Chapter 9
Forest Fire Simulation:
Efficient Realization Based on Cellular Automata

Severin Staudinger
University of Vienna, Austria

ABSTRACT

In this chapter a heuristic forest fire model based on cellular automata is presented and realized for efficiency reasons with the DataFlow programming approach. Real-world images taken by satellites are analyzed and used as the basis for simulations. In the presented forest fire model, natural influences like wind strength and direction, burning behavior, as well as different levels of inflammability are considered. The DataFlow implementation on an FPGA-based Maxeler MAX3 Vectis card was compared to a sequential C version executed on an Intel Xeon E5-2650 2.0 GHz CPU. The author obtained speedups of up to 70 for a strong wind situation and 46 for a random wind setting while reducing energy consumption.

INTRODUCTION

Cellular automata (CA) (Wolfram, 1983) have been introduced in the early 1940s by Stanislaw Ulam and John von Neumann at Los Alamos National Laboratory, New Mexico. Ulam used them to study the growth of crystals, whereas von Neumann modelled a CA-based world of self-replicating robots. While Ulam's CA model is easy to imagine, von Neumann's approach is a complex one and is more or less just a mind game (Shiffman, 2012). Even in a time before powerful computers, Ulam and von Neumann have shown that CA are useful instruments for real-life simulations. Although they were already invented in the early 1940's, cellular automata weren't popular until the invention of Conway's "Game of Life", which was introduced in the work of Gardner (1970). This cellular automaton gained a lot of attention thanks to its ability of generating structures, which literally seem to be living.

The contribution of this chapter is a heuristic forest fire model based on cellular automata. The author's focus is to design an efficient model in order to quickly produce video simulations of the fire propagation. For achieving speedups of up to 70X compared to equivalent software on CPUs, the DataFlow

DOI: 10.4018/978-1-7998-7156-9.ch009

paradigm (Milutinovic et al., 2015) was used. This technology uses so called DFEs (DataFlow Engines) like FPGAs (Field Programmable Gate Arrays). In this paradigm the data is streamed to an accelerator and processed like on an assembly line, meaning that each element is exactly processed like all the others. This fine-granularity makes them well-suited for accelerating the introduced CA-based simulation, since cellular automata offer massive parallelism. Another reason for using DFEs is that they are not only considerably fast for data-intense simulations, but also extremely efficient in energy and space. Therefore, the presented application could be easily used on board of firefighting helicopters in order to navigate the pilot to the most important spot, where the fire should be stopped from further propagating. The consideration of natural influences like wind, burning behavior and inflammability allows the model to make realistic fire propagation predictions, which are useful when wildfires are out of control.

The remainder of this chapter is organized as follows. First, a background on cellular automata is given and related work is discussed. Then, the essence of the forest fire application is presented, and the author explains why the DataFlow paradigm was used. Subsequently, details on the implementation as well as program features are described. After that, the application's performance is evaluated, and the results are discussed. Finally, the last section concludes the chapter and gives an outlook on future work.

BACKGROUND AND RELATED WORK

Cellular automata (CA) are mathematical models, which can be used to realize simulations of natural processes. CA can be described as grids in which individual cells interact with each other in order to form a fluid system (Shiffman, 2012). One major characteristic of CA is taking adjacent cells for each element into account. The set of these surrounding cells is called neighborhood. Most cellular automata use regular or extended "Moore" neighborhoods, but simple ones work with the classic "Von Neumann" neighborhood, in which only the directly surrounding cells are considered (Adamatzky et al., 2008).

In this work the author uses cellular automata in order to simulate the spreading of wildfires. On the one hand, there are several research efforts focusing on fire propagation models based on cellular automata. On the other hand, the high computational effort makes parallelization or use of accelerators necessary. Some research groups use GPUs together with OpenCL (Stone et al., 2010) or CUDA (Manavski et al., 2008). Only few of them use FPGAs (Field Programmable Gate Array) or DataFlow-based approaches.

Back in 2002, four Italian researchers, namely Corsonello, Spezzano, Staino and Talia, published a paper (Corsonello et al., 2002) introducing efficient implementations of cellular automata on FPGAs. They used the low-level language VHDL (Very High Speed Integrated Circuit Hardware Description Language) (Coelho, 1989) to implement a forest fire simulation as well as a thinning algorithm. The runtime of an equivalent software on a general-purpose processor was used as a reference value for the FPGA performance measurements. The reported speedups for the forest fire and thinning algorithm are 24 and 65, respectively.

A few years later the work of van Woudenberg (2006) reported the performance of different cellular automata models in FPGA logic. The author implemented the famous "Game of Life", an HPP model as well as a simplified forest fire simulation. For the implementation itself, the library CAME&L (Cellular Automata Modeling Environment & Library) introduced by Naumov (2004) was used. CAME&L consists of modular components, which are implemented in C++. Van Woudenberg used it to implement some cellular automata which were transformed into FPGA logic with a C++to-VHDL compiler. Since