An Introduction to LATEX: Typesetting your Thesis or Research Paper Part II: Maths, More Elements and Templates

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Today's Plan

- Maths
 - Some Basic Examples and Symbols
 - The $A_{\mathcal{M}}S$ Packages
 - Common Mistakes in Math Mode
 - $A_{\mathcal{M}}S$ Theorems
 - How to Find Symbols for Maths
- More Document Elements
 - Footnotes
 - Bibliographies
 - References and Links
- TikZ and Other Resources
 - TikZ
 - Templates and Resources



LATEX & Maths

LATEX supports two kinds of ways to write maths. The first is *in-line*, i.e., within the text, like $\ln x = \int_1^x \frac{dt}{t}$ for example, or as *displayed maths*, like

$$\ln x = \int_1^x \frac{dt}{t}.$$

- To type maths inline, we use dollar signs, so x+y=z becomes x+y=z. LATEX ensures that the spacing is correct, so it doesn't matter if we write x+y=z, the result is the same (although the code is less legible!).
- For displayed maths, we do $\[x+y=z\]$.

Inline and Displayed Maths

```
\begin{document}
   Suppose a right-angled triangle has side lengths $a$, $b$ and
   $c$. Then Pythagoras' theorem states that \[a^2+b^2=c^2,\]
   where $c$ is the longest side, i.e., the \emph{hypotenuse}.
\end{document}
```

Suppose a right-angled triangle has side lengths $a,\,b$ and c. Then Pythagoras' theorem states that

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

where c is the longest side, i.e., the *hypotenuse*.

Math Mode and Symbols

Most mathematical symbols correspond to commands whose names are quite natural. Most commands which are used in *math mode* (i.e., between \dots or \dots cannot be used in *normal mode* (i.e., among the text), and vice-versa. One should not use $\ensuremath{\mbox{emph}}$ or $\ensuremath{\mbox{textbf}}$ in math mode, for example.

Some examples of maths syntax:

$$\begin{array}{lll} & & & e^{i\eta} + 1 = 0 & & e^{i\pi} + 1 = 0 \\ & & & \alpha + \beta = \frac{-b}{2a} & & \alpha + \beta = \frac{-b}{2a} \\ & & a_n = a_{n-1} + a_{n-2} & & a_n = a_{n+1} + a_{n+2} \\ & & \sum_{n=1}^{\infty} \frac{1}{n^s} & & \end{array}$$

More Examples

$$(A \land Cap \mathcal B) \land C \qquad (A \cap \mathcal{B}) \times C$$

$$\prod_p \land (1 - frac1\{p^s\} \land f-1\} \qquad \prod_p \left(1 - \frac{1}{p^s}\right)^{-1}$$

$$\mathbf \ x = (x, y, z) \qquad \mathbf{x} = (x, y, z)$$

$$f \land b \qquad \qquad f: A \to B$$

$$\nabla f \land f: A \to B$$

The American Mathematical Society $(A_{\mathcal{M}}S)$ Packages

The AMS provides the packages (\usepackage) amsmath for maths environments, amssymb for extra maths symbols and fonts, and amsthm for having numbered theorems (theorem 1, remark 2, etc.).

Some common uses of amssymb are the blackboard (\mathbb) and Fraktur (\mathfrak) fonts.

```
\mathbb R \setminus \mathbb Z \mathbb{R} \setminus \mathbb{Z} \mathfrak {AaBbCc} \mathfrak{AaBbCc}
```

amsmath provides the \text command, e.g.

```
2\mathbb Z = \{x\in\mathbb Z : \text{$x$ is even}} produces 2\mathbb{Z} = \{x \in \mathbb{Z} : x \text{ is even}\}.
```

Other math mode environments

The equation environment produces numbered equations, which we will use later.

```
We have
\begin{equation}
   \frac1{2\pi i}\int_\gamma
   z^n\,dz = 0,
\end{equation}
for $n\neq -1$.
```

```
We have \frac{1}{2\pi i} \int_{\gamma} z^n dz = 0, \qquad (1) for n \neq -1.
```

amsmath also provides the gather and align environments.

Other math mode environments

amsmath also provides the gather and align environments.

```
\begin{gather}
   x^2 - 3 = 0 
   \implies x^2 = 3 \
   \implies x = \pm \sqrt 3
\end{gather}
```

$$x^2 - 3 = 0 \tag{1}$$

$$\implies x^2 = 3 \tag{2}$$

$$\implies x = \pm \sqrt{3} \tag{3}$$

If you don't want numbering, use the gather* and align* environments instead.

Other math mode environments

amsmath also provides the gather and align environments.

```
\begin{align}
    x^2(x^2+x+1)(x+2) k = x^2(x^3+x^2+x+2x^2+2x+2) 
                       \&= x^2(x^3+3x^2+3x+2) \
                       k = x^5 + 3x^4 + 3x^3 + 2x^2
\end{align}
```

$$x^{2}(x^{2}+x+1)(x+2) = x^{2}(x^{3}+x^{2}+x+2x^{2}+2x+2)$$
 (1)

$$= x^2(x^3 + 3x^2 + 3x + 2) (2)$$

$$= x^5 + 3x^4 + 3x^3 + 2x^2 \tag{3}$$

If you don't want the line numbering, use the gather* and align* environments instead.

- Never use math mode as a substitute for emphasised or italic text! Surely you can tell the difference/difference between them!
- Use the appropriate commands for mathematical functions like sine, logarithms, etc., $\sin x$ gives $\sin x$, $\sin x$ gives $\sin x$. If your function has no corresponding command, you can use amsmath's \operatorname, e.g., $\operatorname{command}(a,b)$ gives $\operatorname{hcf}(a,b)$.
- In integrals, use the half-space command \, between the integrand and differentials, e.g.

\int\sin x dx
$$\int \sin x dx$$
 X \int\sin x\,dx $\int \sin x dx$ \iff

Similarly, we do \$100\,\mathrm{cm}\$ or simply 100\,cm in normal mode to get $100\,\mathrm{cm}$.

• To show the type of a function, use the \colon command, not a literal:, the latter is for ratios.

g:A\to B
$$g:A \to B$$
 X $g \cdot Colon A \cdot Colon B \cdot Colon A \cdot Colon B \cdot$

 Displayed maths should be read just as if it is inline, so punctuation and appropriate capitalisation is important there too. E.g.:

If we consider the equation

$$x + 1 = 2$$
.

 $\underline{\mathbf{s}}$ ubtracting 1 from both sides allows us to conclude that

$$x = 1$$
.

Consider the equation:

$$x + 1 = 2$$

<u>Subtracting</u> 1 from both sides allows us to conclude that:

$$x = 1$$



For vector norms, use \| and not two | characters:

Similarly, for inner-products or other angle brackets, use \langle and \rangle, not < and > (which are only for inequalities).

<\mathbf x, y >
$$< x,y >$$
 \\langle x,y\rangle $< x,y >$ \\rangle

 Know the difference between big operators and the smaller infix counterparts. For example, the union of multiple sets $\bigcup_{i=1}^n A_i$ uses \bigcup, whereas $A \cup B$ simply uses \cup. Switching them gives ugly results like $\bigcup_{i=1}^{n} A_i$ and $A \bigcup B$. Similarly, $\backslash \text{Sigma}(\Sigma)$ and $\backslash \text{Pi}(\Pi)$ should not be confused with $\backslash \text{sum}$ (\sum) and $\operatorname{prod}(\prod)$.

 If you want to subscript something with a word/text, make sure you use \text or \mathrm.

\sigma_{normal}
$$\sigma_{normal}$$
 \ \sigma_\mathrm{normal} σ_{normal} \ \sigma_

• Some people discover the \displaystyle command and use it to type maths in text! This ruins the line spacing, LATEX has two different math modes for a reason. In text, sums should look like $\sum_{k=0}^{\infty} \frac{x^k}{k!} \text{ and not } \sum_{k=0}^{\infty} \frac{x^k}{k!}, \text{ which as you can clearly see, has made the paragraph look very ugly. Same goes for integrals, fractions, etc.}$

Theorem Environments

The amsthm package is useful for theorem—proof type documents. If you include it, you can then define various environments such as the theorem environment, lemma, and so on, but you do have to define these yourself in the preamble, i.e., before \begin{document}.

My personal set up would usually looks something like this:

```
% AMS Theorem Environments
\theoremstyle{plain}
\newtheorem{theorem}{Theorem}[section]
\newtheorem{lemma}[theorem]{Lemma}
\newtheorem{prop}[theorem]{Proposition}
\theoremstyle{definition}
\newtheorem{definition}[theorem]{Definition}
\newtheorem*{notation}{Notation}
\theoremstyle{remark}
\newtheorem{remark}[theorem]{Remark}
```

An Example

```
\section{First Proof of Vinogradow's Theorem}
\begin{notation}
   We write f(x)=O(g(x)), or equivalently, f(x)\l g(x),
   to denote the fact that for some constant $C>0$,
   f(x) \mid c c g(x)  for all x under consideration;
   usually for all $x$ larger than some fixed constant.
\end{notation}
\begin{definition} [von Mangoldt Function]
   Let n\in \mathbb{N}. Then the emph{von Mangoldt function}
   $\Lambda\colon\mathbb N\to\mathbb R$ is defined by
   \Lambda(n)=\log p\ if n=p^k for some prime p\ and
   non-negative integer $k$, and $\Lambda(n)=0$ otherwise.
\end{definition}
\begin{theorem} [Vinogradow, 1937]
   Let $A>0$ be fixed. Then
```

An Example

\section{First Proof of Vinogra \begin{notation}

We write f(x)=0(g(x)), or to denote the fact that for $f(x) \leq C g(x)$ for all usually for all \$x\$ larger

\end{notation}

\begin{definition} [von Mangoldt Let \$n\in\mathbb N\$. Then t \$\Lambda\colon\mathbb N\to\ $\Lambda(n)=\log p$ if n=p

non-negative integer \$k\$, a

\end{definition}

\begin{theorem}[Vinogradow, 193 Let \$A>0\$ be fixed. Then

First Proof of Vinogradow's Theorem

Notation. We write f(x) = O(g(x)), or equivalently $f(x) \ll g(x)$, to denote the fact that for some C > 0, $|f(x)| \le C g(x)$ for all x under consideration; usually for all x larger than some fixed constant.

Definition 1.1 (von Mangoldt Function). Let $n \in \mathbb{N}$. Then the von Mangoldt function $\Lambda : \mathbb{N} \to \mathbb{R}$ is defined by $\Lambda(n) = \log p$ if $n = p^k$ for some prime p and non-negative integer k, and $\Lambda(n) = 0$ otherwise.

Theorem 1.2 (Vinogradow, 1937), Let A > 0 be fixed. Then

$$\sum_{n_1+n_2+n_3=N} \Lambda(n_1) \Lambda(n_2) \Lambda(n_3) \sim \frac{N^2}{2} \mathfrak{S}(N),$$

where $\mathfrak{S}(N) = \prod_{p|N} \left(1 - \frac{1}{(p-1)^2}\right) \prod_{p\nmid N} \left(1 + \frac{1}{(p-1)^3}\right)$.

Proof. Assume the Generalised Riemann Hypothesis and apply Hardy-Littlewood's circle method.

Remark 1.3. Observe that as a consequence, every sufficiently large odd number can be written as a sum of three primes.

Proof without assuming GRH

This is harder. First we need to prove the following result.

Lemma 2.1. Let $\alpha \in [0,1]$ and consider a rational approximation a/qof α (i.e., $|\alpha - \frac{a}{a}| \le \frac{1}{a^2}$ and hcf(a, q) = 1). Then

$$\sum_{n \leq N} \Lambda(n) \, e^{2\pi i n \alpha} \ll (Nq^{-1/2} + N^{4/5} + N^{1/2}q^{1/2}) \log^4 N.$$

Some observations

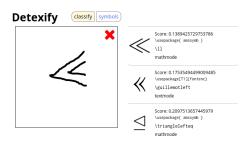
- The counter resets after a new section because the definition of theorem was given the optional [section] argument (alternatively you can do chapter, subsection, etc.)
- The other environments made use of the same counter as theorem because they were all given the [theorem] argument. If we did not do this, then they will be numbered independently.
- The notation environment has no numbering, since we used the \newtheorem* command. Sometimes it's common to have, say, both a theorem environment and a theorem* environment, so if you want you can have both numbered and non-numbered theorems:

```
\newtheorem{theorem}{Theorem}[section]
\newtheorem*{theorem*}{Theorem}
```

How to find symbols

There are thousands of maths symbols available, so it would be pointless trying to list them all, you tend to pick up the appropriate commands for them as you go along.

A good resource for finding maths symbols is an app called DeT_EXify. You can access this online at detexify.kirelabs.org, or download the mobile app. This allows you to draw the symbol you want, and find the best match.



Enough maths—on to other elements of a LATEX document!

Maths

These are quite easy, you simply use the \footnote command.

This is a sentence in the main text.\footnote{On the other hand, this is a footnote.}

This is a sentence in the main text 1 ¹On the other hand, this is a footnote.

A common mistake is to place a footnote marker before a punctuation mark (e.g. to have ¹. instead of .¹). In general, **footnotes go after** punctuation marks.

LATEX has an inbuilt thebibliography environment, which is okay, but you have to worry about the way the bibliography appears.

```
The circle method was first applied to the ternary Goldbach
problem by Hardy--Littlewood in \cite{hardylittlewood23}.
Nowadays, a concise proof due to Vinogradow is found in
chapter 25 of \cite{davenport}.
\begin{thebibliography}{9}
    \bibitem{davenport} H.\ Davenport, Multiplicative Number
    Theory, 3rd edition, Springer--Verlag, 1995.
    \bibitem{hardylittlewood23} G.\ H.\ Hardy and L.\ E.\
    Littlewood, Some problems of `partito numerorum';
    \textsc{iii}: On the expression of a number as a sum of
    primes, Acta Mathematica 44, pp.\ 1--70, 1923.
\end{thebibliography}
```

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The circle method was first applied to the ternary Goldbach problem by Hardy--Littlewood in \cite{hardylittlewood23}. Nowadays, a concis chapter 25 of \cit \begin{thebibliogr \bibitem{daver Theory, 3rd ed \bibitem{hard Littlewood, So \textsc{iii}: primes, Acta N \end{thebibliogram

The circle method was first applied to the ternary Goldbach problem by Hardy-Littlewood in [2]. Nowadays, a concise proof due to Vinogradow is found in chapter 25 of [1].

References

- [1] H. Davenport, Multiplicative Number Theory, 3rd edition, Springer-Verlag, 1995.
- [2] G. H. Hardy and L. E. Littlewood, Some problems of 'partito numerorum'; III: On the expression of a number as a sum of primes, Acta Mathematica 44, pp. 1-70, 1923

The mandatory argument to the thebibliography environment is the width of the widest label. This is used to indent the bibliography items properly. Since in the example, our labels are of the form [1], [2], etc, we put 9 assuming we will not need more than two-digit labels ([1] up to [9]). If we had more than 10 but less than 100 items, we'd have put 99.

There is a better way to create bibliographies: using BibTEX.

Create a separate .bib file in the same directory as your .tex document, and place in it entries like this:

```
@book{davenport,
   author
             = {Davenport, H.},
   title
             = {Multiplicative Number Theory},
   edition = {third}.
   vear = \{1995\},
   publisher = {Springer--Verlag},
   pages = {145--171}
}
@article{hardylittlewood23,
             = {Hardy, G. H. and Littlewood, J. E.},
   author
             = {Some problems of `partito numerorum';
   title
                {\textsc{iii}}: On the expression of a
                number as a sum of primes},
             = {Acta Mathematica},
   journal
         = {1923},
   vear
   volume = \{44\}.
             = \{1--70\}
   pages
}
```

BibTEX

- Most times, these entries are available online, you can search for them
 on websites such as bibtexsearch.com, or if you find the paper
 online or on, say, Google Scholar, clicking a "cite" button somewhere
 on the page usually produces a BibTEX entry you can just paste into
 your file.
- If you create the entries manually, you can see what different entry types there are (book, article, phdthesis, etc.) and the appropriate entries for each one here: bibtex.com/e/entry-types/.
- Note that the way the authors are written is syntax, and not always the way they are displayed. If you have three or more authors, you still write "and" between each one. The syntax is

Surname1, Name1a Name1b and Surname2, Name2 and Surname3, Name3a Name3b Name3c and ...

Maths

- BibTFX also ignores capitalisation and other text decoration sometimes. If you want to enforce some formatting, wrap it in an extra curly bracket, e.g. writing {G}oldbach will ensure the G is capitalised.
- The green text in our example are the keys which, are placed in the \cite command similarly to when using the thebibliography environment.
- To actually produce the bibliography with BibT_FX, simply do \bibliography{filename} at the point in the document where you want the bibliography to appear, where filename.bib is the corresponding bib file.
 - Similarly to the table of contents, this produces auxiliary files, so you should compile twice to get the correct output.

With the file from before, we now have:

The circle method was first applied to the ternary Goldbach problem by Hardy--Littlewood in \cite{hardylittlewood23}. Nowadays, a concise proof due to Vinogradow is found in chapter 25 of \cite{davenport}.

```
\bibliographystyle{plain}
\bibliography{references}
```

Maths

With the file from before, we now have:

The circle method problem by Hardy Nowadays, a conc chapter 25 of \c

\bibliographysty \bibliography{re

The circle method was first applied to the tornary Coldbach

The circle method was first applied to the ternary Goldbach problem by Hardy–Littlewood in [2]. Nowadays, a concise proof due to Vinogradow is found in chapter 25 of [1].

References

- H. Davenport. Multiplicative Number Theory. Springer– Verlag, third edition, 1995.
- [2] G. H. Hardy and J. E. Littlewood. Some problems of 'partito numerorum'; III: On the expression of a number as a sum of primes. Acta Mathematica, 44:1–70, 1923.

With the file from before, we now have:

```
The circle method was first applied to the ternary Goldbach problem by Hardy--Littlewood in \cite{hardylittlewood23}.

Nowadays, a concise proof due to Vinogradow is found in chapter 25 of \cite{davenport}.

\bibliographystyle{plain}
\bibliography{references}
```

- Only the entries which are cited appear in the references. If the files contain additional entries and you want them to appear, do \nocite{*} before the \bibliography command.
- Try out other bibliography styles: acm, alpha, apalike, siam.

The Index

Maths

It is possible to create indices quite easily in LATEX, but we will not get into it in these slides.

```
Index
A^{\perp}, 16
                                          inner product, 3
C[a, b], 4, 13
                                              space, 3
L^{2}[a,b], see Lebesgue space
                                          isometric, 51
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dual space, 37
                                         operator norm, 35
                                         orthogonal, 16
```

You can see how here: en.wikibooks.org/wiki/LaTeX/Indexing

References

Imagine writing something like this:

"On page 16, in theorem 2.14, we used the illustration from figure 5 to adapt the idea of lemma 1.19 on page 10",

and then later on deciding to restructure parts of your documents, offsetting all the numbering. What a nightmare!

Luckily, environments like figure, table, the amsthm environments, as well as things like sections, etc., all support **labels**. These allow us to refer to items in a document using our labels, and that way, if we move anything around, the label is moved also.

- The command \label{label} creates a label.
- The command \ref{label} prints the number corresponding to the item with label label.
- The command \pageref{label} prints the page number where the item labelled label appears.

References

```
\section{Introduction}
In section \ref{sec:pyth} (page \pageref{sec:pyth}),
we shall see Pythagoras' theorem (theorem~
\ref{thm:pythagoras}). The philosopher Pythagoras is
illustrated in figure~\ref{fig:pythagoras}.
\section{Pythagoras' Theorem}
\label{sec:pvth}
\begin{theorem} [Pythagoras]
    \label{thm:pythagoras}
    In a right-angled triangle, $a^2+b^2=c^2$.
\end{theorem}
\begin{figure}
    \centering \includegraphics{pythagoras}
    \caption{The philosopher Pythagoras}
    \label{fig:pythagoras}
\end{figure}
```

References

Maths

\section{Intro In section \r we shall see \ref{thm:pyth: illustrated in \section{Pyth: \label{sec:pv \begin{theorem \label{thr

In a right \end{theorem} \begin{figure

\centering \caption{ \label{fi \end{figure}



Figure 1: The philosopher Pythagoras

1 Introduction

In section 2 (page 1), we shall see Pythagoras' theorem (theorem 2.1). The philosopher Pythagoras is illustrated in figure 1.

Pythagoras' Theorem

Theorem 2.1 (Pythagoras). In a right-angled triangle, $a^2 + b^2 = c^2$.

Maths

- Notice that the \label command in figures and tables must be used after the \caption{label} command, since that is the command which assigns a number to the figure/table.
- The use of ~ ensures a non-breaking space, e.g. Dr~Ebejer.
- It is possible to avoid having to type the corresponding word (e.g. "theorem \ref{thm:stokes}") and simply to do \cref{thm:stokes}, but this requires the use of the cleveref package.
- You can number equations using the equation environment illustrated earlier (also individual lines of the align/gather environments), label them as usual using the \label command, and refer to them using the \egref command provided by the amsmath package (\cref is fine too).

Links

Maths

The package hyperref allows you to have clickable hyperlinks in your PDF document. To use it, as usual, we do \usepackage{hyperref}.

- References to labels are automatically liked when hyperref is included.
- To link to a website, you do:

```
\href{https://url.com}{text to display}
```

To link an email address, you do:

```
\href{mailto:your@email.com}{text to display}
```

TikZ

A very useful package/tool is the tikz package. This allows you to draw diagrams, plots, graphs in a purely syntactic way. We will not get into it here, but here is a simple example (needs \usepackage{tikz}):

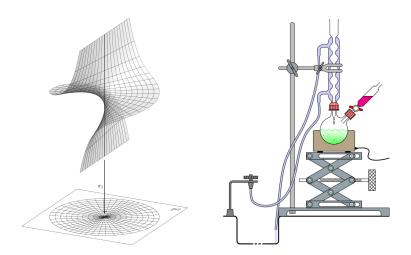
```
\begin{tikzpicture}
    \draw[red] (0,0) circle (0.5cm);
    \draw[blue] (-0.5,-0.5) -- (0.5, 0.5);
\end{tikzpicture}
```



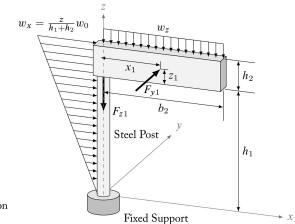
A more detailed introduction to TikZ can be found here: overleaf.com/learn/latex/TikZ_package

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TikZ Showcase



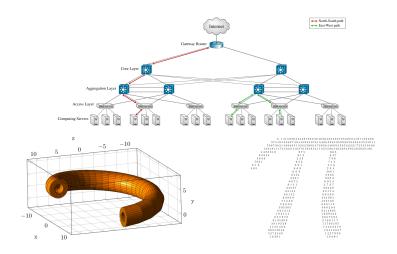
TikZ Showcase





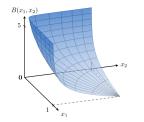
Signpost Cross Section

TikZ Showcase



TikZ Showcase







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Templates and other Resources

- There are multiple document templates for CVs, documents, posters, theses, etc., at:
 - LatexTemplates.com
 - ② Overleaf.com/LaTeX/templates
- A great resource is DeTEXify which we already mentioned, for finding math symbols: detexify.kirelabs.org
- The TEX Stack Exchange website is a great place to find answers to FAQ's, as well as to ask questions yourself: TeX.stackexchange.com
- A dissertation template for UM made by JP is available here:
 www.overleaf.com/latex/template/msc-or-phd dissertation-template-originally-for-the university-of-malta/xhnmbpvkmmqp

Thank you!



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Doctoral School University of Malta

