Stochastic automata and its application

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Abstract— In this paper we consider the role of hidden Markov models (HMM) in speech recognition and analyze its benefits and disadvantages in this process. We compare it with multilayer perceptron networks (MPNs) and consider also the hybrid model, which includes both of them.

Keywords—stochastic automata, hidden Markov models, speech recognition.

I. INTRODUCTION

Stochastic (or probabilistic) automata were introduced by Rabin [1] and Carlyle [2] as a generalization of finite deterministic automata [3]. In the late 1960s and early 1970s, statistical methods in the form of Markov chain were applied to artificial intelligence problems as speech recognition, recognition of printed text, handwritten characters, etc. [4], [5]. The use of statistical methods has become an important step in the development of automatic speech recognition. These models are rich in mathematical structure and hence can form the theoretical basis for use in a wide range of applications. They are significantly improved the quality of recognition. Currently, almost all known speech recognition systems are based on statistical methods.

With a statistical approach, the speech signal is represented as a random sequence of acoustic vectors $Y = (y_1, y_2, \cdots, y_n)$, which is converted to the sequence of words W, having the greatest likelihood (aposteriori probability) among all candidates:

$$W_{max} = \underset{w}{\arg\max}\, P(W|Y) .$$

Here, argmax indicates not to the maximum value, but to the argument on which this maximum is achieved. According to the Bayes formula, the aposteriori probability $P(W|Y)$ can be rewritten in the following form:

$$W_{max} = \underset{w}{\arg\max}\, \frac{P(Y|W) \cdot P(W)}{P(Y)} . \quad (1)$$

The conditional probability $P(Y|W)$ is called an acoustic model and is equal to the probability of the observed sequence Y for a given sequence W, and the probability $P(W)$ is called the language model and equals to a priori probability of appearing the sequence W in the specified language [6]. A priori probability $P(Y)$ of the observed sequence Y does not depend on W and therefore may be removed.

Stochastic automata in the form of hidden Markov models allow creating an acoustic model, i.e. evaluate the conditional probability $P(Y|W)$ for a given sentence W.

II. FINITE MARKOV CHAINS

A finite Markov chain [7] can be considered as a stochastic automaton without inputs and outputs (autonomous automaton). A Markov chain is a triple $C = (S, f, \pi_1)$, where $S = \{s_1, \cdots, s_k\}$ is a set of states, f is a random transition function, which is a mapping $f: S \times S \longrightarrow [0,1]$, π_1 is an initial probability distribution of states $\pi_1: S \longrightarrow [0,1]$. The transition function f is represented by a stochastic transition matrix consisting of conditional probabilities $F = [F(s_j|s_i)]$, $1 \leq i, j \leq k$, whereas distribution π_1 is represented by a stochastic vector:

$$\pi_1(s_1) + \cdots + \pi_1(s_k) = 1 .$$

The set of natural numbers N will be considered as the discrete time. The Markov chain C works (moves) in discrete time. If at time t the chain is in state s_i, then at the next time period it will go to state s_j with probability $F(s_j|s_i)$. A chain motion is a random sequence of states of the following form:

$$Q = (q_1, q_2, \cdots, q_n) , \quad q_t \in S, \quad 1 \leq t \leq n . \quad (2)$$

The probability of concrete sequence (2) is expressed by the formula:

$$P(Q) = \pi_1(q_1) \cdot F(q_2|q_1) \cdot \cdots \cdot F(q_n|q_{n-1}) . \quad (3)$$

Thus, we have the probability distribution on all sequences (2) of length n. The total number of these sequences is equal to k^n, but the probability some of them may be zero, since the initial probability $\pi_1(q_1)$ and the intermediate transition probabilities $F(q_t|q_{t-1})$, $2 \leq t \leq n$, may be zero.

III. HIDDEN MARKOV MODEL

Baum and his colleagues in [8] published the basic theory of hidden Markov model (HMM). Then it was implemented for speech recognition [4], [5]. Until now, HMMs have remained the tool for solving speech recognition problems, but now the situation has begun to change for reasons that will be discussed below.

HMM can be considered as a stochastic automaton with outputs. HMM is a tuple $D = (S, O, f, g, \pi_1)$, where $C = (S, f, \pi_1)$ is a finite Markov chain, $O = \{o_1, \cdots, o_m\}$ is a set of outputs, g is a random output function which is a mapping $g: S \times O \longrightarrow [0,1]$. The output function g is represented by a stochastic output matrix $G = [G(o_j|s_i)]$, $1 \leq i \leq k$, $1 \leq j \leq m$, (emission probabilities).

HMM operates in discrete time and transitions between states occur in the same way as in Markov chains. If at time t the chain is in the state q_t, then at the same time period it issues the signal y_t with the probability $G(y_t|q_t)$. Thus, each sequence of states (2) produce some output sequence:

$$Y = (y_1, y_2, \cdots, y_n) , \quad y_t \in O, \quad 1 \leq t \leq n . \quad (4)$$

The output sequence (4) can be observed directly, while the state sequence (2) is "hidden" from observation, from which the model gets its name.

Consider an example of HMM, which is shown in Fig. 1. Each state s_i, $1 \leq i \leq k$, corresponds to a speech unit of a natural language. Of course, it would be nice to have a separate HMM for each of the possible sentence, but this is

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