

# 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  $Y = (y_1, y_2, \dots, y_n)$ , which is converted to the sequence of words  $W$ , having the greatest likelihood (aposteriori probability) among all candidates:

$$W_{\max} = \operatorname{argmax}_W P(W|Y).$$

Here,  $\operatorname{argmax}$  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:

$$W_{\max} = \operatorname{argmax}_W \frac{P(Y|W) \cdot P(W)}{P(Y)}. \quad (1)$$

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  $S = \{s_1, \dots, s_k\}$  is a set of states,  $f$  is a

random transition function, which is a mapping  $f: S \times S \rightarrow [0,1]$ ,  $\pi_1$  is an initial probability distribution of states  $\pi_1: S \rightarrow [0,1]$ . 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  $\pi_1$  is represented by a stochastic vector:

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

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:

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

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

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

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,  $O = \{o_1, \dots, o_m\}$  is a set of outputs,  $g$  is a random output function which is a mapping  $g: S \times O \rightarrow [0,1]$ . 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:

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

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

# Stochastic Automata Constructive Theory

**Susanne Graf, Michael Schwartzbach**



## **Stochastic Automata Constructive Theory:**

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Kronecker Modeling and Analysis of Multidimensional Markovian Systems Tuğrul Dayar, 2018-09-21 This work considers Kronecker based models with finite as well as countably infinite state spaces for multidimensional Markovian systems by paying particular attention to those whose reachable state spaces are smaller than their product state spaces Numerical methods for steady state and transient analysis of Kronecker based multidimensional Markovian models are discussed in detail together with implementation issues Case studies are provided to explain concepts and motivate use of methods Having grown out of research from the past twenty years this book expands upon the author's previously published book Analyzing Markov Chains using Kronecker Products Springer 2012 The subject matter is interdisciplinary and at the intersection of applied mathematics and computer science The book will be of use to researchers and graduate students with an understanding of basic linear algebra probability and discrete mathematics      Stochastic Automata Ernst-Erich Doberkat, 1881 Provides a general mathematical framework for the analytical aspects of stochastic automata Shows that under certain topological conditions non deterministic automata are generated which in some cases are produced by stochastic automata      *Cybernetics Abstracts*, 1981      **Computer Performance Evaluation** Ramon Puigjaner, Nunzio N. Savino, Bartomeu Serra, 2003-06-26 The need to evaluate computer and communication systems performance and dependability is continuously growing as a consequence of both the increasing complexity of systems and the user requirements in terms of timing behaviour The 10th International Conference on Modelling Techniques and Tools for Computer Performance Evaluation held in Palma in September 1998 was organised with the aim of creating a forum in which both theoreticians and practitioners could interchange recent techniques tools and experiences in these areas This meeting follows the predecessor conferences of this series 1984 Paris 1988 Palma 1994 Wien 1985 Sophia Antipolis 1991 Torino 1995 Heidelberg 1987 Paris 1992 Edinburgh 1997 Saint Malo The tradition of this conference series continued this year where many high quality papers were submitted The Programme Committee had a difficult task in selecting the best papers Many papers could not be included in the program due to space constraints All accepted papers are included in this volume Also a

set of submissions describing performance modelling tools was transformed into tool presentations and demonstrations A brief description of these tools is included in this volume The following table gives the overall statistics for the submissions

**Bulletin** Institute of Mathematics and Its Applications,1975      **Journal of the American Statistical Association** American Statistical Association,1975 A scientific and educational journal not only for professional statisticians but also for economists business executives research directors government officials university professors and others who are seriously interested in the application of statistical methods to practical problems in the development of more useful methods and in the improvement of basic statistical data      **Glossary of Haematological and Serological Terms** Philip Samson,1972 About 580 medical laboratory terms pertinent to the disciplines of hematology and blood transfusion serology Definitions range from short to long Also includes abbreviations synonyms cross references and tables      **SIAM Review** Society for Industrial and Applied Mathematics,1959 Articles include expository or survey papers focusing on important advances in applied or computational mathematics or papers outlining the mathematical and computational challenges in scientific or engineering applications Other features include essays book reviews classroom and industrial notes and problems and solutions      Tools and Algorithms for the Construction and Analysis of Systems ,1999      **Communications** ,1970

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