An Introduction to LaTeX: Typesetting your Thesis or Research Paper

Part II: Maths, More Elements and Templates

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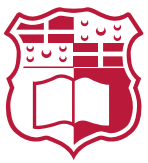

L-Università ta' Malta

Today's Plan

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 `$...$` or `\[...\]`) cannot be used in *normal mode* (i.e, among the text), and vice-versa. One should not use `\emph` or `\textbf` in math mode, for example.

Some examples of maths syntax:

```
e^{i\pi} + 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}
```
$$\sum_{n=1}^\infty \frac 1{n^s}$$

More Examples

```
(A\cap \mathcal B)\times C
```
$(A\cap \mathcal B)\times C$

```
\prod_p\left(1-\frac1{p^s}\right)^{-1}
```
$\prod_p\left(1-\frac1{p^s}\right)^{-1}$

```
\mathbf x=(x,y,z)
```
$\mathbf x=(x,y,z)$

```
f\colon A \to B
```
$f\colon A \to B$

```
\int_{\partial\Omega}\omega
```
$\int_{\partial\Omega}\omega$

```
\int_0^1 \sqrt[3]{x} \,dx
```
$\int_0^1 \sqrt[3]{x}\,dx$

```
\sin\log x
```
$\sin\log x$

The American Mathematical Society ($\mathcal{AMS}$) 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) &= x^2(x^3+x^2+x+2x^2+2x+2) \\
                      &= x^2(x^3+3x^2+3x+2) \\
                      &= x^5+3x^4+3x^3+2x^2
\end{align}
```

$$x^2(x^2+x+1)(x+2) = x^2(x^3+x^2+x+2x^2+2x+2) \quad (1)$$
$$= x^2(x^3+3x^2+3x+2) \quad (2)$$
$$= x^5+3x^4+3x^3+2x^2 \quad (3)$$

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

Some mistakes I have seen

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

```
\int\sin x dx
```
$$\int \sin x dx$$ ✗

```
\int\sin x\,dx
```
$$\int \sin x\,dx$$ ✓

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

Some mistakes I have seen

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

`g:A\to B`	$g : A \to B$	✗
`g \colon A\to B`	$g \colon A \to B$	✓
`1:2`	$1 : 2$	✓

- 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

$$x + 1 = 2,$$

subtracting 1 from both sides allows us to conclude that

$$x = 1.$$

✓

Consider the equation:

$$x + 1 = 2$$

Subtracting 1 from both sides allows us to conclude that:

$$x = 1$$

✗

Some mistakes I have seen

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

`||\mathbf x ||`	$\|\|\mathbf{x}\|\|$	✗
`|\mathbf x|`	$\|\mathbf{x}\|$	✓

  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`	$\langle x, y\rangle$	✓

- 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 $\cup_{i=1}^{n} A_i$ and $A \bigcup B$.
  Similarly, `\Sigma` (Σ) and `\Pi` (Π) should not be confused with `\sum` ($\sum$) and `\prod` ($\prod$).

Some mistakes I have seen

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

`\sigma_{normal}`	σ_{normal}	✗
`\sigma_\mathrm{normal}`	σ_{normal}	✓

- 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 $\sum_{k=0}^{\infty} \frac{x^k}{k!}$ and not $\displaystyle\sum_{k=0}^{\infty} \frac{x^k}{k!}$, 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, $f(x)\ll g(x)$,
    to denote the fact that for some constant $C>0$,
    $|f(x)|\leq C g(x)$ 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 $f(x)=O(g(x))$, or
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\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
                :
```

1 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 $C > 0$, $|f(x)| \leq C\, g(x)$ 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* $\Lambda\colon \mathbb{N} \to \mathbb{R}$ 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.

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.

2 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/q of α (i.e., $|\alpha - \frac{a}{q}| \leq \frac{1}{q^2}$ and $\mathrm{hcf}(a,q) = 1$). Then*

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

1

Some observations

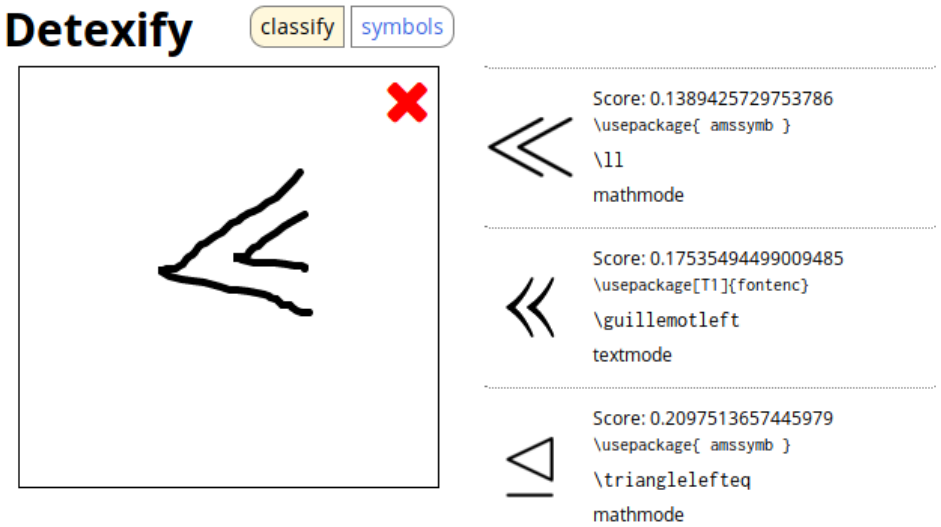
- The counter resets after a new section because the definition of `theorem` was given the optional `[section]` argument (alternatively you can do `chapter`, `subsection`, etc.)
- The other environments made use of the same counter as `theorem` because they were all given the `[theorem]` argument. If 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 DeTEXify. 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!

Footnotes

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]

[1] On 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**.

Bibliographies

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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\begin{thebibliogr
    \bibitem{daver
    Theory, 3rd ed

    \bibitem{hardy
    Littlewood, So
    \textsc{iii}:
    primes, Acta M
\end{thebibliograp
```

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

Bibliographies

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:

BibTeX

```
@book{davenport,
    author    = {Davenport, H.},
    title     = {Multiplicative Number Theory},
    edition   = {third},
    year      = {1995},
    publisher = {Springer--Verlag},
    pages     = {145--171}
}

@article{hardylittlewood23,
    author    = {Hardy, G. H. and Littlewood, J. E.},
    title     = {Some problems of `partito numerorum';
                 {\textsc{iii}}:  On the expression of a
                 number as a sum of primes},
    journal   = {Acta Mathematica},
    year      = {1923},
    volume    = {44},
    pages     = {1--70}
}
```

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 ...
```

BibTeX

- BibTeX 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 BibTeX, 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.

Bibliographies

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}
```

Bibliographies

With the file from before, we now have:

```
The circle method was first applied to the ternary Goldbach
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Nowadays, a conc
chapter 25 of \c

\bibliographysty
\bibliography{re
```

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*. 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.

Bibliographies

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

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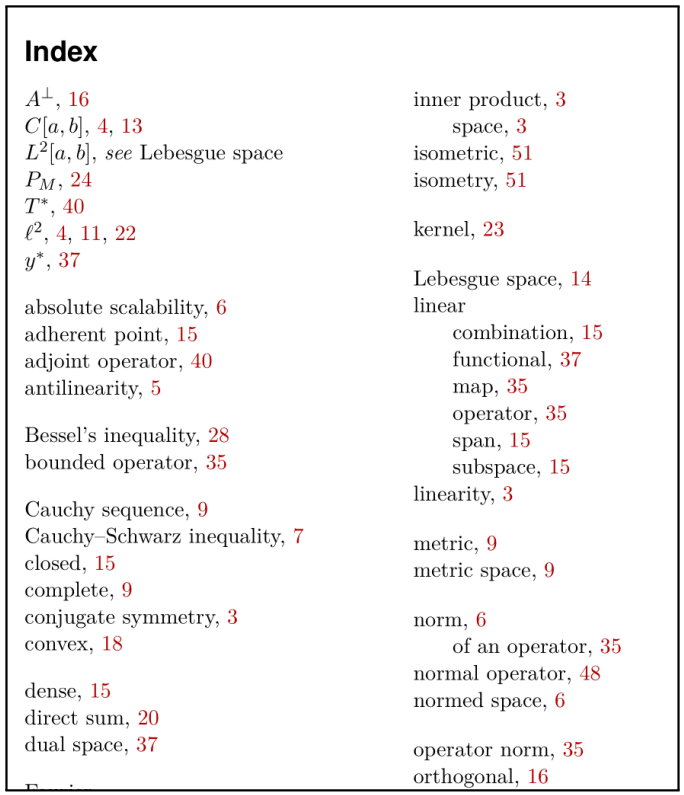

- Only the entries which are cited appear in the references. If the files contain additional entries and you want them to appear, do `\nocite{*}` before the `\bibliography` command.
- Try out other bibliography styles: `acm`, `alpha`, `apalike`, `siam`.

The Index

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



Index

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:pyth}

\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

```
\section{Intr
In section \r
we shall see
\ref{thm:pyth
illustrated i

\section{Pyth
\label{sec:py

\begin{theore
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    In a righ
\end{theorem}

\begin{figure
    \centerin
    \caption{
    \label{fi
\end{figure}
```

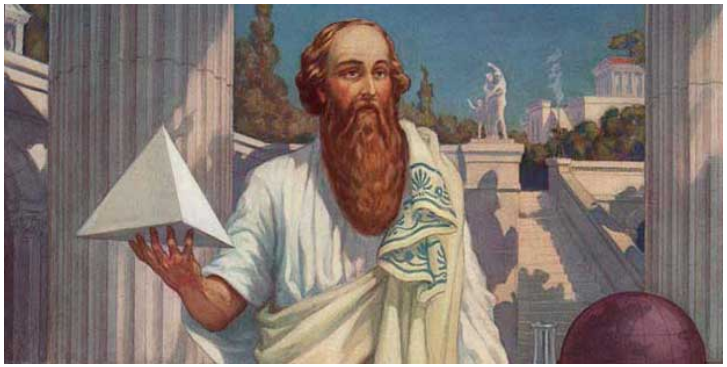


Figure 1: The philosopher Pythagoras

1 Introduction

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

2 Pythagoras' Theorem

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

1

References

- 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 `\eqref` command provided by the `amsmath` package (`\cref` is fine too).

Links

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}
```

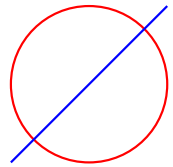
- To link an email address, you do:

```
\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}`):

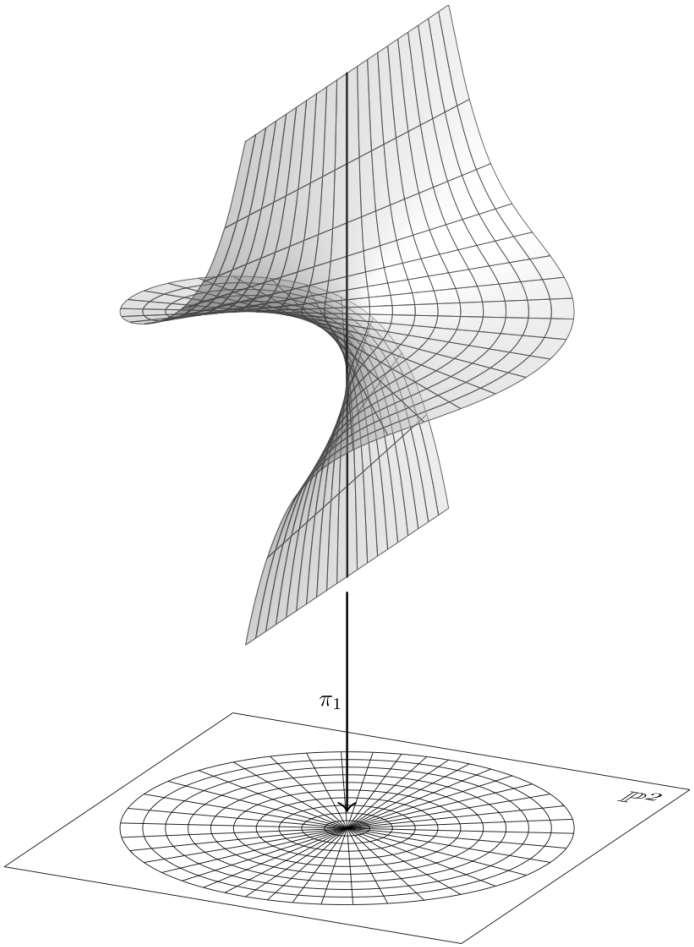
```
\begin{tikzpicture}
    \draw[red] (0,0) circle (0.5cm);
    \draw[blue] (-0.5,-0.5) -- (0.5, 0.5);
\end{tikzpicture}
```

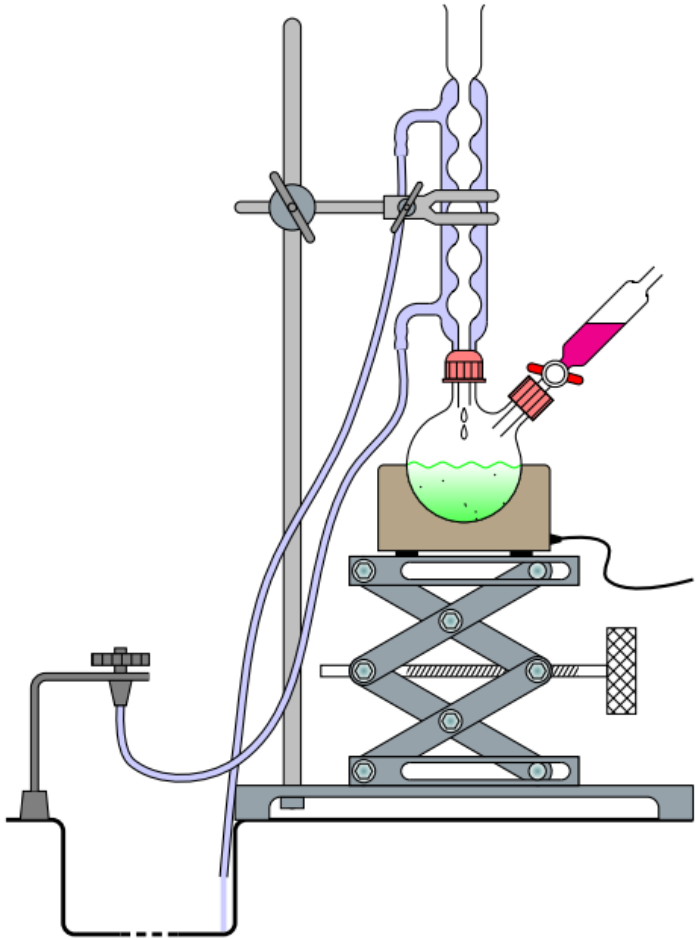


A more detailed introduction to TikZ can be found here:

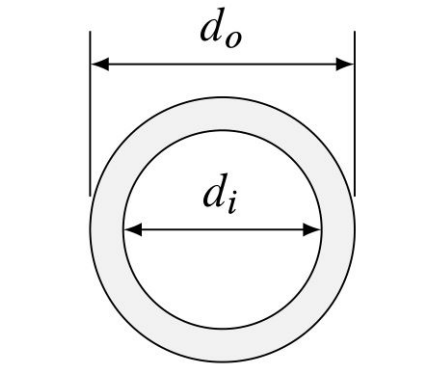
overleaf.com/learn/latex/TikZ_package

TikZ Showcase

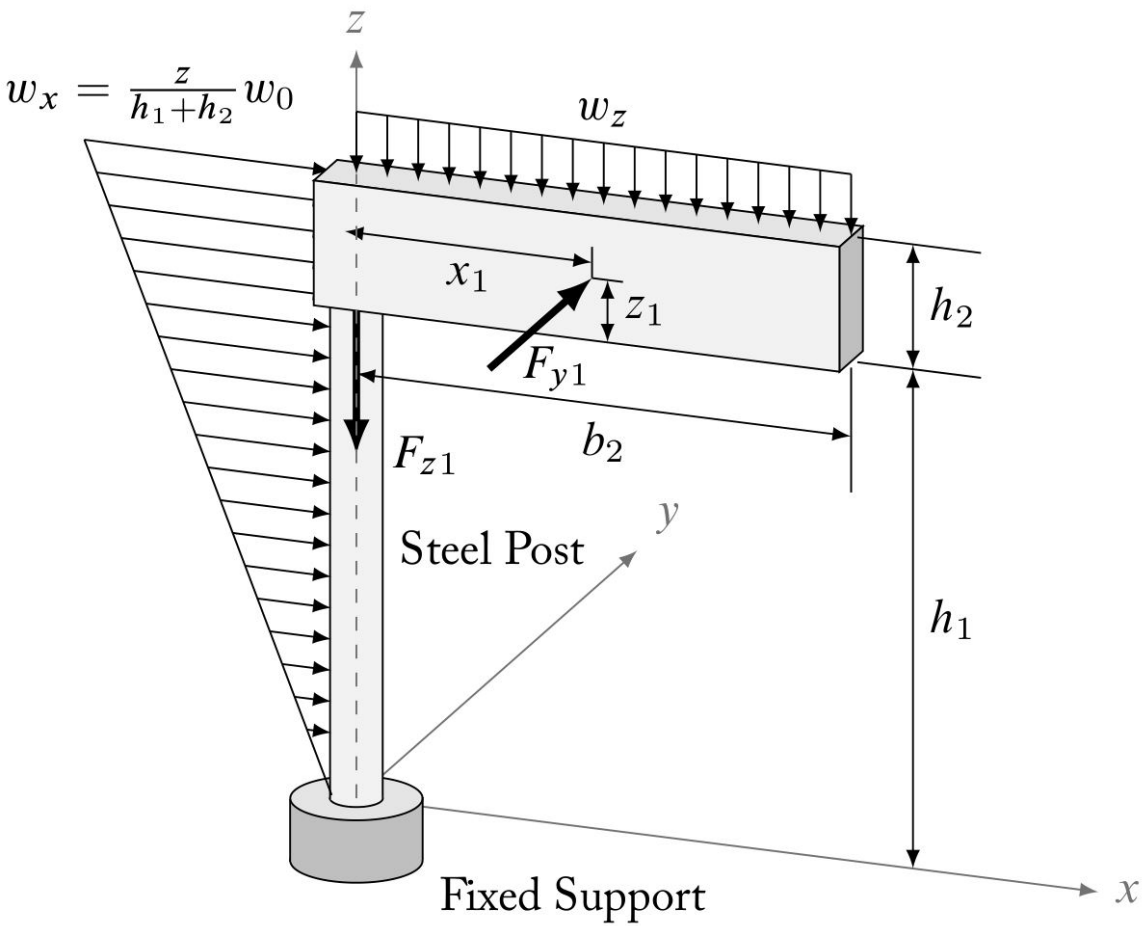




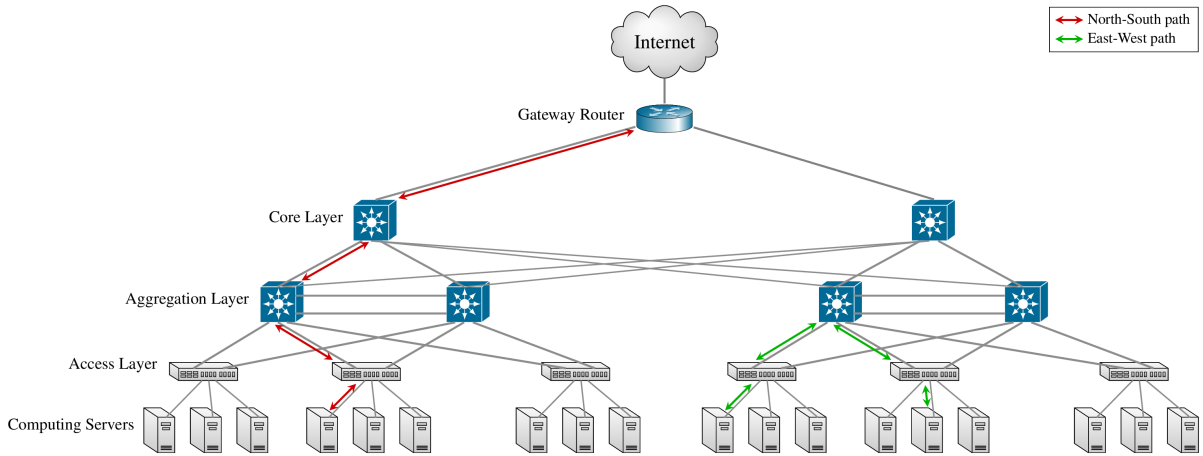
TikZ Showcase

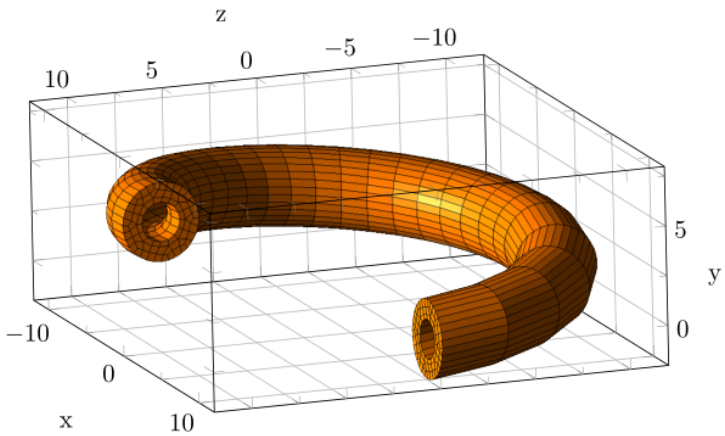


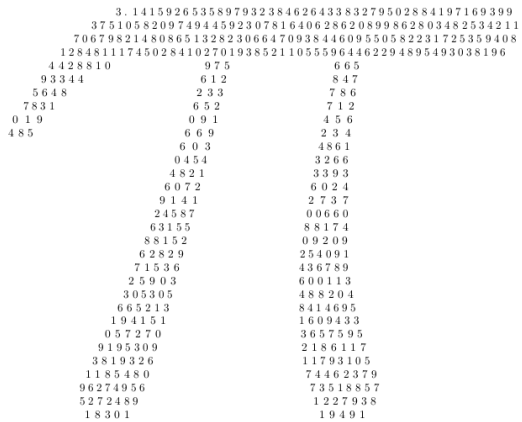
Signpost Cross Section



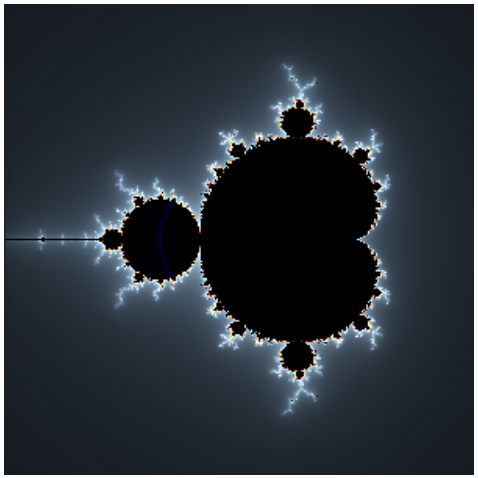
TikZ Showcase

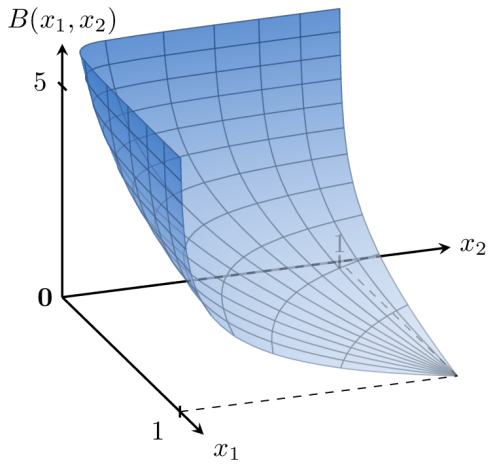


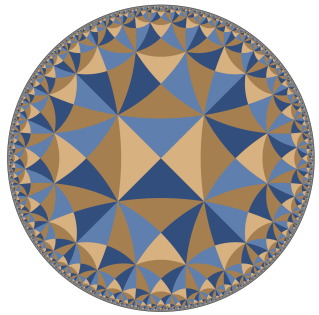




TikZ Showcase







Templates and other Resources

- There are multiple document templates for CVs, documents, posters, theses, etc., at:
  1. 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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