Entropy measures and predictive recognition as mirrored in gating and lexical decision over multimorphemic Hungarian noun forms

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Talk at the workshop
Quantitative measures in morphology
and morphological development

UCSD Center for Human Development, January 15-16, 2011
The team
Csaba Kornél Dani Klára Judit
Outline

- The relevance of information theory for word processing
- The structure of Hungarian nouns and entropy
- Gating studies on word stem and information value
- Scrambled words and the onset superiority
- Effects of morphological complexity and information value on lexical decisions
Stages in the relevance of Info Theory for language

- Early enthusiasm
- Severe critic
- New possibilities:

- 1950 Shannon
- 1960 Chomsky
- 1990 Kostic

- Miller
- G. Miller
- Saffran
Early proposals for info theory related morphology

- Antal László (1964) over words, the tendency is gradually decreasing entropy. Morpheme boundaries correspond to sudden drops in entropy.

- \textit{igaz-ság-os-ak-at} \textit{‘true-th-full-Plur-Accus’ truefulls}

Morphemes are identified by plateaus of entropy.
Structure of Hungarian nouns

- stem – derivation – possession- possPlu- PossPers- Possessed- Plural-case

It is easy to assign numbers for these arborizations:
- number of branches
- token and type entropies
- at different decision points
Structure of Hungarian nouns

Illustration: a small subtree of the tree of possible Hungarian noun inflections. The full tree is about 50 times larger.
Inflectional suffixes

ház  house

ház-at house ACC

ház-ak housePlur

ház-am house-PossMe

ház-ak-at housePlurAcc

ház-a-m-at housePoss1stSingAcc
Derivational suffixes

ház *house*

ház-as ‘*housey*’ i.e. *married*

ház-as-ság ‘*house-y-ness*’ i.e. *marriage*
Both derivation and inflection

- ház house
- ház-as-ság marriage
- ház-as-ság-a-i-m-ban marriage
  PossPlur1stSing-IN
  ‘in my marriages’
Issues of morphology processing

1. Segmentation: morfotactics, primacy
2. Lexical access: analytic, holistic, mixed acoustic and orthographic access files
3. Formal combinatorics: arguments
4. Semantic integration: transparency issues
5. Stem allomorphy: ? Separate routes?
Series of studies

- Gating
- Scrambling reconstruction
- Lexical decision

**Questions**
- Role of entropy related predictability in recognition
- The primacy issue in word recognition
- What happens with morphologically complex word forms?
Gating

- Four types of words

<table>
<thead>
<tr>
<th></th>
<th>Rare</th>
<th>Frequent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>böllér</td>
<td>kenyér</td>
</tr>
<tr>
<td></td>
<td>pigsticker</td>
<td>bread</td>
</tr>
<tr>
<td>Late</td>
<td>pincsi</td>
<td>város</td>
</tr>
<tr>
<td></td>
<td>pekingese</td>
<td>town</td>
</tr>
</tbody>
</table>
WEB based study

- Frequent words were recognized in 300 msecs.
- Rare words at the longest presentation.

<table>
<thead>
<tr>
<th>Time (msecs)</th>
<th>90</th>
<th>120</th>
<th>210</th>
<th>300</th>
<th>390</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of correct responses (%)</td>
<td>0.00</td>
<td>5.00</td>
<td>10.00</td>
<td>15.00</td>
<td>20.00</td>
</tr>
</tbody>
</table>

- Rare Early Uniqueness Point
- Rare Late Uniqueness Point
- Frequent Early Uniqueness Point
- Frequent Late Uniqueness Point

frequent words were recognized in 300 msecs.
rare words at the longest presentation.
Lab gating study

clear interaction between uniqueness point and frequency
Instructions also have a top down effect

Effects of constraints, frequency, and uniqueness points on gating recognition.

Constraint: dysyllabic noun instruction
Summary of the gating effects

- a syllable length segment can lead to 50 percent correct recognition in line with prediction e.g. from cohort theory
- this is related to the uniqueness point issue as well, the more rivals to a word, the later the recognition point.
- frequency facilitates recognition
- in rare words there is a more strictly bottom up recognition process, competing neighbors have no effect in their case.
- top down effect of constraints in the instructions: grammatical and morphotactic constraints also played a role in Hungarian.
Comparing with the MOKK corpus based entropies

<table>
<thead>
<tr>
<th>corpus</th>
<th>pages (million)</th>
<th>token (million)</th>
<th>type (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>full</td>
<td>3,5</td>
<td>1486</td>
<td>19,1</td>
</tr>
<tr>
<td>60% Foreign excluded</td>
<td>3,125</td>
<td>1310</td>
<td>15,4</td>
</tr>
<tr>
<td>92% Only text with diacritics</td>
<td>1,918</td>
<td>928</td>
<td>10,9</td>
</tr>
<tr>
<td>96% Typos as in normal text</td>
<td>1,221</td>
<td>589</td>
<td>7,2</td>
</tr>
</tbody>
</table>
Effects of entropy: different indicators

- **prefixtypeoccurrenceslog** number of word forms in the corpus starting with the given prefix. We work with the base 2 logarithm of this value.

  - **prefixfreqlog** – Number of tokens in our corpus starting with the given prefix. (logarithm)
  - **entropy** – Entropy of the corpus, conditioned on the given prefix. Informally, it is our amount of uncertainty about an unknown word from the corpus, when we are told its prefix. Formally, it is defined as

    \[
    H(W \mid x) = \sum_{w \in W} p(w \mid x) \log_2 p(w \mid x)
    \]

- **entropychange** – The decrease in entropy when compared to the previous gate.
Entropy is greater in frequent words at point 4

Uniqueness point: decrease in entropy
Gating gates for the different entropy and word competition effects
Entropy and uniqueness point

Entropy has a statistically significant relationship with recognition rate, even when we control for uniqueness point and frequency.
Entropy effects

- All measures have a significant effect on recognition rate.
- The effect of entropy change (a highly non-monotonous function of prefix-length) means that the recognition point follows a sudden drop of the entropy value, which is the hypothesis we started from.
- The effect of entropy when controlled for uniqueness point can be interpreted as showing that entropy is a refinement of the naive uniqueness point metric.
The importance of beginnings: reconstruction of scrambled words

Percent correct guesses

<table>
<thead>
<tr>
<th></th>
<th>Begin+End</th>
<th>Begin</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>szitimkus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sötbténe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mléény</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The priming study

RROBLÉMA
Priming effect of beginnings: spoiled word slows down at beginning and end
Decisions over long multimorphemic words: Pléh and Juhász 1995

bathtub effect
Aithchison
### Systematic study

- **stem**  
  `böllér`  
  ‘sticker’

- **plural**  
  `böllér-ek`  
  ‘stickers’

- **case**  
  `böllér-nek`  
  ‘stickerDAT’

- **Plur + case**  
  `böllér-ek-nek`  
  ‘stickersDAT’
böllérnek
Correctness of acceptance-rejection as a function of word structure

The diagram shows the proportion of correct responses (%) across different error conditions: correct, error in stem, vowel harmony error in marker, non-existing marker, vowel harmony error in case, and non-existing case. The graph compares 'Rare' and 'Frequent' error conditions.
Reaction time data in the lexical decision task

Response times (ms)

- Rare
- Frequent

correct  error in stem  vowel harmony error in marker  non existing marker  vowel harmony error in case  non existing case
Paired comparions

Correct forms were slower to be accepted.
Non existing stems were slower to be rejected than non existing markers (i.e. word middle errors) or case markers.
No clear bath tub effect in the reaction times.
Word ending case marker errors were recognized slower.
In frequent items word middle distortions lower performance

Prop. of correct resp. (%)
Reaction times in both frequent and rare items are fast in word middle non-existing form errors.
Planned further analysis

• Correlate decisions and times with rivaling tokens at the manipulated point
• Correlate with different entropy measures
• Combined entropy of the stems and the endings
Summary

• There is a strong word onset primacy in Hungarian as well
• Word recognition is more sensitive to entropy values and morphological structure than to frequency itself
• Entropy change is important in explaining neighborhood effects