LaTeX Workshop 2: Mathematics

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Today's workshop will introduce you to advanced math commands. We'll quickly cover new commands, then barrage you with exercises so that you can practice what you've learned.

Many of these commands are not built into LaTeX and will only work if the right package is loaded. The packages we'll require today are `amsmath`, `amssymb`, and `amsthm`. To load these packages, add the following line of text to the preamble of your document:

```
\usepackage{amsmath, amssymb, amsthm}
```

For a more extensive description of LaTeX's mathematical capabilities, see the LaTeX Wikibook at `en.wikibooks.org/wiki/LaTeX`.[1]

1 Aligned Objects: Matrices and `cases`

Last time we saw that LaTeX has environments for making aligned equations, the `align` and `align*` environments. In this section we'll describe two other types of aligned environments in LaTeX, for making matrices and for making case-by-case definitions.

$$\begin{pmatrix} \lambda_1 & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \lambda_n \end{pmatrix} \qquad f(x) = \begin{cases} 1, & \text{if } x \in \mathbb{Q}, \\ 0, & \text{if } x \in \mathbb{R} \setminus \mathbb{Q}. \end{cases}$$

1.1 Matrices

Here is an example of a matrix made with LaTeX.

[1] If we haven't said so already, the LaTeX Wikibook is an excellent source of information about LaTeX.

```
\[
\begin{pmatrix}
a & b\\
c & d
\end{pmatrix}
\]
```

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix}$$

What does this syntax mean? Every time LaTeX sees `&` it advances to the next column, and every time LaTeX sees `\\` it advances to a new row. The environment `pmatrix` makes matrices enclosed in parentheses. Other matrix environments include `matrix` (no parentheses), `bmatrix` (for `[ ]`), and `vmatrix` (for `| |`).

1.1.1 Dots

Typesetting an $n \times n$ matrix requires vertical, horizontal, and downward-sloped ellipses, as in the example at the beginning of this section.

`\ldots`	`\cdots`	`\vdots`	`\ddots`
$\ldots$	$\cdots$	$\vdots$	$\ddots$

The distinction between `\ldots` and `\cdots` is subtle: `\ldots` aligns the ellipsis with the bottom of the text while `\cdots` centers the ellipsis. Typographical style considerations dictate which of the two commands to use. For matrices and binary operations, use `\cdots`. For lists, use `\ldots`.

`x_1,\,x_2,\,\ldots,\,x_n`	`x_1 + x_2 + \cdots + x_n`
$x_1, x_2, \ldots, x_n$	$x_1 + x_2 + \cdots + x_n$

The command `\,` adds a little space after each comma. We'll talk more about it later.

1.2 `cases`

Here is an example of a case-by-case definition, written in LaTeX.

```
\[
|x| =
\begin{cases}
\phantom{-}x,
 & \text{if } x\geq 0,\\
-x, & \text{if } x<0.
\end{cases}
\]
```

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

If you understand matrices you should understand the `cases` environment perfectly well: syntactically, the `cases` environment is a matrix that has exactly two rows.

A few other commands require explanation here. The command `\phantom{-}` adds an invisible $-$ to make the spacing come out right. (Try removing `\phantom{-}`

and see what comes out.) The command `\text{...}` typesets its argument as regular text. Why did we add a space after `if`?

2 Accents and Font Styles in Math Mode

Some formulas require accents or special font styles. For example, mathematicians often indicate that the variable v stands for a vector by bolding it – like $\mathbf{v}$ – or by putting an arrow over it – like $\vec{v}$. The table below gives common accents and styles.

`\mathbf{v}`	`\mathbb C`	`\mathcal S`	`\mathfrak B`
$\mathbf{v}$	$\mathbb{C}$	$\mathcal{S}$	$\mathfrak{B}$
`\dot y`	`\ddot y`	`\overline{a+b}`	`\vec v`
$\dot{y}$	$\ddot{y}$	$\overline{a+b}$	$\vec{v}$
`\hat x`	`\widehat{x+y}`	`\tilde x`	`\widetilde{x+y}`
$\hat{x}$	$\widehat{x+y}$	$\tilde{x}$	$\widetilde{x+y}$

3 Spacing

LaTeX allows fine control over spacing in math mode.

`\!`	`\,`	`\>`	`\;`	`\quad`	`\qquad`	`\phantom{a+b}`
$\!$	$\,$	$\>$	$\;$	$\quad$	$\qquad$	

The command `\!` adds *negative* space. Use it if LaTeX adds too much space to your formula and you want to tighten it.

`x^2/2`	$x^2/2$
`x^2\!/2`	$x^2\!/2$

The command `\phantom{ }` adds as much white space as its argument takes up. We already encountered it in the section on the `cases` environment.

Most of the spacing changes you'll make with these commands are subtle, yet mark the difference between nice math and ugly math. The more time you spend typing math and reading it, the better an eye you'll develop for these sorts of spacing questions. In the meantime, we recommend placing `\,` before dx in integrals. Compare an integral with `\,` with one without it.

`\int_0^1 f(x)g(x)dx`	$\int_0^1 f(x)g(x)dx$
`\int_0^1 f(x)g(x)\,dx`	$\int_0^1 f(x)g(x)\,dx$

4 Equation Numbering

It is often useful to number equations that are particularly important so that they may be referred to later.

```
\begin{equation}
x^n + y^n \neq z^n
\label{fermat}
\end{equation}
```

$$x^n + y^n \neq z^n \tag{1}$$

The command `\label{fermat}` tells LaTeX that the name of the equation is `fermat`. We can reference it in the text using the command `\eqref`.

```
I proved \eqref{fermat},
but the margin
was too small
to contain it.
```

I proved (1), but the margin was too small to contain it.

To number a series of aligned equations, use the `align` environment. If you do not want to number a specific line in a series of aligned equations, place the command `\nonumber` on that line.

```
\begin{align}
z^n &= x^n + y^n
\nonumber\\
&\neq (x+y)^n
\end{align}
```

$$\begin{aligned} z^n &= x^n + y^n \\ &\neq (x+y)^n \end{aligned} \tag{2}$$

5 Delimiters

Some expressions are so large that placing them in standard-size parentheses would look awful, like the following.

```
\[
(\int_0^1 f(x)\,dx)^2
\]
```

$$(\int_0^1 f(x)\,dx)^2$$

To make the sizes come out right, use `\left` before the left parenthesis and `\right` before the right parenthesis.

```
\[
\left(\int_0^1 f(x)\,dx\right)^2
\]
```

$$\left(\int_0^1 f(x)\,dx\right)^2$$

The `\left` and `\right` commands also work for other delimiters.

```
\[
\left\|\frac{x}{y}\right\|
\]
```

$$\left\|\frac{x}{y}\right\|$$

6 Making Math Operators

LaTeX comes with pre-defined commands for the most commonly used math operators, such as log and sin. But sometimes you may need to use an operator that has not already been defined. The proper way to do this is with the `\operatorname` command.

```
The subspace $A = \operatorname{span}\{x_1,x_2\}$
```

The subspace $A = \operatorname{span}\{x_1, x_2\}$

7 Theorem Environments

Professional mathematics publications often separate theorems, definitions, and other important information from the text, like so.

Theorem 1. *If $n \geq 3$, the equation $x^n + y^n = z^n$ has no integer solutions.*

Doing this in LaTeX requires the `amsthm` package, which you should have already loaded. To make a theorem, you have to first tell `amsthm` to define a new environment. The command to use is `\newtheorem`, which takes two arguments. The first is the name of the new environment, and the second is what should be displayed. For instance, placing `\newtheorem{theorem}{Theorem}` in the preamble allows us to make a theorem using the newly defined `theorem` environment.

```
\newtheorem{theorem}{Theorem}
...
\begin{theorem}
Every finite $p$-group
has nontrivial center.
\end{theorem}
```

Theorem 2. *Every finite p-group has nontrivial center.*

To prevent LaTeX from numbering the environment, use the `\newtheorem*` command.

```
\newtheorem*{proposition}{Proposition}
...
\begin{proposition}
Every finite $p$-group
has nontrivial center.
\end{proposition}
```

Proposition. *Every finite p-group has nontrivial center.*

Every environment that is created in this way takes an *optional argument*. We haven't talked about optional arguments so far, but the basic concept is very simple. An optional argument for a command, if there is one, must be placed in square brackets `[ ]`. For example, the square root command `\sqrt` takes an optional argument indicating the degree of the radical.

`\sqrt[n]{x^2+1}` $\sqrt[n]{x^2+1}$.

The optional argument for an `amsthm` environment indicates text to be placed in parentheses.

```
\begin{theorem}[Feit-Thompson]
Every group
of odd order
is solvable.
\end{theorem}
```

Theorem 3 (Feit-Thompson)**.** *Every group of odd order is solvable.*

7.1 Proofs

The `amsthm` package does come with one environment predefined, the `proof` environment, which does just what you expect.

```
\begin{proof}
A trivial exercise
for the reader.
\end{proof}
```

Proof. A trivial exercise for the reader. □

If you end a proof with a displayed equation, the Halmos box[2] may not go in the right position. To place it in a specific spot, use the command `\qedhere`.

```
\begin{proof}
Just observe that
\[
1 + 1 = 2.
\]
\end{proof}
```

Proof. Just observe that

$$1 + 1 = 2.$$

□

```
\begin{proof}
Just observe that
\[
1 + 1 = 2.
\qedhere
\]
\end{proof}
```

Proof. Just observe that

$$1 + 1 = 2. \qquad \square$$

7.2 Theorem Styles

There are three possible styles for environment defined using `amsthm`: namely `plain` (the default), `definition`, and `remark`. To specify a style, group `\newtheorem` commands into blocks according to the style you would like them to have, then place `\theoremstyle{<style>}` before each block. For instance, part of your preamble might look like

```
\theoremstyle{theorem}
\newtheorem{theorem}{Theorem}
\newtheorem{proposition}{Proposition}
\newtheorem{lemma}{Lemma}

\theoremstyle{definition}
\newtheorem{definition}{Definition}
\newtheorem{exercise}{Exercise}

\theoremstyle{remark}
\newtheorem*{remark}{Remark}
```

[2] The Halmos box is the symbol □.