A Crash Course on Typesetting Mathematics Using TeX & LaTeX

Yan-Bin Jia

Robotics Lab Meeting

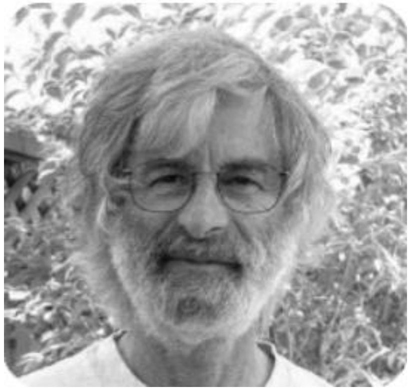
January 13, 2017

TeX and LaTeX

TeX is a typesetting system developed by Donald Ervin Knuth in 1978.

Donald Knuth (Stanford)

ACM Turing Award (1974)
National Medal of Science (1979)



Leslie Lamport (Microsoft Research)

ACM Turing Award (2013)

LaTeX, developed by Leslie Lamport, is a macro package based on TeX.

More than 90% of scientific publications today are written in LaTeX, or even in plain TeX.

* Photos from https://amturing.acm.org/byyear.cfm.

Overleaf: LaTeX Environment

https://www.overleaf.com/learn/latex/Environments

Advantages:

- ♦ Online collaborations of writers on the same document.
- ♦ Nothing to install.
- ♦ Intuitive writing platform.
- ♦ LaTeX help and documentation.

Disadvantage:

- ♠ Potential to plagiarize your work if someone hacks your Overleaf account or that of your coauthors'.

Structure of a LaTeX File `foo.tex`

```
\documentclass[11pt]{article}
\usepackage{epsfig}         % standard macros
…
\usepackage{my_def_env}     % user defined macros

\def\ubhat{\hat{\ub}}       % self-definitions

\title{Nonlinear Optimization\\ {\small (Com S 477/577 Notes)}}

\author{{\bf Yan-Bin Jia}}
\date{Nov 8, 2016}
```

Preamble

```
\begin{document}
\maketitle

\section{Introduction}
…
\section{Golden Section Search}
…
\section{Conclusion}
…
```

Main part

```
\begin{thebibliography}{9}
\bibitem{Luenberger}
D.~G. Luenberger.
\newblock {\em Linear and Nonlinear Programming}.
\newblock Addison-Wesley, 2nd edition, 1984.
…
\end{thebibliography}
\end{document}
```

Bibliography

Execution of a LaTeX File

commands in Linux

`foo.tex`

`latex foo.tex`

`foo.dvi, foo.aux, etc.`

`dvips -tletter -o foo.ps foo.dvi`

`foo.ps`

`ps2pdf foo.ps foo.pdf`

`foo.pdf`

Using BibTeX

BibTeX helps you create the bibliography part of the paper.

To make this work, you need to create in advance `.bib` files which include, for instance, all the papers and books you have read or plan to reference.

Sample BibTeX File `mech.bib`

```
@book{Newton1686,
author    =        "Issac Newton",
title     =        "Philosophiae Naturalis Principia Mathematica",
publisher=         "Royal Society Press, London",
year      =        1686
}

@article{Poisson1827,
author    =       "S.~D.~Poisson",
title     =       "Note sur I'Extension des Fils et des Plaques \'{e}lastiques",
journal   =       "Annales de Chimie et de Physique",
volume    =       36,
pages     =       "384-387",
year      =       1827
}

@article{Stronge90,
author    =       "W.~J.~Stronge",
title     =       "Rigid body collisions with friction",
journal   =       "Proceedings of the Royal Society of London A",
volume    =       431,
number    =       1881,
pages     =       "168--181",
year      =       1990
}
```

Sample LaTeX File `impact.tex`

```
\documentclass[10pt]{article}

\def\bibdir{/home/jia/research/readings}

\title{Analysis and Computation of Two Body Impact in Three Dimensions}

\author{Yan-Bin Jia and Feifei Wang
        Department of Computer Science\\
        Iowa State University\\
        Ames, IA 50011, USA \\
        Email: jia@iastate.edu
       }

\def\bibdir{/home/jia/research/readings}  % directory where the
                                           % bibtex files reside.

\begin{document}

\bibliography{\bibdir/mech}  % look up mech.bib for bibliography info
\bibliographystyle{plain}

\maketitle
```

Cont'd

```
\begin{abstract}
{\it A formal impulse-based analysis is presented ... }
\end{abstract}

\section{Introduction}

...

The impact problem cannot be solved under conservation of momentum alone. Three
hypotheses were introduced by Newton~\cite{Newton1686},
Poisson~\cite{Poisson1827}, and Stronge~\cite{Stronge90} to respectively
quantify the relationships between the pre- and post-impact velocities, between
the impulses accumulated during the two impact phases: compression and
restitution, and between the energies accumulated/released during these phases.

...

\end{document}
```

All the citation entries `Newton1686`, `Poisson1827`, and `Stronge90` are compiled into the file `impact.aux` when you run "`latex impact.tex`".

Generating the `.bbl` file

commands

`impact.tex`

⇓ `latex impact.tex`

`impact.aux`

⇓ `bibtex impact`

`impact.bbl`

`bibtex` will look up the file `mech.bib` for the entries `Newton1686`, `Poission1827`, and `Stronge90` to compile them under certain format into the file `impact.bbl`.

The File `impact.bbl`

```
\begin{thebibliography}{1}

\bibitem{Newton1686}
Issac Newton.
\newblock {\em Philosophiae Naturalis Principia Mathematica}.
\newblock Royal Society Press, London, 1686.

\bibitem{Poisson1827}
S.~D.~Poisson.
\newblock Note sur i'extension des fils et des plaques \'{e}lastiques.
\newblock {\em Annales de Chimie et de Physique}, 36:384--387, 1827.

\bibitem{Stronge90}
W.~J.~Stronge.
\newblock Rigid body collisions with friction.
\newblock {\em Proceedings of the Royal Society of London A},
  431(1881):168--181, 1990.

\end{thebibliography}
```

Cut-and-Paste

Append the contents of `impact.bbl` to `impact.tex`.

```
\section{Introduction}

...

The impact problem cannot be solved under conservation of momentum alone. Three
hypotheses were introduced by Newton~\cite{Newton1686},
Poisson~\cite{Poisson1827}, and Stronge~\cite{Stronge90} to respectively
quantify the relationships between the pre- and post-impact velocities, between
the impulses accumulated during the two impact phases: compression and
restitution, and between the energies accumulated/released during these phases.

...

\begin{thebibliography}{1}

\bibitem{Newton1686}
Issac Newton.
\newblock {\em Philosophiae Naturalis Principia Mathematica}.
\newblock Royal Society Press, London, 1686.
...
\end{thebibliography}
\end{document}
```

One Last Thing

Comment out the `biblilography` lines in `impact.tex`. Otherwise, the bibliography will be generated twice.

```
\begin{document}

%\bibliography{\bibdir/mech}  % look up mech.bib for bibliography info
%\bibliographystyle{plain}
```

Run LaTeX again

Execute a ... ng with

“latex i ... vi,

impact.p

Analysis and Computation of Two Body Impact in Three Dimensions

Yan-Bin Jia and Feifei Wang
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Iowa State University
Ames, IA 50011, USA
Email: jia,wangff@iastate.edu

January 14, 2017

Abstract

A formal impulse-based analysis is presented …

1 Introduction

...

The impact problem cannot be solved under conservation of momentum alone. Three hypotheses were introduced by Newton [1], Poisson [2], and Stronge [3] to respectively quantify the relationships between the pre- and post-impact velocities, between the impulses accumulated during the two impact phases: compression and restitution, and between the energies accumulated/released during these phases. ...

References

[1] Issac Newton. *Philosophiae Naturalis Principia Mathematica*. Royal Society Press, London, 1686.

[2] S. D. Poisson. Note sur i'extension des fils et des plaques élastiques. *Annales de Chimie et de Physique*, 36:384–387, 1827.

[3] W. J. Stronge. Rigid body collisions with friction. *Proceedings of the Royal Society of London A*, 431(1881):168–181, 1990.

Including Figures

♠ TeX/LaTeX is not friendly with drawing figures.

- Drawing commands are limited and clumsy to use.
- It does not follow the What You See Is What You Get (WYSIWYG) principle.

♦ Generate figures/images using a different software.

- Within Windows you may draw one using PowerPoint, print the screen, and then paste it within Paint for clipping.
- Within Linux or Ubuntu, you could use Xfig or some other drawing program.

…

♦ Insert the generated images into LaTeX. Refer to instructions below:

https://www.overleaf.com/learn/latex/Inserting_Images

Spacings

3 inches = 1000 pixels
1 inch = 72 pts
1em = current font size (10pt, 12pt)
\quad = 1 em
\qquad = 2 quads

\, (thin space) = 1/6 of a quad
\; (thick space) = 5/18 of a quad
\> (medium space) = 2/9 of a quad
\! (negative thin space) = -1/6 of a quad

```
\begin{center}
$\sin \theta$\\
$\sin \!  \theta$\\
$\sin \,  \theta$\\
$\sin \>  \theta$\\
$\sin \;  \theta$\\
$\sin \quad  \theta$\\
$\sin \qquad \theta$
\end{center}
```

$$\sin \theta$$
$$\sin \! \theta$$
$$\sin \, \theta$$
$$\sin \> \theta$$
$$\sin \; \theta$$
$$\sin \quad \theta$$
$$\sin \qquad \theta$$

Math Blackboard Fonts

For representing sets of numbers

To use it, include in the preamble of your latex file:

```
\usepackage{amssymb}
```

`$\mathbb{N}$`	$\mathbb{N}$
`$\mathbb{Z}$`	$\mathbb{Z}$
`$\mathbb{Q}$`	$\mathbb{Q}$
`$\mathbb{R}$`	$\mathbb{R}$
`$\mathbb{c}$`	$\mathbb{C}$

The symbols

`$\Re(z)$`	$\Re(z)$
`$\Im(z)$`	$\Im(z)$

denote real and imaginary parts of a complex number.

Vectors

A vector is usually in bold face.

```
\[
\mathbf{v} = {2\choose 3}
\]
```

$$\mathbf{v} = {2\choose 3}$$

But it is bold and roman. How to make it bold and italic?

```
\[
\mbox{\boldmath $v$} = {2\choose 3}
\]
```

$$\boldsymbol{v} = {2\choose 3}$$

To Make Life Easier

Define `\vb` in the preample or in a style file

```
\def\vb{\mbox{\boldmath $v$}}
```

Then simply use

```
\[
\vb = {2\choose 3}
\]
```

$$\boldsymbol{v} = {2 \choose 3}$$

Alternative

To access bold symbols in math mode:

```
\usepackage{bm}
```

```
\[
{\bm v} = {2\choose 3}
\]
```

$$\boldsymbol{v} = \binom{2}{3}$$

Norm of a Vector

Arc length of a curve

```
\[
s = \int || \alpha'(t)|| \, dt
\]
```

$$s = \int ||\alpha'(t)||\, dt$$

Spacing between the two vertical lines is not good. Use `\|` instead.

```
\[
s = \int \| \alpha'(t)\| \, dt
\]
```

$$s = \int \|\alpha'(t)\|\, dt$$

Angle Brackets to Represent a Sequence

```
\[
< s_1, s_2, s_3 >
\]
```

$$< s_1, s_2, s_3 >$$

Bad spacing!

Use

```
\[
\langle s_1, s_2, s_3 \rangle
\]
```

$$\langle s_1, s_2, s_3 \rangle$$

Subscripts and Superscripts

```
\[
x^2
\]
```

$$x^2$$

```
\[
2^{2^{2^n}}
\]
```

$$2^{2^{2^n}}$$

```
\[
x_2^{90}
\]
```

$$x_2^{90}$$

```
\[
p(x) = a_n x^n + a_{n-1} x^{n-1} + \cdots + a_1 x + a_0
\]
```

$$p(x) = a_n x^n + a_{n-1} x^{n-1} + \cdots + a_1 x + a_0$$

Mnemonic Subscripts

```
\[
E_{min}
\]
```

$$E_{min}$$

The appearance suggests that E has three indices m, i, n, whereas you mean to have one word as a subscript.

Instead, use

```
\[
E_{\rm min}
\]
```

$$E_{\rm min}$$

Bold Subscripts

Add `\usepackage{bm}` to use `\bm`.

```
$T_{\bm p} M$: tangent space of a surface $M$ at a
point $\pb$ on $M$.
```

$T_{\boldsymbol{p}}M$: tangent space of a surface M at a point $\boldsymbol{p}$ on M.

`\boldmath` will not reduce to subscript size.

```
$T_{\mbox{\boldmath $p$}} M$
```

$$T_{\boldsymbol{p}}M$$

Bold Subscripts (cont'd)

```
$\nabla_{\hat{\bm t}} \hat{\bm n}$: covariant derivative of
the unit normal field $\hat{\bm n}$ on a surface with
respect to a unit tangent vector $\hat{\bm t}$.
```

$\nabla_{\hat{\boldsymbol t}} \hat{\boldsymbol n}$: covariant derivative of the unit normal field $\hat{\boldsymbol n}$ on a surface with respect to a unit tangent vector $\hat{\boldsymbol t}$.

Sets

```
$\{1, 2, 3\}$
```

$$\{1,2,3\}$$

too crowded

$

Integrals

```
\[
\int_0^t \|\alpha'(u)\|  du
\]
```

$$\int_0^t \|\alpha'(u)\|du$$

Need some space here!

```
\[
\int_0^t \|\alpha'(u)\| \, du
\]
```

$$\int_0^t \|\alpha'(u)\|\,du$$

Double Integrals

```
\[
\int\int_{{\rm int}(\alpha)} \left({\partial g\over
\partial x}
- {\partial f\over \partial y}\right)\, dx dy =
\int_{\alpha} f(x, y) \, dx + g(x, y) \, dy.
\]
```

$$\int\int_{\mathrm{int}(\alpha)} \left(\frac{\partial g}{\partial x} - \frac{\partial f}{\partial y}\right)\, dx dy = \int_{\alpha} f(x,y)\, dx + g(x,y)\, dy.$$

✗

```
\[
\int\!\!\!\int_{{\rm int}(\alpha)} \left({\partial g\over
\partial x}
- {\partial f\over \partial y}\right)\, dx \, dy \;\;=\;\;
\int_{\alpha} f(x, y) \, dx + g(x, y) \, dy.
\]
```

$$\int\!\!\!\int_{\mathrm{int}(\alpha)} \left(\frac{\partial g}{\partial x} - \frac{\partial f}{\partial y}\right)\, dx\, dy \;\;=\;\; \int_{\alpha} f(x,y)\, dx + g(x,y)\, dy.$$

Display Style vs Text Style

```
The sum $\sum_{i=1}^n {1\over i}$ is a Harmonic number.
```

The sum $\sum_{i=1}^n {1\over i}$ is a Harmonic number.

```
The sum $\displaystyle \sum_{i=1}^n {1\over i}$ is a Harmonic number.
```

The sum $\displaystyle \sum_{i=1}^n {1\over i}$ is a Harmonic number.

```
The sum
\[
\sum_{i=1}^n {1\over i}
\]
is a Harmonic number.
```

The sum

$$\sum_{i=1}^n {1\over i}$$

is a Harmonic number.

Cont'd

```
\[
\Delta I_2 \leq - {m_2 h \over 1 + {k_1\over k_2} (1 + m_2)}
\]
```

$$\Delta I_2 \leq - {m_2 h \over 1 + {k_1\over k_2} (1 + m_2)}$$

```
\[
\Delta I_2 \leq - {m_2 h \over 1 + {\displaystyle
{k_1\over k_2}} (1 + m_2)}
\]
```

$$\Delta I_2 \leq - {m_2 h \over 1 + {\displaystyle {k_1\over k_2}} (1 + m_2)}$$

Parentheses

```
\[
\gammab(s) = (a\cos {s\over c}, a\sin{s\over c}, {bs\over c})
\]
```

$$\gamma(s) = (a\cos\frac{s}{c}, a\sin\frac{s}{c}, \frac{bs}{c})$$

Parentheses too small!

Nested Parentheses

```
\[
\Bigg(1 + \bigg(2 + \Big(3 + (4 + 5) \Big) \bigg) \Bigg)
\]
```

$$\Bigg(1 + \bigg(2 + \Big(3 + (4 + 5) \Big) \bigg) \Bigg)$$

Equation Alignment

```
\begin{eqnarray*}
f_1(x_1, x_2, \ldots, x_n) & = & 0 \\
f_2(x_1, x_2, \ldots, x_n) & = & 0 \\
                           & \vdots & \\
f_n(x_1, x_2, \ldots, x_n) & = & 0
\end{eqnarray*}
```

* means no numbering of equations.

$$\begin{aligned} f_1(x_1, x_2, \ldots, x_n) &= 0 \\ f_2(x_1, x_2, \ldots, x_n) &= 0 \\ &\vdots \\ f_n(x_1, x_2, \ldots, x_n) &= 0 \end{aligned}$$

Referencing Equations

```
\begin{eqnarray}
```
No *. Number equations.

```
f_1(x_1, x_2, \ldots, x_n) & = & 0 \nonumber \\
f_2(x_1, x_2, \ldots, x_n) & = & 0 \nonumber \\
                           & \vdots & \label{eqn:system} \\
f_n(x_1, x_2, \ldots, x_n) & = & 0 \nonumber
\end{eqnarray}

The system~(\ref{eqn:system}) consists of~$n$ equations in~$n$ variables.
```

$$\begin{aligned} f_1(x_1, x_2, \ldots, x_n) &= 0 \\ f_2(x_1, x_2, \ldots, x_n) &= 0 \\ &\vdots \\ f_n(x_1, x_2, \ldots, x_n) &= 0 \end{aligned} \qquad (5)$$

The system (5) consists of n equations in n variables.

Equation Spanning Multiple Lines

```
\begin{eqnarray}
f(\xb) & = & f(\xb^*) + \left( {\partial f \over \partial x_1}(\xb^*) (x_1-x_1^*)
   + \cdots + {\partial f \over \partial x_n}(\xb^*) (x_n-x_n^*)\right)
   \nonumber \\
& &  + \, {1\over 2}\left({\partial^2 f\over \partial x_1^2}(\xb^*) (x_1 - x_1^*)^2
   + {\partial^2 f\over \partial x_1 \partial x_2}(\xb^*) (x_1 - x_1^*) (x_2 -x_2^*)
   + \cdots + {\partial^2 f\over \partial x_n^2}(\xb^**) (x_n - x_n^*)^2
   \right)  \nonumber \\
& & + \, \cdots \nonumber \\
& = & f(\xb^*) + \nabla f(\xb^*) (\xb - \xb^*) + {1\over 2}(\xb-\xb^*)^T
H(\xb^*)(\xb-\xb^*)  + O\Bigl(\|\xb-\xb^*\|^3\Bigr).  \label{eqn:taylor}
\end{eqnarray}
```

$$
\begin{aligned}
f(\boldsymbol{x}) &= f(\boldsymbol{x}^*) + \left(\frac{\partial f}{\partial x_1}(\boldsymbol{x}^*)(x_1 - x_1^*) + \cdots + \frac{\partial f}{\partial x_n}(\boldsymbol{x}^*)(x_n - x_n^*) \right) \\
&\quad + \frac{1}{2}\left(\frac{\partial^2 f}{\partial x_1^2}(\boldsymbol{x}^*)(x_1 - x_1^*)^2 + \frac{\partial^2 f}{\partial x_1 \partial x_2}(\boldsymbol{x}^*)(x_1 - x_1^*)(x_2 - x_2^*) + \cdots + \frac{\partial^2 f}{\partial x_n^2}(\boldsymbol{x}^*)(x_n - x_n^*)^2 \right) \\
&\quad + \cdots \\
&= f(\boldsymbol{x}^*) + \nabla f(\boldsymbol{x}^*)(\boldsymbol{x} - \boldsymbol{x}^*) + \frac{1}{2}(\boldsymbol{x} - \boldsymbol{x}^*)^T H(\boldsymbol{x}^*)(\boldsymbol{x} - \boldsymbol{x}^*) + O\Bigl(\|\boldsymbol{x} - \boldsymbol{x}^*\|^3\Bigr). \qquad (6)
\end{aligned}
$$

Usage of Tilde ~ (1)

- Prevent line breaking

A new line should not start with a mathematical variable, symbol, or formula. To prevent line breaking, add a tilde (~) to join the variable with its preceding word.

```
In physics, the letter~$a$ often denotes acceleration.
```

↑

no line breaking before a

In physics, the letter a often denotes acceleration.

Usage of Tilde ~ (2)

- Prevent addition of extra space

  Extra blank space is inserted following a period which LaTeX thinks would end a sentence by default.

`D. E. Knuth`	✗	D. E. Knuth
`D.~E.~Knuth`	✓	D. E. Knuth

Usage of Tilde ~ (3)

- Prevent line breaking before a citation.

```
The impact problem cannot be solved under conservation of momentum alone. Three
hypotheses were introduced by Newton~\cite{Newton1686},
Poisson~\cite{Poisson1827}, and Stronge~\cite{Stronge90} to respectively
quantify the relationships between the pre- and post-impact velocities, between
the impulses accumulated during the two impact phases: compression and
restitution, and between the energies accumulated/released during these phases.
```

Never Starts a Sentence with a Math Variable or Symbol

```
$a$ denotes acceleration.
```

a denotes acceleration. ✗

Rephrase the sentence as

```
Denote by~$a$ acceleration.
```

Denote by a acceleration.

or

```
We use~$a$ to denote acceleration.
```

We use a to denote acceleration.

Fractions

```
\[a + b \over 2\]
```

$$\frac{a+b}{2}$$

```
\[
{{a\over b}\over 2}
\]
```

$$\frac{\frac{a}{b}}{2}$$

✗

```
\[
{{a/b}\over 2}
\]
```

$$\frac{a/b}{2}$$

✓

Continued Fractions

```
\[
{a_0 + {1 \over {a_1 + {1\over {a_2 +
{1 \over  {a_3 + {1\over a_4}} }}}}}}
\]
```

$$a_0 + {1 \over {a_1 + {1\over {a_2 + {1 \over {a_3 + {1\over a_4}} }}}}}$$

```
\[
{a_0 + {\displaystyle 1 \over  {a_1 +
{1\over {\displaystyle a_2 + \displaystyle
{1\over {\displaystyle a_3 + {1\over a_4}} }}}}}}
\]
```

$$a_0 + {\displaystyle 1 \over {a_1 + {1\over {\displaystyle a_2 + \displaystyle {1\over {\displaystyle a_3 + {1\over a_4}} }}}}}$$

Either display may look okay depending on the rest of the equation.

\choose

Binomial coefficient:

```
\[
m+2 \choose n
\]
```

$$\binom{m+2}{n}$$

Also convenient for describing a column vector with two entries.

```
\[
x \choose y
\]
```

$$\binom{x}{y}$$

\atop

\atop is like \over without the fraction line.

```
\[
x^2 + 2x + 1 \atop x + 1
\]
```

$$x^2 + 2x + 1 \atop x + 1$$

Square Root

```
\[
\sqrt{ 1 + \sqrt{1 + \sqrt{1+ \sqrt{1 + \sqrt{1 + x}}} }}
\]
```

$$\sqrt{1+\sqrt{1+\sqrt{1+\sqrt{1+\sqrt{1+x}}}}}$$

Delimiters

```
\[
\pi(n) = \sum_{m=2}^n \lfloor
(\sum_{k=1}^{m-1} \lfloor (m/k) / \lceil m/k \rceil \rfloor)^{-1}
\rfloor
\]
```

$$\pi(n) = \sum_{m=2}^{n} \lfloor (\sum_{k=1}^{m-1} \lfloor (m/k)/\lceil m/k \rceil \rfloor)^{-1} \rfloor$$

X

Standard Functions

```
\[
sin(\alpha + \beta) = sin(\alpha) cos(\beta) + cos(\alpha) sin(\beta)
\]
```

$$sin(\alpha + \beta) = sin(\alpha)cos(\beta) + cos(\alpha)sin(\beta)$$

``sin'' is typeset as the product of three variables s, i, n.

Function Name by Meaning

Typeset such name in the Roman font.

```
\[
gcd(p, q) = gcd(q, r)
\]
```

$$gcd(p, q) = gcd(q, r)$$

✗

g,c,d are typeset as three multiplied variables!

✓

Multi-letter ``Identifiers''

```
\[
\it last = first
\]
```

$$\it last = first$$

```
\[
available + \sum_{i=1}^n \max \Big( full(i), reserved(i)\Big)
= capacity
```

Ellipses

`$(x_1, ..., x_n)$`	$(x_1, ..., x_n)$	X
`$(x_1, \ldots, x_n)$`	$(x_1, \ldots, x_n)$	
`$x_1 + \cdots + x_n$`	$x_1 + \cdots + x_n$	
`$x_1 = \cdots = x_n = 0$`	$x_1 = \cdots = x_n = 0$	

Matrices (I)

```
\[
\left(
\begin{array}{cc}
1 & 2 \\
3 & 4
\end{array}
\right)
\]
```

$$\left(\begin{array}{cc} 1 & 2 \\ 3 & 4 \end{array}\right)$$

Matrices (II)

```
\[
H(\xb) =
\left(\begin{array}{cccc}
{\partial^2 f\over \partial x_1^2} & {\partial^2 f\over \partial x_1\partial x_2}
& \cdots & {\partial^2 f\over \partial x_1\partial x_n} \\[.1in]
{\partial^2 f\over \partial x_2\partial x_1} & {\partial^2 f\over \partial x_2^2}
& \cdots & {\partial^2 f\over \partial x_2\partial x_n} \\[.1in]
\vdots & \vdots & \ddots & \vdots \\
{\partial^2 f\over \partial x_n\partial x_1} & {\partial^2 f\over \partial
x_n\partial x_2} & \cdots & {\partial^2 f\over \partial x_n^2}
\end{array}\right)
\]
```

Hessian of f:

$$H(x) = \left(\begin{array}{cccc}
\frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_1 \partial x_n} \\[.1in]
\frac{\partial^2 f}{\partial x_2 \partial x_1} & \frac{\partial^2 f}{\partial x_2^2} & \cdots & \frac{\partial^2 f}{\partial x_2 \partial x_n} \\[.1in]
\vdots & \vdots & \ddots & \vdots \\
\frac{\partial^2 f}{\partial x_n \partial x_1} & \frac{\partial^2 f}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_n^2}
\end{array}\right)$$

A Big Matrix

```
\begin{equation*}
{\partial \fb\over\partial \xb} = {1\over 2}
\left( \begin{array}{cc|cc|ccc|c}
0 & -\wb^T & \multicolumn{2}{c|}{\multirow{2}*{\Huge $0$}} &
\multicolumn{3}{c|}{-\rb^T} & \multirow{2}*{\Huge $0$} \\
\wb & - \wb\times & & & \multicolumn{3}{c|}{r_0 I_3 + \rb \times} & \\[.1in]\hline
& & & & & & & \\
0 & -\vb^T & 0 & -\omegab^T & \multicolumn{3}{c|}{-\sb^T} & -\rb^T \\
\vb & \vb\times & \omegab & -\omegab\times &
\multicolumn{3}{c|}{s_0I_3 + \sb\times} & r_0 I_3 -\rb \times \\[.1in]\hline
& & & & & & & \\
\multicolumn{2}{c|}{\multirow{3}*{\Huge $0$}} &
\multicolumn{2}{c|}{\multirow{3}*{\Huge $0$}} &
0 & {\displaystyle 2\omega_z{I_2-I_3\over I_1}} &
{\displaystyle 2\omega_y{I_2-I_3\over I_1}} & \multirow{3}*{\Huge $0$} \\[.1in]
& & & & {\displaystyle 2w_z{I_3 - I_1\over I_2}}  & 0 &
{\displaystyle 2w_x{I_3 - I_1\over I_2}}  & \\[.1in]
& & & & {\displaystyle 2w_y{I_1 - I_2\over I_3}}  &
{\displaystyle 2w_x{I_1 - I_2\over I_3}}  & 0 & \\[.1in]
\hline \multicolumn{2}{c|}{\multirow{3}*{\Huge $0$}} &
\multicolumn{2}{c|}{\multirow{3}*{\Huge $0$}} &
\multicolumn{3}{c|}{\multirow{3}*{\Huge $0$}} &
\multicolumn{1}{c}{\multirow{3}*{\Huge $0$}} \\
& & & & & & &
\end{array} \right)
\end{equation*}
```

Cont'd

$$
\frac{\partial f}{\partial x} = \frac{1}{2}
\left(\begin{array}{c|c|c|c}
\begin{matrix} 0 & -w^T \\ w & -w\times \end{matrix} & 0 & \begin{matrix} -r^T \\ r_0 I_3 + r\times \end{matrix} & 0 \\
\hline
\begin{matrix} 0 & -v^T \\ v & v\times \end{matrix} & \begin{matrix} 0 & -\omega^T \\ \omega & -\omega\times \end{matrix} & \begin{matrix} -s^T \\ s_0 I_3 + s\times \end{matrix} & \begin{matrix} -r^T \\ r_0 I_3 - r\times \end{matrix} \\
\hline
0 & 0 & \begin{matrix} 0 & 2\omega_z \frac{I_2 - I_3}{I_1} & 2\omega_y \frac{I_2 - I_3}{I_1} \\ 2w_z \frac{I_3 - I_1}{I_2} & 0 & 2w_x \frac{I_3 - I_1}{I_2} \\ 2w_y \frac{I_1 - I_2}{I_3} & 2w_x \frac{I_1 - I_2}{I_3} & 0 \end{matrix} & 0 \\
\hline
0 & 0 & 0 & 0
\end{array}\right)
$$

Fine Tuning

For more fine points of mathematical typesetting, check out Chapters 16 – 19 of the book by Donald Knuth.