Hidden Markov Modeling for network communication channels

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Paper Organization:

- Introduction to HMMs and the model proposed
- Expectation-Maximization algorithm description
- State sequence inference
- Application in real traces
Notation:

\( K \): number of states;
\( Y \): state sequence;
\( \Gamma \): transition matrix;
\( P \): observation matrix;
\( \pi \): initial probability distribution;
\( X \): loss process;

The model can be defined by:

\[ \theta = (\Gamma, P) \]
Algorithm proposed:

1. Initialize $K=2$
2. Apply the EM algorithm
3. Calculate the log-likelihood of the HMM
4. Calculate the relative benefit of this model ($\varepsilon_n$)
5. If $\varepsilon_n$ high (not accurate)
   
   K++
   
   go to step 2
The Model:

Only models the loss process, delay not included

The loss process is modeled as a valve
What is HMM?

"is a doubly embedded stochastic process with an underlying stochastic process that is not observable, but can only be observed through another set of stochastic processes that produce the sequence of observations."

Lawrence R. Rabiner

Example:

dishonest casino
Transitions:

\[
\psi^k_t(i, j) \propto \alpha^k_t(i) \hat{\Gamma}_{ij}(k) \beta^k_{t+1}(j) \{ X_{t+1}, \hat{p}_j(k) \}
\]
Parameters Estimation (Training):

\[ \begin{align*}
\theta & \\
\alpha & \beta \\
\psi & \gamma \\
\theta^+ & \\
\varepsilon & \text{END}
\end{align*} \]

\[ \alpha^k_t(i) = \text{Prob}\{X^t_1, Y_t = i | \hat{\theta}_k\} \]

\[ \beta^k_t(i) = \text{Prob}\{X^T_{t+1}, Y_t = i | \hat{\theta}_k\} \]

\[ \psi^k_t(i, j) = \text{Prob}\{Y_t = i, Y_{t+1} = j | X, \hat{\theta}_k\} \]

\[ \gamma^k_t(i) = \text{Prob}\{Y_t = i | X, \hat{\theta}_k\} \]
State Estimation:

**Marginal Posterior Mode**

\[ L(Y_t | X = x; \theta) \]

Less sensitive to data inadequacy

**Viterbi:**

\[ L(Y | X = x; \theta) \]

produces a sequence that is more likely
Results:

Ex1:
non Hidden Markov Model needs 10 states
Hidden Markov Model needs only 2 states

Ex2:
non Hidden Markov Model needs 42 states
Hidden Markov Model needs only 4 states
Conclusions:

- The use of HMM can drastically decrease the number of states
- The procedure developed can be used in adaptive applications

Achievement:

- Procedure for choosing the number of states