Learning to Organize Knowledge with N-Gram Machines

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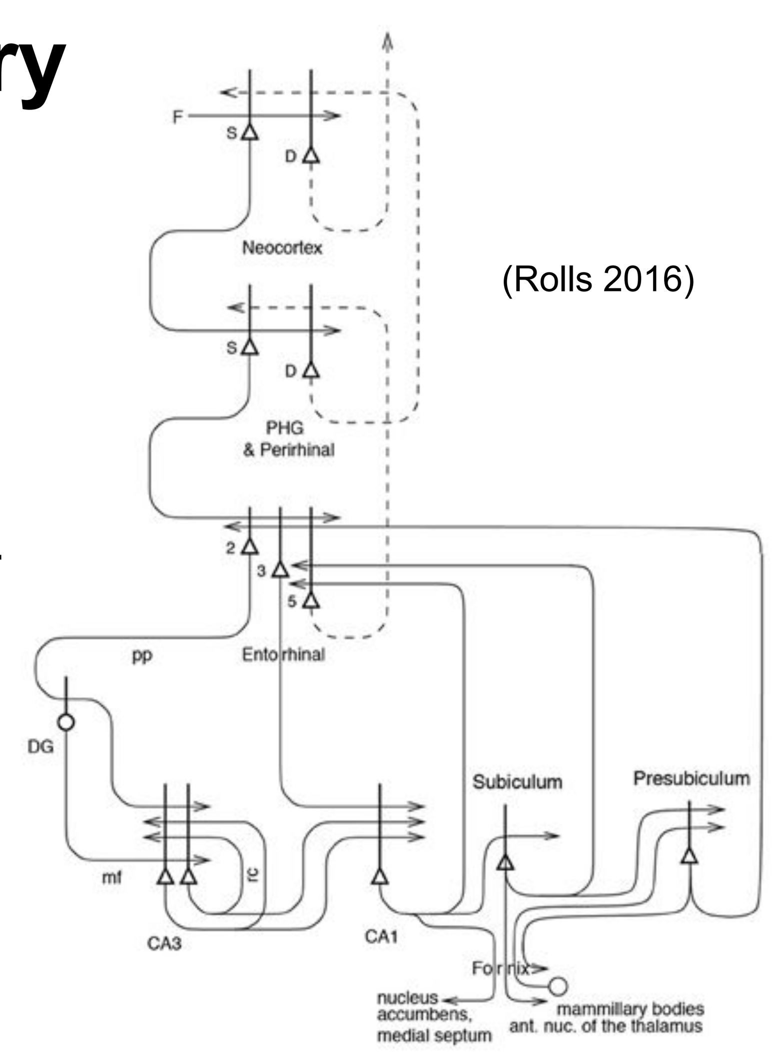
Scalability & Intelligence

- "Methods that scale with computation are the future of AI" -- Richard Sutton, 2017
- **Hippocampus** studies (Wickman 2012; Bartol+ 2015) suggests that human memory capacity may be somewhere between 10 terabytes and 100 terabytes.
- **Modern search engines** (Brin & Page 1998) respond to users' requests within fraction of a second from large data, but are weak at understanding and reasoning.

Hippocampal Circuitry

- *Hippocampus* and *neocortex* are complementary systems -- *rapid storage of experience* vs *gradually build semantic representations from accumulated data.*
- *Episodic memory* can store and retrieve events through autoassociation -- completing memory from partial cues, which enables efficient storage & retrieval.
- The recurrent structure in *CA3 collateral system* allows the generation process to be informed by external input to provide a fuller and more coherent version.
- *Sharp-wave ripple (SWR)* during sleep replays earlier experiences at x10 speed with goal-dependent weightings, and trains the neocortex.



(Rolls 2016)

End-to-end QA Models

- With vector space semantic representations the inference time is linear to text size. E.g., MemN2N (Sukhbaatar+ 2015)

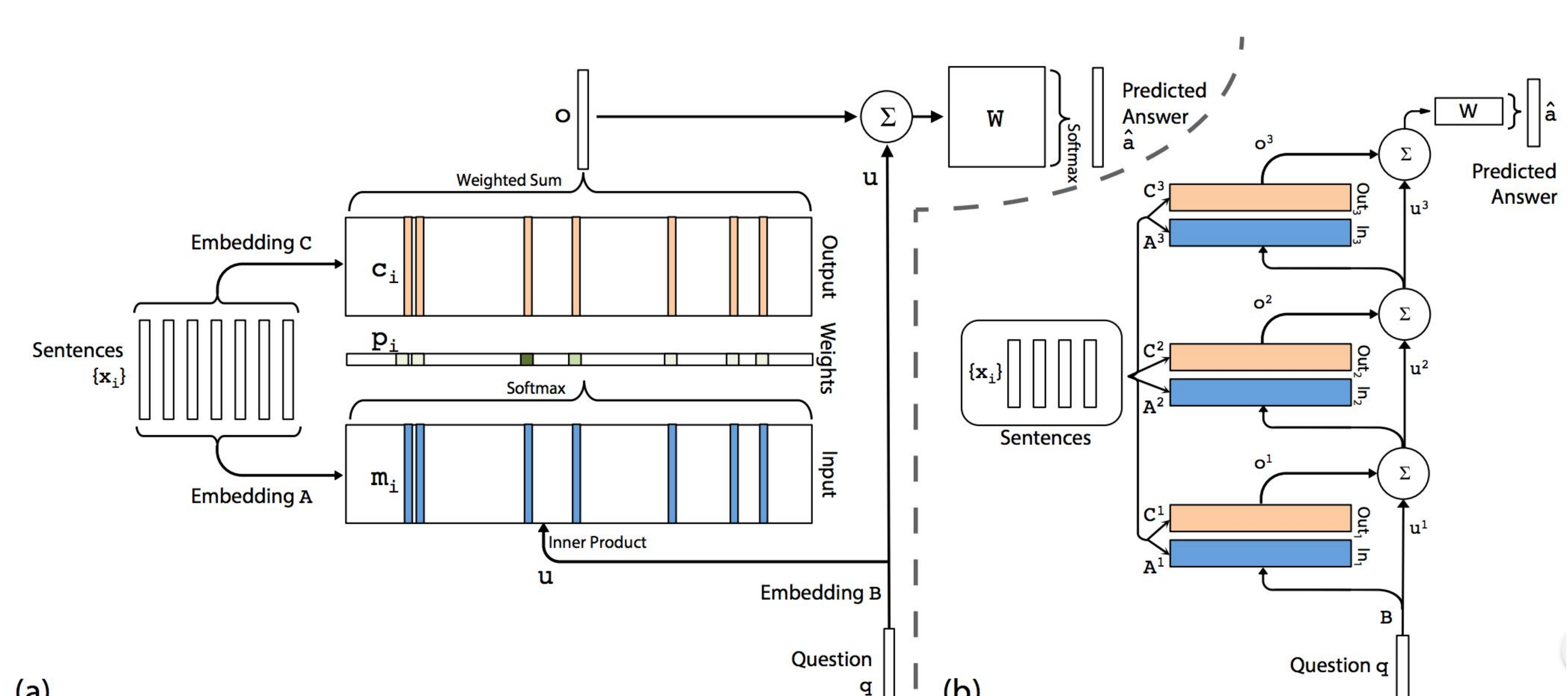


Figure 1: (a): A single layer version of our model. (b): A three layer version of our model. In practice, we can constrain several of the embedding matrices to be the same (see Section 2.2).

NGM Framework

- Probabilistic Knowledge storage

s_{i-1} for co-references

$$P(\Gamma|s;\theta_{\text{enc}}) = \Pi_{\Gamma_i\in\Gamma} P(\Gamma_i|s_i, s_{i-1};\theta_{\text{enc}})$$

Table 1: Example of probabilistic knowledge storage. Each sentence may be converted to a distribution over multiple tuples, but only the one with the highest probability is shown here.

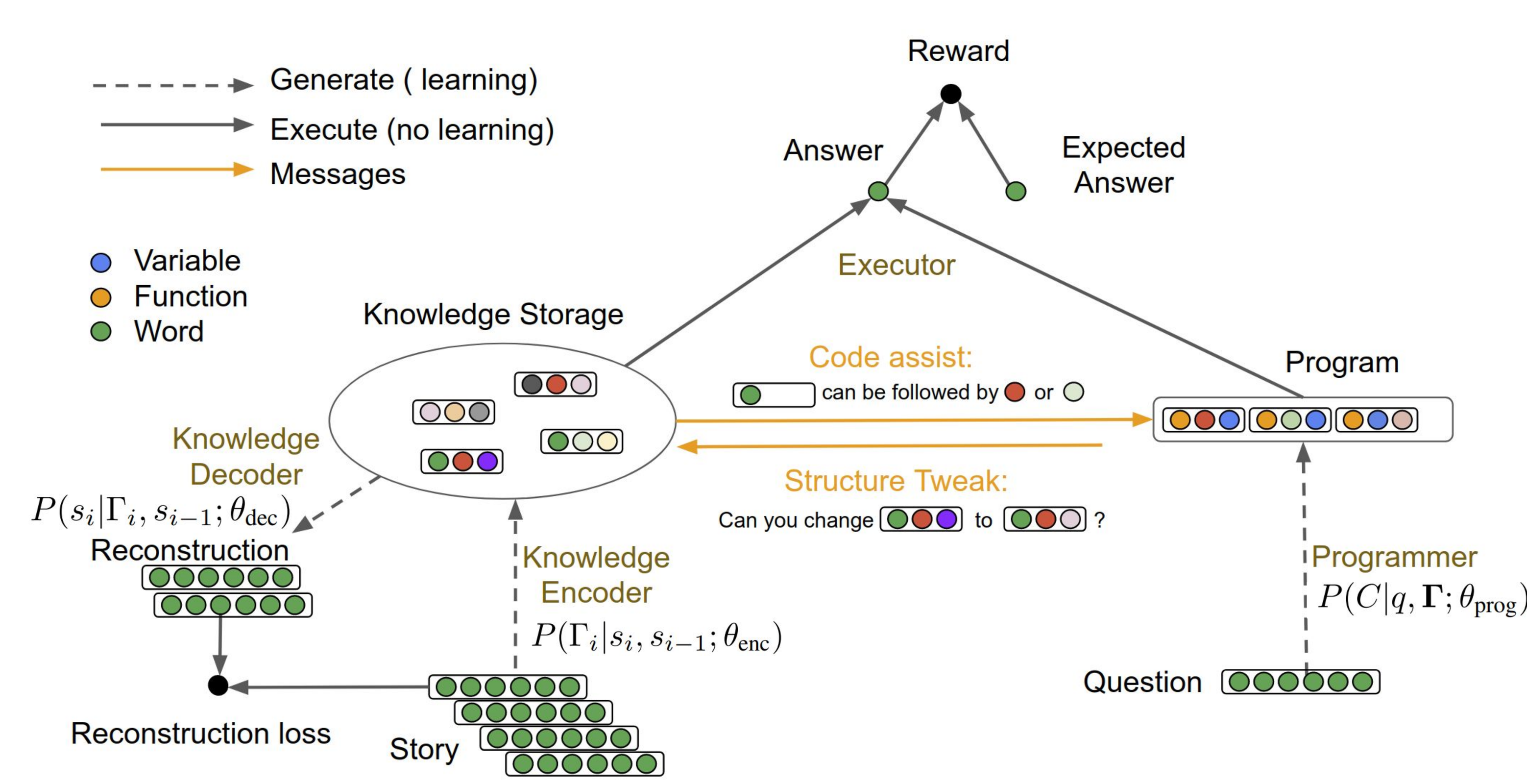
Sentences	Knowledge tuples		
	Time stamp	Symbols	Probability
Mary went to the kitchen.	1	mary to kitchen	0.9
Mary picked up the milk.	2	mary the milk	0.4
John went to the bedroom.	3	john to bedroom	0.7
Mary journeyed to the garden.	4	mary to garden	0.8

- Programs

Table 2: Functions in N-Gram Machines. The knowledge storage on which the programs can execute is Γ, and a knowledge tuple Γ_i is represented as $(i, (\gamma_1, \dots, \gamma_N))$. "FR" means *from right*.

Name	Inputs	Return
Hop	$v_1 \dots v_L$	$\{\gamma_{L+1} \mid \text{if } (\gamma_1 \dots \gamma_L) == (v_1, \dots, v_L), \forall\Gamma \in \mathbf{\Gamma}\}$
HopFR	$v_1 \dots v_L$	$\{\gamma_{N-L} \mid \text{if } (\gamma_{N-L+1} \dots \gamma_N) == (v_L, \dots, v_1), \forall\Gamma \in \mathbf{\Gamma}\}$
Argmax	$v_1 \dots v_L$	$\text{argmax}_i\{(\gamma_{L+1}, i) \mid \text{if } (\gamma_1 \dots \gamma_L) == (v_1, \dots, v_L), \forall\Gamma_i \in \mathbf{\Gamma}\}$
ArgmaxFR	$v_1 \dots v_L$	$\text{argmax}_i\{(\gamma_{N-L}, i) \mid \text{if } (\gamma_{N-L+1} \dots \gamma_N) == (v_L, \dots, v_1), \forall\Gamma_i \in \mathbf{\Gamma}\}$

- Seq2Seq models



$$O^{QA}(\theta_{\text{enc}}, \theta_{\text{prog}}) = \sum_{\mathbf{\Gamma}}\sum_{C} P(\mathbf{\Gamma}|\mathbf{s};\theta_{\text{enc}})P(C|q,\mathbf{\Gamma};\theta_{\text{prog}})R(\mathbf{\Gamma}, C, a),$$

$$O^{AE}(\theta_{\text{enc}}, \theta_{\text{dec}}) = \mathbb{E}_{p(z|x;\theta_{\text{enc}})}[\log p(x|z;\theta_{\text{dec}})] + \sum_{z\in\mathbf{Z}^N(x)} \log p(x|z;\theta_{\text{dec}}),$$

all tuples of length N which only consist of words from x

- Inference & optimization
  - Beam search instead of MCMC to reduce variances
  - To solve a hard search problem
    - Stabilized auto-encoding (AE)
    - Structure tweak (ST)
  - Coordinate descent by REINFORCEs with replays

Experiment Results

- Extractive bAbI tasks

Test accuracy on bAbI tasks with auto-encoding (AE) and structure tweak (ST)

	Task 1	Task 2	Task 11	Task 15	Task 16
MemN2N	1.000	0.830	0.840	1.000	0.440
QA	0.007	0.027	0.000	0.000	0.098
QA + AE	0.709	0.551	**1.000**	0.246	**1.000**
QA + AE + ST	**1.000**	**0.853**	**1.000**	**1.000**	**1.000**

- Auto-encoding and structural tweaking help to learn good representations.

QA	QA + AE	QA + AE + ST
went went went	daniel went office	daniel went office
mary mary mary	mary back garden	mary went garden
john john john	john back kitchen	john went kitchen
mary mary mary	mary grabbed football	mary got football
there there there	sandra got apple	sandra got apple
cats cats cats	cats afraid wolves	cat afraid wolves
mice mice mice	mice afraid wolves	mouse afraid wolves
is is cat	gertrude is cat	gertrude is cat

- Example solution

Table 6: Task 2 Two Supporting Facts

Story	Knowledge Storage
Sandra journeyed to the hallway.	Sandra journeyed hallway
John journeyed to the bathroom.	John journeyed bathroom
Sandra grabbed the football.	Sandra got football
Daniel travelled to the bedroom.	Daniel journeyed bedroom
John got the milk.	John got milk
John dropped the milk.	John got milk
Question	**Program**
Where is the milk?	ArgmaxFR milk got Argmax V1 journeyed

- Constant inference time