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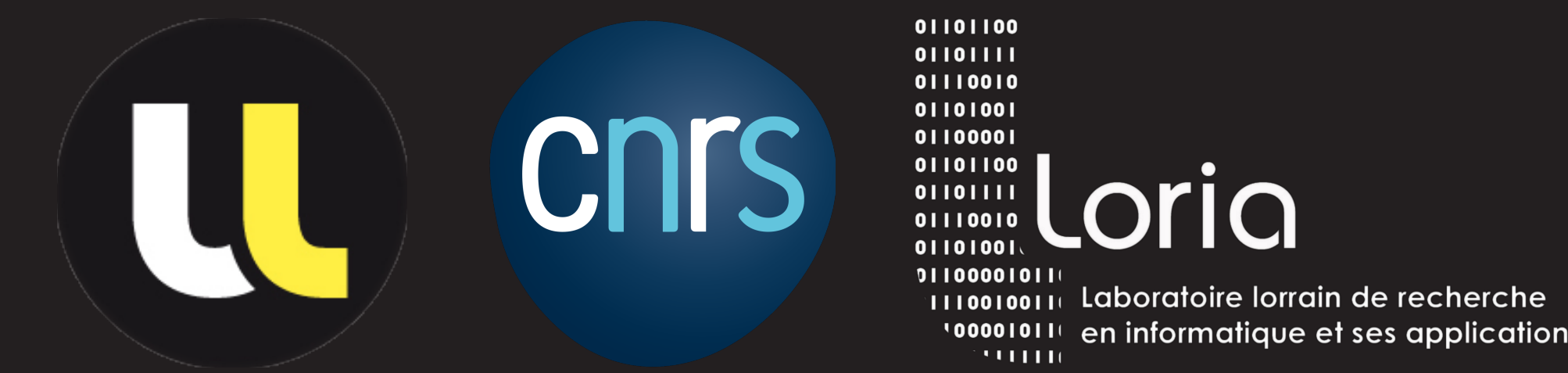


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A Neural Approach for Detecting Morphological Analogies

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Proportional Analogy

Notation:

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

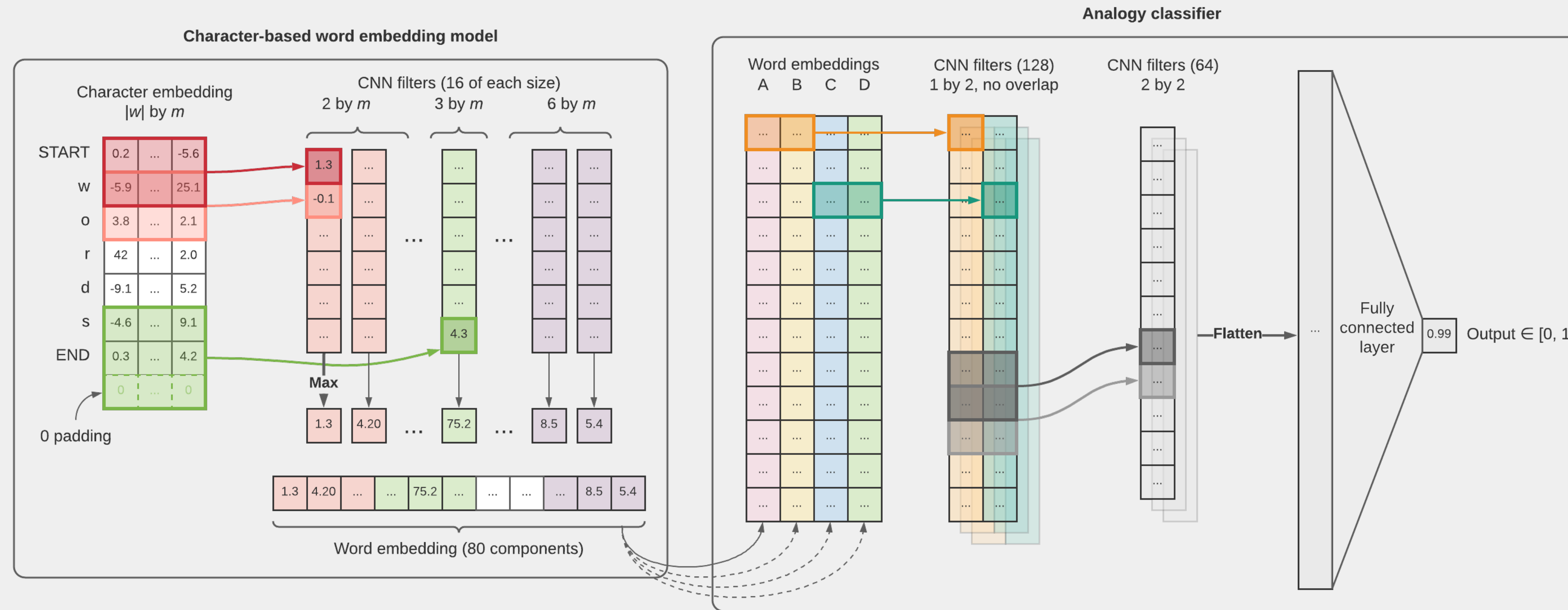
3 Core properties:

- 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: 3×8 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

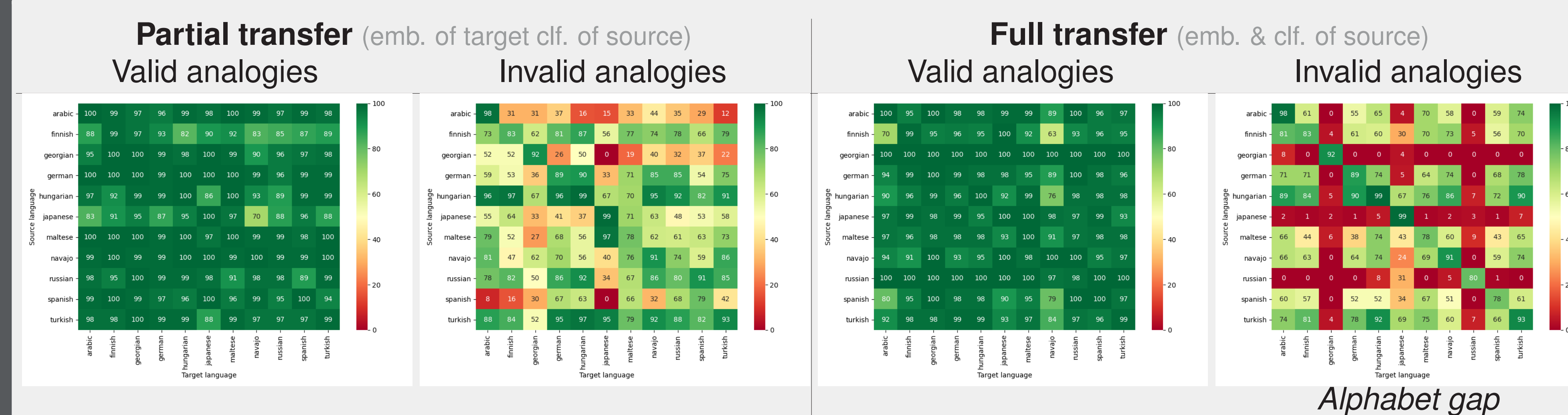
Language	CNN (ours)		Best Baseline		Number of analogies in the data	
	Valid	Invalid	Valid	Invalid	Training	Test
<i>Sigmorphon2016 task 1 (inflection) [2]</i>						
Arabic	99.89	97.52	34.21 (Alea@10)	97.79 (Kolmo@1)	373240	555312
Finnish	99.44	82.62	25.60 (Lepage)	98.78* (Alea@1)	1342639	4691453
Georgian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

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