

An Introduction to \LaTeX :

Typesetting your Thesis or Research Paper

Part II: Maths, More Elements and Templates

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1 Maths

- Some Basic Examples and Symbols
- The \mathcal{AMS} Packages
- Common Mistakes in Math Mode
- \mathcal{AMS} Theorems
- How to Find Symbols for Maths

2 More Document Elements

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- References and Links

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- TikZ
- Templates and Resources

L^AT_EX & Maths

L^AT_EX 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 $x + y = z$. L^AT_EX 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 *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:

$$e^{i\pi} + 1 = 0$$

$$\alpha + \beta = \frac{-b}{2a}$$

$$a_n = a_{n-1} + a_{n-2}$$

$$\sum_{n=1}^{\infty} \frac{1}{n^s}$$

$$e^{i\pi} + 1 = 0$$

$$\alpha + \beta = \frac{-b}{2a}$$

$$a_n = a_{n-1} + a_{n-2}$$

$$\sum_{n=1}^{\infty} \frac{1}{n^s}$$

More Examples

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

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

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

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

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

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

`f\colon A \to B`

$f: A \rightarrow B$

`\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 (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.

<code>\mathbb R</code>	<code>\setminus</code>	<code>\mathbb Z</code>	$\mathbb{R} \setminus \mathbb{Z}$
<code>\mathfrak {AaBbCc}</code>			\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}
    \frac{1}{2\pi i} \int_{\gamma} z^n dz = 0,
    \quad z^n, dz = 0,
\end{equation}
for  $n \neq -1$ .
```

We have

$$\frac{1}{2\pi i} \int_{\gamma} z^n dz = 0, \quad (1)$$

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 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 *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., `$\operatorname{hcf}(a,b)$` gives $\operatorname{hcf}(a,b)$.
- In integrals, use the half-space command `\,`, between the integrand and differentials, e.g.

$$\begin{array}{ll} \text{\texttt{\textbackslash int\sin x dx}} & \int \sin x dx \quad \times \\ \text{\texttt{\textbackslash int\sin x\,,dx}} & \int \sin x dx \quad \checkmark \end{array}$$

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

`1:2`

$g : A \rightarrow B$ ✗

$g \colon A \rightarrow B$ ✓

$1 : 2$ ✓

- 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:

<code> \mathbf{x} </code>	$ \mathbf{x} $	✗
<code>\ \mathbf{x}\ </code>	$\ \mathbf{x}\ $	✓

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

<code><\mathbf{x}, y></code>	$<\mathbf{x}, y>$	✗
<code>\langle \mathbf{x}, y \rangle</code>	$\langle \mathbf{x}, y \rangle$	✓

- 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, `\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`.

<code>\sigma_{normal}</code>	σ_{normal}	✗
<code>\sigma\mathrm{normal}</code>	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 $\sum_{k=0}^{\infty} \frac{x^k}{k!}$, 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 Vinogradov'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}
 $\Lambda:\mathbb{N}\rightarrow\mathbb{R}$  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}[Vinogradov, 1937]
  Let  $A>0$  be fixed. Then
  \[
  \vdots
  \]
```


An Example

```
\section{First Proof of Vinogradov}
\begin{notation}
```

We write $f(x)=O(g(x))$, 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 the
 $\Lambda(n) = \log p$ if $n = p^k$
non-negative integer k , and

```
\end{definition}
```

```
\begin{theorem}[Vinogradov, 1937]
```

Let $A > 0$ be fixed. Then

⋮

1 First Proof of Vinogradov'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* $\Lambda: \mathbb{N} \rightarrow \mathbb{R}$ 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 (Vinogradov, 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. \square

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 $\gcd(a, q) = 1$). Then

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

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:

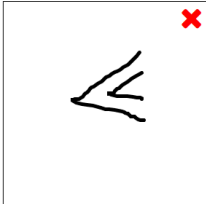
```
\newtheorem{theorem}{Theorem}[section]
\newtheorem*{theorem*}{Theorem}
```

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 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.

Detexify classify symbols



Score: 0.1389425729753786
`\usepackage{ amssymb }`
`\ll`
`mathmode`

Score: 0.17535494499009485
`\usepackage[T1]{fontenc}`
`\guillemotleft`
`textmode`

Score: 0.2097513657445979
`\usepackage{ amssymb }`
`\trianglelefteq`
`mathmode`

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

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**.

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 Vinogradov 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{thebibliography}{}
  \bibitem{davenport}
    Davenport, H., Multiplicative Number Theory, 3rd edition, Springer-Verlag, 1995.
  \bibitem{hardylittlewood23}
    Hardy, G. H. and Littlewood, L. E., Some problems of 'partitio numerorum'; III: On the expression of a number as a sum of primes, Acta Mathematica 44, pp. 1-70, 1923
\end{thebibliography}
```

The circle method was first applied to the ternary Goldbach problem by Hardy--Littlewood in [2]. Nowadays, a concise proof due to Vinogradov 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 'partitio 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 Bib \TeX .

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

BibT_EX

```
@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}
}
```


BibT_EX

- BibT_EX 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_EX, 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 Vinogradov is found in chapter 25 of `\cite{davenport}`.

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

Bibliographies

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The circle method was first applied to the ternary Goldbach problem by Hardy. Nowadays, a concise proof is found in chapter 25 of \c

```
\bibliographystyle{plain}
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```

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References

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

Bibliographies

With the file from before, we now have:

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```
\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	
A^\perp , 16	inner product, 3
$C[a, b]$, 4, 13	space, 3
$L^2[a, b]$, see Lebesgue space	isometric, 51
P_M , 24	isometry, 51
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ℓ^2 , 4, 11, 22	Lebesgue space, 14
y^* , 37	linear
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adherent point, 15	functional, 37
adjoint operator, 40	map, 35
antilinearity, 5	operator, 35
Bessel's inequality, 28	span, 15
bounded operator, 35	subspace, 15
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Cauchy-Schwarz inequality, 7	metric, 9
closed, 15	metric space, 9
complete, 9	norm, 6
conjugate symmetry, 3	of an operator, 35
convex, 18	normal operator, 48
dense, 15	normed space, 6
direct sum, 20	operator norm, 35
dual space, 37	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: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{Intro
In section \ref{sec:pyth}
we shall see
\ref{thm:pyth}
illustrated in

\section{Pytha
\label{sec:py

\begin{theore
  \label{th
  In a right
\end{theorem}

\begin{figure}
  \centering
  \caption{
  \label{fig
\end{figure}

```

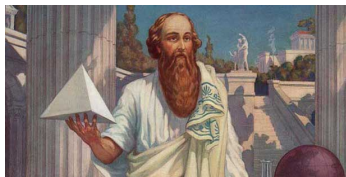


Figure 1: The philosopher Pythagoras

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

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 linked 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}`):

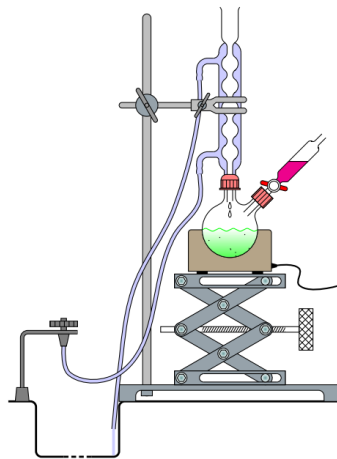
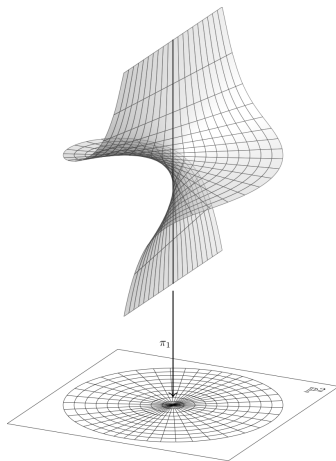
```
\begin{tikzpicture}
  \draw[red] (0,0) circle (0.5cm);
  \draw[blue] (-0.5,-0.5) -- (0.5, 0.5);
\end{tikzpicture}
```



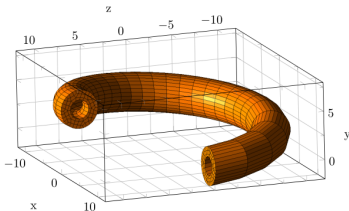
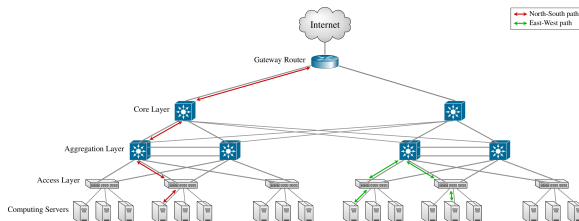
A more detailed introduction to TikZ can be found here:

overleaf.com/learn/latex/TikZ_package

TikZ Showcase



TikZ Showcase

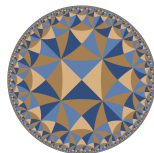
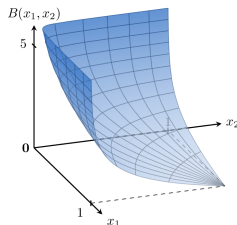
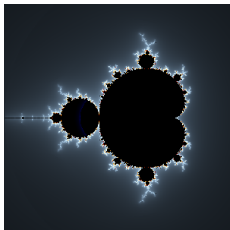


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5648 233 786
7831 852 712
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685213 8614805
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3859326 11793186
1185888 74462379
98274958 73518857
5272469 1227798
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```


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 DeT_EXify which we already mentioned, for finding math symbols: detexify.kirelabs.org
- The T_EX 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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