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# A Neural Approach for Detecting Morphological Analogies

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## Proportional Analogy

### Notation:

▶  $A : B :: C : D$  (read "A is to B as C is to D")

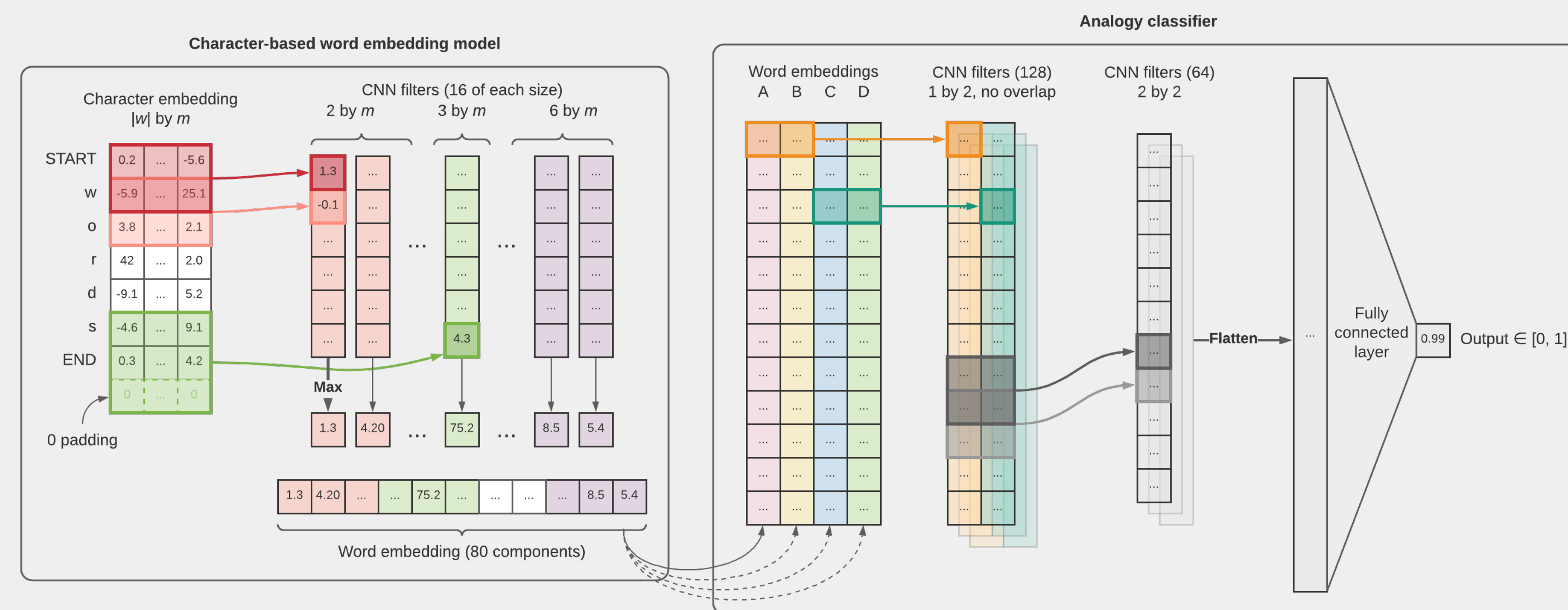
### 3 Core properties:

- 1  $A : B :: C : D \rightarrow C : D :: A : B$  (symmetry)
- 2  $A : B :: C : D \rightarrow A : C :: B : D$  (central permutation)
- 3  $A : B :: A : B$  (reflexively)

### Morphology:

- ▶ "read is to readable as count is to countable"
- ▶ *aalto : aalloksi :: spirituaali : spirituaaliksi* (Finnish)

## Proposed Approach: Morphological Embedding + CNN Classifier



## Baselines

### 1 Classifier:

- ▶ Lepage Classifier [3]
  - ▶ matrix based approach to align characters between words and find common sub-words

### 2 Solvers:

- ▶ find missing  $x$  making  $A : B :: C : x$  valid; if expected  $D$  in top 1 or 10 solutions, valid analogy
- ▶ Kolmogorov Complexity [6]:
  - ▶ minimize complexity of  $f$  such that  $B = f(A)$  and  $f(C)$  is computable;  $x = f(C)$
- ▶ Alea [5]:
  - ▶ random permutations of the characters of  $B$  not in  $A$  and those of  $C$  (Monte-Carlo method)

## Training and Evaluation Procedure

Analogies obtained by aligning morphological transformations:

- ▶ *dog*, to NUM=PLURAL, *dogs*
- ▶ *cat*, to NUM=PLURAL, *cats*
- ▶ resulting analogy: *dog : dogs :: cat : cats*

For each analogy  $A : B :: C : D$  extracted from the data (use max 50000 of the available analogies):

- 1 embed  $A, B, C$ , and  $D$
- 2 permute embeddings using properties of proportional analogy:
  - Train. & eval.: 8 valid analogies
  - Training: 3 invalid analogies
  - Evaluation:  $3 \times 8$  invalid analogies and their equivalent forms
- 3 aggregate over all permutations:
  - Training: loss (Binary Cross-Entropy)
  - Evaluation: accuracy

$A : B :: C : D$  (base form)       $C : D :: A : B$   
 $A : C :: B : D$        $B : A :: D : C$        $D : B :: C : A$   
 $D : C :: B : A$        $C : A :: D : B$        $B : D :: A : C$

Table: 8 equivalent forms per analogy

$B : A :: C : D$        $C : B :: A : D$        $A : A :: C : D$

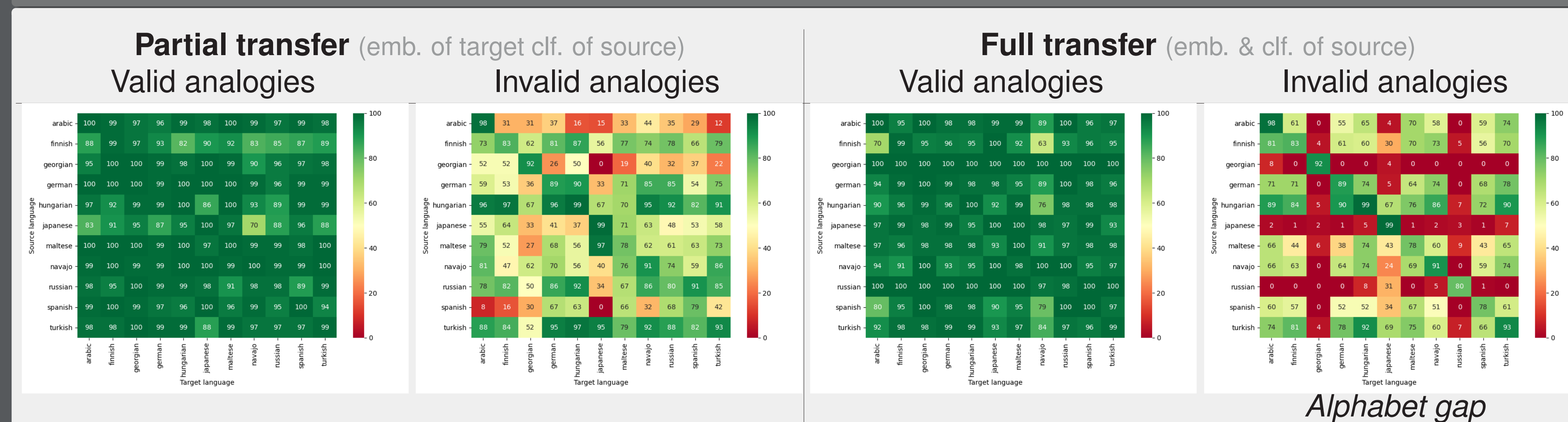
Table: 3 invalid analogies per analogy

## Classification Results

Language	CNN (ours)		Best Baseline		Number of analogies in the data	
	Valid	Invalid	Valid	Invalid	Training	Test
<i>Sigmorphon2016 task 1 (inflection) [2]</i>						
Arabic	<b>99.89</b>	<b>97.52</b>	34.21 (Alea@10)	<b>97.79</b> (Kolmo@1)	373240	555312
Finnish	<b>99.44</b>	82.62	25.60 (Lepage)	<b>98.78*</b> (Alea@1)	1342639	4691453
Georgian	<b>99.83</b>	91.71	93.20 (Kolmo@10)	<b>95.21</b> (Alea@1)	3553763	8368323
German	<b>99.48</b>	89.01	86.90 (Alea@10)	<b>97.19</b> (Alea@1)	994740	1480256
Hungarian	<b>99.99</b>	<b>98.81</b>	36.80 (Kolmo@10)	<b>98.40</b> (Kolmo@1)	3280891	66195
Maltese	<b>99.96</b>	<b>77.83</b>	78.05 (Alea@10)	69.29 (Kolmo@1)	104883	3707
Navajo	<b>99.53</b>	90.82	21.45 (Kolmo@10)	<b>94.93</b> (Kolmo@1)	502637	4843
Russian	<b>97.95</b>	79.85	42.37 (Alea@10)	<b>93.88</b> (Lepage)	1965533	6421514
Spanish	<b>99.94</b>	78.33	85.90 (Alea@10)	<b>86.62</b> (Lepage)	1425838	4794504
Turkish	<b>99.48</b>	<b>92.63</b>	44.76 (Alea@10)	91.40 (Kolmo@1)	606873	11360
<i>Japanese Bigger Analogy Test Set [4]</i>						
Japanese	<b>99.99</b>	<b>98.65</b>	19.20 (Kolmo@10)	<b>98.13</b> (Lepage)	18487	7923

**123** no significant difference  
**123** best result, significant difference between baselines and ours  
 \* obtained on 4000 analogies (too slow on 50000)

## Transferability



## Perspectives

- ✓ explore transferability [1]
- ✓ balancing data
- ✓ regression (analogy solving)
  - ▶ qualitative analysis of embedding model
  - ▶ other domains (images, text, explanations, etc.)

## Bibliography

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