End-To-End Memory Networks
Supplementary Material

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1 Results on 10k QA dataset

	Baseline			MemN2N									
Task	Strongly Supervised MemNN	LSTM	MemNN WSH	BoW	PE	PE LS	PE LS RN	PE LS LW RN*	1 hop PE LS joint	2 hops PE LS joint	3 hops PE LS joint	PE LS RN joint	PE LS LW joint
1: 1 supporting fact	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2: 2 supporting facts	0.0	81.9	39.6	0.6	0.4	0.5	0.3	0.3	62.0	1.3	2.3	1.0	0.8
3: 3 supporting facts	0.0	83.1	79.5	17.8	12.6	15.0	9.3	2.1	80.0	15.8	14.0	6.8	18.3
4: 2 argument relations	0.0	0.2	36.6	31.8	0.0	0.0	0.0	0.0	21.4	0.0	0.0	0.0	0.0
5: 3 argument relations	0.3	1.2	21.1	14.2	0.8	0.6	0.8	0.8	8.7	7.2	7.5	6.1	0.8
6: yes/no questions	0.0	51.8	49.9	0.1	0.2	0.1	0.0	0.1	6.1	0.7	0.2	0.1	0.1
7: counting	3.3	24.9	35.1	10.7	5.7	3.2	3.7	2.0	14.8	10.5	6.1	6.6	8.4
8: lists/sets	1.0	34.1	42.7	1.4	2.4	2.2	0.8	0.9	8.9	4.7	4.0	2.7	1.4
9: simple negation	0.0	20.2	36.4	1.8	1.3	2.0	0.8	0.3	3.7	0.4	0.0	0.0	0.2
10: indefinite knowledge	0.0	30.1	76.0	1.9	1.7	3.3	2.4	0.0	10.3	0.6	0.4	0.5	0.0
11: basic coreference	0.0	10.3	25.3	0.0	0.0	0.0	0.0	0.1	8.3	0.0	0.0	0.0	0.4
12: conjunction	0.0	23.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
13: compound coreference	0.0	6.1	12.3	0.0	0.1	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0
14: time reasoning	0.0	81.0	8.7	0.0	0.2	0.0	0.0	0.1	30.9	0.2	0.2	0.0	1.7
15: basic deduction	0.0	78.7	68.8	12.5	0.0	0.0	0.0	0.0	42.6	0.0	0.0	0.2	0.0
16: basic induction	0.0	51.9	50.9	50.9	48.6	0.1	0.4	51.8	47.3	46.4	0.4	0.2	49.2
17: positional reasoning	24.6	50.1	51.1	47.4	40.3	41.1	40.7	18,6	40.0	39.7	41.7	41.8	40.0
18: size reasoning	2.1	6.8	45.8	41.3	7.4	8.6	6.7	5.3	9.2	10.1	8.6	8.0	8.4
19: path finding	31.9	90.3	100.0	75.4	66.6	66.7	66.5	2.3	91.0	80.8	73.3	75.7	89.5
20: agent's motivation	0.0	2.1	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean error (%)	3.2	36.4	39.2	15.4	9.4	7.2	6.6	4.2	24.5	10.9	7.9	7.5	11.0
Failed tasks (err. $> 5\%$)	2	16	17	9	6	4	4	3	16	7	6	6	6

Table 1: Test error rates (%) on the 20 bAbI QA tasks for models using 10k training examples. Key: BoW = bag-of-words representation; PE = position encoding representation; LS = linear start training; RN = random injection of time index noise; LW = RNN-style layer-wise weight tying (if not stated, adjacent weight tying is used); joint = joint training on all tasks (as opposed to per-task training); $*$ = this is a larger model with non-linearity (embedding dimension is $d = 100$ and ReLU applied to the internal state after each hop. This was inspired by [1] and crucial for getting better performance on tasks 17 and 19).

References

[1] B. Peng, Z. Lu, H. Li, and K. Wong. Towards Neural Network-based Reasoning. *ArXiv preprint: 1508.05508*, 2015.

Story (1: 1 supporting fact)	Support	Hop 1	Hop 2	Hop 3
Daniel went to the bathroom.		0.00	0.00	0.03
Mary travelled to the hallway.		0.00	0.00	0.00
John went to the bedroom.		0.37	0.02	0.00
John travelled to the bathroom.	yes	0.60	0.98	0.96
Mary went to the office.		0.01	0.00	0.00
Sandra journeyed to the kitchen.		0.01	0.00	0.00
Where is John? Answer: bathroom Prediction: bathroom				

Story (2: 2 supporting facts)	Support	Hop 1	Hop 2	Hop 3
John dropped the milk.		0.06	0.00	0.00
Daniel travelled to the bedroom.		0.00	0.00	0.00
John took the milk there.	yes	0.88	1.00	0.00
Sandra went back to the bathroom.		0.00	0.00	0.00
John moved to the hallway.	yes	0.00	0.00	1.00
Mary went back to the bedroom.		0.00	0.00	0.00
Where is the milk? Answer: hallway Prediction: hallway				

Story (3: 3 supporting facts)	Support	Hop 1	Hop 2	Hop 3
John moved to the hallway.		0.00	0.00	0.00
John grabbed the football.	yes	0.00	1.00	0.00
John journeyed to the garden.		0.35	0.00	0.00
Sandra moved to the hallway.		0.00	0.00	0.00
John went back to the hallway.	yes	0.00	0.00	1.00
John journeyed to the garden.	yes	0.62	0.00	0.00
Where was the football before the garden? A: hallway P: hallway				

Story (4: 2 argument relations)	Support	Hop 1	Hop 2	Hop 3
The garden is north of the kitchen.	yes	0.84	1.00	0.92
The kitchen is north of the bedroom.		0.16	0.00	0.08
What is north of the kitchen? Answer: garden Prediction: garden				

Story (5: 3 argument relations)	Support	Hop 1	Hop 2	Hop 3
Jeff travelled to the bedroom.		0.00	0.00	0.00
Jeff journeyed to the garden.		0.00	0.00	0.00
Fred handed the apple to Jeff.	yes	1.00	1.00	0.98
Mary went to the garden.		0.00	0.00	0.00
Fred went back to the bathroom.		0.00	0.00	0.00
Fred got the milk there.		0.00	0.00	0.00
Mary journeyed to the kitchen.		0.00	0.00	0.00
Who gave the apple to Jeff? Answer: Fred Prediction: Fred				

Story (6: yes/no questions)	Support	Hop 1	Hop 2	Hop 3
Sandra travelled to the bedroom.		0.06	0.00	0.01
John took the football there.		0.00	0.00	0.00
Sandra travelled to the office.		0.00	0.45	0.16
Sandra went to the bedroom.	yes	0.89	0.39	0.04
Daniel went back to the kitchen.		0.00	0.16	0.00
John took the apple there.		0.00	0.00	0.00
Mary got the milk there.		0.00	0.00	0.00
Is Sandra in the bedroom? Answer: yes Prediction: Yes				

Story (7: counting)	Support	Hop 1	Hop 2	Hop 3
Daniel moved to the office.		0.00	0.00	0.00
Mary moved to the office.		0.00	0.00	0.00
Sandra picked up the apple there.	yes	0.14	0.00	0.92
Sandra dropped the apple.	yes	0.12	0.00	0.00
Sandra took the apple there.	yes	0.73	1.00	0.08
John went to the bedroom.		0.00	0.00	0.00
How many objects is Sandra carrying? Answer: one Prediction: one				

Story (8: lists/sets)	Support	Hop 1	Hop 2	Hop 3
John moved to the hallway.		0.00	0.00	0.00
John journeyed to the garden.		0.00	0.00	0.00
Daniel moved to the garden.		0.00	0.01	0.00
Daniel grabbed the apple there.	yes	0.03	0.00	0.98
Daniel got the milk there.	yes	0.97	0.02	0.00
John went back to the hallway.		0.00	0.00	0.00
What is Daniel carrying? Answer: apple,milk Prediction: apple,milk				

Story (9: simple negation)	Support	Hop 1	Hop 2	Hop 3
Sandra is in the garden.		0.60	0.99	0.00
Sandra is not in the garden.	yes	0.37	0.01	1.00
John went to the office.		0.00	0.00	0.00
John is in the bedroom.		0.00	0.00	0.00
Daniel moved to the garden.		0.00	0.00	0.00
Is Sandra in the garden? Answer: no Prediction: no				

Story (10: indefinite knowledge)	Support	Hop 1	Hop 2	Hop 3
Julie is either in the school or the bedroom.		0.00	0.00	0.00
Julie is either in the cinema or the park.		0.00	0.00	0.00
Bill is in the park.		0.00	0.00	0.00
Bill is either in the office or the office.	yes	1.00	1.00	1.00
Is Bill in the office? Answer: maybe Prediction: maybe				

Story (11: basic coherence)	Support	Hop 1	Hop 2	Hop 3
Mary journeyed to the hallway.		0.00	0.01	0.00
After that she journeyed to the bathroom.		0.00	0.00	0.00
Mary journeyed to the garden.		0.00	0.00	0.00
Then she went to the office.		0.01	0.06	0.00
Sandra journeyed to the garden.	yes	0.97	0.42	0.00
Then she went to the hallway.	yes	0.00	0.50	1.00
Where is Sandra? Answer: hallway Prediction: hallway				

Story (12: conjunction)	Support	Hop 1	Hop 2	Hop 3
John and Sandra went back to the kitchen.		0.08	0.00	0.00
Sandra and Mary travelled to the garden.		0.05	0.00	0.00
Mary and Daniel travelled to the office.		0.00	0.00	0.00
Mary and John went to the bathroom.		0.01	0.00	0.00
Daniel and Sandra went to the kitchen.	yes	0.74	1.00	1.00
Daniel and Mary journeyed to the office.		0.06	0.00	0.00
Where is Sandra? Answer: kitchen Prediction: kitchen				

Story (13: compound coherence)	Support	Hop 1	Hop 2	Hop 3
Sandra and Daniel travelled to the bathroom.		0.13	0.00	0.00
Afterwards they went back to the office.		0.01	0.00	0.00
Daniel and Mary travelled to the hallway.		0.01	0.00	0.00
Following that they went back to the office.		0.06	0.04	0.00
Mary and Sandra moved to the hallway.	yes	0.59	0.02	0.00
Then they went to the kitchen.	yes	0.02	0.94	1.00
Where is Sandra? Answer: kitchen Prediction: kitchen				

Story (14: time reasoning)	Support	Hop 1	Hop 2	Hop 3
This morning Julie went to the cinema.		0.00	0.03	0.00
Julie journeyed to the kitchen yesterday.		0.00	0.04	0.01
Fred travelled to the cinema yesterday.		0.00	0.05	0.01
Bill travelled to the office yesterday.		0.00	0.07	0.01
This morning Mary travelled to the bedroom.	yes	0.97	0.27	0.01
Yesterday Mary journeyed to the cinema.	yes	0.01	0.33	0.96
Where was Mary before the bedroom? Answer: cinema Prediction: cinema				

Story (15: basic deduction)	Support	Hop 1	Hop 2	Hop 3
Cats are afraid of wolves.	yes	0.00	0.99	0.62
Sheep are afraid of wolves.		0.00	0.00	0.31
Winona is a sheep.		0.00	0.00	0.00
Emily is a sheep.		0.00	0.00	0.00
Gertrude is a cat.	yes	0.99	0.00	0.00
Wolves are afraid of mice.		0.00	0.00	0.00
Mice are afraid of wolves.		0.00	0.00	0.07
Jessica is a mouse.		0.00	0.00	0.00
What is gertrude afraid of? Answer: wolf Prediction: wolf				

Story (16: basic induction)	Support	Hop 1	Hop 2	Hop 3
Lily is a swan.		0.00	0.00	0.00
Brian is a frog.	yes	0.00	0.98	0.00
Lily is gray.		0.07	0.00	0.00
Brian is yellow.	yes	0.07	0.00	1.00
Julius is a swan.		0.00	0.00	0.00
Bernhard is yellow.		0.04	0.00	0.00
Julius is green.		0.06	0.00	0.00
Greg is a frog.	yes	0.76	0.02	0.00
What color is Greg? Answer: yellow Prediction: yellow				

Story (17: positional reasoning)	Support	Hop 1	Hop 2	Hop 3
The red square is below the red sphere.	yes	0.37	0.95	0.58
The red sphere is below the triangle.	yes	0.63	0.05	0.43
Is the triangle above the red square? Answer: yes Prediction: no				

Story (18: size reasoning)	Support	Hop 1	Hop 2	Hop 3
The suitcase is bigger than the chest.	yes	0.00	0.88	0.00
The box is bigger than the chocolate.		0.04	0.05	0.10
The chest is bigger than the chocolate.	yes	0.17	0.07	0.90
The chest fits inside the container.		0.00	0.00	0.00
The chest fits inside the box.		0.00	0.00	0.00
Does the suitcase fit in the chocolate? Answer: no Prediction: no				

Story (19: path finding)	Support	Hop 1	Hop 2	Hop 3
The hallway is north of the kitchen.		1.00	1.00	1.00
The garden is south of the kitchen.	yes	0.00	0.00	0.00
The garden is east of the bedroom.	yes	0.00	0.00	0.00
The bathroom is south of the bedroom.		0.00	0.00	0.00
The office is east of the garden.		0.00	0.00	0.00
How do you go from the kitchen to the bedroom? Answer: s,w Prediction: n,n				

Story (20: agent's motivation)	Support	Hop 1	Hop 2	Hop 3
Yann journeyed to the kitchen.		0.00	0.00	0.00
Yann grabbed the apple there.		0.00	0.00	0.00
Antoine is thirsty.	yes	0.17	0.00	0.98
Jason picked up the milk there.		0.01	0.00	0.00
Antoine travelled to the kitchen.		0.77	1.00	0.00
Why did antoine go to the kitchen? Answer: thirsty Prediction: thirsty				

Figure 1: Examples of attention weights during different memory hops for the bAbi tasks. The model is PE+LS+RN with 3 memory hops that is trained separately on each task with 10k training data. The support column shows which sentences are necessary for answering questions. Although this information is not used, the model succesfully learns to focus on the correct support sentences on most of the tasks. The hop columns show where the model put more weight (indicated by values and blue color) during its three hops. The mistakes made by the model are highlighted by red color.