ECE57000 Lecture 8: Hidden Markov Models (HMMs)

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Size Hyperparameters and Indices

- L: number of sentences
- l: sentence index
- $I(l)$: number of words in sentence l
- i: word position in sentence l
- K: number of words in dictionary
- k: word index in dictionary
- J: number of states
- j: state index

Random Variables

- $T_{li} \in \{1, \ldots, J\}$: state index at position i of sentence l
- $W_{li} \in \{1, \ldots, K\}$: word index at position i of sentence l

Model Parameters

- $b_j = \Pr(T_{l1} = j)\ (\forall l)$
- $a_{jj'} = \Pr(T_{li+1} = j' | T_{li} = j)\ (\forall l)(\forall i)$
- $c_{jk} = \Pr(W_{li} = k | T_{li} = j)\ (\forall l)(\forall i)$

Sampling

1. $i := 1$
2. Sample T_i from b.
3. Sample W_i from c_{T_i}.
4. $i := i + 1$
5. Sample T_i from $a_{T_{i-1}}$.
6. Go to 3.

Forward Probabilities

- $\alpha_{lij} = \Pr(W_{l1} = k_{l1}, ..., W_{li} = k_{li}, T_{li} = j | a, b, c)$

Backward Probabilities

- $\beta_{lij} = \Pr(W_{li+1} = k_{li+1}, ..., W_{lI(l)} = k_{lI(l)}, T_{li} = j | a, b, c)$

Forward Algorithm

- $\alpha_{l1j} = b_j c_j W_{l1} \ (\forall l)(\forall j)$
- $\alpha_{lij} = \left(\sum_{j'} \alpha_{li-1j'} a_{j'j} \right) c_j W_{li} \ (\forall l)(\forall i > 1)(\forall j)$

Backward Algorithm

- $\beta_{lI(l)j} = 1 \ (\forall l)(\forall j)$
- $\beta_{lij} = \sum_{j'} a_{jj'} c_{j'} w_{li+1} \beta_{li+1j'} \ (\forall l)(\forall i < I(n))(\forall j)$

Likelihood Estimation

- $\Pr(W_{l1} = k_{l1}, ..., W_{lI(l)} = k_{lI(l)} | a, b, c)$
- $= \sum_j \alpha_{lI(l)j}$
- $= \sum_j b_j c_{lW_{l1}} \beta_{l1j}$

Forward-Backward Algorithm

- $\gamma_{lij} = \Pr(W_{l1} = k_{l1}, ..., W_{lI(l)} = k_{lI(l)}, T_{li} = j | a, b, c) \propto \alpha_{lij}\beta_{lij}$

Baum-Welch Reestimation Procedure

- $b_j :\propto \sum_l \gamma_{l1j} \ (\forall j)$
- $a_{jj'} :\propto \sum_{l,i} \gamma_{lij}\gamma_{li+1j'} \ (\forall j)(\forall j')$
- $c_{jk} :\propto \sum_{l,i,W_{li}=k} \gamma_{lij} \ (\forall j)(\forall k)$