Machine Learning and Applications (MLAP) Open Examination 2016-2017

Exam Number: **Y1403115**

The EM algorithm

1 Task 1

For each state (square), the algorithm counts the number of times it was a starting state, the number of times it was transitioned to from each other state, and the number of times each reward was awarded in it. Counts are normalised so probabilities sum to 1.

2 Task 2

The implementation of the EM algorithm closely follows the steps outlined in Lecture 19.

1. First the parameters are initialised with uniform distributions. The alpha recursion and the average log-likelihood for each episode are computed iteratively using the forward algorithm.

$$\alpha^n(h_n) = p(v_t^n|h_t)\sum_{h_{t-1}} p(h_t|h_{t-1})\alpha^n(h_{t-1}) \qquad \alpha^n(h_1) = p(v_1^n|h_1)p(h_1) \tag{1}$$

$$Loglikelihood = \frac{1}{N}\sum_{n=1}^{N}\sum_{t=1}^{T}\log\sum_{h_t}\alpha(h_t) \tag{2}$$

2. The beta recursion for each episode is computed iteratively using the backward algorithm.

$$\beta^n(h_{t-1}) = \sum_{h_t} p(v_t^n|h_t)p(h_t|h_{t-1})\beta^n(h_t) \qquad \beta^n h_T = 1 \tag{3}$$

3. When computing alpha and beta they are scaled in order to prevent numerical underflow [1].

$$\alpha^n(h_t) = \frac{\alpha^n(h_t)}{\sum_{h_t}\alpha^n(h_t)} \qquad \beta^n(h_t) = \frac{\beta^n(h_t)}{\sum_{h_t}\beta^n(h_t)} \tag{4}$$

4. Hidden state marginals γ and pairwise marginals ξ are computed for each episode.

$$\gamma^n = p(h_t|v_{1:T}^n) = \frac{\alpha^n(h_t)\beta^n(h_t)}{\sum_{h_t'}\alpha^n(h_t')\beta^n(h_t')} \tag{5}$$

$$\xi^n = p(h_t, h_{t+1}|v^n_{1:T}) = \frac{\alpha^n(h_t)p(v^n_{t+1}|h_{t+1})p(h_{t+1}|h_t)\beta^n(h_{t+1})}{\sum\limits_{h'_t}\sum\limits_{h'_{t+1}} \alpha^n(h'_t)p(v^n_{t+1}|h'_{t+1})p(h'_{t+1}|h'_t)\beta^n(h'_{t+1})} \tag{6}$$

5. Initial, transition and emission probabilities are updated using hidden state marginals and pairwise marginals in three separate function. Parameters are normalised in order for probabilities to sum to 1.

$$p^{new}(h_1) = \frac{1}{N}\sum_{n=1}^{N}\gamma^n(h_1) \tag{7}$$

$$p^{new}(h_{t+1}|h_t) = \frac{\sum\limits_{n=1}^{N}\sum\limits_{t=1}^{T_n-1}\xi^n(h_t, h_{t+1})}{\sum\limits_{n=1}^{N}\sum\limits_{t=1}^{T_n-1}\sum\limits_{h_{t+1}}\xi^n(h_t, h_{t+1})} \tag{8}$$

$$p^{new}(v_t = i|h_t) = \frac{\sum\limits_{n=1}^{N}\sum\limits_{t=1}^{T_n-1} I[v^n_t = i]\gamma^n(h_t)}{\sum\limits_{n=1}^{N}\sum\limits_{t=1}^{T_n-1}\gamma^n(h_t)} \tag{9}$$

6. If the change in log-likelihood is smaller than the threashold 0.01, the algorithm terminates, otherwise it proceeds with the next iteration.

3 Task 3

3.1 Difference in log-likelihood for different EM runs

The EM algorithm is guaranteed to converge to a local maximum of the likelihood. However it is very susceptible to changes in the initial conditions. When the HMM parameters are initialised randomly at each run, the algorithm converges to the closest local minimum. This local minimum is very likely different from the one reached in the previous run. This means that across different EM runs different values for the log-likelihood are expected.

3.1.1 Difference in behaviour of EM when using random versus uniform parameter initialisation

When using uniform distributions for initial parameters of the HMM, the EM algorithm always achieves the same log-likelihood. Furthermore, the transition and

4 Task 4

Manifold learning

Construction/Implementation

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Data proximity graphs

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Algorithm

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Face recognition

References

[1] L. R. Rabiner, “A tutorial on hidden markov models and selected applications in speech recognition,” *Proceedings of the IEEE*, vol. 77, pp. 257–286, Feb 1989.