MATHEMATICAL TYPESETTING WITH LATEX

Knuth's statement on the purpose of TEX

> . . . This is a handbook about TEX, a new typesetting system intended for the creation of beautiful books—and especially for books that contain a lot of mathematics.

MATHEMATICAL TYPESETTING WITH LATEX

TEX'S PROCESSING MODES

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- **Paragraph mode: the default mode**
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  - **Inline mathematics**
  - **Displayed mathematics**

TEX'S PROCESSING MODES

- Paragraph mode: the default mode
- Math mode: when using mathematical symbols
- Left-to-right (LR) mode: like paragraph mode, but does not wrap around; it just keeps on going from left to right

EXAMPLES OF INLINE MATHEMATICS

- The square root of the number n is denoted $\sqrt{n}$ or $n^{1/2}$.
- According to Einstein, $E = mc^2$ where $\ldots$

EXAMPLES OF DISPLAYED MATHEMATICS

- **Some equations get displayed with an equation number as in**

  According to Einstein,
  $$E = mc^2 \tag{1}$$
  where ...

- **Some equations are displayed without an equation number as in**

  It follows from (1) that
  $$c = \sqrt{\frac{E}{m}}.$$

MATHEMATICAL TYPESETTING PACKAGES

LaTeX has many built-in mathematical typesetting features.

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- **Mathematical symbols such as**
  - **Greek letters (upper/lower case and variants)**
  - **calligraphic letters**
  - **diverse symbols (relations, arrows, operators, etc.)**
  - **log-like functions**

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- Delimiters (parentheses, brackets, curly brackets, etc.)
- **Arrays (especially matrices)**

MATHEMATICAL TYPESETTING PACKAGES

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But sometimes even more are needed.

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LaTeX has many built-in mathematical typesetting features.

But sometimes even more are needed.

This is where certain packages come in.

- **What other features could one want?**

MATHEMATICAL TYPESETTING PACKAGES

- **What other features could one want?**
  - **many more mathematical symbols**
  - **special mathematical fonts**
  - **special mathematical environments**

MATHEMATICAL TYPESETTING PACKAGES

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- **What packages are used for typesetting mathematics?**

MATHEMATICAL TYPESETTING PACKAGES

- What other features could one want?
- **What packages are used for typesetting mathematics?**
  - **latexsym**
  - **amsbsy**
  - **amsmath**
  - **amssymb**
  - **amsthm**
  - **amscd**

    $\vdots$

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- What packages are used for typesetting mathematics?
- **How about other packages of interest?**
  - **color**
  - **graphics**
  - **fancyhdr**
  - **showkeys**

    ⋮

MATHEMATICAL TYPESETTING PACKAGES

- What other features could one want?
- What packages are used for typesetting mathematics?
- How about other packages of interest?
- **How are packages invoked?**

  To load a package, put the command

  `\usepackage`$[options]\{pkgs\}$

  in your preamble.

GETTING INTO MATH MODE

Actually, there are two math modes:

- **inline**
- **displayed**

USING INLINE MATHEMATICS MODE

To insert inline mathematics into text in paragraph mode enclose the math between `\(` and `\)`.

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Thus, to produce

The area of a circle of radius r is πr^2.

you can type

```
The area of a circle of radius \( r \) is \( \pi r^2 \).
```

USING INLINE MATHEMATICS MODE

To insert inline mathematics into text in paragraph mode enclose the math between `\(` and `\)`.

As an alternative to using `\(` and `\)`, you can use `$` and `$`, that is, a pair of dollar signs as in

```
The area of a circle of radius $r$ is $ \pi r^2 $.
```

USING DISPLAYED MATHEMATICS MODE

To display mathematics (within text in paragraph mode) without an equation number, enclose the math between `\[` and `\]`.

Thus, to produce

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

you can type

```
\[ a^2 + b^2 = c^2 \]
```

USING DISPLAYED MATHEMATICS MODE

You can also display mathematics without an equation number by enclosing it in the `equation*` environment.

The previous equation can be typed as

```
\begin{equation*}
a^2 + b^2 = c^2
\end{equation*}
```

USING DISPLAYED MATHEMATICS MODE

You can also display mathematics without an equation number by enclosing it in the `equation*` environment.

To do this <u>with</u> an equation number, you type

```
\begin{equation}
a^2 + b^2 = c^2
\end{equation}
```

which produces

$$a^2 + b^2 = c^2 \tag{2}$$

SOME CHARACTERISTICS OF MATH MODE

- **Alphabetic characters are typeset in "math italic" font.**

  Thus, when you type `$x$` **LaTeX produces** x**.**

SOME CHARACTERISTICS OF MATH MODE

- Alphabetic characters are typeset in “math italic” font.

- Distinct adjacent (mathematical) symbols are not separated by space, even if they are typed with space between them. Thus

```
\[ 2    \times     2    =    4    .   \]
```

  becomes

$$2 \times 2 = 4.$$

SOME CHARACTERISTICS OF MATH MODE

- Alphabetic characters are typeset in “math italic” font.
- Distinct adjacent (mathematical) symbols are not separated by space, even if they are typed with space between them.
- **Typing distinct (mathematical) symbols together without space can sometimes lead to errors. Thus, typing `$\alphax$` instead of `$\alpha x$` will lead to an error statement.**

  Note that typing `$\alpha x$` produces αx.

MORE CHARACTERISTICS OF MATH MODE

- **Space between adjacent characters in math mode can be adjusted with spacing commands such as**

`\␣`	interword space
`\,`	thin space
`\!`	negative thin space
`\quad`	1 em space
`\qquad`	2 em space
`\hspace{len}`	horizontal space of length len

MORE CHARACTERISTICS OF MATH MODE

- Space between adjacent characters in math mode can be adjusted with spacing commands.
- Text set in other fonts can be used within math mode by means of the command `\mbox`. For example,

$$X = P + C \mbox{ (by Goldman's resolution theorem)}$$

was typed as

```
\[ X = P+C \mbox{ (by Goldman's resolution theorem)} \]
```

ALPHABETIC MATH FONTS

Lowercase Greek Alphabet

α	`\alpha`	ν	`\nu`
β	`\beta`	ξ	`\xi`
γ	`\gamma`	π	`\pi`
δ	`\delta`	ρ	`\rho`
ϵ	`\epsilon`	σ	`\sigma`
ζ	`\zeta`	τ	`\tau`
η	`\eta`	υ	`\upsilon`
θ	`\theta`	ϕ	`\phi`
ι	`\iota`	χ	`\chi`
κ	`\kappa`	ψ	`\psi`
λ	`\lambda`	ω	`\omega`

Note: There is no special command for the Greek letter omicron (o).

Variants of Lowercase Greek Letters

$\digamma$	`\digamma`	ϑ	`\vartheta`
ε	`\varepsilon`	$\varkappa$	`\varkappa`
ϱ	`\varrho`	ϖ	`\varpi`
φ	`\varphi`	ς	`\varsigma`

Note: Commands in this list beginning with `\var` **require the** `amsmath` **package.**

Uppercase Greek Letters and their Variants

Γ	`\Gamma`	$\varGamma$	`\varGamma`
Δ	`\Delta`	$\varDelta$	`\varDelta`
Θ	`\Theta`	$\varTheta$	`\varTheta`
Λ	`\Lambda`	$\varLambda$	`\varLambda`
Ξ	`\Xi`	$\varXi$	`\varXi`
Π	`\Pi`	$\varPi$	`\varPi`
Σ	`\Sigma`	$\varSigma$	`\varSigma`
Υ	`\Upsilon`	$\varUpsilon$	`\varUpsilon`
Φ	`\Phi`	$\varPhi$	`\varPhi`
Ψ	`\Psi`	$\varPsi$	`\varPsi`
Ω	`\Omega`	$\varOmega$	`\varOmega`

Note: Commands in this list beginning with `\var` **require the** `amsmath` **package.**

ALPHABETIC MATH FONTS

Math alphabet	Input	Output
math italic	`\mathit{a}`	a
math italic	`\mathnormal{a}`	$\mathnormal{a}$
math bold	`\mathbf{a}`	$\mathbf{a}$
math roman	`\mathrm{a}`	a
math sans serif	`\mathsf{a}`	a
math typewriter	`\mathtt{a}`	$\mathtt{a}$

ALPHABETIC MATH FONTS

Math alphabet	Input	Output
math italic	`\mathit{a}`	a
math italic	`\mathnormal{a}`	$\mathnormal{a}$

`(ordinary)` $abcdefghijklmnopqrstuvwxyz$

`\mathnormal` $\mathnormal{abcdefghijklmnopqrstuvwxyz}$

`\mathit` $\mathit{abcdefghijklmnopqrstuvwxyz}$

ALPHABETIC MATH FONTS

Bold math italic can be obtained by using the command `\boldsymbol{}` **within math mode.**

Thus

`$\boldsymbol{abcdefghijklmnopqrstuvwxyz}$`

produces

$\boldsymbol{abcdefghijklmnopqrstuvwxyz}$

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Bold math italic can be obtained by using the command `\boldsymbol{}` **within math mode.**

Thus

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produces

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Because `\boldsymbol` **is so much to type, I insert**
`\newcommand\bmi{\boldsymbol}`
in the preamble (of my root file).

ALPHABETIC MATH FONTS

This works for numerals too.

$\mathbf{0123456789}$

ALPHABETIC MATH FONTS

Math alphabet of symbols	Input	Output
calligraphic	`\mathcal{A}`	$\mathcal{A}$

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calligraphic	`\mathcal{A}`	$\mathcal{A}$

The command

`$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$`

produces

$\mathcal{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$

Math alphabet of symbols	Input	Output
math Fraktur	`\mathfrak{a}`	$\mathfrak{a}$
math Fraktur	`\mathfrak{A}`	$\mathfrak{A}$

ALPHABETIC MATH FONTS

Math fraktur font

The command

`$\mathfrak{abcdefghijklmnopqrstuvwxyz}$`

produces

$\mathfrak{abcdefghijklmnopqrstuvwxyz}$

and

`$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$`

produces

$\mathfrak{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$

Math alphabet of symbols	Input	Output
mathscr	`\mathscr{A}`	$\mathscr{A}$

Math alphabet of symbols	Input	Output
mathscr	`\mathscr{A}`	$\mathscr{A}$

The command,

`$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$`

produces

$\mathscr{ABCDEFGHIJKLMNOPQRSTUVWXYZ}$

ALPHABETIC MATH FONTS

Symbols commonly used for number systems:

Letter	Stands for
$\mathbb{N}$	**the natural numbers**
$\mathbb{Z}$	**the integers**
$\mathbb{R}$	**the real numbers**
$\mathbb{Q}$	**the rational numbers**
$\mathbb{C}$	**the complex numbers**

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The command

```
$\Bbb{NZRQC}$
```

produces

$\mathbb{NZRQC}$

SYMBOLIC MATH FONTS

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The standard set includes the following groups

- **Binary operations**
- **Binary relations**
- **Arrows**
- **Miscellaneous symbols**
- **Variable-sized symbols**
- **Log-like functions**

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The standard set includes the following groups

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See Lamport (Section 3.3) and Grätzer (Appendix A).

Binary operations

$+$	`$+$`	**addition**
$-$	`$-$`	**subtraction**
$\times$	`$\times$`	**multiplication**
$\div$	`$\div$`	**division**
$/$	`$/$`	**division (shilling form)**
$\ast$	`$\ast$`	**asterisk**
$\star$	`$\star$`	**star**
$\cup$	`$\cup$`	**set-theoretic union**
$\cap$	`$\cap$`	**set-theoretic intersection**
$\pm$	`$\pm$`	**plus or minus**
$\bullet$	`$\bullet$`	**bullet**

SYMBOLIC MATH FONTS: A SAMPLER

Binary relations

$=$	`$=$`	**equals**
$\neq$	`$\neq$`	**not equal to**
$<$	`$<$`	**less than**
$\leq$	`$\leq$`	**less than or equal to**
$>$	`$>$`	**greater than**
$\geq$	`$\geq$`	**greater than or equal to**
$\in$	`$\in$`	**element of**
$\subset$	`$\subset$`	**contained in (strictly)**
$\subseteq$	`$\subseteq$`	**contained in (possibly equals)**
$\supset$	`$\supset$`	**contains**
$\supseteq$	`$\supseteq$`	**contains (possibly equals)**
$\equiv$	`$\equiv$`	**equivalent to**
$\parallel$	`$\parallel$`	**parallel to**

Arrows

$\rightarrow$	`$\rightarrow$`
$\Rightarrow$	`$\Rightarrow$`
$\longrightarrow$	`$\longrightarrow$`
$\Longrightarrow$	`$\Longrightarrow$`
$\leftrightarrow$	`$\leftrightarrow$`
$\Leftrightarrow$	`$\Leftrightarrow$`
$\longleftrightarrow$	`$\longleftrightarrow$`
$\Longleftrightarrow$	`$\Longleftrightarrow$`
$\downarrow$	`$\downarrow$`
$\nearrow$	`$\nearrow$`
$\mapsto$	`$\mapsto$`

SYMBOLIC MATH FONTS: A SAMPLER

Variable-sized symbols

$\sum_{i=1}^n$	`$\sum_{i=1}^n$`	**in-text style**
$\displaystyle{\sum_{i=1}^n}$	`$\displaystyle{\sum_{i=1}^n}$`	
$\prod_{i=1}^n$	`$\prod_{i=1}^n $`	**in-text style**
$\displaystyle{\prod_{i=1}^n}$	`$\displaystyle{\prod_{i=1}^n}$`	
$\int_a^b$	`$\int_a^b $`	**in-line style**
$\displaystyle{\int_a^b}$	`$\displaystyle{\int_a^b}$`	

Miscellaneous symbols

$\emptyset$	`$\emptyset$`
∇	`$\nabla$`
$\|$	`$\|$`
$\forall$	`$\forall$`
$\exists$	`$\exists$`
$\backslash$	`$\backslash$`
∂	`$\partial$`
∞	`$\infty$`
ℓ	`$ \ell`

Variable-sized symbols

$\cup_{i=1}^n$	`$\cup_{i=1}^n$`	**in-line style**
$\displaystyle{\bigcup_{i=1}^n}$	`$\displaystyle{\bigcup_{i=1}^n}$`	
$\cap_{i=1}^n$	`$\cap_{i=1}^n$`	**in-line style**
$\displaystyle{\bigcap_{i=1}^n}$	`$\displaystyle{\bigcap_{i=1}^n}$`	

Log-like functions (operators)

$\sin$	`$\sin$`
$\arctan$	`$\arctan$`
$\cosh$	`$\cosh$`
$\arg$	`$\arg$`
$\log$	`$\log$`
$\ln$	`$\ln$`
$\det$	`$\det$`
$\dim$	`$\dim$`
$\max$	`$\max$`
$\inf$	`$\inf$`
$\limsup$	`$\limsup$`

HYPHENS, DASHES, AND MINUS SIGNS

- **Hyphens are used to:**
  - ⋆ **break multisyllabic words across lines**
  - ⋆ **create new words like "quasi-linear"**
  - ⋆ **make compound words like "wall-to-wall carpets"**
  - ⋆ **spell out numbers like "thirty-seven"**

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- **Dashes come in two lengths:**
  - ⋆ **the en dash – typed as** `--`
  - ⋆ **the em dash — typed as** `---`
- **Minus signs:**
  - ⋆ **are made by typing hyphens in math mode as in** `$-1$`
  - ⋆ **can be faked by typing an en dash in paragraph mode**

ALL SORTS OF DOTS

In addition to periods and bullets, there are several kinds of ellipses.

- **Plain ellipsis:** $\ldots$ **typed** `$\ldots$` **as in**

  A, B, C, . . . , Z (in paragraph mode) and

  $$f_i(x) \geq 0 \qquad \text{for all } i = 1, \ldots, n.$$

  in math mode

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- **Plain ellipsis:** $\ldots$ **typed** `$\ldots$`
- **Centered ellipsis:** $\cdots$ **typed** `$\cdots$` **as in**

$$p_1 + \cdots + p_k = 1.$$

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In addition to periods and bullets, there are several kinds of ellipses.

- **Plain ellipsis:** $\ldots$ **typed** `$\ldots$`
- **Centered ellipsis:** $\cdots$ **typed** `$\cdots$`
- **Vertical ellipsis:** $\vdots$ **typed** `$\vdots$` **as in**

$$x = \begin{pmatrix} x_1 \\ \vdots \\ x_n \end{pmatrix}.$$

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In addition to periods and bullets, there are several kinds of ellipses.

- **Plain ellipsis:** $\ldots$ **typed** `$\ldots$`
- **Centered ellipsis:** $\cdots$ **typed** `$\cdots$`
- **Vertical ellipsis:** $\vdots$ **typed** `$\vdots$`
- **Diagonal ellipsis:** $\ddots$ **typed** `$\ddots$` **as in**

$$D = \begin{pmatrix} \lambda_1 & & \\ & \ddots & \\ & & \lambda_n \end{pmatrix}.$$

ALL SORTS OF DOTS

In addition to periods, bullets, and ellipses, there are several other uses of dots.

These include:

- **math accents (embellishments)**
- **filling with dots**
- **shading**

DELIMITERS

Delimiters act something like parentheses: ( ).

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Some examples of delimiters are

$($	`$($`	$)$	`$)$`
$[$	`$[$`	$]$	`$]$`
$\{$	`$\{$`	$\}$	`$\}$`
$\backslash$	`$\backslash$`	$/$	`$/$`
$\langle$	`$\langle$`	$\rangle$	`$\rangle$`
$\lceil$	`$\lceil$`	$\rceil$	`$\rceil$`
$\lfloor$	`$\lfloor$`	$\rfloor$	`$\rfloor$`
$\ulcorner$	`$\ulcorner$`	$\urcorner$	`$\urcorner$`
$\llcorner$	`$\llcorner$`	$\lrcorner$	`$\lrcorner$`

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Generally speaking:

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Generally speaking:

- delimiters usually come in pairs (left and right)
- **curly braces are special**

Pairs of curly braces without the previous backslash are ignored by LaTeX, but can be very useful to the typist. In a sense, they act like insulation when no other delimiter is there to do the job.

`$\PhiBK$` **generates an error, whereas** `${\Phi}BK$` **does not.**

DELIMITERS

Delimiters act something like parentheses: ( ).

Generally speaking:

- delimiters usually come in pairs (left and right)
- curly braces are special
- **some delimiters are of fixed size**

DELIMITERS WITHOUT PARTNERS

The commands `\left` and `\right` must be used in pairs, but not necessarily with the same delimiter, as illustrated by

$$\left(\frac{a}{b}, \frac{c}{d}\right] .$$

DELIMITERS WITHOUT PARTNERS

The commands `\left` and `\right` must be used in pairs, but not necessarily with the same delimiter.

When `$\left\{$` is wanted, but `$\right\}$` is not, the latter can be replaced by `$\right.$` as done in

$$f(x) = \left\{ \begin{array}{lll} x^2+1 & \text{if} & x \geq 0 \\ 0 & \text{if} & x < 0 \end{array} \right.$$

MATH ACCENTS

Many accents used in non-English languages are available in LaTeX. For these there are commands that apply in paragraph mode.

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Many accents used in non-English languages are available in LaTeX.

But there are some special accents that are used in math mode. The standard ones are illustrated below on the letter x.

$\hat{x}$	`$\hat{x}$`	$\bar{x}$	`$\bar{x}$`
$\tilde{x}$	`$\tilde{x}$`	$\vec{x}$	`$\vec{x}$`
$\check{x}$	`$\check{x}$`	$\breve{x}$	`$\breve{x}$`
$\acute{x}$	`$\acute{x}$`	$\grave{x}$	`$\grave{x}$`
$\dot{x}$	`$\dot{x}$`	$\ddot{x}$	`$\ddot{x}$`

Other math accents (for example triple and quadruple dots) are available with the `amsmath` **package.**

BROADER MATH ACCENTS

Sometimes a wider hat or tilde is needed.

Compare

$\hat{X}$	`$\hat{X}$`	$\tilde{X}$	`$\tilde{X}$`

with

$\widehat{X}$	`$\widehat{X}$`	$\widetilde{X}$	`$\widetilde{X}$`

SOME MATH COMMANDS WITH ARGUMENTS

We have already used three math mode commands that take arguments.

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Two of these are

- **the square-root function**
- **the built-up fraction**

To illustrate:

`$\sqrt{x+1}$`	**yields**	$\sqrt{x+1}$
`$\frac{x+1}{y+3}$`	**yields**	$\frac{x+1}{y+3}$

SOME MATH COMMANDS WITH ARGUMENTS

We have already used three math mode commands that take arguments.

Two of these are

- the square-root function
- the built-up fraction

The third command is `\mbox{`*text*`}`**. For example**

```
\[ x^2 \geq 0 \qquad \mbox{for all } x \in \Bbb{R} \]
```

produces

$$x^2 \geq 0 \qquad \mbox{for all } x \in \mathbb{R}$$

SOME MATHEMATICAL ENVIRONMENTS

Among the most often used LaTeX environments for doing mathematical typesetting are

- **tabular**
- **array**
- **equation**
- **theorem (and other sorts of proclamations)**

SOME MATHEMATICAL ENVIRONMENTS

The `tabular` environment

- **does not require math mode to be in force, but it can be used in math mode**
- **arranges information by columns (and rows)**
- **puts the information in a given column in one of three positions: left, center, or right**
- **can put horizontal and vertical lines into the tabular material**
- **will allow a table within a table**
- **can put information into a subset of the columns**

EXAMPLE USING TABULAR ENVIRONMENT

BLOOD PRESSURE LOG

DATE	TIME	BLOOD PRESSURE		PULSE	
		SYSTOLIC	DIASTOLIC	MACHINE	MANUAL
8/22	1:25pm	137	83	60	63
8/23	1:30pm	147	72	56	61
8/24	1:31pm	115	75	60	65

EXAMPLE OF TABULAR FORM

TODAY'S GAMES AND PITCHERS

					LAST 3 STARTS		
		Pitcher	**W-L**	**ERA**	**W-L**	**IP**	**ERA**
Houston		Oswald (R)	14-6	3.35	1-0	17.1	3.63
at Mets	1:10p	Martinez (R)	1-0	3.60	1-0	5.0	3.60
Washington		Bergmann (R)	3-5	4.30	1-0	15.1	3.52
at Atlanta	1:05p	Cormier (R)	2-4	6.69	2-1	17.2	3.06
Milwaukee		Sheets (R)	11-4	3.36	1-0	15.1	2.93
at Cincinnati	1:15p	Dumatrait (L)	0-3	13.00	0-2	8.2	18.68
Chicago		Trachsel (R)	6-9	4.48	0-2	19.1	2.33
at Pittsburgh	1:35p	Morris (R)	8-9	4.54	1-1	16.2	4.86
Florida		Willis (L)	8-14	5.01	0-2	20.1	5.75
at Philadelphia	1:35p	Moyer (L)	12-11	5.13	1-2	16.1	6.61
San Diego		Young	9-6	2.63	0-2	13.1	9.45
at Colorado	3:05p	Fogg (R)	8-9	5.01	1-1	15.0	6.60
Los Angeles		Penny (R)	15-4	2.82	1-1	18.0	5.00
at San Francisco	4:05p	Cain (R)	7-14	3.83	2-1	16.2	4.32
St. Louis		Thompson (R)	6-5	5.07	0-1	15.0	5.40
at Arizona	4:40p	Davis (L)	13-11	3.98	3-0	20.2	2.16

SOME MATHEMATICAL ENVIRONMENTS

The `array` environment

- **is commonly used for typesetting matrices**
- **works like the tabular environment but for use in math mode**
- **allows for arrays within arrays**

Example of `array` environment

$$A = \left[\begin{array}{lcr} 0 & 0001 & 1 \\ 00 & 001 & 11 \\ 000 & 01 & 111 \end{array}\right]$$

which can be typed as

```
\[ A = \left[ \begin{array}{lcr}
0 & 0001 & 1 \\
00 & 001 & 11 \\
000 & 01 & 111
\end{array}\right] \]
```

Example of `matrix` environment

$$A = \left[\begin{matrix} 0 & 0001 & 1 \\ 00 & 001 & 11 \\ 000 & 01 & 111 \end{matrix} \right]$$

which can be typed as

```
\[ A = \left[ \begin{matrix}
0 & 0001 & 1 \\
00 & 001 & 11 \\
000 & 01 & 111
\end{matrix}\right] \]
```

Note: The `matrix` environment centers each column.

Example of nested arrays

$$\begin{array}{lc}
\mbox{minimize} & f(x) = \sum_{j = 1}^n f_j(x_j) \\ [10pt]
\mbox{subject to} & \begin{array}[t]{rcl}
g_i(x) = 0 & \quad & i = 1, \ldots, k \\ [10pt]
g_i(x) \geq 0 & & i = k+1, \ldots, m
\end{array}\end{array}$$

This was typed as follows.

```
\[ \begin{array}{lc}
\mbox{minimize} & f(x) = \sum_{j = 1}^n f_j(x_j) \\ [10pt]
\mbox{subject to} & \begin{array}[t]{rcl}
g_i(x) = 0 & \quad & i = 1, \ldots, k \\ [10pt]
g_i(x) \geq 0 & & i = k+1, \ldots, m
\end{array}\end{array}\]
```

More about equations

$$0 \neq 1 \tag{1}$$

Sometimes we need to group a batch of equations as in the following example.

The first-order (KKT) conditions of the quadratic program

$$\text{minimize } (1/2)x^T Dx + c^T x \quad \text{subject to } x \geq 0$$

are

$$\begin{gather} c + Dx \geq 0 \tag{2}\\ x \geq 0 \tag{3}\\ x^T(c + Dx) = 0 \tag{4} \end{gather}$$

For this we use the `gather` environment.

```
\begin{gather} c + Dx \geq 0\\x \geq 0\\x^T(c + Dx) = 0
\end{gather}
```

To group a batch of equations as "subequations" we use the `gather` **environment inside the** `subequations` **environment. Thus**

```
\begin{subequations}\begin{gather}
c + Dx \geq 0 \\
x \geq 0 \\
x^T(c + Dx) = 0
\end{gather}\end{subequations}
```

produces

$$c + Dx \geq 0 \tag{1a}$$

$$x \geq 0 \tag{1b}$$

$$x^T(c + Dx) = 0 \tag{1c}$$

Suppressing equation numbers

Sometimes it is desirable to omit some equation numbers while using the `gather` environment.

The command `\notag` or `\nonumber` at the end of an equation line will do this as in

```
\begin{subequations}\begin{gather}
c + Dx \geq 0 \\
x \geq 0 \notag \\
x^T(c + Dx) = 0
\end{gather}\end{subequations}
```

Multiline equations can be handled with `multline`. Thus

```
\begin{multline}
(x_1 + x_2 + x_3 + x_4)^2\\
=x_1^2 + x_2^2 + x_3^3 + x_4^2+2(x_1x_2 + x_1x_3 + x_1x_4)\\
+2(x_2x_3 + x_2x_4 + x_3x_4)
\end{multline}
```

gives

$$\begin{multline}(x_1 + x_2 + x_3 + x_4)^2\\ =x_1^2 + x_2^2 + x_3^3 + x_4^2+2(x_1x_2 + x_1x_3 + x_1x_4)\\ +2(x_2x_3 + x_2x_4 + x_3x_4) \tag{2}\end{multline}$$

SOME MATHEMATICAL ENVIRONMENTS

Defining theorem-like structures

- **Theorem**
- **Lemma**
- **Corollary**
- **Proposition**
- **Definition**
- **Remark**
- **Hypothesis**
- **Conjecture**

are often used in mathematical work.

SOME MATHEMATICAL ENVIRONMENTS

Defining theorem-like structures can be done with a declaration called `\newtheorem`.

Here is an example.

Defining theorem-like structures can be done with a declaration called `\newtheorem`**.**

Here is an example.

Suppose we have put the following declaration in the preamble of our document.

```
\newtheorem{prop}{Proposition}
```

SOME MATHEMATICAL ENVIRONMENTS

When a theorem-like structure is used to state something that calls for a proof, the `proof` **environment will produce the word "Proof" and put a little square (flush right) at the end of the argument in place of the old-fashioned "q.e.d."**

Using the `proof` **environment requires that the command** `\usepackage{amsthm}` **be added to the preamble of the document.**

Thus we can write

SOME MATHEMATICAL ENVIRONMENTS

Proposition 1. *LaTeX rocks!*

Proof. Left to the reader. $\square$

SOME MATHEMATICAL ENVIRONMENTS

Proposition 1. *LaTeX rocks!*

Proof. Left to the reader. □

This is gotten by typing

```
\begin{prop}  \LaTeX{} rocks! \end{prop}
\begin{proof} Left to the reader. \end{proof}.
```