Typing Mathematics in LaTeX

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1 What is LaTeX?

1.A History of TeX and LaTeX

In the late 1970's, Donald Knuth, a computer scientist, was unhappy with the state of mathematical typesetting, and during the following 10 years created a computer language known as TeX to typeset mathematical documents. He placed the software in the public domain, so that anyone interested in professionally typsetting mathematical documents could freely use it. Since that time, it has become the standard method to typeset mathematics, and most mathematical journals, as well as many science, engineering, and economics journals expect submissions of research papers to be in TeX format.

The original TeX system is extremely flexible, but this flexibility produced a steep learning curve. In the early 1990's, a frontend for TeXwas developed by Leslie Lamport, and named LaTeX. Rather than being a new program, LaTeX consists primarily of format and style files which set default parameters for documents typeset using TeX. It does slightly change the behavior of TeX, but the most important features are the same. Nowadays it is seldom necessary to distinguish between TeX and LaTeX.

For more information about the history of TeX and LaTeX, see the following web pages.

- https://www.tug.org/whatis.html: History of TeX.
- https://en.wikipedia.org/wiki/TeX: Wikipedia page on TeX.
- https://en.wikipedia.org/wiki/LaTeX: Wikipedia page on LaTeX.

1.B Features of LaTeX

LaTeX allows for the easy typesetting of mathematical formulas. For instance, in order to type the quadratic formula,

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

one can just type

```
\[x=\frac{-b\pm\sqrt{b^2-4ac}}{2a}\].
```

LaTeX has powerful commands for formatting chapters and sections of documents as well as the ability to format bibliographies that we will not use in the class. It has an advanced algorithm to determine hyphenation of words, as well as the ability to type nearly every symbol that would be desired. With additional packages, LaTeX can be used to type in languages such as Hebrew, Arabic, Chinese, Japanese, etc. Packages are available to typset musical notation, chess notation, and other difficult typesetting problems.

In addition to all this, LaTeX contains a complete programming language; it is possible (although usually inconvenient) to do any type of calculation in the system.

2 Using Overleaf

Overleaf is an online service which provides access to the LaTeX typesetting system. It allows you to use LaTeX without having to install the software on your own computer. Your documents will be available from anywhere in the world when you log into the system.

2.A Creating an Overleaf account

Open your favorite web browser, and navigate to www.overleaf.com. Select **Register** in the upper right corner. You will be prompted to enter an e-mail address and a password. Once you do this, select "New Project" and choose to create a blank project. You will be taken to a page that has the formatting code for a new document, as well as a compiled version of the blank document. Feel free to experiment with the system.

If you wish to exit this document and create a new one, select the button in the top left corner that looks like  (directly to the right of the menu button). This will take you to a list of all of your projects, and allow you to create a new project.

2.B Compiling a project

Once you have typed in some mathematics, to see what it will look like when printed, press the green button at the top center of the page labelled "Recompile." This will convert the LaTeX code that you have typed into human readable mathematics.

2.C Downloading a completed project

Once you have completed a project, you may want to download the PDF, to share with others by e-mail (or to turn in). To do this, while viewing the project, select the Menu button in the upper left corner. At the top of the menu, you will have two options to download; the first, "Source", will download a .zip file of the source code for your project. The second will download a PDF file.

3 Formatting

3.A Formatting a document

In order to get a properly formatted LaTeX document, you need to enter some commands to tell LaTeX what format you want to use. Typically, a minimal document will have the following lines included:

```
\documentclass{amsart}
\begin{document}
Your text goes here.
\end{document}
```

The area before the `\begin{document}` command is called the preamble of the document and sets up the formatting. For most purposes, you should not have to worry about the format of the document, or the format of the pages. These will all be determined by the document class that is loaded.

Many journals have style files that provide document classes for their journal. For example, the LaTeX style files for submissions to journals of the IEEE (Institute of Electrical and Electronics Engineers) can be downloaded at

http://ieeeauthorcenter.ieee.org/crate-your-ieee-article/use-authoring-tools-and-ieee-article-templates/ieee-article-templates.

Submissions to journals of the AMS (American Mathematical Society) can be formatted using the document class `amsart`, which is included in LaTeX.

Many other style files are available on the Overleaf web site or by searching the internet.

3.B Titles, chapters, and sections

All formatting of titles, chapters, and sections in your document should be controlled by the style file. Typically, at the beginning of your file (in the preamble, before the `\begin{document}` command) you will have lines reading

```
\title{Your title here}
\author{Your name here}
```

and to begin a chapter or section, you will type

```
\chapter{This is the title of the chapter}
\section{This is the title of this section}
\subsection{This is the title of this subsection}
```

LaTeX will format the chapter and section titles and number them according to guidelines in the style file.

3.C Text

In LaTeX, you can type normal text much like you would in a word processor. Place your cursor at the point where you want the text, and begin typing. Some features are different than most word processors. When LaTeX compiles your input, it will ignore most blank space (other than blank lines between words). It will also ignore the fact that you have moved to a new line. In order to start a new paragraph, press enter twice, leaving a blank line between the old paragraph and the new paragraph. Generally, you should not have to start a new line without starting a new paragraph; in the unlikely event that you need to, type `\newline`.

Note that if you want to align words on different lines, you cannot do this simply by typing spaces. You will need to use a `tabular` environment to create a table.

It is possible to put text in boldface or italics; for example you can type the command `\textbf{Bold}` to obtain **Bold**, or `\textit{Italics}` to get *Italics*. Note the use of the curly brackets to specify how far the change in font should go. Other fonts that are available are `\texttt{Typewriter}` to give `Typewriter` (which is useful for computer code), or `\textsc{SmallCaps}` to give SmallCaps.

Typically, font sizes will be decided by the document style, and should not be manually changed. Nevertheless, there are commands available to obtain different sizes of type.

LaTeX Command	Output
`{\HUGE Test}`	Test
`{\Huge Test}`	Test
`{\LARGE Test}`	Test
`{\Large Test}`	Test
Test	Test
`{\small Test}`	Test
`{\tiny Test}`	Test

3.D Numbered lists

In order to bet a numbered list of bulletpoints, you can use `\begin{enumerate}`, as follows:

```
\begin{enumerate}
\item Note that each item is individually indented and numbered.
\item If you want to use bullet points instead of numbered items,
replace \texttt{enumerate} by \texttt{itemize}.
\end{enumerate}
```

produces

1. Note that each item is individually indented and numbered.
2. If you want to use bullet points instead of numbered items, replace `enumerate` by `itemize`.

4 Math Mode

4.A Inline Math Mode

Most mathematical formulas are typed using italics for variables. As you read more and more mathematics, it will look strange to you to see variable names written without italics. In order to make it easy to type mathematics and mathematical symbols, LaTeX has a "math mode" that automatically places variables in italics, allows the insertion of codes for mathematical symbols, and adjusts the spacing of mathematical symbols. There are two ways to enter math mode; you can use a dollar sign to begin and end math mode, or you can begin math mode with `\(` and end it with `\)`. For example, if you wish to typset $a^2 + b^2 = c^2$ you might type either `$a^2+b^2=c^2$` or `\(a^2+b^2=c^2\)`. Typically you should put an entire formula into math mode; it will give poor results if you were to type `$a^2$+$b^2$=$c^2$`; the spacing would be wrong: $a^2+b^2=c^2$. It is important to note that *any* mathematics should be typed in math mode; if you have a variable called a, it would look strange to say "for any value of a" but makes sense to say "for any value of a."

The math mode obtained using a dollar sign is called inline math mode. It is best used for formulas that are fairly short and do not extend very far in the vertical direction. For tall formulas, you should put the formula in a displayed equation, as described below.

4.B Displayed Equations

In mathematics, equations are very important, and it is often useful to set them apart from regular text. To do this, there is a special math mode that will place an equation on a line of its own in math mode, and center the line. This mode is started with `\[` and ended with `\]`. For instance, if I wanted to type the equation $a^2 + b^2 = c^2$ as a displayed equation, I could type `\[a^2+b^2=c^2.\]` to obtain

$$a^2 + b^2 = c^2.$$

Taller equations should always be put into displayed equations, to avoid disrupting the spacing of text lines: Notice how $(x + y)^n = \sum_{k=0}^{n} \binom{n}{k} x^k y^{n-k}$ disrupts the line spacing of the text, while

$$(x + y)^n = \sum_{k=0}^{n} \binom{n}{k} x^k y^{n-k}$$

does not.

One important thing to notice is that mathematical formulas typically arise as part of a sentence; as such, they should be punctuated correctly. If a formula ends a sentence, it should have a period at the end; if it ends a phrase, it should have a comma. Punctuation for displayed equations must be inserted inside the `\[ \]` that start and end the formula.

5 Common Symbols

Essentially any symbol that you want to type can be typed using a command in LaTeX. Some symbols, such as $ are used to start and end LaTeX formatting, and must be typed in special ways. Below is a table of very common mathematical symbols and how to type them. A more comprehensive collection of tables can be found at https://oeis.org/wiki/List_of_LaTeX_mathematical_symbols, and a much more comprehensive list (338 pages long) can be found at http://tug.ctan.org/info/symbols/comprehensive/symbols-letter.pdf. Note that many of the symbols listed in this last document require additional packages to be loaded to use them. Some of the common symbols below are included in the `amsmath` package, which can be loaded by typing `\usepackage{amsmath}` before the `\begin{document}` line.

TeX Code	Output
`$a\in A$`	$a \in A$
`$A\times B$`	$A \times B$
`$A\cdot B$`	$A \cdot B$
`$\emptyset=\{\}$`	$\emptyset = \{\}$
`$P\implies (Q\lor R)$`	$P \Rightarrow (Q \lor R)$
`$P\Leftrightarrow (Q\land R)$`	$P \Leftrightarrow (Q \land R)$
`$\lnot P$`	$\neg P$
`$2\neq 3$`	$2 \neq 3$
`$x\notin\{a,b,c\}$`	$x \notin \{a, b, c\}$
`$A\subseteq B$`	$A \subseteq B$
`$X\subsetneq Y$`	$X \subsetneq Y$
`$\|x\|$` or `$\vert x\vert$`	$\|x\|$
`$\forall x\in S, \exists y\in T, P(x,y)$`	$\forall x \in S, \exists y \in T, P(x, y)$

Here are some important things to notice about symbols.

- Curly brackets are used in LaTeX to group things together. In order to get curly brackets in output, you need to use `\{` and `\}` instead of just `{` and `}`. In contrast, you just need to type parentheses and square brackets without the backslash.
- If the code for a symbol is followed by a letter, there must be a space between them. For instance `$a\inA$` will give an error message (LaTeX does not know the symbol `\inA`), so is must be typed `$a\in A$`. This is not true for symbols followed by a number; `$2\neq3$` will work fine, even though `$2\neqx$` will not.
- The codes `\land`, `\lor`, and `\lnot` can easily be remembered, since they stand for "logical and," "logical or," and "logical not." Codes for symbols cannot include numbers, so LaTeX knows that when it sees a number, it has reached the end of the code.
- The vertical line for the absolute value symbol is on your keyboard (a shifted backslash, right above the enter key).

6 Formatting mathematics

6.A Superscripts and subscripts

In mathematics, superscripts are used very often for exponents, and subscripts are often quite common. Hence, LaTeX makes it quite easy to insert them into formulas.

To type an exponent, such as x^2, you just need to type `$x^2$` (the caret is a shifted 6). If the exponent has more than one character in it, you need to surround it by curly braces; otherwise, only the first character will be in the exponent; for example, `$x^10$` prints as $x^1 0$, but `$x^{10}$` prints correctly as x^{10}. Exponents can be as long as you like; if they are too long or too tall, they may not be easy to read.

Subscripts are formatted exactly like exponents, using the underscore symbol; for example `$x_{10}$` produces x_{10}.

6.B Expandable delimiters

Often, you may wish to put a large formula into parentheses, square brackets, curly brackets, or absolute value bars. This can look strange if the parentheses are not large enough. For instance, `\[(\sum_{i=1}^{100} 2i),\]` produces

$$(\sum_{i=1}^{100} 2i),$$

which just looks wrong. Typing `\[\left(\sum_{i=1}^{100} 2i\right).\]` instead, produces

$$\left(\sum_{i=1}^{100} 2i\right).$$

Note that `\left(` and `\right)` must come in pairs; the size of the parentheses will adjust to fit everything between the `\left(` and the corresponding `\right)`. The `\left` and `\right` commands can also be used with `[ ]`, `\{ \}`, or `| |`, and the symbol on the left need not match the symbol on the right. For instance, you could write `\[S_x=\left[\frac{x^2-1}{x^2+1},\frac{x^2+1}{x^2-1}\right),\]` to produce

$$S_x = \left[\frac{x^2-1}{x^2+1}, \frac{x^2+1}{x^2-1}\right),$$

indicating a half open interval of real numbers.

6.C Square roots

To type a square root, use the command `\sqrt`. For instance, to type $\sqrt{2}$ you can just type `$\sqrt 2$` (or `$\sqrt2$` since 2 is a number). The argument inside the square root can be a large formula; it should be encased in curly brackets, or only the first character will be covered by the square root symbol. For instance, `$\sqrt b^2-4ac$` looks like $\sqrt{b}^2 - 4ac$; to type this correctly, it should be `$\sqrt{b^2-4ac}$`, which produces $\sqrt{b^2-4ac}$.

Cube roots are less common, and are written as `$\sqrt[3]{b^2-4ac}$` which produces $\sqrt[3]{b^2-4ac}$. The 3 can actually be replaced by any symbol or formula, although a large formula will not be very readable.

6.D Fractions

Mathematicians love to stack things on top of each other and separate them by a horizontal bar. Hence, this is pretty easy to do in LaTeX. To typeset the fraction

$$\frac{x^2+2x+1}{x+1}$$

I just typed `\[\frac{x^2+2x+1}{x+1}\]`. Notice that the command `\frac` has two formulas after it in curly braces; the first is the numerator and the second is the denominator. These formulas can be as complicated as you like.

6.E Combining formatting

Here is an example of how you can combine these different formatting tools. This is more complicated than anything that you will need to type in this class.

$$\frac{x}{y} = \frac{\sqrt[3]{\frac{1}{2}\left(-q+\sqrt{q^2+\frac{4p^3}{27}}\right)} + \sqrt[3]{\frac{1}{2}\left(-q-\sqrt{q^2+\frac{4p^3}{27}}\right)}}{\omega\sqrt[3]{\frac{1}{2}\left(-q+\sqrt{q^2+\frac{4p^3}{27}}\right)} + \omega^2\sqrt[3]{\frac{1}{2}\left(-q-\sqrt{q^2+\frac{4p^3}{27}}\right)}}$$

was typed as

```
\[\frac{x}{y}=
\frac
{  \root3\of{\frac{1}{2}\left(-q+\sqrt{q^2+\frac{4p^3}{27}}\right)}
   +{\root3\of{\frac{1}{2}\left(-q-\sqrt{q^2+\frac{4p^3}{27}}\right)}}
}
{\omega\root3\of{\frac{1}{2}\left(-q+\sqrt{q^2+\frac{4p^3}{27}}\right)}
  +
  \omega^2\root3\of{\frac{1}{2}\left(-q-\sqrt{q^2+\frac{4p^3}{27}}\right)}}
}
\]
```

6.F Alignment of multiple equations

Often, in order to show the steps of a solution, mathematicians will want to align multiple equations. This is done using a LaTeX environment that is available in the `amsmath` package. To load this package use the document class `amsart` or write `\usepackage{amsmath}` before the `\begin{document}` line. For instance, we might want to type

$$\begin{aligned}\frac{(x+y)^2-(x-y)^2}{4} &= \frac{(x^2+2xy+y^2)-(x^2-2xy-y^2)}{4}\\ &= \frac{x^2+2xy+y^2-x^2+2xy-y^2}{4}\\ &= \frac{4xy}{4}\\ &= xy\end{aligned}$$

This can be typed as:

```
\begin{align*}
\frac{(x+y)^2-(x-y)^2}4&=\frac{(x^2+2xy+y^2)-(x^2-2xy-y^2)}{4}\\
&=\frac{x^2+2xy+y^2-x^2+2xy-y^2}{4}\\
&=\frac{4xy}{4}\\
&=xy
\end{align*}
```

Notice that each line of the formula ends with a `\\` to indicate the end of the line. In addition, each line contains a single ampersand, `&`; the lines will be lined up so that the (invisible) ampersands form a vertical line. Placing the ampersands right next to the equals signs forces the equal signs to line up.

7 A sample LaTeX document

Below is a sample barebones LaTeX document that can be used as a template for your documents.

```
\documentclass{amsart}
\title{This is your title}
\author{Your name goes here}
\date{today}
\begin{document}
\maketitle
\section{Introduction}
\subsection{What is \LaTeX?}
This subsection would contain information about what \LaTeX\ is.
\subsection{How to use \LaTeX}
This subsection would contain information about how to use \LaTeX.
\end{document}
```

8 How to learn more about LaTeX

8.A In class

When we cover a new topic in class that has special symbols, I will be happy to tell you the LaTeX code for the new symbols. I am also happy to discuss formatting mathematics in LaTeX during my office hours.

8.B Tutorials

There are many online introductions to LaTeX that are far more comprehensive than we will need in this class. Some of them are at

https://tobi.oetiker.ch/lshort/lshort-letter.pdf
http://www.math.harvard.edu/texman/
http://ricardo.ecn.wfu.edu/~cottrell/ecn297/latex_tut.pdf
https://www.sharelatex.com/learn/Learn_LaTeX_in_30_minutes.

8.C Detexify

There is a web site, http://detexify.kirelabs.org, that will allow you to draw any symbol you like, and will attempt to show you the LaTeX code to produce that symbol. It works best if you can accurately draw the symbol.

8.D Existing LaTeX documents

One great way to learn how to type mathematics in LaTeX is to look at documents that have been typed using LaTeX. The website https://arxiv.org has thousands of mathematics and physics papers, almost all typed in LaTeX, with the LaTeX source available for download.

8.E Stackexchange

There is a TeX stackexchange site, where you can ask questions and get detailed answers about any aspect of LaTeX at https://tex.stackexchange.com/. these questions and answers are indexed on Google, so if you search for "type matrix in latex" you can easily find a page explaining how to typeset a matrix in LaTeX (in several different ways).