CS4110 - Project Assignment

Design and Implementation of an Insertion Sorting Algorihim

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*Abstract* — The scope of this document discusses the consideration of design and implementation of an insertion sorting algorithm in both hardware and software. We will go into greater detail with our insight and present the four implementations for our insertion sorting algorithm that consists of an ASIP, an FSMD, a single-thread C program in Zynq/Vitis IDE, and an IP generated with Vitis HLS and used in Zynq/Vitis IDE.

Keywords—Hardware, Software, Basys-3, Zybq, RTL, HLS, C, VHDL, FSMD, ASIP ISA, Vivado, Vitis

# Introduction

This assignment is written as a technical paper that goes through our process regarding our design and implementation of an insertion sorting algorithm with an input array of 8-bit unsigned numbers for four tasks in mind: 1) expanding our basic ASIP ISA, 2) creating an FSMD in VHDL, 3) coding it in Vitis IDE / Zynq and 4) creating a user IP block in Vitis HLS.

The AMD's Vitis Core Development Kit with the recommended version of 2023.2 was needed for this assignment as it includes applications like Vivado and Vitis HLS for our hardware and software implementation respectively.

Two development boards were used to carry out our testing and implementation of our insertion sorting algorithm. This includes the Digilent Basys-3 [2] and the Digilent Zybq-7000 (or Zybo-Z7) [3]. The Basys-3 was utilized for our first and second task because it was equipped with a Field Programmable Gate Array (FPGA) [2]. The ZYBO board was used for the third and last task as ZYBO development board has a Zynq 7000 System on Chip (SoC), which includes an FPGA, an ARM Cortex-A9 CPU, and connectivity peripherals [3].

# Insertion Sorting Algorihim

An insertion sorting algorithm is a very simple, straightforward method for sorting entries in a list or array in an ascending and descending order. The algorithm constructs a sorted segment of the array of one element at a time, placing each element into its proper position relative to the already-sorted area [1].

Initially, the algorithm treats the first member of the list as a sorted sublist with only that one entry. It then considers the next element in the list and compares it to those in the sorted sublist. If the new element is smaller than any of the elements in the sorted sublist, it is relocated until it reaches its proper position. This procedure repeats for each successive entry in the list, with the algorithm ensuring that the sorted sublist expands one element at a time while keeping its order.

(MAYBE SHOW PSEUDO CODE)

In the case of a list of numbers such as [4, 3, 5, 1, 2], insertion sort would begin at the first element of the array by considering element (4) as a sorted sublist. After comparing element 3 with element 4, it determines that element 3 should come before element 4. 3 is inserted in front of it, while 4 is moved to the right. The third element (5) is then considered by the algorithm. The two sorted elements (3 and 4) are already less than 5, thus nothing is changed. After the other elements in the sorted sublist (3, 4, and 5) have been shifted, the fourth element (1) is inserted at the front after being compared with every other element. The fifth element (2) is finally added between 1 and 3, resulting in the fully sorted list [1, 2, 3, 4, 5].

(SHOW FIGURE)

Insertion sort has the advantage of sorting the list in place, which eliminates the need for additional memory for a second list. This increases efficiency in terms of space complexity. However, it has a somewhat high time complexity for big lists, as it must constantly compare and shift entries, resulting in a worst-case time complexity of O(n²), where "n" is the number of elements in the list.

(SHOW GRAPH OF TIME-COMPLEXITY)

# ASIP

(WRITE SOMETHING HERE…)

# FSMD

(WRITE SOMETHING HERE…)

# Single-Thread C-Program

(WRITE SOMETHING HERE…)

# HLS Synthisis

(WRITE SOMETHING HERE…)

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##### References

1. Wikipedia Contributors, “Insertion sort,” Wikipedia, Sep. 07, 2024. https://en.wikipedia.org/wiki/Insertion\_sort# (accessed Oct. 20, 2024).
2. Digilent, “Basys 3 FPGA Board Reference Manual”, April 2016.
3. Digilent, “ZYBO FPGA Board Reference Manual”, February 2017.