Character–based recurrent neural networks for morphological relational reasoning

Supplemental material

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ABSTRACT

This is the supplemental material provided for *Character-based recurrent neural networks for morphological relational reasoning.*

1 EXAMPLE OUTPUT

The following tables contain example output generated by the model when evaluating on the validation set. The samples are not representative, they are just picked as illustrations demonstrating in what cases the model works and when it fails. Incorrect output is massively overrepresented. The accuracy of the model is 95.60% for English, 83.26% for Finnish, 89.12% for German, 70.54% for Russian, and 90.10% for Swedish. For more details, see the paper.

Model size. Table 1 shows prediction accuracy for different sizes of the hidden state in the RNN modules. Although the difference in performance between the explored values is small, using a hidden size of 50 obtained the best score on both the validation and test sets.

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*A large portion of this work was done while O.M. was a PhD student at Chalmers university of technology, Sweden

Olof Mogren, Richard Johansson

Table 1:
Prediction accuracy of the proposed model
on English validation set
using different hidden sizes

Size	Accuracy
25	94.15%
50	94.60%
75	94.40%
100	**96.40%**
150	93.80%
200	93.35%
250	91.40%

Table 2: **English:** Correct (top), and incorrect (bottom) example outputs from the model. Samples from English validation set

Correct:

Demo word 1	Demo word 2	Query	Target	Output
misidentify	misidentifies	bottleneck	bottlenecks	bottlenecks
obliterate	obliterated	prig	prigged	prigged
ventilating	ventilates	disorganizing	disorganizes	disorganizes
crank	cranker	freckly	frecklier	frecklier
debauchery	debaucheries	bumptiousness	bumptiousnesses	bumptiousnesses

Incorrect:

Demo word 1	Demo word 2	Query	Target	Output
repackage	repackaged	outrun	outran	outrunned
misinformed	misinform	gassed	gas	gass
julep	juleps	catfish	catfish	catfishes
cedar	cedars	midlife	midlives	midlifs
affrays	affray	buzzes	buzz	buzze

Table 3: **Finnish:** Correct (top), and incorrect (bottom) example outputs from the model. Samples from Finnish validation set.

Correct:

Demo word 1	Demo word 2	Query	Target	Output
pyöri	pyörimäisillään	seikkaile	seikkailemaisillaan	seikkailemaisillaan
assosiatiivisuudet	assosiatiivisuuksina	mahahapot	mahahappoina	mahahappoina
viestintäsatelliitit	viestintäsatelliittiin	ahneudet	ahneuteen	ahneuteen
paikossa	paikot	tasapuolisuudessa	tasapuolisuudet	tasapuolisuudet
seminormiin	seminormit	viestintäsatelliittiin	viestintäsatelliitit	viestintäsatelliitit
päälaenlohkoin	päälaenlohkot	hillopurkein	hillopurkit	hillopurkit
siamankeineen	siamankeina	trieereineen	trieereinä	trieereinä
falangeina	falangina	timantteina	timanttina	timanttina
glaukofaaneina	glaukofaani	mukavuusavioliittoina	mukavuusavioliitto	mukavuusavioliitto

Incorrect:

Demo word 1	Demo word 2	Query	Target	Output
konjugoimaisillaan	konjugoi	leimautumaisillaan	leimautui	leimaudui
augiitteina	augiitit	meininkeinä	meiningit	meininkit
päätueksi	päätukina	bulevardisportiksi	bulevardisportteina	bulevardisporttina
ortodoksikirkoksi	ortodoksikirkkoina	päätueksi	päätukina	päätuina
anodeissa	anodina	betonirampeissa	betoniramppina	betonirampina
puhelinlaskulta	puhelinlaskuna	tunnolta	tuntona	tunnona

Olof Mogren, Richard Johansson

Table 4: **German:** Correct (top), and incorrect (bottom) example outputs from the model. Samples from German validation set.

Correct:

Demo word 1	Demo word 2	Query	Target	Output
erwürben	erwerben	abandonnierten	abandonnieren	abandonnieren
erwerben	erwürben	abandonnieren	abandonnierten	abandonnierten
abgeschmackten	abgeschmackteste	zirconiumhaltigen	zirconiumhaltigste	zirconiumhaltigste
abgeschmackteste	abgeschmackten	zirconiumhaltigste	zirconiumhaltigen	zirconiumhaltigen
gebärfähigen	gebärfähigstes	herzhaften	herzhaftestes	herzhaftestes
gebärfähigstes	gebärfähigen	herzhaftestes	herzhaften	herzhaften
Bleichstoffe	Bleichstoff	Transportvorgänge	Transportvorgang	Transportvorgang
Hufschläge	Hufschlag	Knäste	Knast	Knast
Knäste	Knast	Hufschläge	Hufschlag	Hufschlag

Incorrect:

Demo word 1	Demo word 2	Query	Target	Output
angeschlagenste	angeschlagener	schmälste	schmaler	schmäler
angeschlagener	angeschlagenste	schmaler	schmälste	schmalste
Zugriffe	Zugriff	Sandstürme	Sandsturm	Sandstürm
Zugriff	Zugriffe	Sandsturm	Sandstürme	Sandsturme
Bleichstoff	Bleichstoffe	Transportvorgang	Transportvorgänge	Transportvorgange
Hufschlag	Hufschläge	Knast	Knäste	Knaste
Knast	Knäste	Hufschlag	Hufschläge	Hufschlage
Äste	Astes	Aufwände	Aufwandes	Aufwändes
Astes	Äste	Aufwandes	Aufwände	Aufwande

Table 5: **Russian:** Correct (top), and incorrect (bottom) example outputs from the model. Samples from Russian validation set

Correct:

Demo word 1	Demo word 2	Query	Target	Output
шлифуете	шлифуем	медлите	медлим	медлим
терпя	терпите	предпринимая	предпринимаете	предпринимаете
укоряете	укоряешь	спешиваетесь	спешиваешься	спешиваешься
путешествовали	путешествовать	проверяли	проверять	проверять
валяться	валяюсь	подлаживать	подлаживаю	подлаживаю
валяюсь	валяться	подлаживаю	подлаживать	подлаживать
собираются	собирайся	разумеют	разумей	разумей
благодари	благодарили	покрывай	покрывали	покрывали

Incorrect:

Demo word 1	Demo word 2	Query	Target	Output
подлаживать	подлаживаю	глядеть	гляжу	гляду
подлаживаю	подлаживать	гляжу	глядеть	гляжать
предупреждай	предупреждаешь	лечи	лечишь	лечёшь
подбирает	подбирай	пялится	пялься	пялись
испустя	испусти	проникая	проникай	проникить
делим	делящий	высимся	высящийся	высившийся
отплываем	отплывающий	делим	делящий	делищий

Table 6: **Swedish:** Correct (top), and incorrect (bottom) example outputs from the model. Samples from Swedish validation set

Correct:

Demo word 1	Demo word 2	Query	Target	Output
attackdykare	attackdykare	pillranden	pillrande	pillrande
attackdykare	attackdykare	pillrande	pillranden	pillranden
involverade	involverar	sprack	spricker	spricker
spricker	sprack	iriserar	iriserade	iriserade
sprack	spricker	iriserade	iriserar	iriserar
bensintank	bensintankar	arbetstid	arbetstider	arbetstider
slipkloss	slipklossar	stenåldershjärna	stenåldershjärnor	stenåldershjärnor
underfundighet	underfundigheter	attackdykare	attackdykare	attackdykare
attackdykare	attackdykare	pillranden	pillrande	pillrande
attackdykare	attackdykare	pillrande	pillranden	pillranden
pillranden	pillrande	täckglas	täckglas	täckglas
pillrande	pillranden	täckglas	täckglas	täckglas

Incorrect:

Demo word 1	Demo word 2	Query	Target	Output
involverar	involverade	spricker	sprack	sprickte
otillbörligare	otillbörlig	hårömmare	håröm	hårömm
blekas	blek	likas	lika	lik
misstagas	missta	ledas	leda	led
krylla	kryllade	skräddarsy	skräddarsydde	skräddarsyde
dödförklara	dödförklarade	storgråt	storgrät	storgråtte

Relation embeddings.   The embeddings computed by the model in the relation encoder is shown in Figures 1, 2, 3, 4.

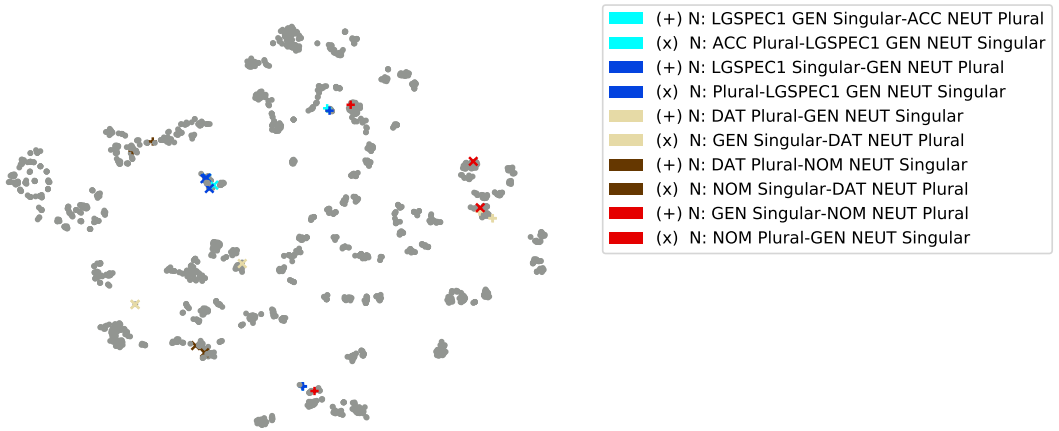|	
(+)	N: LGSPEC1 GEN Singular-ACC NEUT Plural
(x)	N: ACC Plural-LGSPEC1 GEN NEUT Singular
(+)	N: LGSPEC1 Singular-GEN NEUT Plural
(x)	N: Plural-LGSPEC1 GEN NEUT Singular
(+)	N: DAT Plural-GEN NEUT Singular
(x)	N: GEN Singular-DAT NEUT Plural
(+)	N: DAT Plural-NOM NEUT Singular
(x)	N: NOM Singular-DAT NEUT Plural
(+)	N: GEN Singular-NOM NEUT Plural
(x)	N: NOM Plural-GEN NEUT Singular

Figure 1: t-SNE visualization of all demo relation pairs from German validation set embedded using the relation encoder. Each word pair is represented by one point in the plot. A subset of the points are colored by the relation type that they represent

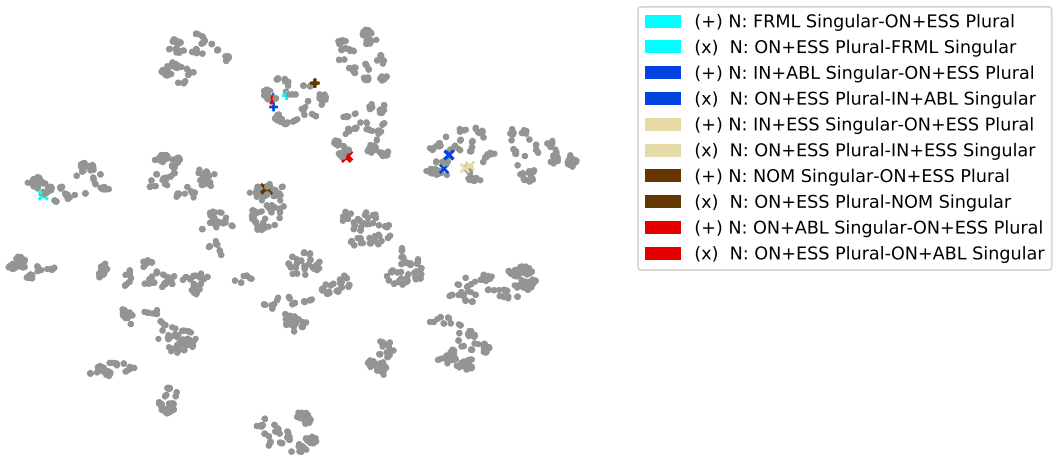|	
(+)	N: FRML Singular-ON+ESS Plural
(x)	N: ON+ESS Plural-FRML Singular
(+)	N: IN+ABL Singular-ON+ESS Plural
(x)	N: ON+ESS Plural-IN+ABL Singular
(+)	N: IN+ESS Singular-ON+ESS Plural
(x)	N: ON+ESS Plural-IN+ESS Singular
(+)	N: NOM Singular-ON+ESS Plural
(x)	N: ON+ESS Plural-NOM Singular
(+)	N: ON+ABL Singular-ON+ESS Plural
(x)	N: ON+ESS Plural-ON+ABL Singular

Figure 2: t-SNE visualization of all demo relation pairs from Finnish validation set embedded using the relation encoder. Each word pair is represented by one point in the plot. A subset of the points are colored by the relation type that they represent
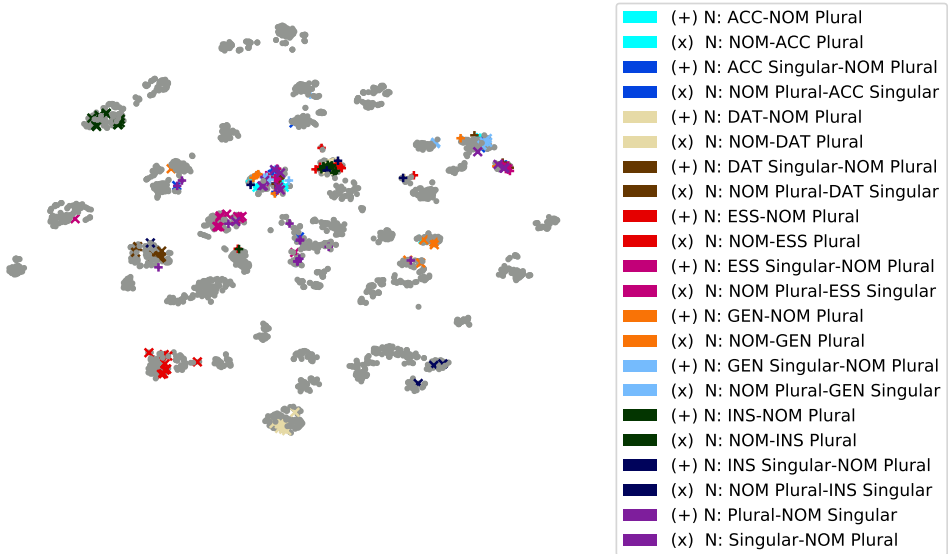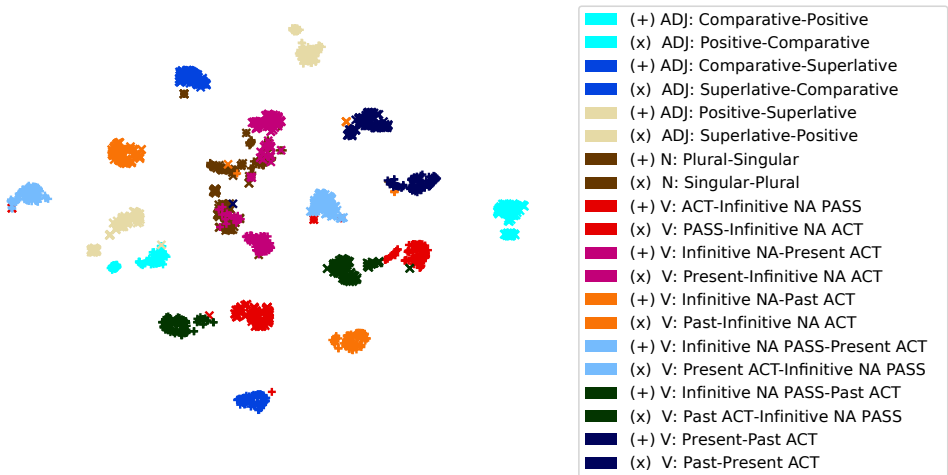
Legend:
- (+) N: ACC-NOM Plural
- (x) N: NOM-ACC Plural
- (+) N: ACC Singular-NOM Plural
- (x) N: NOM Plural-ACC Singular
- (+) N: DAT-NOM Plural
- (x) N: NOM-DAT Plural
- (+) N: DAT Singular-NOM Plural
- (x) N: NOM Plural-DAT Singular
- (+) N: ESS-NOM Plural
- (x) N: NOM-ESS Plural
- (+) N: ESS Singular-NOM Plural
- (x) N: NOM Plural-ESS Singular
- (+) N: GEN-NOM Plural
- (x) N: NOM-GEN Plural
- (+) N: GEN Singular-NOM Plural
- (x) N: NOM Plural-GEN Singular
- (+) N: INS-NOM Plural
- (x) N: NOM-INS Plural
- (+) N: INS Singular-NOM Plural
- (x) N: NOM Plural-INS Singular
- (+) N: Plural-NOM Singular
- (x) N: Singular-NOM Plural

Figure 3: t-SNE visualization of all demo relation pairs from Russian validation set embedded using the relation encoder. Each word pair is represented by one point in the plot. A subset of the points are colored by the relation type that they represent

Legend:
- (+) ADJ: Comparative-Positive
- (x) ADJ: Positive-Comparative
- (+) ADJ: Comparative-Superlative
- (x) ADJ: Superlative-Comparative
- (+) ADJ: Positive-Superlative
- (x) ADJ: Superlative-Positive
- (+) N: Plural-Singular
- (x) N: Singular-Plural
- (+) V: ACT-Infinitive NA PASS
- (x) V: PASS-Infinitive NA ACT
- (+) V: Infinitive NA-Present ACT
- (x) V: Present-Infinitive NA ACT
- (+) V: Infinitive NA-Past ACT
- (x) V: Past-Infinitive NA ACT
- (+) V: Infinitive NA PASS-Present ACT
- (x) V: Present ACT-Infinitive NA PASS
- (+) V: Infinitive NA PASS-Past ACT
- (x) V: Past ACT-Infinitive NA PASS
- (+) V: Present-Past ACT
- (x) V: Past-Present ACT

Figure 4: t-SNE visualization of all demo relation pairs from Swedish validation set embedded using the relation encoder. Each word pair is represented by one point in the plot, colored by the relation type that they represent

Query embeddings. The embeddings computed by the model in the query encoder is shown in Figures 5, 6, 7, 8.
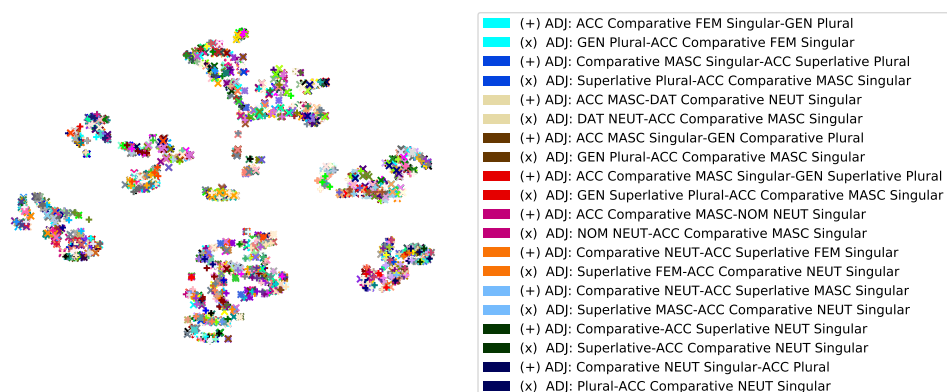

Figure 5: t-SNE visualization of all query words from German validation set embedded using the query encoder. Each word is represented by one point in the plot. A subset of the points are colored by the relation type that they represent
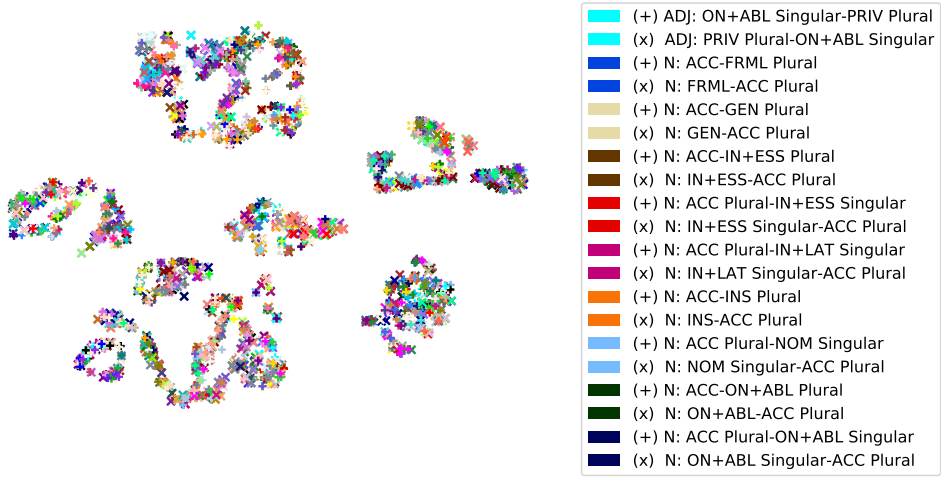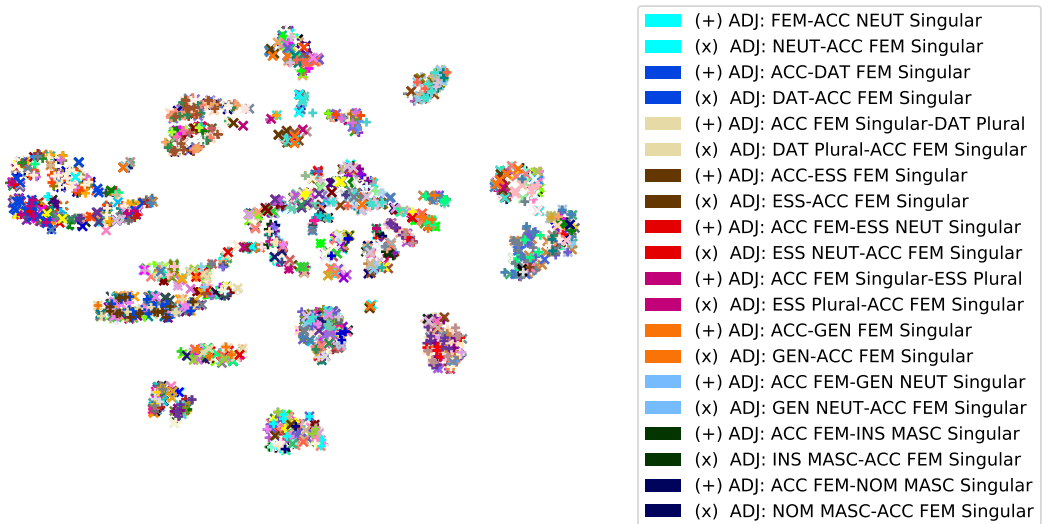
Figure 6: t-SNE visualization of all query words from Finnish validation set embedded using the query encoder. Each word is represented by one point in the plot. A subset of the points are colored by the relation type that they represent
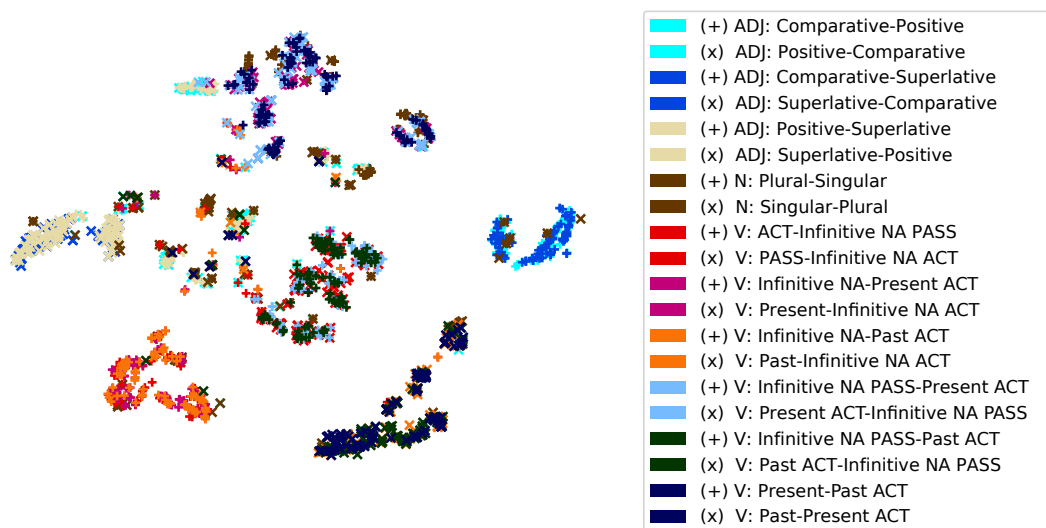

Figure 7: t-SNE visualization of all query words from Russian validation set embedded using the query encoder. Each word is represented by one point in the plot. A subset of the points are colored by the relation type that they represent

Figure 8: t-SNE visualization of all query words from Swedish validation set embedded using the query encoder. Each word is represented by one point in the plot, colored by the relation type that they represent