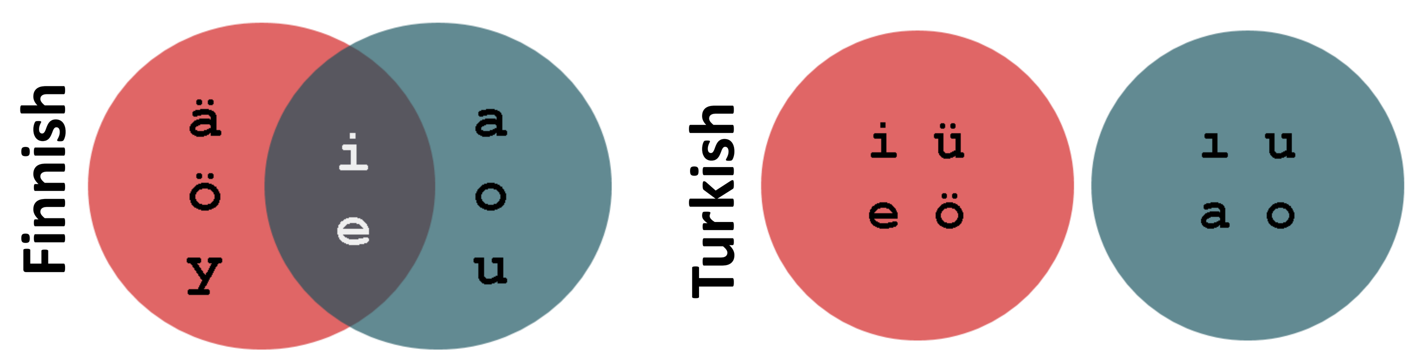
# The Acquisition of Vowel Harmony from Simple Local Statistics

Spencer Caplan Jordan Kodner

University of Pennsylvania

## Vowel Harmony

- **System-wide vowel alternation patterns** in languages across the world
- Affects roots and affixes, and languages may have multiple processes
- Vowels are either **neutral** or **harmonizing**. Harmonizing vowels are partitioned into sets.
- Generally, **words contain vowels from only one harmonizing set**




- **"Spreading" of phonological features**
  Frontness (Turkish, Finnish…)
  ATR (Mongolian, Fula…)
  Roundess (Turkish, Warlpiri…)
- **Turkish**
  baş-lar vs. beşev-ler
- **Finnish**
  …kissansakaankopahan vs.
  …myydellänsäkäänköhän

## Early Acquisition

- Infants **as young as seven months** are sensitive to vowel harmony alternations in acoustic input in preferential listening over continuous unsegmented speech [4]

**A computational model should:**

- **Connect raw input to phonological theory**
- **Require little data** and function over unsegmented speech (rather than individual words from a wordlist)
- **Leverage plausible cognitive tools** (online processing, simple calculations, innate ability to differentiate consonants and vowels) [1]

## Distributional Hypothesis

1. **In non-harmonizing languages** (eg English), no particular vowels should be more or less likely to follow one another **(near-uniform co-occurrence distribution)**
2. **In harmonizing languages** (eg Turkish, Finnish), **we expect strongly non-uniform co-occurrence distributions,** since vowel co-occurrence is partitioned by the phonology

## Model Implementation

1. **Over word list OR unsegmented input,**
2. **Tabulate vowel co-occurrence matrix** counting adjacent vowels ignoring consonants
3. **Convert to normalized conditional probabilities**
4. **Remove neutral vowels** with *normP* consistently below threshold proportional to vowel set cardinality
5. **Find featural partition** (eg online k-means clustering, k=2)
6. **Collapse over features and repeat.**

**Example Input:** *kababesisata*

**Co-occurence Matrix:**

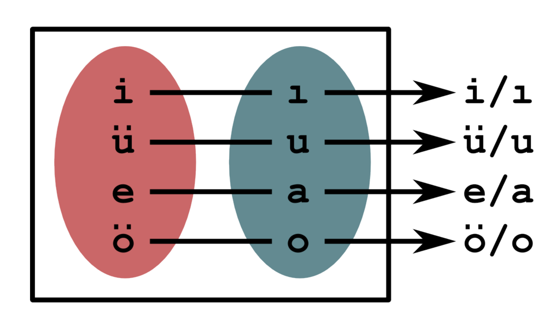
| | A | E | I |
|---|---|---|---|
| A | 2 | 0 | 1 |
| E | 1 | 0 | 0 |
| I | 0 | 1 | 0 |

**Vowel Freqs:**
$C(a)=4, C(e)=1, C(i)=1$

**Probs:** $P(a)=4/6, P(e), P(i)=1/6$

$$normP(a|e) = \frac{C(a|e)}{C(a)P(e)}$$

$$Threshold = \frac{0.5}{\#Vowels}$$




## Results

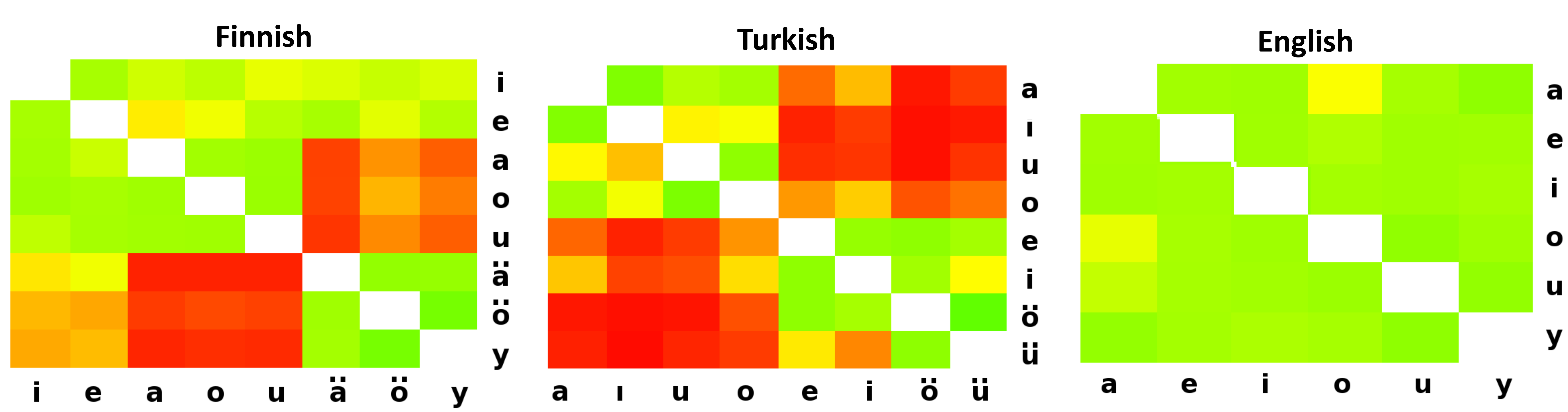
| Language | Primary | Secondary | Neutral Vowels | Harmony Found |
|---|---|---|---|---|
| Hungarian | yes | yes | 2 | **Primary only** |
| Turkish | yes | yes | (2ary only) | yes |
| Finnish | yes | - | 2 | yes |
| Warlpiri | yes | - | 1 | yes |
| Uyghur | yes | - | - | yes |
| Estonian | remnant | - | - | **finds remnant** |
| German | - | - | - | no |
| English | - | - | - | no |

- **Primary harmony correctly partitioned for all harmonizing languages.**
- Secondary harmony was discovered for **Turkish**.
- No harmony identified for **English** and **German**.
- Partial historical system discovered for **Estonian**
- **Hungarian** results depend on removing vowel length from orthography.

## Empirical Questions

- Is primary harmony in fact acquired first?
- Are children sensitive to more complex harmony processes early on?
- Must harmony function over a single phonological feature?
- How do learners differentiate productive harmony (eg Finnish, Turkish) from non-productive (eg Estonian, Uzbek)? (cf [5])
- How helpful is harmony in word segmentation tasks?
- What minimum signal-to-noise ratio is necessary? Harmony exceptions (eg common in Turkish) and average word length in infant-directed-speech affect this.

## Distributional Cues




- Heatmaps showing *normP* for each vowel pair in Finnish, Turkish, and English
- **Red** indicates low *normP* (unlikely to co-ocur) and **Green** is high *normP*
- Self-*normP* is omitted
- The distribution for **English** (non-harmonizing) is **near-uniform**
- **Turkish** is clearly partitioned into its **two harmonizing sets**
- **Finnish neutral i and e are distinct** from harmonizing vowels

## Acknowledgements

We thank Charles Yang, Mitch Marcus, Ryan Budnick, the University of Pennsylvania's 2016 LORELEI research team, and the Penn Language Development and Language Processing Lab. This research was funded by the DARPA LORELEI program under Agreement No. HR0011-15-2-0023.

## Selected References

**[1]** Aslin, Richard N., Jenny R. Saffran, and Elissa L. Newport. Psychological science 9.4 (1998): 321-324. **[2]** Clements, George N. Bloomington: Indiana University Linguistics Club (1976). **[3]** Goldsmith, John, and Jason Riggle. Natural Language & Linguistic Theory 30.3 (2012): 859-896. **[4]** Mintz, Toby et al.*Cognition* 171 (2018): 95-107. **[5]** Yang, Charles. Linguistic variation yearbook 5.1 (2005).

## Code and Contact

**https://github.com/scaplan/VowelHarmonyAcquisition**

{spcaplan, jkodner}@sas.upenn.edu