LaTeX for MAT-299, MAT-415, and MAT-470

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Directions: This document covers the necessary LaTeX skills for MAT-299, MAT-415, and MAT-470. Please note that there are often several ways to achieve your desired output, and this resource may introduce different approached from your prior learning.

LaTeX Preliminaries

LaTeX is a modern typesetting system that enables users to produce highly customized, technical documents for use in science, mathematics, and communication. LaTeX is the standard system for published scientific documents (https://www.latex-project.org/). In this document, we will introduce the basics of LaTeX and how it will be used in you course. While this resource is optional, it is strongly recommended to ensure you are prepared for the assignments that utilize LaTeX.

LaTeX (pronounced "lay-tech" or "lah-tech") is a typesetting system commonly used for creating documents with complex formatting, such as academic papers, research articles, theses, books, and presentations. Unlike traditional word processors, which focus on WYSIWYG (What You See Is What You Get) editing, LaTeX emphasizes separating content and formatting, allowing users to focus on the content while the system takes care of the presentation.

Overview of LaTeX

LaTeX is particularly popular among academics, researchers, and professionals in various fields due to its exceptional typographic quality and ability to handle documents with mathematical equations, references, tables, and bibliographies. It is based on the TeX typesetting system, which was created by Donald Knuth in the late 1970s.

One of LaTeX's strengths is its precise control over document layout and formatting, which is achieved through the use of commands and macros. Users write their documents in plain text, adding LaTeX commands to define the structure, styles, and elements of the document. This separation of content and formatting offers several advantages, such as consistent document formatting, easy collaboration, and the ability to focus on writing without being distracted by design details.

LaTeX documents are typically compiled using a LaTeX compiler (such as TeXstudio), which transforms the plain text input along with the LaTeX commands into a beautifully typeset output. The resulting documents can be saved in various formats, such as PDF, DVI (Device Independent), and more.

In this introduction to LaTeX, we will cover the basics of text formatting, mathematical equations, and mathematical symbols. You are provide templates for assignments that handle the packages, document structure, and other LaTeX requirements so that you can focus on the basics of LaTeX and the mathematical content of your course.

Typesetting Mathematics in LaTeX

In this course, you will need to use LaTeX to generate mathematical expressions. There are two ways to do this, inline math mode and display math mode. The primary method of entering equations in LaTeX for this course will be using inline mode. This method allows you to type mathematics in the same line as other text. This is helpful when you are explaining your process and steps. The most common way to type inline math is by surrounding it in '\$' characters. For instance, if we wanted to include $e^{i\pi}+1=0$, we would write '\$e^{i\pi}+1=0\$'. Notice that we use '\pi' for π and that the entirety of the exponent is surrounded by braces (more on that in a few lines). Note that it is common to put the '$' symbol around variables even if they are not in an expression, such as in the examples below. You can also use inline math by surrounding the desired math with a backslash and parentheses as is shown in the examples in a following section.

Display math mode separates the mathematics from any text and centers it on the page. You can enter display mode by surrounding the equations in '$$', using the backslash with bracket, or by using '\begin{equation*}'. The '*' symbol in the '\begin{equation*}' portion suppresses the numbering of equations. The examples below show the different ways to use inline and displayed math. In the following examples sections we see how this would be rendered in a PDF by the editor.

Finally, you may have noticed that braces, {}, play an important role in LaTeX. Think of braces as a way of grouping or collecting. In the above example, $e^{i\pi}+1=0$, the braces serve to group the content that we want to put in the exponent. If we do not use the braces, the editor assumes that only the character immediately after the ˆ symbol is the exponent and produces the following output: $e^i\pi + 1 = 0$.

Examples in LaTeX

Here, we show some examples of combining text and mathematics to describe the Pythagorean Theorem. The first section shows the LaTeX as it would be written in the editor, with the following section showing how it would be rendered by the editor. Notice the use of the % symbol for comments that are not rendered by the editor as well as the use of '\\' for a new line.

LaTeX for Pythagorean Theorem

```
% Inline Math Mode using '$...$'
The Pythagorean Theorem is one of the most well-known equations
in mathematics. It is the relationship between sides of a right
triangle. For a right triangle with legs $A$ and $B$ and
hypotenuse $C$, the relationship can be described by the
equation $A^2 + B^2 = C^2$.

% Inline Math Mode using '\(...\)'
The Pythagorean Theorem is one of the most well-known equations
in mathematics. It is the relationship between sides of a right
triangle. For a right triangle with legs $A$ and $B$ and
hypotenuse $C$, the relationship can be described by the
equation  \(A^2 + B^2 = C^2\).

% Display Math Mode with '$$...$$'
The Pythagorean Theorem is one of the most well-known equations
in mathematics. It is the relationship between sides of a right
triangle. For a right triangle with legs $A$ and $B$ and
hypotenuse $C$, the relationship can be described by the
equation:
$$A^2 + B^2 = C^2$$
```

```latex
% Display Math Mode with \[...\]
The Pythagorean Theorem is one of the most well-known
equations in mathematics. It is the relationship between
sides of a right triangle. For a right triangle with legs
$A$ and $B$ and hypotenuse $C$, the relationship can be
described by the equation:
\[A^2 + B^2 = C^2\]

% Display Math Mode with \begin{equation*}
The Pythagorean Theorem is one of the most well-known
equations in mathematics. It is the relationship between
sides of a right triangle. For a right triangle with legs
$A$ and $B$ and hypotenuse $C$, the relationship can be
described by the equation:

\begin{equation*}
A^2 + B^2 = C^2
\end{equation*}
```

Rendered Pythagorean Theorem

The Pythagorean Theorem is one of the most well-known equations in mathematics. It is the relationship between sides of a right triangle. For a right triangle with legs A and B and hypotenuse C, the relationship can be described by the equation $A^2 + B^2 = C^2$.

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$$A^2 + B^2 = C^2$$

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$$A^2 + B^2 = C^2$$

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$$A^2 + B^2 = C^2$$

Formatting Text

The ability to format text is an essential feature of LaTeX. For the purposes of this class, we will focus on formatting text within inline math mode and some basic formatting options for text. LaTeX has many options for formatting and this breadth of options can be overwhelming at first. However, these courses focus on mathematical proof and your problem-solving process, and not on perfectly formatted text. The examples below highlights a few options that you may find useful.

Lists and newlines

The two most common lists that you may work with are unordered (bulleted) and ordered (numbered). Unordered lists can be generated using itemize environment, with each entry preceded by \item.

LaTeX for Unordered List

```
\begin{itemize}
    \item List Item 1
    \item List Item 2
\end{itemize}
```

Rendered Unordered List

- List Item 1
- List Item 2

LaTeX for Ordered List

```
\begin{enumerate}
    \item List Item 1
    \item List Item 2
\end{enumerate}
```

Rendered Ordered List

(1) List Item 1

(2) List Item 2

Newlines are generally created by leaving a blank line in a document (usually by pressing the enter key twice). Additional options include two backslashes \\ or `\newline`. There are nuances to using newlines which you may wish to explore further but are not the focus of this course.

Formatting within Inline Math Mode

In this section we cover the basics of formatting within the math environment. We will focus on aligning, spacing, and inserting text.

LaTeX for Aligning

```
\begin{align*}
    2x + 3y &= 7 \\
    4x - y &= 1
```

```
\end{align*}
```

Notice that the align environment requires the use of the ampersand '&' symbol to locate the appropriate alignment and the double backslash for each newline. It is important to note that the '*' symbol is used here to suppress the equation numbering.

Rendered Aligning

$$\begin{align*}
2x + 3y &= 7\\
4x - y &= 1
\end{align*}$$

LaTeX for Spacing in Math Mode

Generally, the spacing in math mode is sufficient. However, there may be instances where spacing needs to be adjusted for clarity. For instance, $A = \{x \in \mathbb{R}||x| < 1\}$ is much more "cramped", compared to $A = \{x \in \mathbb{R} \mid |x| < 1\}$. The only difference between the two is the inclusion of spaces within math mode. Below, we show several different spacing options and their impact on the output.

```
\begin{align*}
    y &= mx + b\\
    y &= mx\, +\, b\\
    y &= mx\: +\: b\\
    y &= mx\; +\; b\\
    y &= mx\ +\ b\\
    y &= mx\quad +\quad b\\
    y &= mx\qquad +\qquad b\\
\end{align*}
```

Rendered Spacing in Math Mode

$$\begin{align*}
y &= mx + b\\
y &= mx\, +\, b\\
y &= mx\: +\: b\\
y &= mx\; +\; b\\
y &= mx\ +\ b\\
y &= mx\quad +\quad b\\
y &= mx\qquad +\qquad b
\end{align*}$$

LaTeX for Text in Math Mode

There may be instances in math mode, such as in the align environment, where we wish to add text to better communicate ideas. Below, we show how to add text to aligned equations.

```
\begin{align*}
    \sim (P \land Q) &=\, \sim P \lor \sim Q && \text{De
Morgan's law}\\
    \sim (P \lor Q) &=\, \sim P \land \sim Q && \text{De
Morgan's law}
\end{align*}
```

Don't worry if all the LaTeX above isn't clear at this point. Important LaTeX syntax will be introduced throughout this resource, with the goal of the above section to highlight how text can be used in math mode. Additionally, you may be familiar with the use of '$\neg$' for negation. Different authors may use this symbol or '$\sim$' to indicate negation. It is good to be familiar with both!

Rendered Text in Math Mode

$$\begin{align*}
\sim (P \land Q) &=\, \sim P \lor \sim Q && \text{De Morgan's law}\\
\sim (P \lor Q) &=\, \sim P \land \sim Q && \text{De Morgan's law}
\end{align*}$$

Truth Tables

In order to construct a truth table, you will need to create an array with the appropriate number of columns. In the below example (taken from section 2.5 of the MAT-299 text), there are 6 columns to create. This is done using the '`\begin{array}`' command followed by a 'c' for each column and a | as a separator for vertical lines. Use the '&' character to separate the columns both in your heading and in the table. Use '`\hline`' to create horizontal lines. At the end of every row, type '\\' for a new line. With this approach, you can make truth tables of any size.

LaTeX for Truth Table

```
\begin{equation*}
\begin{array}{|c | c || c |c |c ||c |}
\hline
P & Q & (P \lor Q) & (P \land Q) & \sim(P \land Q) & (P \lor Q)
\land \sim(P \land Q) \\
\hline\hline
T & T & T & T & F & \mathbf{F} \\
\hline
T & F & T & F & T & \mathbf{T} \\
\hline
F & T & T & F & T & \mathbf{T} \\
\hline
F & F & F & F & T & \mathbf{F} \\
\hline
\end{array}
\end{equation*}
```

Rendered Truth Table

P	Q	$(P \lor Q)$	$(P \land Q)$	$\sim(P \land Q)$	$(P \lor Q) \land \sim(P \land Q)$
T	T	T	T	F	$\mathbf{F}$
T	F	T	F	T	$\mathbf{T}$
F	T	T	F	T	$\mathbf{T}$
F	F	F	F	T	$\mathbf{F}$

In this example, we see that '|c | c || c |c |c ||c |' means that there are six columns in the table and each separated by one or two vertical lines. The double vertical bars, '||', produce the two bars that appear after the second and fifth columns. The letter 'c' means the value will be centered within the column, with the letters 'l' and 'r' indicating left-aligned and right-aligned, respectively.

Matrices

In order to construct a matrix, you follow a process similar to what you did to create a truth table. LaTeX offers a few commands for matrices, and we will show examples of two options below. To start, you will need create a matrix using either '`\begin{pmatrix}`' for a matrix with parentheses or '`\begin{bmatrix}`' for a matrix with brackets. Use the '&' character to separate each entry and '`\\`' at the end of every row. With this approach, you can make matrices of any size and shape.

LaTeX for Matrices

```
\begin{equation*}
 % The 5x5 Identity Matrix using pmatrix
\begin{pmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1
\end{pmatrix}


% The 5x5 Identity Matrix using bmatrix
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1
\end{bmatrix}
\end{equation*}
```

Rendered Matrices

$$\begin{pmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1
\end{pmatrix}$$

$$\begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1
\end{bmatrix}$$

Cayley Tables

In order to construct a Cayley table, you will need to use the tabular environment with the appropriate number of columns. In the below example (Table 3.10 of the MAT-415 text), there are 6 columns to create. This is done using the '`\begin{tabular}`' command followed by a 'c' for each column and a | as a separator for vertical lines. Use the '&' character to separate the columns both in your heading and in the table. Use '`\hline`' to create horizontal lines. At the end of every row, type '`\\`' for a new line. With this approach, you can make Cayley tables of any size.

LaTeX for Truth Table

```
\begin{equation*}
\begin{tabular}{c | c c c c c }
+ & 0 & 1 & 2 & 3 & 4\\
\hline
0 & 0 & 1 & 2 & 3 & 4\\
1 & 1 & 2 & 2 & 4 & 0\\
2 & 2 & 3 & 4 & 0 & 1\\
3 & 3 & 4 & 0 & 1 & 2\\
4 & 4 & 0 & 1 & 2 & 3\\
\end{tabular}
\end{equation*}
```

Rendered Truth Table

+	0	1	2	3	4
0	0	1	2	3	4
1	1	2	2	4	0
2	2	3	4	0	1
3	3	4	0	1	2
4	4	0	1	2	3

In this example, we see that 'c | c c c c c' means that there are six columns in the table with the first and second columns separated by a vertical line. The letter 'c' means the value will be centered within the column, with the letters 'l' and 'r' indicating left-aligned and right-aligned, respectively.

Other Mathematical Formatting

In this portion of this resource, we review the LaTeX code for some additional mathematical expressions not covered in the prior sections. This is not an exhaustive list, and there are many resources that provide the LaTeX for any symbols you may need. Before providing the list, there is one last topic that is important for appropriately formatting mathematics in LaTeX.

Sizing Delimiters

In LaTeX, `\left` and `\right` are commands used to automatically size delimiters (such as parentheses, brackets, or braces) according to the content they enclose. This is particularly useful in mathematical expressions where the default size of delimiters might not be sufficient for clarity. The `\left` command is placed before an opening delimiter (e.g., (, [,), with the `\right` command coming before a closing delimiter (e.g.,),],). When used together, LaTeX adjusts the size of the delimiters to match the height of the enclosed content.

For example, notice the differences in how the parentheses are rendered in the below example.

LaTeX for Sizing Delimiters

```
\begin{align*}
    \frac{d^2y}{dx^2} &= \frac{d}{dx}\left(\frac{dy}{dx}\right)
    && \text{with left, right}\\
    \frac{d^2y}{dx^2} &= \frac{d}{dx}(\frac{dy}{dx}) && \text{
    without left, right}
\end{align*}
```

Rendered Piecewise-defined Functions

$$
\begin{align*}
\frac{d^2y}{dx^2} &= \frac{d}{dx}\left(\frac{dy}{dx}\right) && \text{with left, right}\\
\frac{d^2y}{dx^2} &= \frac{d}{dx}(\frac{dy}{dx}) && \text{without left, right}
\end{align*}
$$

Piecewise-defined Functions

The \begin{cases} environment creates a properly aligned, easy-to-read piecewise function. Each case is written in the form of an expression followed by a condition, separated by an ampersand &, and a newline is created with \\to define multiple cases. We proceed with Example 1.2.5 from the MAT-470 text.

LaTeX for Piecewise-defined Functions

```
\begin{equation*}
|x| =
\begin{cases}
x & \text{if } x \geq 0, \\
-x & \text{if } x < 0.
\end{cases}
\end{equation*}
```

Rendered Piecewise-defined Functions

$$|x| = \begin{cases} x & \text{if } x \geq 0, \\ -x & \text{if } x < 0. \end{cases}$$

Escaping

In LaTeX, certain characters have special meanings because they are used to define commands or formatting. To use these characters as regular text (instead of invoking their special function), you need to "escape" them by placing a backslash ('\') in front of the character. This tells LaTeX to treat it as a literal character rather than a command.

Common Characters That Need Escaping

Symbol	**LaTeX Command**
#: Used for arguments in macros	To use it as text: \#
$: Used to enter math mode	To use it as text: '\$'
%: Denotes comments	To use it as text: '\%'
&: Used for column alignment.	To use it as text: '\&'
_: Used for subscripts in math mode.	To use it as text: '_'
{ and }: Used for grouping.	To use it as text: '\{ or \}'
^: Used for superscripts in math mode.	To use it as text: '\^'
\: Used for commands.	To use it as text: '\textbackslash'

Troubleshooting LaTeX

It is normal to encounter errors when compiling your work in LaTeX. As with the other sections of this resource, this is not an exhaustive list, but rather provides effective practices for using LaTeX.

(1) **Compile Often**: Compiling (using the Build & View option) after each change to your document reduces the number of errors that need to be reviewed at any one point.

(2) **Review the Log**: LaTeX generates an error log after compilation. The error message typically includes the line number and a brief description of the problem. Even if the message is unclear, focus on the line where the error occurred. The line number provided in the error log may not always be exact. Check a few lines before and after the indicated line for potential mistakes. Finally, always start by carefully reading the first error in the log, as it might trigger subsequent issues.

(3) **Check for Syntax Errors**: Common errors include missing the '\' character prior to commands, forgetting to close a set of curly braces, '{', forgetting the '\end{...}' component of environments. Another common syntax error is forgetting to end math mode or including mathematics outside of math mode.

(4) **Review Special Characters**: Certain characters (like %, &, $, _, {, }, ^) have special meanings in LaTeX. Using these without proper escaping can cause errors. A character can be escaped by putting a backslash in front of it. The backslash character can be created by using the '\textbackslash' command.

(5) **Deleting Components of the Template**: For these courses, a template file is used to simplify the process. Deleting components of the template can cause unexpected errors.

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Table of Common Symbols

Symbol	LaTeX Command	Example	Rendered
$\mathbb{R}$	`\mathbb{R}`	`x \in \mathbb{R}`	$x \in \mathbb{R}$
$\mathbb{Z}$	`\mathbb{Z}`	`n \in \mathbb{Z}`	$n \in \mathbb{Z}$
$\mathbb{N}$	`\mathbb{N}`	`n \in \mathbb{N}`	$n \in \mathbb{N}$
$\mathbb{Q}$	`\mathbb{Q}`	`p \in \mathbb{Q}`	$p \in \mathbb{Q}$
π	`\pi`	`\pi = 3.14`	$\pi = 3.14$
$\sum$	`\sum`	`\sum_{i=1}^{n} i`	$\sum_{i=1}^{n} i$
$\int$	`\int`	`\int_a^b f(x)\,dx`	$\int_a^b f(x)\,dx$
$\lim$	`\lim`	`\lim_x\to 0 f(x)\,dx`	$\lim_x \to 0 f(x)$
∞	`\infty`	`\lim_{x\to\infty} f(x)`	$\lim_{x\to\infty} f(x)$
$\sqrt{x}$	`\sqrt{x}`	`\sqrt{x}`	$\sqrt{x}$
$\frac{x}{y}$	`\frac{x}{y}`	`\frac{x-x_1}{y-y_1}`	$\frac{x-x_1}{y-y_1}$
$\geq$	`\geq`	`x \geq y`	$x \geq y$
$\leq$	`\leq`	`x \leq y`	$x \leq y$
α	`\alpha`	`\alpha + \beta = 1`	$\alpha + \beta = 1$
Δ	`\Delta`	`\Delta y`	Δy
$\land$	`\land`	`P \land Q`	$P \land Q$
$\lor$	`\lor`	`P \lor Q`	$P \lor Q$
$\neg$	`\neg`	`\neg P`	$\neg P$
$\subset$	`\subset`	`A \subset B`	$A \subset B$
$\subseteq$	`\subseteq`	`A \subseteq B`	$A \subseteq B$
$\supseteq$	`\supseteq`	`B \supseteq A`	$B \supseteq A$
$\not\subseteq$	`\not\subseteq`	`A \not\subseteq B`	$A \not\subseteq B$
$\forall$	`\forall`	`\forall x \in X, P(x)`	$\forall x \in X, P(x)$
$\exists$	`\exists`	`\exists x \in X, P(x)`	$\exists x \in X, P(x)$
$\exists!$	`\exists!`	`\exists! x \in X, P(x)`	$\exists! x \in X, P(x)$
$\emptyset$	`\emptyset`	`A = \emptyset`	$A = \emptyset$
$\cup$	`\cup`	`A \cup B`	$A \cup B$
$\cap$	`\cap`	`A \cap B`	$A \cap B$
$\times$	`\times`	`A \times B`	$A \times B$
$\in$	`\in`	`x \in A`	$x \in A$
$\notin$	`\notin`	`x \notin A`	$x \notin A$
$\Rightarrow$	`\Rightarrow`	`P \Rightarrow Q`	$P \Rightarrow Q$
$\Leftrightarrow$	`\Leftrightarrow`	`P \Leftrightarrow Q`	$P \Leftrightarrow Q$
$\rightarrow$	`\rightarrow`	`f: A \rightarrow B`	$f: A \rightarrow B$
$\mapsto$	`\mapsto`	`x \mapsto f(x)`	$x \mapsto f(x)$
$\mid$	`\mid`	`\{x \mid P(x)\}`	$\{x \mid P(x)\}$
$\mathcal{P}$	`\mathcal{P}`	`\mathcal{P}(A)`	$\mathcal{P}(A)$
$\overline{A}$	`\overline{A}`	`A - \overline{A}`	$A - \overline{A}$
$\binom{n}{k}$	`\binom{n}{k}`	`\binom{n}{k}}`	$\binom{n}{k}$
$\circ$	`\circ`	`f \circ g`	$f \circ g$
$\langle ... \rangle$	`\langle...\rangle`	`\langle 1, 2, 3\rangle`	$\langle 1, 2, 3\rangle$