On the Design of Stable, High Performance Sigma Delta Modulators

by

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The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the thesis entitled:

On the Design of Stable, High Performance Sigma Delta Modulators

submitted by **Brett Christopher Hannigan** in partial fulfillment of the requirements for the degree of **Master of Applied Science** in **Biomedical Engineering**.

Examining Committee:

Guy Dumont, Electrical and Computer Engineering
Supervisor

Abstract

This document provides brief instructions for using the `ubcdiss` class to write a **UBC!**-conformant dissertation in LaTeX. This document is itself written using the `ubcdiss` class and is intended to serve as an example of writing a dissertation in LaTeX. This document has embedded **URL!**s (**URL!**s) and is intended to be viewed using a computer-based **PDF!** (**PDF!**) reader.

Note: Abstracts should generally try to avoid using acronyms.

Note: at **UBC!** (**UBC!**), both the **GPS!** (**GPS!**) Ph.D. defence programme and the Library's online submission system restricts abstracts to 350 words.

Lay Summary

The goal of this work was a method to better design analog-to-digital converters with special interest to recording weak bio-signals, such as those from electroencephalography and electrocardiography.

The sigma delta architecture of analog-to-digital converters is known for having high resolution for signals of this class while requiring fewer expensive analog circuit components. However, as its performance is increased, it tends to become unstable, a point at which the digitized signal no longer accurately represents the original.

To this end, a theory and set of software tools were developed that use mathematical optimization and control theory to design sigma delta circuits with varying degrees of performance and stability. It is even possible to generate a design that is guaranteed to be stable. The method is generalizable to any kind of signal, medical or otherwise. These developments were used to analyze and synthesize designs and will hopefully inspire future high-resolution analog-to-digital converters.

Preface

At **UBC!**, a preface may be required. Be sure to check the **GPS!** guidelines as they may have specific content to be included.

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List of Symbols

P_Q In-band quantization noise power.

$S(\lambda)$ Sensitivity function.

$T(\lambda)$ Complementary sensitivity function.

Δ Quantization step size.

λ Placeholder for the continuous-time Laplace variable s or discrete-time z-transformation variable z.

e Feedback error signal.

n Filter order.

u Quantizer input signal.

y Digital bitstream output signal.

Glossary

A/D analog-to-digital.

AAF antialiasing filter.

CLANS closed-loop analysis of noise shaper.

CT continuous-time.

D/A digital-to-analog.

DRF digital reconstruction filter.

DT discrete-time.

ECG electrocardiography.

EEG electroencephalography.

FIR finite impulse response.

GKYP generalized Kalman-Yakubovič-Popov.

IIR infinite impulse response.

LF loop filter.

LMI linear matrix inequality.

NTF noise transfer function, equivalent to the sensitivity function.

OSR oversampling ratio.

PPG photoplethysmography.

SQNR signal-to-quantization-noise ratio.

STF signal transfer function, equivalent to the complementary sensitivity function.

Acknowledgments

I would like to thank my supervisor Prof. Guy Dumont for his support of my research and openness to help as well as the other members of the BC Children's Hospital Research Institute's Digital Health Innovation Lab team.

I gratefully acknowledge the funding recieved from industry partner ESS Technologies whose participation in the Mitacs Accelerate program allowed me to write this thesis. The staff at ESS have been especially helpful, many thanks to Martin Mallinson and Chris Petersen in particular whose enthusiastic technical guidance and anecdoes about electronics, mathematics, and the early days of computing were a source of inspiration. Finally, thank you to the others who attended my progress meetings and provided valuable feedback.

Chapter 1

Introduction

The conversion of signals between analog and digital domanis is an often encountered problem in signal processing. For an analog signal to be represented digitally, it must undergo the processes of sampling and quantization (Figure 1.1). The former is the conversion from continuous-time (CT) to discrete-time (DT) and can be done without loss of information by the Nyquist-Shannon sampling theorem, given a sufficiently high sample rate. The latter is the mapping from an infinite set of possible values to a finite number of quantization levels. Unlike sampling, the process of quantization is non-injective and thus irreversible. The design of signal conversion circuits that minimize the error introduced by quantization is a major problem in mixed signal electronics.

Sigma delta modulation is a widely used technique for analog-to-digital (A/D) and digital-to-analog (D/A) conversion of signals that provides high resolution through the techniques of oversampling and noise shaping. Oversampling trades throughput for resolution, thus the sigma delta modulator generally lies between integrating converters, which are specialized for near-dc signals, and high-speed architectures, such as successive approximation and flash. The sigma delta quantization scheme is especially applicable to signals with low to moderate frequency content. Signals with these properties include most biosignals such as those recorded electrically (electroencephalography (EEG), electrocardiography (ECG)) or through other means using transducers (photoplethysmography (PPG)), as well as audio signals.

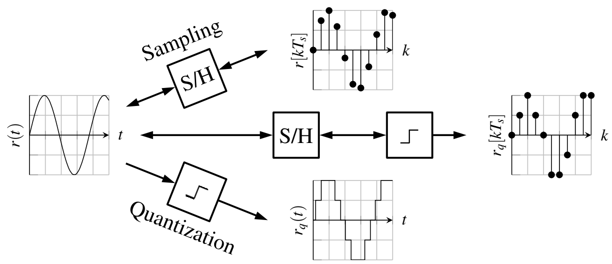

Figure 1.1: A continuous-time, continuous-value signal $r(t)$ is sampled to produce a discrete-time, continuous-value signal $r[kT_s]$. $r(t)$ independently undergoes quantization to yield a continuous-time, discrete-value signal $r_q(t)$. When both processes are applied in sequence, a discrete-time, discrete-value signal $r_q[kT_s]$ is the result.

1.1 Oversampling and Noise Shaping

Oversampling is simply the process where the analog signal is sampled at a rate higher than what the sampling theorem would dictate for perfect reconstruction, expressed as the oversampling ratio (OSR) relative to the Nyquist frequency. It may seem that this does not have a direct benefit *per se*, but it allows a less demanding analog antialiasing filter (AAF) to be used, saving circuit area. It also permits the quantization error to be spread across a larger bandwidth to increase resolution. Assuming quantization error can be modelled by white noise, oversampling reduces the in-band quantization noise power P_Q by a factor directly proportional to OSR [2] as seen in Equation 1.1, where Δ is the difference between quantization levels. These two advantages — reducing analog circuit complexity and increasing resolution — are common goals in sigma delta modulator design.

$$P_Q = \frac{\Delta^2}{12 \cdot OSR} \tag{1.1}$$

It may appear that oversampling alone quickly becomes impractical because one must approach very high sampling frequencies to increase the signal-to-quantization-noise ratio (SQNR) substantially. However, this assumes that the quantization noise is evenly distributed across the spectrum. Noise shaping is the use of a filter operating on the oversampled signal to push quantization noise out of the signal band where it can be removed by digital reconstruction filter (DRF). This

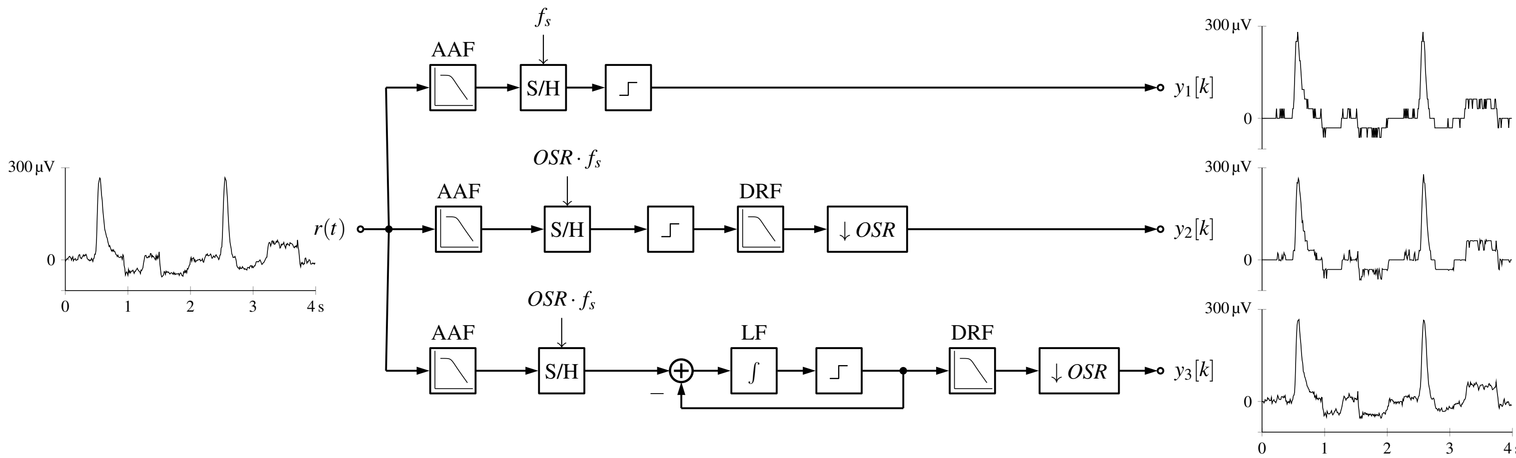

Figure 1.2: A comparison between naïve quantization (top), 10 times oversampled quantization (middle), and first order sigma delta modulation (bottom). The graphs on the right show the increasing quality of an EEG signal [1] sampled to a final rate of 100 Hz and quantized with 5 bits by each scheme.

behaviour is implemented by wrapping the filter and quantizer in a feedback loop. With the same white noise assumption, the tradeoff between in-band shaped quantization noise and OSR is improved for ideal loop filters when order n is increased as shown in Equation 1.2 [2]. The effect of oversampling and noise shaping is demonstrated in Figure 1.2.

$$P_Q = \frac{\Delta^2 \pi^{2n}}{12\,(2n+1) \cdot OSR^{2n+1}} \tag{1.2}$$

1.2 Basic Structure

We introduce the basic block diagram of a sigma delta modulator and nomenclature that will be used herein. For brevity, we limit the scope to sigma delta A/D converters but the concepts are easily transferrable to the D/A case. Modulators can be one of two main classes, CT or DT referring to the nature of the loop filter (LF).

1.2.1 Discrete-Time Modulator

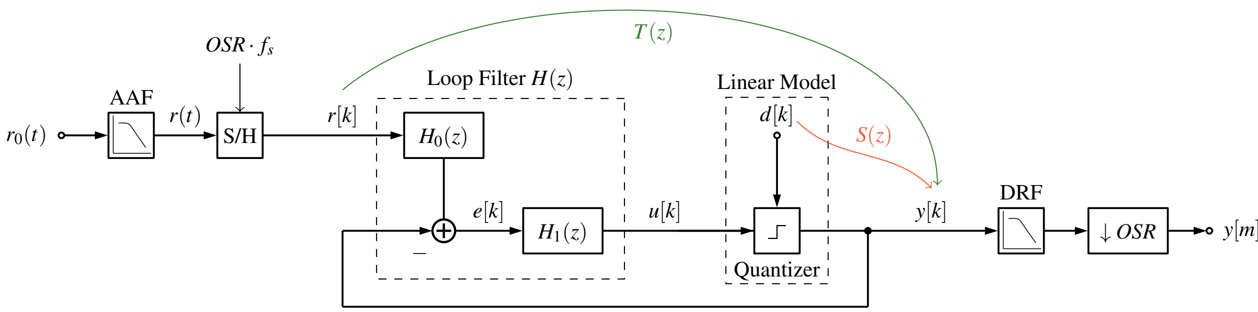

Figure 1.3: The basic block diagram of a DT sigma delta A/D converter.

For the DT class of modulators, we reference Figure 1.3. The analog front-end includes the AAF and sample-and-hold block. This subsystem conditions the input signal $r_0(t)$ and samples it outside the loop to produce DT signal $r[k]$. In the modulator loop, the 2-input 1-output LF operates on $r[k]$ and the feedback signal, producing intermediate signal $u[k]$ with shaped noise. Then, $u[k]$ undergoes quantization, which is modelled as the addition of an error signal $d[k]$ producing quantizer output $y[k]$. The quantizer output is fed back to the LF and also passed along. The final subsystem filters the signal from the shaped noise in the digital domain with a downsampling DRF to yield the final digital output $y[m]$.

From a control systems perspective, there are a couple of transfer functions that will be used to analyze and synthesize loop filters. The sensitivity function $S(\lambda)$, where $\lambda = z$, is known as the noise transfer function (NTF) of the modulator because it shows how the quantization noise is filtered in the linearized model. The complementary sensitivity function $T(\lambda)$ is known as the signal transfer function (STF) of the modulator and shows how the signal is transformed by the modulator loop.

1.2.2 Continuous-Time Modulator

For the CT class of modulators, we reference Figure 1.4. The structure is similar except the LF operates directly on analog input $r(t)$ in the CT domain and sampling

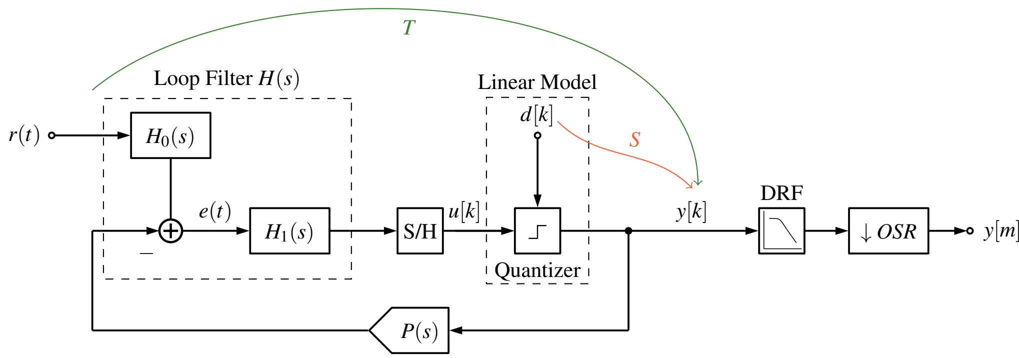

Figure 1.4: The basic block diagram of a DT sigma delta A/D converter.

is done inside the loop. The AAF is no longer necessary in most cases as the LF precedes the sampling block and implicitly attenuates components of the signal that would result in aliasing. Finally, signal $y[k]$ must undergo D/A conversion during feedback, modelled witht the pulse transfer function $P(s)$.

The NTF and STF of a CT sigma delta modulator are more difficult to define because they are transfer functions involving both CT and DT signals. The DT equivalence principle states that there is a DT modulator model that exactly describes the CT design at the sampling instants, because the modulator is overall a sampled data system [3, Sec. 3.2]. Thus, DT transfer functions can be derived for this purpose. However, these equivalent transfer functions may be difficult to manipulate due to their dependence on $P(s)$. For the purposes of this thesis, we omit the sampling block during design and use the simplification that $S(\lambda)$ and $T(\lambda)$ are CT ($\lambda = s$) transfer functions mapping $d(t) \to y(t)$ and $r(t) \to y(t)$, respectively.

1.3 Loop Filter

Together, quantization and noise shaping permit a coarser quantizer element to be used. A common design pattern is to use a high (> 2) order LF paired with a 1-bit quantizer, which is advantageous from a circuit design perspective because a quantizer with just two levels is inherently linear. In addition, low order sigma delta loops often suffer from spurious tones [4, Sec. 2.6.1]. Unfortunately, as LF order is increased, the tendency of the loop to become unstable does as well. While first and second order designs are provably stable for DC inputs [5], high order filters require careful design to avoid instability. Ensuring stability while maintaining performance is a difficult task due to the presence of the highly nonlinear quantizer. Note that the nonlinearity makes analysis complicated, a stable linear model does not imply a stable modulator while an unstable model can even result in a stable modulator [6].

The design of the noise shaping loop filter is the focus of this thesis. Modelling the loop filter as a 2-input 1-output system as shown in Section 1.2 allows the NTF to be determined by $H_1(\lambda)$ alone while the STF can be modified independently with filter $H_0(\lambda)$, without loss of generality:

$$\begin{aligned} S(\lambda) &= \frac{1}{1-H_1(\lambda)} \\ T(\lambda) &= \frac{H_0(\lambda)}{1-H_1(\lambda)}. \end{aligned}$$

We desire an NTF that results in a stable linear model, rejects noise in the signal band as much as possible, and has low gain in the out-of-band region to promote stability. The STF is less important as $H_0(\lambda)$ can be interpreted as a pre-filter to modify the STF, but we prefer unity gain in the signal band.

For a first order modulator, a pure integrator can be used as the loop filter $H_0(\lambda)$. For higher orders, it is common to choose a prototype NTF from a family of filters. For example, the popular Delta Sigma Toolbox for MATLAB [4, Appx. B] uses a Chebyshev type II filter for this purpose. The choice of filter greatly affects the stability of the loop, so the traditional design procedure involves extensive simulation under varying input conditions to ensure instability is unlikely during normal operation. Once unstable, the filter states must be reset in order to restore operation. Various schemes to detect the onset of instability [7] and avoid it with gain scaling [8], internal linear feedback [9], and automatic resetting schemes [10].

1.4 Related Works

Optimization techniques have been used to design NTFs with more degrees of freedom than those made with a single filter prototype. A simple example is that from [4, Sec. 4.3], where the zeros of the prototype NTF are optimized by approximating the integral of the NTF in the pass-band, then minimizing it analytically by equating its derivative to zero. The procedure results in an optimal spreading of zeros across the signal bandwidth for the given NTF poles. One of the first optimization-based approaches to NTF design was the closed-loop analysis of noise shaper (CLANS) methodology that minimizes P_Q under the white quantization noise assumption [11]. This is done using nonlinear optimization to find stable NTF pole locations that minimize the accumulation of quantization error subject to some stability and realizability constraints.

Using the principles from $\mathscr{H}_\infty$ control and its associated linear matrix inequality (LMI) methods, one can define the quantizer as a very simple feedthrough plant and introduce weighting filters on the feedback error signal e, loop filter output u, and quantizer output y to design the loop filter as a controller for various performance and stability constraints [12]. However, the system is bound to the order of the plant augmented with weighting filters and relies on the designer to choose the weights. Choosing weighting filters that are ideal is almost as difficult a task as just choosing the prototype NTF directly. Despite this, if a known AAF or DRF is specified in advance, it may be used as a sort of weighting filter and an optimal LF can be designed around it [13]. Applications for this method could be optimizing the STF to a psychoacoustic model or making use of existing filters in the signal path.

More recently, the generalized Kalman-Yakubovič-Popov (GKYP) lemma has been applied to sigma delta modulator design. The lemma provides a link between a finite frequency domain inequality, such as specifications on the NTF gain, and a linear matrix inequality condition, which can be solved using efficient interior point methods. Using this lemma, the techniques of $\mathscr{H}_\infty$ control can be applied to a transfer function but restricted to a frequency band. This eliminates the need for weighting filters that specify a select band of interest. Unfortunately, the problem becomes non-convex and hard to solve if both poles and zeros are to be optimized simultaneously as is the case with an infinite impulse response (IIR) filter. As a workaround, the NTF poles may be fixed to a prototype design and just the zeros optimized [14], similar to what was described above. Alternatively, a finite impulse response (FIR) NTF form may be assumed [15, 16] then possibly converted to IIR form using approximate methods such as least-squares or Yule-Walker [17]. Aside from the large delay introduced, the FIR form is not the optimal choice according to [18]. Iterative methods have shown promise in providing a workaround to the non-convexity associated with direct IIR design. A survey of some of these methods is presented in [**?**].

1.5 Organization of this Thesis

This document provides a quick set of instructions for using the `ubcdiss` class to write a dissertation in LaTeX. Unfortunately this document cannot provide an introduction to using LaTeX. The classic reference for learning LaTeX is **?** 's book [**?**]. There are also many freely-available tutorials online; Andy Roberts' online LaTeX tutorials[1] seems to be excellent. The source code for this docment, however, is intended to serve as an example for creating a LaTeX version of your dissertation.

We start by discussing organizational issues, such as splitting your dissertation into multiple files, in Section 1.6. We then cover the ease of managing cross-references in LaTeX in Section 1.7. We cover managing and using bibliographies with BibTeX in Section 1.8. We briefly describe typesetting attractive tables in Section 1.9. We briefly describe including external figures in Section 1.10, and using special characters and symbols in Section 1.11. As it is often useful to track different versions of your dissertation, we discuss revision control further in Section 1.13. We conclude with pointers to additional sources of information in Section 1.15.

[1] http://www.andy-roberts.net/misc/latex/

1.6 Suggested Thesis Organization

The specifies a particular arrangement of the components forming a thesis.[2] This template reflects that arrangement.

In terms of writing your thesis, the recommended best practice for organizing large documents in LaTeX is to place each chapter in a separate file. These chapters are then included from the main file through the use of `\include{file}`. A thesis might be described as six files such as `intro.tex`, `relwork.tex`, `model.tex`, `eval.tex`, `discuss.tex`, and `concl.tex`.

We also encourage you to use macros for separating how something will be typeset (e.g., bold, or italics) from the meaning of that something. For example, if you look at `intro.tex`, you will see repeated uses of a macro `\file{}` to indicate file names. The `\file{}` macro is defined in the file `macros.tex`. The consistent use of `\file{}` throughout the text not only indicates that the argument to the macro represents a file (providing meaning or semantics), but also allows easily changing how file names are typeset simply by changing the definition of the `\file{}` macro. `macros.tex` contains other useful macros for properly typesetting things like the proper uses of the latinate *exempli gratiā* and *id est* (i.e., `\eg` and `\ie`), web references with a footnoted **URL!** (`\webref{url}{text}`), as well as definitions specific to this documentation (`\latexpackage{}`).

1.7 Making Cross-References

LaTeX make managing cross-references easy, and the `hyperref` package's `\autoref{}` command[3] makes it easier still.

A thing to be cross-referenced, such as a section, figure, or equation, is *labelled* using a unique, user-provided identifier, defined using the `\label{}` command. The thing is referenced elsewhere using the `\autoref{}` command. For example, this section was defined using:

```
\section{Making Cross-References}
\label{sec:CrossReferences}
```

[2]See http://www.grad.ubc.ca/current-students/dissertation-thesis-preparation/order-components

[3]The `hyperref` package is included by default in this template.

References to this section are made as follows:

```
We then cover the ease of managing cross-references in \LaTeX\
in \autoref{sec:CrossReferences}.
```

`\autoref{}` takes care of determining the *type* of the thing being referenced, so the example above is rendered as

> We then cover the ease of managing cross-references in LaTeX in Section 1.7.

The label is any simple sequence of characters, numbers, digits, and some punctuation marks such as ":" and "–"; there should be no spaces. Try to use a consistent key format: this simplifies remembering how to make references. This document uses a prefix to indicate the type of the thing being referenced, such as `sec` for sections, `fig` for figures, `tbl` for tables, and `eqn` for equations.

For details on defining the text used to describe the type of *thing*, search `diss.tex` and the `hyperref` documentation for `autorefname`.

1.8 Managing Bibliographies with BibTeX

One of the primary benefits of using LaTeX is its companion program, BibTeX, for managing bibliographies and citations. Managing bibliographies has three parts: (i) describing references, (ii) citing references, and (iii) formatting cited references.

1.8.1 Describing References

BibTeX defines a standard format for recording details about a reference. These references are recorded in a file with a `.bib` extension. BibTeX supports a broad range of references, such as books, articles, items in a conference proceedings, chapters, technical reports, manuals, dissertations, and unpublished manuscripts. A reference may include attributes such as the authors, the title, the page numbers, t. A reference can also be augmented with personal attributes, such as a rating, notes, or keywords.

Each reference must be described by a unique *key*.[4] A key is a simple sequence of characters, numbers, digits, and some punctuation marks such as ":" and "–";

[4] Note that the citation keys are different from the reference identifiers as described in Section 1.7.

there should be no spaces. A consistent key format similifies remembering how to make references. For example:

$\boxed{\textit{last-name}}$–$\boxed{\textit{year}}$–$\boxed{\textit{contracted-title}}$

where *last-name* represents the last name for the first author, and *contracted-title* is some meaningful contraction of the title. Then **?** 's seminal article on aspect-oriented programming [**?**] (published in **?**) might be given the key `kiczales-1997-aop`.

An example of a BibTEX `.bib` file is included as `biblio.bib`. A description of the format a `.bib` file is beyond the scope of this document. We instead encourage you to use one of the several reference managers that support the BibTEX format such as JabRef[5] (multiple platforms) or BibDesk[6] (MacOS X only). These front ends are similar to reference manages such as EndNote or RefWorks.

1.8.2 Citing References

Having described some references, we then need to cite them. We do this using a form of the `\cite` command. For example:

```
\citet{kiczales-1997-aop} present examples of crosscutting
from programs written in several languages.
```

When processed, the `\citet` will cause the paper's authors and a standardized reference to the paper to be inserted in the document, and will also include a formatted citation for the paper in the bibliography. For example:

> **?**] present examples of crosscutting from programs written in several languages.

There are several forms of the `\cite` command (provided by the `natbib` package), as demonstrated in Table 1.1. Note that the form of the citation (numeric or author-year) depends on the bibliography style (described in the next section). The `\citet` variant is used when the author names form an object in the sentence, whereas the `\citep` variant is used for parenthetic references, more like an endnote. Use `\nocite` to include a citation in the bibliography but without an actual reference.

[5] http://jabref.sourceforge.net
[6] http://bibdesk.sourceforge.net

Table 1.1: Available `cite` variants; the exact citation style depends on whether the bibliography style is numeric or author-year.

Variant	Result
`\cite`	Parenthetical citation (e.g., "[**?**]" or "(**?** **?**)")
`\citet`	Textual citation: includes author (e.g., "**?**]" or or "**?** (**?**)")
`\citet*`	Textual citation with unabbreviated author list
`\citealt`	Like `\citet` but without parentheses
`\citep`	Parenthetical citation (e.g., "[**?**]" or "(**?** **?**)")
`\citep*`	Parenthetical citation with unabbreviated author list
`\citealp`	Like `\citep` but without parentheses
`\citeauthor`	Author only (e.g., "**?** ")
`\citeauthor*`	Unabbreviated authors list (e.g., "**?** ")
`\citeyear`	Year of citation (e.g., "**?** ")

1.8.3 Formatting Cited References

BibTEX separates the citing of a reference from how the cited reference is formatted for a bibliography, specified with the `\bibliographystyle` command. There are many varieties, such as `plainnat`, `abbrvnat`, `unsrtnat`, and `vancouver`. This document was formatted with `abbrvnat`. Look through your TEX distribution for `.bst` files. Note that use of some `.bst` files do not emit all the information necessary to properly use `\citet{}`, `\citep{}`, `\citeyear{}`, and `\citeauthor{}`.

There are also packages available to place citations on a per-chapter basis (`bibunits`), as footnotes (`footbib`), and inline (`bibentry`). Those who wish to exert maximum control over their bibliography style should see the amazing `custom-bib` package.

1.9 Typesetting Tables

?] made one grievous mistake in LATEX: his suggested manner for typesetting tables produces typographic abominations. These suggestions have unfortunately been replicated in most LATEX tutorials. These abominations are easily avoided simply by ignoring his examples illustrating the use of horizontal and vertical rules (specifically the use of `\hline` and `|`) and using the `booktabs` package instead.

The `booktabs` package helps produce tables in the form used by most professionally-edited journals through the use of three new types of dividing lines, or *rules*. Tables 1.1 and 1.2 are two examples of tables typeset with the `booktabs` package. The `booktabs` package provides three new commands for producing rules: `\toprule` for the rule to appear at the top of the table, `\midrule` for the middle rule following the table header, and `\bottomrule` for the bottom-most at the end of the table. These rules differ by their weight (thickness) and the spacing before and after. A table is typeset in the following manner:

```
\begin{table}
\caption{The caption for the table}
\label{tbl:label}
\centering
\begin{tabular}{cc}
\toprule
Header & Elements \\
\midrule
Row 1 & Row 1 \\
Row 2 & Row 2 \\
% ... and on and on ...
Row N & Row N \\
\bottomrule
\end{tabular}
\end{table}
```

See the `booktabs` documentation for advice in dealing with special cases, such as subheading rules, introducing extra space for divisions, and interior rules.

1.10 Figures, Graphics, and Special Characters

Most LaTeX beginners find figures to be one of the more challenging topics. In LaTeX, a figure is a *floating element*, to be placed where it best fits. The user is not expected to concern him/herself with the placement of the figure. The figure should instead be labelled, and where the figure is used, the text should use `\autoref` to reference the figure's label. Figure 1.5 is an example of a figure. A figure is generally included as follows:

```
\begin{figure}
\centering
\includegraphics[width=3in]{file}
```

LaTeX Rocks!

Figure 1.5: Proof of LaTeX's amazing abilities

```
\caption{A useful caption}
\label{fig:fig-label}   % label should change
\end{figure}
```

There are three items of note:

1. External files are included using the `\includegraphics` command. This command is defined by the `graphicx` package and can often natively import graphics from a variety of formats. The set of formats supported depends on your TeX command processor. Both `pdflatex` and `xelatex`, for example, can import GIF, JPG, and PDF. The plain version of `latex` only supports EPS files.

2. The `\caption` provides a caption to the figure. This caption is normally listed in the List of Figures; you can provide an alternative caption for the LoF by providing an optional argument to the `\caption` like so:

   ```
   \caption[nice shortened caption for LoF]{%
       longer detailed caption used for the figure}
   ```

   GPS! (**GPS!**) generally prefers shortened single-line captions in the LoF: multiple-line captions are a bit unwieldy.

3. The `\label` command provides for associating a unique, user-defined, and descriptive identifier to the figure. The figure can be can be referenced elsewhere in the text with this identifier as described in Section 1.7.

See Keith Reckdahls excellent guide for more details, *Using imported graphics in LaTeX2e*[7].

1.11 Special Characters and Symbols

LaTeX appropriates many common symbols for its own purposes, with some used for commands (i.e., `\ { } & %`) and mathematics (i.e., `$ ^ _`), and others are automagi-

[7] http://www.ctan.org/tex-archive/info/epslatex.pdf

Table 1.2: Useful LaTeX symbols

LaTeX	Result	LaTeX	Result
\texttrademark	™	\&	&
\textcopyright	©	\{ \}	{ }
\textregistered	®	\%	%
\textsection	§	\verb!~!	~
\textdagger	†	\$	$
\textdaggerdbl	‡	\^{}	^
\textless	<	_	_
\textgreater	>		

cally transformed into typographically-preferred forms (i.e., – `') or to completely different forms (i.e., <>). Table 1.2 presents a list of common symbols and their corresponding LaTeX commands. A much more comprehensive list of symbols and accented characters is available at: http://www.ctan.org/tex-archive/info/symbols/comprehensive/

1.12 Changing Page Widths and Heights

The `ubcdiss` class is based on the standard LaTeX `book` class [**?**] that selects a line-width to carry approximately 66 characters per line. This character density is claimed to have a pleasing appearance and also supports more rapid reading [**?**]. I would recommend that you not change the line-widths!

1.12.1 The `geometry` Package

Some students are unfortunately saddled with misguided supervisors or committee members whom believe that documents should have the narrowest margins possible. The `geometry` package is helpful in such cases. Using this package is as simple as:

```
\usepackage[margin=1.25in,top=1.25in,bottom=1.25in]{geometry}
```

You should check the package's documentation for more complex uses.

1.12.2 Changing Page Layout Values By Hand

There are some miserable students with requirements for page layouts that vary throughout the document. Unfortunately the `geometry` can only be specified once, in the document's preamble. Such miserable students must set LaTeX's layout parameters by hand:

```
\setlength{\topmargin}{-.75in}
\setlength{\headsep}{0.25in}
\setlength{\headheight}{15pt}
\setlength{\textheight}{9in}
\setlength{\footskip}{0.25in}
\setlength{\footheight}{15pt}

% The *sidemargin values are relative to 1in; so the following
% results in a 0.75 inch margin
\setlength{\oddsidemargin}{-0.25in}
\setlength{\evensidemargin}{-0.25in}
\setlength{\textwidth}{7in}       % 1.1in margins (8.5-2*0.75)
```

These settings necessarily require assuming a particular page height and width; in the above, the setting for `\textwidth` assumes a US Letter with an 8.5" width. The `geometry` package simply uses the page height and other specified values to derive the other layout values. The `layout` package provides a handy `\layout` command to show the current page layout parameters.

1.12.3 Making Temporary Changes to Page Layout

There are occasions where it becomes necessary to make temporary changes to the page width, such as to accomodate a larger formula. The `chngpage` package provides an `adjustwidth` environment that does just this. For example:

```
% Expand left and right margins by 0.75in
\begin{adjustwidth}{-0.75in}{-0.75in}
% Must adjust the perceived column width for LaTeX to get with it.
\addtolength{\columnwidth}{1.5in}
\[ an extra long math formula \]
\end{adjustwidth}
```

1.13 Keeping Track of Versions with Revision Control

Software engineers have used **RCS!** (**RCS!**) to track changes to their software systems for decades. These systems record the changes to the source code along with context as to why the change was required. These systems also support examining and reverting to particular revisions from their system's past.

An **RCS!** can be used to keep track of changes to things other than source code, such as your dissertation. For example, it can be useful to know exactly which revision of your dissertation was sent to a particular committee member. Or to recover an accidentally deleted file, or a badly modified image. With a revision control system, you can tag or annotate the revision of your dissertation that was sent to your committee, or when you incorporated changes from your supervisor.

Unfortunately current revision control packages are not yet targetted to non-developers. But the Subversion project's TortoiseSVN[8] has greatly simplified using the Subversion revision control system for Windows users. You should consult your local geek.

A simpler alternative strategy is to create a GoogleMail account and periodically mail yourself zipped copies of your dissertation.

1.14 Recommended Packages

The real strength to LaTeX is found in the myriad of free add-on packages available for handling special formatting requirements. In this section we list some helpful packages.

1.14.1 Typesetting

`enumitem`: Supports pausing and resuming enumerate environments.

`ulem`: Provides two new commands for striking out and crossing out text (`\sout{text}` and `\xout{text}` respectively) The package should likely be used as follows:

```
\usepackage[normalem,normalbf]{ulem}
```

[8] http://tortoisesvn.net/docs/release/TortoiseSVN_en/

to prevent the package from redefining the emphasis and bold fonts.

chngpage: Support changing the page widths on demand.

mhchem: Support for typesetting chemical formulae and reaction equations.

Although not a package, the `latexdiff`[9] command is very useful for creating changebar'd versions of your dissertation.

1.14.2 Figures, Tables, and Document Extracts

pdfpages: Insert pages from other PDF files. Allows referencing the extracted pages in the list of figures, adding labels to reference the page from elsewhere, and add borders to the pages.

subfig: Provides for including subfigures within a figure, and includes being able to separately reference the subfigures. This is a replacement for the older `subfigure` environment.

rotating: Provides two environments, sidewaystable and sidewaysfigure, for typesetting tables and figures in landscape mode.

longtable: Support for long tables that span multiple pages.

tabularx: Provides an enhanced tabular environment with auto-sizing columns.

ragged2e: Provides several new commands for setting ragged text (e.g., forms of centered or flushed text) that can be used in tabular environments and that support hyphenation.

1.14.3 Bibliography Related Packages

bibunits: Support having per-chapter bibliographies.

footbib: Cause cited works to be rendered using footnotes.

[9] http://www.ctan.org/tex-archive/support/latexdiff/

bibentry: Support placing the details of a cited work in-line.

custom-bib: Generate a custom style for your bibliography.

1.15 Moving On

At this point, you should be ready to go. Other handy web resources:

- **CTAN!** (**CTAN!**)[10] is *the* comprehensive archive site for all things related to TEX and LATEX. Should you have some particular requirement, somebody else is almost certainly to have had the same requirement before you, and the solution will be found on **CTAN!**. The links to various packages in this document are all to **CTAN!**.

- An online reference to LATEX commands[11] provides a handy quick-reference to the standard LATEX commands.

- The list of Frequently Asked Questions about TEX and LATEX[12] can save you a huge amount of time in finding solutions to common problems.

- The teTEX documentation guide[13] features a very handy list of the most useful packages for LATEX as found in **CTAN!**.

- The `color`[14] package, part of the graphics bundle, provides handy commands for changing text and background colours. Simply changing text to various levels of grey can have a very dramatic effect.

- If you're really keen, you might want to join the TEX Users Group[15].

[10] http://www.ctan.org
[11] http://www.ctan.org/get/info/latex2e-help-texinfo/latex2e.html
[12] http://www.tex.ac.uk/cgi-bin/texfaq2html?label=interruptlist
[13] http://www.tug.org/tetex/tetex-texmfdist/doc/
[14] http://www.ctan.org/tex-archive/macros/latex/required/graphics/grfguide.pdf
[15] http://www.tug.org

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Appendix A

Supporting Materials

This would be any supporting material not central to the dissertation. For example:

- additional details of methodology and/or data;
- diagrams of specialized equipment developed.;
- copies of questionnaires and survey instruments.