清华大学

计算机组成原理

计算机实验报告

支持 THCO MIPS 指令系统的流水线计算机设计与实现

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Abstract

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The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too…

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Chapter 1

Chapter Title Here

1.1 Welcome and Thank You

Welcome to this LaTeX Thesis Template, a beautiful and easy to use template for writing a thesis using the LaTeX typesetting system.

If you are writing a thesis (or will be in the future) and its subject is technical or mathematical (though it doesn't have to be), then creating it in LaTeX is highly recommended as a way to make sure you can just get down to the essential writing without having to worry over formatting or wasting time arguing with your word processor.

LaTeX is easily able to professionally typeset documents that run to hundreds or thousands of pages long. With simple mark-up commands, it automatically sets out the table of contents, margins, page headers and footers and keeps the formatting consistent and beautiful. One of its main strengths is the way it can easily typeset mathematics, even heavy mathematics. Even if those equations are the most horribly twisted and most difficult mathematical problems that can only be solved on a super-computer, you can at least count on LaTeX to make them look stunning.

1.2 Learning LaTeX

LaTeX is not a wysiwyg (What You See is What You Get) program, unlike word processors such as Microsoft Word or Apple's Pages. Instead, a document written for LaTeX is actually a simple, plain text file that contains no formatting. You tell LaTeX how you want the formatting in the finished document by writing in simple commands amongst the text, for example, if I want to use italic text for emphasis, I write the \emph{text} command and put the text I want in italics in between the curly braces. This means that LaTeX is a "mark-up" language, very much like HTML.

1.2.1 A (not so short) Introduction to LaTeX

If you are new to LaTeX, there is a very good eBook – freely available online as a PDF file – called, "The Not So Short Introduction to LaTeX". The book's title is typically shortened to just lshort. You can download the latest version (as it is occasionally updated) from here: http://www.ctan.org/tex-archive/info/lshort/english/lshort.pdf

It is also available in several other languages. Find yours from the list on this page: http://www.ctan.org/tex-archive/info/lshort/

It is recommended to take a little time out to learn how to use LaTeX by creating several, small 'test' documents, or having a close look at several templates on:
http://www.LaTeXTemplates.com
Making the effort now means you're not stuck learning the system when what you really need to be doing is writing your thesis.

1.2.2 A Short Math Guide for LaTeX

If you are writing a technical or mathematical thesis, then you may want to read the document by the AMS (American Mathematical Society) called, "A Short Math Guide for LaTeX". It can be found online here: http://www.ams.org/tex/amslatex.html under the "Additional Documentation" section towards the bottom of the page.

1.2.3 Common LaTeX Math Symbols

There are a multitude of mathematical symbols available for LaTeX and it would take a great effort to learn the commands for them all. The most common ones you are likely to use are shown on this page: http://www.sunilpatel.co.uk/latex-type/latex-math-symbols/

You can use this page as a reference or crib sheet, the symbols are rendered as large, high quality images so you can quickly find the LaTeX command for the symbol you need.

1.2.4 LaTeX on a Mac

The LaTeX distribution is available for many systems including Windows, Linux and Mac OS X. The package for OS X is called MacTeX and it contains all the applications you need – bundled together and pre-customized – for a fully working LaTeX environment and work flow.

MacTeX includes a custom dedicated LaTeX editor called TeXShop for writing your '.tex' files and BibDesk: a program to manage your references and create your bibliography section just as easily as managing songs and creating playlists in iTunes.

1.3 Getting Started with this Template

If you are familiar with LaTeX, then you should explore the directory structure of the template and then proceed to place your own information into the THESIS INFORMATION block of the main.tex file. You can then modify the rest of this file to your unique specifications based on your degree/university. Section 1.5 on page 6 will help you do this. Make sure you also read section 1.7 about thesis conventions to get the most out of this template.

If you are new to LaTeX it is recommended that you carry on reading through the rest of the information in this document.

Before you begin using this template you should ensure that its style complies with the thesis style guidelines imposed by your institution. In most cases this template style and layout will be suitable. If it is not, it may only require a small change to bring the template in line with your institution's recommendations. These modifications will need to be done on the MastersDoctoralThesis.cls file.

1.3.1 About this Template

This LaTeX Thesis Template is originally based and created around a LaTeX style file created by Steve R. Gunn from the University of Southampton (UK), department of Electronics and Computer Science. You can find his original thesis style file at his site, here: http://www.ecs.soton.ac.uk/~srg/softwaretools/document/templates/

Steve's ecsthesis.cls was then taken by Sunil Patel who modified it by creating a skeleton framework and folder structure to place the thesis files in. The resulting template can be found on Sunil's site here: http://www.sunilpatel.co.uk/thesis-template

Sunil's template was made available through http://www.LaTeXTemplates.com where it was modified many times based on user requests and questions. Version 2.0 and onwards of this template represents a major modification to Sunil's template and is, in fact, hardly recognisable. The work to make version 2.0 possible was carried out by Vel and Johannes Böttcher.

1.4 What this Template Includes

1.4.1 Folders

This template comes as a single zip file that expands out to several files and folders. The folder names are mostly self-explanatory:

Appendices – this is the folder where you put the appendices. Each appendix should go into its own separate .tex file. An example and template are included in the directory.

Chapters – this is the folder where you put the thesis chapters. A thesis usually has about six chapters, though there is no hard rule on this. Each chapter should go in its own separate .tex file and they can be split as:

- Chapter 1: Introduction to the thesis topic
- Chapter 2: Background information and theory
- Chapter 3: (Laboratory) experimental setup
- Chapter 4: Details of experiment 1
- Chapter 5: Details of experiment 2
- Chapter 6: Discussion of the experimental results
- Chapter 7: Conclusion and future directions

This chapter layout is specialised for the experimental sciences.

Figures – this folder contains all figures for the thesis. These are the final images that will go into the thesis document.

1.4.2 Files

Included are also several files, most of them are plain text and you can see their contents in a text editor. After initial compilation, you will see that more auxiliary files are created by LaTeX or BibTeX and which you don't need to delete or worry about:

example.bib – this is an important file that contains all the bibliographic information and references that you will be citing in the thesis for use with BibTeX. You can write it manually, but there are reference manager programs available that will create and manage it for you. Bibliographies in LaTeX are a large subject and you may need to read about BibTeX before starting with this. Many modern reference managers will allow you to export

your references in BibTeX format which greatly eases the amount of work you have to do.

MastersDoctoralThesis.cls – this is an important file. It is the class file that tells LaTeX how to format the thesis.

main.pdf – this is your beautifully typeset thesis (in the PDF file format) created by LaTeX. It is supplied in the PDF with the template and after you compile the template you should get an identical version.

main.tex – this is an important file. This is the file that you tell LaTeX to compile to produce your thesis as a PDF file. It contains the framework and constructs that tell LaTeX how to layout the thesis. It is heavily commented so you can read exactly what each line of code does and why it is there. After you put your own information into the THESIS INFORMATION block – you have now started your thesis!

Files that are not included, but are created by LaTeX as auxiliary files include:

main.aux – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main .tex file.

main.bbl – this is an auxiliary file generated by BibTeX, if it is deleted, BibTeX simply regenerates it when you run the main.aux file. Whereas the .bib file contains all the references you have, this .bbl file contains the references you have actually cited in the thesis and is used to build the bibliography section of the thesis.

main.blg – this is an auxiliary file generated by BibTeX, if it is deleted BibTeX simply regenerates it when you run the main .aux file.

main.lof – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main .tex file. It tells LaTeX how to build the List of Figures section.

main.log – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main .tex file. It contains messages from LaTeX, if you receive errors and warnings from LaTeX, they will be in this .log file.

main.lot – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main .tex file. It tells LaTeX how to build the List of Tables section.

main.out – this is an auxiliary file generated by LaTeX, if it is deleted LaTeX simply regenerates it when you run the main .tex file.

So from this long list, only the files with the .bib, .cls and .tex extensions

are the most important ones. The other auxiliary files can be ignored or deleted as LaTeX and BibTeX will regenerate them.

1.5 Filling in Your Information in the main.tex File

You will need to personalise the thesis template and make it your own by filling in your own information. This is done by editing the main.tex file in a text editor or your favourite LaTeX environment.

Open the file and scroll down to the second large block titled THESIS INFORMATION where you can see the entries for University Name, Department Name, etc ...

Fill out the information about yourself, your group and institution. You can also insert web links, if you do, make sure you use the full URL, including the http:// for this. If you don't want these to be linked, simply remove the \href{url}{name} and only leave the name.

When you have done this, save the file and recompile main.tex. All the information you filled in should now be in the PDF, complete with web links. You can now begin your thesis proper!

1.6 The main.tex File Explained

The main.tex file contains the structure of the thesis. There are plenty of written comments that explain what pages, sections and formatting the LaTeX code is creating. Each major document element is divided into commented blocks with titles in all capitals to make it obvious what the following bit of code is doing. Initially there seems to be a lot of LaTeX code, but this is all formatting, and it has all been taken care of so you don't have to do it.

Begin by checking that your information on the title page is correct. For the thesis declaration, your institution may insist on something different than the text given. If this is the case, just replace what you see with what is required in the DECLARATION PAGE block.

Then comes a page which contains a funny quote. You can put your own, or quote your favourite scientist, author, person, and so on. Make sure to put the name of the person who you took the quote from.

Following this is the abstract page which summarises your work in a condensed way and can almost be used as a standalone document to describe

what you have done. The text you write will cause the heading to move up so don't worry about running out of space.

Next come the acknowledgements. On this page, write about all the people who you wish to thank (not forgetting parents, partners and your advisor/supervisor).

The contents pages, list of figures and tables are all taken care of for you and do not need to be manually created or edited. The next set of pages are more likely to be optional and can be deleted since they are for a more technical thesis: insert a list of abbreviations you have used in the thesis, then a list of the physical constants and numbers you refer to and finally, a list of mathematical symbols used in any formulae. Making the effort to fill these tables means the reader has a one-stop place to refer to instead of searching the internet and references to try and find out what you meant by certain abbreviations or symbols.

The list of symbols is split into the Roman and Greek alphabets. Whereas the abbreviations and symbols ought to be listed in alphabetical order (and this is not done automatically for you) the list of physical constants should be grouped into similar themes.

The next page contains a one line dedication. Who will you dedicate your thesis to?

Finally, there is the block where the chapters are included. Uncomment the lines (delete the % character) as you write the chapters. Each chapter should be written in its own file and put into the Chapters folder and named Chapter1, Chapter2, etc…Similarly for the appendices, uncomment the lines as you need them. Each appendix should go into its own file and placed in the Appendices folder.

After the preamble, chapters and appendices finally comes the bibliography. The bibliography style (called authoryear) is used for the bibliography and is a fully featured style that will even include links to where the referenced paper can be found online. Do not underestimate how grateful your reader will be to find that a reference to a paper is just a click away. Of course, this relies on you putting the URL information into the BibTeX file in the first place.

1.7 Thesis Features and Conventions

To get the best out of this template, there are a few conventions that you may want to follow.

One of the most important (and most difficult) things to keep track of in such a long document as a thesis is consistency. Using certain conventions and ways of doing things (such as using a Todo list) makes the job easier. Of course, all of these are optional and you can adopt your own method.

1.7.1 Printing Format

This thesis template is designed for double sided printing (i.e. content on the front and back of pages) as most theses are printed and bound this way. Switching to one sided printing is as simple as uncommenting the oneside option of the documentclass command at the top of the main.tex file. You may then wish to adjust the margins to suit specifications from your institution.

The headers for the pages contain the page number on the outer side (so it is easy to flick through to the page you want) and the chapter name on the inner side.

The text is set to 11 point by default with single line spacing, again, you can tune the text size and spacing should you want or need to using the options at the very start of main.tex. The spacing can be changed similarly by replacing the singlespacing with onehalfspacing or doublespacing.

1.7.2 Using US Letter Paper

The paper size used in the template is A4, which is the standard size in Europe. If you are using this thesis template elsewhere and particularly in the United States, then you may have to change the A4 paper size to the US Letter size. This can be done in the margins settings section in main.tex.

Due to the differences in the paper size, the resulting margins may be different to what you like or require (as it is common for institutions to dictate certain margin sizes). If this is the case, then the margin sizes can be tweaked by modifying the values in the same block as where you set the paper size. Now your document should be set up for US Letter paper size with suitable margins.

1.7.3 References

The biblatex package is used to format the bibliography and inserts references such as this one (Hawthorn, Weber, and Scholten, 2001). The options used in the main.tex file mean that the in-text citations of references are formatted with the author(s) listed with the date of the publication.

Multiple references are separated by semicolons (e.g. (Wieman and Hollberg, 1991; Hawthorn, Weber, and Scholten, 2001)) and references with more than three authors only show the first author with et al. indicating there are more authors (e.g. (Arnold et al., 1998)). This is done automatically for you. To see how you use references, have a look at the Chapter1.tex source file. Many reference managers allow you to simply drag the reference into the document as you type.

Scientific references should come before the punctuation mark if there is one (such as a comma or period). The same goes for footnotes[1]. You can change this but the most important thing is to keep the convention consistent throughout the thesis. Footnotes themselves should be full, descriptive sentences (beginning with a capital letter and ending with a full stop). The APA6 states: "Footnote numbers should be superscripted, [...], following any punctuation mark except a dash." The Chicago manual of style states: "A note number should be placed at the end of a sentence or clause. The number follows any punctuation mark except the dash, which it precedes. It follows a closing parenthesis."

The bibliography is typeset with references listed in alphabetical order by the first author's last name. This is similar to the APA referencing style. To see how LaTeX typesets the bibliography, have a look at the very end of this document (or just click on the reference number links in in-text citations).

A Note on bibtex

The bibtex backend used in the template by default does not correctly handle unicode character encoding (i.e. "international" characters). You may see a warning about this in the compilation log and, if your references contain unicode characters, they may not show up correctly or at all. The solution to this is to use the biber backend instead of the outdated bibtex backend. This is done by finding this in main.tex: backend=bibtex and changing it to backend=biber. You will then need to delete all auxiliary BibTeX files and navigate to the template directory in your terminal (command prompt). Once there, simply type biber main and biber will compile your bibliography. You can then compile main.tex as normal and your bibliography will be updated. An alternative is to set up your LaTeX editor to compile with biber instead of bibtex, see here for how to do this for various editors.

[1] Such as this footnote, here down at the bottom of the page.

Table 1.1: The effects of treatments X and Y on the four groups studied.

Groups	Treatment X	Treatment Y
1	0.2	0.8
2	0.17	0.7
3	0.24	0.75
4	0.68	0.3

1.7.4 Tables

Tables are an important way of displaying your results, below is an example table which was generated with this code:

```
\begin{table}
\caption{The effects of treatments X and Y on the four groups studied.}
\label{tab:treatments}
\centering
\begin{tabular}{l l l}
\toprule
\tabhead{Groups} & \tabhead{Treatment X} & \tabhead{Treatment Y} \\
\midrule
1 & 0.2 & 0.8\\
2 & 0.17 & 0.7\\
3 & 0.24 & 0.75\\
4 & 0.68 & 0.3\\
\bottomrule\\
\end{tabular}
\end{table}
```

You can reference tables with \ref{<label>} where the label is defined within the table environment. See Chapter1.tex for an example of the label and citation (e.g. Table 3.6).

1.7.5 Figures

There will hopefully be many figures in your thesis (that should be placed in the Figures folder). The way to insert figures into your thesis is to use a code template like this:

```
\begin{figure}
\centering
\includegraphics{Figures/Electron}
\decoRule
```

```
\caption[An Electron]{An electron (artist's impression).}
\label{fig:Electron}
\end{figure}
```

Also look in the source file. Putting this code into the source file produces the picture of the electron that you can see in the figure below.

Figure 1.1: An electron (artist's impression).

Sometimes figures don't always appear where you write them in the source. The placement depends on how much space there is on the page for the figure. Sometimes there is not enough room to fit a figure directly where it should go (in relation to the text) and so LaTeX puts it at the top of the next page. Positioning figures is the job of LaTeX and so you should only worry about making them look good!

Figures usually should have captions just in case you need to refer to them (such as in Figure 1.1). The \caption command contains two parts, the first part, inside the square brackets is the title that will appear in the List of Figures, and so should be short. The second part in the curly brackets should contain the longer and more descriptive caption text.

The \decoRule command is optional and simply puts an aesthetic horizontal line below the image. If you do this for one image, do it for all of them.

LaTeX is capable of using images in pdf, jpg and png format.

1.7.6 Typesetting mathematics

If your thesis is going to contain heavy mathematical content, be sure that LaTeX will make it look beautiful, even though it won't be able to solve the equations for you.

The "Not So Short Introduction to LaTeX" (available on CTAN) should tell you everything you need to know for most cases of typesetting mathematics. If you need more information, a much more thorough mathematical guide is available from the AMS called, "A Short Math Guide to LaTeX" and can be downloaded from: ftp://ftp.ams.org/pub/tex/doc/amsmath/short-math-guide.pdf

There are many different LaTeX symbols to remember, luckily you can find the most common symbols in The Comprehensive LaTeX Symbol List.

You can write an equation, which is automatically given an equation number by LaTeX like this:

```
\begin{equation}
E = mc^{2}
\label{eqn:Einstein}
\end{equation}
```

This will produce Einstein's famous energy-matter equivalence equation:

$$E = mc^2 \tag{1.1}$$

All equations you write (which are not in the middle of paragraph text) are automatically given equation numbers by LaTeX. If you don't want a particular equation numbered, use the unnumbered form:

```
\[ a^{2}=4 \]
```

1.8 Sectioning and Subsectioning

You should break your thesis up into nice, bite-sized sections and subsections. LaTeX automatically builds a table of Contents by looking at all the \chapter{}, \section{} and \subsection{} commands you write in the source.

The Table of Contents should only list the sections to three (3) levels. A chapter{} is level zero (0). A \section{} is level one (1) and so a \subsection{} is level two (2). In your thesis it is likely that you will even use a subsubsection{}, which is level three (3). The depth to which the Table of Contents is

formatted is set within MastersDoctoralThesis.cls. If you need this changed, you can do it in main.tex.

1.9 In Closing

You have reached the end of this mini-guide. You can now rename or overwrite this pdf file and begin writing your own Chapter1.tex and the rest of your thesis. The easy work of setting up the structure and framework has been taken care of for you. It's now your job to fill it out!

Good luck and have lots of fun!

Guide written by —
Sunil Patel: www.sunilpatel.co.uk
Vel: LaTeXTemplates.com

Chapter 2

Chapter Title Here

2.1 Main Section 1

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam ultricies lacinia euismod. Nam tempus risus in dolor rhoncus in interdum enim tincidunt. Donec vel nunc neque. In condimentum ullamcorper quam non consequat. Fusce sagittis tempor feugiat. Fusce magna erat, molestie eu convallis ut, tempus sed arcu. Quisque molestie, ante a tincidunt ullamcorper, sapien enim dignissim lacus, in semper nibh erat lobortis purus. Integer dapibus ligula ac risus convallis pellentesque.

2.1.1 Subsection 1

Nunc posuere quam at lectus tristique eu ultrices augue venenatis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aliquam erat volutpat. Vivamus sodales tortor eget quam adipiscing in vulputate ante ullamcorper. Sed eros ante, lacinia et sollicitudin et, aliquam sit amet augue. In hac habitasse platea dictumst.

2.1.2 Subsection 2

Morbi rutrum odio eget arcu adipiscing sodales. Aenean et purus a est pulvinar pellentesque. Cras in elit neque, quis varius elit. Phasellus fringilla, nibh eu tempus venenatis, dolor elit posuere quam, quis adipiscing urna leo nec orci. Sed nec nulla auctor odio aliquet consequat. Ut nec nulla in ante ullamcorper aliquam at sed dolor. Phasellus fermentum magna in augue gravida cursus. Cras sed pretium lorem. Pellentesque eget ornare odio. Proin accumsan, massa viverra cursus pharetra, ipsum nisi lobortis velit, a malesuada dolor lorem eu neque.

2.2 Main Section 2

Sed ullamcorper quam eu nisl interdum at interdum enim egestas. Aliquam placerat justo sed lectus lobortis ut porta nisl porttitor. Vestibulum mi dolor, lacinia molestie gravida at, tempus vitae ligula. Donec eget quam sapien, in viverra eros. Donec pellentesque justo a massa fringilla non vestibulum metus vestibulum. Vestibulum in orci quis felis tempor lacinia. Vivamus ornare ultrices facilisis. Ut hendrerit volutpat vulputate. Morbi condimentum venenatis augue, id porta ipsum vulputate in. Curabitur luctus tempus justo. Vestibulum risus lectus, adipiscing nec condimentum quis, condimentum nec nisl. Aliquam dictum sagittis velit sed iaculis. Morbi tristique augue sit amet nulla pulvinar id facilisis ligula mollis. Nam elit libero, tincidunt ut aliquam at, molestie in quam. Aenean rhoncus vehicula hendrerit.

Chapter 3

实验设计

3.1 CPU 流水结构

3.1.1 整体设计

我们设计并实现了五级流水结构的 CPU，对每条指令的处理分为 IF、ID、EXE、MEM、WB 五个阶段。采用 25M 时钟，每个时钟周期流水线的每一个阶段完成一条指令的一部分，不同阶段并行完成不同指令的不同部分。同时每两个阶段之间均有一个段间锁存器，用与接收上一阶段的信号并在下一个时钟上升沿到来时传递到下一阶段。

流水线五个阶段的功能与所占用的资源如下：

IF：根据输入的 PC 值从内存中取出指令。在执行写入命令时，还需要根据 PC 值向内存中写入用户指令。占用资源：IM、PC、总线

ID：根据 IF 阶段读取的指令进行译码，从寄存器堆中读出所需寄存器的值。占用资源：寄存器组

EXE：根据 ID 阶段生成的控制信号、操作数和操作符进行计算，将结果传递到下一阶段。占用资源：ALU

MEM：根据 ID 阶段生成的控制信号执行写入内存和读取内存的操作，在实现时还需考虑串口的读写与 VGA/Keyboard 的读写访问。占用资源：DM、总线

WB：根据控制信号执行写回寄存器的操作。占用资源：寄存器组

3.1.2 数据通路

我们设计的数据通路见 Figure 3.1.

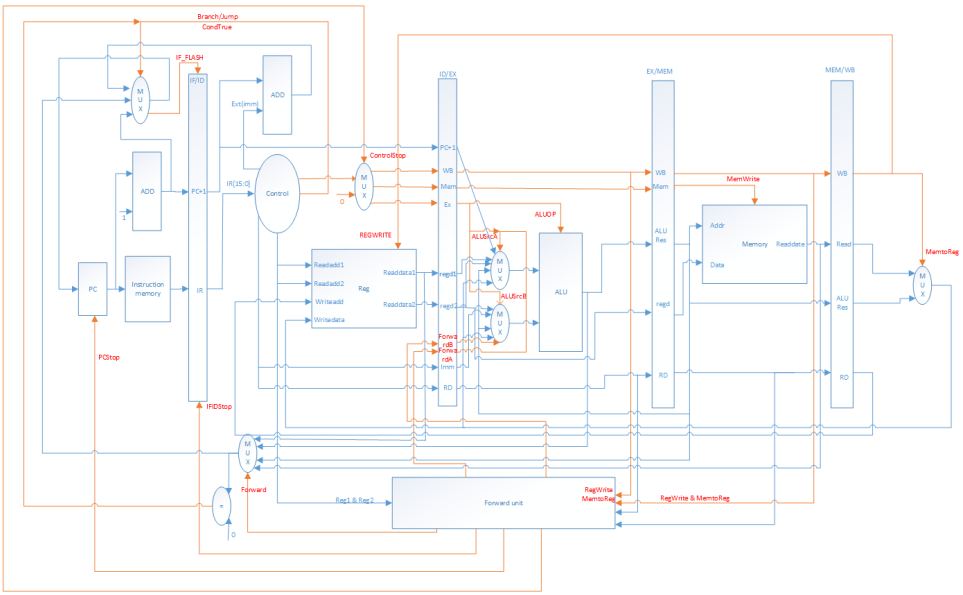

Figure 3.1: 数据通路.

在数据通路的设计上，我们基本遵循经典的五级流水线结构，但是在其基础之上有了一些变化和改进。

我们将处理数据冲突的模块全部放在了 Forward Unit 中。既可以将在 EXE、MEM 的计算结果流回到下一条指令的 EXE 阶段，同时也可以对访存操作的数据冲突进行插气泡处理。Forward Unit 模块还可以处理跳转指令的数据冲突，这样整体结构更加简洁。

我们新增 PC 模块，同于计算下一周期取指的 PC 值，根据跳转信号进行计算，可以解决控制冲突。具体实现见冲突处理部分。

3.1.3 控制信号

在 ID 阶段译码的过程中，会产生很多控制信号，针对我们所需实现的 30 条指令的指令集，我们设计的控制信号为：

ALUOP：ALU 运算器的操作符,包括 ADD(加法)、SUB(减法)、ASSIGNA(赋操作数 A 的值)、ASSIGNB(赋操作数 B 的值)、AND(与)、OR(或)、SLL(逻辑左移)、SRA(算数右移)、EQUAL(判断相等)、LESS(判断小于)、EMPTY(无操作)。

SRCREGA：读取第一个寄存器值的控制使能。1 表示 IR[10:8]，0 表示特殊寄存器。

SRCREGB：读取第二个寄存器值的控制使能。1 表示 IR[10:8]，0 表示 IR[7:5]。

REGDST：写回寄存器编号的控制使能。00 表示特殊寄存器，01 表示 IR[10:8]，10 表示 IR[7:5]，11 表示 IR[4:2]。

ALUSRCA：ALU 运算器第一个操作数的选择信号。00 表示 Reg[IR[10:8]], 01 表示 Reg[IR[7:5]]，10 表示 EPC。

ALUSRCB：ALU 运算器第二个操作数的选择信号。1 表示 reg[IR[7:5]], 0 表示 extend(imm)。

EXTOP：立即数扩展方式。0 表示符号扩展，1 表示零扩展。

MEMTOREG：读取内存并写回寄存器使能。

REGWRITE：写回寄存器使能。

MEMWRITE：内存写使能。

BRANCH：B 指令跳转信号。00 表示无 B 型跳转, 10 表示无条件跳转, 01 表示不等条件跳转，11 表示相等条件跳转。

JUMP：J 指令跳转使能。

对于每条指令的控制信号，见表 3.1 3.5，其中的'x' 表示没有使用。

Table 3.1: Control Signals

	ADDIU	ADDIU3	ADDSP	ADDU	AND	B
ALUOP	ADD	ADD	ADD	ADD	AND	EMPTY
SRCREGA	1	1	0	1	1	x
SRCREGB	x	x	x	0	0	x
REGDST	01	10	00	11	01	x
ALUSRCA	00	00	00	00	00	x
ALUSRCB	0	0	0	1	1	x
EXTOP	0	0	0	x	x	0
MEMTOREG	0	0	0	0	0	0
REGWRITE	1	1	1	1	1	0
MEMWRITE	0	0	0	0	0	0
BRANCH	00	00	00	00	00	10
JUMP	0	0	0	0	0	0

Table 3.2: Control Signals

	BEQZ	BNEZ	BTEQZ	CMP	CMPI	JALR
ALUOP	EMPTY	EMPTY	EMPTY	EQUAL	EQUAL	ASSIGNA
SRCREGA	1	1	0	1	1	1
SRCREGB	x	x	x	0	x	x
REGDST	x	x	x	00	00	00
ALUSRCA	x	x	x	00	00	10
ALUSRCB	x	x	x	1	0	x
EXTOP	0	0	0	x	0	x
MEMTOREG	0	0	0	0	0	0
REGWRITE	0	0	0	1	1	1
MEMWRITE	0	0	0	0	0	0
BRANCH	11	01	11	00	00	00
JUMP	0	0	0	0	0	1

Table 3.3: Control Signals

	JR	JRRA	LI	LW	LW_SP	MFIH
ALUOP	EMPTY	EMPTY	ASSIGNB	ADD	ADD	ASSIGNA
SRCREGA	1	0	x	1	0	0
SRCREGB	x	x	x	x	x	x
REGDST	x	x	01	10	01	01
ALUSRCA	x	x	x	00	00	00
ALUSRCB	x	x	0	0	0	x
EXTOP	x	x	1	0	0	x
MEMTOREG	0	0	0	1	1	0
REGWRITE	0	0	1	1	1	1
MEMWRITE	0	0	0	0	0	0
BRANCH	00	00	00	00	00	00
JUMP	1	1	0	0	0	0

Table 3.4: Control Signals

	MFPC	MOVE	MTIH	MTSP	NOP	OR
ALUOP	ASSIGNA	ASSIGNA	ASSIGNA	ASSIGNA	EMPTY	OR
SRCREGA	x	x	1	x	x	1
SRCREGB	x	0	x	0	x	0
REGDST	01	01	00	00	x	01
ALUSRCA	10	01	00	01	x	00
ALUSRCB	x	x	x	x	x	1
EXTOP	x	x	x	x	x	x
MEMTOREG	0	0	0	0	0	0
REGWRITE	1	1	1	1	0	1
MEMWRITE	0	0	0	0	0	0
BRANCH	00	00	00	00	00	00
JUMP	0	0	0	0	0	0

Table 3.5: Control Signals

	SLL	SLTI	SRA	SUBU	SW	SW_SP
ALUOP	SLL	LESS	SRA	SUB	ADD	ADD
SRCREGA	x	1	x	1	1	0
SRCREGB	0	x	0	0	0	1
REGDST	01	00	01	11	x	x
ALUSRCA	01	00	01	00	00	00
ALUSRCB	0	0	0	1	0	0
EXTOP	1	0	1	x	0	0
MEMTOREG	0	0	0	0	0	0
REGWRITE	1	1	1	1	0	0
MEMWRITE	0	0	0	0	1	1
BRANCH	00	00	00	00	00	00
JUMP	0	0	0	0	0	0

除了以上通过译码器产生的控制信号外，还有 FORWARD UNIT 产生的冲突处理信号，我们将在下一节详细说明。

3.1.4 冲突处理

结构冲突

我们采用指令与数据分离存储的方式来避免结构冲突问题。用 RAM1 和 RAM2 分别存储数据和指令。但在监控程序功能中有一个 A 指令需要向指令存储器中写入用户指令，这时，我们通过在 MEM 阶段判断写入地址是否为指令内存地址区间，并产生控制信号 IFWE。在 IF 阶段如果接收到信号 IFWE，则将流水线暂停一个周期用来写入指令。

数据冲突

我们在这里仅讨论两种不涉及跳转的数据冲突，两种冲突分别为涉及访存和不涉及访存的冲突。比如：

Example1: ADDU R1 R2 R3; SLL R3 R3 0x00

Example2: LW R1 R3 0x00; SLL R3 R3 0x00

数据冲突产生原因是前一条指令或者前两条指令需要写回寄存器，而当前的指令又要访问寄存器中的值。这时我们通过增加旁路的方式将之前的计算结果传输到当前的操作数上。

在 FORWARD UNIT 中，通过判断上一条指令 (或上两条指令) 的写回寄存器编号与当前目的寄存器编号是否相等来判断是否发生数据冲突。对于涉及访存的数据冲突，我们需要插入气泡等待一个周期，使得上一条指令 MEM 阶段执行完毕取出内存数之后, 再参与下一条指令的运算。FORWARD UNIT 产生的控制信号为：

FORWARDA：ALU 第一个操作数选择信号。00 表示无冲突，使用 ID 阶段读取的寄存器的值；01 表示与上一条指令发生冲突, 选择 ALU 的结果；10 表示与上两条指令发生冲突，选择 MEM 的结果

FORWARDB：ALU 第二个操作数选择信号。与 FORWARDA 类似。

PCSTOP，IFIDSTOP，CONTROLSTOP：插入气泡的控制信号。

控制冲突

控制冲突是由于 B 指令与 J 指令而产生的。我们将跳转地址的计算放在 ID 阶段执行。这样，在控制器译码结束后，可以直接计算出跳转后的 PC 值，故这种做法不需要分支预测，可以提高速度。另外，我们采用打开延迟槽的策略，对跳转指令的后一条指令继续执行。

在实际的冲突中，控制冲突往往与数据冲突结合在一起，比如：

Example3: ADDU R1 R2 R3; JR R3;

Example4: LW R1 R3 0x00; BEQZ R3 0x10;

在以上的两个例子中，既发生了控制冲突，同时也存在数据冲突。我们同样使用增加旁路的办法，唯一的不同在于旁路的信号需要传送到 ID 阶段进行计算。FORWARD UNIT 模块同样可以产生数据冲突的信号，用于选择跳转所需的寄存器的值。在 PC 模块中，根据跳转信号与冲突选择信号选取下一条指令的 PC 值。

3.2 寄存器堆

寄存器堆用于存放所有寄存器的值,用于在 ID 阶段读取寄存器值与 WB 阶段写回寄存器的值。读寄存器值为组合逻辑，在信号稳定之前读取的值被锁在 ID_EXE 段间的锁存器中，故不会对后面的结果产生影响。写寄存器值为时序逻辑，必须等待信号稳定后才能写回。由于 MEM_WB 段间锁存器在上升沿触发，故在下降沿进行写回，此时信号已经稳定。

我们将 R0-R7 这八个通用寄存器放在寄存器堆中，同时还将 SP、RA、IH、T 四个系统寄存器也放在寄存器堆中，以方便处理。这样，寄存器的编号需要从三位扩展为四位。各寄存器的编号见表 3.6.

Table 3.6: Register Cluster

符号	含义	编号
R0	通用寄存器	0000
R1	通用寄存器	0001
R2	通用寄存器	0010
R3	通用寄存器	0011
R4	通用寄存器	0100
R5	通用寄存器	0101
R6	通用寄存器	0110
R7	通用寄存器	0111
SP	栈顶指针寄存器	1001
T	T 标志寄存器	1010
IH	中断寄存器	1011
RA	返回值寄存器	1100

3.3 存储器

3.4 中断处理

我们实现了四种类型的中断，其中包括两种硬件中断 (ESC 中断：返回到中断 PC ; Control C 中断：返回到监控程序)，软件中断，时钟中断。下面对这四种中断分别介绍。

3.4.1 ESC 硬件中断

ESC 硬件中断是通过在用户程序执行时，键盘摁下 ESC 键产生的中断，在监控程序执行时无效。ESC 中断发生时，调用中断处理程序输出中断号，并返回到发生中断的指令继续执行。

这部分硬件中断会复用监控程序的 delint 中断处理代码，在中断处理程序中需要用到中断时的 PC 以及中断号，所以需要在发生中断时通过硬件来保存 PC 与中断号，并跳到中断处理程序。在 IF_ID 的段间锁存器中加入状态机，来处理 ESC 中断。状态机见 Figure 3.2.

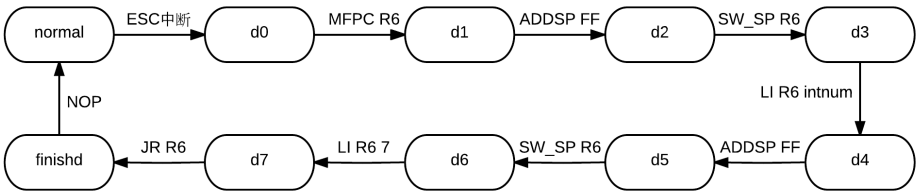

Figure 3.2: ESC 硬件中断状态机.

其中箭头上的指令为每个状态机下输出的指令，用来向栈中存储 PC 值和中断号。保存完毕后，跳到中断处理程序执行，同时状态回到 normal。

3.4.2 Control C 硬件中断

ESC 硬件中断的不足在于对于死循环的用户程序，中断发生后无法跳出死循环，而是继续回到中断发生的位置执行。我们希望仿照真正计算机上的 Control C 功能，可以实现跳出用户程序的功能。

Control C 中断的处理与 ESC 硬件中断类似，但是不需要再次返回中断时的 PC，而是直接跳到监控程序的 BEGIN 部分即可。所以处理过程比 ESC 更加简单，只需要在中断发生后将中断号入栈即可，不需要保存 PC 值。同时需要在监控程序中加入 Control C 中断的处理。状态机见 Figure 3.3.

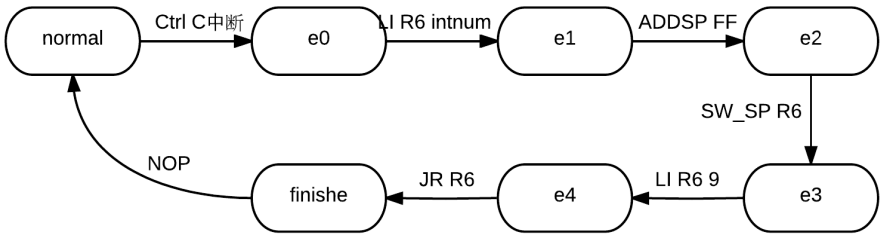

Figure 3.3: Control C 硬件中断状态机.

3.4.3 软件中断

软件中断的原理与 ESC 硬件中断一样，通过在控制器译码时产生软件中断的信号，传到 IF_ID 段间锁存器，同时将软件中断号同时传回，按照 ESC 的状态机处理软件中断。

3.4.4 时钟中断

时钟中断指计时时钟到一定的时间后，产生中断信号。我们做时钟中断的原因是为了之后的多道程序，多道程序需要分时执行两套监控程序，故需要有分时机制。多道程序的细节在后面讨论，这里仅讨论一下时钟中断的处理。

时钟中断的处理过程与 ESC 硬件中断基本一致，但是需要注意的一个地方是 ESC 硬件中断只会发生在用户程序中, 这时我们就可以随意使用 R6、R7 的值 (因为用户程序不允许使用)。但是时钟中断可以发生在任何地方, 在执行监控程序时也会有时钟中断，所以要首先保存 R6 的值，才可以执行后续的保存现场的指令。状态机见 Figure 3.4.

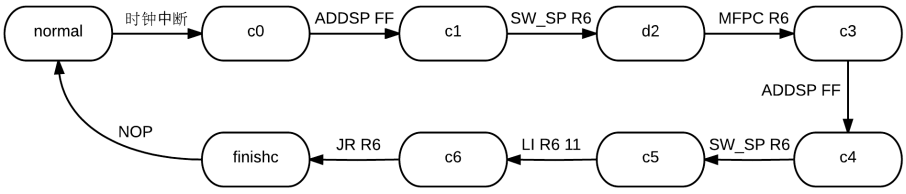

Figure 3.4: 时钟中断状态机.

3.5 I/O

3.6 多道程序

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