Numeracy for Language Models:

Evaluating and Improving their Ability to Predict Numbers

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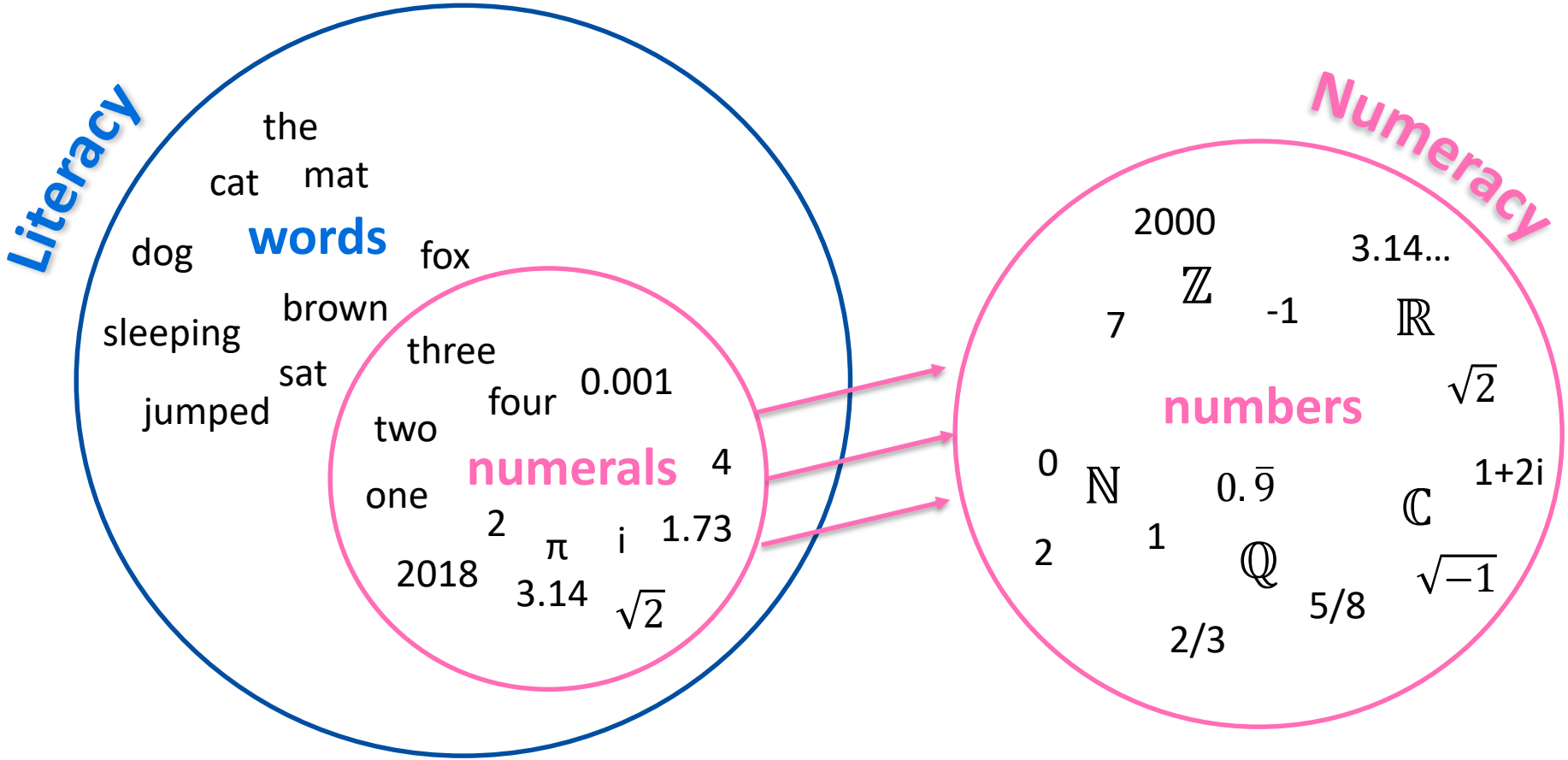
Machine Reading Group

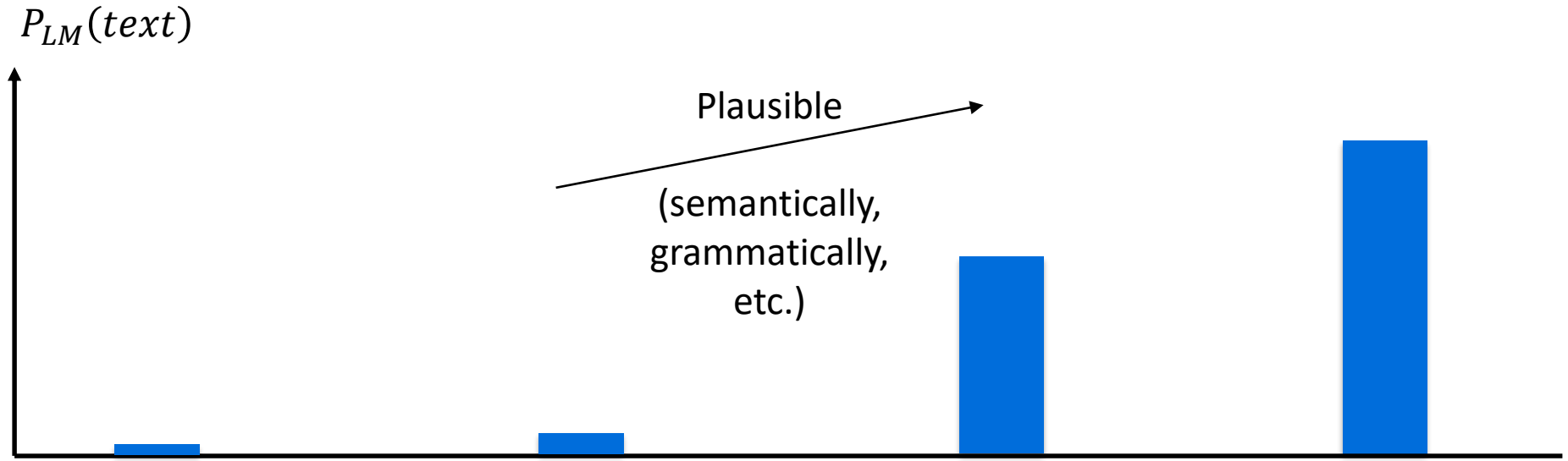
UCL

Farr The Farr Institute of Health Informatics Research

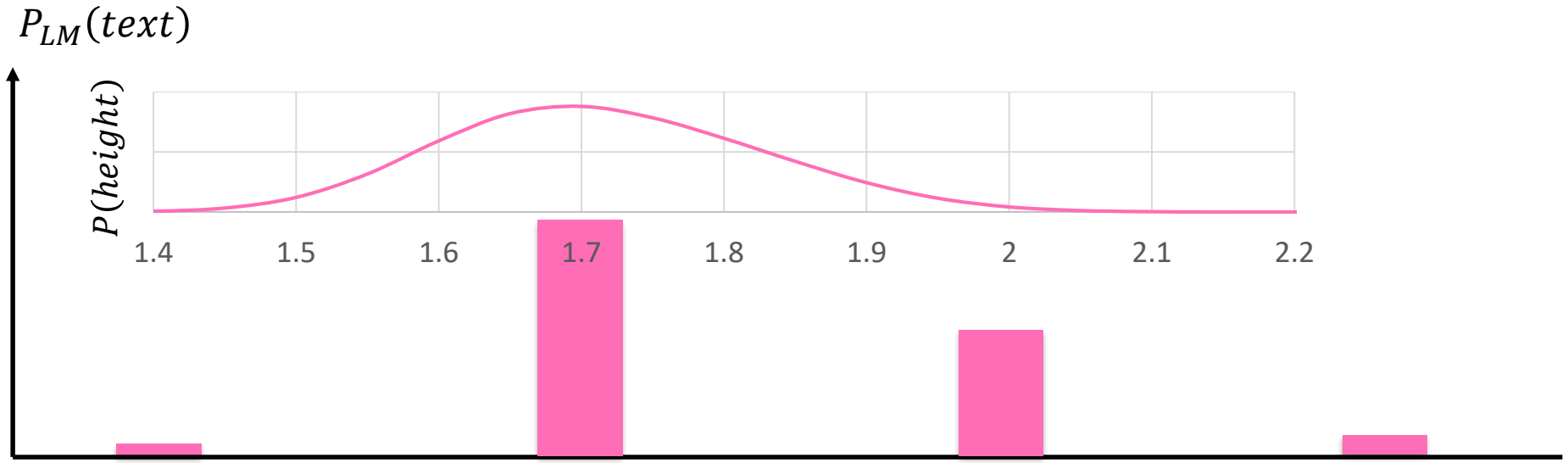
Numeracy


Literacy
the
cat
mat
words
dog
fox
sleeping
brown
sat
jumped
three
four
0.001
two
numerals
4
one
2
π
i
1.73
2018
3.14
$\sqrt{2}$
Numeracy
2000
3.14…
$\mathbb{Z}$
7
-1
$\mathbb{R}$
$\sqrt{2}$
numbers
0
$\mathbb{N}$
$0.\bar{9}$
1+2i
$\mathbb{C}$
2
1
$\mathbb{Q}$
$\sqrt{-1}$
5/8
2/3

Literate Language Models



Numerate Language Models



‘John is **0** m tall’ ‘John is **1.7** m tall’ ‘John is **2** m tall’ ‘John is **999** m tall’

Numeracy Matters

0.5
‘Unemployment of the US is 5 %’
50
500

0.0
23.2
‘Patient’s temperature is 36.6 degrees’
41.9
98.6

0
‘Our model is 10 times better than the baseline’
100
1000

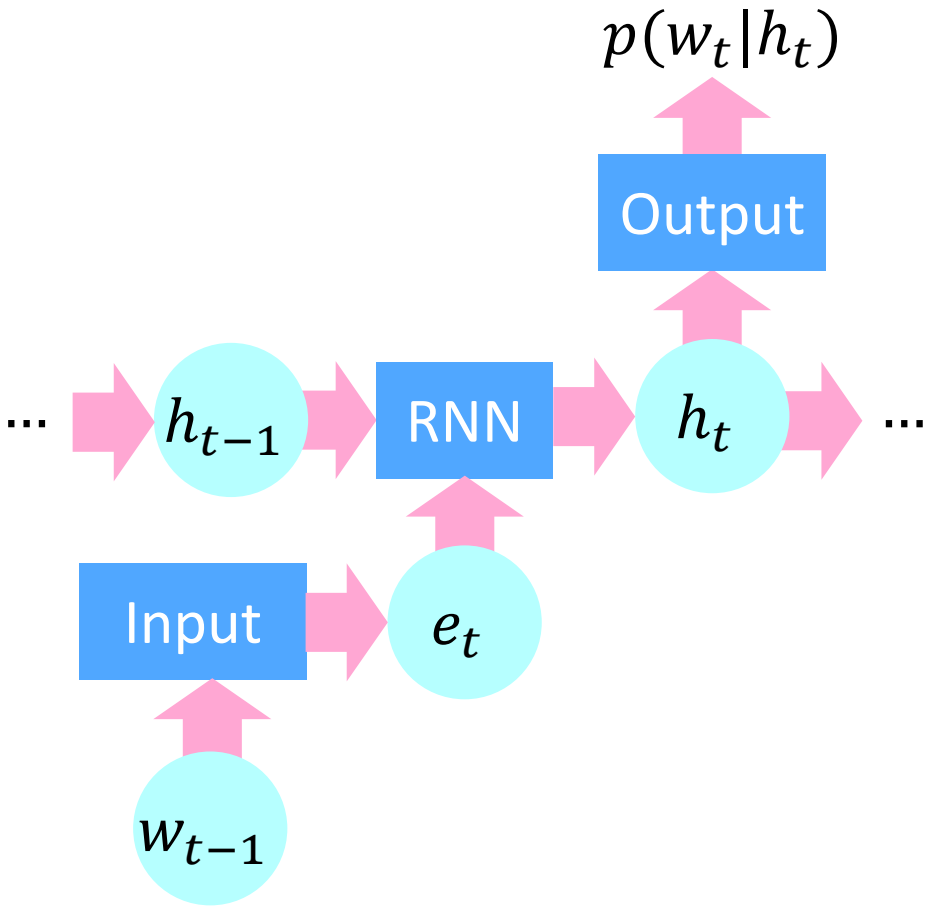
Q1: Are existing LMs numerate?

Q2: How to improve the numeracy of LMs?

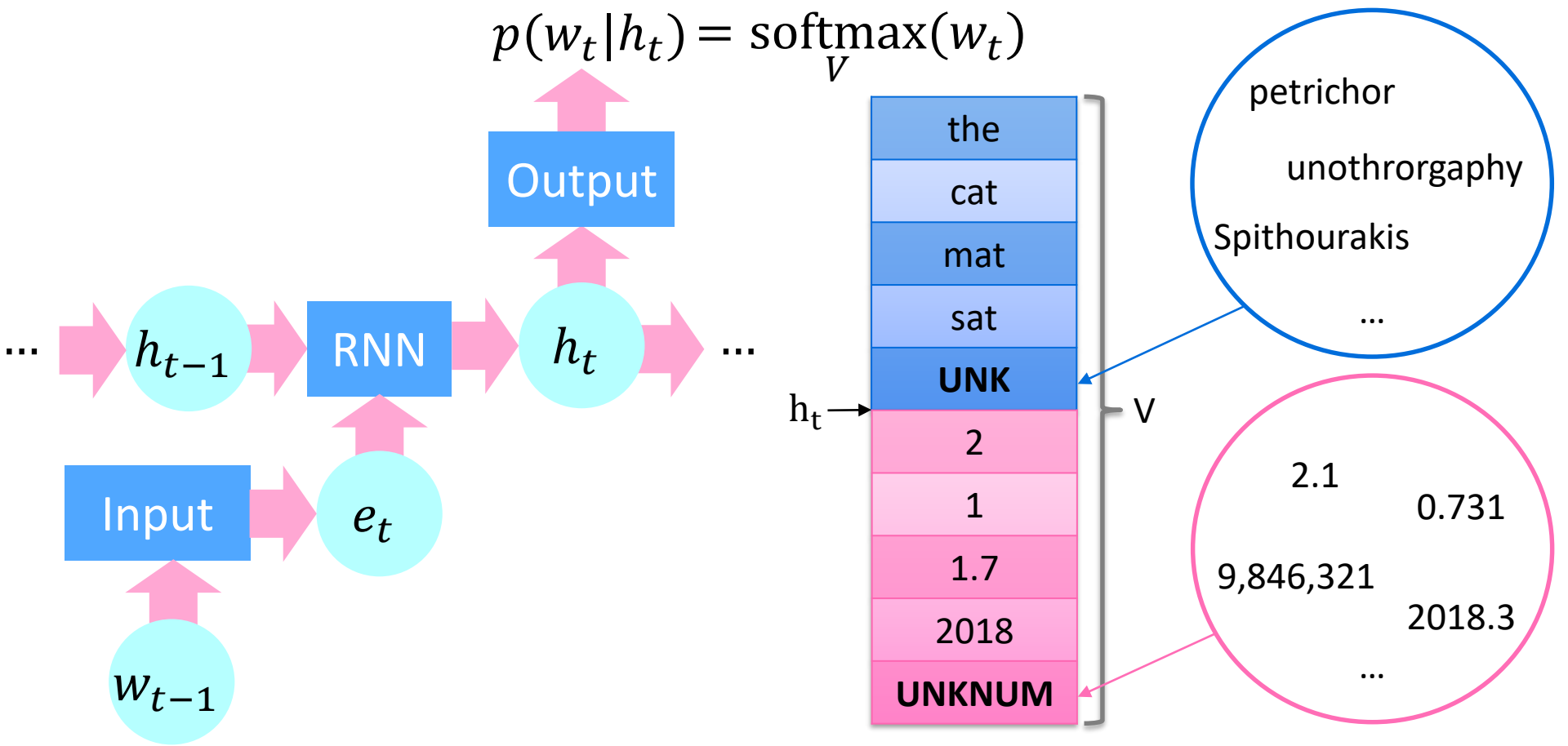
Q1: Are existing LMs numerate?

Q2: How to improve the numeracy of LMs?

A Neural Language Model



A Neural Language Model



Evaluation: Adjusted Perplexity

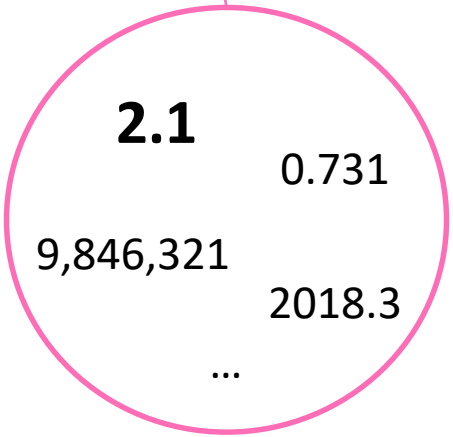
Perplexity

John is **2.1** m tall

$p(2.1) = p($ UNKNUM $)$

BUT

$+$
$p(0.731)$
$+$
$p(9{,}846{,}321)$
$+$
$\vdots$



Evaluation: Adjusted Perplexity

Perplexity

John is **2.1** m tall

$$p(2.1) = p(\ \text{UNKNUM}\ )$$

BUT

$$+\ p(0.731) + p(9{,}846{,}321) + \vdots$$

2.1

0.731

9,846,321

2018.3

…

Adjusted Perplexity [Ueberla, 1994]

$$p(2.1) = \frac{p(\ \text{UNKNUM}\ )}{|w \in \text{UNKNUM}|}$$

from test data

a.k.a. Unknown-Penalised Perplexity

[Ahn et al., 2016]

Datasets

Clinical Dataset

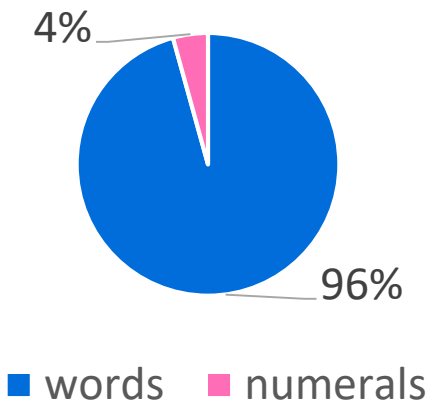
16,015 clinical patient reports

Source: London Chest Hospital

Scientific Dataset

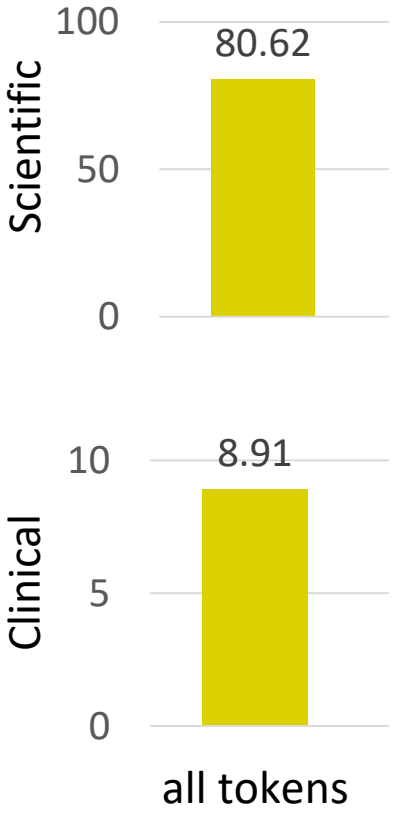
20,962 paragraphs
from scientific papers

Source: ARXIV



Results: Adjusted Perplexity

(Lower is better)



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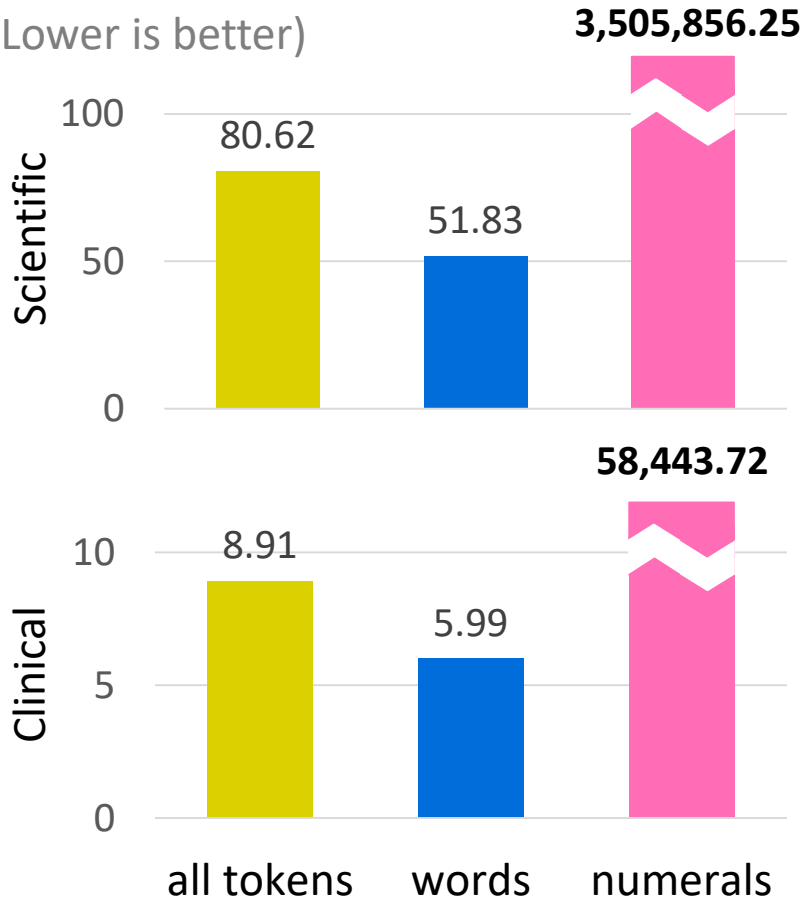

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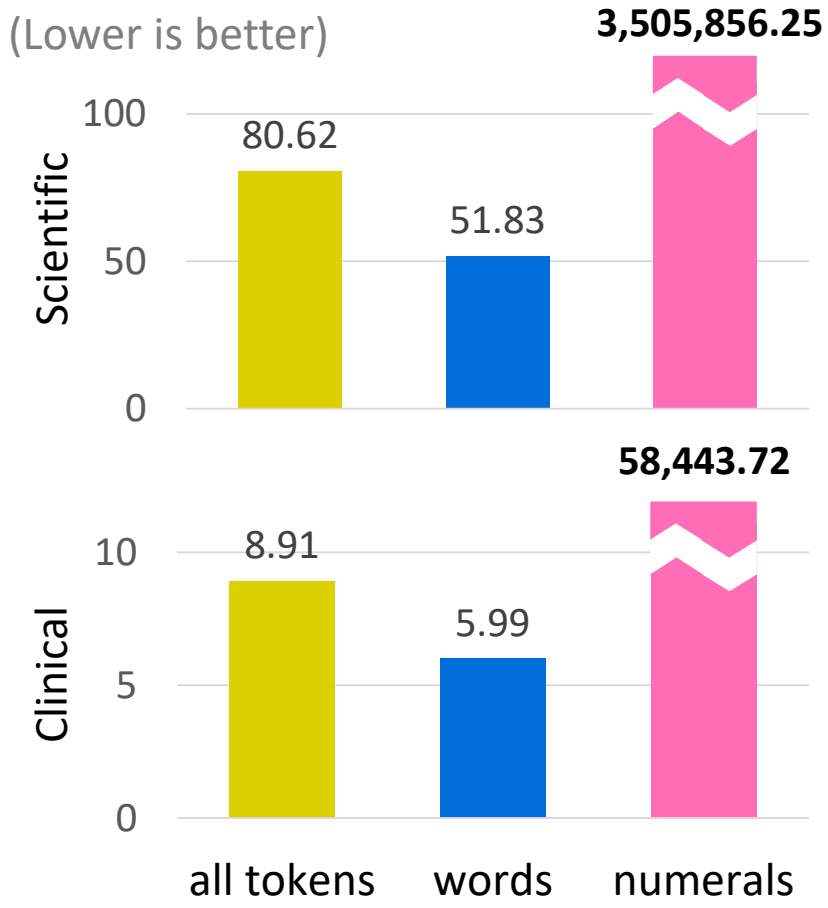
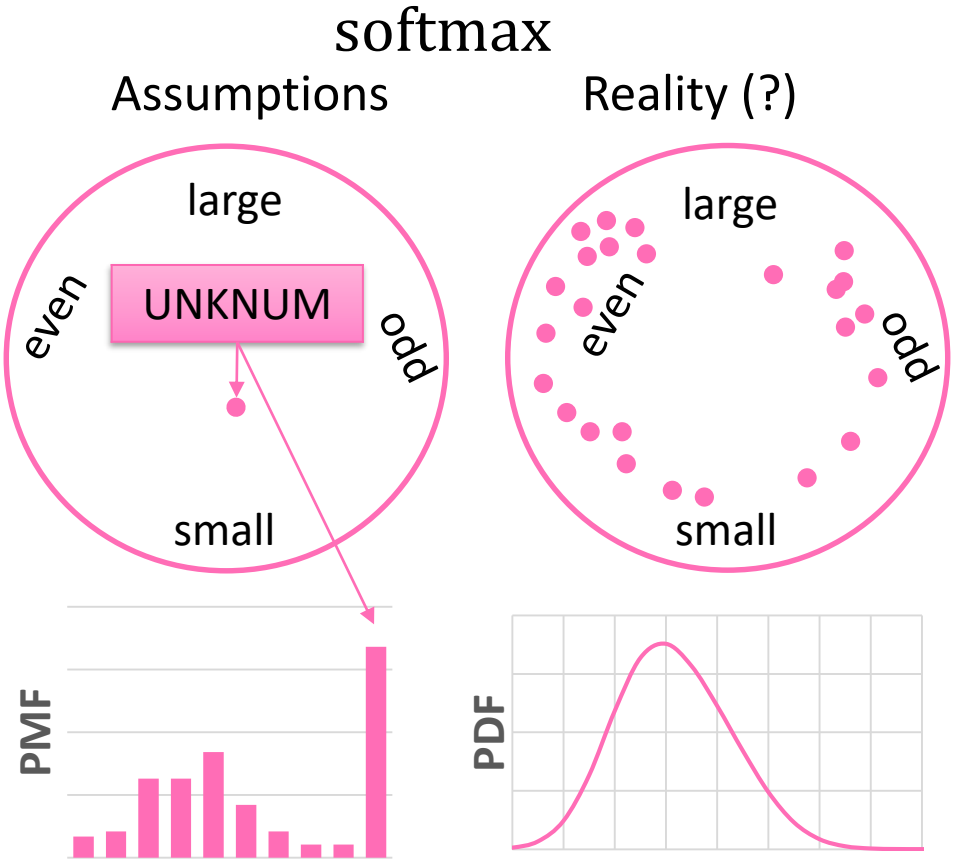
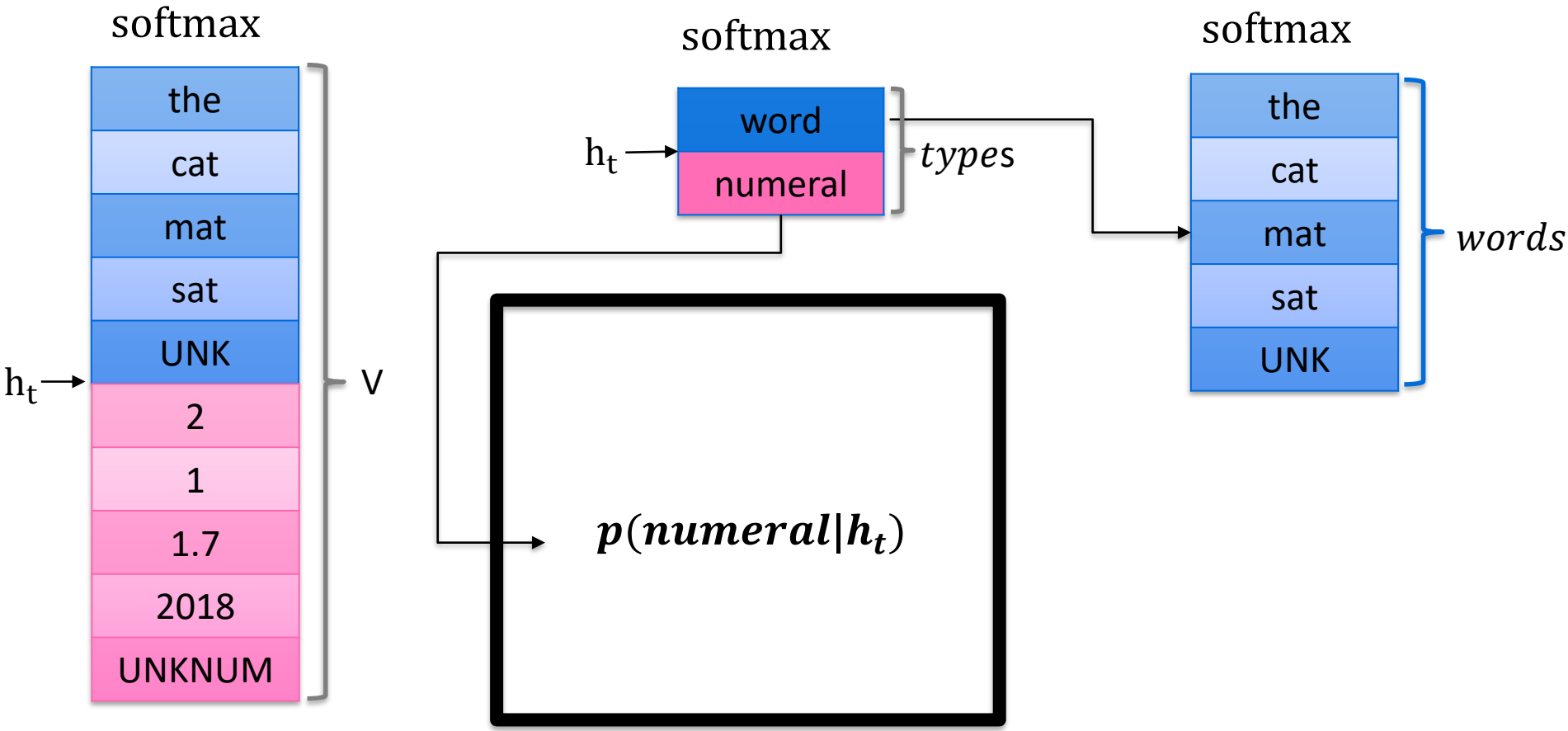




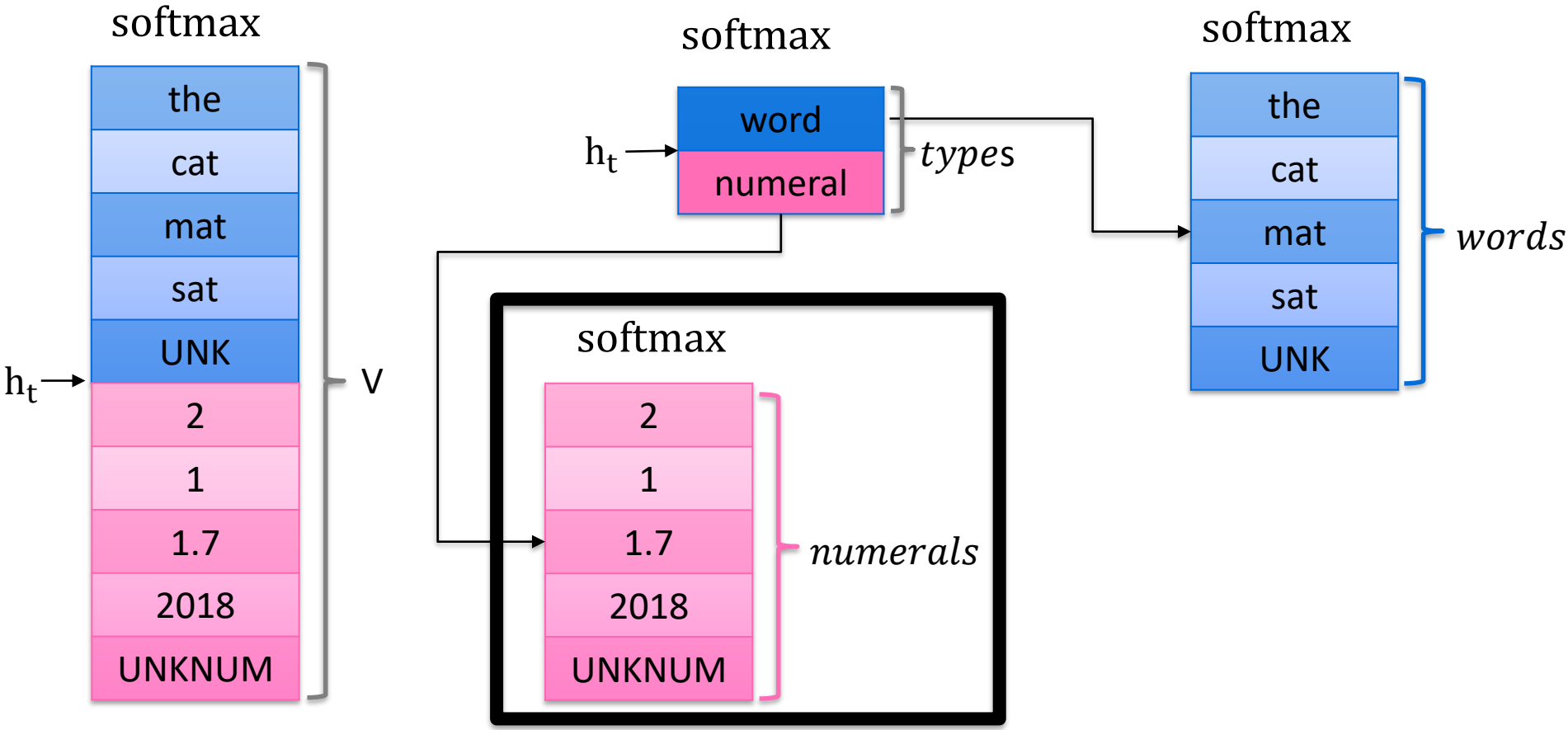
Q1: Are existing LMs numerate?

Q2: How to improve the numeracy of LMs?

Strategy: Softmax & Hierarchical Softmax



Strategy: Softmax & Hierarchical Softmax



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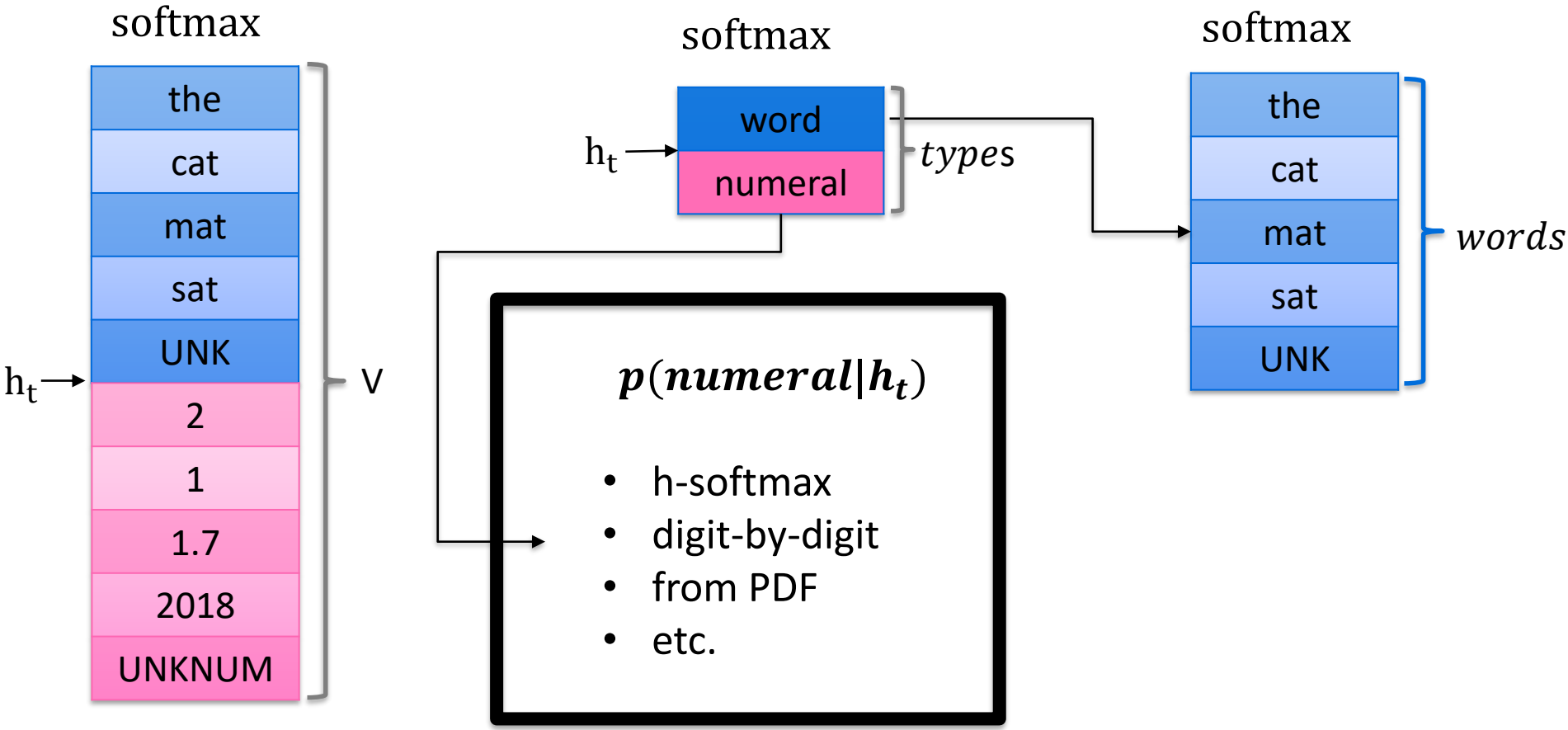
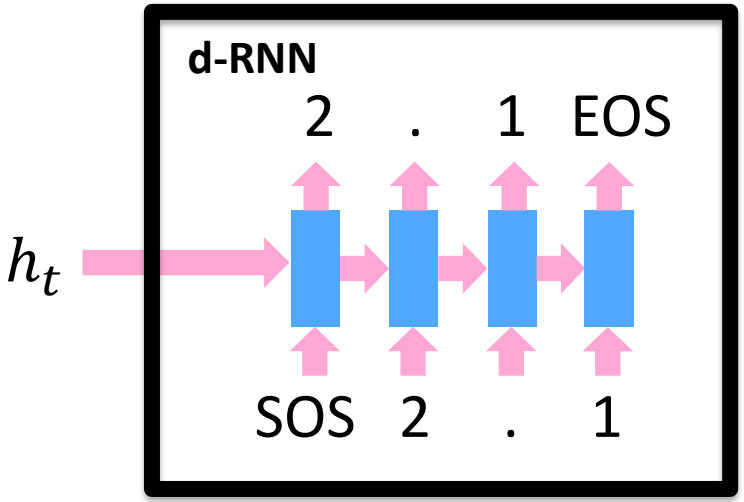


Strategy: Digit-by-Digit Composition

$$p(2.1) = p(2)p(.|2)p(1|2.)p(EOS|2.1)$$



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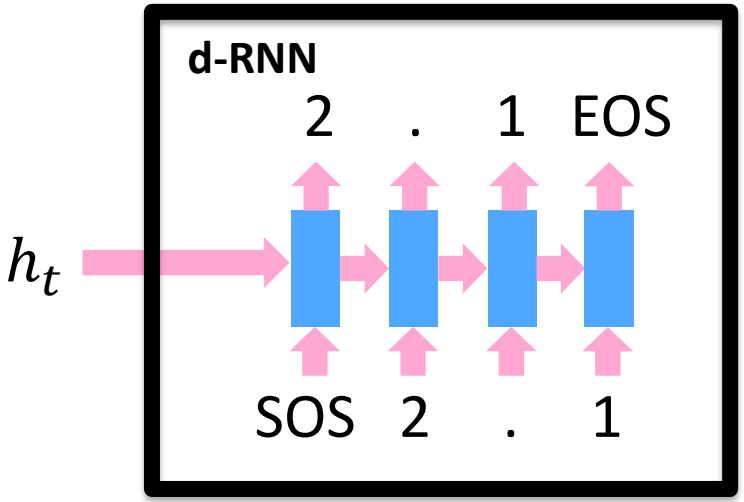
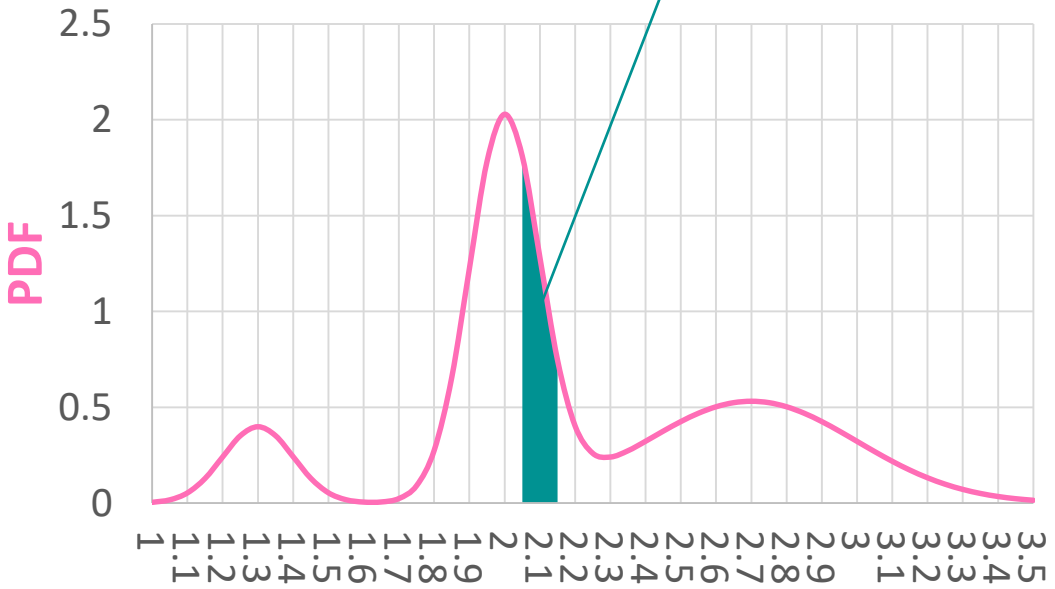


Strategy: from continuous PDF

$$p(\textbf{numeral} = 2.1) = p_{PMF}(2.05 < \textbf{number} < 2.15 \,|\text{precision} = 1\,) \times\; p(\text{precision} = 1\,)$$



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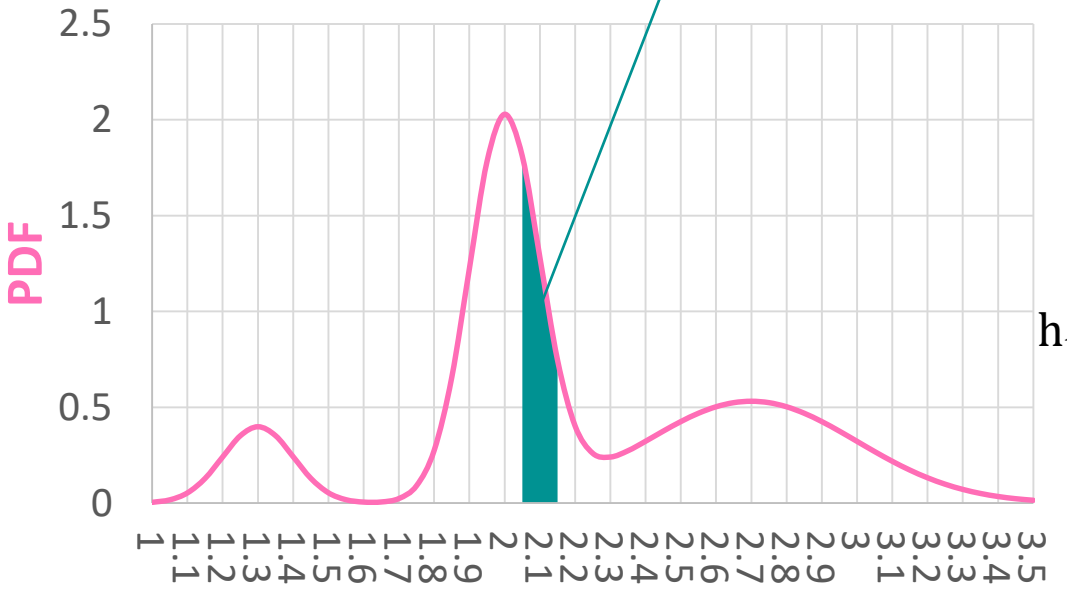
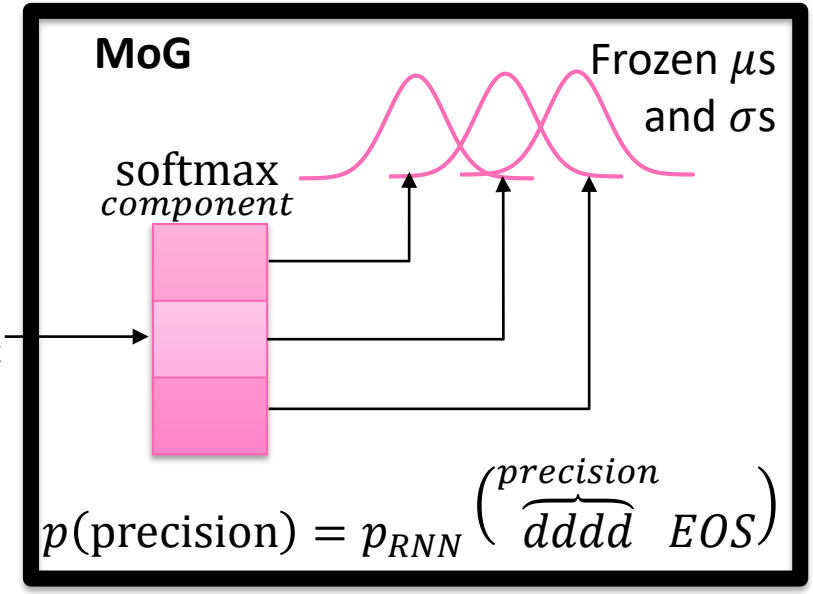
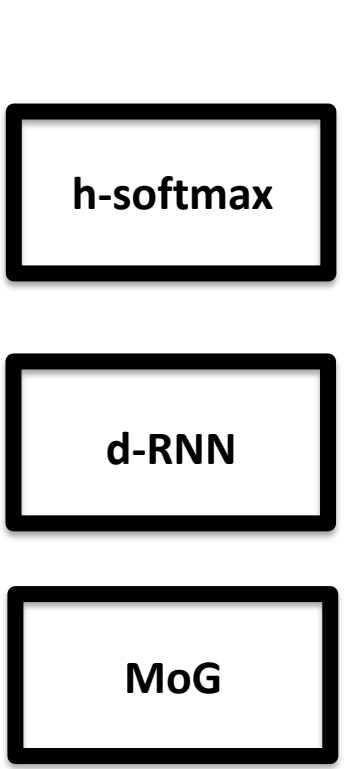
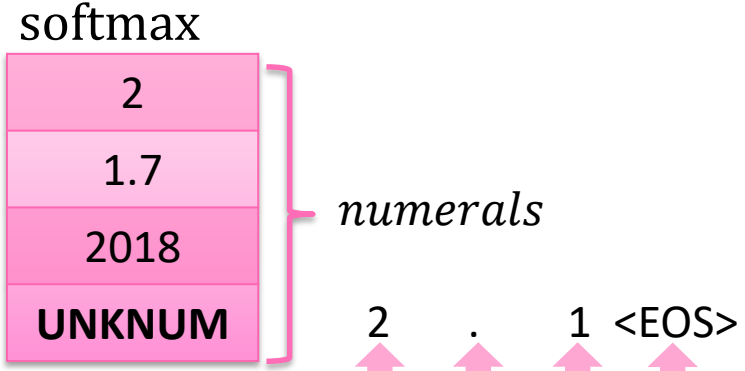
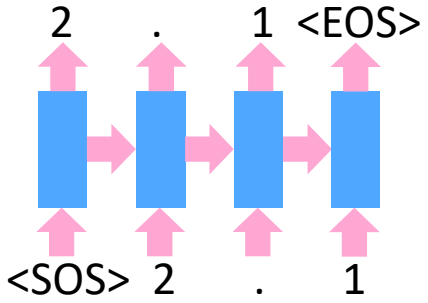


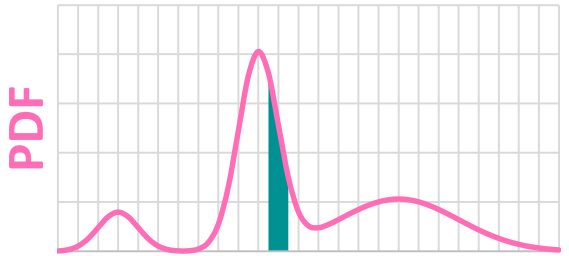


Overview of Strategies









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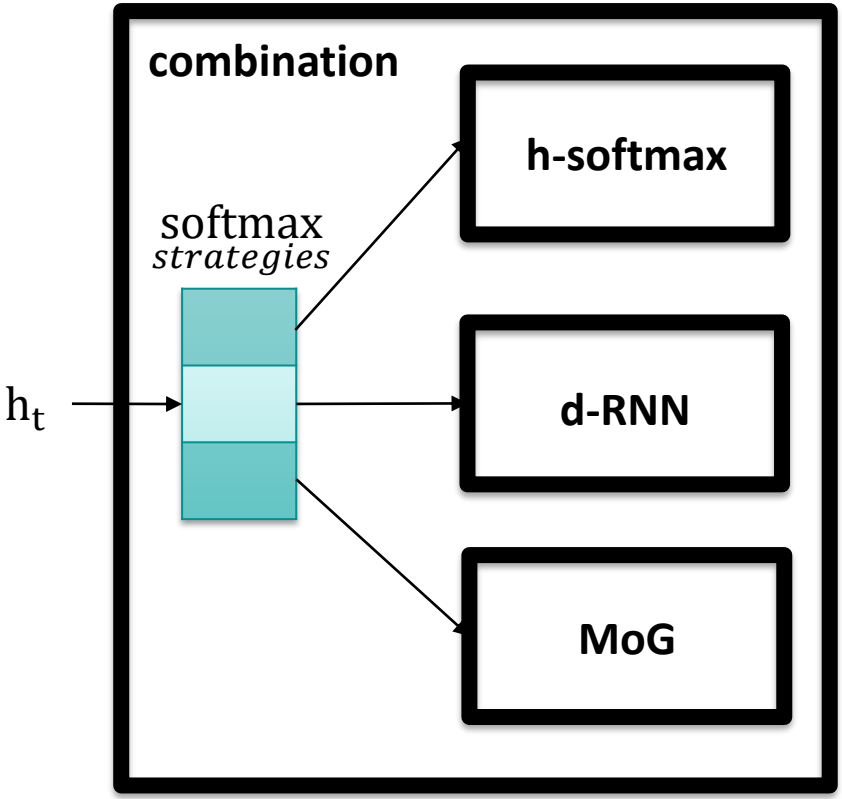
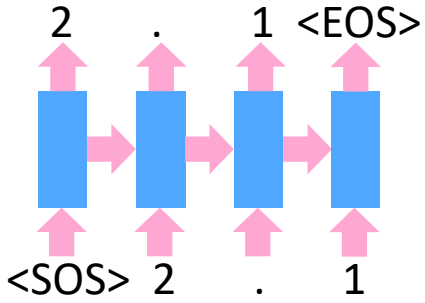
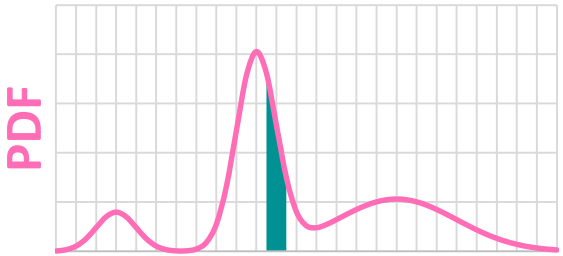
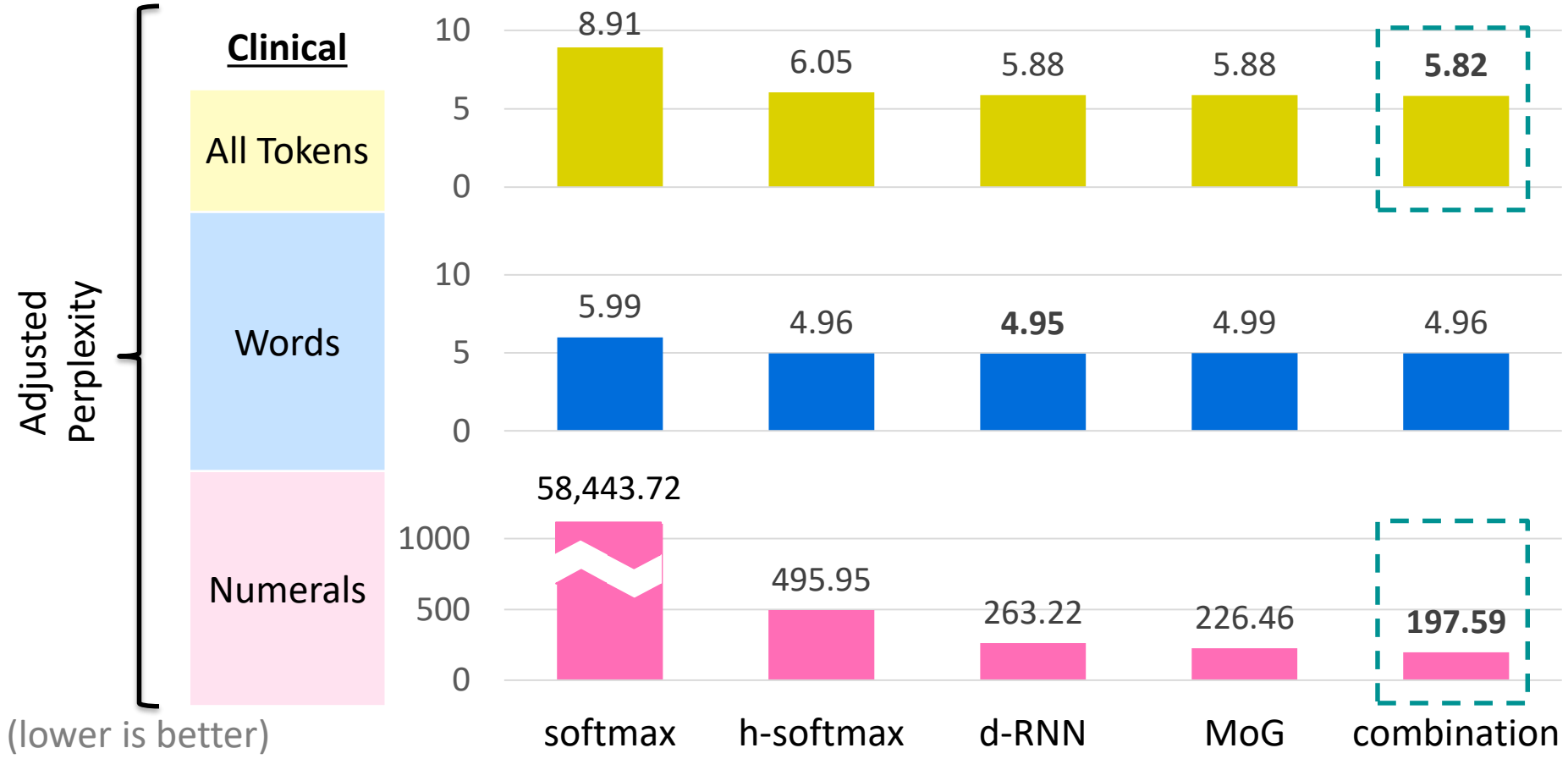


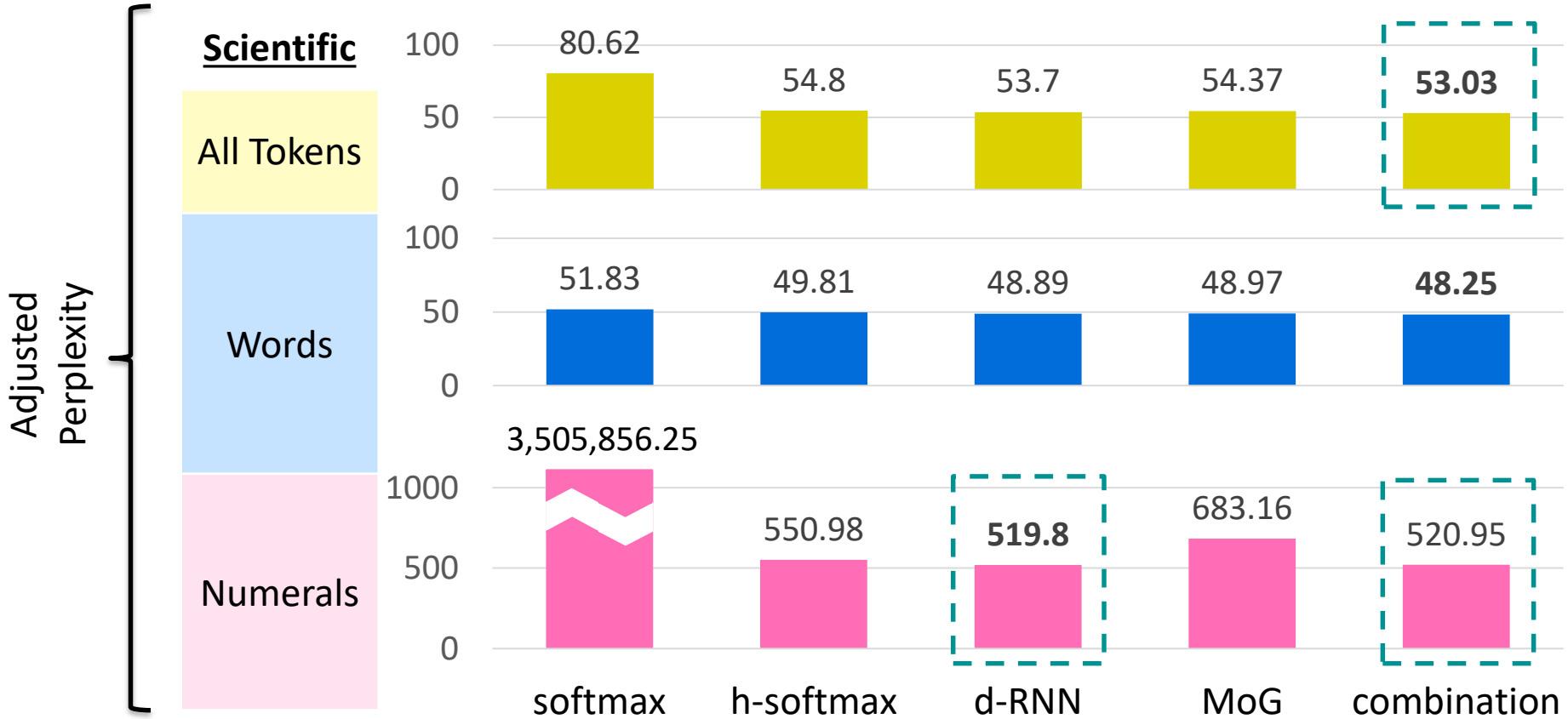




Results: Language Modelling (1)



Results: Language Modelling (2)



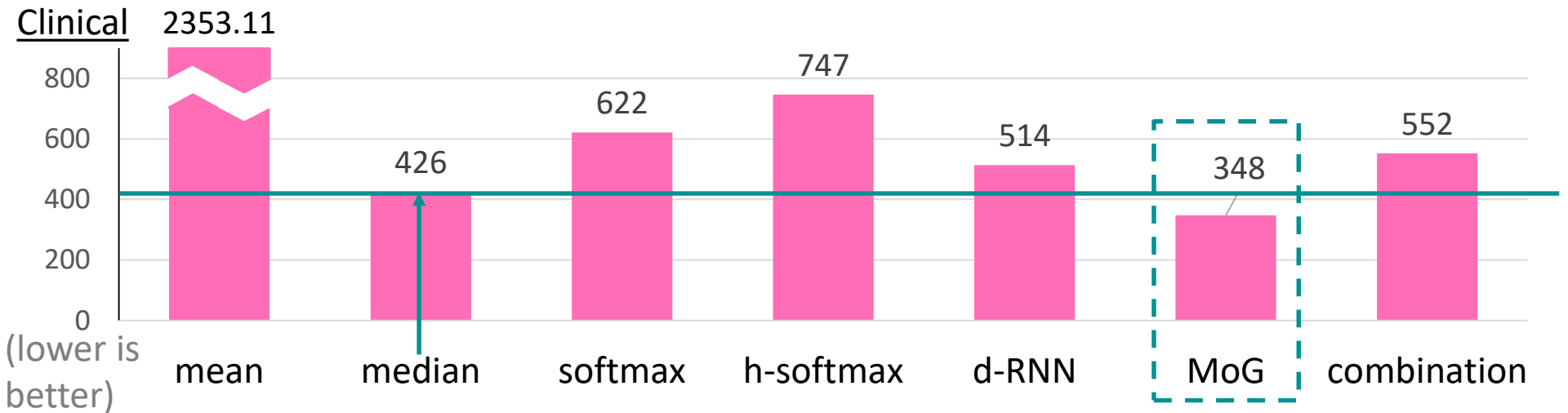
(lower is better)

Results: Number Prediction

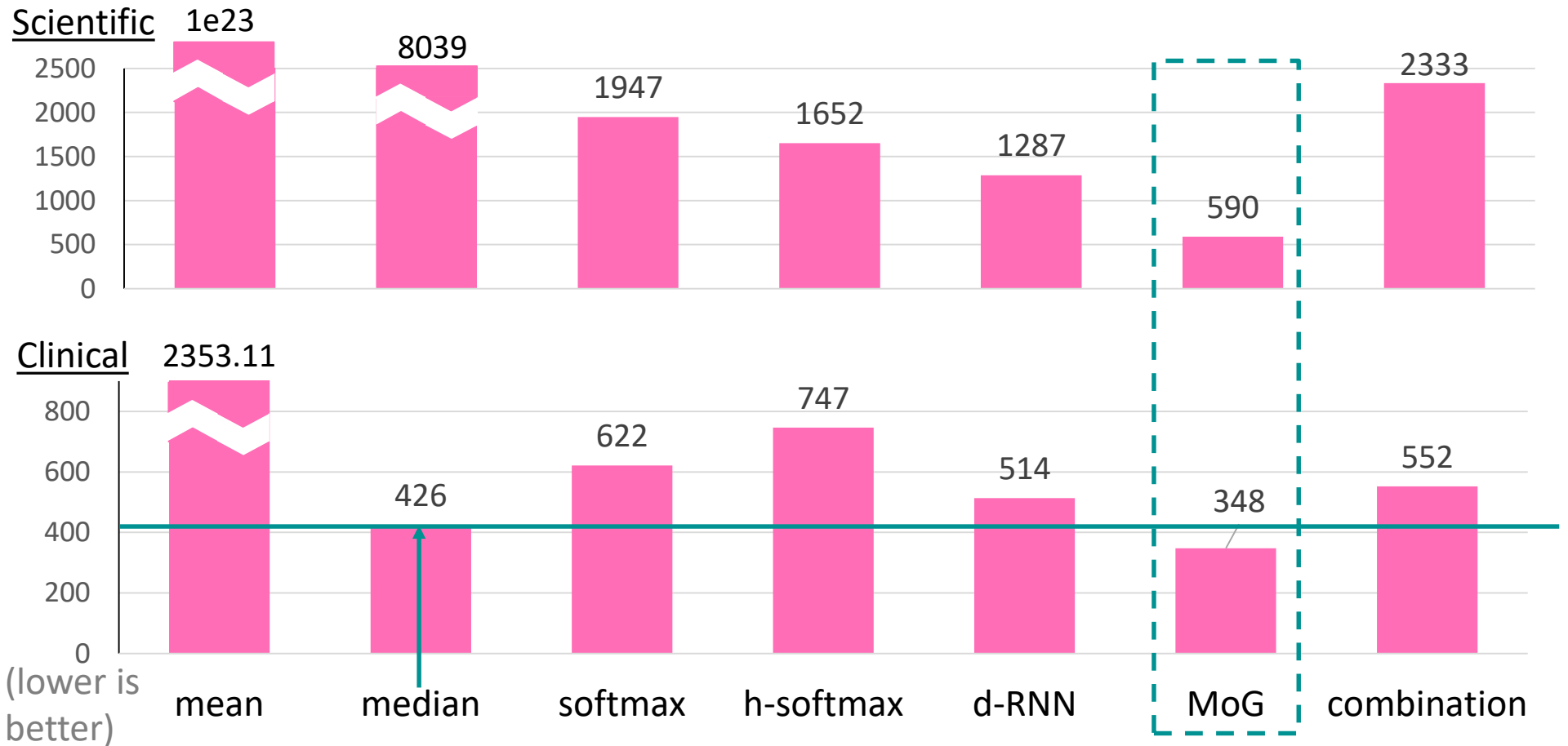
numeral → number

`2.1' 2.1

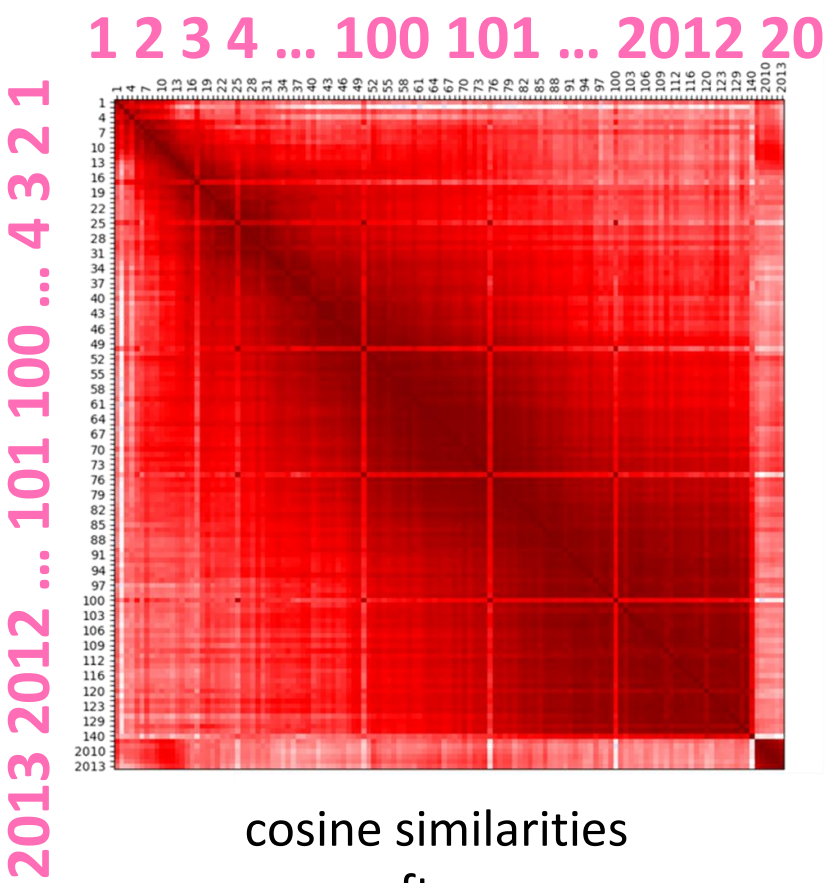
$$MAPE = \frac{prediction - target}{target} \times 100\%$$



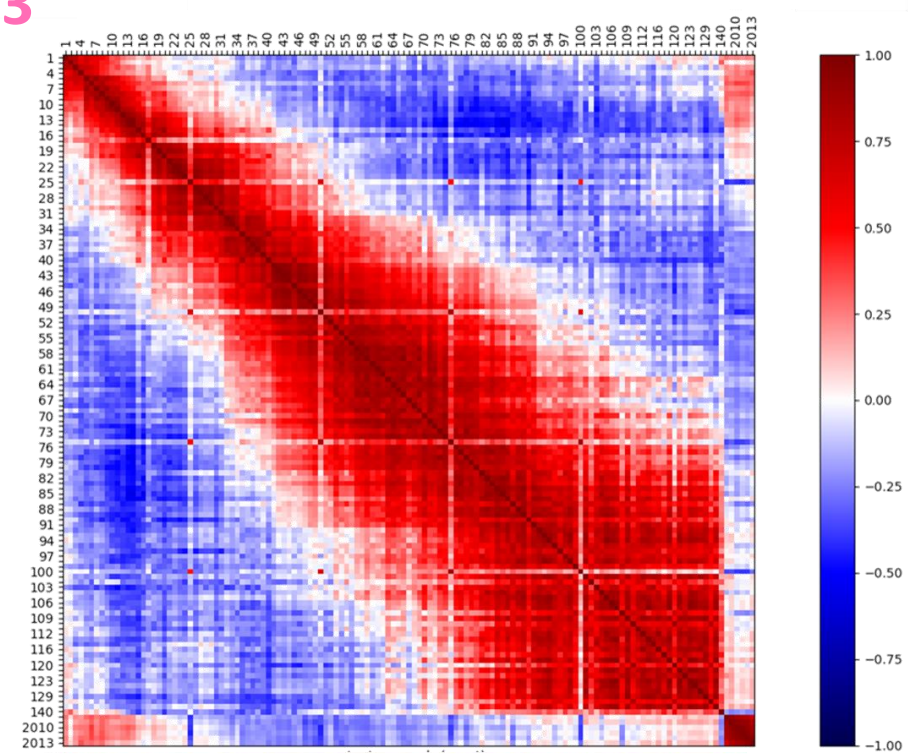
Results: Number Prediction



Softmax versus Hierarchical Softmax

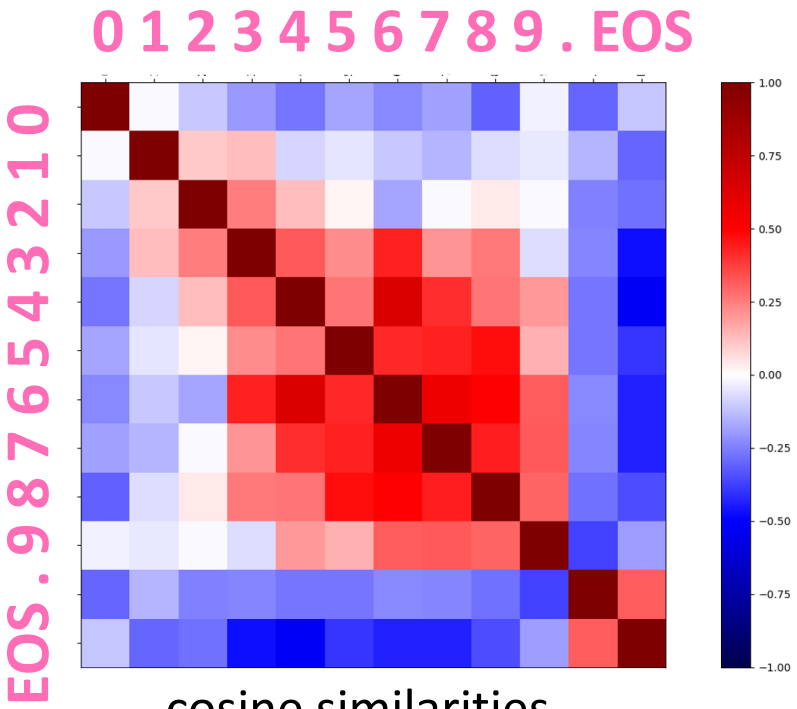


cosine similarities
softmax



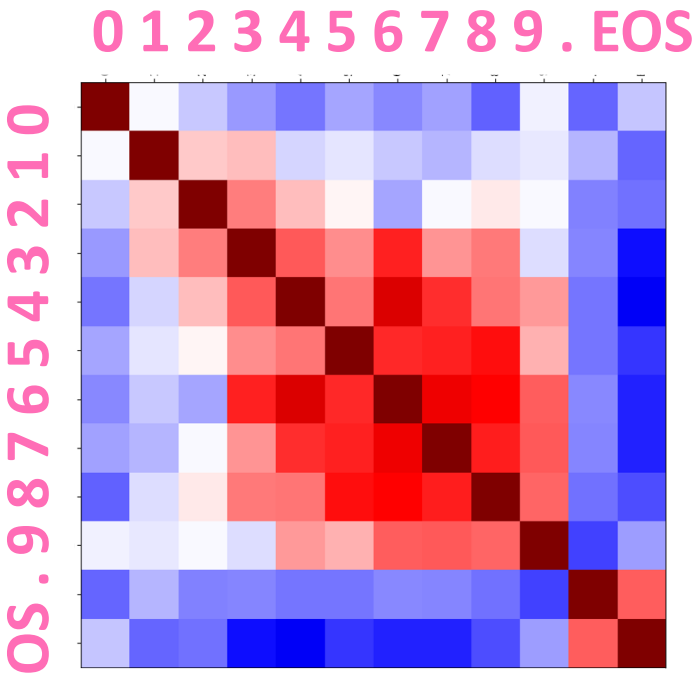
cosine similarities
h-softmax

Analysis: d-RNN and Benford's Law

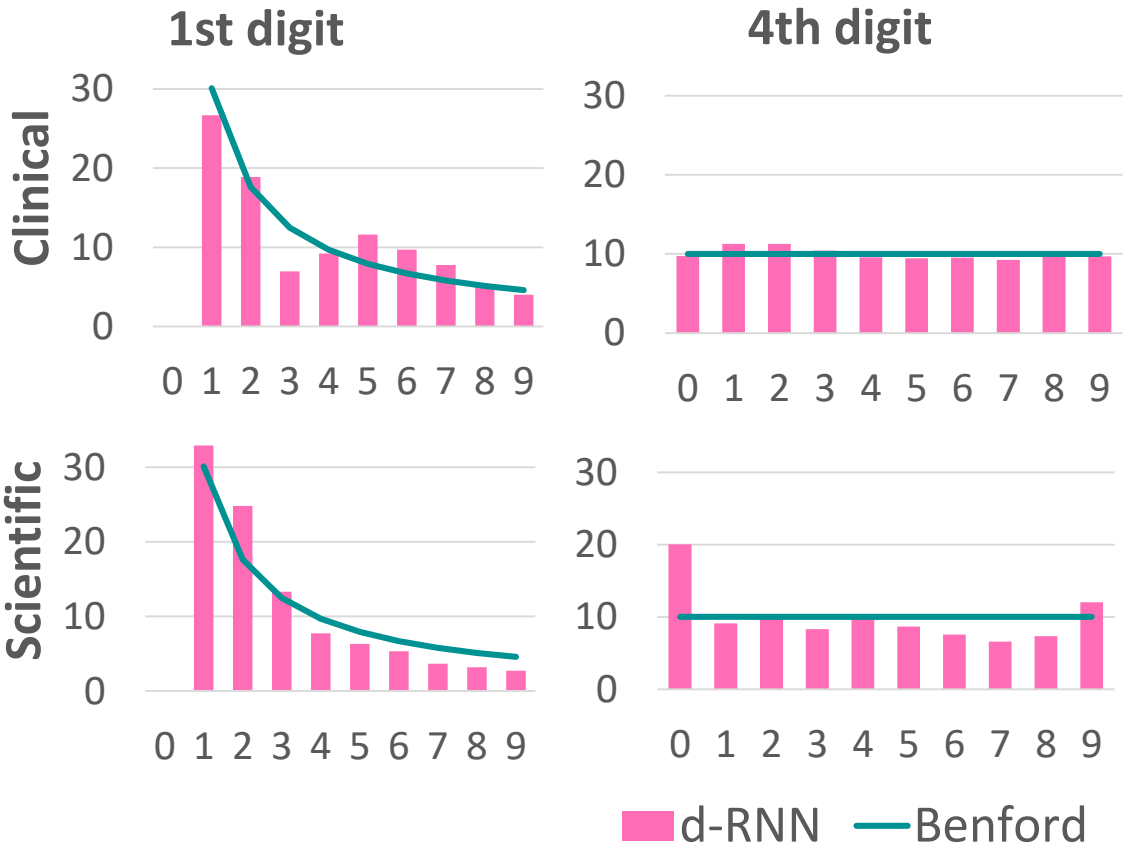


cosine similarities
d-RNN

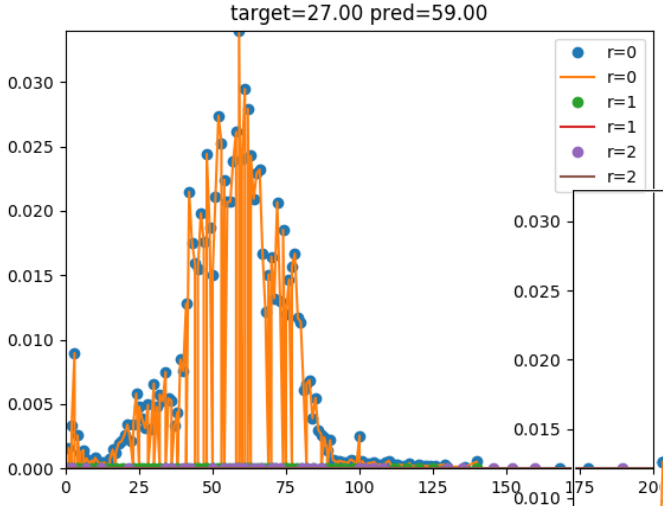
Analysis: d-RNN and Benford's Law



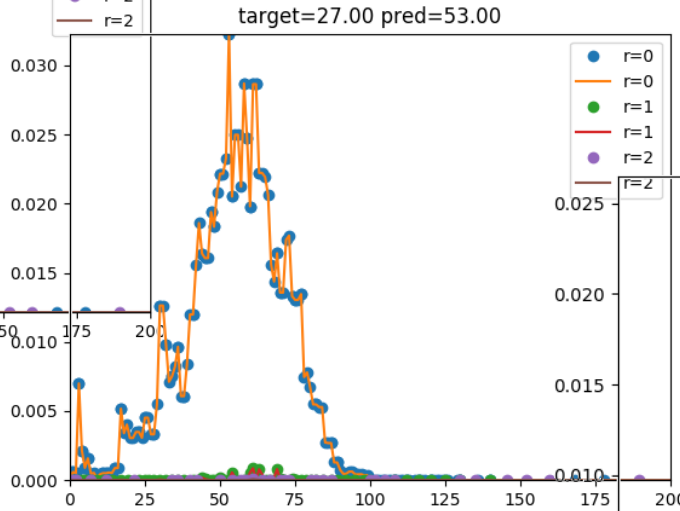
cosine similarities
d-RNN



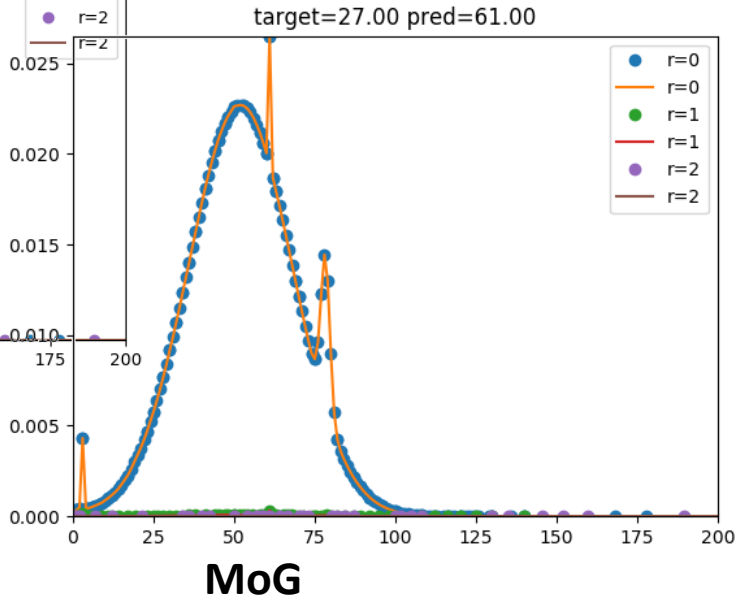
Analysis: Model Predictions



h-softmax



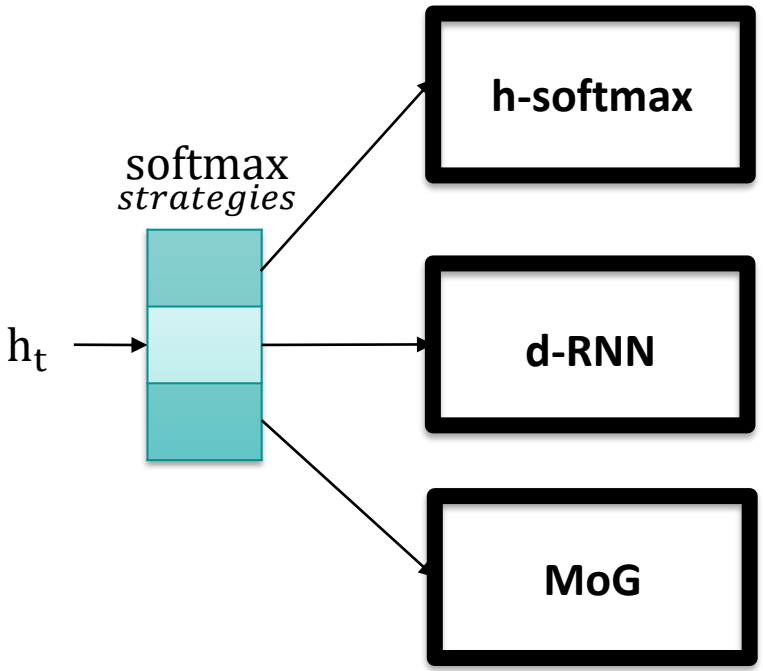
d-RNN



MoG

‘… ejective fraction : ____ % …’

Analysis: Strategy Selection



4 out of 17 segments
Enhancement > 25 %
Li et al. 2003

Small integers,
percentiles,
years

measured 32 x 31 mm
NGC 6334 stars

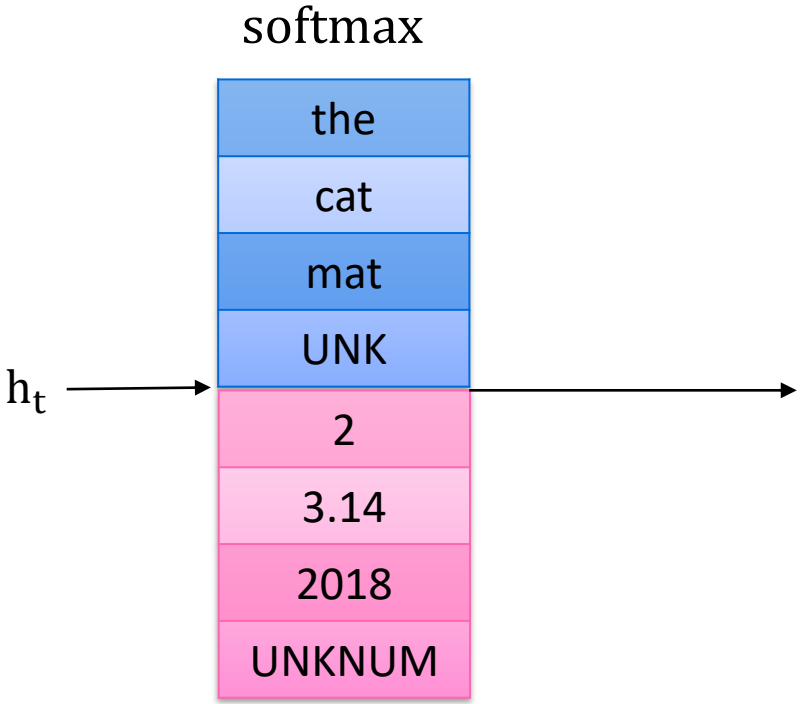
2-digit integers,
some ids

Ejective fraction: 27.00 %
Ejective fraction: 35.00 %
HIP 12961 and GL 676

reals,
some ids

Conclusion (1)

Are existing LMs numerate?



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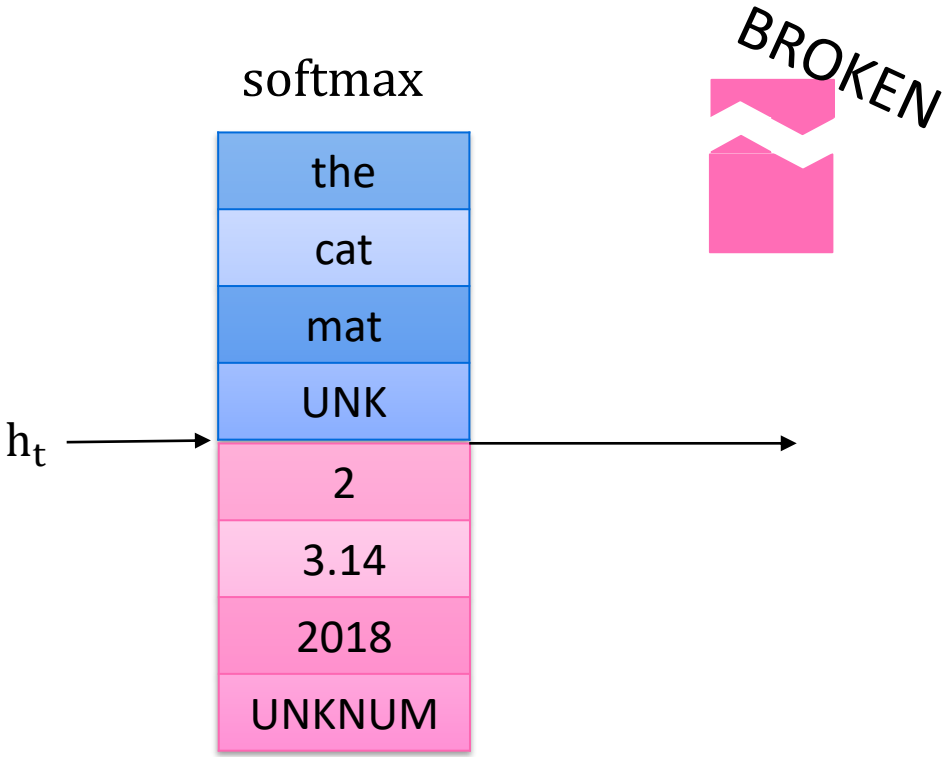


BROKEN

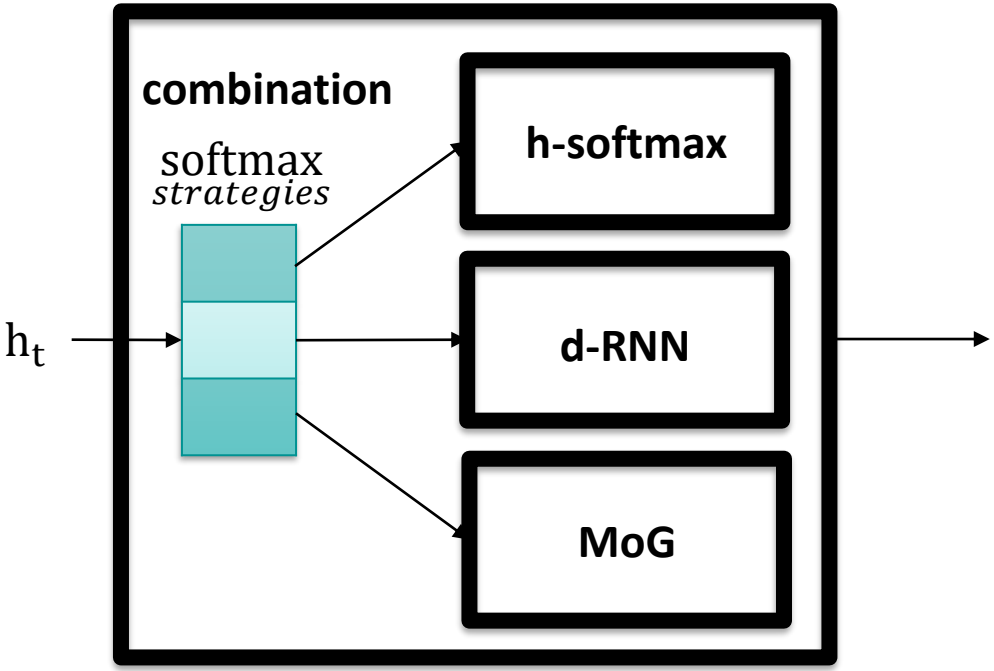
‘John’s height is ___ ’

0 2 1 25 999 3 UNKNUM 3.14 2018 50

Conclusion (2)

How to improve

the numeracy of LMs?



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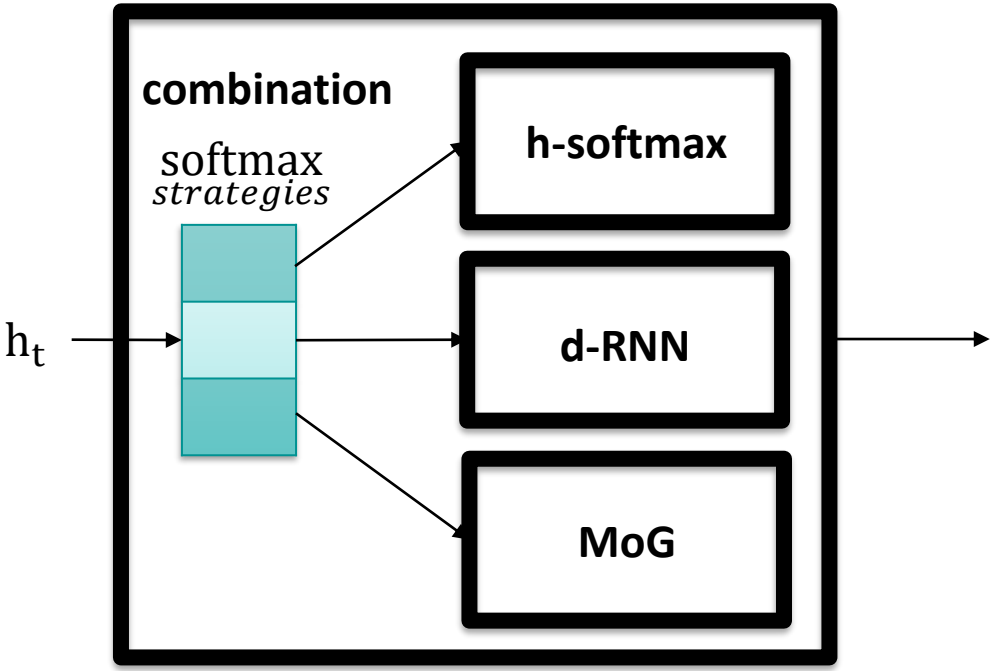


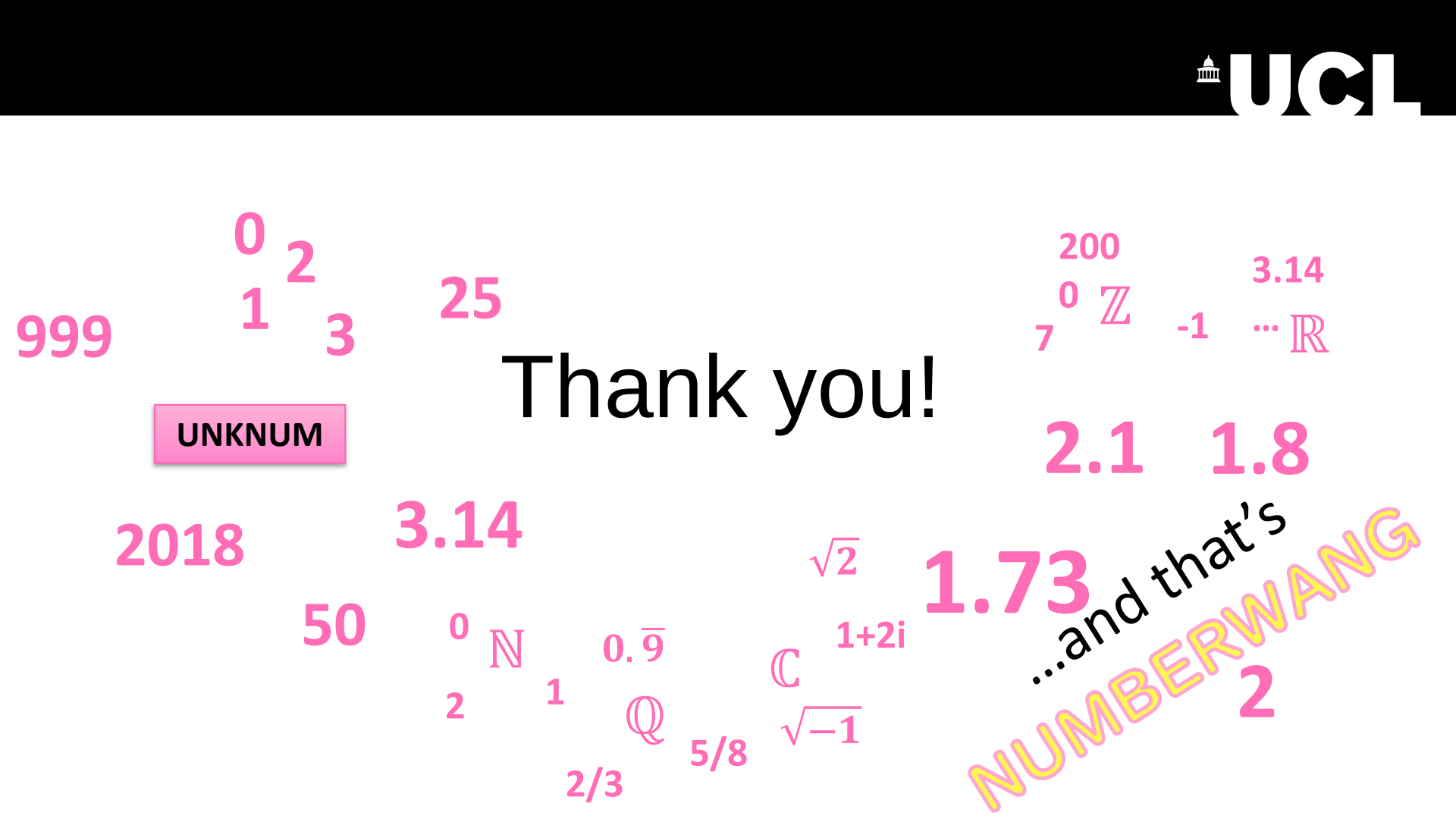
‘John’s height is ___ ’

2.1

1.8

1.73

2


0
2
1
3
25
999
200
0
$\mathbb{Z}$
7
-1
3.14
... $\mathbb{R}$
Thank you!
UNKNUM
2.1
1.8
2018
3.14
$\sqrt{2}$
1.73
...and that's
50
0
$\mathbb{N}$
$0.\overline{9}$
1+2i
$\mathbb{C}$
NUMBERWANG
2
1
$\mathbb{Q}$
$\sqrt{-1}$
5/8
2/3