Lecture 17

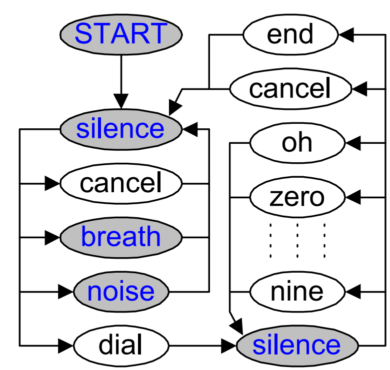
Continuous Speech Recognition

- Grammar Model
- Small Vocabulary Recogniser
- Pruning
- Continuous Speech Recognition
- Large Vocabulary Recognition
- Phoneme models
  - Triphones
  - Tied states

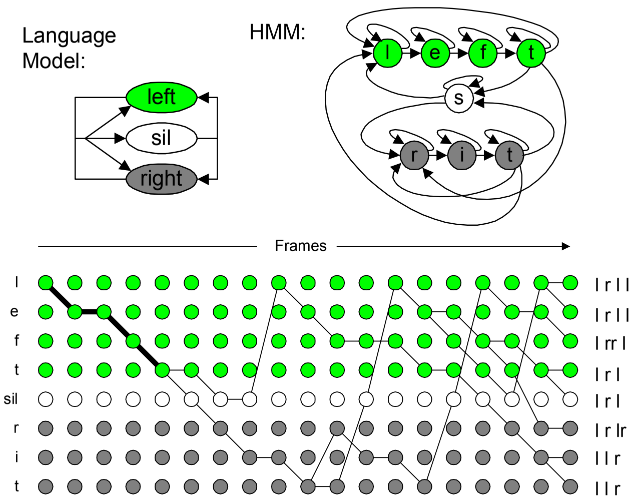
Grammar Model

- A grammar model defines the allowable word sequences
  - Each transition between words is given a probability
- We include a number of noise and silence models.
- Replace each word by the states that make up its model to give a single huge HMM
- If a word appears twice in the grammar, its model states must be duplicated.

Grammar for Telephone Dialler



2-word grammar example

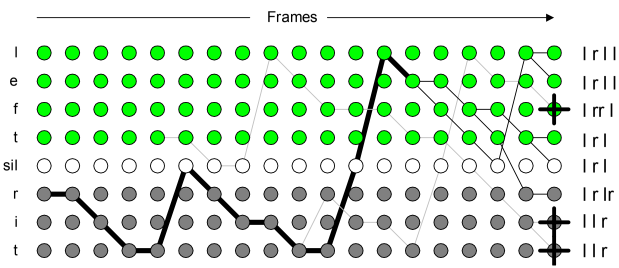


- For each new frame, we use the Viterbi algorithm to finds the best path that ends in each of the possible states.
- The first word is definitely “left” since all paths converge when you trace them backwards in time.
- The diagram is simplified: each word would actually have more states.

Small Vocabulary Recogniser

- One model for each word + silence, noise, cough etc
- Typically 10 to 15 states per word ⇒ <2000 states
- Need training examples of each word:
  - Single user (*speaker dependent*): >10 examples of each word
  - Many different users (*speaker independent*): >100 examples of each word
- Performance (with no grammatical constraints on word sequence)
  - Digits 0 to 9: <1% speaker independent error rate
  - Alphabet A to Z: <10% speaker independent error rate
    - This is a hard test because many letters sound similar: B,C,D,E,G,P,T & V

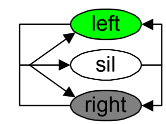
Pruning



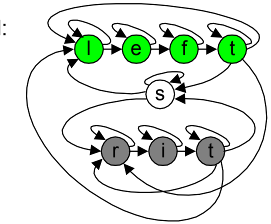
- At each frame find the log probability of the best path and remove any paths whose log probability is more than w less than the best.
- This technique can remove a large fraction of the paths:
  - Reduces recognition delay (e.g. all remaining paths start l r l)
  - Saves computation (fewer probabilities to check)
- The technique is known as a beam search: w is called the beam width

Continuous Speech Recognition

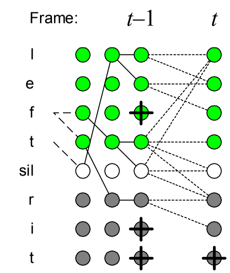
Language Model:

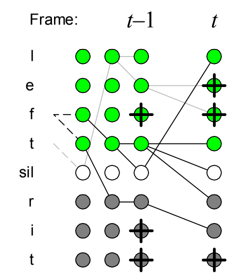


HMM:



- As each new frame arrives, we extend the lattice by one column.
- Determine the possible predecessors for each state from the HMM diagram.
- Select the predecessor with highest probability and calculate B(t,s) for each state s.
- Prune any paths whose probability is much lower than the best path.
- Trace remaining paths backwards to find point of convergence.



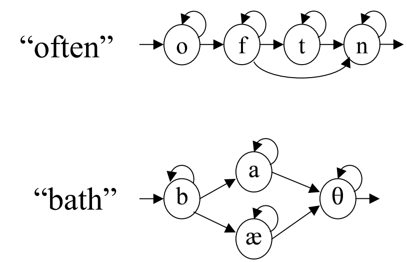


Large Vocabulary Recognition

- Problems with recognising large vocabularies (>1000 words)
  - The searching task is now enormous: every alignment + word sequence ⇒ essential to have a good language model to limit the number of possible word sequences.
  - Very large memory requirements to store all the models.
  - More of the words are highly confusable ⇒ need to improve the acoustic modelling
    - Simple gaussian assumption is no longer good enough. Need $20F$ parameters to describe distribution instead of only $2F$.
  - Huge amount of training data required: 100s of hours of speech.
  - Must usually be able to cope with words that are not in the training data at all.

Phoneme Models

- All English words can be constructed from around 43 different phonemes:
  - Have a model for each phoneme
  - Construct a word or sentence by joining together the phonemes that make it up.
  - Some words may need alternative pronunciations:



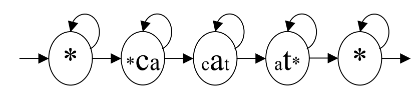
Uniphone Models

- *Uniphone* models have a single model for each phoneme
  - Typically 3 states per model
  - Total number of distinct states = 3 × 43 = 129 ⇒ very little training data needed
- Bad news:
  - Poor performance because the way in which a phoneme is pronounced depends on its context
    - Anticipatory coarticulation: speakers start to say one phoneme before they have finished the previous one ⇒ each phoneme is strongly affected by its neighbours.
    - In some cases phonemes can be affected by non-adjacent phonemes that occur later in the sentence but this is a smaller effect.

Triphone Models

- *Triphone* models have a 43^2 different models for each phoneme: one for each possible combination of preceding and succeeding phoneme.
  - Some phoneme combinations never occur in English words so only about 60,000 phonemes are actually required
  - It is worth having whole-word models for a few common words whose pronunciation is non-standard: “the”, “and” etc.
  - 60,000 models × 3 states × 39 features × 20 parameters = 140,000,000 parameters to train.

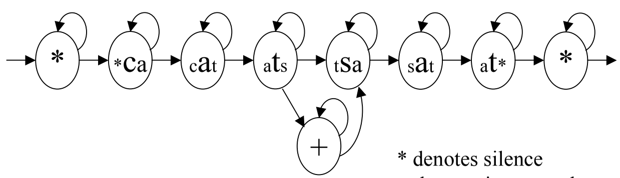
“cat”



* denotes silence

Cross-word triphones

"cat sat"



* denotes silence
\+ denotes inter-word gap

- Best results are obtained if triphones extend across words
  - We insert an optional "inter-word gap" between each word
  - Ignore the inter-word gap when considering which version of the triphone to use.

Training triphone models

- As with all HMMs, we start with a crude set of models and iteratively improve them:
  - Create a set of uniphone models: need some training data for which we know the beginning and end times of each individual phoneme.
    - For the rest of the training procedure, we only need to know what words are contained in each training sentence and not their start and end times.
  - Duplicate each of these monophone models 43^2 times to make an initial set of triphone models.
  - Repeat until convergence(*Viterbi* re-estimation):
    - Create a model for each of the training sentences by joining together the appropriate triphone models and then align each sentence with its model.
    - Re-estimate each state of each model by calculating the means and variances of all the feature vectors that were assigned to that state by the *best* alignment.
  - Repeat the previous step but this time use a weighted average of all possible alignments (*Baum-Welch* re-estimation).

Tied states

- Problem: there is always too little training data
  - Some triphones will occur very rarely, or even never, in the training data.
  - Solution: merge states that you expect to be similar
    - states that are tied together in this way combine their training examples and so get better estimates
  - can use phonetic knowledge to guide which states should be tied together
    - For example: the triphones shIm and shIn are followed by nasal consonants that are very similar so we can tie together their first two states.

Four versions of the phoneme “i”: