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
Acoustics are not enough

- 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 state
Hidden Markov Model

Set of states \( S = \{s_1, \ldots, s_N\} \)
Output alphabet \( K = \{k_1, \ldots, k_M\} \)

Initial state probabilities \( \Pi = \{\pi_i\}, i \in S \)
State transition probabilities \( A = \{a_{ij}\}, i, j \in S \)
State emission probabilities \( B = \{b_{ijk}\}, i, j \in S, k \in K \)

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 programming (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
HMM Topology

1 state

3 state

3 state with skips
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
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 awb@cs.cmu.edu before 3:30pm Monday 13th September