09 August. 09

Examiner's Report

Student: **Patrick Suggate**
Degree: **Master of Science thesis in Electronics**
Title: **OpenVGA: An Open-Source PCI Graphics Adapter**

First of all, I would like to thank the Physics Department for choosing me to examine Patric's thesis.

The thesis describes developed of open-source PCI graphics adaptor named OpenVGA. Open-source hardware is relatively new feild which has become possible due to the advances in FPGA technology. Although it is more limited than open-source software, it makes promises to become useful for educational and research & development purposes. Patrick has developed all essential components of VGA compatible graphics adapter, including the overall architecture, PCB, HDL and software components.

Major

The complexity and amount of work which has been done is the project is quite impressive. Patrick demonstrates very high level of technical competency, knowledge and ability to develop a complex hardware/software system along. He is equally confident in discussing the low level design, computer architecture issues, as well as the electronics. The depth and level of comprehension used in the arguments in choosing an appropriate solution is high. Patrick demonstrates the ability to critically discuss the aspects of various related engineering topics. He also demonstrates the mastery in HDL programming and electronics design.

The most interesting part of the thesis is implementation and comparison of two processor cores, TTA16 and RISC16. This topic along would already be sufficient for the thesis and contains interesting research component. Patrick critically evaluates different processor architectures for suitability and efficiency in OpenVGA. He applies the correct strategies and methodologies in his analyses.

However, the thesis is too long. Even the appendixes are used to extend the main discussion in the chapters, instead of supplementing the main text with technical information or data. A few chapters lack the introduction and conclusion. Used informal/spoken language makes it very difficult to read. Often the author does not follow the formal grammatical rules of English language; the sentences are too long and too complex. The amount of typos is excessive. As far as I could, those placed were marked in pencil; they must be corrected.

The thesis would also greatly benefit if the focus was directed from the details of implementation and development to the research elements which are many in the thesis, but unfortunately not in the general focus.

Minor

The following are my detailed comments
and should be taken as notes for the necessary corrections.

Common:

In some cases caption to Figures and Tables are used not to explain it but as an additional place for an argument. Those must be corrected.

Chapter 1

The chapter introduces the purpose, relevance, limitations of the project, and also outlines the thesis. Four goals of OpenVGA project have been stated which seems to be directly translated into the goals of the thesis. This in my view disadvantages the thesis as it underemphasises the research components and makes a design the main focus in the thesis. E.g. the second goal stated on page 15 has not been achieved in the thesis. This would probably not impact the overall outcome of the thesis, unless the goals of OpenVGA project have been identified as the goals of the thesis, which they have.

Chapter 2

The chapter makes a retrospective overview of earlier graphics adaptors including VGA and its clones and improved standards. The technical aspects of VGA have been discussed as well a few other similar to OpenVGA projects. Some of the projects, like Open Graphics Projects, have been presented in details as Manticore is mentioned in just 2.5 lines and includes no reference. A comparison of objectives of OpenVGA and other projects unfortunately has not been done.

For corrections:

- Table 2.1 is not referred in the text.
- Paragraph 2.2.4 needs a reference.

Chapter 3

This chapter gives an outline of OpenVGA with references to the correspondent sections of later chapters.

For corrections:

- On p. 29 USB UART is referred first time but not explained. Later in the text is becomes clear that it is UART to USB component.
- First paragraph on p. 32 is unclear due to the used language. Rephrasing is needed.
- On the same page TTA16 and RISC16 cores are discussed. Other options have been mentioned however no reference is given. The decision to develop TTA16 and

RISC16 lacks a supporting argument. "It was developed to compare with TTA16, the first OpenGA processor" is insufficient (RISC16, page 33 second paragraph). Only later in Chapter 4 the rational becomes more or less evident.

- On page 35, section 3.2.6, first paragraph, a reference is needed when PCI Local Bus features are compared to other implementations.

Chapter 4

This Chapter describes the architecture and programming approaches for TTA16 and RISC16 processor cores. It also gives significant details and describes the issues of implementing the cores in Spartan 3 FPGA. A great deal of analyses and comparison of these two cores from point of view suitability and effectiveness for OpenVGA is given.

For corrections:

- First paragraph on p. 37 requires a reference.
- On p. 40
  - The formula should have a number.
  - It's unclear what is performance τ and/or in what units.
  - The calculations are difficult to correspond to the text.
- On p. 42 the last paragraph needs restructuring as pencilled in the thesis.
- On p. 46 reference to Figure 4.5 should be 4.4 instead.
- References to Table 7.2 from 4.5 on pp 46 & 47, 58, 66 are too far from the table. Consider moving the table to Chapter 4.
- On p. 53 Figure 4.7 caption is too long and referrers back to the text. Most of it should be said in the text instead.
- Table on p. 56 has no caption or number.
- Table 4.4 instead of caption has an additional to the text argument.
- On p. 64 Figure 4.12 is not a figure, could be just text.

Chapter 5

This Chapter describes implementation and issues of access to the local memory and specifically organization and operation of memory cache.

For corrections:

- On p. 72 reference to the Figure 6.8, reference is too far and does not illustrate much.
- On the same page, third paragraph is unclear. Rephrase.

- Description of the bug on p. 73 shall belong to one of the Appendixes. The last sentence on p. 74 contains 7 comas and 3 verbs "to be" what makes difficult to follow the meaning.
- The formulas and followed calculations on pp 75-76 should be enumerated.
- Figure 5.6 should be on page 77.
- Figure 5.7 is not referred in the text.
- On p. 83 last sentence referrers to non-existing Section 5.5.
- 5.3 suggest rather unusual definition of DMA as well as functional purpose. Possibly this module needs another name as it does not fully fit under concept of Direct Memory Access.

Chapter 6

The chapter elaborates on the various aspects of I/O and data synchronization in OpenVGA.

For corrections:

- In 6.1 referred Figure 3.1 does not designate any crystal oscillator, though it's been referred in the text.
- In 6.1.2 second sentence is inaccurate as "possibly" implies uncertainty or lack of knowledge or data. Rephrasing is needed, including in the related footnote.
- In 6.2 for the sake of accuracy 133 MHz PCI-X should be mentioned as it is back compatible to PCI. Reference is also needed there.
- On the same page, last paragraph, the argument for two clock cycles is not valid in general case. It is either required referring to the particular frequencies or a correct statement for the general case.

Chapter 7

This chapter concludes the thesis.

For corrections:

- The first paragraph does not sound grammatically, rephrasing is needed.
- On p. 104 the statement "This numbers are approximate and depend a lot on many other factors" devaluate any further referring to this data.
- On p. 108 in the first paragraph of 7.3 the statement "There is no free and open implementation of a VGA-compatible graphics adaptor" contradicts to the overview in Chapter 2. The last sentence of the paragraph is unclear.
- On p. 109 in 7.3.3 the reasons and relevance of referring to the hardware computations and ray-tracing are unclear for an unprepared reader and should be supported by more references.
- The reference [38] on p 114 is incomplete.

- On p 110 in "New Features", it is stated that VGA-compatibility is "straight-forward". VGA-compatibility is also stated as one of the project's goals. Nevertheless it has not been done, and thesis is not clear on the reasons why.

25 April 2007

Office of Postgraduate Studies, College of Sciences, Otago University

To whom it may concern

Here is my examiner's report of Patrick Suggate's thesis "OpenVGA: An Open-Source PCI Graphics Adapter".

Introduction

The thesis is structured as seven chapters and five appendices with a total of 148 pages.

Chapter 1 introduces the thesis, describing the motivation and relevance, and concludes with a roadmap of the thesis.

Chapter 2 is a background chapter on graphics adapters, describing how they work, and other related open graphics projects.

Chapter 3 outlines the OpenVGA hardware development

Chapter 4 describes two processor cores developed by the author; a transport triggered processor and a more conventional 16-bit RISC architecture. These architectures are optimised for small programs, in particular, character mapping for a graphics adapter.

Chapter 5 describes the implementation of an SDRAM controller and a two-way set associative data cache. A cache simulator was developed for assessing the line size, replacement policy, write policy, and set associativity.

Chapter 6 describes the problems with multiple clock domains and methods use to bridge them. In this chapter the author discusses how the PCI bridge was implemented and how the VGA and DVI controller operated.

Chapter 7 summarises the project, describing all the sub-systems the author developed. He then has a brief comparison of the processor cores he developed with some other processor cores. He shows that his processors compete favourably in terms of speed and size. Finally, the author presents suggestions for future work.

There are many facets to this thesis; the author has done hardware development for a FPGA based PCI card, system on chip firmware development, developed two processor architectures, and developed a number of software tools such as assemblers, format converters, and cache simulators. None of these things are trivial.

Comments

The thesis is well written with a good introduction describing the motivation for the project. The author clearly likes doing things his own way (a criticism that could also be levelled at this reviewer!).

While I understand that the author is trying to develop an open source system and is reluctant to

use proprietary processor cores it would have been useful to see a comparison with the performance of a processor such a PicoBlaze.

Trying to get DDR SDRAM operating on a two layer board was ambitious. Even if it worked it would have made a good source of electrical interference!

The author noticed an occasional freeze with his SDRAM controller. Perhaps there is a metastability problem or unforeseen race-condition? These sort of problems are extremely difficult to find and may require the use of a model-checker. The author has done well not to have many more of these problems. This is testimony to the care he has shown and his understanding of dealing with multiple clock domains and asynchronous signals.

There is no mention of how the FPGA firmware is loaded; I assume using an external JTAG programmer? It would have been useful to have a mechanism to allow loading of the firmware via the PCI bus.

From a compiler developers perspective I like the ability for condition codes to not be automatically set; this simplifies adding spill code. I would have liked to have seen an overflow flag to simplify signed-comparisons.

Specific criticisms

1. There are a number of statements that would have been useful to reference, for example, in paragraphs 4 and 5 on page 16, and the Manticore system on page 28.
2. page 30. It is unlikely that DDR SDRAM will work without termination resistors since the voltage thresholds assume the use of termination resistors. Perhaps fly-by termination could have been used to place the resistors in a more convenient location?
3. page 31. The DDR SDRAM was likely to be getting hot due to latch-up resulting from signal overshoot due to the lack of termination resistors.
4. page 71. Paragraph 2 says that Figure 5.3 shows bidirectional data transfer whereas the figure shows DDR operation.
5. page 77. Appendix ??. The author should have checked the LaTeX log file!
6. page 86. 'previously mentioned logic cores'. Should be more specific and refer to the section(s).
7. page 101. 'due to time constraints'. I'm not surprised!
8. There are a number of references that do not state how they were published. There are also inconsistent of capitalisations of acronyms such as FPGA and SDRAM that can be solved with curly braces in the BibTeX files.
9. page 137. Is it straightforward to implement a MFSR 'decrementer'? A reference would have been useful.
10. page 139. You need the dereference operator before the casts, oh and memcpy usually is char based so the casts should be to char pointers.

There are many other minor grammatical errors, too numerous to list; I am happy to return copy of the thesis with these annotated.

Summary

In summary, Patrick Suggate has produced an excellent thesis. The thesis is well written, shows excellent understanding, is reasonably well referenced, and the diagrams are clear and well drawn. While there are a more typographic errors than I would have like, I do not think a revision is required to correct them. This is my only disappointment of the thesis. The author obviously did not put

as much care into proofing as he did with the technical parts of the thesis. It is obvious that some sections were not spell-checked.

The author has clearly has spent much time on this project. He shows an excellent understanding on many aspects of computer system design and has battled with a number of complicated interfaces. It would have been useful to have seen more benchmarking of the processor cores compared with other architectures in the literature. I would also have liked to have seen more referencing of the literature on computer architectures but given the extent of Patrick's accomplishments I guess I'm being churlish.