What Does It Mean to Understand?

Improving the Performance of Unitary Recurrent Neural Networks and Applying Them to the Automatic Text Understanding Problem

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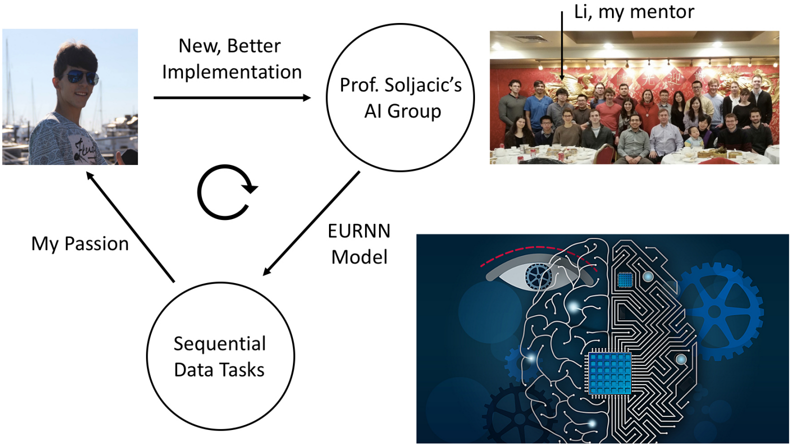
The Purpose Behind **Artificial** Intelligence

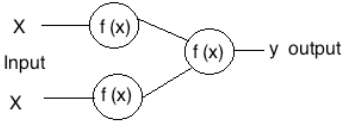


(MIT News) and (Prof. Soljacic's group)

The Artificial **Neural** Network

- An Analogy

Biological Neural Network

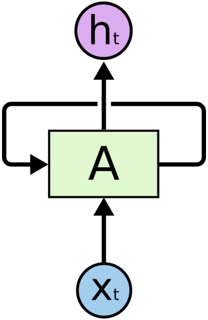


Artificial Neural Network

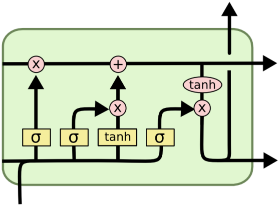
(Dasan)

The Artificial **Recurrent** Neural Network

- Concept of Recurrence



General Model

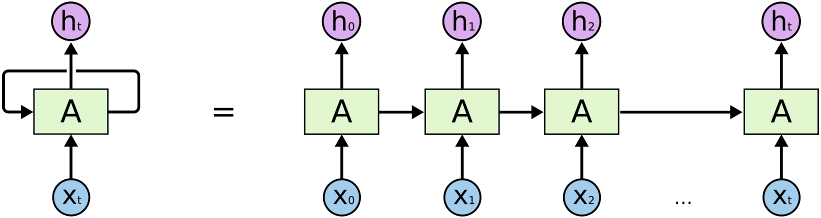


Long Short-Term Memory (LSTM) Model

(Olah)

The Artificial **Recurrent** Neural Network

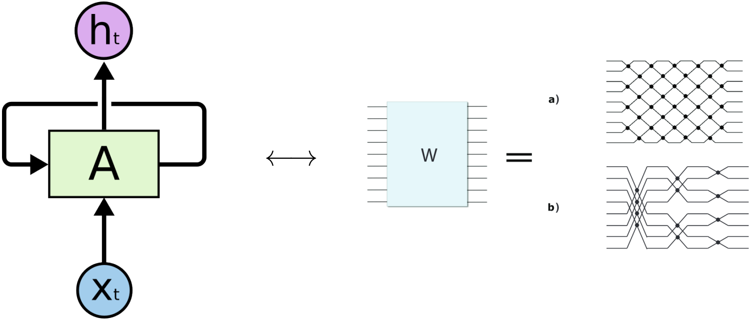
- Concept of Recurrence



(Olah)

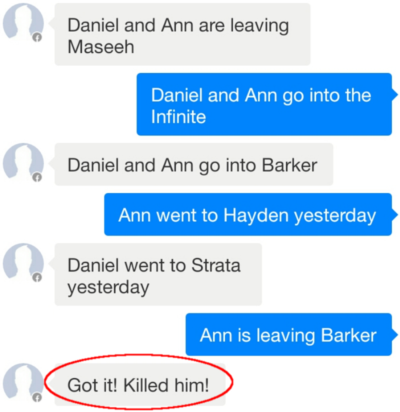
The Artificial **Unitary** Recurrent Neural Network

- The Unitary Matrix



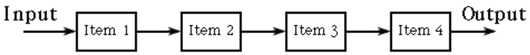
(Jing et. al)

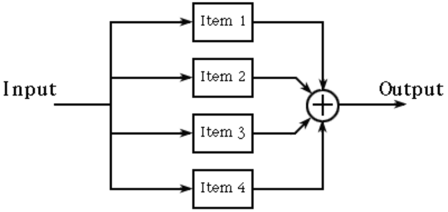
The Artificial **Unitary** Recurrent Neural Network



- Dr. Sillman: *Where is Daniel?*

Optimizations of the model

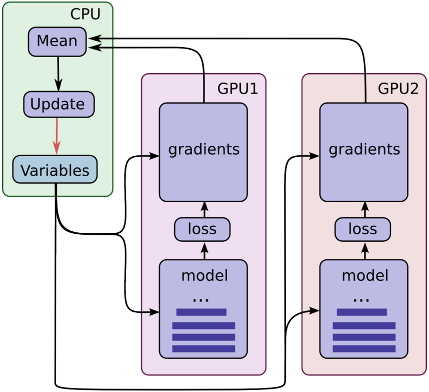




(Volans)

- Parallelization

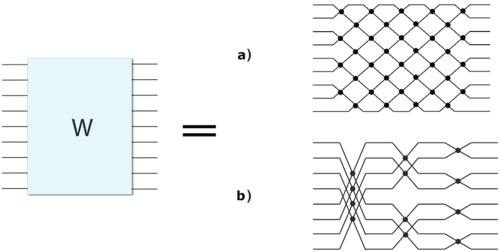
Optimizations of the model



(PipelineAI)

- Parallelization
- TensorFlow Adaptation

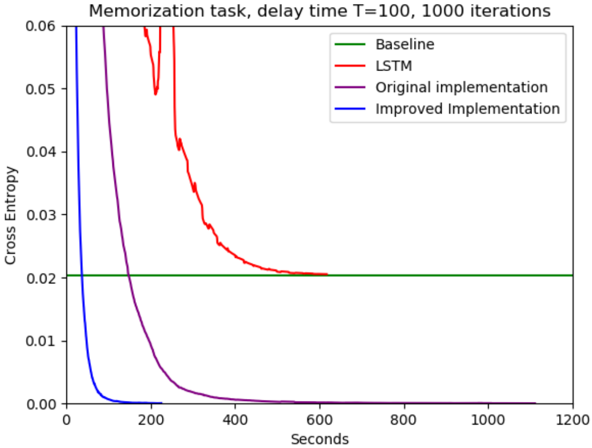
Optimizations of the model



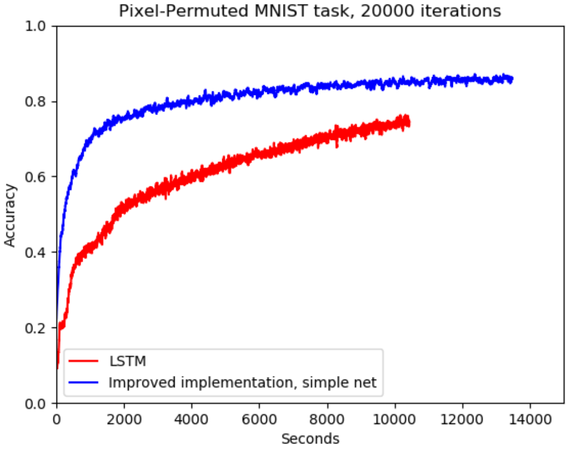
(Jing et al.)

- Parallelization
- TensorFlow Adaptation
- Hyperparameter Expansion

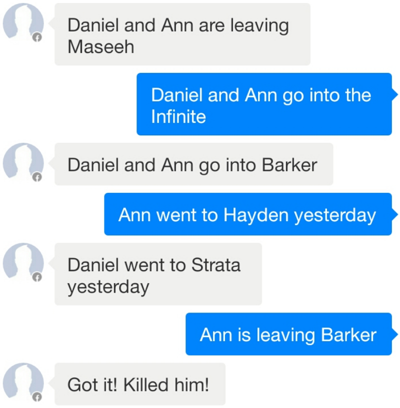
Benchmark: Memorization Task



Benchmark: Handwritten Digit Recognition Task

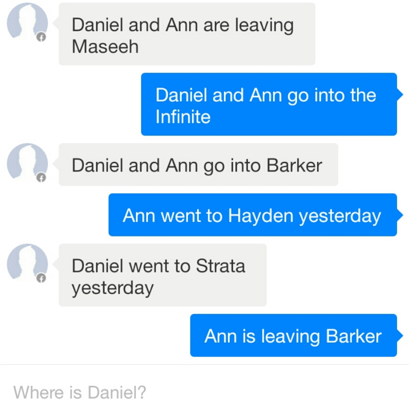


Automatic Text Understanding

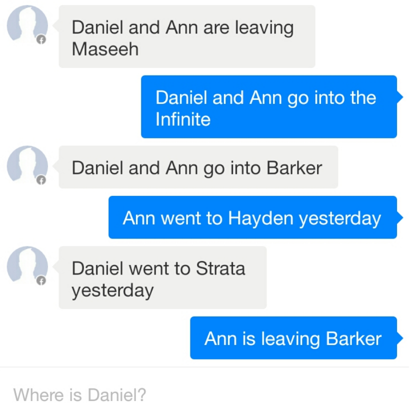


- Dr. Sillman: *Where is Daniel?*

Automatic Text Understanding

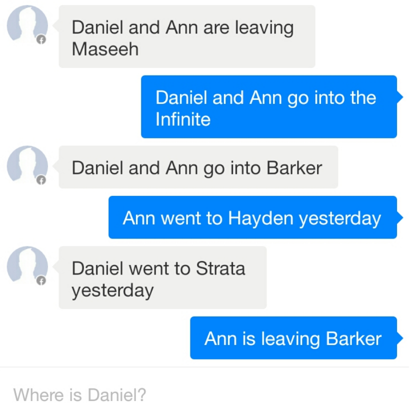


Automatic Text Understanding



Daniel	and	...	is	Where
0	1	...	16	17

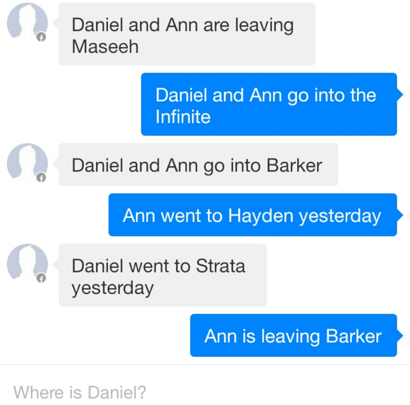
Automatic Text Understanding



Daniel	and	...	is	Where
0	1	...	16	17

Where is Daniel? $\longrightarrow$ *(17, 16, 0)*

Automatic Text Understanding



Daniel	and	...	is	Where
0	1	...	16	17

$$\textit{Where is Daniel?} \longrightarrow (17,\ 16,\ 0)$$

$$\downarrow$$

$$([0,0,\ldots,0,1],\ [0,0,\ldots,1,0],\ [1,0,\ldots,0,0])$$

Automatic Text Understanding

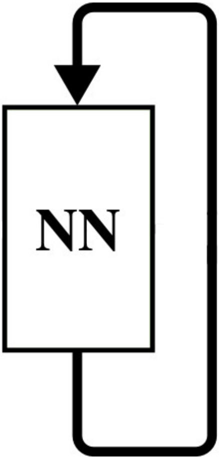
$$\begin{array}{l} 0 \rightarrow \\ 1 \rightarrow \\ 0 \rightarrow \\ \vdots \\ 0 \rightarrow \\ 0 \rightarrow \\ 0 \rightarrow \end{array}$$

Automatic Text Understanding

$$\begin{array}{l} 0 \rightarrow \\ 1 \rightarrow \\ 0 \rightarrow \\ \vdots \\ 0 \rightarrow \\ 0 \rightarrow \\ 0 \rightarrow \end{array}$$

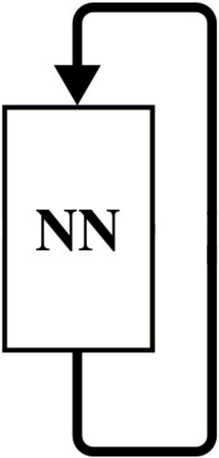
Automatic Text Understanding

$0 \rightarrow$
$1 \rightarrow$
$0 \rightarrow$
$\vdots$
$0 \rightarrow$
$0 \rightarrow$
$0 \rightarrow$



Automatic Text Understanding

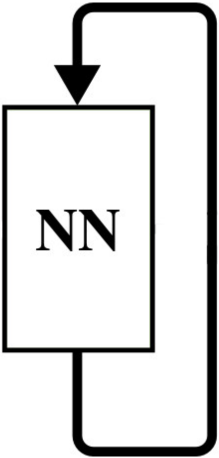
$0 \rightarrow$
$1 \rightarrow$
$0 \rightarrow$
$\vdots$
$0 \rightarrow$
$0 \rightarrow$
$0 \rightarrow$



$\rightarrow$ 0.12 (12%)
$\rightarrow$ 0.01 (1%)
$\rightarrow$ 0.07 (7%)
$\vdots$
$\rightarrow$ 0.24 (24%)
$\rightarrow$ 0.56 (56%)
$\rightarrow$ 0.00 (0%)

Automatic Text Understanding

$0 \rightarrow$		$\rightarrow$ 0.12 (12%)	Daniel
$1 \rightarrow$		$\rightarrow$ 0.01 (1%)	and
$0 \rightarrow$		$\rightarrow$ 0.07 (7%)	Ann
$\vdots$		$\vdots$	$\vdots$
$0 \rightarrow$		$\rightarrow$ 0.24 (24%)	Strata
$0 \rightarrow$		$\rightarrow$ 0.56 (56%)	**Barker**
$0 \rightarrow$		$\rightarrow$ 0.00 (0%)	Where



bAbI Tasks Dataset

Task 1: Single Supporting Fact

Mary went to the bathroom.
John moved to the hallway.
Mary travelled to the office.
Where is Mary? A:office

(Facebook)

bAbI Tasks Dataset

Task	Our model	LSTM
1 - Single Supporting Fact	50.5%	**52.0%**
2 - Two Supporting Facts	**31.8%**	15.1%
3 - Three Supporting Facts	**25.4%**	19.1%
4 - Two Arg. Relations	71.2%	**73.5%**
5 - Three Arg. Relations	**67.1%**	34.4%
6 - Yes/No Questions	**52.9%**	50.5%
7 - Counting	**71.3%**	56.5%
8 - Lists/Sets	**68.2%**	38.8%
9 - Simple Negation	61.8%	**63.8%**
10 - Indefinite Knowledge	**46.0%**	45.1%
11 - Basic Coreference	72.3%	**74.1%**
12 - Conjunction	73.4%	**76.1%**
13 - Compound Coreference	**94.0%**	83.0%
14 - Time Reasoning	**36.4%**	18.6%
15 - Basic Deduction	**55.0%**	21.2%
16 - Basic Induction	**48.8%**	32.2%
17 - Positional Reasoning	48.4%	**50.6%**
18 - Size Reasoning	**89.5%**	89.2%
19 - Path Finding	**7.9%**	6.6%
20 - Agents Motivations	**95.5%**	90.6%
Mean Performance	**58.4%**	49.6%

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bAbI Tasks Dataset

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Conclusion

- Five times the efficiency of the original implementation
- Greater accuracy than state-of-the-art model on bAbI tasks dataset
- Introduction of the theoretical model to a real-life task

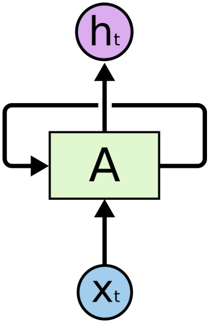
Future work

- Decomposition model improvements
- Low-level operations optimization
- Application for speech recognition

Acknowledgements

- Li Jing
- Rumen Dangovski
- Dr. Jenny Sendova
- Andrew Jin, Charles Tam, Stanislav Atanasov, William McInroy, Hristo Stoyanov, Milen Ferev
- RSI, CEE, MIT
- America for Bulgaria Foundation, International Foundation "Sts. Cyril & Methodius"

The Recurrent Neural Network



$$m^{(t)} = \sigma(U * x^{(t)} + W * m^{(t-1)})$$

$$h^{(t)} = W * m^{(t)} + b$$

Exploding and Vanishing Gradients Problems

Training rule: $W_{i,j} - \lambda * \frac{\partial C}{\partial W_{i,j}}$

$$\frac{\partial C}{\partial h^{(t)}} = \frac{\partial C}{\partial h^{(T)}} \frac{\partial h^{(T)}}{\partial h^{(t)}} = \frac{\partial C}{\partial h^{(T)}} \prod_{k=t}^{T-1} \frac{\partial h^{(k+1)}}{\partial h^{(k)}} = \frac{\partial C}{\partial h^{(T)}} \prod_{k=t}^{T-1} D^{(t)} W$$

Jing et al.'s Approach

- General representation

$$\begin{aligned} W_n &= DR_{2,1}^{-1} R_{3,1}^{-1} \dots R_{N,N-2}^{-1} R_{N,N-1}^{-1} \\ &= DR_{2,1}^{'} R_{3,1}^{'} \dots R_{N,N-2}^{'} R_{N,N-1}^{'} \end{aligned}$$

Jing et al.'s Approach

- Simple Net Decomposition Model

$$
\begin{aligned}
W &= D(R^{(1)}_{1,2} R^{(1)}_{3,4} \ldots R^{(1)}_{N/2-1,N/2}) \times \\
&\times (R^{(2)}_{2,3} R^{(2)}_{4,5} \ldots R^{(2)}_{N/2-1,N/2-1}) \times \ldots \\
&= D F^{(1)}_a F^{(2)}_b \ldots F^{(L)}_b
\end{aligned}
$$

$$
\begin{aligned}
F^{(l)}_a &= R^{(l)}_{1,2} R^{(l)}_{3,4} \ldots R^{(l)}_{N/2-1,N/2} \\
F^{(l)}_b &= R^{(l)}_{2,3} R^{(l)}_{4,5} \ldots R^{(l)}_{N/2-1,N/2-1}
\end{aligned}
$$

Jing et al.'s Approach

- Lightweight Decomposition Model

$$W = DF_1 F_2 \dots F_{log(N)}$$

F_i - rotation matrices for $(2kp + j, (2k+1)p + j)$,
$p = N/2t, \; k \in 0, \dots, 2^{i-1}$, and $j \in 1, \dots, p$

Jing et al.'s Approach

$$\mathbf{F}x = v_1 * x + v_2 * permute(x)$$

- Simple Net Decomposition Model

$$v_1 = (e^{i\phi_1^{(l)}} \cos\theta_1^{(l)},\ \cos\theta_1^{(l)},\ e^{i\phi_2^{(l)}} \cos\theta_2^{(l)},\ \cos\theta_2^{(l)}, \ldots)$$
$$v_2 = (-e^{i\phi_1^{(l)}} \sin\theta_1^{(l)},\ \sin\theta_1^{(l)},\ -e^{i\phi_2^{(l)}} \sin\theta_2^{(l)},\ \sin\theta_2^{(l)}, \ldots)$$
$$permute(x) = (x_2, x_1, x_4, x_3, x_6, x_5, \ldots)$$

- Lightweight Decomposition Model

$$v_1 = (e^{i\phi_1^{(l)}} \cos\theta_1^{(l)},\ e^{i\phi_2^{(l)}} \cos\theta_2^{(l)}, \ldots,\ \cos\theta_1^{(l)},\ \cos\theta_2^{(l)}, \ldots)$$
$$v_2 = (-e^{i\phi_1^{(l)}} \sin\theta_1^{(l)},\ -e^{i\phi_2^{(l)}} \sin\theta_2^{(l)}, \ldots,\ \sin\theta_1^{(l)},\ \sin\theta_2^{(l)}, \ldots)$$
$$permute(x) = (x_{N/2} + 1, x_{N/2} + 2, \ldots, x_N, x_1, x_2, \ldots)$$