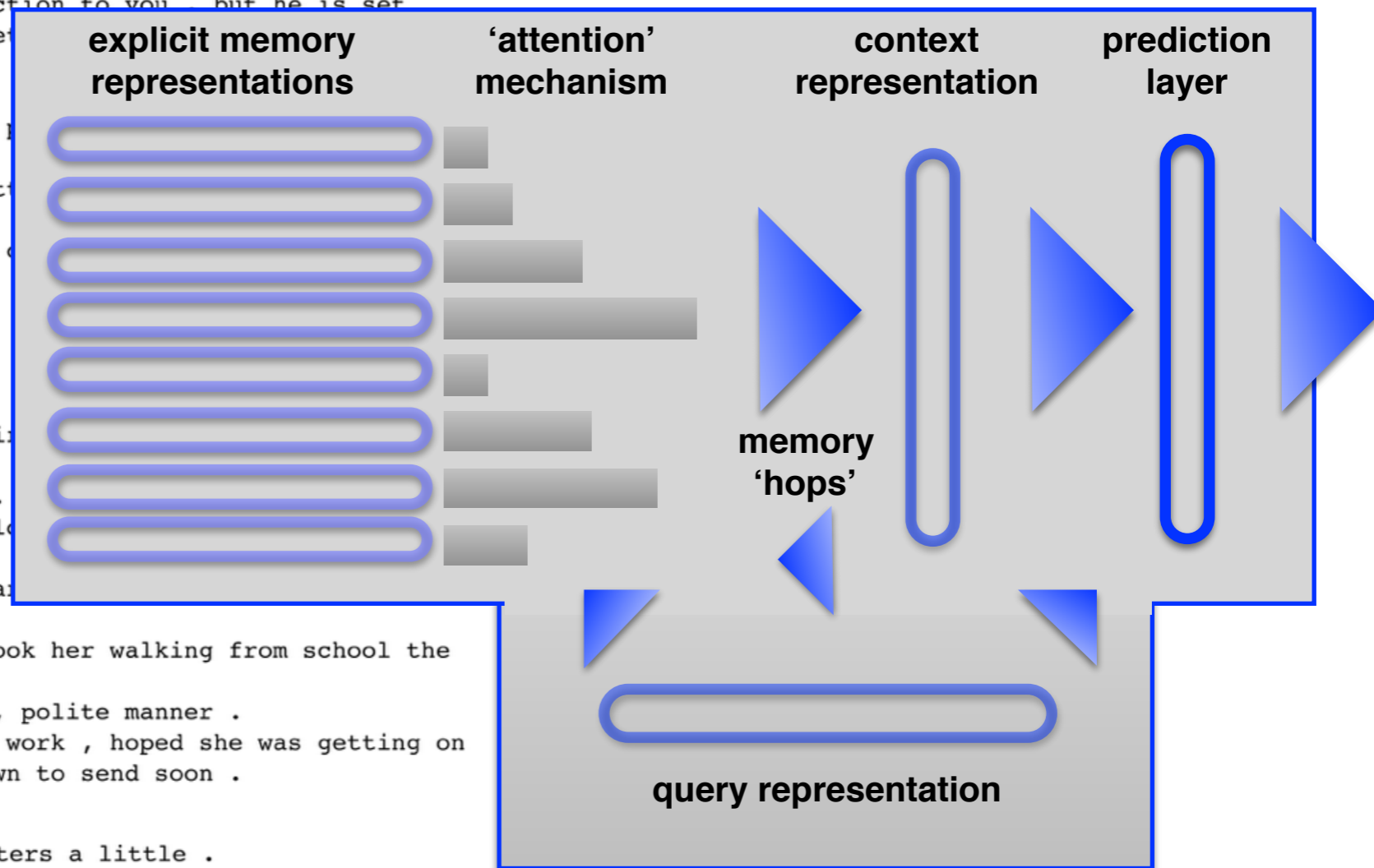
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9 `` Yes .  
10 Thirteen and fourteen and big for their age .  
11 You ca n't whip 'em -- that is the trouble .  
12 A man might , but they 'd twist you around their  
13 You 'll have your hands full , I 'm afraid .  
14 But maybe they 'll behave all right after all .  
15 Mr. Baxter privately had no hope that they would  
best .  
16 She could not believe that Mr. Cropper would ca  
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



Three ways to represent text in  
memory

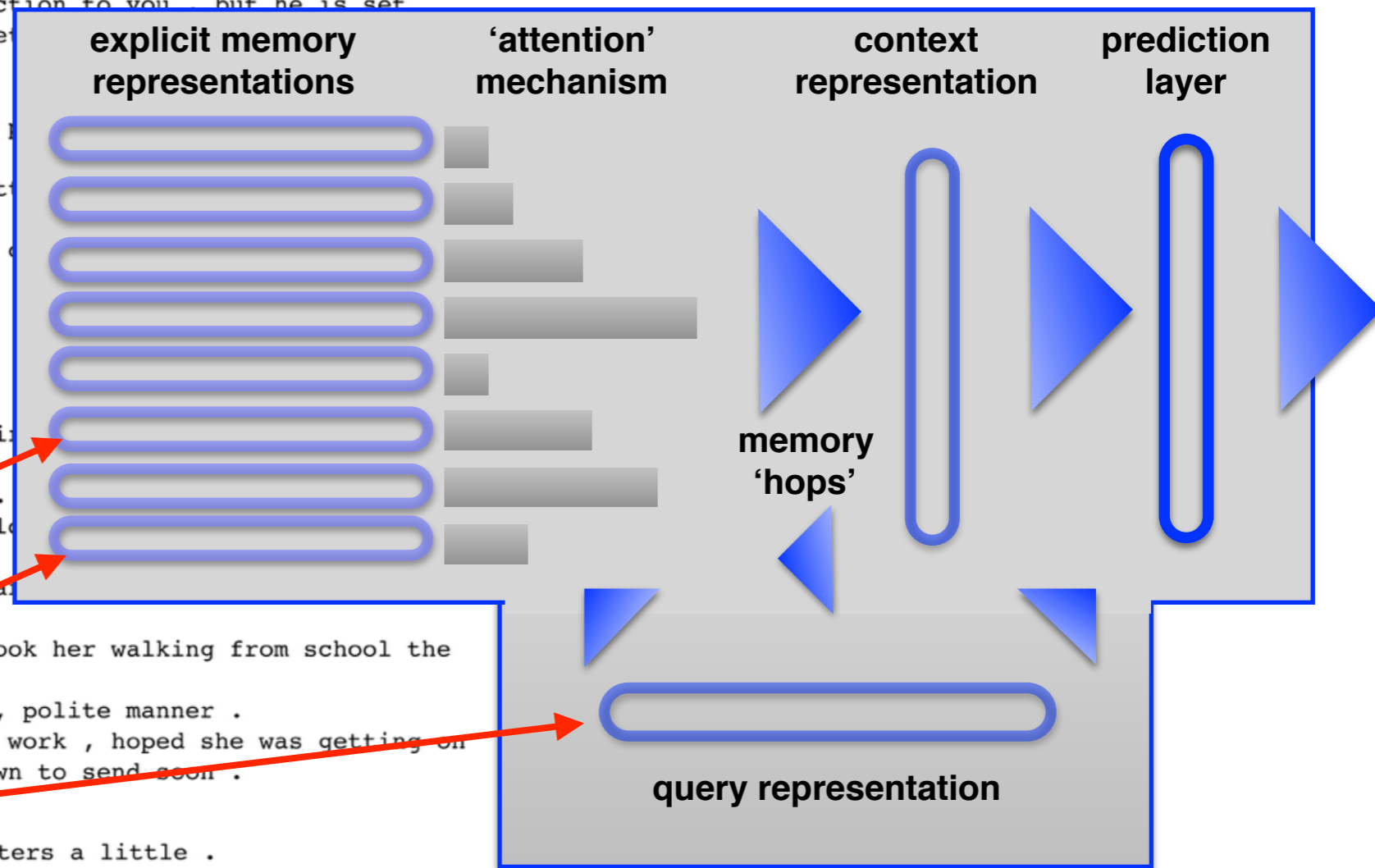
# 1: Lexical Memory

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  
against female teachers , and when a Cropper is set  
change him .  
3 He says female teachers ca n't keep order .  
4 He 's started in with a spite at you on general  
it .  
5 They know he 'll back them up in secret , no mat  
his opinions .  
6 Cropper is sly and slippery , and it is hard to  
7 `` Are the boys big ? ''  
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9 `` Yes .  
10 Thirteen and fourteen and big for their age .  
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C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

a: Baxter



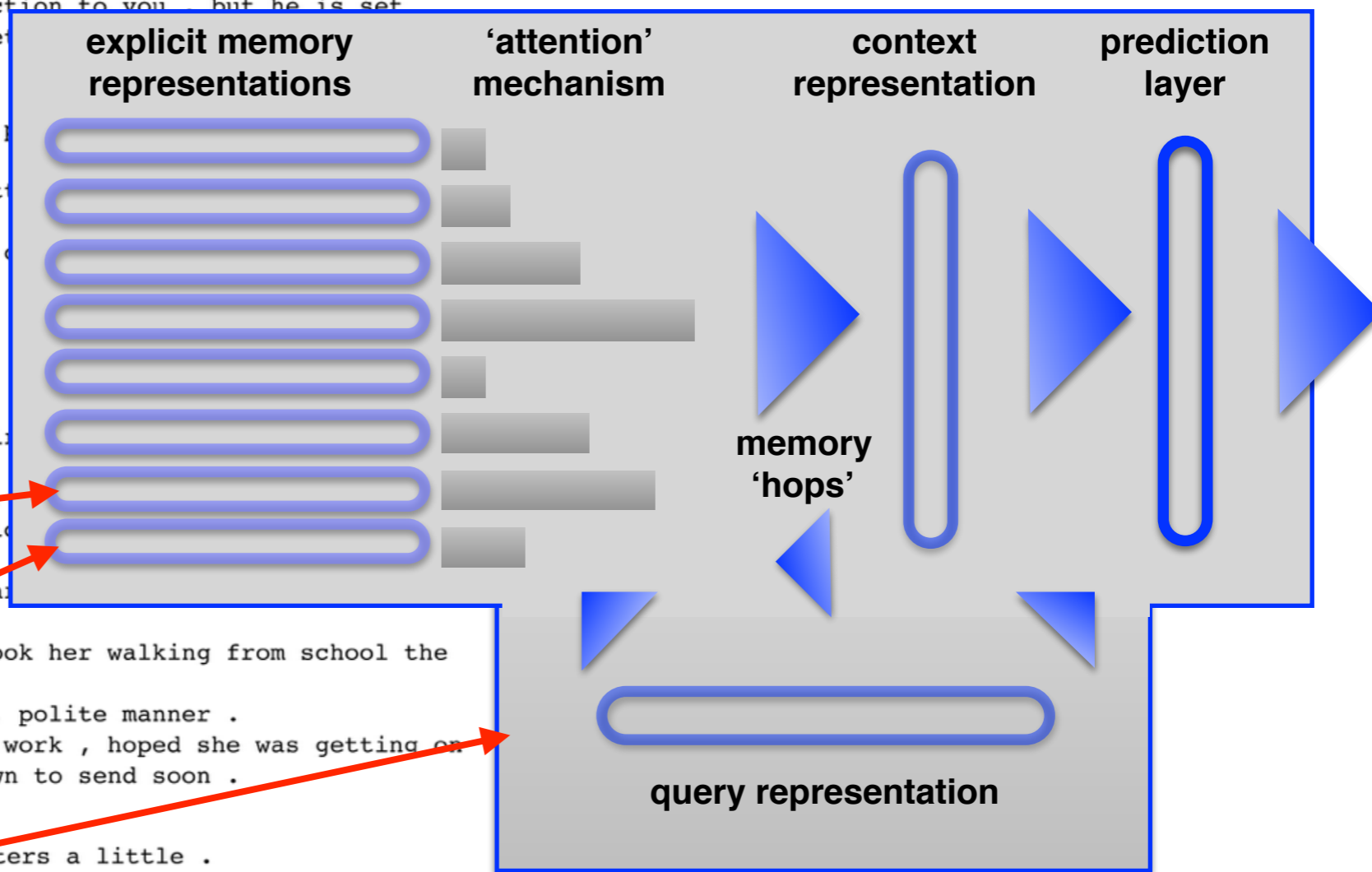
# 2: Window Memory

**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  
change him .  
3 He says female teachers ca n't keep order .  
4 He 's started in with a spite at you on general  
it .  
5 They know he 'll back them up in secret , no mat  
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 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**  
best.  
16 She could **not believe that Mr. Cropper would ca**  
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



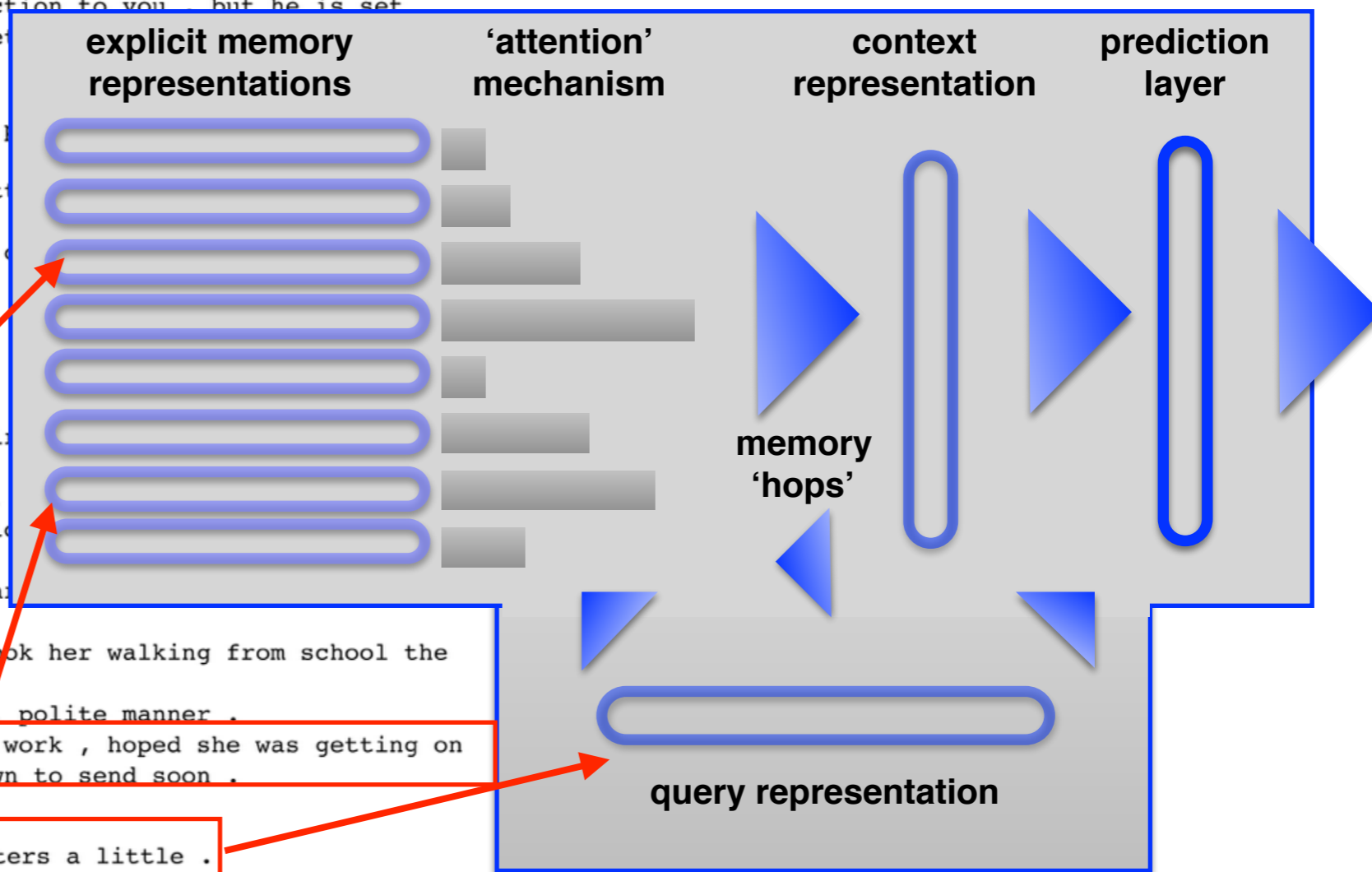
# 3: Sentence Memory

S: 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  
change him .  
3 He says female teachers ca n't keep order .  
4 He 's started in with a spite at you on general  
it .  
5 They know he 'll back them up in secret , no mat  
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 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  
best .  
16 She could not believe that Mr. Cropper would ca  
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 .

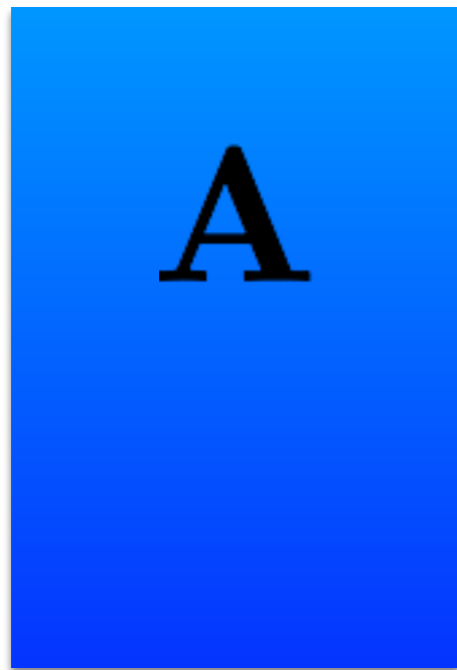
C: Baxter, Cropper, Esther, course, fingers, manner, objection, opinion, right, spite.

a: Baxter

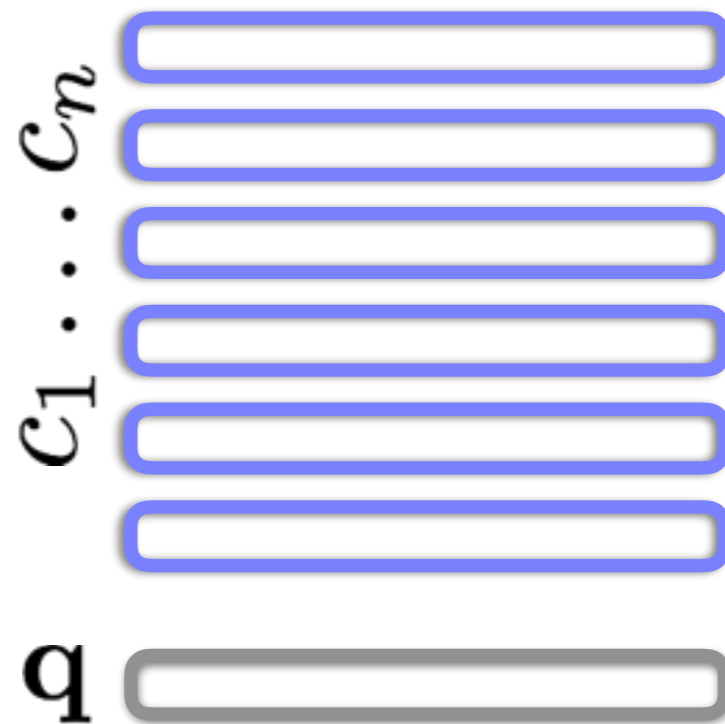


# Self-supervision for memory retrieval

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 ca n'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 ca n'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 .  
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Q: She thought that Mr. \_\_\_\_\_ had exaggerated matters a little .

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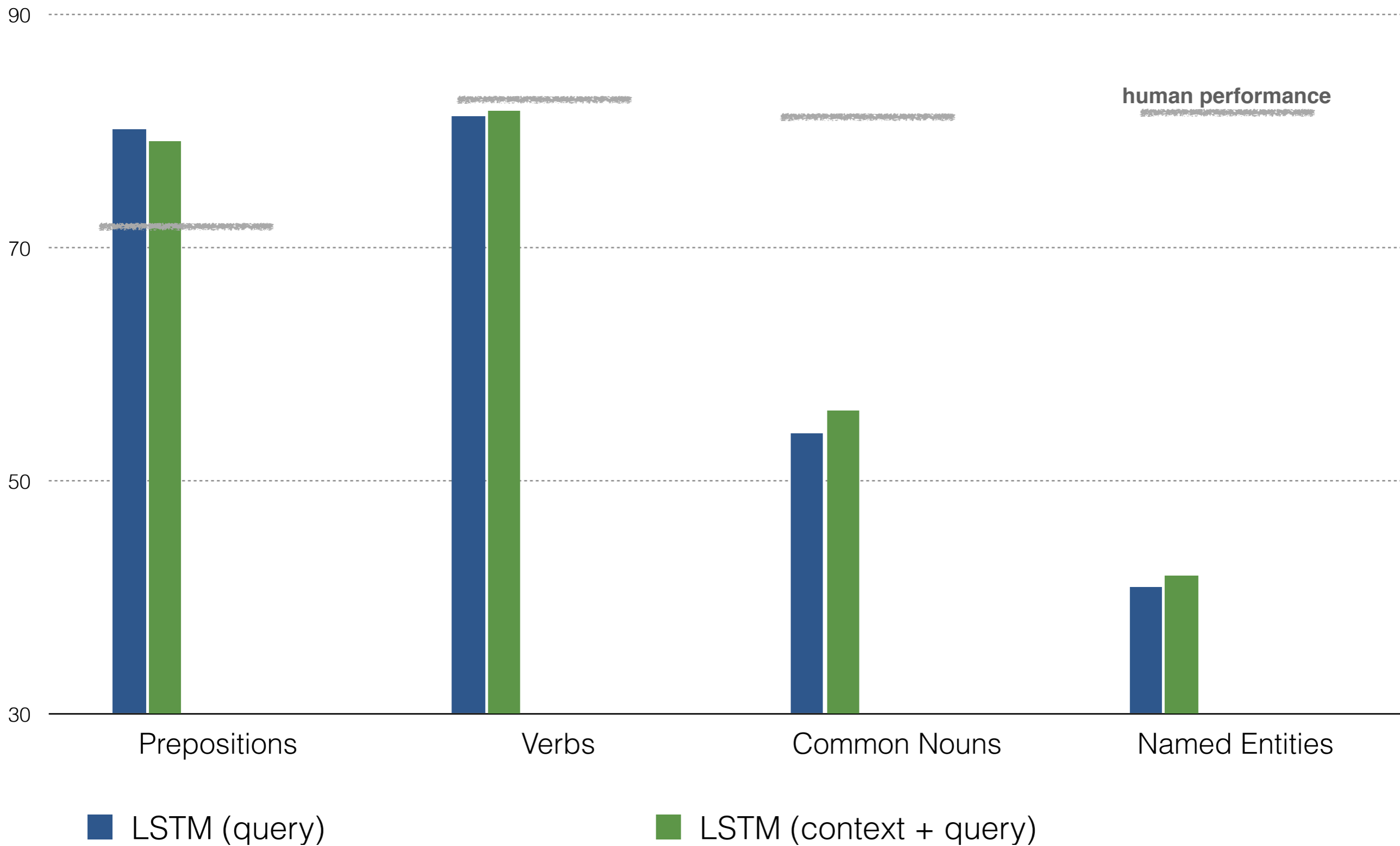
a: Baxter

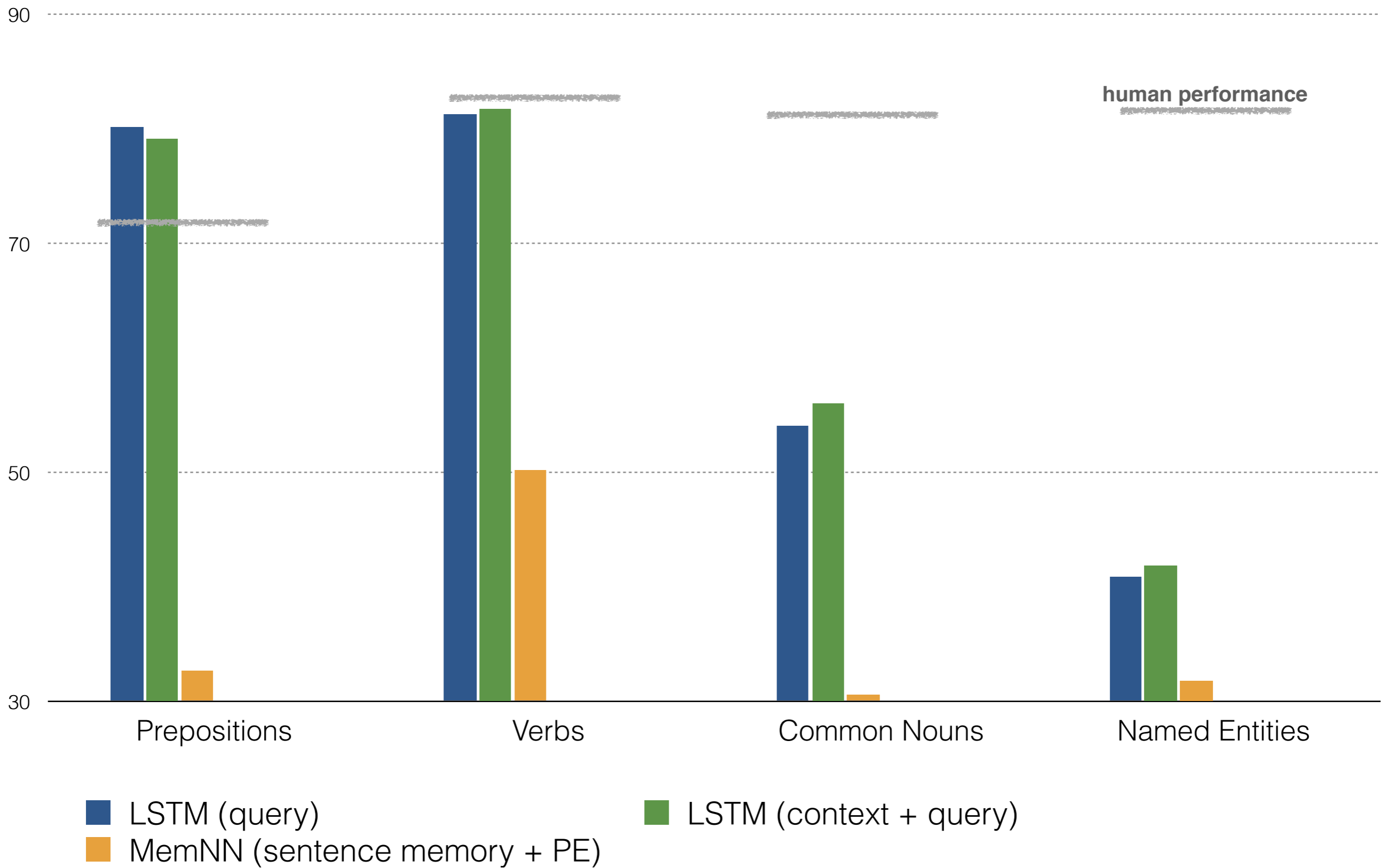


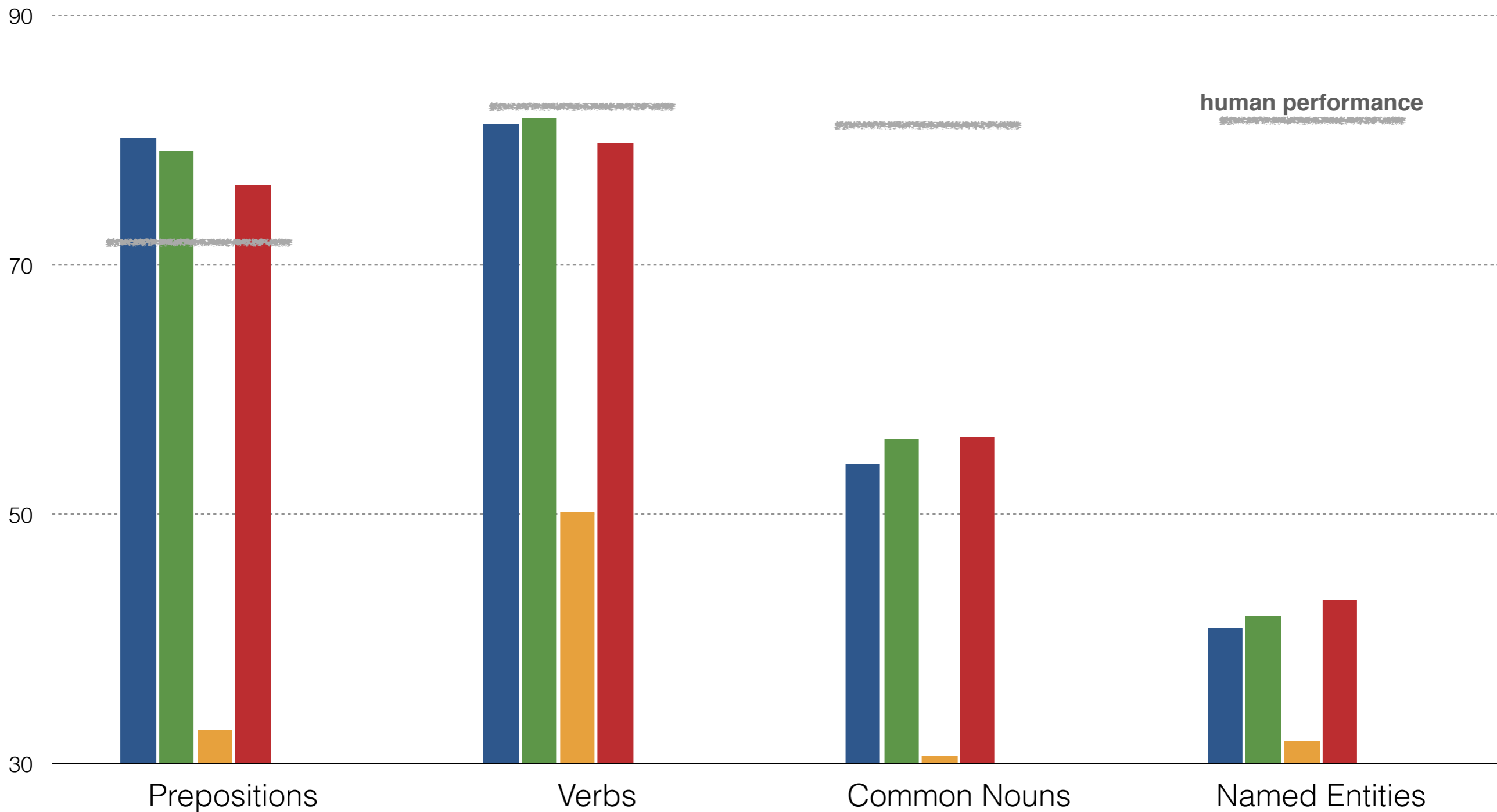


# Results







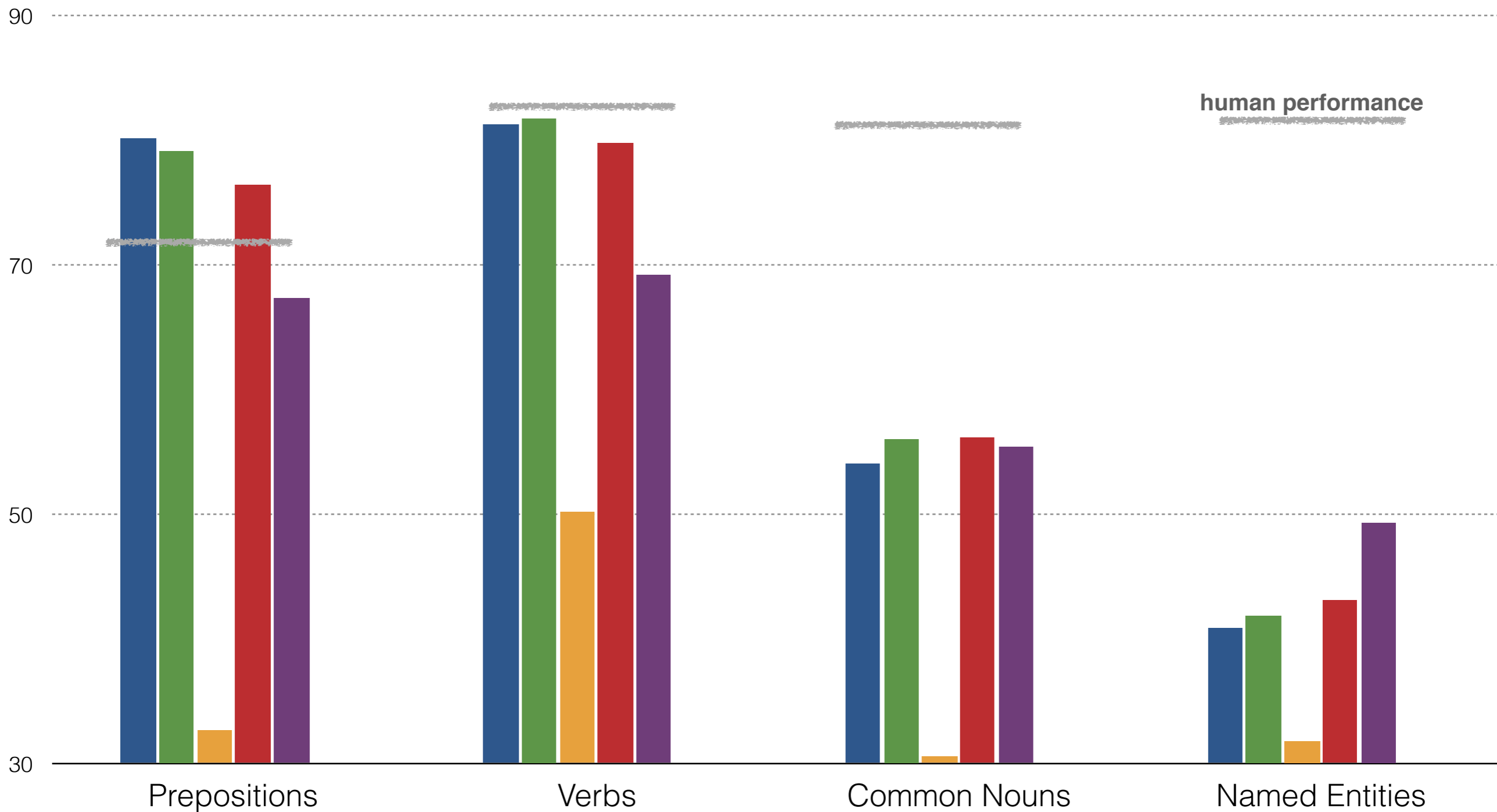


■ LSTM (query)

■ MemNN (sentence memory + PE)

■ LSTM (context + query)

■ MemNN (word memory)



■ LSTM (query)

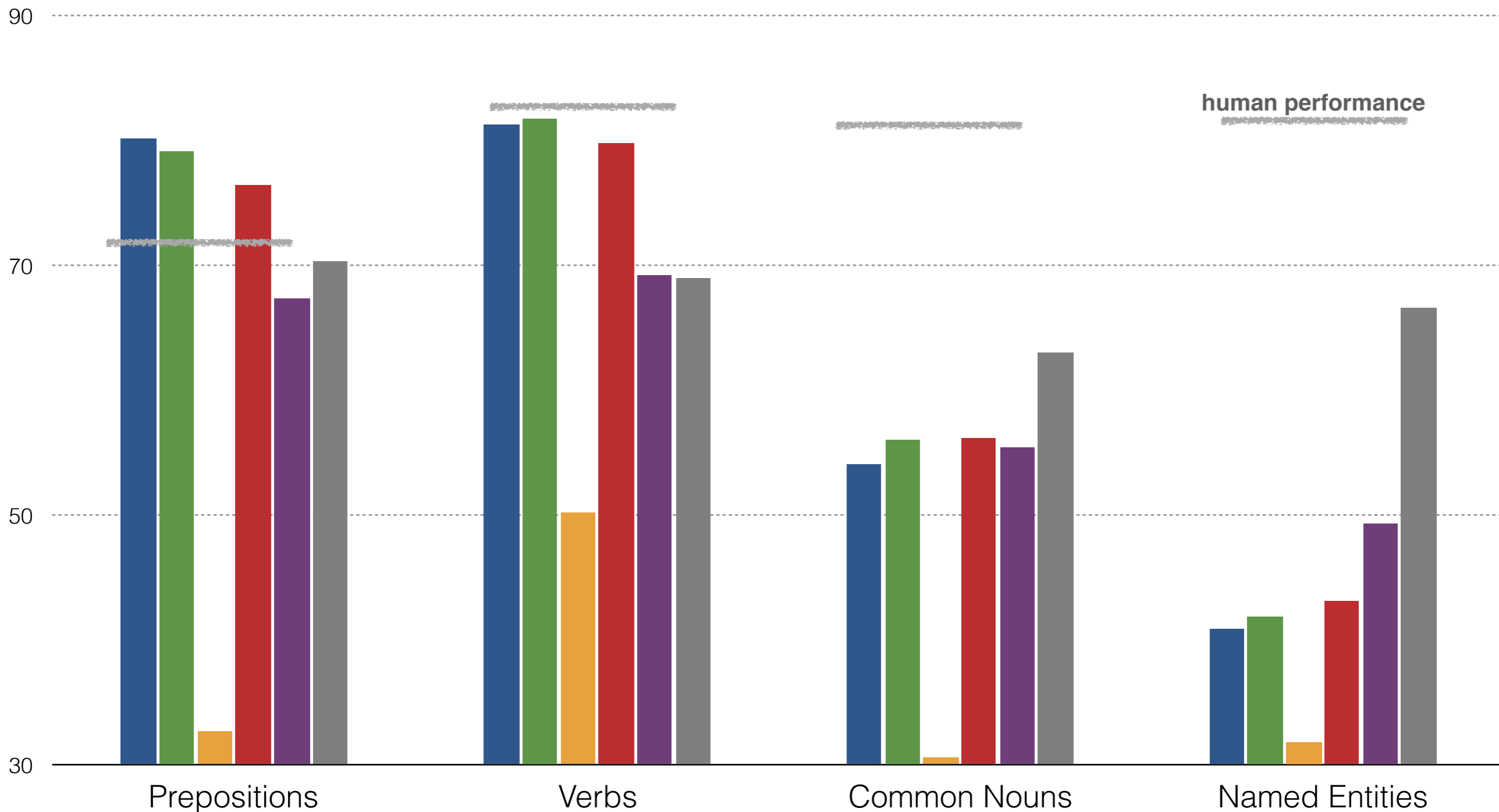
■ MemNN (sentence memory + PE)

■ MemNN (window memory)

■ LSTM (context + query)

■ MemNN (word memory)

human performance



■ LSTM (query)

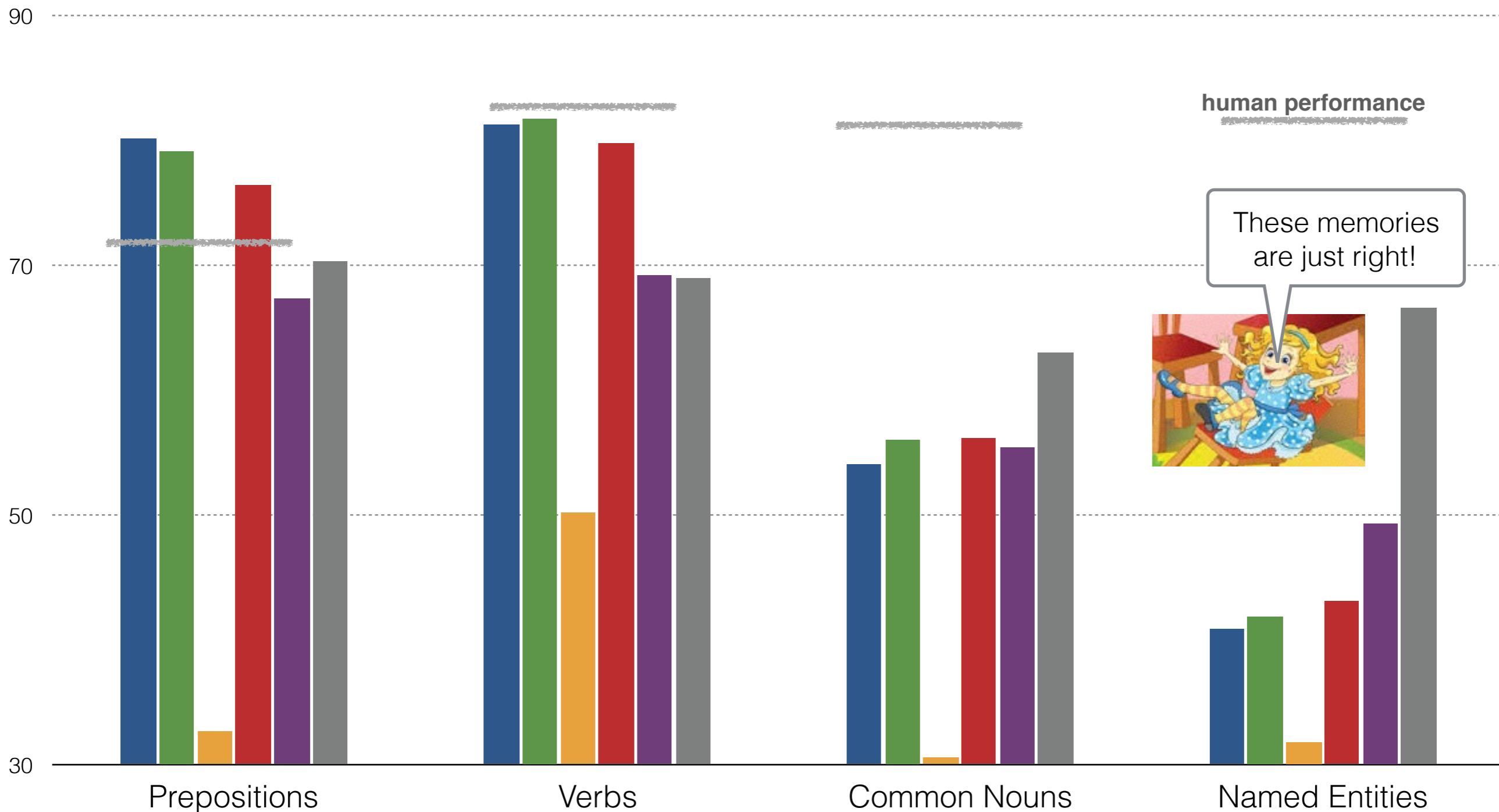
■ MemNN (sentence memory + PE)

■ MemNN (window memory)

■ LSTM (context + query)

■ MemNN (word memory)

■ MemNN (window memory + self-sup)



■ LSTM (query)

■ MemNN (sentence memory + PE)

■ MemNN (window memory)

■ LSTM (context + query)

■ MemNN (word memory)

■ MemNN (window memory + self-sup)

# 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:

<b>@entity0</b>	Chris Christie	<b>@entity12</b>	New Jersey
<b>@entity3</b>	Washington	<b>@entity17</b>	U.S. Senate
<b>@entity6</b>	Congress	<b>@entity31</b>	Potomac River
<b>@entity8</b>	Republican	<b>@entity35</b>	Mets
<b>@entity11</b>	NAACP		

CNN news article

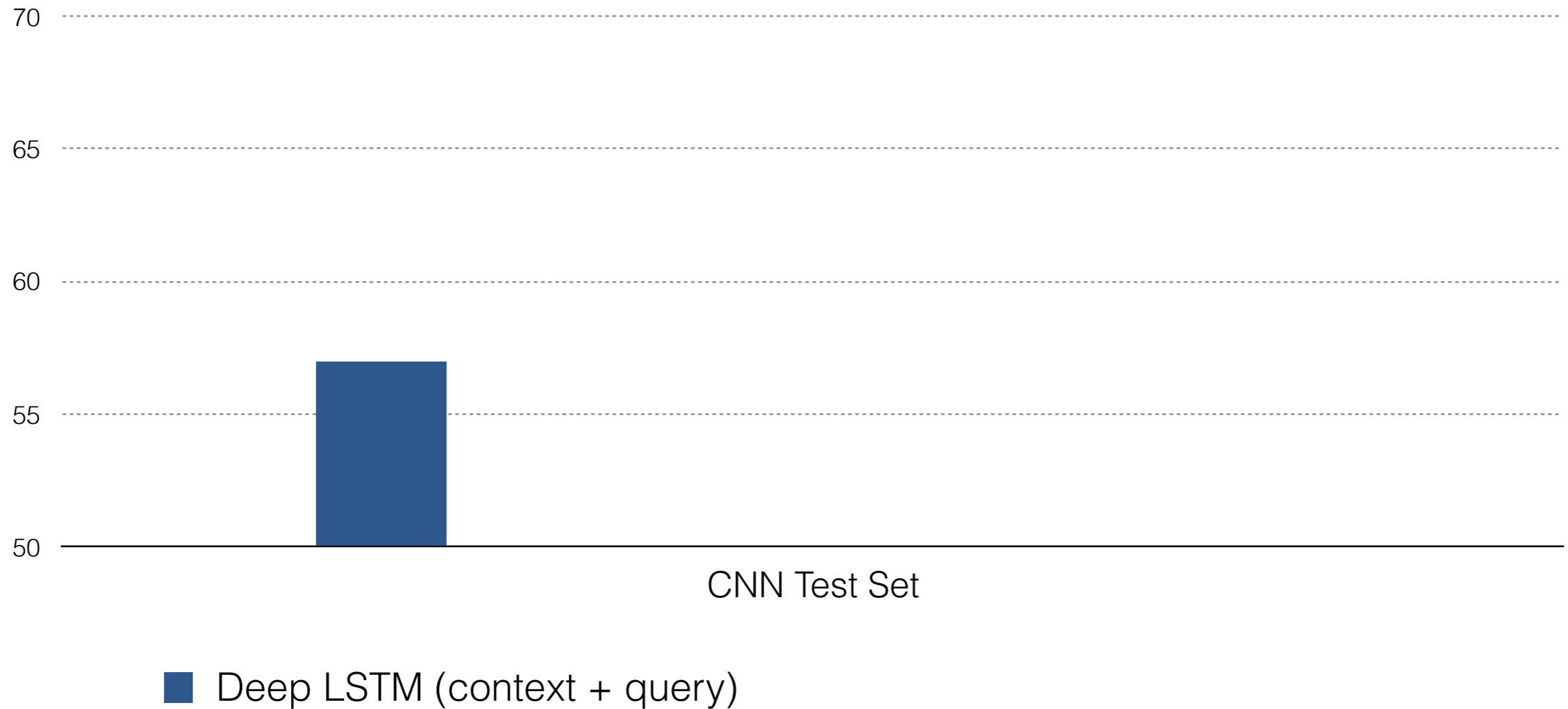


more like  
a paraphrase

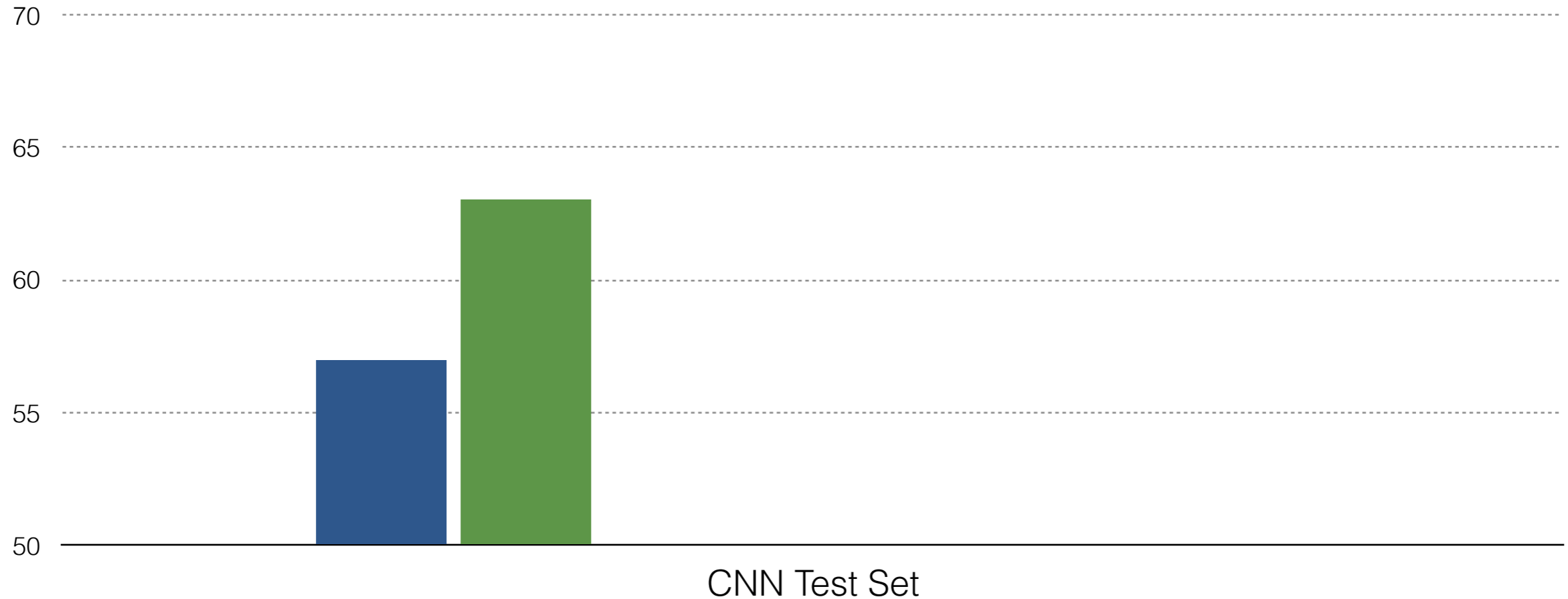




# DeepMind reading comprehension benchmark

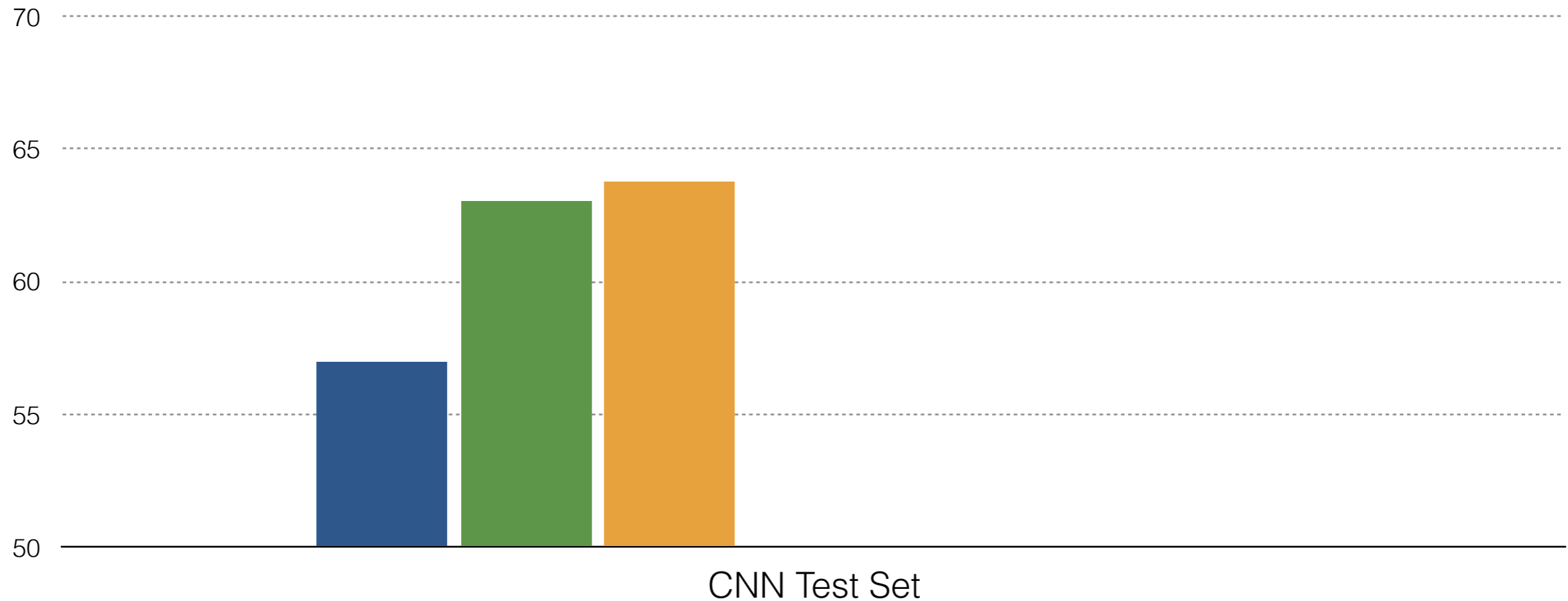


# DeepMind reading comprehension benchmark



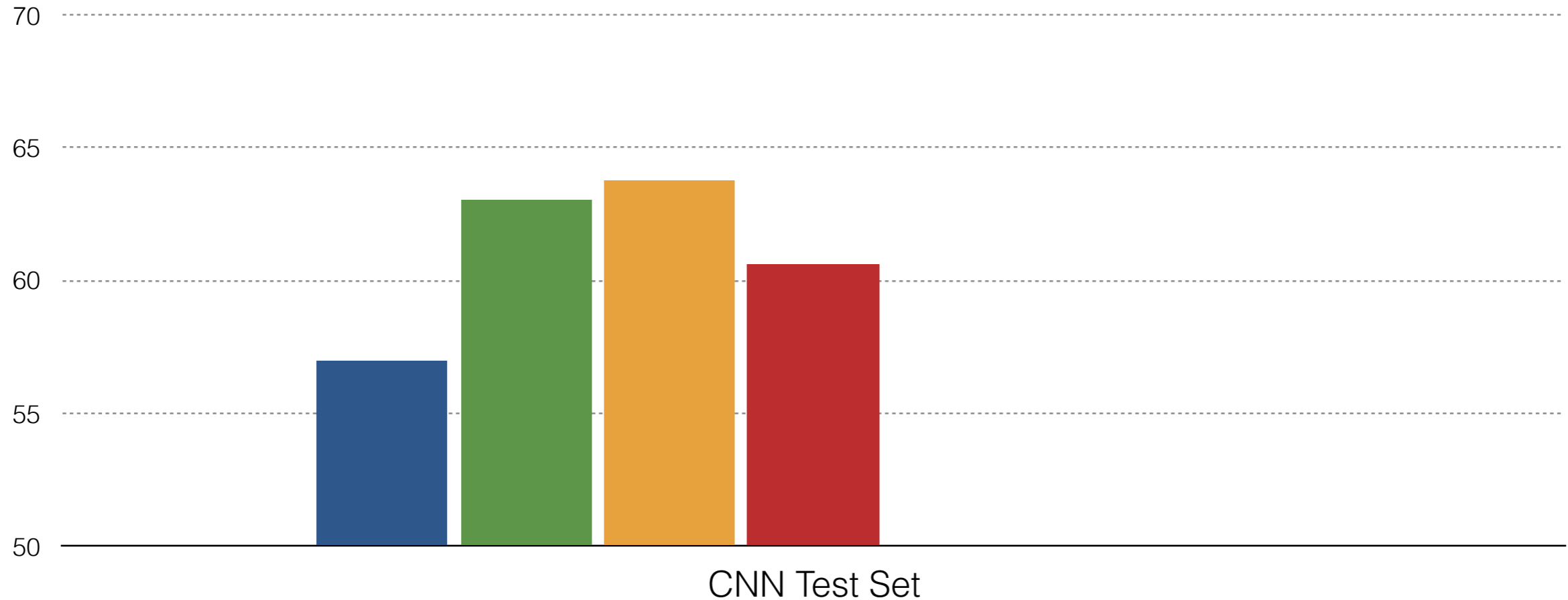
- Deep LSTM (context + query)
- Contextual LSTM ("Attentive Reader")

# DeepMind reading comprehension benchmark



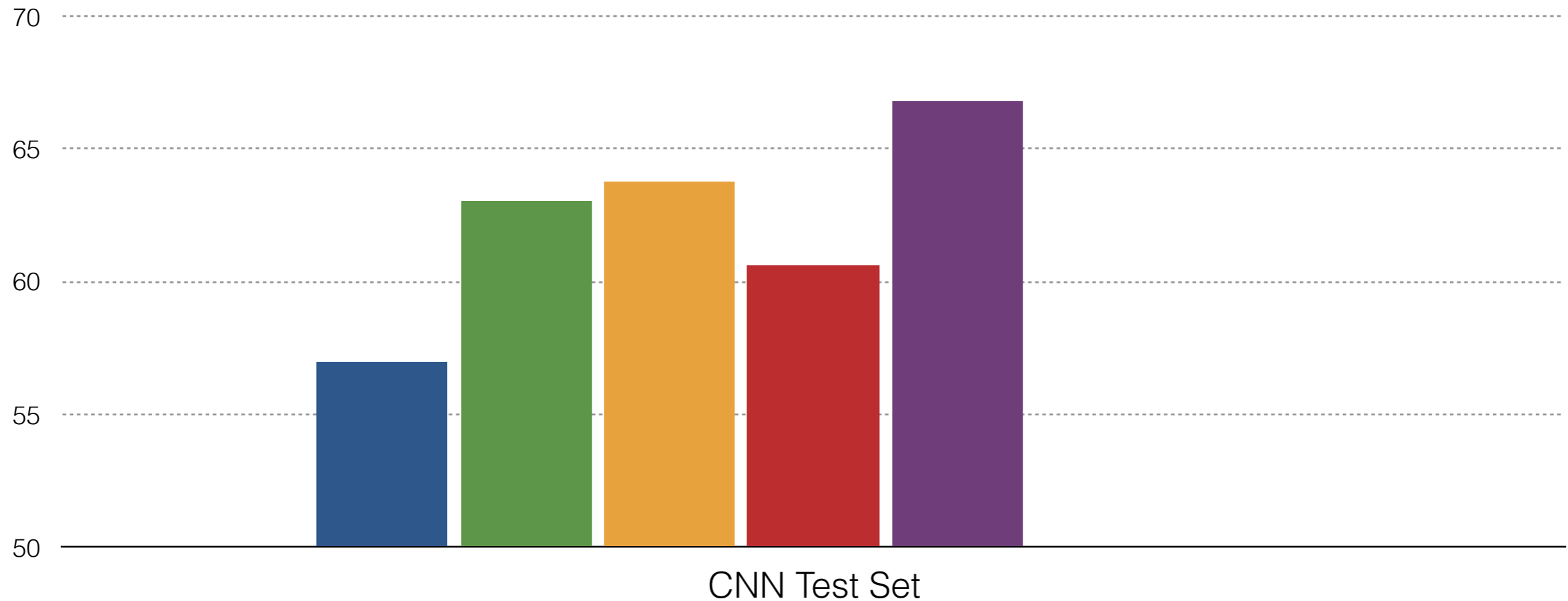
- Deep LSTM (context + query)
- Contextual LSTM ("Attentive Reader")
- Contextual LSTM ("Impatient Reader")

# DeepMind reading comprehension benchmark



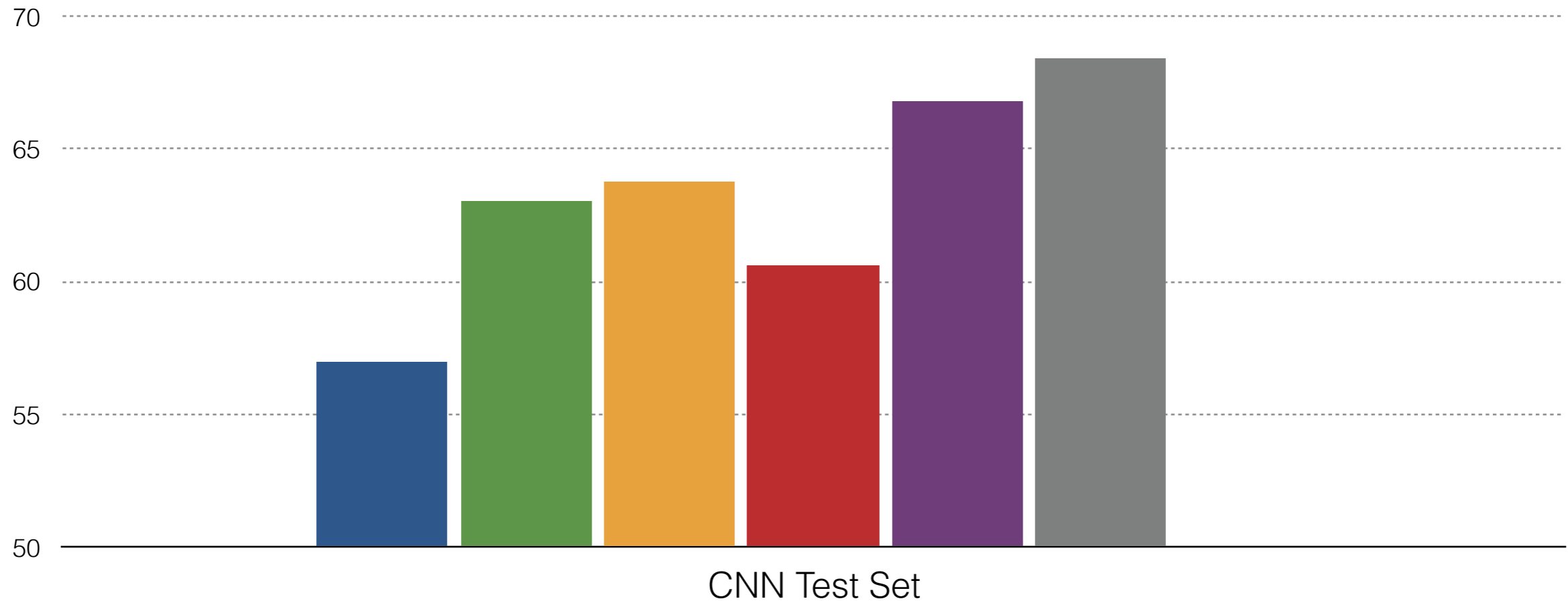
- Deep LSTM (context + query)
- Contextual LSTM ("Attentive Reader")
- Contextual LSTM ("Impatient Reader")
- MemNN (window memory)

# DeepMind reading comprehension benchmark



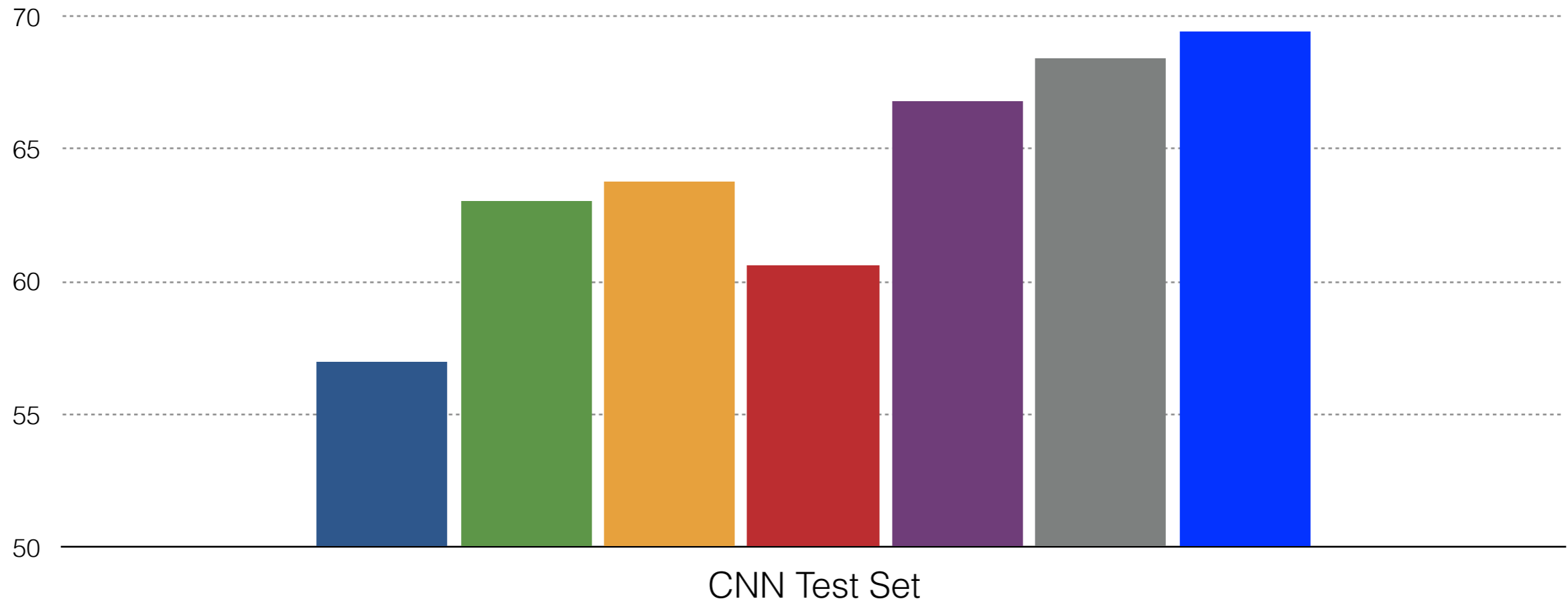
- Deep LSTM (context + query)
- Contextual LSTM ("Attentive Reader")
- Contextual LSTM ("Impatient Reader")
- MemNN (window memory)
- MemNN (window memory + self-sup)

# DeepMind reading comprehension benchmark



- 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)

# DeepMind reading comprehension benchmark



- 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)

# 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



# 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

<https://research.facebook.com>

Any  
questions?



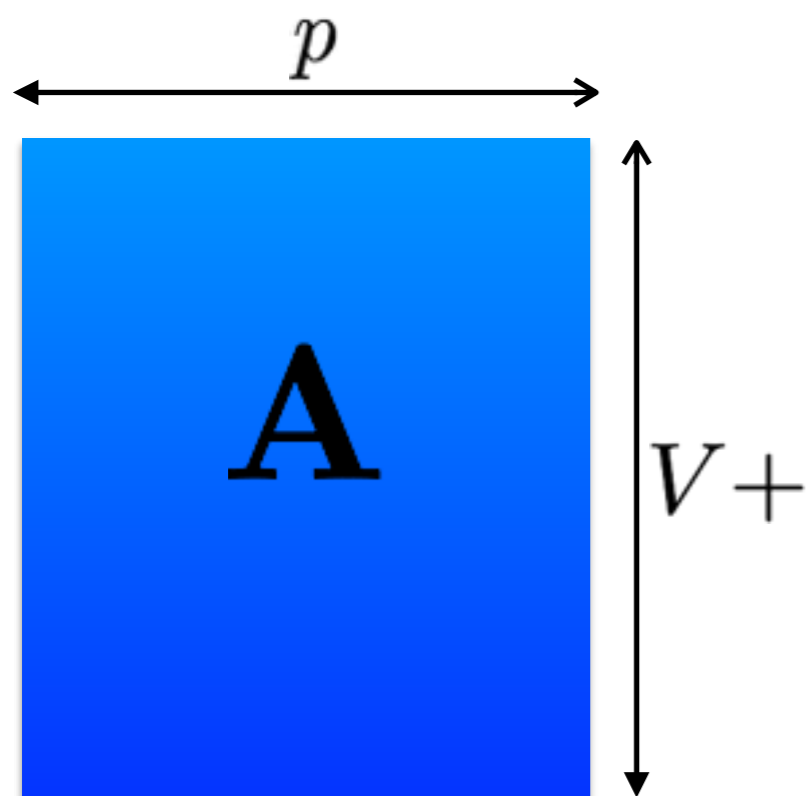
# Thanks

Antoine Bordes  
Sumit Chopra  
Jason Weston

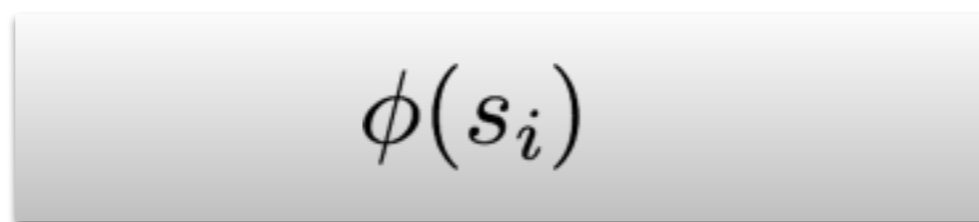


Facebook AI Research

embedding matrix



sparse sentence  
representation



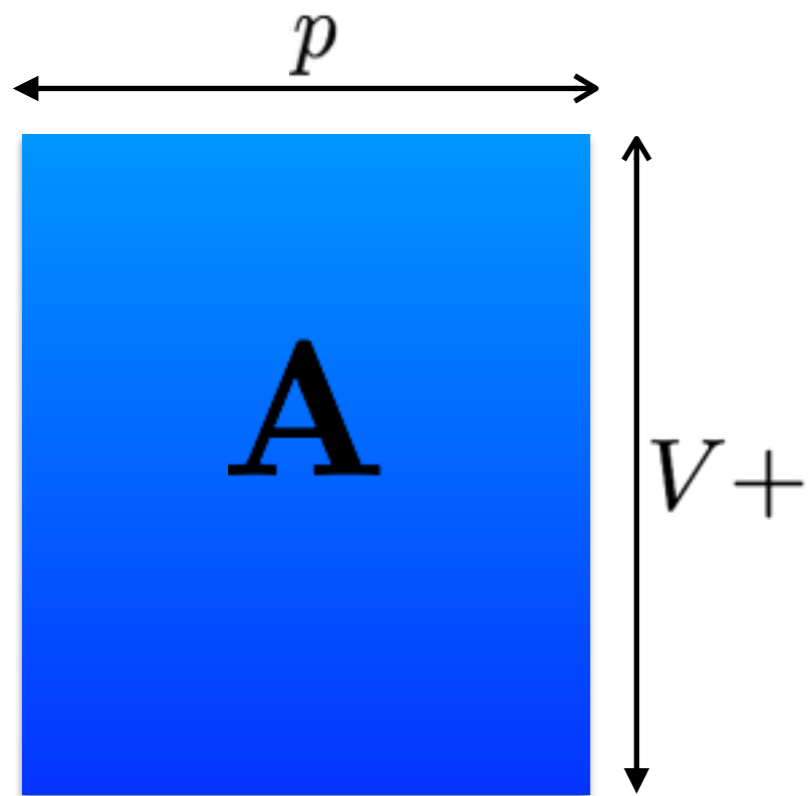
distributed memory  
representation



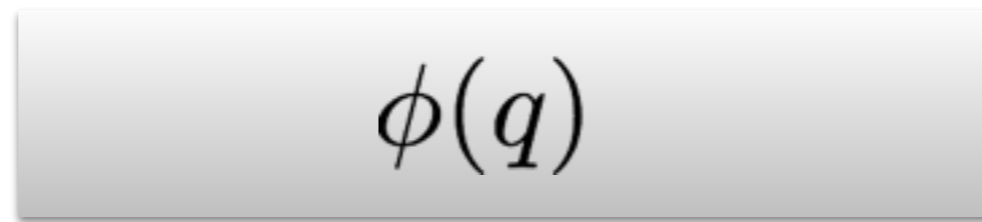
$$c_i = \mathbf{A}\phi(s_i)$$

$$m_i = \mathbf{B}\phi(s_i)$$

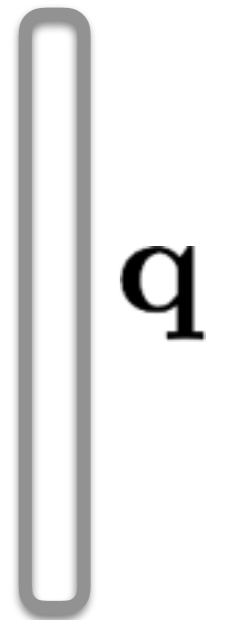
embedding matrix



sparse query representation



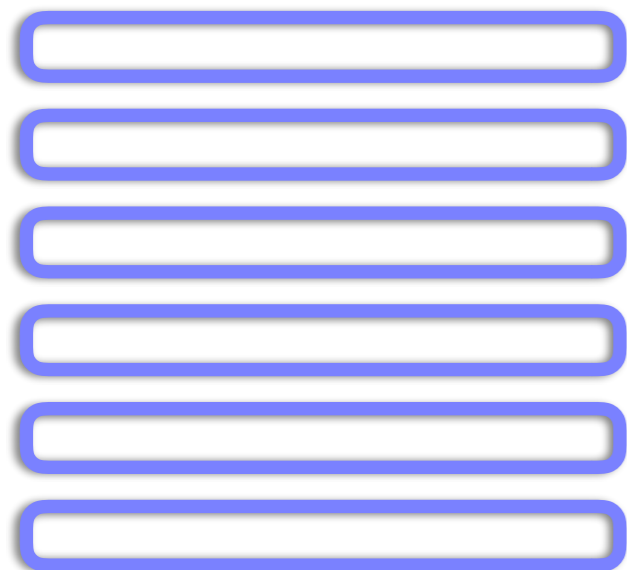
distributed query representation



$$\mathbf{q} = \mathbf{A}\phi(q)$$

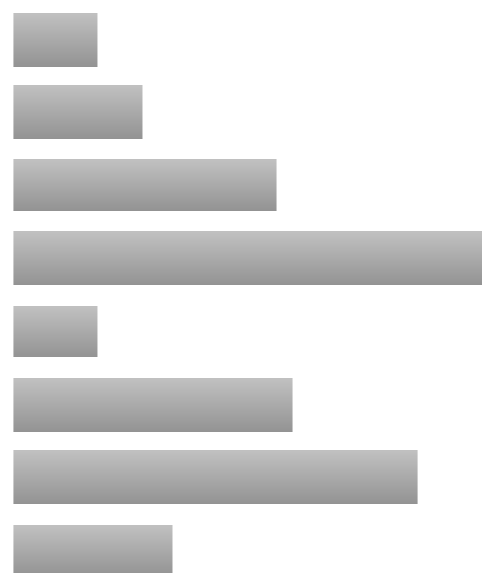
**memory  
representations  
(content)**

$m_1 \dots m_n$



**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

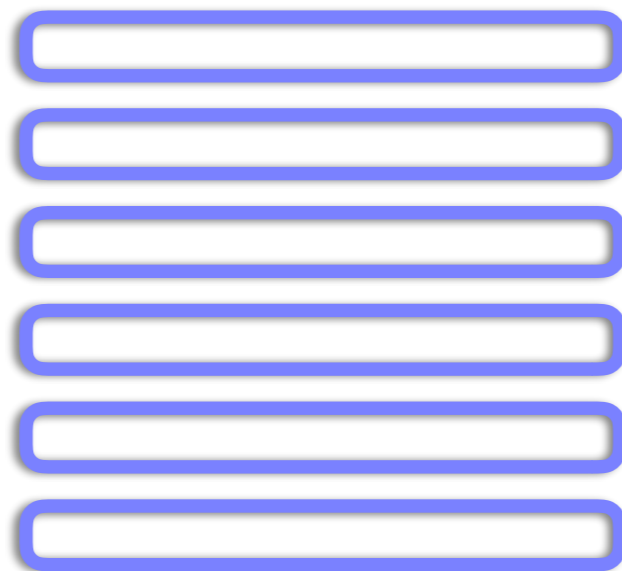
**distributed  
query  
representation**

$q$



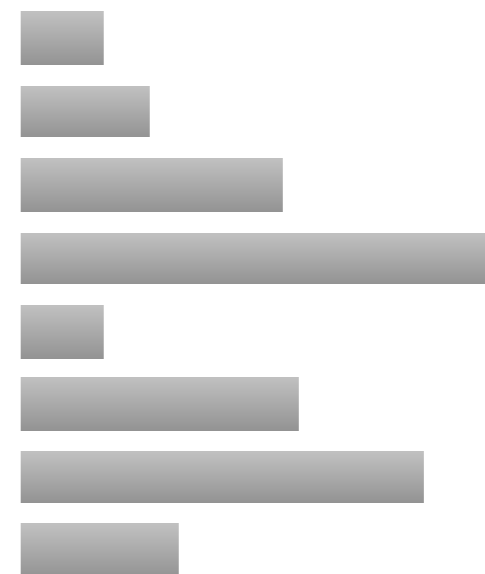
**memory  
representations  
(addressing)**

$c_1 \dots c_n$



**softmax  
distribution**

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



**context  
representation**

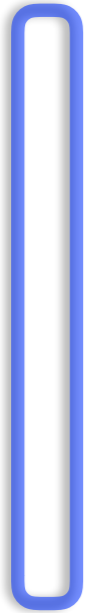
**query  
representation**

**prediction  
layer**

$$m_{O_1} = \sum_i \alpha_i m_i$$

$\mathbf{q}$

$$\mathbf{q}' = \mathbf{H}\mathbf{q} + m_{O_1}$$



**answer  
distribution**

$$\hat{\mathbf{a}} = \textit{softmax}(\mathbf{U}\mathbf{q}')$$



# Other details

Sukhbaatar et al. 2015

- Temporal Encoding of memory position

$$c_i = \mathbf{A}\phi(s_i) \longrightarrow c_i = \mathbf{A}\phi(s_i) + \mathbf{T}_A(i)$$

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

$$c_i = \mathbf{A}\phi(s_i) \longrightarrow c_i = \sum_j l_j \odot \mathbf{A}x_{ij}$$