Speech recognition and synthesis

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: Recognition 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?
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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?
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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 (eg, coarticulation)
- Adapt to rate, hypo/hyperarticulation
- ⇒ standard HMM models cannot store enough information
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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
ASR: Structure-based approach

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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
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van Son & Weenink (IFA, ACLC)  
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ASR: Speech recognition by unit synthesis

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- Don’t abstract, use examples directly
- Store speech of many speakers
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- Store different styles of speech, and label them
- $\Rightarrow$ Template-, exemplar-, instance- based ASR
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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
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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.
ASR: Cookbook

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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]
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ASR: Architectural overview

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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
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- Speech units cannot be adapted to needs
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- Model speech stochastically and select most likely utterance
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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*
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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]
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Decision-tree based context clustering

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

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

<table>
<thead>
<tr>
<th>module</th>
<th>size</th>
</tr>
</thead>
<tbody>
<tr>
<td>decision tree spectrum</td>
<td>102 kbyte</td>
</tr>
<tr>
<td>decision tree $F_0$ duration</td>
<td>156 kbyte</td>
</tr>
<tr>
<td>decision tree duration</td>
<td>116 kbyte</td>
</tr>
<tr>
<td>distribution spectrum</td>
<td>457 kbyte</td>
</tr>
<tr>
<td>distribution $F_0$ duration</td>
<td>81 kbyte</td>
</tr>
<tr>
<td>distribution 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>
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Reduce footprint

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

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<td>spectrum</td>
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</tr>
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<td>$F_0$ duration</td>
<td>156 kbyte</td>
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<td>34 kbyte</td>
</tr>
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Reduce footprint

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Comparison

- Unit selection often very good, sometimes really bad
- HMM often bad (vocoder)
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Advantage:
- High quality at waveform level

Disadvantage:
- Discontinuity
- Hit or miss
- Large run-time data
- Fixed voice

Disadvantage:
- Vocoder speech
- Buzzing

Advantage:
- Smooth
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Further Reading I

James F. Allen, Donna K. Byron, Myroslava Dzikovska, George Ferguson, Lucian Galescu, and Amanda Stent.
Toward conversational human-computer interaction.

P. Boersma.
Praat, a system for doing phonetics by computer.

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

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.
Further Reading II

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

- Lexicon
- Template Concatenation Models
  \[ \delta (T|W) \]
  \[ P(T) \]
- Statistical Language Model
  \[ P(W) \]
- Finite State Grammar
  \[ \delta (W) \]

Template Concatenation Costs

Language Model Software

DTW Tokenpassing Search Engine

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

Recognized Word/Template String/Lattice

Feature Extraction

\[ X(t) \]

Bottom-up Template Selection Algorithm

Local Distance Measures

HMM
- Lexicon, LM, Feature extraction: *idem*
- HMM + GMM: Templates + local scaling
- Viterbi: DTW
- Context dependent (CD) phoneme HMMs: CD local scaling + context based transition costs
- Not available: Costs based on meta-information

van Son & Weenink (IFA, ACLC)  Speech recognition and synthesis  Fall 2007  291 / 339
Architectural overview HMM based synthesis

1. **Speech Database**
   - Speech signal
   - Excitation parameter extraction
   - Spectral parameter extraction
   - Training of HMM
   - Excitation parameters
   - Spectral parameters
   - Labels

2. **Text**
   - Text analysis
   - Labels
   - Parameter generation from HMM
   - Context-dependent HMMs & duration models
   - Excitation parameters
   - Spectral parameters
   - Excitation generation
   - Synthesis filter
   - Synthesized speech

---

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