Chapter 45
Cognitive Computation: An Exact Bayesian Inference Stochastic Machine

Marvin Faix
CNRS, France

Emmanuel Mazer
CNRS, France

Raphaël Laurent
Probayes, France

Mohamad Othman Abdallah
Probayes, France

Ronan Le Hy
Probayes, France

Jorge Lobo
University of Coimbra, Portugal

ABSTRACT

Probabilistic programming allows artificial systems to better operate with uncertainty, and stochastic arithmetic provides a way to carry out approximate computations with few resources. As such, both are plausible models for natural cognition. The authors' work on the automatic design of probabilistic machines computing soft inferences, with an arithmetic based on stochastic bitstreams, allowed to develop the following compilation toolchain: given a high-level description of some general problem, formalized as a Bayesian Program, the toolchain automatically builds a low-level description of an electronic circuit computing the corresponding probabilistic inference. This circuit can then be implemented and tested on reconfigurable logic. This paper describes two circuits as validating examples. The first one implements a Bayesian filter solving the problem of Pseudo Noise sequence acquisition in telecommunications. The second one implements decision making in a sensorimotor system: it allows a simple robot to avoid obstacles using Bayesian sensor fusion.

DOI: 10.4018/978-1-7998-1754-3.ch045

INTRODUCTION

The present study is a subproject of BAMBI (Bottom-up Approaches to Machines dedicated to Bayesian Inference (www.bambi-fet.eu): an European collaborative research project relying on the theory of Bayesian inference as a tool to understand natural cognition and aiming at designing bio-inspired computing devices. The main hypothesis underpinning the project is that, since living beings are using energy efficient information processing systems able to cope with uncertainty, Bayesian models may account for some of their abilities at the macroscopic level. For example, Bayesian models for language learning, behavior prediction or decision making are numerous in human studies (Tenenbaum, 2011). Indeed, effective perception and decision making needs to take into account the intrinsic incompleteness of any world representation. This can be done optimally with Bayesian inference (Jaynes, 2003).

Complementary to these rather macroscopic approaches, the bottom-up approach adopted within the framework of BAMBI is to study how probabilistic inference can be made at the biochemical scale and how biochemical cascades of cell signaling can perform the necessary probabilistic computations (Houillon, 2010) The BAMBI project includes testing these hypotheses on *Chlamydomonas reinhardtii*, a well-studied mobile unicellular microalgae. Should these hypotheses hold, then the authors further conjecture that probabilities are coded with binary telegraphic signals: this is supported by the fact that the extremely fast conformation transitions of alosteric molecules, which govern the exchange of information inside the cell, can be modeled by Poisson processes.

Extending this bottom-up approach to artifacts, the goal of the project is to design electronic machines based on similar principles. Here are the objectives that are set for such a machine: it needs to take into account the uncertainty of its inputs, to be fault tolerant, and to meet low power needs. The purpose of this paper is to present an initial solution: a compilation toolchain automatically generating electronic circuits to carry out Bayesian inference, which are based on the temporal coding of probability values as bitstreams, run without floating point unit arithmetic, and are very lightened in terms of electronic components. As illustrating examples, the paper describes the design of a Bayesian filter which devises categories out of a noisy temporal series, and the design of a simple decision system based on Bayesian sensor fusion.

The paper is organized as follows. After presenting similar approaches in the literature, it shows how Bayesian Programs are used to specify inferences and how they can be compiled into specifications for the appropriate circuit. Next, it introduces a set of logic operators to perform the arithmetic operations with stochastic logic. Then it describes a toolchain that starts with a Bayesian Program and generates a hardware description program in VHDL (VHSIC Hardware Description Language, where VHSIC stands for Very High Speed Integrated Circuit) describing the corresponding Bayesian inference machine which has been implemented and tested on reconfigurable logic hardware: FPGA (Field-Programmable Gate Array). The way the obtained machine works is illustrated on a simple inference example, which allows highlighting a fundamental problem with the temporal coding of probabilities: the time dilution of probabilities during the inference process. A solution to this problem is presented and illustrated through a more complex example: the design of an electronic implementation of a Bayesian Filter aimed at solving the problem of Pseudo Noise sequence acquisition in telecommunications. The same approach is then used to produce a circuit allowing a robotic sensorimotor system to take decisions using Bayesian fusion of imprecise sensor information so as to adapt its motor commands to avoid obstacles.