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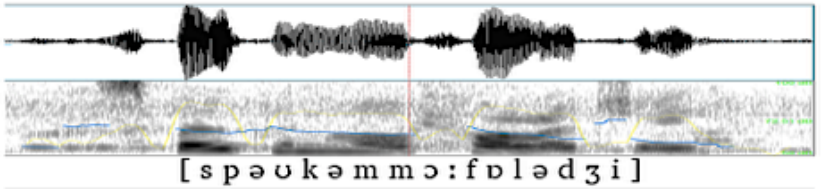

NDL Modeling of Maltese Plurals and Intuitions of Native Speakers

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Maltese Plurals

- 2 main strategies to build the plural of a noun:
  - **Sound Plural** *sptar – sptarijiet* 'hospital(s)'
  - **Broken Plural** *ballun – blalen* 'ball(s)'

- There is variation within the two different plural forms:
  - a number of sound plural suffixes, between 4 and 39 different broken plural patterns

- There is also variation in the choice of the plural forms:
  - *bandiera* (sg.) *bnadar* (broken pl.) vs. *bandieri* (sound pl.) 'flag'

Maltese Plurals: Predictability

- Is it possible to predict pluralisation of novel words?
- Can novel items be classified as broken or sound plurals?

Predicting Maltese Plurals: Previous accounts

- Farrugia & Rosner (2008) used an *artificial neural network* to compute broken plural forms on the basis of the classification of Schembri (2012)
- Results: the model did not perform well in generalizing to new forms
- Problem: neural networks usually use many hidden layers→ what are consequences for human learning?

Predicting Maltese Plurals: Previous accounts

- More recently: Drake & Sharp (2017) present an account that is based on different implementations of the generalized context model (GCM; see Nosofsky, 1990)
- Results: their best performing *restricted GCM* model had an accuracy of 77.3% (over 5-fold cross-validation)
  - GCM: classification based on similarity of existing items
  - restricted: classification of test forms only on categories that have the same CV patterns the model was trained on

Predicting Maltese Plurals: Our work

- Previous accounts focus on broken plural prediction only
  - ➢How to account for the choice of plural forms?

- We are using the *Naive Discriminative Learner* introduced by Baayen et al. (2011) to predict both, sound and broken plurals
  - ➢3 steps: Corpus → Production Experiment → NDL modeling

Maltese Plurals: Hypothesis

- The phonotactics of the singular determines the shape of the plural
- More frequent items are more likely to be generalized than infrequent items.

Maltese Plurals: Corpus

- Corpus of 2369 Maltese singular-plural pairs
- Words were taken from Schembri (2012) and an online corpus by Gatt and Čéplö (2013)
- Checked with *Ġabra:* online lexicon for Maltese (Camilleri, 2013)
- CV structure
- Corpus frequency number
- Number of syllables

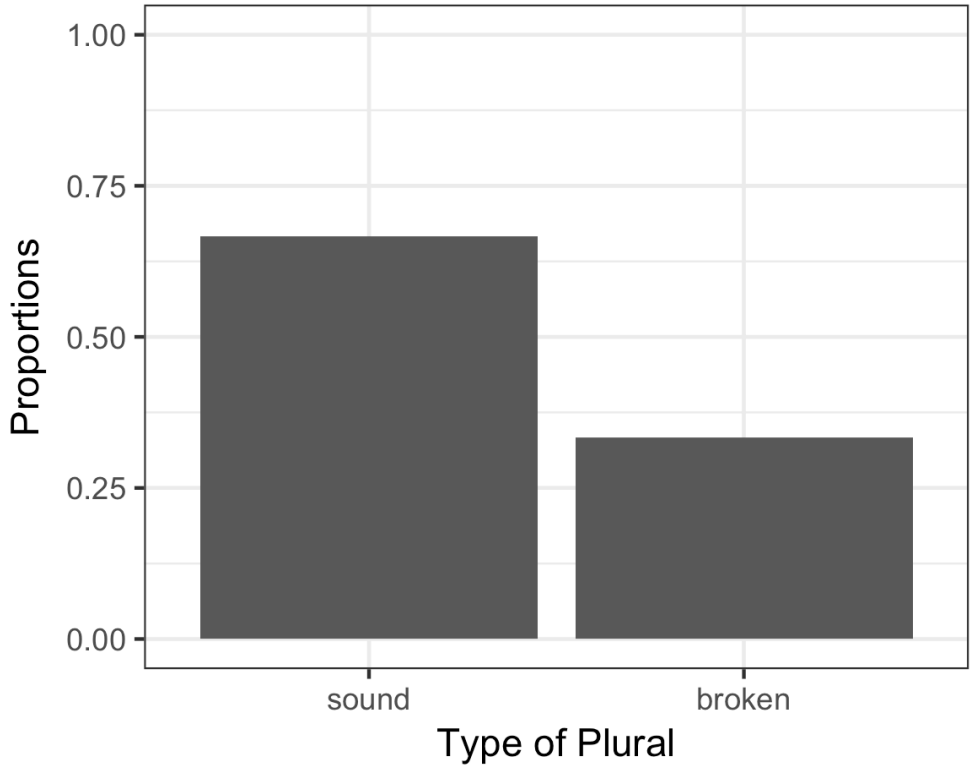


Figure: Distribution of plural types in Corpus

Maltese Experiment: Method

- **Production task with visual presentation**
- Maltese native speakers were asked to produce plural forms for existing Maltese singulars and phonotactically legal nonce singulars (Berko-Gleason, 1958)
- Nonce forms were constructed from words of our corpus of 2369 Maltese nominals by changing either the consonants or the vowels or both systematically, e.g.: sema ‚sky‘ —> fera soma fora
- The results are three lists of wug words: C, V, CV
- The words of our corpus used as base had either a sound plural form, a broken plural form or both plural forms: SP, BP, BOTH

Maltese Experiment: Stimuli

- We chose **90 nonce words**:
  - 30 from list C
    - 10 Base Broken Plural
    - 10 Base Sound Plural
    - 10 Base Both
  - 30 from list V
    - 10 Base Broken Plural
    - 10 Base Sound Plural
    - 10 Base Both
  - 30 from list CV
    - 10 Base Broken Plural
    - 10 Base Sound Plural
    - 10 Base Both
- And **22 existing nouns**:
  - 5 frequent sound plural words, 5 infrequent sound plural words
  - 5 frequent broken plural words, 5 infrequent broken plural words
  - 2 training items (1 sound plural, 1 broken plural)

Maltese Experiment: Results

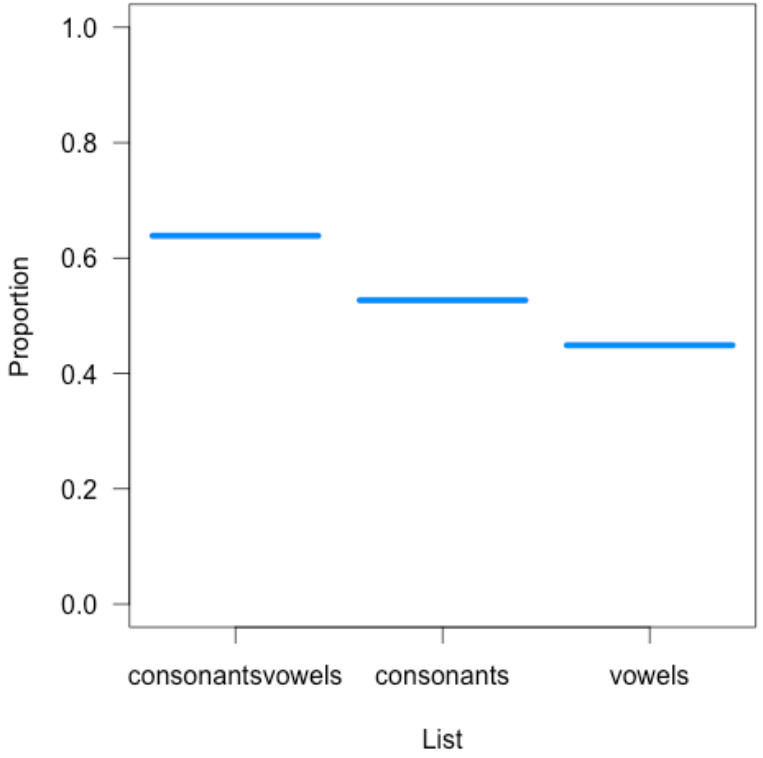
glmer with lme4 package (Bates, Maechler, Bolker & Walker, 2015)

dependent variable:
Answers of participants (binary, Sound or Broken Plural)

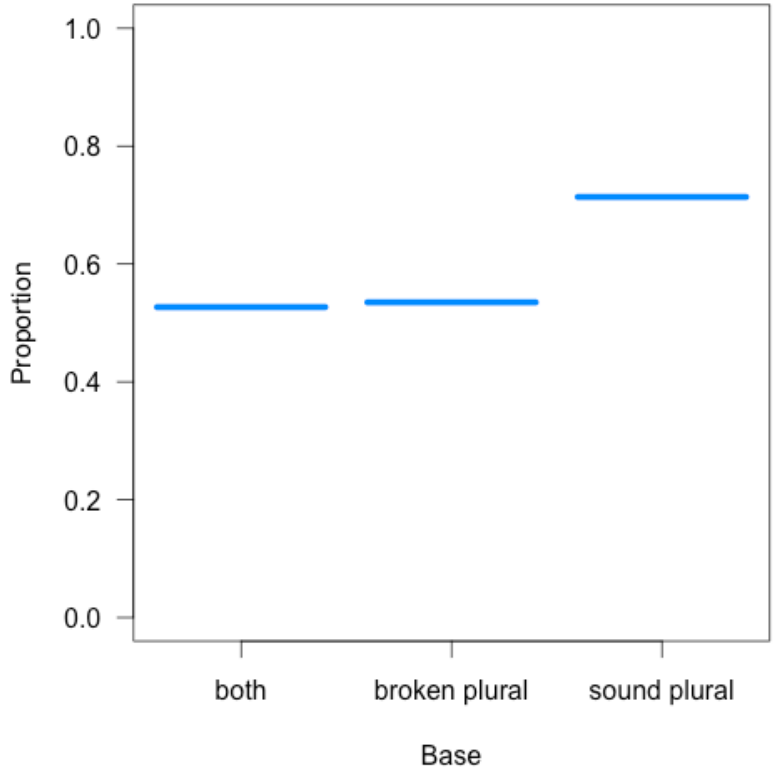
independent variables:
List = C, V, CV
Base =SP, BP, BOTH

random effects: Singular, Speaker

Maltese Experiment: Results – List & Base

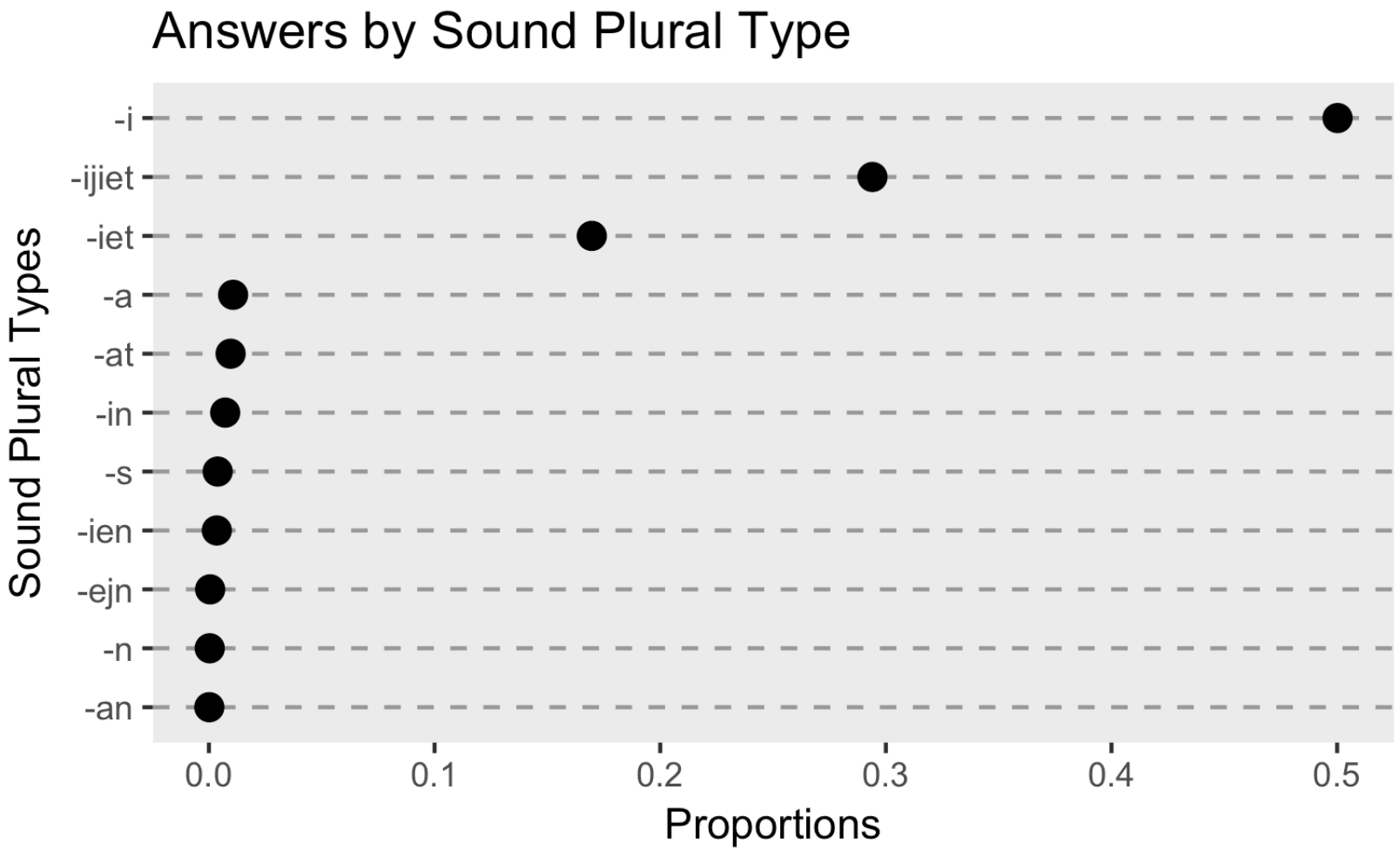


Significant difference between $List_{consonantsvowels}$ and $List_{vowels}$ ($p<0.001$)

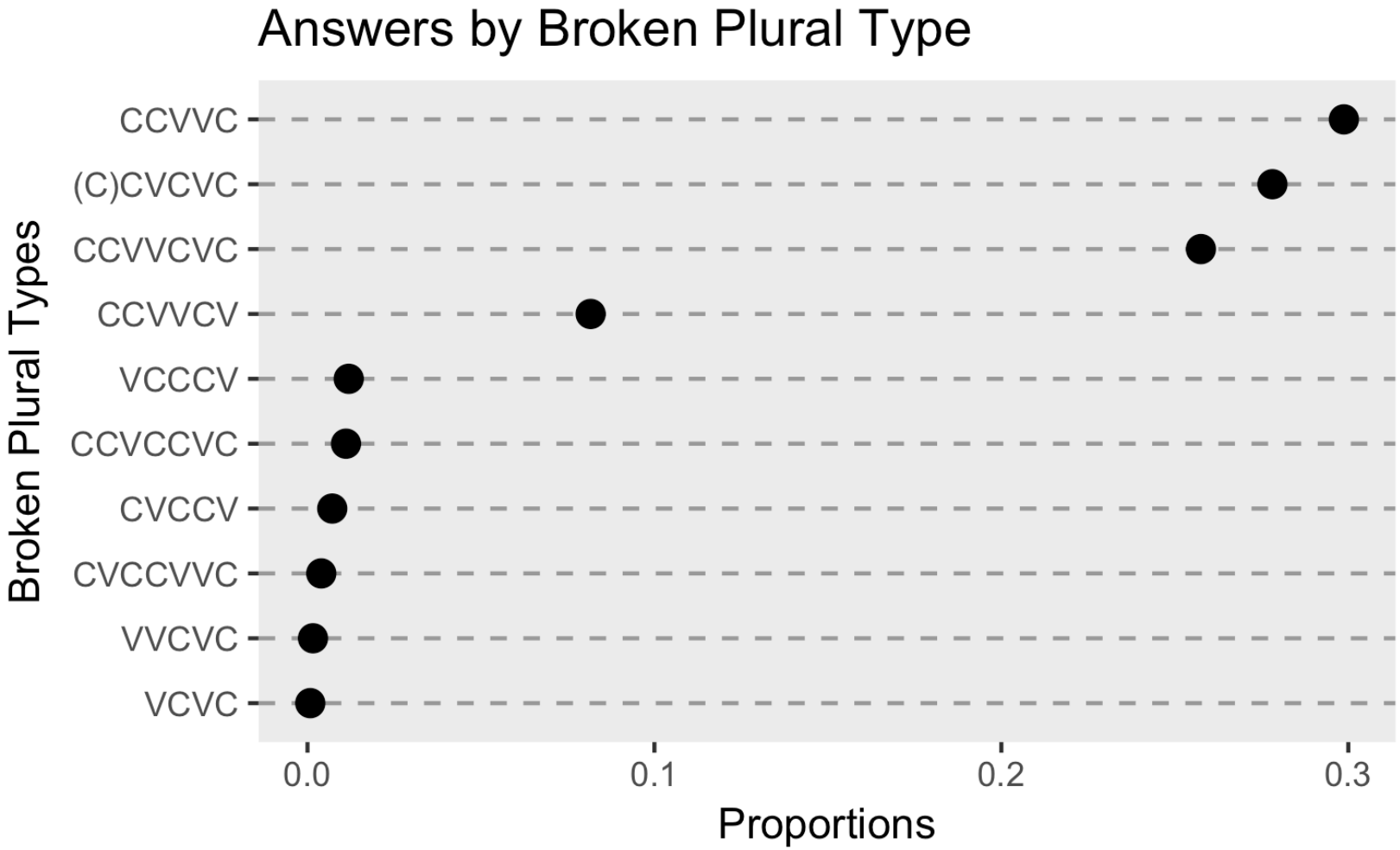


Significant difference between $Base_{brokenplural}$ and $Base_{soundplural}$ ($p<0.001$)

Maltese Experiment: Results – Sound Plurals



Maltese Experiment: Results – Broken Plurals



Maltese Experiment: Results – Existing Words

Frequent		Infrequent	
Sound	Broken	Sound	Broken
5 (of 400)	1 (of 400)	14 (of 400)	177 (of 400)
1,3%	0,3%	3,5%	44,3%

Table: Proportion of errors in plural forms for existing singular nouns

- Error Types: no answer, repetition of singular form, non-canonical plural forms = forms we do not find in the dictionary

Summary: Results so far

- Changing consonants and vowels influenced the choice of plural forms
- The plural form of the existing word used as base for nonce words influenced the choice of plural
- Participants produced broken plurals for nonce words with the most frequent CV structure, sound plurals for nonce words with most common suffixes

Naive Discriminative Learning

Baayen (2011), Baayen et al. (2011)

- Computational model of morphological processing
- NDL simulates a learning process
- Supervised learning
- Has been used successfully to model language acquisition (Ramscar, Yarlett, Dye, Denny & Thorpe, 2010)
- Central idea:

  learning = exploring how events are inter-related, they become associated (see also Plag & Balling, 2016)
- inter-related events: *Cues* and *Outcomes*

Naive Discriminative Learning

Baayen (2011), Baayen et al. (2011)

- Based on Rescorla-Wagner equations that are well established in cognitive psychology (Rescorla & Wagner, 1972)
- Associations between cues and outcomes at a given time, whereas the strength of an association, the association weight, is defined as follows (Evert&Arppe, 2015):

  - No change if a cue is not present in the input
  - Increased if the cue and outcome co-occur
  - Decreased if the cue occurs without the outcome

- Danks (2003) equilibrium equations: define association strength when a stable state is reached → „adult state of the learner“ (Baayen, 2011)
- Implementation as R package *ndl*

Naive Discriminative Learning

Baayen (2011), Baayen et al. (2011)

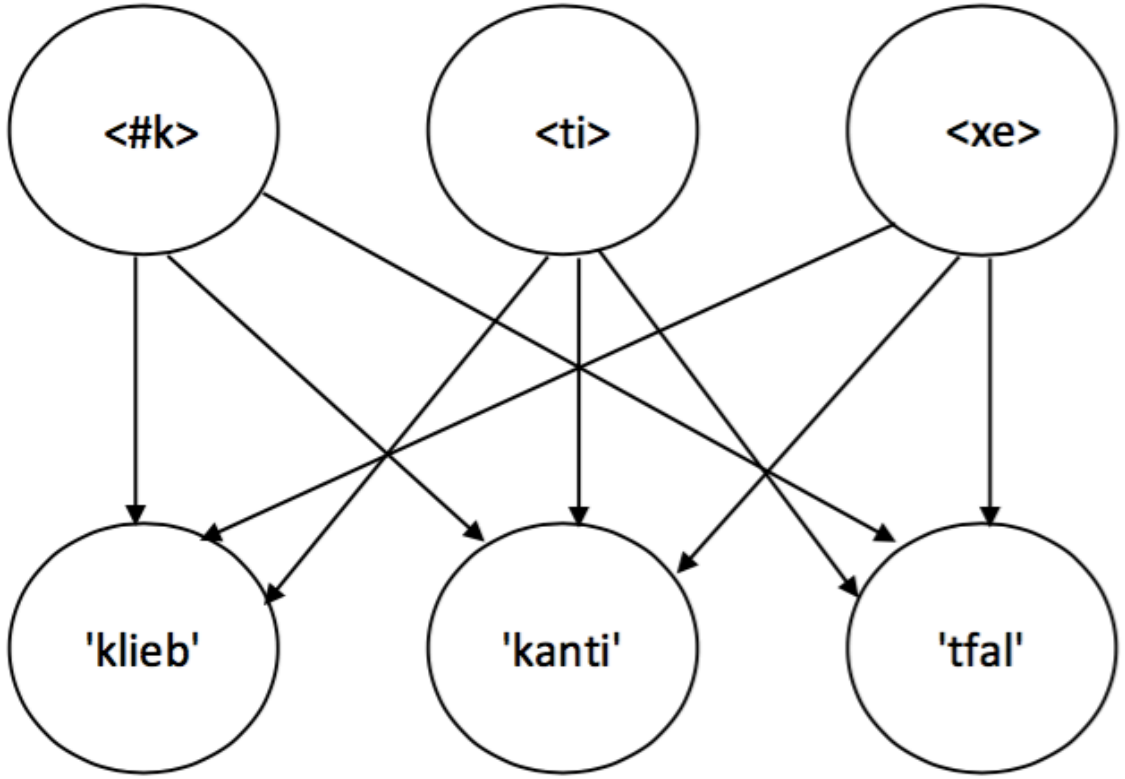


Figure: Association between Cues and Outcomes

Modeling our Data: Naive Discriminative Learning

- We trained the NDL model on our corpus
- We formulated our singular items in n-grams (unigrams, bigrams, trigrams) and calculated how the NDL learner would classify them

Singulars	Cues	Outcomes
esperiment ‘experiment’	#e_es_sp_pe_er_ri_im_me_en_nt_t#	sound plural
barma ‘twist’	#b_ba_ar_rm_ma_a#	sound plural
tokka ‘pen’	#t_to_ok_kk_ka_a#	broken plural
midwa ‘clinic’	#m_mi_id_dw_wa_a#	broken plural
qassis ‘priest’	#q_qa_as_ss_si_is_s#	sound plural

Table: Training data set for the NDL model using bigrams as cues

Modeling our Data: Naive Discriminative Learning

- The associations between cue and outcome are weighted
- We used NDL to predict classification of existing singular forms and nonce words

Cue	Broken Plural	Sound Plural
#k	-0.12	0.62
ke	0.42	-0.42
el	0.17	-0.17
lb	0.17	-0.16
b#	0.42	0.07
sum (kelb)	1,06	-0,06

Table: Example for NDL association weights predicting outcome „broken“ for singular *kelb* using bigrams as cues

Modeling our Data: Naive Discriminative Learning

- We compared the classification of participants with the prediction of different cue implementations in NDL
- What implementation best models the intuitions of native speakers on plural formation in Maltese?

Results: NDL model 1 – Unigrams as Cues

example:
kelb ‘dog’ → k_e_l_b

	broken	sound
broken	0.08	0.92
sound	0.05	0.95

Table: Classification of experimental items by NDL with unigrams as cues

- Very good prediction for sound plurals
- Very poor prediction for broken plurals

Results: NDL model 2 – Bigrams as Cues

example:
kelb ‘dog’ → #k_ke_el_lb_b#

	broken	sound
broken	0.59	0.41
sound	0.33	0.67

Table: Classification of experimental items by NDL with bigrams as cues

- Acceptable prediction for both plural types

Results: NDL model 3 – Trigrams as Cues

example:
kelb ‘dog’ → #ke_kel_elb_lb#

	broken	sound
broken	0.66	0.34
sound	0.52	0.48

Table: Classification of experimental items by NDL with trigrams as cues

- Good prediction for broken plurals
- Prediction for sound plurals are chance

Results: Discussion

- Trigrams are the best predictors for broken plurals – unigrams the worst
- Unigrams are the best predictors for sound plurals – trigrams the worst
  - Participants used sound plurals more often and corpus contains more sound plurals: when predicting plural forms with just one element of a word (=unigrams), sound plurals will be the default
  - Phonotactics (=trigrams= syllables) is especially important for broken plural predictions

Results: Discussion

- glmer model indicates that changing consonants and vowels influenced the choice of plural forms
- Can the NDL model capture this?
- How important are consonants and vowels for the NDL model?
- We changed vowels in cues to V, consonants to C to delete vowel and consonant identity:

  - barma ‘twist’ → #b_bV_Vr_rm_mV_V#
  - barma ‘twist’ → #C_Ca_aC_CC_Ca_a#

Results: NDL models – Vowels as V

unigrams

	broken	sound
broken	0.13	0.87
sound	0.06	0.94

example:
kelb ‘dog’ → k_V_l_b

bigrams

	broken	sound
broken	0.39	0.61
sound	0.25	0.75

example:
kelb ‘dog’ → #k_kV_Vl_lb_b#

trigrams

	broken	sound
broken	0.49	0.51
sound	0.42	0.58

example:
kelb ‘dog’ → #kV_kVl_Vlb_lb#

Table: Classification of experimental items with vowels in cues annotated as “V”

Results: NDL models – Consonants as C

unigrams

NDL not able to predict plural forms

example:
kelb ‘dog’ → C_e_C_C

bigrams

	broken	sound
broken	0.17	0.83
sound	0.06	0.94

example:
kelb ‘dog’ → #C_Ce_eC_CC_C#

trigrams

	broken	sound
broken	0.02	0.98
sound	0.02	0.98

example:
kelb ‘dog’ → #Ce_CeC_eCC_CC#

Table: Classification of experimental items with consonants in cues annotated as “C”

Results: Discussion

- When all consonants of the experimental items are changed to C we find very poor predictions for broken plurals, regardless of the size of gram
  - ➢Consonants are slightly more important for generalization of broken plurals!
- When all vowels of the experimental items are changed to V we find a slightly better performance for broken plurals (especially with bigrams and trigrams), nevertheless we cannot replicate the good results of our NDL model 2
  - ➢ an abstract representation of consonants and vowels makes the NDL model worse

Modeling our Data: Naive Discriminative Learning

- Let´s compare our results with other models that have been used with Arabic broken plural nouns:

➢Our best NDL model: 65.3%

➢Dawdy-Hesterberg & Pierrehumbert (2014) used modified versions of the Generalised Context Model (Nakisa, Plunkett & Hahn, 2001, Albright & Hayes, 2003): Accuracy of the models ranged between 55.31 – 65.97%

Discussion

- Native speakers are able to generalize to novel nouns and use the most common suffixes and CV patterns for this task
- Consonants and vowels are important for the generalizations of Maltese plurals as
  - changing consonants and vowels influenced the choice of plural form of participants and
  - using abstract representations influenced the performance of the NDL models.
- Phonotactics of the singular determines the plural form

Grazzi ħafna!

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