Pluralization in the grammar of native speakers: Phonotactics determines singular-plural mapping in Maltese

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Maltese

- Semitic language with characteristics of Maghrebi Arabic, influenced by Sicilian, Italian and English
- National language of Malta, other official language: English
- Spoken by about 400,000 people
2 main strategies to build the plural of a noun:

**Sound Plural**: concatenative via suffixation

*annimal* – *annimali* 'animal(s)'

**Broken Plural**: non-concatenative via internal restructuring of singular stem

*ballun* – *blalen* ‘ball(s)’

High amount of variation:

different sound plural suffixes, between 4 and 39 different broken plural patterns

*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?
Previous accounts focus on broken plural prediction only (Farrugia & Rosner, 2008; Drake & Sharp, 2017)

- Farrugia & Rosner (2008): artificial neural network → it did not generalize well to new forms

→ How to account for the choice of plural forms?
We are using the Naive Discriminative Learner by Baayen, Milin, Đurđević, Hendrix & Marelli (2011) to predict both, sound and broken plurals

- 3 steps: Data Set - Production Experiment - NDL modeling
Maltese Plurals

Hypothesis

1. The phonotactics of the singular determines the shape of the plural

2. More frequent items are more likely to be generalized than infrequent items
Maltese Experiment
Data Set

- We created a data set of 2369 Maltese nominals
- Words were taken from Schembri (2012) and an online corpus by Gatt & Čéplö (2013)
- Checked with Ġabra: online lexicon for Maltese (Camilleri, 2013)
- CV structure
- Corpus frequency number for each word
Figure 1: Distribution of Plural Types in our Data Set
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, 1958)
- Nonce forms were constructed from words of our data set 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 data set used as base had either a sound plural form, a broken plural form or both plural forms: SP, BP, BOTH
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 - List

glmer with lme4 package (Bates, Mächler, 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
Does the change of consonants, vowels or both to build nonce words have an effect on the produced plural type of the nonce words?
Figure 2: Results of glmer model with variable: List

Significant difference between List CV and List V (p<0.001)
Does the plural form of the existing word that has been used as a base for the nonce word have an effect on the produced plural type of the nonce words?
Figure 3: Results of glmer model with variable: Base

Significant difference between Base Broken and Base Sound (p<0.001)
-i and -ijiet are the most common suffixes in our data set, too.
According to Schembri (2012) the patterns CCVVC, (C)CVCVC and CCVVCVC are highly productive in Maltese.
Table 1: Proportion of pluralization errors for existing singular nouns

<table>
<thead>
<tr>
<th></th>
<th>frequent</th>
<th>infrequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>sound</td>
<td>5/400; 1.3%</td>
<td>14/400; 3.5%</td>
</tr>
<tr>
<td>broken</td>
<td>1/400; 0.3%</td>
<td>177/400; 44.3%</td>
</tr>
</tbody>
</table>

- Error = 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)

- Cognitive two-layer network
- 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 (Plag & Balling, 2016)
- Inter-related events: Cues and Outcomes
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*
Figure 4: Association between Cues and Outcomes
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

<table>
<thead>
<tr>
<th>Singulr</th>
<th>Cues</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>qassis ‘priest’</td>
<td>#q_qa_as_ss_si_is_s#</td>
<td>sound plural</td>
</tr>
<tr>
<td>tokka ‘pen’</td>
<td>#t_to_ok_kk_ka_a#</td>
<td>broken plural</td>
</tr>
</tbody>
</table>

Table 2: 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

<table>
<thead>
<tr>
<th>Cue</th>
<th>Broken Plural</th>
<th>Sound Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td>#k</td>
<td>−0.12</td>
<td>0.62</td>
</tr>
<tr>
<td>ke</td>
<td>0.42</td>
<td>−0.42</td>
</tr>
<tr>
<td>el</td>
<td>0.17</td>
<td>−0.17</td>
</tr>
<tr>
<td>lb</td>
<td>0.17</td>
<td>−0.16</td>
</tr>
<tr>
<td>b#</td>
<td>0.42</td>
<td>0.07</td>
</tr>
<tr>
<td>sum</td>
<td>1.06</td>
<td>−0.06</td>
</tr>
</tbody>
</table>

Table 3: Example for NDL association weights predicting outcome „broken“ for singular *kelb*
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?
example: kelb = k_e_l_b ’dog’

<table>
<thead>
<tr>
<th></th>
<th>broken</th>
<th>sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>broken</td>
<td>0.08</td>
<td>0.92</td>
</tr>
<tr>
<td>sound</td>
<td>0.05</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Table 4: Classification of experimental items by NDL using unigrams as cues

- Very good prediction for sound plurals
- Very poor prediction for broken plurals
Example: \texttt{kelb = \#k\_ke\_el\_lb\_b\# 'dog'}

<table>
<thead>
<tr>
<th></th>
<th>broken</th>
<th>sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>broken</td>
<td>0.59</td>
<td>0.41</td>
</tr>
<tr>
<td>sound</td>
<td>0.33</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Table 5: Classification of experimental items by NDL using bigrams as cues

- Acceptable prediction for both plural types
Modeling our Data: Naive Discriminative Learning
Results - Trigrams as Cues

Example: kelb = #ke_kel_elb_lb# 'dog'

<table>
<thead>
<tr>
<th></th>
<th>broken</th>
<th>sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>broken</td>
<td>0.66</td>
<td>0.34</td>
</tr>
<tr>
<td>sound</td>
<td>0.52</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Table 6: Classification of experimental items by NDL using 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
- 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

**Vowel as V**

<table>
<thead>
<tr>
<th></th>
<th>broken</th>
<th>sound</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>unigrams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>broken</td>
<td>0.13</td>
<td>0.87</td>
</tr>
<tr>
<td>sound</td>
<td>0.06</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>bigrams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>broken</td>
<td>0.39</td>
<td>0.61</td>
</tr>
<tr>
<td>sound</td>
<td>0.25</td>
<td>0.75</td>
</tr>
<tr>
<td><strong>trigrams</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>broken</td>
<td>0.49</td>
<td>0.51</td>
</tr>
<tr>
<td>sound</td>
<td>0.42</td>
<td>0.58</td>
</tr>
</tbody>
</table>

**Table 7**: NDL models with vowels in cues changed to “V”
### Results

**Consonants as C**

<table>
<thead>
<tr>
<th></th>
<th>broken</th>
<th>sound</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>bigrams</strong></td>
<td>broken 0.17</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>sound 0.06</td>
<td><strong>0.94</strong></td>
</tr>
<tr>
<td><strong>trigrams</strong></td>
<td>broken 0.02</td>
<td><strong>0.98</strong></td>
</tr>
<tr>
<td></td>
<td>sound 0.02</td>
<td><strong>0.98</strong></td>
</tr>
</tbody>
</table>

**Table 8:** NDL models with consonants in cues changed to “C”
- 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
Let’s compare our results with other models that have been used with Arabic broken plural nouns:

- Our best NDL model: 65.3%
- Pierrehumbert (2002) used modified versions of the Generalised Context Model (Nakisa, Plunkett & Hahn, 2001; Albright & Hayes, Albright & Hayes): Accuracy of the models ranged between 55.31 – 65.97%
→ Is it possible to predict pluralisation of novel words?
→ Can novel items be classified as broken or sound plurals?
  - 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!


We thank Holger Mitterer for offering us the opportunity to use the Cognitive Science Lab at the University of Malta for conducting our experiment. We thank our colleagues from the DFG-Research Unit FOR2373 and our colleagues from the Għaqda Internazzjonali tal-Lingwistika Maltija for their advice and feedback.
In total:

**5404 sound plural** answers for wug words only
(6387 for wugs + existing words)

**1262 broken plural** answers for wug words only
(1986 for wugs + existing words)