University
Of Dundee

MATHEMATICS & COMPUTER SCIENCE

A LaTeX Guide

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Computer Science Report 94/01

November 23, 1994
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Contents

1 Introduction

This report briefly introduces the LaTeX system for typesetting mathematical documents. It was written for our students and colleagues at the University of Dundee but, apart from some of the details in Section 2, the contents may be of interest to would-be LaTeXers at other institutions.

One of the best ways to learn about LaTeX is to study examples of LaTeX documents and, when necessary, to consult reference books such as those listed on page 28. The authoritative reference for LaTeX is [9]. An easy-to-read introduction is given in [10]. LaTeX makes use of a program called TeX [8]—most TeX commands can be used in LaTeX and useful examples may be found in [1]. See also [2, 3, 4, 7].

On the Dundee system the directory `/home/staff/dfg/LaTeX` contains examples of LaTeX documents. For those not having access to this system, these files are available by anonymous ftp at the site `ftp.mcs.dundee.ac.uk` in the directory `pub/LaTeX`. We recommend that you copy these files to a directory of your own, run the `.tex` files through LaTeX and preview the results. (See Section 2 for details of how to do this.)

1.1 Motivation

LaTeX is widely used in the mathematical sciences, particularly in the numerical analysis and computer science communities. Good reasons for learning LaTeX include the following.

- Mathematical formulas can be produced quite easily. TeX knows a great deal about the way to format mathematics, and hence your documents will look good.
- Equations and references can be labelled, so that cross-referencing is automated.
- The `.tex` files are standard ASCII files, and hence they can be produced using your favourite text editor and they can be emailed to your friends and colleagues.
- LaTeX is available at many universities and research institutions, and can be run on PCs, workstations and mainframe computers.
- The "`dvi`" files produced by the system can be sent to a variety of output devices. At Dundee, the available output devices are the computer screen and various printers.
- If you plan to pursue an academic career then LaTeX skills will prove useful. Many journals now encourage authors to submit manuscripts electronically using LaTeX (or similar systems such as TeX and AMSTeX).

A word of warning is in order. LaTeX makes it possible to produce an impressive-looking document that is riddled with mistakes and inconsistencies. Hence, you should not be deceived by the aesthetics of the output. When you write mathematics, your main concern should be to present your ideas clearly and correctly. LaTeX has been designed to relieve you of the burden of typesetting, so that you can concentrate on the content of the document.
Special spellcheckers are available on some systems, for example the Unix command

```
texspell example
```

will strip out the TEX or LATEX commands from the file `example.tex` and then run it through a spellchecker, giving a list of unrecognised words.

1.2 Writing Mathematics

The new book [5] is aimed at writers of mathematics. It covers a range of topics including English usage, punctuation, revising a draft, writing slides for a talk, using filters, pipes and spellcheckers, and publishing a paper. It also discusses LATEX and other computing aids.

2 Running LATEX

Before running LATEX, you must create a file with a `.tex` extension, such as the file `example.tex` that has been provided (and reproduced on page 4). To run LATEX on the file, type the Unix command

```
latex example.tex
```

in a "command tool" window (alternatively, you can just type "`latex example`", since the `.tex` extension is taken for granted). You will see that a warning message is generated. This happens because the file includes references to labelled equations, and LATEX must be run twice (sometimes three times) in order to sort out the references properly. Hence you should type "`latex example.tex`" once more.

If you list the contents of the current directory, you will see that the file `example.dvi` has been created. The extension `dvi` stands for *device independent*. The file can be understood by any one of several devices; in our case we may display the file on the screen or request a printed hardcopy. To save paper and money, you should always check that the output is correct by displaying it on the screen before printing. This is called *previewing*, and it is done by typing in a "command tool" window

```
xdvi example.dvi
```

(or just "`xdvi example`", or "`xdvi -geometry 800x900+0+0 example`"). The previewer is controlled by the mouse and allows you to browse through your document.

In order for the printers to understand `dvi` files they have to be translated into "PostScript" using

```
dvips -o tmp.ps example.dvi
```

which writes the output to the file `tmp.ps`. The `dvips` command has many options (try "`man dvips`"). In particular, it is possible to print a few pages from a large document:

```
dvips -o tmp.ps -p 2 -l 5 example.dvi
```

will select pages 2 to 5. The PostScript file may be printed on your default printer in the Sun Laboratory by using

```
lpr -c tmp.ps
```

To preview the `tmp.ps` file on the screen, you can use

```
ghostview tmp.ps &
```

This conversion is necessary if you include Matlab or Maple figures in your document since `xdvi` will not display these.

To produce a hardcopy on the laser printer `-Plw`, type "`dvips -Plw example.dvi`". This combines the operations of converting the file into PostScript format and sending the result to the laser printer.

Please be aware that the `.dvi` and `.ps` files can be very large, taking up a lot of computer memory. Hence it is good practice to delete files with extensions `.dvi`, `.aux`, `.log` (but not, of course, your `.tex` files) as soon as you have made use of them—they can be regenerated from the `.tex` files if necessary.

2.1 Local Installation

At Dundee we are using version 3.14 of LaTeX. The system files are stored under the directory `/mcs/share/lib/tex` in directories

`bib`: files referred to when using `bibtex` (see [6]).

`fonts`: fonts you can specify, as described in Chapter 2 of [10].

`formats`: system format files for all the versions of TeX at Dundee.

`inputs`: various style files and, in some cases, `.tex` files describing their usage.

Manual pages to look at are: bibtex, detex, dvips, latex, texeqn, texmatch, texspell.

2.2 M.Sc. Theses

M.Sc. students are free to produce documents (and, in particular, MSc theses) in any manner, and hence it is not strictly necessary for you to learn about LaTeX. A skeleton version of a thesis is available:

`/mcs/share/lib/tex/inputs/duthesis.tex`

Note, however, that it is the responsibility of each student to ensure that his/her thesis meets with the University requirements.

3 Basic LaTeX

We begin with an example. Illustrated below is the LaTeX document `example.tex`. The contents of the file are reproduced on the left and, in the box, we show the output produced (of course, when this file is run, it will produce output to fit the standard A4 page—this is specified by the `a4` in the first line).

```
\documentstyle[12pt, a4]{article}
\begin{document}
\centerline{\Large\bf Sample \LaTeX\ Document}

\bigskip
This is a short document to
illustrate the basic use of \LaTeX.

Simply leave a blank line to get a
new paragraph.

Mathematical expressions in line,
such as $y = 3\sin x^2$, are
obtained with dollar signs.  For
displayed equations like
$$y = 3\sin x^2$$ use double dollar
signs. Numbered equations are also
possible:
\begin{equation}\label{eq}
y = 3\sin x^2.
\end{equation}
Because we have labelled the
equation we can refer to it without
having to know its number---the
preceding equation was number
(\ref{eq}).

Powers (superscripts), as in $x^2$,
are obtained with \verb+^+; more
complicated powers must live in
curly brackets: $x^{2+\alpha}$.

Likewise, the subscripts in $y_3$
and $y_{n+1}$ are obtained with an
underscore.

Combining them gives symbols like
$x_{n+1}^{2+\alpha}$.
\end{document}
```

Sample LaTeX Document

This is a short document to illustrate the basic use of LaTeX.
Simply leave a blank line to get a new paragraph.
Mathematical expressions in line, such as $y = 3\sin x^2$, are obtained with dollar signs. For displayed equations like

$$y = 3\sin x^2$$

use double dollar signs. Numbered equations are also possible:

$$y = 3\sin x^2. \tag{1}$$

Because we have labelled the equation we can refer to it without having to know its number—the preceding equation was number (1).
Powers (superscripts), as in x^2, are obtained with ^; more complicated powers must live in curly brackets: $x^{2+\alpha}$.
Likewise, the subscripts in y_3 and y_{n+1} are obtained with an underscore.
Combining them gives symbols like $x_{n+1}^{2+\alpha}$.

To format documents in LaTeX we embed commands in the text that tell it to perform tasks such as "start a new section", "display an equation", "make an integral sign", etc. These commands are words beginning with a backslash "\".

There are a large number of such commands, but we can cope with most situations with a relatively small subset.

LaTeX generally regards groups of characters separated by spaces as *words* (a "newline" generated by the Return key is also thought of as a space). The number of spaces between words is immaterial—the output will look the same.

A period (full stop) "`.`" signifies the end of a sentence and LaTeX will usually follow it with a larger space than normal. If you use the period as in etc. which is not the end of a sentence, input it as `etc.\␣` (we often use ␣ to emphasise the presence of a space). The command `\␣` forces LaTeX to leave a normal space.

A blank line—or any number of blank lines together—signifies the end of a paragraph. Judicious use of blank lines and spaces can make your `.tex` file much easier to read and understand for humans. A new paragraph is automatically indented by LaTeX (except when it is the first in a section). If you want to override this, terminate a line with `\\` or use `\noindent` on a line of its own following the blank line.

The following characters have a special meaning in LaTeX

`\  &  $  %  ~  _  {  }  #  ^`

and some may be printed in the document by preceding them with a backslash.

```
To print out special characters in
the text \&, say, put them in
\{braces\}, use a backslash.
```

To print out special characters in the text &, say, put them in {braces}, use a backslash.

This does not apply to `\  ~  ^`.

If a `%` sign is included in a line without being preceded by a backslash, the *remainder of the line is ignored*. This provides a mechanism for introducing comments into the source code. Look at the next example carefully and compare the input with the output.

```
It is likely that 50\% of the time
you will be frustrated because you
forgot to precede the % symbol by
a backslash.
```

It is likely that 50% of the time you will be frustrated because you forgot to precede the a backslash.

The special characters can also be displayed in a typewriter font using `\verb+%$ text\~+` which gives `%$ text\~`. The character immediately following `\verb`, in this case `+`, is treated as a "bracket" and everything will be printed out "verbatim" up to the next occurrence of that character. See also the "verbatim" environment in Section 4.4 which is used throughout the current document to produce the "raw" LaTeX.

3.1 Fonts

We often need characters of different sizes for titles, headings, etc. The default size of characters is 10 points(pts), a point being an archaic printing term for 1/72inch. Other available options are 11pt and 12pt (this document is typeset in 12pt). The font can be specified in the opening line

`\documentstyle[12pt, a4]{article}`

of the `.tex` file. To get words or characters of different sizes in the text we may temporarily change the font.

```
For large text use the {\large
large} command. Order a lager with
{\Large Large} or {\LARGE LARGE}.
Smaller text needs the
{\small small} command.
Silly effects are possible,
for example,
{\LARGE w}{\Large o}{\large r}{\normalsize d}{\small s}.
```

For large text use the large command. Order a lager with Large or LARGE. Smaller text needs the small command. Silly effects are possible, for example, words.

Among the commands for changing font size are

`\Huge \huge \LARGE \Large \large \normalsize \small \footnotesize`

When using these commands, they, and the words to be affected, are enclosed in curly braces { ... } to limit their scope. Note also that a space separates the command from the text.

```
We may emphasize text by using a
different style of
font---making text {\bf bold}, or
{\em emphasised}, {\it
italicised}, {\sl slanted},
{\rm the standard roman typeface},
{\sc small caps} or
{\tt imitate a typewriter}.
```

We may emphasize text by using a different style of font— making text **bold**, or *emphasised*, *italicised*, *slanted*, the standard roman typeface, SMALL CAPS or `imitate a typewriter`.

We can cope with foreign alphabets to get accents like

```
\^{o}, \'{e}, \`{a} or \"{u}. We
can therefore properly set the
names of the well known
Scandinavian Numerical Analysts
{\AA}ke Bj\"{o}rck and
S.~P.~N{\o}rsett (N{\o}rwegian).
```

ô, é, à or ü. We can therefore properly set the names of the well known Scandinavian Numerical Analysts Åke Björck and S. P. Nørsett (Nørwegian).

In the preceding paragraph we used the tilde "~" in `S.~P.~N{\o}rsett`. It acts as an "unbreakable space" meaning that the spacing between the initials and surname will remain but the whole name, initials+surname, will be treated as one word and not "broken" across line boundaries.

4 Environments

Environments are sections of the text that we wish LaTeX to treat differently from the main body. Examples are lists, tables, equations, etc. Each has an environment name that is communicated to LaTeX by

`\begin`{*environment name*}

text, table or equations in the environment

`\end`{*environment name*}

We shall give examples of the most common environments.

4.1 Lists

There are several different types of list–making constructions, including "bulletted" lists made with `itemize` and numbered lists with `enumerate`. The examples are from DJH's "101 Writing Tips".

```
\begin{itemize}
  \item  Every sentence should
   make sense in isolation.
   Like that one.
  \item Excessive hyperbole is
   literally the kiss of death.
  \item Similes are about as
  much use as a chocolate teapot.
\end{itemize}
```

- Every sentence should make sense in isolation. Like that one.
- Excessive hyperbole is literally the kiss of death.
- Similes are about as much use as a chocolate teapot.

The items may be labelled manually using square brackets after the "`\item`",

```
\begin{itemize}
  \item[a)]  Mixed metaphors can
kill two birds without a paddle.
  \item[b)] Sufficient clarity is
necessary, but not necessarily
sufficient.
\end{itemize}
```

a) Mixed metaphors can kill two birds without a paddle.

b) Sufficient clarity is necessary, but not necessarily sufficient.

or automatically

```
\begin{enumerate}
  \item Spellcheckers are not
  perfect; they can kiss my errs.
  \item Somebody once said
   that all quotes should be
   accurately attributed.
\end{enumerate}
```

1. Spellcheckers are not perfect; they can kiss my errs.
2. Somebody once said that all quotes should be accurately attributed.

and we can embed a list within a list (labelling is automatic)

```
\begin{enumerate}
  \item Punctuation
   \begin{enumerate}
      \item  Don't use commas, to
       separate text unnecessarily.
      \item Avoid ugly abr'v'ns.
   \end{enumerate}
   \item General
   \begin{enumerate}
     \item Injecting enthusiasm
      probably won't do any harm.
     \item Take care with pluri.
   \end{enumerate}
\end{enumerate}
```

1. Punctuation

   (a) Don't use commas, to separate text unnecessarily.

   (b) Avoid ugly abr'v'ns.

2. General

   (a) Injecting enthusiasm probably won't do any harm.

   (b) Take care with pluri.

4.2 Centering and Spacing

We may centre single lines and emphasise the text quite simply with (note the American spelling of center)

```
\centerline{\large\bf Title}

The text starts here\ldots.
```

Title

The text starts here....

To centre several consecutive lines, we use the "center" environment.

```
\begin{center}
  {\large\bf Assignment 1}

  Sue d'Onym

  MS601
\end{center}
The answers to questions \ldots.
```

Assignment 1

Sue d'Onym

MS601

The answers to questions ....

The vertical spacing between lines can be altered using `\bigskip`, `\medskip`, `\smallskip`. Spot the differences:

```
\begin{center}
  {\large\bf Assignment 1}
  \medskip

  Sue d'Onym
  \smallskip

  MS601
\end{center}
\bigskip

The answers to questions \ldots.
```

Assignment 1

Sue d'Onym

MS601

The answers to questions ....

These spacing commands must be either preceded or followed by a blank line.

4.3 Tables

There are two environments related to tables, the first, called "`tabular`", gives the table and the second, "`table`", is used to specify a caption and a possible label for cross–referencing.

The `tabular` environment opens with a line of the form

`\begin{tabular}`{*format*}

where the format tells LaTeX how many columns there are to be and whether they should be left justified (`l`), centered (`c`), right justified (`r`), or have a specified width (`p{...}`).

```
\begin{tabular}{lrc}
  Name & Mark & Grade \\  \hline
  Emma Winner     & 90 & A\\
  Scott Passmark  & 51 & C\\
  Shirley Knott   &  5 & F
\end{tabular}
```

Name	Mark	Grade
Emma Winner	90	A
Scott Passmark	51	C
Shirley Knott	5	F

Notice

- The `{lrc}` specifies that the first column should be left justified, the second right justified and the third centered.
- The entries on each row of the table are separated by `&`.
- Each line except the last terminates with `\\`, unless you include `\hline` for producing a horizontal line.
- The table is printed at the left edge of the "page".

Vertical lines can be drawn by including "`|`" at appropriate points in the format specification. In the next example we also center the table on the page.

```
Some text in here followed by a blank line

\centerline{
 \begin{tabular}{|l||r|c|}\hline
   Name & Mark & Grade \\
   \hline\hline
   Emma Winner     & 90 & A\\
   Scott Passmark  & 51 & C\\
   Shirley Knott   &  5 & F\\\hline
 \end{tabular}
}

Some more text (note the blank line).
```

Some text in here followed by a blank line

Name	Mark	Grade
Emma Winner	90	A
Scott Passmark	51	C
Shirley Knott	5	F

Some more text (note the blank line).

The `\centerline{` command's closing bracket follows the `\end{tabular}` so it applies to the whole table.

We now put the table in a "`table`" environment and give it a caption and a label. We must center it with the "`center`" environment rather than `\centerline`. By including a label in the caption with `\label{mytable}`, we can refer to this table anywhere in the document by `\ref{mytable}`.

The `[h]` on the command `\begin{table}[h]` for opening the table environment tells LaTeX that you wish the table to appear **h**ere (where it has been typed in); the other options are `[t]`, for **t**op of page and **b** for **b**ottom of page.

```
The results given in
Table~\ref{mytable} show the very
satisfactory performance of the
1994 class, with a class average of
50\% (note that we can refer to
the number of the Table before it
appears).
\bigskip

\begin{table}[h]
  \begin{center}
    \begin{tabular}{lrc}\hline
      Name & Mark & Grade \\  \hline
      Emma Winner     & 99 & A\\
      Chance Scone    & 46 & F\\
      Shirley Knott   &  5 & F\\\hline
    \end{tabular}
    \caption{\label{mytable}Class Mark List}
  \end{center}
\end{table}
```

The results given in Table 1 show the very satisfactory performance of the 1994 class, with a class average of 50% (note that we can refer to the number of the Table before it appears).

Name	Mark	Grade
Emma Winner	99	A
Chance Scone	46	F
Shirley Knott	5	F

Table 1: Class Mark List

4.4 Verbatim

This is an extremely useful environment for printing out sections of computer code, raw LaTeX, etc. since it prints out the text exactly as it was input and uses a (nonproportionally spaced) typewriter font.

```
\begin{verbatim}

function [T] = Tridiag(a,N)
% A Matlab m-file for constructing
% the NxN tridiagonal matrix
%
%       [ a -1  0 . ..  0]
%       [-1  a -1 0 ..  0]
%       [ 0 -1  . .     .]
%       [ .  .  . .     .]
%       [ 0  .  .-1  a -1]
%       [ 0  .  . 0 -1  a]
%
% Useage: A = tridiag(a,N)
T = a*eye(N) - ...
      diag(ones(N-1,1), 1) -...
        diag(ones(N-1,1),-1);

\end{verbatim}
```

```
function [T] = tridiag(a,N)
% A Matlab m-file for constructing
% the NxN tridiagonal matrix
%
%       [ a -1  0 . ..  0]
%       [-1  a -1 0 ..  0]
%       [ 0 -1  . .     .]
%       [ .  .  . .     .]
%       [ 0  .  .-1  a -1]
%       [ 0  .  . 0 -1  a]
%
% Useage: A = tridiag(a,N)
T = a*eye(N) - ...
      diag(ones(N-1,1), 1) -...
        diag(ones(N-1,1),-1);
```

5 Exercise 1.

Produce a `.tex` *file which, when run through* LaTeX*, will reproduce the document shown on the next page.*

Note that

- `\pounds` *gives the £ sign.*
- *The command* `\LaTeX\␣` *produces the* LaTeX *logo. The trailing space forced with* `\␣` *stops the logo from running into the word that follows.*
- *Today's date is obtained with* `\today`*.*
- *Lines are "flushed right" (right justified) by* `\flushright{..text..}`*. The lines that are flushed right should contain your own name, the date the final document was produced and the full path name of the associated* `.tex` *file.*
- *Pay close attention to the size and style of the fonts.*
- *You should use the* LaTeX *feature for numbering and cross–referencing tables (the table number you obtain will not then coincide with that given here).*
- *Dashes of different lengths are produced by* `-` *(-),* `--` *(–) and* `---` *(—).*

Numerical Analysis and Programming

M.Sc. Course

The Numerical Analysis and Programming (NAP) M.Sc. Course at the University of Dundee contains lecture units on

1. **Programming and Software Tools**
   This includes lectures and laboratory sessions on
   (a) Introduction to Unix
   (b) Matlab
   (c) Maple
   (d) Fortran
   (e) LaTeX
2. **Numerical Linear Algebra**
3. **Optimization**
4. **Ordinary Differential Equations**
5. **Partial Differential Equations**
6. **Approximation Theory and Integral Equations**

Details of the staff involved in teaching these courses are given in Table 2.

Two of the books for the LaTeX section are very reasonably priced— The Cookbook [10] costs about £5, and Nick Higham's book [5] costs $21.50 ($12.00 *for a SIAM student member*).

This file: `~dfg/Latex/exercise1.tex`
D. F. Griffiths, November 23, 1994

	Office	Extension	email
Dr. M. A. Aves	23/2/9	4479	`maves@mcs`
Dr. P. J. Davies	23/1/16	4477	`pdavies@mcs`
Prof. R. Fletcher	21/1/3	4490	`fletcher@mcs`
Dr. D. F. Griffiths	23/1/1	4467	`dfg@mcs`
Dr. D. J. Higham	23/1/10	4474	`dhigham@mcs`
Ms. A. Lambert	23/2/13	4485	`alambert@mcs`
Dr. S. Leyffer	21/2/6	4494	`sleyffer@mcs`
Dr. P. D. Smith	23/2/3	4482	`pdsmith@mcs`
Prof. G. A. Watson	23/1/8	4472	`gawatson@mcs`

Table 2: Course Lecturers

6 Vertical and Horizontal Spacing

In Section 4.2 we described how standard units of vertical spacing could be introduced into a document with `\bigskip, \medskip, \smallskip`—remember that they must appear before or after a blank line in order to be effective.

Greater control of vertical spacing is possible with `\vspace` and `\vspace*`. The command `\vspace{2.2in}` will leave a vertical space of 2.2inches, whereas `\vspace{3.5cm}` gives 3.5cms. Other units of length are `mm` (millimetres), `em` (the width of the letter "m"—the widest character), `ex` (the height of the letter "x") and `pt` for points. `\vspace{-0.25in}` will "move up" 0.25 inches. LaTeX will not produce what it thinks is superfluous space at the top and bottom of pages; if you want to override this use `\vspace*`.

Similarly, `\hspace{2.2in}` will leave a horizontal space of 2.2inches (except at the start of a line when you will need to use `\hspace*{2.2in}`).

`\hfill` in the middle of a line makes an "infinitely stretchable horizontal space"—text to the left of it is pushed to the left margin and that to the right of it to the right margin.

```
Get out your rulers and measure
the lengths obtained.
\vspace{0.75in}

Push right\hspace{1in}one inch.

Push right\hfill to the end.

Left\hfill Middle\hfill Right.
```

Get out your rulers and measure the lengths obtained.

Push right   one inch.
Push right   to the end.
Left   Middle   Right.

7 Creating Sections and Subsections

In this document we have considered only the "article" type of document style—it is specified in the header

`\documentstyle[12pt,a4]{article}`

The items in square brackets are optional and refer to special "style" files that are read in prior to formatting the document. For example, `a4` refers to the file `a4.sty` available at Dundee which specifies the European A4 page size, rather than the smaller default size. Omitting `[12pt,a4]` will result in the default font (10pt) and page size being used.

The last argument `{article}` specifies the document style. Also available are "chapter", "report", "book" and "letter". In article style, we may break the text into sections with the command

`\section{Name of Section}`

which will give a numbered section (LaTeX automatically looks after the numbering). We may also give it a label, `\section{Name of Section\label{mysect}}`, and then refer to it in the text with "`It was shown in Section~\ref{mysect}...`". To get unnumbered sections, we use

`\section*{Name of Section}`.

Similar rules apply to `\subsection{...}` and `\subsubsection{...}`.

8 Typesetting Mathematics

Section 3 gave some simple examples of mathematical typesetting. Mathematical symbols are typeset in an italic–like font; compare the correct form x, a, produced by `$x, a$`, with the normally typed "x, a". Some commonly used symbols and the commands used to produce them are given in Table 3.

In contrast, mathematical functions such as "log" and "sin" are typeset in Roman typeface (the same as the text). This allows for clearer reading of equations; compare $\sin x, \cos y$ with $sin x, cos y$. The former used `$\sin x, \cos y$` and the latter, `$sin x, cos y$`. Thus, for a function such as "diag" which does not appear in the list given in Table 4, we could use `{\rm diag}` to give "${\rm diag}(a_1, a_2, \ldots, a_n)$".

The ellipsis "$\ldots$" in the previous line was produced using `\ldots`. Notice that the dots are aligned with the base of the characters. Another form "$\cdots$" is produced by `\cdots`. This is more appropriate for use with $+, -, =$ as in $a_1 + a_2 + \cdots + a_n$. Also available are `\vdots` giving "$\vdots$" and `\ddots` giving "$\ddots$".

`\alpha`	α	`\beta`	β	`\gamma`	γ	`\delta`	δ
`\epsilon`	ϵ	`\varepsilon`	ε	`\zeta`	ζ	`\eta`	η
`\theta`	θ	`\vartheta`	ϑ	`\kappa`	κ	`\lambda`	λ
`\mu`	μ	`\nu`	ν	`\xi`	ξ	`\pi`	π
`\rho`	ρ	`\sigma`	σ	`\tau`	`\tau`	`\phi`	ϕ
`\varphi`	φ	`\chi`	χ	`\psi`	ψ	`\omega`	ω
`\Gamma`	Γ	`\Delta`	Δ	`\Theta`	Θ	`\Lambda`	Λ
`\Xi`	Ξ	`\Pi`	Π	`\Sigma`	Σ	`\Phi`	Φ
`\Psi`	Ψ	`\Omega`	Ω				
`\pm`	$\pm$	`\mp`	$\mp$	`\times`	$\times$	`\circ`	$\circ$
`\cap`	$\cap$	`\cup`	$\cup$	`\nabla`	∇	`\\|`	$\Vert$
`\ell`	ℓ	`\Re`	$\Re$	`\Im`	$\Im$	`\partial`	∂
`\infty`	∞	`\Box`	$\Box$	`\exists`	$\exists$	`\forall`	$\forall$
`\le`	$\le$	`\subset`	$\subset$	`\subseteq`	$\subseteq$	`\geq`	$\geq$
`\ll`	$\ll$	`\supset`	$\supset$	`\supseteq`	$\supseteq$	`\gg`	$\gg$
`\in`	$\in$	`\equiv`	$\equiv$	`\sim`	$\sim$	`\approx`	$\approx$
`\ne`	$\ne$	`\propto`	$\propto$	`\div`	$\div$	`\ast`	$\ast$
`\to`	$\to$	`\mapsto`	$\mapsto$	`\Rightarrow`	$\Rightarrow$	`\Longrightarrow`	$\Longrightarrow$
`\sum`	$\sum$	`\int`	$\int$	`\prod`	$\prod$	`\oint`	$\oint$

Table 3: A selection of mathematical symbols. The last row of symbols will scale in size to fit the context.

\sin	\cos	\tan	\csc	\sec	\cot
\arcsin	\arccos	\arctan	\exp	\log	\ln
\sinh	\cosh	\tanh	\coth	\max	\min
\det	\deg	\dim	\lim	\inf	\sup

Table 4: A selection of mathematical functions.

8.1 Some Examples

```
$$
x = \frac{1+y}{1+2z^2}
$$
$$
x_3 + y^{n+2} = z\sqrt{b^2-4ac}
$$
$$
S_n = a_1 + a_2 + \cdots + a_n.
$$
$$
S_n = \sum_{j=1}^n a_j.
$$
$$
a_n = 3 + (-1)^n,\qquad n = 1,2,\ldots,N.
$$
```

$$x = \frac{1+y}{1+2z^2}$$

$$x_3 + y^{n+2} = z\sqrt{b^2-4ac}$$

$$S_n = a_1 + a_2 + \cdots + a_n.$$

$$S_n = \sum_{j=1}^n a_j.$$

$$a_n = 3 + (-1)^n,\qquad n = 1,2,\ldots,N.$$

`\quad` and `\qquad` give measures of horizontal spacing. A `\quad` is this much |$\quad$| space and a `\qquad` is this much |$\qquad$|.

```
$$
\int_{x=0}^\infty x\,e^{-x^2}dx
        = \frac{1}{2}.
$$
$$
\lim_{n\to\infty}(1+\frac{x}{n})^n
        = e^x.
$$
$$
\max_{1\le x\le 2}x + \frac{1}{x}
        = \frac{5}{2}.
$$
$$
\min_{0\le x<\infty}x + \frac{1}{x} = 1.
$$
```

$$\int_{x=0}^\infty x\,e^{-x^2}dx = \frac{1}{2}.$$

$$\lim_{n\to\infty}(1+\frac{x}{n})^n = e^x.$$

$$\max_{1\le x\le 2}x + \frac{1}{x} = \frac{5}{2}.$$

$$\min_{0\le x<\infty}x + \frac{1}{x} = 1.$$

Some functions take on a different look when used “inline”, rather than in displayed equations.

```
a) $\int_{x=0}^\infty x\,e^{-x^2}dx
        = \frac{1}{2}.$

b) $\lim_{n\to\infty}(1+\frac{x}{n})^n
        = e^x.$

c) $\max_{1\le x\le 2}x + \frac{1}{x}
        = \frac{5}{2}.$

d) $\min_{0\le x<\infty}x + \frac{1}{x} = 1.$
```

a) $\int_{x=0}^\infty x\,e^{-x^2}dx = \frac{1}{2}.$

b) $\lim_{n\to\infty}(1+\frac{x}{n})^n = e^x.$

c) $\max_{1\le x\le 2}x + \frac{1}{x} = \frac{5}{2}.$

d) $\min_{0\le x<\infty}x + \frac{1}{x} = 1.$

8.2 Equation Environments

We have seen instances of the "plain" equation environment enclosed in `$$...$$`. In order to number the equation, we replace this construct with
`\begin{equation} ...\end{equation}`.
If the environment contains a label such as `\label{fermat}`, we can refer to the equation by its label—(`\ref{fermat}`)—rather than its number. Labels, whether they be for equations, tables, figures or sections, must be unique. See the example in Section 3. Additional spaces typed into equations have no effect—LaTeX has very firm ideas about how much space is required. You should use this flexibility of including spaces to make the input more readable.
In order to format sets of equations or long equations that do not fit onto one line we need a more elaborate environment. This is provided by
`\begin{eqnarray} ...\end{eqnarray}`
which is like a table having precisely three columns. Each column is separated by `&` and terminated by `\\`. The first column is left justified, the second centered and the third right justified. Each row of the array will be numbered (and may therefore be labelled) but this may be turned off by including `\nonumber` in the row; a complete set of unnumbered equations is obtained with
`\begin{eqnarray*} ...\end{eqnarray*}`
It is usual, but not essential, to align equations around the `=` sign.

```
\begin{eqnarray}
  y&=  & x^4 + 4,         \nonumber\\
   &=  &(x^2+2)^2 - 4x^2,\nonumber\\
   &\le&(x^2+2)^2.        \label{yineq}
\end{eqnarray}
\begin{eqnarray*}
  x + y + z                 &=&1,\\
 \alpha y + (\beta+\gamma)z &=& 1/2,\\
 \alpha\gamma z             &=& 1/6.
\end{eqnarray*}
\begin{eqnarray}
 e^x&\approx& 1+x+ x^2/2! + x^3/3! +
      \nonumber\\
    &       & \quad  x^4/4! + x^5/5!.
\end{eqnarray}
```

$$\begin{aligned} y &= x^4+4, \\ &= (x^2+2)^2-4x^2, \\ &\le (x^2+2)^2. \qquad (2) \end{aligned}$$

$$\begin{aligned} x+y+z &= 1, \\ \alpha y+(\beta+\gamma)z &= 1/2, \\ \alpha\gamma z &= 1/6. \end{aligned}$$

$$\begin{aligned} e^x \approx\ & 1+x+x^2/2!+x^3/3!+ \\ & \quad x^4/4!+x^5/5!. \qquad (3) \end{aligned}$$

Occasionally we need to "tinker" with the spacing in formulae by using one of

Thin Space: `\,` Medium: `\:` Thick `\;` Negative thin `\!`.

For example, compare `\int \sin x dx` giving $\int \sin x dx$ with `\int \sin x \,dx` giving $\int \sin x \, dx$.

8.3 Brackets

In addition to `[ ( ... ) ]` we may use curly brackets in equations *provided they are preceded by a backslash*: `\{ ... \}`. If larger brackets are required, we use

`\left\{ \left[ \left( \left| ...\right| \right) \right] \right\}`

Each `\left` **must** be accompanied by a `\right`, although the type of bracket used need not be the same.

```
Horner's rule for evaluating the polynomial
$$
p(x) = 1 + x + x^2/2 + x^3/6 + x^4/24 + x^5/120
$$
expresses it in the form
$$
p(x) = 1 + (1 + (\frac{1}{2} + (\frac{1}{6} +  (\frac{1}{24} +
         \frac{1}{120}x)x)x)x)x,
$$
saving a considerable amount of computing time if $p(x)$ is to be
evaluated for many different $x$ values. Compare this formatting with
$$
p(x) = 1 + \left(1 + \left(\frac{1}{2} + \left(\frac{1}{6} + \left(
 \frac{1}{24} + \frac{1}{120}x \right)x\right)x\right)x\right)x.
$$
```

Horner's rule for evaluating the polynomial

$$p(x) = 1 + x + x^2/2 + x^3/6 + x^4/24 + x^5/120$$

expresses it in the form

$$p(x) = 1 + (1 + (\frac{1}{2} + (\frac{1}{6} + (\frac{1}{24} + \frac{1}{120}x)x)x)x)x,$$

saving a considerable amount of computing time if $p(x)$ is to be evaluated for many different x values. Compare this formatting with

$$p(x) = 1 + \left(1 + \left(\frac{1}{2} + \left(\frac{1}{6} + \left(\frac{1}{24} + \frac{1}{120}x \right)x\right)x\right)x\right)x.$$

8.4 Arrays and Matrices

To format arrays and matrices (rectangular arrays of mathematical expressions) we use the "`array`" environment, which must occur within one of the mathematical environments described in Section 8.2. Each row of the array must contain the same number of entries, separated by & and terminated by \\. Each column of entries may be left or right justified or centered.

```
An example of a $3\times7$ array is
\begin{equation} \label{eqarray}
  \left.
  \begin{array}{l c l c c c r}
    1 &=& x &+& y &+& z\\
    1 &=& x^2 &+& y^2 &+& z^2\\
    1 &=& x^3 &+& y^3 &+& z^3
  \end{array}
  \right\}
\end{equation}
```

An example of a 3×7 array is

$$\left.\begin{array}{lclcccr} 1 &=& x &+& y &+& z\\ 1 &=& x^2 &+& y^2 &+& z^2\\ 1 &=& x^3 &+& y^3 &+& z^3 \end{array}\right\} \qquad (4)$$

The descriptor {lclcccr} specifies that the first and third columns should be left justified, the last should be right justified and the remaining columns centered. (In this example, left justification of the 5th and 7th columns would produce a neater alignment.) The number of items in the descriptor list must not be less than the number of columns. An entry may be empty. The brace is produced by \right\} (observe the backslash) for which there must be a matching left bracket, in this case a dummy \left.; the size of the brace is determined by the size of the object that the brackets enclose.

```
The system (\ref{eqarray}) may be
written in the matrix-vector form
$A{\bf u} = {\bf e}$, where
$$
A = \left[
  \begin{array}{ccc}
    1   & 1   & 1\\
    x   & y   & z\\
    x^2 & y^2 & z^2
  \end{array}
  \right], \quad
{\bf u} =
  \left[
  \begin{array}{c}
    x\\ y\\z
  \end{array}
  \right]
$$
and ${\bf e} = [1,1,1]^T$. The determinant of $A$ is given by
$$
\left|  \begin{array}{ccc}
    1   & 1   & 1\\
    x   & y   & z\\
    x^2 & y^2 & z^2
  \end{array} \right|  = (x-y)(y-z)(z-x)
$$
so that it is nonsingular precisely when the three values $x,y,z$
are all distinct.
```

The system (4) may be written in the matrix-vector form $A\mathbf{u} = \mathbf{e}$, where

$$A = \left[\begin{array}{ccc} 1 & 1 & 1\\ x & y & z\\ x^2 & y^2 & z^2 \end{array}\right], \quad \mathbf{u} = \left[\begin{array}{c} x\\ y\\ z \end{array}\right]$$

and $\mathbf{e} = [1,1,1]^T$. The determinant of A is given by

$$\left|\begin{array}{ccc} 1 & 1 & 1\\ x & y & z\\ x^2 & y^2 & z^2 \end{array}\right| = (x-y)(y-z)(z-x)$$

so that it is nonsingular precisely when the three values x, y, z are all distinct.

A useful construct is given by

```
The Kronecker delta is defined by
$$\delta_{i,j} =
  \left\{
    \begin{array}{ll}
      1 & {\rm when~} i=j\\
      0 & {\rm when~} i\ne j.
    \end{array}
  \right.
$$
```

The Kronecker delta is defined by

$$\delta_{i,j} = \left\{ \begin{array}{ll} 1 & {\rm when~} i=j\\ 0 & {\rm when~} i\ne j. \end{array} \right.$$

in which `{\rm when~}` typesets the contents of the braces in roman font and `~` forces a normal space.

Ellipses (see page 14) of different kinds are useful for formatting matrices.

```
The $N\times N$ tridiagonal matrix
$$
T = \left[
  \begin{array}{ccccc}
    a &  b   &  0   &\cdots& 0\\
    c &  a   &  b   &      &\vdots\\
    0 &\ddots&\ddots&\ddots& 0\\
    \vdots&  &  c   &  a   & b\\
    0 & \cdots&  0   &  c   & a
  \end{array}
  \right]
$$
has eigenvalues
$$
\lambda_j = a + \sqrt{bc}\cos \frac{2\pi j}{N+1},\quad N = 1,2,\ldots,N.
$$
```

The $N\times N$ tridiagonal matrix

$$T = \left[\begin{array}{ccccc} a & b & 0 &\cdots& 0\\ c & a & b & &\vdots\\ 0 &\ddots&\ddots&\ddots& 0\\ \vdots& & c & a & b\\ 0 & \cdots& 0 & c & a \end{array} \right]$$

has eigenvalues

$$\lambda_j = a + \sqrt{bc}\cos \frac{2\pi j}{N+1},\quad j = 1,2,\ldots,N.$$

8.5 Hats and Underlining

We simply give a number of examples illustrating what may be achieved in a math environment.

$\hat u$	`\hat u`	$\widehat u$	`\widehat u`	$\widehat{u+v}$	`\widehat{u+v}`
$\tilde u$	`\tilde u`	$\widetilde u$	`\widetilde u`	$\widetilde{u+v}$	`\widetilde{u+v}`
$\dot u$	`\dot u`	$\underline u$	`\underline u`	$\underline{u+v}$	`\underline{u+v}`
$\ddot u$	`\ddot u`	$\bar u$	`\bar u`	$\overline{u+v}$	`\overline{u+v}`
$\vec u$	`\vec u`	$\overline{\bar{u}+v}$	`\overline{\bar{u}+v}`	$\stackrel{\triangle}{=}$	`\stackrel{\triangle}{=}`

9 Abbreviations

LaTeX is a verbose language, the commands tend to be long strings that become tedious to type. To overcome this, we can define abbreviations. For example, if we include the line

```
\newcommand{\beq}{\begin{equation}}
```

then LaTeX will expand all subsequent occurrences of `\beq` to `\begin{equation}`
The general format of `\newcommand` is

`\newcommand{\`*name*`}[`*number*`]{`*definition*`}`

where *name* is the name you choose for the command, *number* is the number of arguments the command is to have and the definition is self–explanatory.

```
%% Make some definitions
\newcommand{\RR}{I\!\!R}          % uses \! for negative space
\newcommand{\beq}{\begin{equation}}
\newcommand{\eeq}{\end{equation}}
\newcommand{\Dxa}[2]{\frac{\partial #1}{\partial #2}}
\newcommand{\Dx}[1]{\frac{\partial\phantom{x_1}}{\partial x_#1}}
\newcommand{\frc}[2]{\textstyle{ \frac{#1}{#2} }\displaystyle}
\newcommand{\gfrc}[2]{\mbox{$ {\textstyle{\frac{#1}{#2}}\displaystyle}$}}
\newcommand{\vc}[2]{[#1_1,#1_2,\ldots,#1_#2]^T}
%% Now start using them
Let $A\in\RR^{m\times n}$ denote
a rectangular array and define
\beq
    z = {\bf y}^TA{\bf x},
\eeq
where ${\bf x} = \vc{x}{n}\in\RR^n$
and ${\bf y} = \vc{y}{m}\in\RR^m$.
Then
\beq
\Dx{i}z = \sum_{j=1}^m a_{j,i}y_j,
          \quad j=1,2,\ldots,n.
\eeq
Solve the equation
\beq
 \gfrc{1}{2}\sin\theta +
 \gfrc{1}{3}\cos\theta=\frac{5}{6}.
\eeq
We can also use \verb+gfrc+ in the
text, as in \mbox{\gfrc{1}{2}+
\gfrc{1}{3}= $\frac{5}{6}$}---note
the different sizes involved. We
have enclosed the entire sum in an
\verb+mbox+ to avoid it being
split at a line boundary.
```

Let $A \in I\!\!R^{m\times n}$ denote a rectangular array and define

$$z = \mathbf{y}^T A\mathbf{x}, \tag{5}$$

where $\mathbf{x} = [x_1, x_2, \ldots, x_n]^T \in I\!\!R^n$ and $\mathbf{y} = [y_1, y_2, \ldots, y_m]^T \in I\!\!R^m$. Then

$$\frac{\partial}{\partial x_i} z = \sum_{j=1}^m a_{j,i}y_j, \quad j = 1, 2, \ldots, n. \tag{6}$$

Solve the equation

$$\textstyle\frac{1}{2}\displaystyle\sin\theta + \textstyle\frac{1}{3}\displaystyle\cos\theta = \frac{5}{6}. \tag{7}$$

We can also use `gfrc` in the text, as in $\frac{1}{2}+ \frac{1}{3}= \frac{5}{6}$—note the different sizes involved. We have enclosed the entire sum in an `mbox` to avoid it being split at a line boundary.

An error will result if you inadvertently use the name of an existing LaTeX command, or one of your own. The remedy is either to choose a different name or to define it using

`\renewcommand` instead. In the definitions of commands with arguments, `#1, #2,...` indicate where the first, second,... arguments are to be placed.

The difference between the definitions of `\frc` (for fractions) and `\gfrc` is that the former can only be used in a mathematical environment (since `\frac` is only known there). By including `\mbox{$...$}` in `\gfrc` we have embedded a mathematical environment(`$...$`) and then protected it with `\mbox`.
The TEX construct `\phantom{x_1}` is useful in that it leaves the amount of space that would have been taken if x_1 had been formatted at that position.
Definitions that are used frequently in many different files may be kept in a separate file called, for example, `defns.tex`. Then, in the preamble to any LATEX document, they may be read in using (the extension `.tex` is assumed)

`\input{defns}`

If the file `defns.tex` and the main `.tex` file are not in the same directory then a suitable path name must be given (e.g. `\input{/home/staff/dfg/TEX/defns}`).

10 Troubleshooting

You will inevitably make errors when typing LATEX documents and thereby produce constructs that the processor does not understand. Here we describe some common occurrences—for a more exhaustive list see Chapter 6 of [9].

If an error occurs, part of the output will resemble

```
! Missing $ inserted.
<inserted text>
               $
<to be read again>
                  \mathop
\sin ->\mathop
              {\rm sin}\nolimits
l.13 such as y = 3\sin
                       x^2$, are
?
```

which indicates that the error was detected on line 13 (`l.13`) of the `.tex` file. In this case, the `$` that should have initiated the math environment was omitted (and so LATEX complained about `\sin`). To continue, type `q` at the question mark.

Errors are of this type are common, a `{` without the matching `}`, a `\begin{...}` without the matching `\end{...}` or a `\left(` without a `\right)`. Others are

- using special characters without protecting them or without using backslash,
- mistyping a command (e.g. typing `\tin` instead of `\sin`),
- attempting to define a new command (`\newcommand`) with a name that already exists,
- specifying a format for a table that does not match the actual number of columns (perhaps you forgot to end each line except the last with `\\`).

11 Including PostScript Figures in LaTeX

Figures (or files) produced in PostScript may be included in a LaTeX document using the `epsf` style. The header of the LaTeX file should be amended to

```
\documentstyle[12pt,a4,epsf]{article}
```

Then, we may use (leave a blank line before and after the figure, otherwise it will be incorporated into the text)

```
\begin{figure}[hb]
\centerline{
   \epsfxsize=3in
   \epsffile{/home/staff/dfg/Matlab/pdes_exact_sols/kdv1.eps}
   \epsfxsize=3in
   \epsffile{/home/staff/dfg/Matlab/pdes_exact_sols/kdv2.eps}
           }
    \caption[kdv]{\label{kdvfig}Two-soliton solution of the KdV
       equation.  The right hand figure is a contour plot of that
       on the left.}
\end{figure}
```

to produce

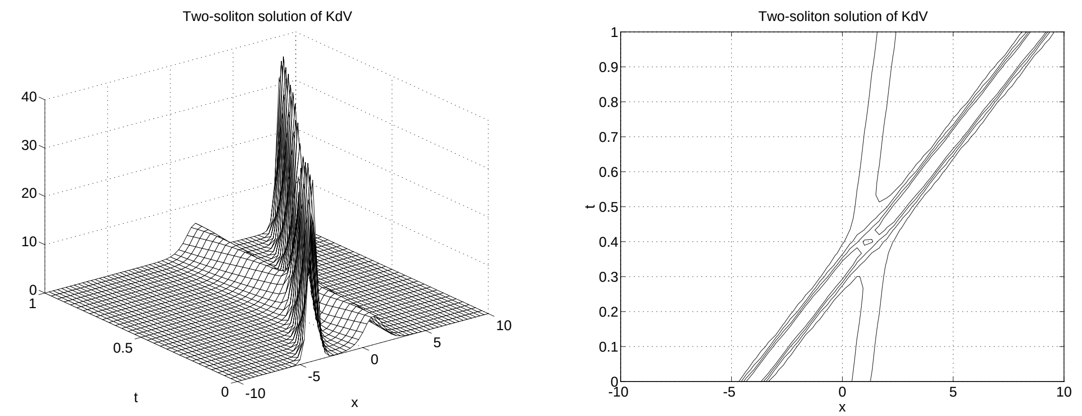

Figure 1: Two-soliton solution of the KdV equation. The right hand figure is a contour plot of that on the left.

in which,

- `\begin{figure}[bh]` introduces a "figure" environment which is to be placed either at the the current typing position `h` (for **h**ere, first preference) or at the **b**ottom of the page: `b` (second preference) . It is also possible to specify `t` for **t**op of the page. If, because of other constraints, LaTeX cannot meet these requirements it may place the figure on the next page or even at the end of the document.

- `\epsfxsize=3in` gives the physical width required for the picture; the height will be scaled so that the original aspect ratio of the figure is preserved (we could also specify `\epsfysize=3in` instead, but not both x– and y–sizes).

- `\epsffile{...}` gives the name of the file to be inserted. Two files are called, so that two pictures will be inserted side by side (separate them with `\newline` or `\\` for one above the other).
- The argument `[kdv]` to `\caption` gives a label for LaTeX to use for its own internal processing (for a list of figures, should one be needed). It is not necessary in the present example, but it is in cases (such as Exercise 2) where the text of the caption uses a `\ref{...}`.
- A label is included in the caption so that the figure may be referred to with `(\ref{fig:kdv})` anywhere in the document.

12 Making a Bibliography

An example of a Bibliography constructed using `bibtex` is given on page 28 (see [6]). A more straightforward approach is given by the example:

```
\bibliographystyle{plain}
\begin{thebibliography}{99}

   \bibitem{Borde} Arvind Borde,  {\em \TeX\  by Example}, Academic Press,
        1992.

   \bibitem{Diller93} Antoni Diller,  {\em {\LaTeX} Line by Line: Tips and
        Techniques for Document Processing}, John Wiley, 1993.

   \bibitem{Goossens94} M. Goossens and F. Mittlebach and A. Samarin,  {\em
        A {\LaTeX} Companion}, Addison--Wesley, 1994.

\end{thebibliography}
```

This produces

References

[1] Arvind Borde, *TEX by Example*, Academic Press, 1992.

[2] Antoni Diller, LATEX *Line by Line: Tips and Techniques for Document Processing*, John Wiley, 1993.

[3] M. Goossens and F. Mittlebach and A. Samarin, *A* LATEX *Companion*, Addison–Wesley, 1994.

In this example we have another environment "`thebibliography`".

- The `{99}` tells LATEX how wide the labels are going to be in the output (two digits).
- Each item on the list starts with `\bibitem` and the argument that follows in curly braces is the short (unique) code for the citation.
- The way that the references appear is determined by the `\bibliographystyle` command (see [5]) and also by the way the `\bibitem` entries are formatted.

To refer to, say, the book by Borde, we may use

```
Examples of \TeX\ may be found in \cite{Borde}.
```

which produces: Examples of TEX may be found in [1]. Similarly,

```
See also \cite{Borde,Diller93,Goossens94}.
```

produces: See also [2, 3, 1]. Do not leave any spaces in a list when citing multiple entries.

LATEX may have to be run two or three times on a file containing a bibliography or other labels before it will get all the cross–referencing correct.

13 Exercise 2.

Produce a `.tex` *file which, when run through* LaTeX*, will reproduce the following document. Your equation/table/figure numbers might not coincide with those given. The figure used may be found in the PostScript file*

`/home/staff/dfg/Matlab/pdes_exact_sols/heat.eps`

Programming and Software Tools

LaTeX Assignment 2.

These are some examples of mathematical expressions taken from [1] that have been typeset in LaTeX.

We begin by looking at the various types of Initial Value Problems (IVPs) that can arise for the model parabolic equation

$$u_t = u_{xx}, \quad t > 0. \tag{8}$$

The Pure Initial Value Problem(Pure IVP).

In this type of situation, also known as the Cauchy problem, the domain of the problem is the entire real line $(-\infty, \infty)$ and, to generate a well–posed problem, we impose the initial condition $u(x, 0) = f(x), x \in I\!R$.

The fundamental solution of (8) is given in this case by (See Fig. 2)

$$g(x,t) = \sqrt{\frac{1}{4\pi t}} e^{-x^2/4t} \tag{9}$$

with which we may construct the general solution of (8) as

$$u(x,t) = \int_{-\infty}^{\infty} g(x-\xi, t) f(\xi)\, d\xi. \tag{10}$$

Let U_m^n denote the solution of

$$U_m^{n+1} = U_m^n + r\delta_x^2 U_m^n \tag{11}$$

which we shall refer to as the FTCS method (Forward Time, Centred Space). On recalling the definition of δ_x^2 it becomes

$$U_m^{n+1} = rU_{m-1}^n + (1-2r)U_m^n + rU_{m+1}^n. \tag{12}$$

In this method the value U_m^{n+1} at the new time level is computed from three consecutive values at the current time level—the method is *explicit.*

The Crank–Nicolson method leads to

$$-rU_{m-1}^{n+1} + 2(1+r)U_m^{n+1} - rU_{m+1}^{n+1} = rU_{m-1}^n + 2(1-r)U_m^n + rU_{m+1}^n \tag{13}$$

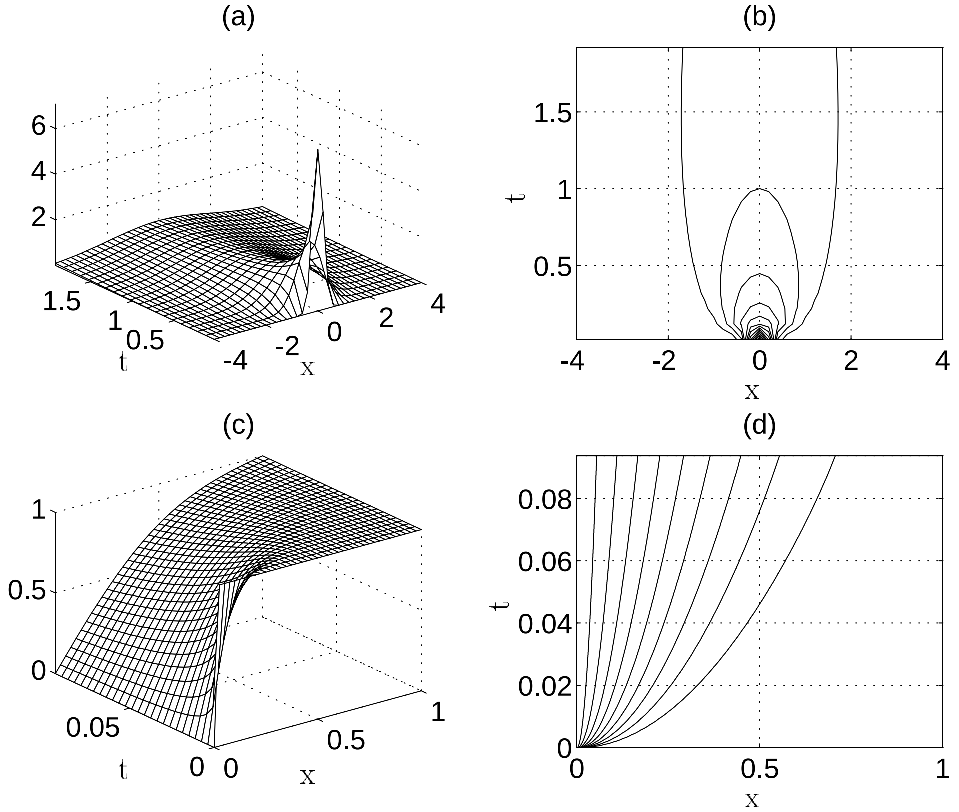

Figure 2: Solutions of the Heat Equation: (a), (b) – the fundamental solution (9) and its contours $u = n/2, n = 1, 2, \ldots, 14$.

and may be expressed in matrix–vector form as

$$\left.\begin{array}{rcl} A\mathbf{D}^{n+1} & = & \mathbf{U}^n \\ \mathbf{U}^{n+1} & = & 2\mathbf{D}^{n+1} - \mathbf{U}^n \end{array}\right\} \qquad (14)$$

where A denotes the $(M-1) \times (M-1)$ matrix

$$A = \begin{bmatrix} 1+r & -\frac{1}{2}r & 0 & \cdots & 0 \\ -\frac{1}{2}r & 1+r & -\frac{1}{2}r & & \\ 0 & -\frac{1}{2}r & \ddots & \ddots & \\ & & \ddots & & -\frac{1}{2}r \\ 0 & & & -\frac{1}{2}r & 1+r \end{bmatrix}.$$

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14 Great Moments in LaTeX History

1986: First recorded use of the phrase 'typographically challenged' in reference to non-LaTeXusers.

1987: Student inadvertently writes PhD thesis completely in `tabular` environment.

1988: Leading mathematical journal rejects manuscript on the grounds that 'too many of the variables have fancy tildes over them.'

1989: Using "..." instead of `\ldots` becomes a criminal offence.

1989: Number of rain forests that could have been saved if people had bothered to make full use of LaTeX previewers reaches double figures.

1990: Killer strain of LaTeX evolves, replacing the '`Rerun to get cross-references right`' message with '`Do that again and I delete your files`'.

1991: •-overuse receives the official status of 'syndrome.'

1992: Somebody finally finds a use for the $\bowtie$ symbol.

1992: Extensive testing shows that 98.3% of the time no matter which of the `[h]`, `[t]`, `[b]` or `[p]` options is used, LaTeX will put your `table` at the end of the document.

1992: 'I `\heartsuit\␣\LaTeX`' car stickers go on sale.

1993: Over-zealous author publishes book in which every word appears in index.

1993: National survey reveals that 6 out of 10 LaTeX users think `\iota` will produce an extremely small space.

1994: Latest release of LaTeX includes the `\jargonfill` command, which fills the remainder of a page with impressive sounding technical phrases.

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