1. TTS and ASR: A synthesis
   - Introduction
   - ASR
   - HMM based TTS
   - Bibliography

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Introduction

Classical
TTS: Text $\Rightarrow$ Accents $\Rightarrow$ Phonemes $\Rightarrow$ Prosody $\Rightarrow$ Sound
ASR: Sound $\Rightarrow$ MFCC $\Rightarrow$ HMM $\Rightarrow$ Language Model $\Rightarrow$ Text

TTS and ASR: Two unconnected technologies?

- Both synthesis and recognition work by comparing speech to a stored model
- Recognition works by synthesizing speech
- Synthesis works by reproducing stored speech
- Can a synthesizer really be used to recognize?
- Can a recognizer really be used to synthesize?
Introduction

New and Improved

ASR: Text ⇔ Accents ⇔ Phonemes ⇔ Prosody ⇔ Sound?

TTS: Sound ⇔ MFCC ⇔ HMM ⇔ Language Model ⇔ Text?

TTS and ASR: Recognize by synthesis, or synthesize by recognition

- Both synthesis and recognition work by comparing speech to a stored model
- Recognition works by synthesizing speech
- Synthesis works by reproducing stored speech
- Can a synthesizer really be used to recognize?
- Can a recognizer really be used to synthesize?
Introduction: The computational challenge

There is no data like more data, but how to use it?

- Computers become exponentially faster over time
- Speech corpora become exponentially larger over time
- Current HMM speech recognition only marginally better than 10 years ago
- Current synthesis idem
- How can computer speed and corpus size be harnessed?
ASR: Standard HMM

Problems in HMM

- Conditional Independent and Identical Distribution (IID)
- Speech can be described as a sequence of discrete units (phonemes)
- Strip all non-verbal (indexial) information
- Cannot use indexial information (e.g., coarticulation)
- Adapt to rate, hypo/hyperarticulation
- ⇒ standard HMM models cannot store enough information
ASR: Structure-based approach

Model the parameters of speech production

- Establish mathematical models for stochastic trajectories or segments
- Eg, piecewise polynomials, linear dynamic systems, nonlinear dynamic systems
- Model speech dynamics i.o. acoustics (hypo/hyperarticulation, rate)
- Hidden dynamic models look at articulation
  ⇒ Articulatory Synthesis
- Combine hidden dynamic vectors with observed acoustic feature vectors
- ⇒ Explicitely model and train other factors
Speech contains two types of information

- Verbal information
- Indexial (non-verbal) information
- Words versus Form
- HMM handles the words, but not the Form
- Form includes $F_0$ and speaking rate
- Form also includes speaker specific information
- Fine phonetic detail can influence recognition
- Eg, 1st syllable of *ham* versus *hamster*
- ASR model needed that can handle indexial information
ASR: Speech recognition by unit synthesis

HMM derives abstract model from examples

- Don’t abstract, use examples directly
- Store speech of many speakers
- For each speaker, store lots of speech (words)
- Store different styles of speech, and label them
- $\Rightarrow$ Template-, exemplar-, instance- based ASR
ASR: Template based

- Store as much speech as possible
- Add transcriptions and labels
- Store all indexial and textual information
- What was said, by whom, and how
- Words are stored as many example feature vectors “trajectories”
- Preserving as many details as possible
- Incoming signal is compared to sequences of trajectories
Train knowledge sources of a template based recognizer

1. Segment and transcribe the training database. The result is a segmentation file with phoneme transcriptions and phonetic boundary timings.
2. Merge consecutive segments at will to produce supra-phonemic templates.
3. Determine meta-information for each segment.
4. Determine suitable transition costs to each pair of possible meta-tags.
5. Assign suitable acoustic scaling matrices for each frame in the database.
6. Calculate an indexing structure for fast k-nearest neighbours selection.
7. Compute weights to combine the different knowledge sources.
A template is the representation of an actual segment of speech. It consists of:

- a sequence of consecutive acoustic feature vectors (or frames)
- a transcription of the sounds or words it represents (typically one or more phonetic symbols)
- knowledge of neighbouring templates (a template number if no templates overlap)
- a tag with meta-information
Correspondence between HMM and Template based ASR

- Distances are calculated to template cluster centroids
- Clustered acoustic vectors are a kind of degenerated HMM
- Train the costs of going from one template (fragment) to another

[De Wachter et al.(2007)De Wachter, Matton, Demuynck, Wambacq, Cools, and Van Compernolle]
HMM based TTS: The challenge of TTS

There is never enough speech

- Every utterance and situation are different
- “Expressive” speech needs even more different utterances
- Recording a new speaker for every new application is not acceptable
- Speaker time becomes limiting factor
- ...and it is never enough
HMM based TTS: Speech synthesis by HMM recognition

Unit selection is inflexible

- Speech units cannot be adapted to needs
- Abstract from specific speaker and example
- Model speech stochastically and select most likely utterance
HMM based TTS: HMM models

Add a lot of flexibility

- HMM states can average over a cluster of contexts
- Store the dynamics of spectral change etc.
- HMM models for a new speaker can be learned
- New speaker or language *only* needs the difference
- The difference can be determined on just a little speech
- HMM TTS is *adaptable*
- (and you can indeed synthesize *MFCC* vectors)
HMM based TTS

Store abstract, generalized units

- HMM states summarize spectrum words
- Model intonation (excitation) separately
- Label HMMs with contextual information

[Tokuda et al.(2002)Tokuda, Zen, and Black]
HMM based TTS:

- Many contextual factors (e.g., phone identity factors, stress-related factors, locational factors)
- Context-dependent HMMs
- Not enough speech and time ⇒ Cluster

[Tokuda et al.(2002)Tokuda, Zen, and Black]
HMM based TTS:

<table>
<thead>
<tr>
<th>module</th>
<th>size</th>
</tr>
</thead>
<tbody>
<tr>
<td>decision tree</td>
<td></td>
</tr>
<tr>
<td>spectrum</td>
<td>102 kbyte</td>
</tr>
<tr>
<td>$F_0$</td>
<td>156 kbyte</td>
</tr>
<tr>
<td>duration</td>
<td>116 kbyte</td>
</tr>
<tr>
<td>distribution</td>
<td></td>
</tr>
<tr>
<td>spectrum</td>
<td>457 kbyte</td>
</tr>
<tr>
<td>$F_0$</td>
<td>81 kbyte</td>
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<tr>
<td>duration</td>
<td>39 kbyte</td>
</tr>
<tr>
<td>converter</td>
<td>3 kbyte</td>
</tr>
<tr>
<td>synthesizer</td>
<td>34 kbyte</td>
</tr>
<tr>
<td>total</td>
<td>988 kbyte</td>
</tr>
</tbody>
</table>

Table 1. Binary file size of HTS run-time engine.

Reduce footprint

- Small enough for PDAs
- Ten times Real-Time (on P4)
- HTS example using Alan’s voice

[Tokuda et al.(2002)Tokuda, Zen, and Black]
HMM based TTS:

Classical Unit Selection scheme

- Concatenate using Target and Concatenation costs
- Use whole speech database
- Concatenate in real time

[Tokuda et al.(2002)Tokuda, Zen, and Black]
HMM based TTS:

HTS scheme

- Cluster all units on context in advance
- But use only statistics of cluster, not original templates
- Concatenation cost corresponds to dynamic feature parameter

[Tokuda et al.(2002)Tokuda, Zen, and Black]
HMM based TTS:

Table 2. Relation between unit selection and generation approaches.

<table>
<thead>
<tr>
<th></th>
<th>HTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clustering (possible use of HMM)</td>
<td>Clustering (use of HMM)</td>
</tr>
<tr>
<td>Multi-template</td>
<td>Statistics</td>
</tr>
<tr>
<td>Single tree</td>
<td>Multiple tree (Spectrum, F0, duration)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantage:</th>
<th>Disadvantage:</th>
</tr>
</thead>
<tbody>
<tr>
<td>● High quality at waveform level</td>
<td>● Vocodered speech (buzzy)</td>
</tr>
<tr>
<td>● Discontinuity</td>
<td>● Smooth</td>
</tr>
<tr>
<td>● Hit or miss</td>
<td>● Stable</td>
</tr>
<tr>
<td>● Large run-time data</td>
<td>● Small run-time data</td>
</tr>
<tr>
<td>● Fixed voice</td>
<td>● Various voices</td>
</tr>
</tbody>
</table>

Comparison

- Unit selection often very good, sometimes really bad
- HMM often bad (vocoder)
- HMM is much smaller and adaptable (retraining)

[Tokuda et al.(2002) Tokuda, Zen, and Black]

van Son & Weenink (IFA, ACLC)  Speech recognition and synthesis  Fall 2008
Further Reading I

James F. Allen, Donna K. Byron, Myroslava Dzikovska, George Ferguson, Lucian Galescu, and Amanda Stent.
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Praat, a system for doing phonetics by computer.

P. Boersma and D. Weenink.
Praat 4.2: doing phonetics by computer.

Template-Based Continuous Speech Recognition.
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Further Reading II

Daniel Jurafsky and James H. Martin.  
*Speech and Language Processing.*  
Updates at http://www.cs.colorado.edu/

A spoken dialog system for the dutch public transport information service.  
Link is to an older version.

Keiichi Tokuda, Heiga Zen, and Alan W. Black.  
An HMM-based speech synthesis system applied to English, 2002.  

W. Wesseling and R. J. J. H. van Son.  
Timing of experimentally elicited minimal responses as quantitative evidence for the use of intonation in projecting TRPs.  

Early Preparation of Experimentally Elicited Minimal Responses.  
Architectural overview template based ASR

DTW Tokenpassing Search Engine

\( \hat{W}, \hat{T} = \arg \max_{W, T} P(W, T | X) \)

Template Database

Local Distance Measures

Template Selection Algorithm

Context Information

HMM

<table>
<thead>
<tr>
<th>Template based</th>
<th>HMM + GMM</th>
<th>Viterbi</th>
<th>Context dependent (CD) phoneme HMMs</th>
<th>Not available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lexicon, LM, Feature extraction</td>
<td>idem</td>
<td>DTW</td>
<td>CD local scaling + context based transition costs</td>
<td>Costs based on meta-information</td>
</tr>
</tbody>
</table>
Architectural overview HMM based synthesis

SPEECH DATABASE

Speech signal

Excitation parameter extraction

Spectral parameter extraction

Labels

Training of HMM

TEXT

Text analysis

Labels

Parameter generation from HMM

context-dependent HMMs & duration models

Excitation generation

Spectral parameters

Synthesis filter

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