

# Classification of cancer pathology reports with Deep Learning methods

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# Overview

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  - ICD-O
- 2 Machine Learning
  - Representations
  - Classic models
  - RNN
  - Attention Models
- 3 Scientific questions
- 4 Materials and Methods
  - Datasets
  - Models
- 5 Experiments
  - Bag-of-words VS word vectors, SVM VS deep learning
  - Preliminary attention VS max
  - Attention VS max, hierarchical VS plain
- 6 Conclusions



# Cancer registries

- ✓ **Collect** administrative and clinical data of a specific region
- ✓ **Quantify** the impact of the disease
- ✓ Provide **analytic** data to healthcare operators and decision makers
- ✓ **Manual** classification of reports



# International Classification of Diseases for Oncology (ICD-O-3)

## Topographical

C \_ \_ . \_

- ✓ first two digits **site**
- ✓ third digit **subsite**

E.g. C50.2 upper-inner quadrant (2) of breast (50)

## Morphological

\_ \_ \_ \_ / \_

- ✓ first four digits **cell type**
- ✓ fifth digit **behaviour**

E.g. 8140/3 is an adenocarcinoma (adeno 8140; carcinoma 3)

the dog is on the table

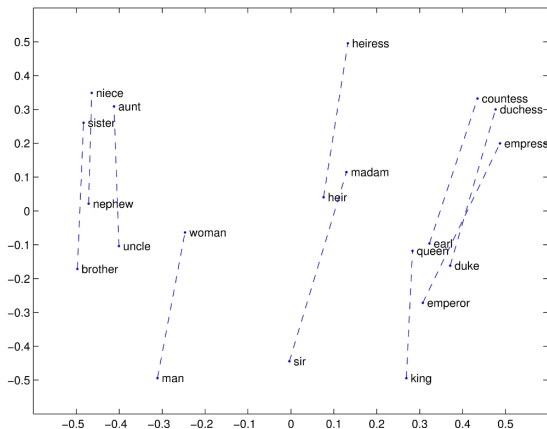
0	0	1	1	0	1	1	1
are	cat	dog	is	now	on	table	the

## Term-Frequency Inverse-Document-Frequency (TF-IDF)

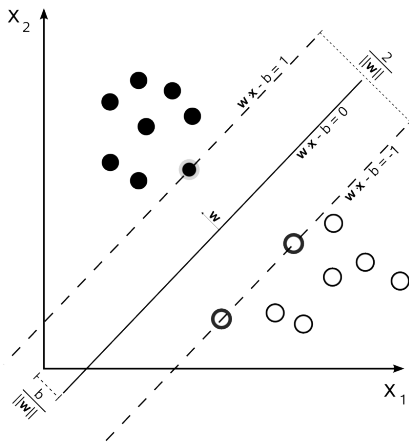
$$w_{i,j} = tf_{i,j} \times \log \left( \frac{N}{df_i} \right)$$

# Word vectors

- ✓ **Transforms** words in vectors
- ✓ **Unsupervised** learning method
- ✓ **Semantic** relations encoded in vector space geometric relations



# Support Vector Machine (SVM)





# Recurrent Neural Network (RNN)

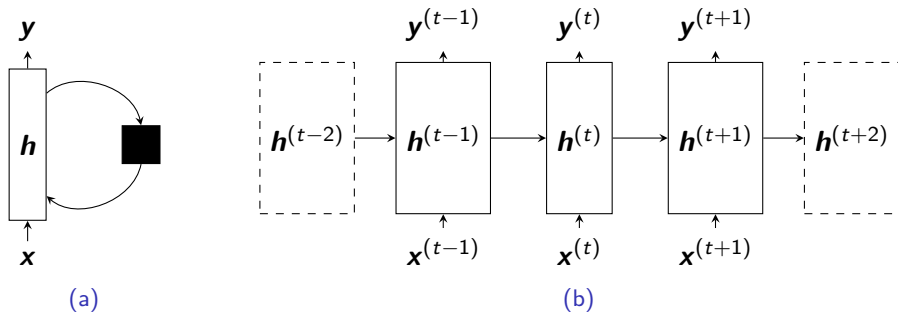
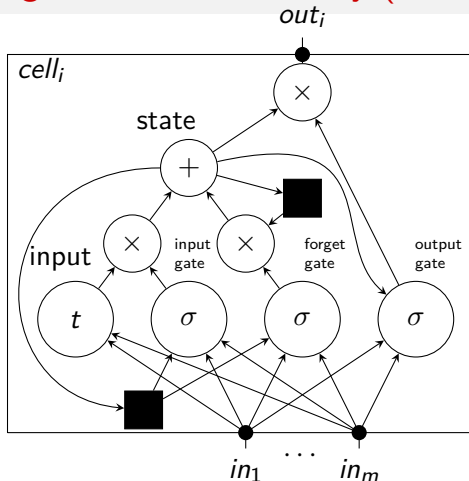


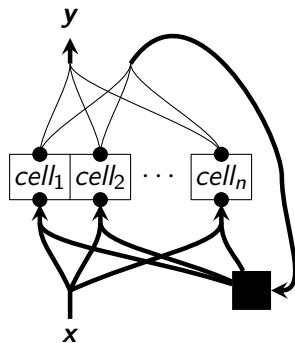
Figure: RNN, folded (a) and unfolded (b) models.

$$h^{(t)} = f(h^{(t-1)}, x^{(t)}; \theta)$$

# Long Short-Term Memory (LSTM)



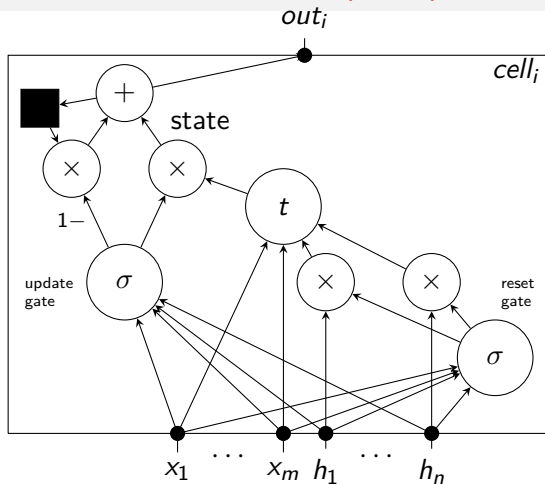
(a)



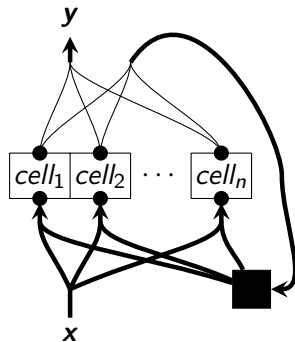
(b)

Figure: memory cell (a), and general scheme (b). The black box is a delay

# Gated Recurrent Unit (GRU)



(a)

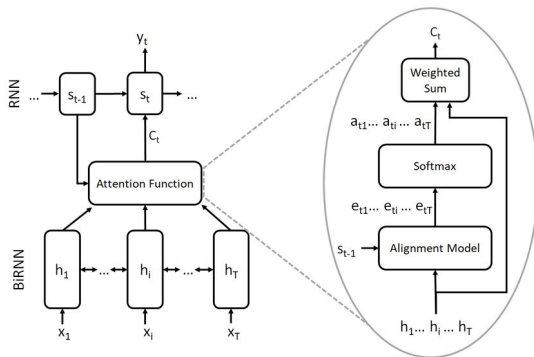


(b)

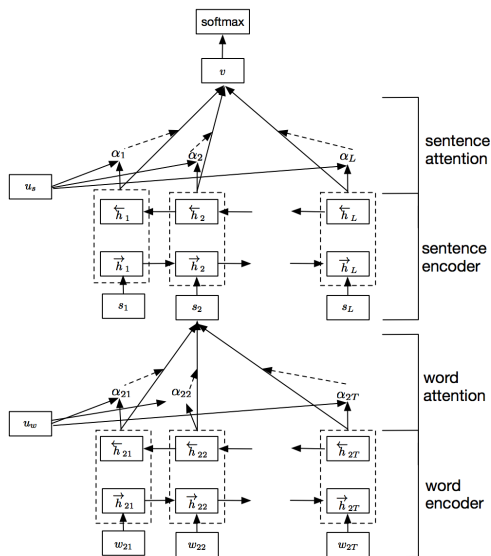
Figure: memory cell (a), and general scheme (b). The black box is a delay

# Attention models

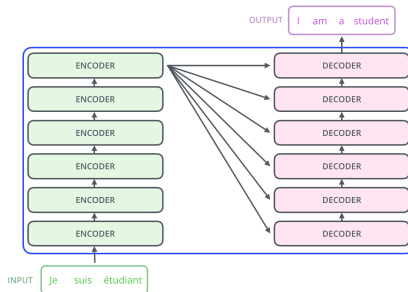
- ✓ Developed for seq-to-seq task
- ✓ State of the art in machine translation



# Hierarchical Attention Network (HAN)



# Bidirectional Encoder Representations from Transformers (BERT)



- ✓ State of the art in many NLP tasks
- ✓ **Attention** based
- ✓ Learn **Context dependent** word representations
- ✓ **Pretrained** on unlabeled data
- ✓ **Fine tuned** to specific task

# Existing works (linear classifiers)

V. Jouhet, G. Defossez, A. Burgun, P. Le Beux, P. Levillain, P. Ingrand, and V. Claveau.

Automated Classification of Free-text Pathology Reports for Registration of Incident Cases of Cancer:.

*Methods of Information in Medicine*, 51(3):242–251, July 2011

- ✓ SVM and Naive Bayes classifiers
- ✓ 5 121 French pathology reports, 26 topographic classes and 18 morphological classes
- ✓ accuracy of 72.6% on topography and 86.4% on morphology

R. Kavuluru, I. Hands, E. B. Durbin, and L. Witt. Automatic extraction of ICD-O-3 primary sites from cancer pathology reports.

In *Clinical Research Informatics AMIA symposium*, 2013

- ✓ SVM, Naive Bayes, and logistic regression
- ✓ 56 426 English reports, 14, 42, and 57 topography classes
- ✓ Micro-averaged F1 measure of 90%

# Existing works (Deep Learning)

J. X. Qiu, H.-J. Yoon, P. A. Fearn, and G. D. Tourassi. Deep Learning for Automated Extraction of Primary Sites From Cancer Pathology Reports.

*IEEE Journal of Biomedical and Health Informatics*, 22(1):244–251, Jan. 2018

- ✓ CNN, word vectors pretrained on PubMed
- ✓ 942 breast and lung cancer English reports, 12 topography classes
- ✓ Micro-averaged F1 score of 72.2% on minimally populated, and 81.1% on well populated classes

S. Gao, M. T. Young, J. X. Qiu, H.-J. Yoon, J. B. Christian, P. A. Fearn, G. D. Tourassi, and A. Ramanathan. Hierarchical attention networks for information extraction from cancer pathology reports.

*Journal of the American Medical Informatics Association*, 25(3):321–330, Mar. 2018

- ✓ RNN with hierarchical attention
- ✓ Same dataset
- ✓ Micro-averaged F1 score of 80%



# New existing work (after thesis)

S. Gao, J. X. Qiu, M. Alawad, J. D. Hinkle, N. Schaefferkoetter, H.-J. Yoon, B. Christian, P. A. Fearn, L. Penberthy, X.-C. Wu, et al. Classifying cancer pathology reports with hierarchical self-attention networks.

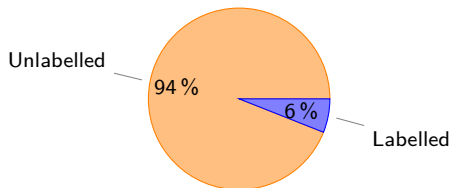
*Artificial Intelligence in Medicine*, 101:101726, 2019

- ✓ RNN with hierarchical self attention
- ✓ 374,899 pathology reports from Louisiana cancer register with
- ✓ 70 labels for site, 7 for laterality, 4 for behavior, 516 for histology and 9 for grade

# Scientific questions

- Q1 Implement **large scale** study on machine learning applied to pathology reports
- Q2 Apply **novel** deep learning techniques, like **attention** models and **BERT**
- Q3 **Compare** classical **bag-of-words** techniques with newer deep learning techniques in this domain
- Q4 **Compare** novel **attention**-based and **hierarchical** techniques with simpler models
- Q5 **Investigate** the contribution and applicability of **unsupervised** learning techniques on uncommon text corpora
- Q6 **Investigate** the possibility to give **interpretation** to deep learning models

# Dataset



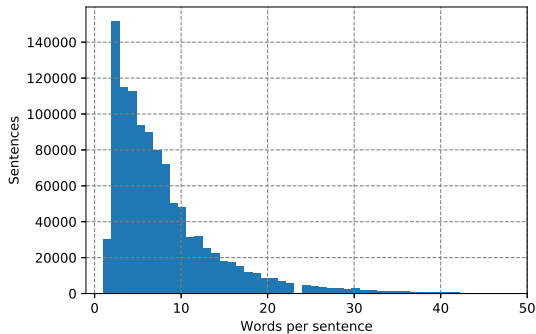
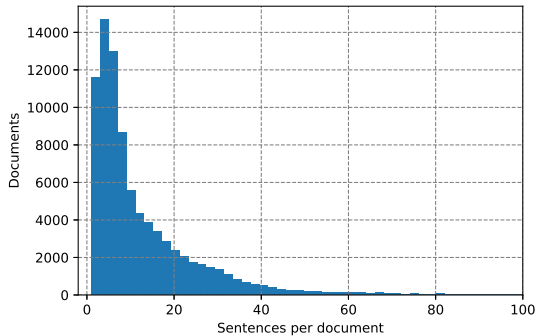
- ✓ 1 592 385 anatomopathological exam results
  - ▶ From Tuscany cancer registry
  - ▶ In period 2004-2013
- ✓ 94 524 (6%) labeled

## Structure

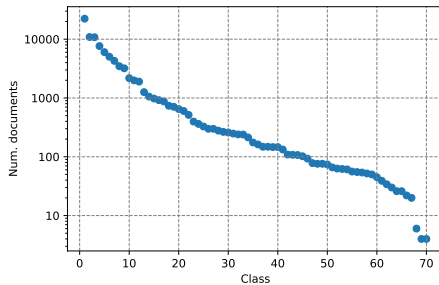
- ✓ 3 text fields: macroscopy, diagnosis, anamnesis
- ✓ field length from 0 to 1368 (quartiles 34, 62, 134)

# Preparation

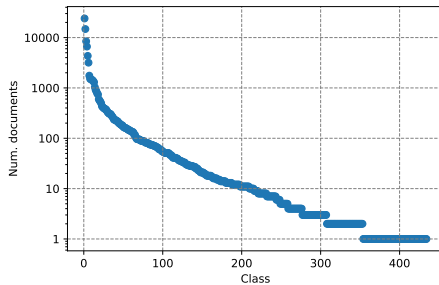
- ✓ Data comes in **two** tables to merge:
  1. neoplasm table, containing administrative and clinical variables
  2. histology table, containing the text fields
    - ▶ there are neoplasms without histology associated
      - ★ (register have access to more data)
    - ▶ there are histologies without neoplasm associated
      - ★ (not tumor biopsies)
- ✓ The 3 text fields are **merged**



## site



## type



# Models

**U-SVM** SVM trained on TF-IDF representations using unigrams

**B-SVM** SVM trained on TF-IDF using unigrams and bigrams

**B-XGB** XGBoost trained on TF-IDF using unigrams and bigrams

**B-LSTM** LSTM trained on TF-IDF using bigrams

**G-CRNN** mixed convolutional and LSTM trained on GloVe

**G-LSTM** LSTM trained on GloVe

**G-GRU** GRU trained on GloVe

**G-ATT** GRU with attention trained on GloVe

**G-ATT<sub>h</sub>** hierarchical GRU with attention trained on GloVe

**BERT** pretrained on unlabeled data and fine tuned with labeled data

**G-MAX** GRU with max pooling trained on GloVe

**G-MAX<sub>h</sub>** hierarchical GRU with max pooling trained on GloVe

**G-MAX<sub>i</sub>** GRU with max pooling, in interpretable setting, trained on GloVe

**G-ATT<sub>i</sub>** GRU with attention, in interpretable setting, trained on GloVe

# B-LSTM, G-CRNN, G-LSTM

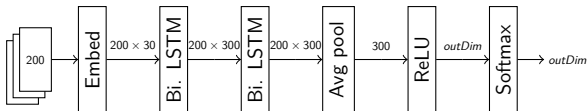


Figure: Scheme for **B-LSTM** model.

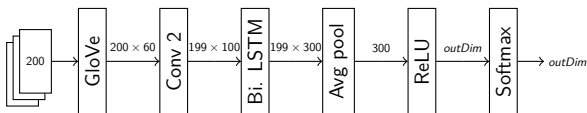


Figure: Scheme for **G-CRNN** model.

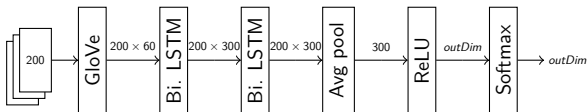


Figure: Scheme for **G-LSTM** model.



## Plain model

$$e_t = E(x_t; \theta^e)$$

$$h_t^f = F(e_t, h_{t-1}^f; \theta^f)$$

$$h_t^r = R(e_t, h_{t+1}^r; \theta^r)$$

$$u_t = G(h_t; \theta^h)$$

$$\phi = A(\mathbf{u}; \theta^a)$$

$$f(\mathbf{x}) = g(\phi; \theta^c)$$

- ✓  $\phi = (h_T^f, h_1^r)$  (in this case  $G$  is the identity function)
- ✓  $\phi = \sum_t a_t(\mathbf{u}; \theta^a) u_t$ ,  $a_t(\mathbf{u}; \theta^a) = \frac{e^{\langle c, c_t \rangle}}{\sum_i e^{\langle c, c_i \rangle}}$ ,  $c_t = C(\mathbf{u}; \theta^a)$
- ✓  $\phi_j = \max_t u_{j,t}$

## Interpretable model

$$e_t = E(x_t; \theta^e)$$

$$h_t^f = F(e_t, h_{t-1}^f; \theta^f)$$

$$h_t^r = R(e_t, h_{t+1}^r; \theta^r)$$

$$u_t = G(h_t; \theta^h)$$

$$f(\mathbf{x}) = A(\mathbf{u}; \theta^a)$$

$$\checkmark \quad \phi = \sum_t a_t(\mathbf{u}; \theta^a) u_t, \quad a_t(\mathbf{u}; \theta^a) = \frac{e^{\langle c, c_t \rangle}}{\sum_i e^{\langle c, c_i \rangle}}, \quad c_t = C(\mathbf{u}; \theta^a)$$

$$\checkmark \quad \phi_j = \max_t u_{j,t}$$

## Hierarchical model

$$e_{s,t} = E(x_{s,t}; \theta^e)$$

$$h_{s,t}^f = F(e_{s,t}, h_{s,t-1}^f; \theta^f)$$

$$h_{s,t}^r = R(e_{s,t}, h_{s,t+1}^r; \theta^r)$$

$$u_{s,t} = G(h_{s,t}; \theta^h)$$

$$\phi_s = A(\mathbf{u}_s; \theta^a)$$

$$\bar{h}_s^f = \bar{F}(\phi_s, \bar{h}_{s-1}^f; \bar{\theta}^f)$$

$$\bar{h}_s^r = \bar{R}(\phi_s, \bar{h}_{s+1}^r; \bar{\theta}^r)$$

$$\bar{\phi} = \bar{A}(\bar{\mathbf{h}}; \bar{\theta}^a)$$

$$f(\mathbf{x}) = g(\bar{\phi}; \theta^c)$$

# Bag-of-words VS word vectors, SVM VS deep learning

## Answered questions

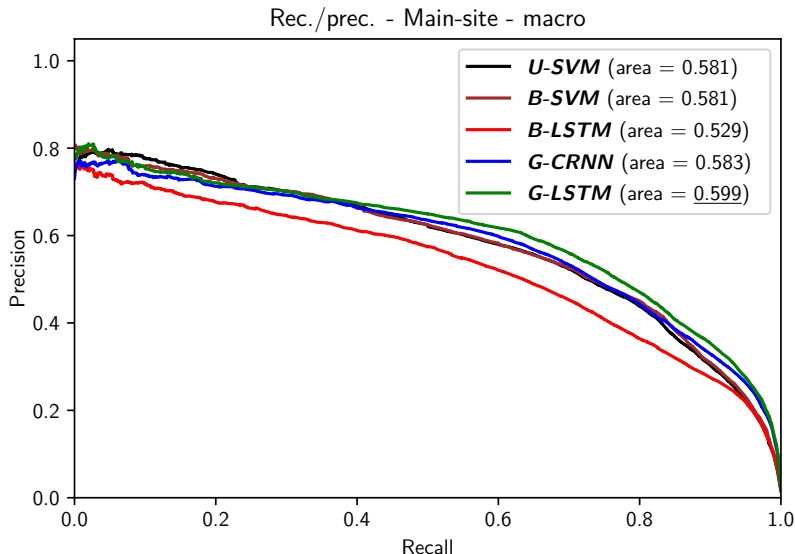
- Q1 Implement **large scale** study on deep learning applied to pathology reports
  - Q3 **Compare** classical **bag-of-words** techniques with newer deep learning techniques in this domain
  - Q5 **Investigate** the contribution and applicability of **unsupervised** learning techniques on uncommon text corpora
- 
- ✓ **10-fold** cross validation
  - ✓ All tasks (**main** site, **site+subsite**, **type**, **behavior**)

# Bag-of-words VS word vectors, SVM VS deep learning

Figure: Results for Main-site task.

		<i>U-SVM</i>	<i>B-SVM</i>	<i>B-LSTM</i>	<i>G-CRNN</i>	<i>G-LSTM</i>
accuracy		$89.8 \pm 2.0$	$89.8 \pm 2.0$	$88.6 \pm 2.0$	$90.0 \pm 1.6$	<u><math>90.5 \pm 1.6</math></u>
kappa		$88.5 \pm 2.2$	$88.6 \pm 2.3$	$87.2 \pm 2.3$	$88.9 \pm 1.8$	<u><math>89.3 \pm 1.8</math></u>
MAPs		$93.0 \pm 1.5$	$93.0 \pm 1.5$	$92.2 \pm 1.5$	$93.5 \pm 1.2$	<u><math>93.8 \pm 1.1</math></u>
MAPc		$61.6 \pm 3.9$	$61.3 \pm 4.0$	$55.7 \pm 3.7$	$62.7 \pm 3.5$	<u><math>64.1 \pm 4.1</math></u>
pre.	ma.	<u><math>65.5 \pm 4.8</math></u>	$64.7 \pm 3.2$	$55.0 \pm 2.8$	$61.5 \pm 3.4$	$61.8 \pm 3.7$
	we.	$88.7 \pm 2.0$	$88.8 \pm 2.0$	$87.8 \pm 1.8$	$89.2 \pm 1.6$	<u><math>89.5 \pm 1.7</math></u>
rec.	ma.	$55.7 \pm 4.1$	$54.7 \pm 3.8$	$51.6 \pm 3.2$	$56.5 \pm 3.0$	<u><math>58.1 \pm 3.5</math></u>
	we.	$89.8 \pm 2.0$	$89.8 \pm 2.0$	$88.6 \pm 2.0$	$90.0 \pm 1.6$	<u><math>90.5 \pm 1.6</math></u>
f1s.	ma.	<u><math>58.4 \pm 4.1</math></u>	$57.5 \pm 3.6$	$52.1 \pm 3.1$	$57.0 \pm 2.7$	$58.2 \pm 3.3$
	we.	$88.9 \pm 2.0$	$89.0 \pm 2.1$	$88.0 \pm 2.0$	$89.3 \pm 1.6$	<u><math>89.7 \pm 1.7</math></u>

# Bag-of-words VS word vectors, SVM VS deep learning



# Preliminary attention VS max

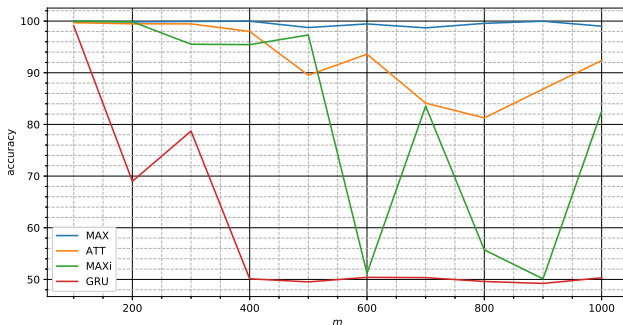
## Answered questions

Q4 Compare novel attention model with simpler max pooling

Q6 Investigate the possibility to give interpretation to deep learning models

- ✓ Artificial dataset
- ✓ Same-size models

# Preliminary attention VS max



0	9	2	1	8	4	2	8	9	1	4	6	8	8	6	6	8	7	3	0	2	5	9	7	9	5	8	2	4	9	5	5	6	5	1	7	6	3	2	2	2
①	3	①	2	5	0	8	9	5	4	0	3	2	3	0	6	0	0	8	6	7	9	1	6	4	0	5	7	0	6	4	6	0	6	1	5	4	3	2	5	2
6	7	4	2	5	2	5	8	9	9	5	7	6	5	4	2	7	9																							
5	3	6	9	0	9	1	8	0	1	5	4	5	0	4	7	1	6	2	3	2	9	2	6	8	8	2	6	1	1	2	3	6	3	6	4	4	6	6	8	9
9	3	5	6	4	2	4	7	0	3	3	8	5	5	4	6	9	2	3	2	9	5	5	3	5	7	8	0	4	7	1	3	6	6	3	8	8	8	8	6	9
6	0	6	④	0	①	5	4	9	5	5	5	9	7	6	5	8	4																							



# Attention VS max, hierarchical VS plain

## Answered questions

- Q1 Implement **large scale** study on deep learning applied to pathology reports
- Q2 Apply **novel** deep learning techniques, like **attention** models and **BERT**
- Q3 **Compare** classical **bag-of-words** techniques with newer deep learning techniques in this domain
- Q4 **Compare** novel **attention**-based and **hierarchical** techniques with simpler models
- Q6 **Investigate** the possibility to give **interpretation** to deep learning models

- ✓ **Temporal** setting
- ✓ On **main site** and **type** tasks
- ✓ Different **difficulty** classes

# Attention VS max, hierarchical VS plain

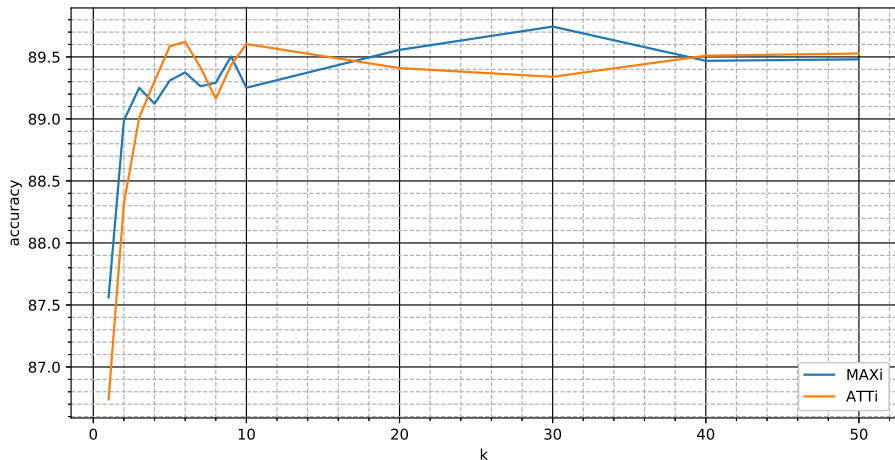
	Topography				Morphology			
	Acc.	Top 3	Top 5	MacroF1	Acc.	Top 3	Top 5	Macro F1
<i>U-SVM</i>	89.7	95.9	96.8	60.0	82.4	94.0	95.6	53.7
<i>B-XGB</i>	89.1	95.8	97.2	58.0	84.1	94.4	96.5	59.6
<i>G-GRU</i>	89.9	96.5	97.7	58.3	83.3	94.6	96.6	55.2
<i>BERT</i>	89.9	96.3	97.8	56.6	84.3	93.2	94.9	51.1
<i>G-MAXi</i>	88.0	95.4	96.2	46.1	73.4	91.0	93.6	31.3
<i>G-MAXh</i>	89.9	96.2	97.8	58.8	83.7	94.4	96.4	54.5
<i>G-ATTTh</i>	89.9	96.3	97.7	58.0	83.7	94.4	96.2	57.5
<i>G-MAX</i>	<b>90.3</b>	<b>96.6</b>	<b>98.1</b>	<b>61.9</b>	84.6	<b>95.0</b>	<b>96.9</b>	59.2
<i>G-ATT</i>	90.1	96.2	97.6	60.0	<b>84.8</b>	94.9	<b>96.9</b>	<b>61.3</b>

	Topography			Morphology		
	easy ( $1000 < s$ ) (4 cls)	avg. ( $100 < s \leq 1000$ ) (18 cls)	hard ( $s \leq 100$ ) (39 cls)	easy ( $1000 < s$ ) (5 cls)	avg. ( $100 < s \leq 1000$ ) (18 cls)	hard ( $s \leq 100$ ) (111 cls)
<i>U-SVM</i>	95.7	<b>86.9</b>	50.9	90.5	68.6	48.4
<i>B-XGB</i>	95.6	86.4	48.2	92.0	72.4	54.8
<i>G-GRU</i>	<b>96.1</b>	72.2	48.0	91.4	71.6	49.7
<i>BERT</i>	95.7	73.2	44.9	<b>92.9</b>	<b>74.4</b>	43.9
<i>G-MAXi</i>	95.0	66.6	31.4	87.1	41.9	25.1
<i>G-MAXh</i>	95.8	72.4	48.8	92.7	71.8	48.8
<i>G-ATTTh</i>	96.0	73.1	47.1	91.9	72.3	52.6
<i>G-MAX</i>	96.0	73.3	<b>53.1</b>	92.7	72.3	53.8
<i>G-ATT</i>	96.0	73.1	50.3	92.8	72.3	<b>56.7</b>

# Interpretability

$y_i$	Relevant $h_{i,j}$	$x_{i,j}$ ; relevant $h_{i,j}$
61	<u>61</u> (PROSTATE GLAND)	DISOMOGENICITA' DIFFUSE . <u>PSA NON PERVENUTO</u> . ADENOCARCINOMA PROSTATICO A GRADO DI DIFFERENZIAZIONE MEDIO - BASSO ( <u>GLEASON 3 + 4</u> ) NEI PRELIEVI DI CUI AI NN . 2 E 3 . AGOBIOPSIA DELLA <u>PROSTATA : 1</u> ) 1 PRELIEVO LL DX . 2 ) 2 PRELIEVI ML DX . 3 ) 2 PRELIEVI M DX . 4 ) 1 PRELIEVO M SX . 5 ) 2 PRELIEVI ML SX . 6 ) 1 PRELIEVO LL SX . 7 ) 1 PRELIEVO <u>TRANSIZIONALE SX . 8</u> ) 1 PRELIEVO <u>TRANSIZIONALE DX</u> .
20	<u>18</u> (COLON) <u>20</u> (RECTUM) <u>21</u> (ANUS AND ANAL CANAL)	ISOLATI FRAMMENTI RIFERIBILI AD ADENOMA <u>TUBULARE INTESTINALE</u> DI ALTO GRADO . FRAMMENTI ( NR . 2 ) DI <u>POLIPO PEDUNCOLATO</u> A 20 CM <u>DALL'</u> ORIFIZIO ANALE . ( ESEGUITA COLORAZIONE EMATOSSILINA - EOSINA ) . <u>-</u>
34	<u>34</u> (BRONCHUS AND LUNG) <u>56</u> (OVARY) <u>67</u> (BLADDER) <u>80</u> (UNKNOWN PRIMARY SITE)	VERSAMENTO PLEURICO SX DI N . D . D . E ADDENSAMENTI POLMONARI DI N . D . D . , NODULI PARETE ADDOMINALE . INFILTRAZIONE <u>CANCERIGNA</u> DEGLI <u>STROMI CONNETTIVO - ADIPOS</u> . IMMUNOISTOCHEMICA : CK7 + , CK20 - , TTF - 1 - , <u>PROTEINA S - 100</u> - . LESIONE DI CM 2 , 0 X 1 , 3 X 0 , 7 . 1 - 2 ) <u>SEZIONI</u> <u>SERIE</u> . <u>-</u>

# Interpretability



**Figure:** Training of a plain GRU model on a dataset created using ***G-MAXi*** and ***G-ATTi*** to keep the first  $k$  words

# Conclusions

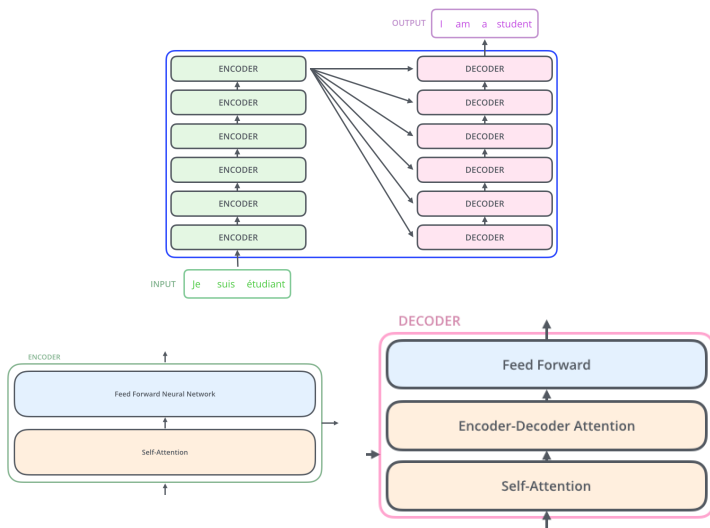
- ✓ We effectively implemented a **large scale** study on classical machine learning and novel deep learning methods applied to pathology reports
- ✓ In this context, **bag-of-words** techniques are not considerably worse than **deep learning**
- ✓ **Hierarchical** model are not beneficial
- ✓ **Attention** models are almost equivalent to a simpler element-wise **max** pooling model
- ✓ **Word vectors** can be effectively employed
- ✓ We can implement **interpretable** models without catastrophic loss

*The End.*

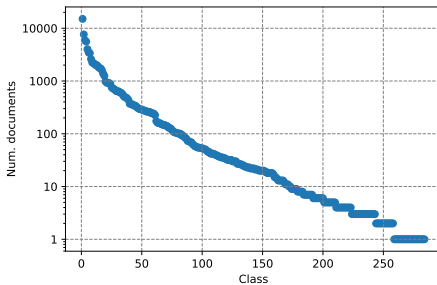


*Questions? Thank you!*

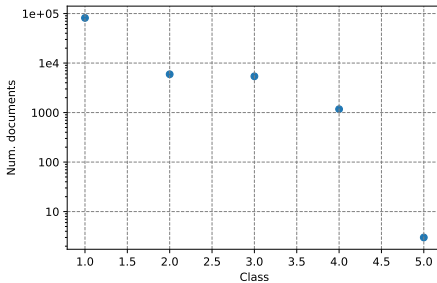
# Bidirectional Encoder Representations from Transformers (BERT)



## site+subsite



## behavior



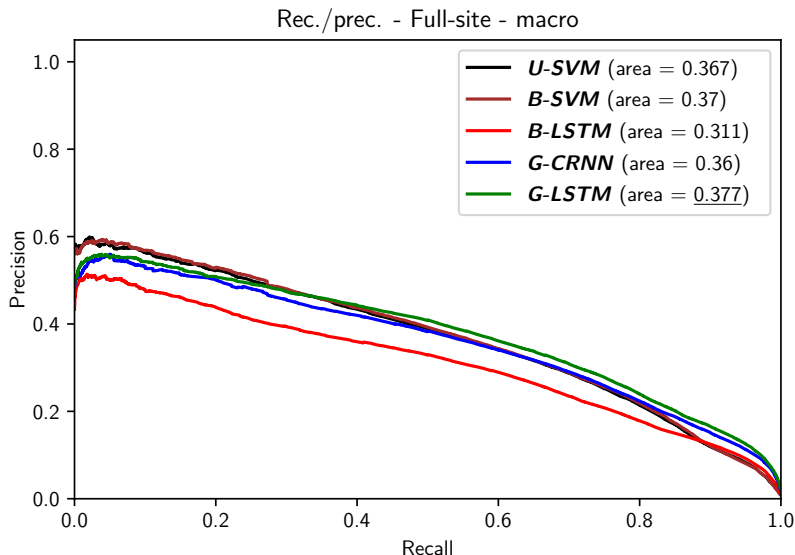


# Bag-of-words VS word vectors, SVM VS deep learning

Figure: Results for Full-site task.

		<i>U-SVM</i>	<i>B-SVM</i>	<i>B-LSTM</i>	<i>G-CRNN</i>	<i>G-LSTM</i>
accuracy		$68.4 \pm 2.3$	$68.7 \pm 2.0$	$67.4 \pm 1.7$	$70.1 \pm 2.1$	<u><math>70.9 \pm 2.0</math></u>
kappa		$66.5 \pm 2.4$	$66.8 \pm 2.1$	$65.6 \pm 1.7$	$68.4 \pm 2.2$	<u><math>69.3 \pm 2.1</math></u>
MAPs		$78.4 \pm 1.9$	$78.4 \pm 1.7$	$78.5 \pm 1.3$	$80.6 \pm 1.4$	<u><math>81.3 \pm 1.4</math></u>
MAPc		$43.1 \pm 2.2$	$43.4 \pm 2.2$	$36.8 \pm 2.3$	$42.9 \pm 2.6$	<u><math>45.0 \pm 2.0</math></u>
pre.	ma.	$41.4 \pm 1.6$	<u><math>41.6 \pm 1.5</math></u>	$33.0 \pm 2.8$	$38.7 \pm 3.1$	$39.8 \pm 2.3$
	we.	$66.3 \pm 1.9$	$67.1 \pm 1.7$	$66.1 \pm 1.3$	$68.8 \pm 1.9$	<u><math>69.5 \pm 1.5</math></u>
rec.	ma.	$35.7 \pm 1.9$	$35.1 \pm 2.1$	$32.0 \pm 2.5$	$36.6 \pm 3.0$	<u><math>38.0 \pm 2.2</math></u>
	we.	$68.4 \pm 2.3$	$68.7 \pm 2.0$	$67.4 \pm 1.7$	$70.1 \pm 2.1$	<u><math>70.9 \pm 2.0</math></u>
f1s.	ma.	$36.6 \pm 1.5$	$36.4 \pm 1.7$	$31.2 \pm 2.3$	$35.9 \pm 2.9$	<u><math>37.3 \pm 2.1</math></u>
	we.	$66.2 \pm 2.1$	$66.8 \pm 1.8$	$66.0 \pm 1.3$	$68.5 \pm 2.0$	<u><math>69.5 \pm 1.8</math></u>

# Bag-of-words VS word vectors, SVM VS deep learning

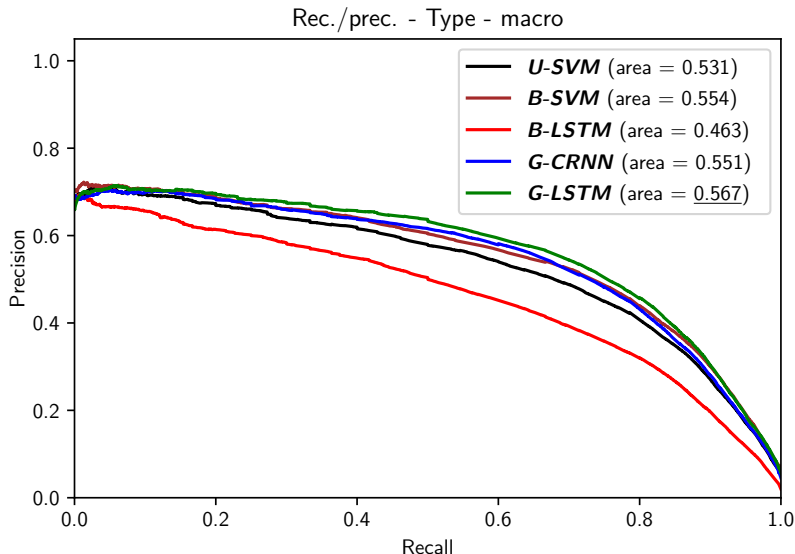


# Bag-of-words VS word vectors, SVM VS deep learning

Figure: Results for Type task.

		<i><b>U-SVM</b></i>	<i><b>B-SVM</b></i>	<i><b>B-LSTM</b></i>	<i><b>G-CRNN</b></i>	<i><b>G-LSTM</b></i>
<b>accuracy</b>		$81.9 \pm 1.9$	$82.9 \pm 2.0$	$82.8 \pm 1.4$	$84.6 \pm 1.4$	<u><math>84.9 \pm 1.5</math></u>
<b>kappa</b>		$79.5 \pm 2.2$	$80.7 \pm 2.3$	$80.6 \pm 1.6$	$82.7 \pm 1.6$	<u><math>83.0 \pm 1.7</math></u>
<b>MAPs</b>		$87.8 \pm 1.3$	$88.6 \pm 1.4$	$88.7 \pm 1.0$	$90.3 \pm 0.9$	<u><math>90.6 \pm 1.0</math></u>
<b>MAPc</b>		$62.4 \pm 1.6$	$64.4 \pm 1.8$	$55.1 \pm 3.1$	$64.2 \pm 1.9$	<u><math>65.9 \pm 1.9</math></u>
<b>pre.</b>	<b>ma.</b>	$56.1 \pm 2.4$	<u><math>58.3 \pm 1.9</math></u>	$47.0 \pm 3.3$	$56.5 \pm 1.8$	$57.0 \pm 2.6$
	<b>we.</b>	$80.3 \pm 1.8$	$81.8 \pm 1.9$	$82.0 \pm 1.3$	$84.1 \pm 1.3$	<u><math>84.3 \pm 1.5</math></u>
<b>rec.</b>	<b>ma.</b>	$51.1 \pm 2.6$	$52.2 \pm 2.2$	$47.0 \pm 2.6$	$56.8 \pm 2.2$	<u><math>58.6 \pm 2.0</math></u>
	<b>we.</b>	$81.9 \pm 1.9$	$82.9 \pm 2.0$	$82.8 \pm 1.4$	$84.6 \pm 1.4$	<u><math>84.9 \pm 1.5</math></u>
<b>f1s.</b>	<b>ma.</b>	$51.4 \pm 2.5$	$52.9 \pm 1.9$	$45.0 \pm 2.9$	$54.6 \pm 1.9$	<u><math>55.5 \pm 2.3</math></u>
	<b>we.</b>	$80.4 \pm 2.0$	$81.7 \pm 2.0$	$81.9 \pm 1.3$	$83.8 \pm 1.4$	<u><math>84.0 \pm 1.5</math></u>

# Bag-of-words VS word vectors, SVM VS deep learning

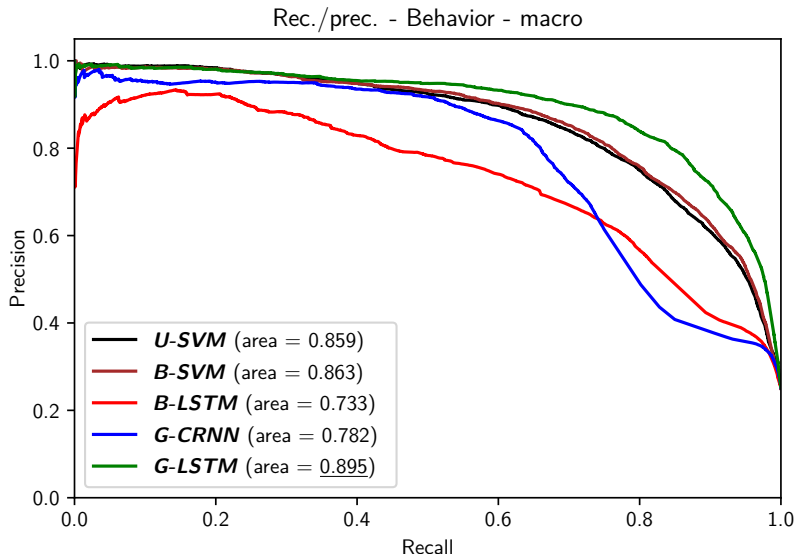


# Bag-of-words VS word vectors, SVM VS deep learning

Figure: Results for Behavior task.

		<i>U-SVM</i>	<i>B-SVM</i>	<i>B-LSTM</i>	<i>G-CRNN</i>	<i>G-LSTM</i>
accuracy		95.9 $\pm$ 1.0	96.0 $\pm$ 1.1	94.1 $\pm$ 3.0	94.4 $\pm$ 4.2	<u>96.5</u> $\pm$ 0.8
kappa		82.3 $\pm$ 4.6	82.8 $\pm$ 5.0	70.4 $\pm$ 25.5	67.6 $\pm$ 35.9	<u>85.6</u> $\pm$ 3.4
MAPs		97.7 $\pm$ 0.6	97.8 $\pm$ 0.6	96.6 $\pm$ 1.8	96.8 $\pm$ 2.5	<u>98.1</u> $\pm$ 0.5
MAPc		85.4 $\pm$ 5.9	85.9 $\pm$ 5.7	71.4 $\pm$ 18.4	75.5 $\pm$ 26.4	<u>89.5</u> $\pm$ 4.2
pre.	ma.	87.0 $\pm$ 5.0	<u>87.9</u> $\pm$ 4.8	69.9 $\pm$ 19.9	72.7 $\pm$ 27.1	85.5 $\pm$ 4.0
	we.	95.8 $\pm$ 1.1	95.9 $\pm$ 1.2	92.6 $\pm$ 6.4	92.1 $\pm$ 9.0	<u>96.6</u> $\pm$ 0.8
rec.	ma.	78.6 $\pm$ 7.3	78.6 $\pm$ 7.4	67.6 $\pm$ 17.4	72.1 $\pm$ 25.4	<u>85.9</u> $\pm$ 4.9
	we.	95.9 $\pm$ 1.0	96.0 $\pm$ 1.1	94.1 $\pm$ 3.0	94.4 $\pm$ 4.2	<u>96.5</u> $\pm$ 0.8
f1s.	ma.	81.7 $\pm$ 6.3	82.0 $\pm$ 6.3	68.0 $\pm$ 18.5	72.1 $\pm$ 26.0	<u>85.5</u> $\pm$ 4.2
	we.	95.8 $\pm$ 1.1	95.9 $\pm$ 1.2	93.2 $\pm$ 4.8	93.1 $\pm$ 6.7	<u>96.5</u> $\pm$ 0.8

# Bag-of-words VS word vectors, SVM VS deep learning



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