Speech Processing 15-492/18-492

Speech Recognition
  Intro
  Acoustic modelling
  HMMs
Speech Recognition

- From acoustics to text
- Acoustic modeling
  - Recognizing all forms of all phonemes
- Language modeling
  - Expectation of what might be said
- We need both to do recognition
Last Saturday in Hawaii, numerous Waipouli vacationers were shocked to find their beach cordoned off for a UC Berkeley Drama enactment of "Personal office space". The play features exclusively topless men and women in an everyday office environment. Richard Carlson, one of the annoyed tourists and a regular swimmer at Waipouli beach, complained that they really knew how to wreck a nice beach with the nudist play. Many of the tourists appeared ruffled by the content and fled the scene to avoid compromising photos.

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Split the task

- **Build Acoustic models**
  - Probability of phones given acoustics
- **Build Language models**
  - Probability of word string
Acoustic models

- Represent all ways to say each phoneme
  - Like “templates” for each phoneme
  - Averages over multiple examples
  - Different phonetic contexts
    - “sow” vs “see” etc
  - Different people speaking
  - Different acoustic environment
  - Different channels
    - (assume channel is similar)
Better Acoustic Models

- **DTW Template**
  - Could be averages over multiple examples
  - Need to be time normalized
    - Linear interpolate or try to match
  - Matching probabilistically
    - What is the probability that example matches
    - Test each frame
Hidden Markov Models

- Markov Process
  - Future can be predicted from the past
    \[ P(X_{t+1} \mid X_t, X_{t-1}, \ldots X_{t-m}) \]

- Hidden Markov Models:
  - When the state is unknown
  - A probability is given for each states
Hidden Markov Model

Set of states
Output alphabet
Initial state probabilities
State transition probabilities
State emission probabilities

\[ S = \{s_1, \ldots, s_N\} \]
\[ K = \{k_1, \ldots, k_M\} \]
\[ \Pi = \{\pi_i\}, i \in S \]
\[ A = \{a_{ij}\}, i, j \in S \]
\[ B = \{b_{ijk}\}, i, j \in S, k \in K \]

A model \( \mu = (A, B, \Pi) \)
Key Requirements

1. Given a model $\mu = (A, B, \Pi)$, how do we efficiently compute how likely an observation is, $P(O \mid \mu)$.  
   - which model is most probable

2. Given observation $O$ and model $\mu$, which state sequence best explains the observations  
   - in a model what states are most likely

3. Given $O$ and a space of models, how do we find the best model to explain $O$  
   - how do we training the thing
Find Probability of Observation

- **Given observation** \( O \) **and model** \( M \)
  - Efficiently file \( P(O|M) \)
  - Called **decoding**
- **Find sum of all paths probabilities**
- **Each path prob** is product **of each transition in state sequence**
- **Use dynamic programing (generalized DTW)**
  - Also used in Chart Parsers, Theorem Provers
Finding the Best Path

- **What is the most probable state sequence**
- **Use Viterbi algorithm**
  - Maximize best sequence
  - At each point hold list possible states
  - Hold back-pointer to best previous state
  - Cumulate values along path
- **Because we are looking for BEST**
  - Can ignore other back-pointers
- **(When looking for N-best need more complex structure)**
Parameter Estimation

- **Called training**
- **Use Maximum Likelihood Estimation**
  - Baum-Welch (forward/backward algorithm)
- **Special case of EM (Expectation Maximization)**
  - Run observation and find current probs (forward)
  - Modify probabilities to make observations best path (backward)
  - Repeat until convergences
- **Not globally optimal**
  - May find local maximum
HMM recognition

- **A bunch of HMM**
  - One for each phone type

- **Each observation (e.g. 10ms frame)**
  - Probability distribution of possible phone type

- **Thus can find most probably sequence**
  - Use Viterbi to find best path
But that’s not enough

- But not all phones are equi-probable
- Find word sequences that maximizes \( P(W \mid O) \)
- Using Bayes’ Law
  \[
  \frac{P(W)P(O \mid W)}{P(O)}
  \]
- Combine models
  - Use HMMs to provide \( P(O \mid W) \)
  - Use language model to provide \( P(W) \)
How many HMM models

- How many models
  - One for each thing you want to recognize:
    - One per phone
    - One per word
    - One per city name …

- What is the size and shape of the model
How many models

- **Context Independent models:**
  - One for each phoneme
  - One for silence, noises

- **Triphone models**
  - Context dependent
  - Phone before and after
  - Need lots of data to train this

- **Tied states (semi-continuous)**
  - Build full triphone models
  - Combine low frequency “similar” phones
  - Train again on smaller set
But even that’s not enough

- **HMM for words**
  - For common words or common in domain
  - *E.g.* City, State (need more than 3 states)
Search space is very large

- **Prune Viterbi search**
  - Best number of paths
  - Some percentage of probability mass
- **Prune lexical trees**
  - Restrict vocabulary
  - Use language model
  - Or even grammar
Some computational issues

- **Probabilities are multiplied along paths**
  - They get **very** small

- **Treat probabilities as logs**
  - Thus add rather than multiple
  - Typically use negative log probabilities
Training

- **How much data do you need**
  - As much as you can get
  - More than 10Hrs (100Hrs, 1000Hrs)
  - Can take months to train

- **The larger the models**
  - The larger the number of parameters
  - More data needs to be used for training
  - Examples are equi-probably (find oy-oy examples is hard)
The right type of data

- **Training data must match intended domain**
  - Male/Female, Native/non-native, UK/US
  - As close to target domain as possible
  - Right channel (cell phone/land line)
How to improve ASR

- *Get more data*
- *Fix bugs*
Summary

- **HMMs**
  - Find probability of observation (decoding)
  - Find best path (Viterbi)
  - Train the parameters (Baum-Welch)

- **Bayes Law**
  - Acoustic model and Language model
Reading

- **Section 8.2 Definition of Hidden Markov Model pp 380-393**
- **Section 8.4 Practical Issues in using HMMS pp 398-405**
- **In Huang et al.**
- **Two page description of the contents emailed to nbach@cs.cmu.edu before 3:30pm Monday (5th) or Wednesday (7th Oct)**