Efficient Rule Scoring for Improved Grapheme-Based Lexicons

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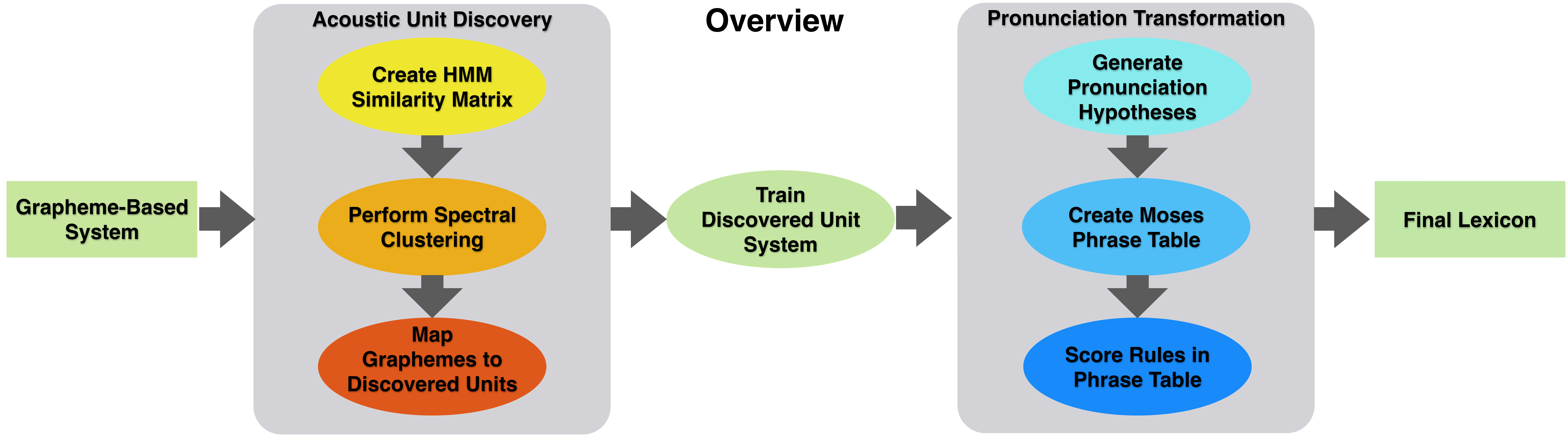
Introduction

- Unlike the other main components of an ASR system, the pronunciation lexicon is largely handmade.
- Low-resource languages may not have expert-defined lexicons.
- We propose a two-stage approach to learning both the lexicon and the underlying acoustic units.
- Our approach relies on an initial baseline grapheme-based system.
- Acoustic units are learned by clustering the context-dependent grapheme-based models.
- Pronunciations are generated by transforming the original lexicon with an SMT-based approach.
- Each individual stage produces a significant improvement over the baseline system.
- Combined, the approach reduces the relative word error rate by 16%.

Overview



Acoustic Unit Discovery

- Acoustic units are discovered by clustering context-dependent grapheme-based HMMs.
- Requires defining a similarity measure between individual HMMs (Equation 1).
- CSD is the Cauchy-Schwarz Divergence measure (Equation 2).
- We use the CSD because a closed form solution for a Mixture of Gaussians exists.

$$\mathrm{HMM}_{\mathrm{sim}}(\mathbf{h},\mathbf{h}') = \sum_{a=1}^{A}\sum_{b=1}^{B} \frac{\alpha_{a,b}}{\mathrm{CSD}(h_a, h'_b)+1}$$

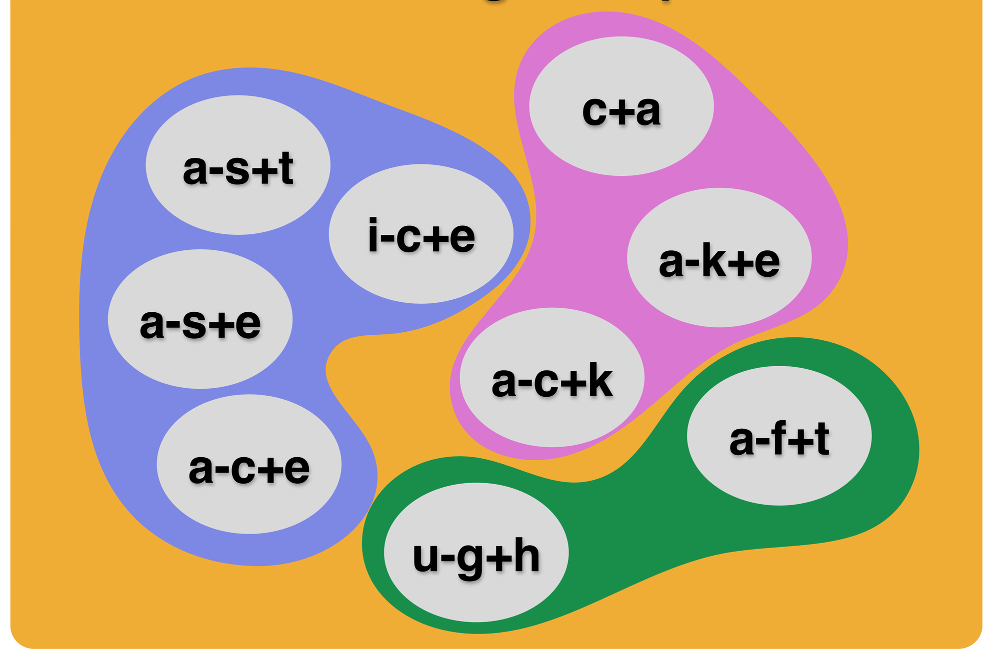
Equation 1

$$\mathrm{CSD}(\mathbf{p},\mathbf{q}) = -\log \frac{\sum_i p_i q_i}{\sqrt{\sum_i p_i^2 \sum_i q_i^2}}$$

Equation 2

- Clustering is performed using spectral clustering.
- We achieved better performance with a k-nearest neighbor similarity graph rather than a similarity matrix.
- Since the optimal number of acoustic units is not known a priori, we tried various numbers of clusters.
- The final clusters group acoustically similar context-dependent HMMs into a single acoustic unit.

Clustering Example



- Based on the clustering, pronunciations are mapped to the new acoustic units.
- Each pronunciation will have the same number of units as in the baseline grapheme-based lexicon.
- The new acoustic units are labeled as numbers since no other label exists.

Pronunciation Mapping

l a u g h →	u3 u2 u9 u4 u8
f a c e →	u4 u2 u5 u7
c a k e s →	u6 u2 u6 u7 u5

Pronunciation Transformation

- Context-dependent acoustic models are trained.
- The training data is decoded in terms of the acoustic units.
- Based on the time-aligned results, each word in the training set has one or more pronunciation hypotheses.
- The example shown uses grapheme units for clarity.

lack	l a k
lack	l e k
lochs	l o c x s
necessary	n e s e s r y
ford	f r d
ford	f r n
caught	k o t

- Using Moses, a phrase table is learned from the pronunciation hypotheses.
- Each entry in the table represents the translation of a sequence of acoustic units into an alternate sequence.
- Moses allows for reordering of units, but we disable this option for our work.
- The phrase table can transform the pronunciations in the original lexicon.

Source	Target	*p(t | s)*
a c k	a k	0.19
c h s	c x s	0.13
c e s s a	s e s e	0.36
f o r d	f r d	0.17
a u g h t	o t	0.25

- The initial translation table decreases performance, so we prune the table.
- Rules are rescored with a single pass.
- The score is based on how often a rule is used for the best pronunciation for a word during forced alignment.
- Only rules that surpass a certain threshold are kept.
- The final transformation works for words unseen during training.

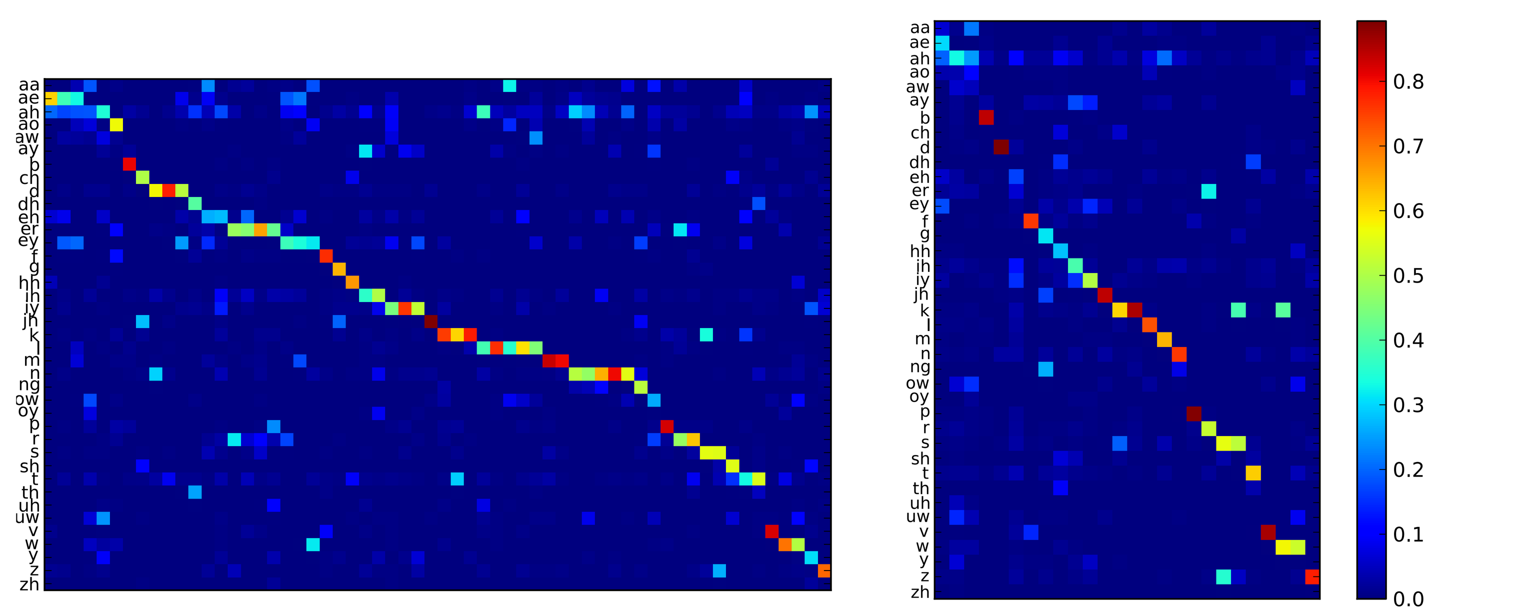
Source	Target	Score
a c k	a k	0.65
c h s	c x s	0.48
c e s s a	s e s e	0.51
f o r d	f r d	0.03
a u g h t	o t	0.08

Results

- WER results are presented on the WSJ0 5k word task.
- Acoustic models are trained with HTK.
- All recognizers use context-dependent models with 2000 tied states.

Unit Type	# Units	Direct	Trans.
Grapheme	26	15.8	14.2
Discovered	39	15.0	13.3
Discovered	50	15.2	14.1
Discovered	60	**14.4**	**13.2**

- Decoding is performed with a bigram LM.
- Direct refers to the lexicon after mapping, and Trans. refers to the lexicon after pronunciation transformation.
- The figures below demonstrate the correlation between the discovered units and phones, and the grapheme units and phones.



Discovered 60 **Grapheme**

- We have proposed a two-stage approach for acoustic unit discovery and pronunciation generation that reduces relative WER by 16% compared to a baseline grapheme-based system.
- We are currently working to apply these techniques to other languages.

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