Digital Systems for the MITRA

(GPU Computing)

Submitted by

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UNIVERSITY OF MAURITIUS

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

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To my parents

Declaration of Authorship

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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UNIVERSITY OF MAURITIUS

Abstract

Faculty of Science

Department of Physics

BSc (Hons) Physics with computing

Digital Systems for the MITRA

(GPU Computing)

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. . . This dissertation describes the development, and testing of software, and general purpose computing hardware for the integration of Digital Systems in the Multi-frequency Interferometry for Astronomy (MITRA) array. High performance software correlation was implemented with the use of the DiFX (Distributed FX) software by Deller et al. (2007) developed as part of the Australian Major National Research Facilities Programme and operated under licence, making it an off the shelf, user-friendly, and custom documented software. Further possibilities offered by General-purpose computing on Graphics Processing Units (GPGPU) were implemented, developed, and tested taking advantage of its advance parallelism, and performance, with typical speedups of . . . observed compared to . . . with the DiFX software . . .

Acknowledgements

The road which lead to the accomplishment of my undergraduate project and dissertation is a long one and was not taken alone.

Above all, as I am a faithful believer, and I believe that nothing happens without a reason, I wish to thank God for everything, and making all of this possible whichever way it may have happened.

I also wish to acknowledge the following, first I am very grateful to my supervisor, Dr. G. K. Beeharry, for the opportunity he gave me to work on the topic, he has been an inspirational lecturer who encouraged me to pursue in the field of scientific computing, also most importantly I wish to thank him for his guidance, useful suggestions during the course of this project, and for his reviews, remarks and comments during the writing process of the dissertation. I express my thanks to the lecturers of the department of physics who during those 3 years here at the University of Mauritius contributed to build up the physicist I am today.

My special thanks goes to the MPhil student, Mr. Vinand Prayag, who was the first to trust me to work with him on the specific topic of software correlation, he was always there to talk and help when I needed advices, both on my project and my dissertation.

I am also thankful to the technical staff of the Mauritius Radio Telescope and that of the department of physics for their help and guidance during the practical sessions and the implementation of my project.

Extra credits goes to my classmates with whom we struggled with the BSc (Hons) Physics course, specially those of the computing branch who will recognise themselves, where the last two years together were a lot of fun and made my stay at the university a lot nicer.

I would also like to thank those closest to me for their support and my family, who has always been behind me and helped me greatly to continue in the field of physics at a university level.

Contents

List of Figures

List of Tables

Abbreviations

CUDA™	**C**ompute **U**nified **D**evice **A**rchitecture
EM	**E**lectro**m**agnetic
FFT	**F**ast **F**ourier **T**ransform
GPU	**G**raphics **P**rocessing **U**nit
GPGPU	**G**eneral **P**urpose **C**omputing on **G**raphics **P**rocessing **U**nits
MEM	**M**aximum **E**ntropy **M**ethod
MITRA	**M**ultifrequency **I**nterferometry **T**elescope for **R**adio **A**stronomy
MRT	**M**auritius **R**adio **T**elescope
NNLS	**n**on-**n**egative **l**east **s**quare **a**lgorithm
R.A.	**R**adio **A**stronomy
SDR	**S**oftware **D**efined **R**adio
VLA	**V**ery **L**arge **A**rray (Radiotelescope)

Physical Constants

Speed of Light	c	$=$	$2.997\ 924\ 58 \times 10^{8}$ ms^{-1} (exact)

Symbols

a	distance	m
P	power	W (Js^{-1})
ω	angular frequency	rads^{-1}

Chapter 1

Introduction

1.1 Digital Systems for the MITRA

...

1.2 Aims and objectives

This project is aimed at the development, and testing of software and general purpose computing hardware for the Multi-frequency Interferometry for Astronomy (MITRA) array project. In so doing it will pave the way for a higher integration of digital systems as opposed to specialised hardware in the synthesis imaging process. The particular application which was focused on was that of high performance software correlation by the use of parallel computing. The central objective was to implement the DiFX (Distributed FX) software by Adam Deller for the MITRA by making it an off the shelf, user-friendly and custom documented software. The second part of the project was to explore the further possibilities opened up by General-purpose computing on Graphics Processing Units (GPGPU) to implement, develop, and test code taking advantage of its advance parallelism, and performance. I hope that the that the work on this particular project will not stay still and that this dissertation will inspire other people to continue to the work, thus from that initiative follows naturally the creation a public git repository: `https://github.com/Benzy-Louis/MITRA_FX-CPU-GPU.git` where those interested to contribute to the project can continue the development, work on the source code, and improve the software and its documentation on their own or contribute for the same to the repository, those interested are freely encouraged to mail me at louis.ruben@gmail.com if they want to contribute or have questions, suggestions on the project or on this dissertation and an appendix is written for the purpose of the use of the git repository . . .

1.3 Outline

The dissertation is composed of . . . main chapters where . . . It is structured as follows *chapter 1* is an introduction to . . . Then *chapter 2* . . .

Chapter 2

Literature Review

[Everything (codes, text, formatting) in this chapter is cheesy for the sake of having a quick overview while preparing the real literature review]

2.1 Mr. Vinand Prayag Lit. Rev. Plan advice

The past

Hardware Correlator -> e.g. MRT room size, hardware . . .

Evolution

Better processing power CPU made it feasible to replace hardware based system by software based ones. A rapid evolution of software defined radio (SDR). Direct applicability to radio astronomy.

Examples

Now we have what we call software telescopes such as the LOFAR powered by IBM supercomputers.

Recently SWINBURNE built a general purpose software correlator the DiFX,

Pros. and cons. of DiFX.

2.2 Tentative listing

Thompson, Moran, and Swenson Jr (2008)

Francesco (2014)

Wilner (2014)

Wikipedia (2014)

pjbevel@gmail.com (2014)

Encyclopedia Britannica (2014a)

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Jheengut (2008)

Platel (2010)

Ginourie (2010)

Pirthee (2013)

Cecile (2014)

Ingala (2013)

NVIDIA (2009)

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Deller, Tingay, Bailes, and West (2007)

Harris, Haines, and Staveley-Smith (2008)

Woods, Inggs, and Langman (2009)

Ord, Greenhill, Wayth, Mitchell, Dale, Pfister, and Edgar (2009)

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Clark, La Plante, and Greenhill (2012)

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Harshavardhan Reddy Suda (2013)

S. Bhatnagar (2014)

Ben Barsdell (2014)

Amr H. Hassan (2014)

Alex Bogert and Smith (2014)

Chapter 3

Synthesis Imaging

...

Chapter 4

Distributed FX Correlation - The DiFX software

...

This work made use of the Swinburne University of Technology software correlator, developed as part of the Australian Major National Research Facilities Programme and operated under licence.

Chapter 5

GPGPU FX Correlation

5.1 The GPU

...

5.2 The xGPU code

...

5.2.1 Tiled Memory Tasking Algorithm

...

Chapter 6

Conclusions and future works

6.1 Conclusions

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6.2 Future works

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Appendix A

Background, mathematical derivations

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Appendix B

DiFX - Custom documentation

B.1 DiFX - Preliminary setup

[Vague content just to fill in, following. . .]

To install the diFX-2.3 software correlator do the following things,

1. Download the source of the software somewhere using the following command

   ```
   svn co https://svn.atnf.csiro.au/difx/master_tags/DiFX-2.3
   ```

2. Install IPP, i.e.

   ```
   >> cd $IPP_PATH
   >> chmod +x install.sh
   >> ./install.sh
   ```

3. Install PGPLOT, following the instructions of the following website:
   http://pendientedemigracion.ucm.es/info/Astrof/software/howto/howto-pgplot.html
   Do the following,

   ```
   >> cd /usr/local/src
   >> mv ~/Downloads/pgplot5.2.tar.gz .
   >> tar zxvf pgplot5.2.tar.gz
   >> mkdir /usr/local/pgplot
   ```

```
>> cd /usr/local/pgplot
>> cp /usr/local/src/pgplot/drivers.list
>> /usr/local/src/pgplot/makemake
 /usr/local/src/pgplot linux g77_gcc_aout
```

Edit the file makefile

```
>> sudo gedit makefile &
```

Change

```
FCOMPL=g77
# to
FCOMPL=gfortran
```

Then save, and compile

```
>> make
>> make cpg
>> make clean
```

Export the paths

```
>> export PGPLOT_DIR=/usr/local/pgplot
>> export PGPLOT_DEV=/Xserve
```

4. Install OpenMPI also.

5. Then go back to install diFX-2.3, edit the setup.bash file,

```
>> cd $DIFX_ROOT
>> sudo gedit setup.bash &
```

6. Change the following paths environment variables, an example here for my setup,

```
####### ROOT PATHS ##########################
export DIFXROOT=/home/ruben/Final_Year_Project/DiFX/DiFX-2.3
export DIFX_PREFIX=$DIFXROOT
export PGPLOTDIR=/usr/local/pgplot/
```

```
export IPPROOT=/opt/intel/ipp/bin/

####### COMPILER ############################
export MPICXX=/usr/local/bin/mpicxx

# ALSO UNCOMMENT THESE THINGS ALSO

####### PORTS FOR DIFXMESSAGE ###############
# Uncomment these to enable DIFX_MESSAGES
export DIFX_MESSAGE_GROUP=224.2.2.1
export DIFX_MESSAGE_PORT=50201
export DIFX_BINARY_GROUP=224.2.2.1
export DIFX_BINARY_PORT=50202
```

7. use the geniepc script with input the path /opt/intel

   ```
   $DIFXROOT/applications/difx_monitor
   ```

8. Then we can start the installation of DiFX-2.3, go back to the root folder of diFX, and do the following,

   ```
   >> source setup.bash
   >> ./install-difx
   ```

9. Now for the preliminary tests I have not automated the scripts which would allow me to run diFX without having to send out preliminary parameters first. To be able to use the program one must set up the RPC. So the rpcbind package has to be installed.

10. To make rpcbind work,

    ```
    >> sudo -i service portmap stop
    >> sudo -i rpcbind -i -w
    >> sudo -i service portmap start
    ```

    Then we can start the calculation server and check it for the host,

```
>> startCalcServer
>> checkCalcServer 127.0.0.1
# Setting up the CALC_SERVER environment variable to the local host
>> export CALC_SERVER=127.0.0.1
```

To see the processes, open another terminal go to the root directory of diFX, source setup.bash and then run

It will display the processes taking place in the calculation, I attached a text file with that info.

```
>> errormon2
```

11. When all this is done, one can try the example files, for the RDV70 data,

```
>> vex2difx example.v2d
>> calcif2 example_1.calc
>> mpirun -np 8 mpifxcorr example_1.input
```

12. When the correlation is done, you can get the FITS-LDI file from it in the following way,

```
>> difx2fits example_1.difx
```

Appendix C

The Git repository

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Appendix D

Progress Log

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