LaTeX for Undergraduates

Jim Hefferon, Saint Michael's College
jhefferon@smcvt.edu

2013-Jan

Professionals in Mathematics write using the program LaTeX (pronounced "la-tech"). This document tells you the LaTeX that you need for writing undergraduate mathematics. It is prescriptive: instead of describing all the possibilities it will just say what to do.

As with any technical material, the only way to learn what's here is enter the commands as you read and to experiment with your own variants. If you have a problem then google it.

First contact

LaTeX runs the typesetting engine TeX (pronounced "tech"). It is well known for its abilities with mathematical and technical text, and for being stable, portable, and virtually bug free. It is Free software.

Don't use a word processor for LaTeX. Start your editor `emacs` and use it to open a new file `test.tex`. Enter the source lines below and save the file. Run the command line '`pdflatex test`' to compile the source. Your output is in the file `test.pdf`, shown after the source.

```
1 \documentclass{article}
2
3 \begin{document}
4 Hello world!
5 \end{document}
```

Hello world!

You write a LaTeX source file in a mixture of text and commands. Commands start with a backslash; an example is `\documentclass`. The `\begin` and `\end` enclose a LaTeX *environment*, a distinct area of the document. A source file has two parts: a preamble setting up the document and then a document body containing the content, which starts with `\begin{document}`.

TEMPLATE With your editor open a new file called `template.tex` and enter these lines, using your own name and email.

```
1 \documentclass[11pt]{article}
2 \usepackage{graphicx}
3 \usepackage{xcolor}
4 \usepackage{hyperref,url}
5 \usepackage{fancyhdr}
6 \usepackage{listings}
```

```
\usepackage[left=1.5in,right=1.5in]{geometry}
\usepackage{amsmath,amsthm,amssymb}
\newtheorem{thm}{Theorem}
\newtheorem{lem}[thm]{Lemma}    % numbered in sequence with thm
\newtheorem{cor}[thm]{Corollary}
\begin{document}
\title{Sample document}
\author{Jim Hef{}feron \\
  Saint Michael's College\\
  \url{jhefferon@smcvt.edu}}
\date{\today}
\maketitle

\end{document}
```

In the future you will start new LaTeX work by copying this template to a fresh file and working there. All the examples below assume this and only show material that you've added, that you've inserted where above there is a blank line.

For example, copy `template.tex` to `first.tex`, add this material below `\maketitle`, and compile. (Later we will go through the commands systematically.)

```
Elementary calculus suffices to evaluate $C$ if we are clever
enough to look at the double integral
\begin{equation*}
  C^2
  =\int_{-\infty}^{+\infty} e^{-x^2} \mathrm{d}x
   \int_{-\infty}^{+\infty} e^{-y^2} \mathrm{d}y\;.
\end{equation*}
```

Elementary calculus suffices to evaluate C if we are clever enough to look at the double integral

$$C^2 = \int_{-\infty}^{+\infty} e^{-x^2}\,dx \int_{-\infty}^{+\infty} e^{-y^2}\,dy\,.$$

Building blocks

LaTeX has a learning curve. We will next establish the basics that you need.

SPECIAL CHARACTERS The backslash is special; you can't just type it in the source or LaTeX thinks that you mean a command. To get a backslash in your output use the command `\textbackslash`. The other special characters, and the input that will get them in output, are: hash tag `\#`, dollar sign `\$`, percent sign `\%`, caret `\^{}`, ampersand `\&`, underscore `\_`, curly braces `\{` and `\}`, and twiddle `\~{}`.

The percent character % makes the rest of the line a comment.[1]

```
The two curves are asmyptotic.  % TODO: check spelling
```

The two curves are asmyptotic.

[1] Except if you precede it with a backslash, or in some other cases such as inside a URL.

BRACES: ARGUMENTS AND GROUPING Some commands need one or more arguments, given in curly braces.

```
\title{Sample document}
```

There is a larger effect at work here: without the braces only the next character would have been affected by the command, that is, the curly braces group the entire surrounded text. You may form groups inside your groups, as deeply nested as you need.

You sometimes need an empty group to keep LaTeX from slurping up whitespace.

```
Without braces, \LaTeX will eat the space
but \LaTeX{} is OK.
```

Without braces, LaTeXwill eat the space but LaTeX is OK.

Some commands have arguments that are optional, enclosed in square brackets.

```
\documentclass[11pt]{article}
```

FONT VARIATIONS Your documents will stick to the font family Computer Modern. It is a family because there are a number of associated fonts: boldface that you access with `\textbf{boldface}` and italic with `\textit{italic}` (note that to emphasize something, instead use the command `\emph{text}`). You also can get small capitals with `\textsc{small caps}` and monospace with `\texttt{typewriter}`. You can nest these `\textbf{\textsc{bold italic}}` but it only has an effect if you have a font with both characteristics.

Usually you don't need to fool with the text size but you can ask for `{\large large}`, or `{\Large larger}`, or `{\LARGE larger still}` or even `{\Huge much too big}`. The other direction has `{\small small}`, `{\footnotesize smaller}`, `{\scriptsize even smaller}`, and `{\tiny teeny}`.

QUOTATION MARKS In your source code do not surround a quote with " marks; LaTeX makes the quote start different than the quote end. Start a quote with two opening single quotes (called grave marks) and end it with two apostrophes.

```
``Students are taught advanced concepts of Boolean algebra, and
formerly unsolvable equations are dealt with by threats of
reprisals.''
\textit{---Woody Allen}
```

“Students are taught advanced concepts of Boolean algebra, and formerly unsolvable equations are dealt with by threats of reprisals.” —*Woody Allen*

Technical text often uses single quotes — as in the first sentence of the next section — and you get those with a single grave and apostrophe.

WHITE CHARACTERS LaTeX treats a space character differently than a regular text character such as an ‘A’: consecutive spaces are the same as one space and spaces at the start of a line get ignored. This allows you to pretty-format your source.

For an explicit space use backslash followed by space. The common use case is for periods that don't end a sentence, where it also suppresses the extra space LaTeX may put in at the end of a sentence.

```
The article appeared in Proc.\ Amer.\ Math.\ Soc.
That's where I saw it.
```

The article appeared in Proc. Amer. Math. Soc. That's where I saw it.

For a hard space, to tie two words so that there will be no line break between them, use a twiddle (this too suppresses the after-period space).

```
Mr.~Watson come here I want you.
```

Mr. Watson come here I want you.

LaTeX treats a lone end of line character as a space but two consecutive ones, or any blank line, starts a new paragraph.[1]

```
One morning I shot an elephant in my pajamas.

What he was doing in my pajamas I'll never know.
```

One morning I shot an elephant in my pajamas.
What he was doing in my pajamas I'll never know.

You usually only need explicit line breaks inside tables and arrays, but in any event get one with a double backslash `\\`.

SPACE You occasionally need explicit spacing. For extra vertical space between paragraphs, your first resource is to use one of `\smallskip`, `\medskip`, or `\bigskip`.

```
Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do
eiusmod tempor incididunt ut labore et dolore magna aliqua.

\smallskip
Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris
nisi ut aliquip ex ea commodo consequat.

\bigskip
Duis aute irure dolor in reprehenderit in voluptate velit esse
cillum dolore eu fugiat nulla pariatur.
```

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.

Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur.

A convenient unit for explicit vertical space is the *ex*, which is the height of an 'x' in the current font so it gives you some portability through font changes. Thus, you might write `\vspace{1.5ex}` (or `\vspace{2in}`). This command has a starred form `\vspace*{1.5ex}` to insert the space even where you typically don't want a blank (LaTeX usually drops vertical space at the end of a page instead of carrying it to the top of the next page; if you want the space even at the top of the next page then use the starred form.)

[1] Except in a special circumstance, such as a listing of computer code.

For horizontal spacing the best unit is the *em*, something like the width of an 'M'. Often you can limit yourself to using `\,` for a small space (3/18-th em), `\:` (4/18-th em) for a medium space, `\;` (5/18-th em) for a large space, `\quad` for a still larger space (something like an em), `\qquad` for twice that space, and finally `\!` for a negative small space.[1] If you need some other size then use a command like `\hspace{1.618em}`. As with vertical space command, the starred form of this command inserts the space even where you typically don't want it.

ENVIRONMENTS LaTeX lets you have areas of the document with their own rules.

```
\begin{verse}
  THE ROAD TO WISDOM?

  Well, it's plain  \\
  and simple to express. \\
  Err and err and err again,  \\
  but less and less and less. \\  % Piet Hein.
\end{verse}
```

THE ROAD TO WISDOM?

Well, it's plain
and simple to express.
Err and err and err again,
but less and less and less.

One way in which the *verse* environment is different from regular text is that it indents the left and right margin.

Environments nest, so you may have a *center* environment that surrounds a *tabular* environment. However, environments cannot overlap so the *tabular* environment must end before the *center*.

INTERPOLATIONS Write a hyphen as in "Cauchy-Schwartz" with one dash `Cauchy-Schwartz`. Ranges, such as "homework numbers 5–15" call for an *en-dash*,[2] which you type using two consecutive dashes `5--15`. The *em-dash*[3] marks a break stronger than that marked by parentheses; for this type three consecutive dashes.

```
\begin{quotation}
``Number theorists are like lotus-eaters---having once tasted of
this food they can never give it up.''
\textit{---Leopold Kronecker}
\end{quotation}
```

"Number theorists are like lotus-eaters—having once tasted of this food they can never give it up." —*Leopold Kronecker*

An *ellipsis* is the three dots that show an intentional omission such as from the middle of a quote, or an unfinished thought.

[1] You most often use these spacing commands in mathematics. [2] It is one en wide. [3] An em wide.

```
Every mathematician worthy of the name has experienced \ldots{}
the state of lucid exaltation in which one thought succeeds
another as if miraculously \ldots{}
this feeling may last for hours at a time, even for days.
Once you have experienced it, you are eager to repeat it but
unable to do it at will, unless perhaps by dogged work \ldots\,.
\textit{---Andre Weil}
```

Every mathematician worthy of the name has experienced ... the state of lucid exaltation in which one thought succeeds another as if miraculously ... this feeling may last for hours at a time, even for days. Once you have experienced it, you are eager to repeat it but unable to do it at will, unless perhaps by dogged work .... —*Andre Weil*

ORGANIZE YOUR SOURCE As with any computer code, sensibly organize your input. Put sentences on separate lines. Put a half dozen blank lines before a new section. Inside environments indent text by two spaces (you might do this for only some environments). When you enter matched things, such as matched curly braces or a `\begin{ environment }-\end{ environment }` pair, type the two commands at the same time and then go back to fill in the contents (note that emacs has *<CTL>-c <CTL>-e* to help with this).

Document structure

PREAMBLE Documents start by declaring their class.

```
\documentclass[option]{class}
```

The common classes are *article* for a short paper, *report* for longer documents containing several chapters, *book* for full-sized books, and *beamer* for slides. Your template uses the *11pt* option to change the size of your document's main font.[1]

A preamble has a list of packages.[2] Your template's preamble brings in the *amsmath* package for production of mathematics according to their standards of the American Mathematical Society. The *graphicx* package lets you include graphics files, *xcolor* adds color, *fancyhdr* lets you change the headers and footers, and *listings* is for computer code. The *geometry* package lets you, among other things, define the margins.

Other things appear in the preamble. There may be document-specific commands.

```
\newcommand{\myname}{Jim Hef{}feron}
```

There may also be setup code, for instance to describe the document name and author.

```
\title{Document name}\author{\myname}
```

SECTIONING Divide the document with `\section{section title}`. Similarly, make subsections with `\subsection{title}`.[3] The starred forms, such as `\section*{title}` omit a number prefix and a table of contents entry.

[1] This is larger than the standard for books and journals but it takes account of professors so old that they cannot read subscripts of subscripts. [2] A package is an add-on set of LaTeX commands to help with some task. One of the strengths of LaTeX is the availability of a tremendous variety of packages, to do whatever you need; see http://www.ctan.org. [3] Had we based the template on the *book* class then we would also have a *chapter* command.

Text

JUSTIFICATION LaTeX will by default use *justification*, where to make the text align with the left and right margins the system will stretch or shrink the the spaces between words.

You can alter that with a *flushleft*, *flushright*, or *center* environment.

```
\begin{center}
  Here lies Lester Moore. \\
  Four slugs from a 44. \\
  No Les.  No Moore.
\end{center}
```

Here lies Lester Moore.
Four slugs from a 44.
No Les. No Moore.

FOOTNOTES As here: `Text.\footnote{Another.}`. Precede commands with `\protect`.

LISTS Make bullet lists with the *itemize* environment, numbered lists with *enumerate* and descriptions with *description* environment.

```
\begin{description}
  \item[First.] We can itemize.
    \begin{itemize}
      \item Bullet points
      \item are ugly
     \end{itemize}
  \item[Second.] We can enumerate.
    \begin{enumerate}
      \item Sub-enumerations
      \item are anal.
    \end{enumerate}
\end{description}
```

First. We can itemize.

- Bullet points
- are ugly

Second. We can enumerate.

1. Sub-enumerations
2. are anal.

Tables

Make tables with the *tabular* environment. Row entries are separated by an ampersand.

```
\begin{center}
  \begin{tabular}{r|l}
    \LaTeX{} abbreviation &unit \\ \hline
    in &inches      \\
    pt &typographical points, $1/72.27$~inch \\
    bp &PostScript point, $1/72$~inch  \\
    em &something like the width of an `M' in the current font \\
    ex &something like the height of an `x' in the current font \\
    mm &millimeters \\
    cm &centimeters
  \end{tabular}
\end{center}
```

LaTeX abbreviation	unit
in	inches
pt	typographical points, 1/72.27 inch
bp	PostScript point, 1/72 inch
em	something like the width of an 'M' in the current font
ex	something like the height of an 'x' in the current font
mm	millimeters
cm	centimeters

That has a column format of `r|l` so LaTeX justifies the first column on the right, then there is a vertical rule separating the columns, and then LaTeX justifies the second column on the left. You can also use `c` for a centered column, `p{1in}` for an inch-wide paragraph column, and `@{-\hspace{.5in}}` to put a dash and a space between two columns.

```
\begin{tabular}{rr@{.}l}
  inch &$2$  &$5$~cm      \\
  foot &$30$ &\ cm\\
  yard &$0$  &$9$ meters \\
  mile &$1$  &$6$ kilometers
\end{tabular}
```

inch	2.5 cm
foot	30. cm
yard	0.9 meters
mile	1.6 kilometers

In particular, omit the default intercolumn space with `@{}` (this includes the half intercolumn space before the first column or after the last column).

For horizontal rules put `\hline` after the line ending double backslash. To have the line only come across columns 2 through 3 use `\cline{2-3}`.

Inside a table's row, the command `\multicolumn{2}{c}{text}` will produce the text centered and spanning two columns. (It suppresses vertical rule column separators so you may want to add one back as in `\multicolumn{2}{c|}{text}`; you can also use this property to remove a column separator with `\multicolumn{1}{c}{text}`.)

Tables are hard. Some things to watch out for are: (a) fewer rules, especially vertical ones, is often better (b) columns of numbers are easier to read if the decimals align, as with the prior table (c) tables may be easier to read if you use `\renewcommand{\arraystretch}{1.2}` to spread the

lines a hair (d) you can distinguish tables from the text body if you use the `\small` font size and (e) format the source so that you can easily make changes later.

Here is an example of a complex table whose formatting makes its contents clearer.[1]

```
{\renewcommand{\arraystretch}{1.2}\small
\begin{tabular}{@{}rrrrcrrr@{}}
          &\multicolumn{3}{c}{$w = 8$}
          &\hspace{2em}
          &\multicolumn{3}{c}{$w = 16$} \\
          \cline{2-4} \cline{6-8}
          &$t=0$ &$t=1$ &$t=2$
                          &&$t=0$ &$t=1$ &$t=2$           \\ \hline
$dir=1$                                                    \\
$c_{top,0}$ &0.0790 &0.1692 &0.2945
                          &&0.3670 &0.7187 &3.1815        \\
$c_{top,1}$ &-0.8651 &50.0476 &5.9384
                          &&-9.0714 &297.0923 &46.2143     \\
$c_{top,2}$ &124.2756 &-50.9612 &-14.2721
                          &&128.2265 &-630.5455 &-381.0930\\[2ex]
$dir=0$                                                    \\
$c_{top,0}$ &0.0357 &1.2473 &0.2119
                          &&0.3593 &-0.2755 &2.1764        \\
$c_{top,1}$ &-17.9048 &-37.1111 &8.8591
                          &&-30.7381 &-9.5952 &-3.0000     \\
$c_{top,2}$ &105.5518 &232.1160 &-94.7351
                          &&100.2497 &141.2778 &-259.7326
\end{tabular}}
```

	$w = 8$			$w = 16$		
	t = 0	t = 1	t = 2	t = 0	t = 1	t = 2
$dir = 1$						
$c_{top,0}$	0.0790	0.1692	0.2945	0.3670	0.7187	3.1815
$c_{top,1}$	-0.8651	50.0476	5.9384	-9.0714	297.0923	46.2143
$c_{top,2}$	124.2756	-50.9612	-14.2721	128.2265	-630.5455	-381.0930
$dir = 0$						
$c_{top,0}$	0.0357	1.2473	0.2119	0.3593	-0.2755	2.1764
$c_{top,1}$	-17.9048	-37.1111	8.8591	-30.7381	-9.5952	-3.0000
$c_{top,2}$	105.5518	232.1160	-94.7351	100.2497	141.2778	-259.7326

Mathematics

Mathematics is where LaTeX shines. Surprisingly often it will know what you mean and will make your work appear exactly as in a professional book or journal, clear and attractive.

[1] Adapted from http://www.inf.ethz.ch/personal/markusp/teaching/guides/guide-tables.pdf.

INLINE AND DISPLAY Mathematics can appear *inline* or *display*, set on a separate line. For inline, enclose the mathematics in LaTeX's mathematics mode delimiters `\(` and `\)`.[1]

```
The composition of two functions is \( f\circ g(x)=f(g(x)) \).
```

The composition of two functions is $f \circ g(x) = f(g(x))$.

```
The number \( \pi(n) \) of primes less than or equal to~\( n \) is
asymptotically equal to \( n/\ln(n) \).
```

The number $\pi(n)$ of primes less than or equal to n is asymptotically equal to $n/\ln(n)$.

Note that the variable n is set as mathematics — leaving out its mathematics delimiters is wrong.

Display style mathematics has more options. Most common is the *equation** environment.

```
\begin{equation*}
  \int \cos(x)\,dx=\sin(x)+C
\end{equation*}
```

$$\int \cos(x)\,dx = \sin(x) + C$$

This environment's unstarred form will number the equation. More display environment options are below.

SUPER- AND SUBSCRIPTS Caret gets you an exponent `x^2`. You may need to group the symbols with curly braces to tell LaTeX what you mean.

```
The expressions \(e^2x\) and \(e^{2x}\) differ.
```

The expressions e^2x and e^{2x} differ.

Underbar gets you a subscript `a_0`; again you may need to group, as in `a_{0,0}`. Sub- and superscripts can nest and you sometimes want both a subscript and a superscript.

```
\begin{equation*}
  \sum_{i=1}^{n_0} i^2
\end{equation*}
```

$$\sum_{i=1}^{n_0} i^2$$

FRACTIONS Get a fraction with this command.

```
Fractions look different inline \(\frac{1}{2}\)
than in a display
\begin{equation*}
  \frac{1}{2}
\end{equation*}
```

Fractions look different inline $\frac{1}{2}$ than in a display

$$\frac{1}{2}$$

[1] You sometimes see dollar signs used in place of the backslash parentheses but this way is better.

You can also just use a slash, as in `x^{3/2}`.

```
The derivative operator \(d/dx\) applies to the quadratic function
\(f(x)=x^2\) to give
\begin{equation*}
  \frac{df}{dx}=2x
\end{equation*}
so the tangent line at \(x=0\) is horizontal.
```

The derivative operator d/dx applies to the quadratic function $f(x) = x^2$ to give

$$\frac{df}{dx} = 2x$$

so the tangent line at $x = 0$ is horizontal.

ROOTS Square root $\sqrt{x^2+y^2}$ is `\sqrt{x^2+y^2}`. Other roots $\sqrt[3]{x^3+y^3}$ use the optional argument `\sqrt[3]{x^3+y^3}`.

SYMBOLS Here are most of the symbols you might use in undergraduate classes. For more see the Comprehensive LaTeX Symbols List[1] and DeTeXify.[2]

With Greek letters, the upper case letters that look just like our everyday Roman letters are never used for mathematics. The lower case omicron is only rarely used.

Lower case	Upper case	Lower case	Upper case
α `\alpha`	A	ν `\nu`	N
β `\beta`	B	ξ `\xi`	Ξ `\Xi`
γ `\gamma`	Γ `\Gamma`	o	O
δ `\delta`	Δ `\Delta`	π `\pi`	
ϵ `\epsilon`		or ϖ `\varpi`	Π `\Pi`
or ε `\varepsilon`	E	ρ `\rho`	P
ζ `\zeta`	Z	σ `\sigma`	Σ `\Sigma`
η `\eta`	H	τ `\tau`	T
θ `\theta`		υ `\upsilon`	Υ `\Upsilon`
or ϑ `\vartheta`	Θ `\Theta`	ϕ `\phi`	
ι `\iota`	I	or φ `\varphi`	Φ `\Phi`
κ `\kappa`	K	χ `\chi`	X
λ `\lambda`	Λ `\Lambda`	ψ `\psi`	Ψ `\Psi`
μ `\mu`	M	ω `\omega`	Ω `\Omega`

Here are some non-Greek characters.

$\mathbb{R}$ `\mathbb{R}`	$\forall$ `\forall`	∞ `\infty`	∂ `\partial`
$\mathbb{Z}$ `\mathbb{Z}`	$\exists$ `\exists`	$\emptyset$ `\emptyset`	∇ `\nabla`
$\mathbb{N}$ `\mathbb{N}`	$\neg$ `\neg`	$\imath$ `\imath`	$\|$ `|`
$\mathbb{C}$ `\mathbb{C}`	$\aleph$ `\aleph`	$\jmath$ `\jmath`	ℓ `\ell`

You can decorate symbols in many ways.

[1] mirror.ctan.org/info/symbols [2] detexify.kirelabs.org/classify.html

$\vec{x}$	`\vec{x}`	f''	`f^{\prime\prime}`	$\overline{x+y}$	`\overline{x+y}`
$\hat{x}$	`\hat{x}`	$\dot{a}$	`\dot{a}`	$\overbrace{x+y}$	`\overbrace{x+y}`
f'	`f^\prime`	$\ddot{a}$	`\ddot{a}`	$\underbrace{x+y}$	`\underbrace{x+y}`

(Use `\imath` and `\jmath` for characters that are the regular italic letters but with the dot missing, because a vector bar over a dotted letter looks awkward.) You can also use `\boldsymbol{x}` and `\widehat{x+y}`.

Mathematicians use dots to show an omission. We've seen low horizontal dots as in $\mathbb{N} = \{0, 1, 2, \ldots\}$ from `\mathbb{N}=\{0,1,2,\,\ldots\}` and there are also centered horizontal dots as in $5050 = 1 + \cdots + 100$ from `5050=1+\cdots+100`. Vertical dots `\vdots` and diagonal dots `\ddots` often appear in matrices.

Some standard named symbols use an abbreviation set in Roman type.

$\cos$ `\cos`	$\arctan$ `\arctan`	$\exp$ `\exp`	$\lim$ `\lim`
$\sin$ `\sin`	$\cosh$ `\cosh`	$\det$ `\det`	$\inf$ `\inf`
$\tan$ `\tan`	$\sinh$ `\sinh`	$\min$ `\min`	$\sup$ `\sup`
$\sec$ `\sec`	$\tanh$ `\tanh`	$\max$ `\max`	$\liminf$ `\liminf`
$\csc$ `\csc`	$\coth$ `\coth`	$\dim$ `\dim`	$\limsup$ `\limsup`
$\cot$ `\cot`	$\ln$ `\ln`	$\gcd$ `\gcd`	$\hom$ `\hom`
$\arccos$ `\arccos`	$\log$ `\log`	$\deg$ `\deg`	$\ker$ `\ker`
$\arcsin$ `\arcsin`	$\lg$ `\lg`	$\arg$ `\arg`	

These are common undergraduate operators and relations.

$\pm$ `\pm`	$\circ$ `\circ`	$\oplus$ `\oplus`	$\odot$ `\odot`
$\div$ `\div`	$\cup$ `\cup`	$\ominus$ `\ominus`	$\vee$ `\vee`
$\cdot$ `\cdot`	$\cap$ `\cap`	$\otimes$ `\otimes`	$\wedge$ `\wedge`
$\times$ `\times`	$*$ `\ast`	$\oslash$ `\oslash`	$\mid$ `\mid`

Some operators resize to fit their context.

$\sum$ `\sum`	$\iint$ `\iint`	$\bigcap$ `\bigcap`	$\bigwedge$ `\bigwedge`
$\prod$ `\prod`	$\iiint$ `\iiint`	$\bigcup$ `\bigcup`	
$\int$ `\int`	$\oint$ `\oint`	$\bigvee$ `\bigvee`	

You will need arrows.

$\leftarrow$ `\leftarrow`	$\longleftarrow$ `\longleftarrow`	$\mapsto$ `\mapsto`
$\rightarrow$ `\rightarrow` or `\to`	$\Longleftarrow$ `\Longleftarrow`	$\longmapsto$ `\longmapsto`
$\leftrightarrow$ `\leftrightarrow`	$\downarrow$ `\downarrow`	
$\Leftarrow$ `\Leftarrow`	$\uparrow$ `\uparrow`	
$\Rightarrow$ `\Rightarrow`	$\updownarrow$ `\updownarrow`	
$\Leftrightarrow$ `\Leftrightarrow`	$\Uparrow$ `\Uparrow`	

For instance, write a function definition $f\colon \mathbb{R} \to \mathbb{R}$ with `f\colon\mathbb{R}\to\mathbb{R}`.

Symbols that surround an expression are *fences*.

`()` `()`	`[]` `[]`	$\{\}$ `\{\}`
$\langle\rangle$ `\langle\rangle`	$\lfloor\rfloor$ `\lfloor\rfloor`	$\lceil\rceil$ `\lceil\rceil`
$\vert\vert$	$\Vert\Vert$ `\Vert\Vert`	

Write `\left` and `\right` in front of a fence to get automatically determined sizes. There must be as many `\left`'s are `\right`'s and they must be on the same output line. To use an only one-sided fence with `\left`, on the other side write `\right.`, including the period.

```
\begin{equation*}
  \left.\frac{\partial f}{\partial x}\right|_{x_0}
\end{equation*}
```

$$\left.\frac{\partial f}{\partial x}\right|_{x_0}$$

If LaTeX gets the fence size wrong you can do it by hand with one of `\big`, `\Big`, `\bigg`, or `\Bigg`.

Arrays and Matrices An *array* is a rectangular arrangement of mathematics. You make an array in mathematical text much like you make a table in plain text.

```
\begin{equation*}
  \begin{array}{ccccc}
    0 &1 &2 &3 &\ldots \\
    \updownarrow &\updownarrow &\updownarrow &\updownarrow \\
    0 &2 &4 &6 &\ldots
  \end{array}
\end{equation*}
```

$$\begin{array}{ccccc} 0 & 1 & 2 & 3 & \ldots \\ \updownarrow & \updownarrow & \updownarrow & \updownarrow & \\ 0 & 2 & 4 & 6 & \ldots \end{array}$$

Sometimes a function's definition is by cases, which is a special kind of array.

```
\begin{equation*}
  f(n)=\begin{cases}
         0              &\text{if \(n=0\)}   \\
         1              &\text{if \(n=1\)}   \\
         f(n-1)+f(n-2) &\text{otherwise}
       \end{cases}
\end{equation*}
```

$$f(n) = \begin{cases} 0 & \text{if } n = 0 \\ 1 & \text{if } n = 1 \\ f(n-1) + f(n-2) & \text{otherwise} \end{cases}$$

A matrix is an array surrounded by a fence. There is a convenient abbreviation.

```
\begin{equation*}
  \begin{pmatrix}
    a  &b \\
    c  &d
  \end{pmatrix}
  \begin{pmatrix}
    x  \\
    y
  \end{pmatrix}
  =
  \begin{pmatrix}
    ax+by \\
    cx+dy
  \end{pmatrix}
\end{equation*}
```

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} ax + by \\ cx + dy \end{pmatrix}$$

In addition to not specifying the parentheses, you don't specify how many columns and that each is centered because *pmatrix* assumes a default of a good number of centered columns. For determinants use `vmatrix`, which also doesn't need a column specifier.

```
\begin{equation*}
  \begin{vmatrix}
    a  &b \\
    c  &d
  \end{vmatrix}
  =ad-bc
\end{equation*}
```

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} = ad - bc$$

THEOREMS In the preamble of template.tex you declare the theorem environments that you might use.

```
\newtheorem{thm}{Theorem}
\newtheorem{lem}[thm]{Lemma}    % numbered in sequence with thm
\newtheorem{cor}[thm]{Corollary}
```

In the body of your document use it this way.

```
\begin{thm}[Lindeberg-L\'evy]
Let \( \{X_i \mid i\in\mathbb{N}\} \) be a sequence of
independent identically distributed random variables,
all with mean~\( \mu \) and finite variance~\( \sigma^2 \).
Then as \( n \) approaches infinity and where \( S_n \) is the
sample average \( (X_1+\cdots+X_n)/n \), the random variables
\( \sqrt{n}(S_n-\mu) \) converge in distribution to a normal
\( \mathcal{N}(0,\sigma^2) \).
\end{thm}
\begin{proof}
See the appendix.
\end{proof}
\begin{cor}
Samples are distributed Normally.
\end{cor}
```

Theorem 1 (Lindeberg-Lévy). *Let* $\{X_i \mid i \in \mathbb{N}\}$ *be a sequence of independent identically distributed random variables, all with mean* μ *and finite variance* σ^2*. Then as* n *approaches infinity and where* S_n *is the sample average* $(X_1+\cdots+X_n)/n$*, the random variables* $\sqrt{n}(S_n-\mu)$ *converge in distribution to a normal* $\mathcal{N}(0,\sigma^2)$*.*

Proof. See the appendix. □

Corollary 2. *Samples are distributed Normally.*

COMPLEX DISPLAYED EQUATIONS There are many more options for displayed equations but we'll only see two. One is for when you need to make a too-long displayed line into multiple lines.

```
\begin{multline*}
    H_c=\frac{1}{2n} \sum^n_{l=0}(-1)^{l}(n-{l})^{p-2}
      \sum_{l _1+\dots+ l _p=l}\prod^p_{i=1} \binom{n_i}{l _i} \\
    \cdot[(n-l )-(n_i-l _i)]^{n_i-l _i}\cdot
      [(n-l )^2-\sum^p_{j=1}(n_i-l _i)^2]
\end{multline*}
```

$$H_c = \frac{1}{2n}\sum_{l=0}^{n}(-1)^l(n-l)^{p-2} \sum_{l_1+\cdots+l_p=l} \prod_{i=1}^{p}\binom{n_i}{l_i} \cdot [(n-l)-(n_i-l_i)]^{n_i-l_i}\cdot[(n-l)^2-\sum_{j=1}^{p}(n_i-l_i)^2]$$

Another is for when you want to align equations.

```
\begin{align*}
  e^{x} &=\sum_{n\in 1..\infty} \frac{1}{n!}x^n        \\
        &=1+x+\frac{x^2}{2}+\frac{x^3}{3!}+\frac{x^4}{4!}
         +\frac{x^5}{5!}+\frac{x^6}{6!}+\cdots
\end{align*}
```

$$
\begin{aligned}
e^x &= \sum_{n\in 1..\infty} \frac{1}{n!}x^n \\
&= 1 + x + \frac{x^2}{2} + \frac{x^3}{3!} + \frac{x^4}{4!} + \frac{x^5}{5!} + \frac{x^6}{6!} + \cdots
\end{aligned}
$$

For both of these the unstarred version will number the equation.

RECIPES Here are some miscellaneous examples, taken from undergraduate mathematics.

```
\begin{equation*}
  \int_{x=1}^{x=\infty} e^{-x}\,dx
\end{equation*}
```

$$\int_{x=1}^{x=\infty} e^{-x}\,dx$$

```
\begin{equation*}
  \{ n\in\mathbb{N} \mid \text{\( n \) is even} \}
\end{equation*}
```

$$\{n \in \mathbb{N} \mid n \text{ is even}\}$$

```
The boiling point of $\text{H}_2\text{O}$ is $212^{\circ}$F.
```

The boiling point of H_2O is 212°F.

Verbatim and Listings

The *verbatim* environment outputs its contents just as it is input, with all line breaks and spaces. For inline material use `\verb!verbatim text!` (you can use any character in place of the exclamation points, but it must be the same character in both places).

For computer code your template has brought in the *listings* package.

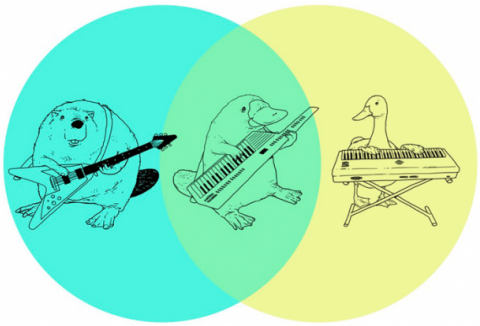
```
\begin{lstlisting}
while True:
    print "Hello World!"
\end{lstlisting}
```

```
while True:
    print "Hello World!"
```

Graphics

Include graphics in the JPG, PNG, or PDF formats[1]

```
\begin{center}
  \includegraphics[width=.4\textwidth]{Keytar-platypus.png}
\end{center}
```



Besides *width*, you can specify *height* or *scale* or leave the option off to get the graphic at its natural size (although in this Venn diagram picture, nothing is natural).

References

Labels and references To refer to something, first *label* it and then *reference* it.

```
\section{Bases and dimension} \label{sec:BasesAndDimension}
This is section~\ref{sec:BasesAndDimension},
starting on page~\pageref{sec:BasesAndDimension}.
```

The label text `sec:BasesAndDimension` is arbitrary, but good practice is to give labels a memorable name with a prefix describing what it labels.

References can point to something later in the document. LaTeX does this by saving each label's information in an auxiliary file. It then starts any run by looking for the `.aux` file from the previous run. This explains why you sometimes get the message, "You should run LaTeX again to get references right" and in your document references look like this.

```
\section{Bases and dimension} \label{sec:BasesAndDimension}
This is section~\ref{sec:BasesAndDimension},
starting on page~\pageref{sec:BasesAndDimension}.
```

Bases and dimension

This is section ??, starting on page ??.

LaTeX has found a reference without an associated label (yet), or a reference that has changed. The solution is to compile again.

Hyper-references The template is set up to makes your cross-references into hyperlinks.

To get a link to a web address, that appears in a suitable font and hyphenates sensibly, use the *url* command.

[1] Graphic from Tenso Graphics at http://tensographics.com/post/7267021251/math-available-at-threadless.

```
My home machine is \url{http://joshua.smcvt.edu}.
```

My home machine is http://joshua.smcvt.edu.

You can make a link out of any text.

```
See the \href{http://joshua.smcvt.edu/proofs}{book's home page}.
```

See the book's home page.

BIBLIOGRAPHY There are advanced bibliographic options for LaTeX but a structure like this one will take you a long way.

```
The most often recommended \LaTeX{} tutorial is~\cite{lshort2e}.
\begin{thebibliography}{9}
  \bibitem{lshort2e}T.~Oetiker; H.~Partl; I.~Hyna; E.~Schlegl:
    \textit{The Not-So-Short Introduction to \LaTeX}
    (2001)
\end{thebibliography}
```

The parameter '9' to the *thebibliography* environment tells LaTeX that the widest bibliography reference number will be no wider than the single digit.

Advanced material

There is a great deal to explore in the LaTeX and TeX ecosystem. Becoming a TeX wizard is a long journey. This section may give you a taste of the power of the tool.

BREAKING Encourage LaTeX to break a line with `\linebreak[2]`; the number can be from 0 to 4, in order of increasing encouragement. Omitting the optional argument is the same as using a 4, and essentially requires a break.

LaTeX will also force a line break with `\\` or `\newline`; the difference from the prior paragraph is that here the broken line will not be justified. You can add vertical space between the two lines with an optional argument `\\[2ex]`. The starred forms `\\*` and `\newline*` prohibit a page break.

Encourage a page break with `\pagebreak[2]`, where again the optional argument runs from 0 to 4 and leaving off the argument is the same as specifying a 4. To start on a new page by filling the bottom of the old with blank space use `\clearpage` or `\cleardoublepage`, which leaves an entire blank page (new chapters should start on an odd page so you sometimes want to leave an extra blank page).

PAGE STYLES Set indents for paragraphs with `\setlength{\parindent}{2em}`. Set the space between paragraphs as in `\setlength{\parskip}{1ex plus 0.5ex minus 0.2ex}` (the *plus* and *minus* gives it some stretch and shrink to cope with what comes in the page). Both commands go in the preamble.

You can adjust the headers and footers on pages. This document uses this arrangement.

```
\fancypagestyle{firstpage}{%
  \fancyhf{} % clear all six fields
  \renewcommand{\headrulewidth}{0pt}
  \renewcommand{\footrulewidth}{0pt}
```

```
}
\fancypagestyle{followingpage}{%
  \fancyhf{}
  \fancyhead[RE,LO]{\LaTeX{} tutorial}
  \fancyhead[LE,RO]{page \thepage}
  \renewcommand{\headrulewidth}{1pt}
  \renewcommand{\footrulewidth}{0pt}
}
\pagestyle{followingpage}
% \AtBeginDocument{\thispagestyle{firstpage}}
```

Briefly, on the first page there is no header or footer, and no head or foot rule (thin line across the page head). All other pages are of type *followingpage* and have a small head rule. They also have headers that on the right side of even-numbered pages have the words 'LaTeX tutorial' and on the other side have the page number.

Including other files You can split long documents into conveniently-sized files. To include material from `filename.tex` use `\include{filename}`.[1]

```
\begin{document}
\tableofcontents
\include{preface}
\include{chapter1}
\include{chapter2}
\end{document}
```

To speed up your development cycle by not recompiling parts that are not changing, put this in the preamble with a list of all the files in the document.

```
  \includeonly{% preface,
               chapter1,
               % chapter2,
               }
```

Comment out the files you are not working on and compile. The document will still have cross-references to the omitted material, but will otherwise only include the part that you left in.

Version control Because LaTeX is text-based it works well with the advanced source code version control systems. For instance, Mercurial took the source of this document with the commands `cd tutorial`, followed by `hg init` then `hg add tutorial.tex` and `hg add tutorial.cls`.

[1] You cannot include a file from an included file and included material causes a page break before and after the inclusion.