A brisk introduction to LaTeX

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Being able to type up your mathematical writing is a beneficial skill to have. Unfortunately, most Office-style WYSIWYG ('what you see is what you get') text editors are not designed for this task—they just can't cope with all the notation. A typical mathematical paper will contain so many mathematical symbols that using graphical methods is unrealistic.

LaTeX[1] is a markup language that allows you to input both text and mathematical notation. Formatting and mathematical notation are input by typing code, and LaTeX process the code to produce beautifully typeset documents.

It is the (unofficial) industry standard amongst mathematicians for writing journal articles, lecture notes, books, posters and presentations. It is not just used by mathematicians: it is one of the most-used methods of typesetting in academia, and being able to use LaTeX is a desirable skill for many jobs in industry.

Aside from this, typesetting mathematical work instills good practice: communicating a proof requires you to select the information you want to convey to the reader, and what information to leave out. Moving from pen(cil)-and-paper to typed up work breaks the habit of 'showing your work', in favour of 'communicating an argument'.

What follows is a brisk introduction to LaTeX that should suffice for the purposes of this course.

1 Finding the software

There are several good LaTeX editors that you can install on your computer—I recommend Texmaker (`http://www.xm1math.net/texmaker/`) if you're new to it, because it's cross-platform and fairly intuitive.

There are also online editors that you can use if you want to avoid installing new software; I highly recommend ShareLaTeX (`http://www.sharelatex.com`), which is free to use and stores your `.tex` files on the cloud.

There is some faffing around to be done with document headers and so on. So that you can avoid this, I've uploaded template `.tex` files to Blackboard that you can use in your homework write-ups.

[1] The word LaTeX is pronounced like 'lay-tek' or 'lah-tek'; some people pronounce the 'k' like the German 'ch' sound, meant to resemble the Greek letter chi (χ). It doesn't really matter, but if you pronounce it like 'lay-teks' then people will think you're talking about something somewhat different.

2 Text mode and math mode

Before we get into the nitty-gritty, I should mention the difference between 'text mode' and 'math mode'.

- **Text mode** is the default mode: the stuff you type will appear as text, and this is the mode you should use when writing anything that isn't mathematical notation.
- You should use **math mode** when you're typing anything which is mathematical notation, including variables, numbers, fractions, square roots, powers, sums, products, binomial coefficients, and so on.

To enter math mode, enclose whatever mathematical notation you are writing with dollar signs (`$`). For example, if I type `$E=mc^2$` then LaTeX shows $E = mc^2$. Sometimes it is convient to put longer expressions on their own line, in which case you can enclose it with double-dollar signs (`$$`); for example, if I type `$$a^2+b^2+c^2=ab+bc+ca$$` then LaTeX displays

$$a^2 + b^2 + c^2 = ab + bc + ca$$

on a line all of its own.

If you need to type text inside math mode (enclosed by `$` signs), you can do that using `\text{...}`, for example the code

```
$$\sum_{i=1}^n i = \frac{n(n+1)}{2} \text{ for all } n \in \mathbb{N}$$
```

gives

$$\sum_{i=1}^{n} i = \frac{n(n+1)}{2} \text{ for all } n \in \mathbb{N}$$

Note the spaces before and after 'for all'; had I left those out of the code, they would not appear because LaTeX ignores spacing in math mode. You can force a space by putting a backslash before a space, for example `$a b$` gives ab but `$a\ b$` gives $a\ b$.

All mathematical notation should be in math mode, including single variables. Notice the difference between the following two lines:

If a and b are both even then so is a+b.

If a and b are both even then so is $a + b$.

While the first is written entirely in text mode, the second is written using math mode for the variables and + sign.

3 Mathematical symbols

The following table lists—I hope—all of the mathematical symbols you will need in this course. If you come across other symbols, please let me know.

Logic		
conjunction, disjunction	$\wedge$, $\vee$	`\wedge`, `\vee`
negation	$\neg$	`\neg`
implication, biconditional	$\Rightarrow$, $\Leftrightarrow$	`\Rightarrow`, `\Leftrightarrow`
exclusive disjunction	$\oplus$	`\oplus`
true, false (in truth table)	$\checkmark$, $\times$	`\checkmark`, `\times`
quantifiers (universal, existential)	$\forall$, $\exists$	`\forall`, `\exists`
Set theory		
element, subset	$\in$, $\subseteq$	`\in`, `\subseteq`
not equal, proper subset	$\neq$, $\subsetneqq$	`\ne`, `\subsetneqq`
intersection, (indexed)	$\cap$, $\bigcap_{i=1}^{n}$	`\cap`, `\bigcap_{i=1}^{n}`
union, (indexed)	$\cup$, $\bigcup_{i=1}^{n}$	`\cup`, `\bigcup_{i=1}^{n}`
relative complement, complement	$X \setminus Y$, X^c	`\setminus`, `X^c`
product, (indexed)	$\times$, $\prod_{i=1}^{n}$	`\times`, `\prod_{i=1}^{n}`
implied lists	$\{1, \dots, n\}$	`\{ 1, \dots, n \}`
indexed sets	$\{x_i \mid i \in I\}$	`\{ x_i \mid i \in I \}`
set-builder notation	$\{x \mid p(x)\}$	`\{ x \mid p(x) \}`
empty, universal set	$\varnothing$, $\mathcal{U}$	`\varnothing`, `\mathcal{U}`
number sets	$\mathbb{N}, \mathbb{Z}, \mathbb{Q}, \mathbb{R}$	`\mathbb{N}`, `\mathbb{Z}`, etc.
Numbers and combinatorics		
multiplication	$m \times n$, $m \cdot n$	`\times`, `\cdot`
fractions, exponents	$\frac{m}{n}$, m^n	`\frac{m}{n}`, `m^{n}`
order relations	$\leq$, $\geq$	`\le`, `\ge`
divisibility, (non-)	$m \mid n$, $m \nmid n$	`\mid`, `\nmid`
binomial coefficient	$\binom{n}{k}$	`\binom{n}{k}`
indexed sum, product	$\sum_{i=1}^{n} a_i$, $\prod_{i=1}^{n} a_i$	`\sum_{i=1}^{n} a_i`, `\prod_{i=1}^{n} a_i`
modular arithmetic	$a \equiv b \bmod n$, $\not\equiv$	`a \equiv b \bmod{n}`, `\not\equiv`
Functions and relations		
functions	$f : X \to Y$, $X \xrightarrow{f} Y$	`\to`, `X \xrightarrow{f} Y`
composition	$g \circ f$	`\circ`
isomorphism	$\cong$	`\cong`
equivalence relations	$\sim$, $\approx$	`\sim`, `\approx`
Structured sets		
order relation	$\preceq$, $\prec$	`\preceq`, `\prec`
group operations	$\cdot$, $\star$, $\circ$	`\cdot`, `\star`, `\circ`

4 Organisation and formatting

When typing up solutions to problem, organisation can be the difference between a masterpiece and an unreadable heap of notation. Here are some tips to help you organise your work:

Sections and paragraphs

You can split your work up into sections, subsections, subsubsections, and even subsubsubsections. To do this, use `\section{Section title}` or `\section*{Section title}`; the former includes a section number, and the latter omits it. To start a new paragraph, simply make two new lines in the code.

Bulleted and enumerated lists

Sometimes it is useful to use bullet points or give an enumerated list. For example, in these notes, I separate the base case from the induction step in proofs by induction by using bullet points.

For a bulleted list you can use the `itemize` environment:

```
\begin{itemize}
\item Something here\dots
\item You can do lists within lists:
  \begin{itemize}
  \item Like this.
  \item Isn't it crazy!
  \end{itemize}
\item Well, not that crazy.
\end{itemize}
```

- Something here...
- You can do lists within lists:
  - Like this.
  - Isn't it crazy!
- Well, not that crazy.

For an enumerated list, you can use the `enumerate` environment. You can play around with different methods of enumeration, which you specify in square brackets `[...]`; personally I like `(1)`, `(i)` and `(a)` the best:

```
\begin{enumerate}[(a)]
\item Here's the first thing;
\item Here's the second thing;
\item And here's the third thing.
\end{enumerate}
```

(a) Here's the first thing;

(b) Here's the second thing;

(c) And here's the third thing.

Definitions, results and proofs

If you use the provided templates, you can make definitions, and state and prove results, using the following environments:

`definition`, `example`, `proposition`, `theorem`, `lemma`, `corollary`, `proof`

They are given a number **m.n**, where m is the section number and n is the position within the section.

Here's an example of a theorem appearing in the third section of a document, in which five definitions, results or examples come before it:

```
\begin{theorem}
If $n \in \mathbb{N}$ then $n \ge 0$.
\end{theorem}

\begin{proof}
This is really obvious.
\end{proof}
```

Theorem 3.6. If $n \in \mathbb{N}$ then $n \geq 0$.
Proof. This is really obvious. □

Note that the box (□) designating the end of the proof is inserted automatically when you close the `proof` environment.

Labels

As you change the contents of a document, the numbering of the definitions, examples and results might change. To refer to a specific result, instead of typing the number and having to change it each time the number changes, you can use the `\label` and `\ref` commands.

An example of this in action is as follows:

```
\begin{definition}
\label{defDivides}
Say $a$ \textbf{divides} $b$ if there
exists $k \in \mathbb{Z}$ such that
$ka=b$.
\end{definition}

We will use Definition \ref{defDivides}
for absolutely nothing.
```

Definition 2.11. Say a **divides** b if there exists $k \in \mathbb{Z}$ such that $ka = b$.

We will use Definition 2.11 for absolutely nothing.

Formatting

In text mode. To put the icing on the cake, you might want to make some words **bold** or *italicised*. This is simple: for bold text type `\textbf{text here}` and for italic text type `\textit{text here}`. In Texmaker and ShareLaTeX you can press `Ctrl+B` and `Ctrl+I` to avoid having to type all this out. Other useful fonts include `monospace` (`\texttt{text here}`), sans-serif (`\textsf{text here}`) and underlined (`\underline{text here}`).

In math mode. There are also various fonts or font styles that you can use inside math mode, including:

- Roman (i.e. not italic): AaBbCc, `\mathrm{AaBbCc}`;
- Bold: $\mathbf{AaBbCc}$, `\mathbf{AaBbCc}`;
- Sans-serif: AaBbCc, `\mathsf{AaBbCc}`;
- Blackboard bold: $\mathbb{ABCDE}$, `\mathbb{ABCDE}` — only capital letters;
- Fraktur: $\mathfrak{AaBbCc}$, `\mathfrak{AaBbCc}`;
- Calligraphic: $\mathcal{ABCDE}$, `\mathcal{ABCDE}` — only capital letters;

Tables

Tables can be created using the `tabular` environment. You can specify how columns are aligned and separated as an argument to the command `\begin{tabular}`: write `l`, `c` or `r` to specify that a column should be aligned left, centre or right, respectively. If you want columns to be separated by a single or double line, enter a single or double bar (`|` or `||`), respectively.

Columns are then separated by ampersands (`&`) and you can move to a new row by entering a double-backslash (`\\`). To insert a horizontal line between two rows, simply enter `\hline`.

Here's an example:

```
\begin{tabular}{c||ccc}
$\times$ & 1 & 2 & 3 \\ \hline \hline
1 & 1 & 2 & 3 \\
2 & 2 & 4 & 6 \\
3 & 3 & 6 & 9 \\
\end{tabular}
```

$\times$	1	2	3
1	1	2	3
2	2	4	6
3	3	6	9

Aligned equations

Occasionally a proof may require you to demonstrate that two terms are equal by proving a sequence of intermediate equations. This can be done using the `align*` environment, which behaves much like the `tabular` environment.

New lines are introduced by inserting a double-backslash (`\\`), and the two columns are separated by an ampersand (`&`). The left column is aligned right, and the right column is aligned left. Here's an example:

```
\begin{align*}
(n+1)!  - n!  & = (n+1)n!  - n!  \\
 & = n \cdot n!  + n!  - n!  \\
 & = n \cdot n!
\end{align*}
```

$$\begin{aligned}(n+1)! - n! &= (n+1)n! - n! \\ &= n \cdot n! + n! - n! \\ &= n \cdot n!\end{aligned}$$

Note that the `align*` environment automatically enters into math mode, so to enter text you should use the `\text` command.

Entering more ampersands will create more columns, whose alignment alternates (right, left, right, left, and so on). For example, to add annotations to each line, you can enter a double-ampersand (`&&`). For example, the following code...

```
\begin{align*}
(n+1)! - n! & = (n+1)n! - n! && \text{by recursive def of factorials} \\
 & = n \cdot n! + n! - n! && \text{by distributivity} \\
 & = n \cdot n! && \text{by cancellation}
\end{align*}
```

...yields the following output:

$$\begin{aligned}(n+1)! - n! &= (n+1)n! - n! && \text{by recursive def of factorials} \\ &= n \cdot n! + n! - n! && \text{by distributivity} \\ &= n \cdot n! && \text{by cancellation}\end{aligned}$$

Note again that, because the `align*` environment automatically enters math mode, any annotations must be made within the `\text` command.

Graphics

To insert graphics into your documents, you need to make sure that the code `\usepackage{graphicx}` is somewhere in the document header, i.e. above the line that says `\begin{document}`.

Images can then be inserted using the `\includegraphics` command. The format is

```
\includegraphics[parameters]{filename}
```

where, in the above, `parameters` denotes information telling LaTeX how large you want the image to be, and `filename` is the name of the image file, which...

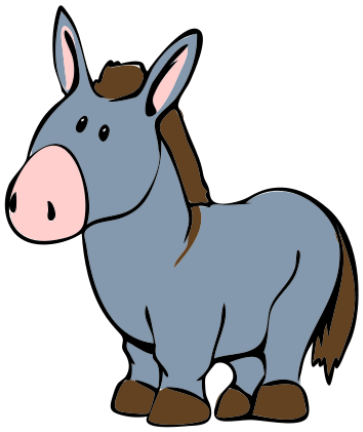
- ...excludes the extension, for example '`donkey`' instead of '`donkey.png`';
- ...includes the path relative to the main .tex file, for example if *donkey.png* is stored in a directory called *images*, you would enter '`images/donkey`' instead of '`donkey`'.

The simplest way to control the size of the image is to enter `[width=k\textwidth]`, where `k` is a scaling factor between 0 and 1.

For example, the following code:

```
\begin{center}
\includegraphics[width=0.3\textwidth]{donkey}
\end{center}
```

yields the following output:



5 Practice page

Use the provided LaTeX template `template.tex` to re-create the following page:

Squarefree integers

Carl Friedrich Gauss, Wednesday 14th September 1831

Introduction

When you've written this page, you will be unstoppable, at least as far as typesetting mathematics is concerned. You will need to implement:

- Text mode stuff: sections, paragraphs, text formatting, labels and references, lists;
- Math mode stuff: definitions and results, aligned equations, etc.

So let's get on with it!

1 Squarefree integers

1.1 Definition and an elementary result

Definition 1.1. An integer a is **squarefree** if it is divisible by no perfect square other than 1. That is, if n^2 divides a then $n^2 = 1$.

Proposition 1.2. A non-zero non-unit a is squarefree if and only if

$$a = p_1 \times p_2 \times \cdots \times p_n$$

for distinct primes $p_1, p_2, \ldots, p_n$.

Proof. We leave the proof as an exercise to the reader. □

1.2 Some examples

Example 1.3. Some concrete examples include:

(i) 5610 is squarefree by Proposition 1.2, since

$$\begin{aligned} 5610 &= 10 \times 561 \\ &= (2 \times 5) \times (11 \times 17) \end{aligned}$$

(ii) 12 is not squarefree since $4 \mid 12$ and $4 = 2^2$.

1

6 More advanced techniques

I should take a moment to emphasise that what matters in this course is your ability to communicate mathematical arguments clearly and correctly. The LaTeX tools discussed so far in this section are more than sufficient for the purposes of this course.

However, if you are interested in pushing your LaTeX skills further or there is a feature you're unsure about how to implement, then I recommend browsing or searching one of the following websites:

- `http://tex.stackexchange.com` — Q&A website about LaTeX
- `https://en.wikibooks.org/wiki/LaTeX` — online LaTeX manual