

# Hardware Implementation of an Invariant Observer



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This dissertation is submitted for the degree of  
*Bachelor of Science*

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## **Declaration**

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other University. This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration, except where specifically indicated in the text. This dissertation contains less than 65,000 words including appendices, bibliography, footnotes, tables and equations and has less than 150 figures.

Marko Stanisic

2014



## Abstract

The Invariant Observer is an approach to implement an alternative hardware realization of the invariant operation published in the paper **Runtime Verification of Embedded Real Time Systems**. The Invariant Observer is a Runtime Verification Unit monitoring a signal  $\phi$  from a System under Test in real time and determining whether the signal is currently in an active state and has been active during the past  $\tau$  clock cycles.

If this is the case then signal  $\phi$  is observed as being invariant within the time interval  $[0, \tau]$ .



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# Chapter 1

## Introduction

### 1.1 Overview of the Bachelor Thesis

In embedded real time systems it is necessary to make efforts to verify a system design. A system design can be formalized by a mathematical specification for a dynamic system model. One approach to system design verification is the deduction, that shows that the design implies the requirements.

In critical Real Time Systems (RTS) timing constraints have to be considered in the requirement engineering. Such Real Time Systems are modelled by states changing over time. Time constraints can be formulated as constraints on the duration of critical states. A real time logic should be able to specify that real time constraints. Generally it seems that two main classes of real time logic are present, explicit or implicit temporal logic.[2]

Explicit temporal logic is an expression of a time variable. The time variable can be the representation of a time interval or a variable in temporal logic. Implicit temporal logic (for example MTL - Metric Temporal Logic) is using temporal operators that constrain the extend of a state. It is based on interval temporal logic and the duration concept. Implicit temporal logic can be very useful to express before/after relations between concurrent actions. For further details [2] can be a good source of information. In runtime verification a monitor evaluates executions of a **System under Test (SUT)** [4]. The evaluation is formalised from a formal specification described in temporal logic.

For ultra critical systems it is important to meet four major requirements:

1. Functionality : cannot change target's behaviour
2. Certifiability: must avoid re-certification
3. Timing : must not interfere with the target's timing
4. Swap : must not exhaust size, weight and power tolerance

A **Runtime Verification Unit (RVU)** is a verification monitor that meets that four major requirements. As part of this requirements, the RVU must be separated from SUT. In fact it is a synthesized hardware that monitors the execution of a SUT.

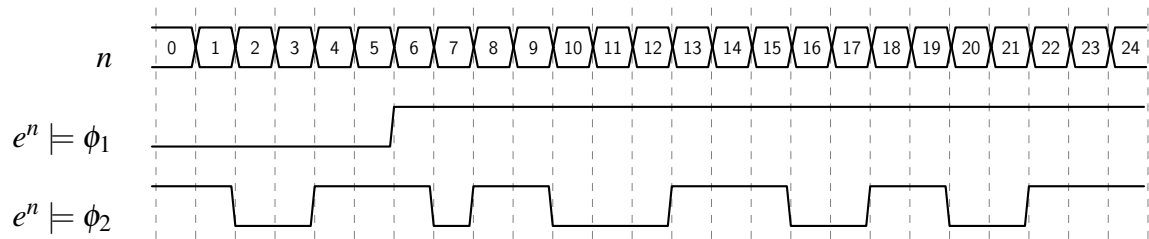
The topic of my thesis “Hardware implementation of an Invariant Observer” can also be considered as a RVU, it evaluates the execution of a SUT and checks it for invariance conditions. My observer is an alternative implementation of the invariant observer INVARIANT-SYMBOL published in [4], that bypass the problem of resource limitation and make use of the significant advantages of a high parallel **Field Programmable Gate Array(FPGA)** hardware implementation. The most important difference is that my observer is not bounded to a specific  $\tau$ , but the observer in [4] are bounded. This feature will be explained in the next section.

In the publication “**Real-Time Runtime Verification on Chip** ” [4] the concept of a RVU and the principles of that Verification Framework are described in great detail.

A survey about the functionality of the invariant observer in the next section.

## 1.2 The Invariant Observer

This section is a survey about the invariant observer and how it works. More details about algorithm are presented in the next chapter.



### 1.3 Where does it come from?





# Chapter 2

## My Second Chapter

### 2.1 Reasonably Long Section Title

I'm going to randomly include a picture Figure 2.1.

If you have trouble viewing this document contact Krishna kks32@cam.ac.uk.

#### Enumeration

1. The first topic is dull
2. The second topic is duller
  - (a) The first subtopic is silly
  - (b) The second subtopic is stupid
3. The third topic is dullest

#### itemize

- The first topic is dull
- The second topic is duller
  - The first subtopic is silly
  - The second subtopic is stupid
- The third topic is dullest

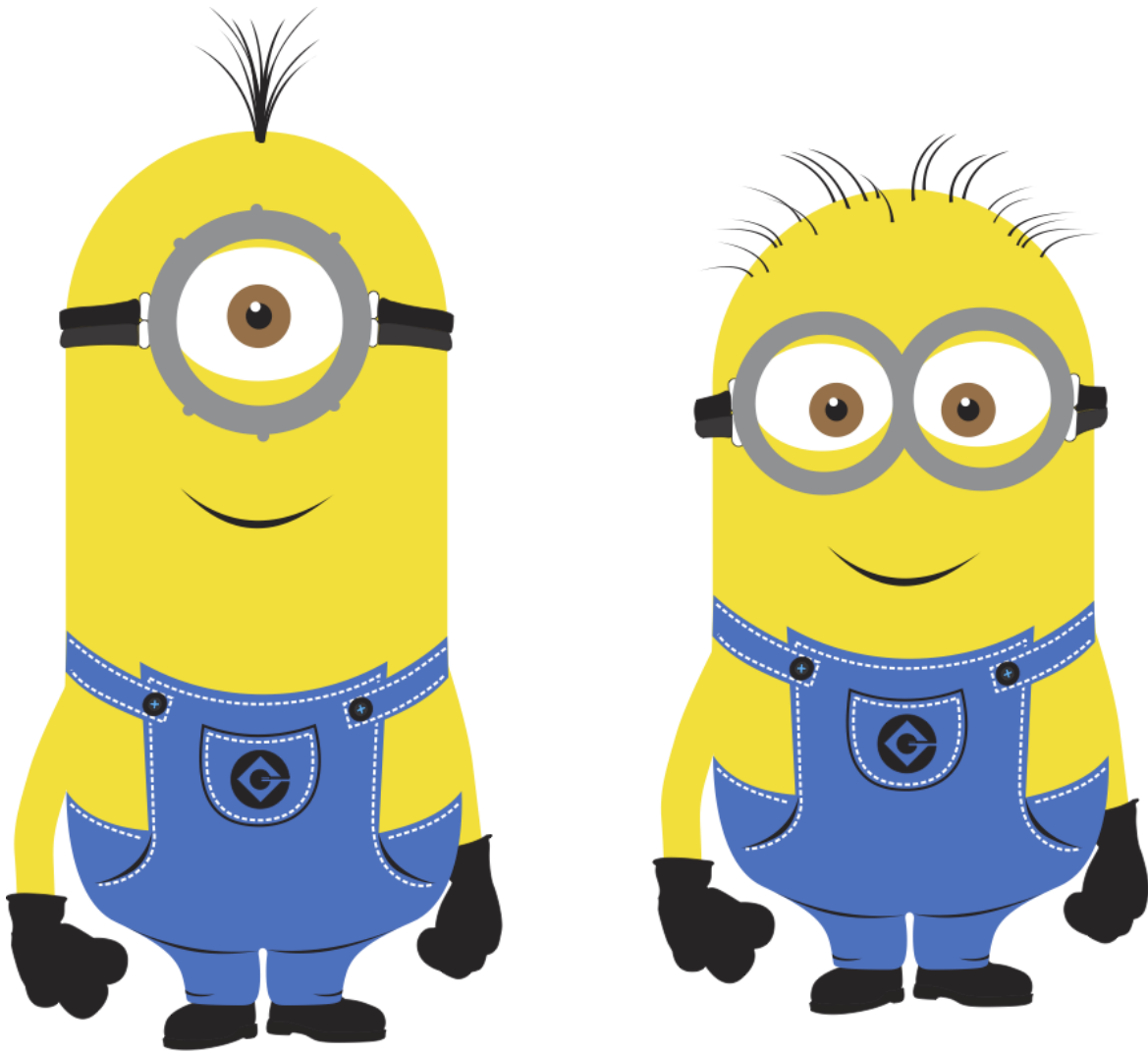


Fig. 2.1 This is just a long figure caption for the minion in Despicable Me from Pixar

## **description**

**The first topic** is dull

**The second topic** is duller

**The first subtopic** is silly

**The second subtopic** is stupid

**The third topic** is dullest

## 2.2 Hidden Section

**Lorem ipsum dolor sit amet, consectetur adipiscing elit.** In magna nisi, aliquam id blandit id, congue ac est. Fusce porta consequat leo. Proin feugiat at felis vel consectetur. Ut tempus ipsum sit amet congue posuere. Nulla varius rutrum quam. Donec sed purus luctus, faucibus velit id, ultrices sapien. Cras diam purus, tincidunt eget tristique ut, egestas quis nulla. Curabitur vel iaculis lectus. Nunc nulla urna, ultrices et eleifend in, accumsan ut erat. In ut ante leo. Aenean a lacinia nisl, sit amet ullamcorper dolor. Maecenas blandit, tortor ut scelerisque congue, velit diam volutpat metus, sed vestibulum eros justo ut nulla. Etiam nec ipsum non enim luctus porta in in massa. Cras arcu urna, malesuada ut tellus ut, pellentesque mollis risus. Morbi vel tortor imperdiet arcu auctor mattis sit amet eu nisi. Nulla gravida urna vel nisl egestas varius. Aliquam posuere ante quis malesuada dignissim. Mauris ultrices tristique eros, a dignissim nisl iaculis nec. Praesent dapibus tincidunt mauris nec tempor. Curabitur et consequat nisi. Quisque viverra egestas risus, ut sodales enim blandit at. Mauris quis odio nulla. Cras euismod turpis magna, in facilisis diam congue non. Mauris faucibus nisl a orci dictum, et tempus mi cursus.

Etiam elementum tristique lacus, sit amet eleifend nibh eleifend sed <sup>1</sup>. Maecenas dapibus augue ut urna malesuada, non tempor nibh mollis. Donec sed sem sollicitudin, convallis velit aliquam, tincidunt diam. In eu venenatis lorem. Aliquam non augue porttitor tellus faucibus porta et nec ante. Proin sodales, libero vitae commodo sodales, dolor nisi cursus magna, non tincidunt ipsum nibh eget purus. Nam rutrum tincidunt arcu, tincidunt vulputate mi sagittis id. Proin et nisi nec orci tincidunt auctor et porta elit. Praesent eu dolor ac magna cursus euismod. Integer non dictum nunc.

---

<sup>1</sup>My footnote goes blah blah blah! ...



Fig. 2.2 Best Animations

Subplots

I can cite Wall-E (see Fig. 2.2b) and Minions in despicable me (Fig. 2.2c) or I can cite the whole figure as Fig. 2.2



# Chapter 3

## My Third Chapter

### 3.1 First Section of the Third Chapter

And now I begin my third chapter here ...

And now to cite some more people Ancy et al. [1], Read [3]

#### 3.1.1 First Subsection in the First Section

...and some more

#### 3.1.2 Second Subsection in the First Section

...and some more ...

##### First subsub section in the second subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

#### 3.1.3 Third Subsection in the First Section

...and some more ...

##### First subsub section in the third subsection

...and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it and some more and some more and some more and some more

and some more and some more and some more ...

#### **Second subsub section in the third subsection**

... and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

## **3.2 Second Section of the Third Chapter**

and here I write more ...

Now we can refer to the table using Table. 3.1.

Table 3.1 Table with Borders

1	2	3
4	5	6
7	8	9



# References

- [1] Christophe Ancey, Philippe Coussot, and Pierre Evesque. Examination of the possibility of a fluid-mechanics treatment of dense granular flows. *Mechanics of Cohesive-frictional Materials*, 1(4):385–403, 1996. URL [http://doi.wiley.com/10.1002/\(SICI\)1099-1484\(199610\)1:4<385::AID-CFM20>3.0.CO;2-0](http://doi.wiley.com/10.1002/(SICI)1099-1484(199610)1:4<385::AID-CFM20>3.0.CO;2-0).
- [2] A.P. Ravn, H. Rischel, and K.M. Hansen. Specifying and verifying requirements of real-time systems. *Software Engineering, IEEE Transactions on*, 19(1):41–55, Jan 1993. ISSN 0098-5589. doi: 10.1109/32.210306.
- [3] C. J. Read. A solution to the invariant subspace problem on the space  $l_1$ . *Bull. London Math. Soc.*, 17:305–317, 1985.
- [4] Thomas Reinbacher, Matthias Függer, and Jörg Brauer. Real-time runtime verification on chip. In Shaz Qadeer and Serdar Tasiran, editors, *Runtime Verification*, volume 7687 of *Lecture Notes in Computer Science*, pages 110–125. Springer Berlin Heidelberg, 2013.



# Appendix A

## How to install L<sup>A</sup>T<sub>E</sub>X

### Windows OS

#### TeXLive package - full version

1. Download the TeXLive ISO (2.2GB) from <https://www.tug.org/texlive/>
2. Download WinCDEmu (if you don't have a virtual drive) from <http://wincdemu.sysprogs.org/download/>
3. To install Windows CD Emulator follow the instructions at <http://wincdemu.sysprogs.org/tutorials/install/>
4. Right click the iso and mount it using the WinCDEmu as shown in <http://wincdemu.sysprogs.org/tutorials/mount/>
5. Open your virtual drive and run setup.pl

or

#### Basic MikTeX - TeX distribution

1. Download Basic-MiK<sub>T</sub>E<sub>X</sub>(32bit or 64bit) from <http://miktex.org/download>
2. Run the installer

3. To add a new package go to Start » All Programs » MikTeX » Maintenance (Admin) and choose Package Manager
4. Select or search for packages to install

## **TexStudio - Tex Editor**

1. Download TexStudio from  
<http://texstudio.sourceforge.net/#downloads>
2. Run the installer

## **Mac OS X**

### **MacTeX - TeX distribution**

1. Download the file from  
<https://www.tug.org/mactex/>
2. Extract and double click to run the installer. It does the entire configuration, sit back and relax.

### **TexStudio - Tex Editor**

1. Download TexStudio from  
<http://texstudio.sourceforge.net/#downloads>
2. Extract and Start

## **Unix/Linux**

### **TeXLive - TeX distribution**

#### **Getting the distribution:**

1. TeXLive can be downloaded from  
<http://www.tug.org/texlive/acquire-netinstall.html>.

2. TexLive is provided by most operating system you can use (rpm,apt-get or yum) to get TexLive distributions

## Installation

1. Mount the ISO file in the mnt directory

```
mount -t iso9660 -o ro,loop,noauto /your/texlive####.iso /mnt
```

2. Install wget on your OS (use rpm, apt-get or yum install)
3. Run the installer script install-tl.

```
cd /your/download/directory
./install-tl
```

4. Enter command 'i' for installation
5. Post-Installation configuration:  
<http://www.tug.org/texlive/doc/texlive-en/texlive-en.html#x1-320003.4.1>
6. Set the path for the directory of TexLive binaries in your .bashrc file

## For 32Bit OS

For Bourne-compatible shells such as bash, and using Intel x86 GNU/Linux and a default directory setup as an example, the file to edit might be

```
edit ~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/i386-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

**For 64Bit**

```
edit ~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/x86_64-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

**Fedora/RedHat/CENTOS:**

```
sudo yum install texlive
sudo yum install psutils
```

**SUSE:**

```
sudo zypper install texlive
```

**Debian/Ubuntu:**

```
sudo apt-get install texlive texlive-latex-extra
sudo apt-get install psutils
```

## Appendix B

### Installing the CUED Class file

$\text{\LaTeX}$ .cls files can be accessed system-wide when they are placed in the  $\langle\text{texmf}\rangle/\text{tex}/\text{latex}$  directory, where  $\langle\text{texmf}\rangle$  is the root directory of the user's  $\text{\TeX}$  installation. On systems that have a local texmf tree ( $\langle\text{texmflocal}\rangle$ ), which may be named “texmf-local” or “localtexmf”, it may be advisable to install packages in  $\langle\text{texmflocal}\rangle$ , rather than  $\langle\text{texmf}\rangle$  as the contents of the former, unlike that of the latter, are preserved after the  $\text{\LaTeX}$  system is reinstalled and/or upgraded.

It is recommended that the user create a subdirectory  $\langle\text{texmf}\rangle/\text{tex}/\text{latex}/\text{CUED}$  for all CUED related  $\text{\LaTeX}$  class and package files. On some  $\text{\LaTeX}$  systems, the directory look-up tables will need to be refreshed after making additions or deletions to the system files. For  $\text{\TeX}$ Live systems this is accomplished via executing “texhash” as root.  $\text{\TeX}$  users can run “initexmf -u” to accomplish the same thing.

Users not willing or able to install the files system-wide can install them in their personal directories, but will then have to provide the path (full or relative) in addition to the filename when referring to them in  $\text{\LaTeX}$ .

