# When grace meets beauty – LaTeX meets mathematics

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## Contents

# When grace meets beauty – LaTeX meets mathematics

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**Abstract:** [2] This essay is about using LaTeX wisely, for writing mathematics oriented documents. It presents a quick overview of LaTeX as a tool for creating mathematical documents, and then, gives you some examples of the facilities provided by LaTeX . It also includes a whole lot of mathematical expressions created using LaTeX . The author hopes that this paper will help you make mathematics, enjoyable for more people.

## 1 Preamble

```
An equation, for me, has no meaning,
unless it expresses a thought of God.
```

Srinivasa Ramanujan

Students (and teachers) of mathematics are aware of the inherent beauty of mathematics. They have learnt to appreciate what many people cannot see – a new form of beauty which pleases the mind and soothes the senses. However, they were till recently, handicapped by not being able to give a visual representation to this beauty. They could see this beauty, only with their "inward eye" (thank you, Mr. Wordsworth), but could not show it out to others who wanted something more visible. That was till Prof. D E Knuth decided to do something remarkable. He set to work, and created TeX. Since then, hundreds of thousands of documents have come up using TeX, and its younger avatar – LaTeX . This paper is a recap of just some of the features of these two remarkable tools, as seen by a lover (and teacher) of mathematics. It will also give you hints on how to use these tools wisely.

[2]This is a Technical Report of Algologic Research and Solutions. The LaTeX source of this document , as well as the rendered version (pdf file) can be obtained from dr-partha@gmail.com Please quote the reference code and date given above.

# 2 A thing of beauty ..

Try making the following maths, using your favourite word-processor. You will know why, it pays to use LaTeX .

LaTeX offers several symbols and artifacts for expressing mathematics. [7] and [8] list more than 5000 symbols, in a well-catalogued and structured form. You can see the commands, as well as the rendered form of these symbols. Since it would be impossible to demonstrate all these symbols in this article, we have shown just a few symbols and their usage, below. In addition, we will also see the various facilities which LaTeX offers to the mathematician.

It is easy to introduce diacritical marks (accent marks) in your text, like this: *Le café français est très bon à cause de son goût. A Noël, tout le monde boit du café.*

## 2.1 Ugly maths

$a = b + c$
$c + d = e$

This is how schoolchildren write maths. Grownups do not write like this. They use LaTeX , to produce neat looking maths texts. They just tell LaTeX what they want, and LaTeX does all the hard work automatically and silently.

## 2.2 Lovely maths (thanks to LaTeX)

LaTeX makes it easy to create lovely maths texts. All the alignment and positioning work is done by LaTeX . You have to worry, just about your maths.

$$a = b + c \tag{1}$$
$$c + d = e \tag{2}$$
$$x = \frac{1}{a + b} \tag{3}$$
$$x = \frac{a}{(b + c + d)} \tag{4}$$
$$x = \frac{(p + q + r + s/c) + \sum_{i=0}^{n} i^3}{a + f} + \sum_{i=0}^{n} (k_0)^{3/5} \tag{5}$$

Notice the neat vertical alignment of the equations. In each equation, notice the centering of the numerator with respect to the denominator. Notice the length of the horizontal fraction-separator line. Notice the size of the sigma symbol. Notice its positioning. Notice the size and positioning of the limits of the sigma. Notice that equations are numbered (you can choose to temporarily stop the numbering). All this is *automatically set* by LaTeX

# 3 An example of clumsy expressions

The following example has been borrowed from [11].

A list of commonly encountered bad LaTeX usage can be found in [12]

## 3.1 Clumsy maths

Reckless usage of LaTeX impacts the clarity and visual appeal of your maths expressions.

$$\begin{aligned} \max \sum_{i \in V} x_i \\ x_i + x_j \leq 1, \forall \{i, j\} \in E \\ x_i \in \{0, 1\}, \forall i \in V \end{aligned}$$

What's wrong with this?
In the above expression:

1. It would be helpful to use a period at the end to denote the conclusion of this mathematical "sentence."

2. The ragged left side of the formulation looks ugly.

3. The quantifiers $\forall$ to the right are too close to the constraints.

## 3.2 Not-so-clumsy maths

A little more thoughtfulness, and proper usage of spacing and alignment will create a more neat-looking expression.

$$\begin{aligned} &\max \sum_{i \in V} x_i && \\ &x_i + x_j \leq 1 && \forall \{i, j\} \in E \\ &x_i \in \{0, 1\} && \forall i \in V. \end{aligned}$$

# 4 Common maths expressions

## 4.1 Fractions

You can make some exotic fractions yourself, like this ::

$$m = \frac{\frac{1}{x} + \frac{1}{y}}{y - z} \tag{6}$$

Or, like this ::

$$1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \cfrac{1}{1 + \dots}}}}} \tag{7}$$

Do you see any "gold" in the above equation ? Well, Barwise and Moss [1] did. This weird looking fraction, is indeed the famous and fascinating *golden ratio*. See [2] for a discussion on the *golden ratio*.

A detailed guide on using LaTeX for creating mathematically rich documents can be found in [9]. There are some simple dos and don'ts for using mathematical style in LaTeX . These are listed in [10]

## 4.2 Spacing and sizing

The mathematically gifted writer will be able express his ideas in the most beautiful fashion since all the sizing and positioning is done automatically by LaTeX .

Notice that $\sqrt[3]{x * y}$ looks different from $\sqrt[3]{\frac{x*y}{p+q+r-f}}$

which is different from

$$\sqrt[7]{\frac{\sqrt[5]{\frac{a+b+c}{d-e-f}}}{\sqrt[3]{\frac{x*y}{p+q+r-f}}}} * (x+y)^{(w+z)}$$

Notice that the size of the individual variables x, y, z etc. gets automatically adjusted. The size of the root symbol gets adjusted automatically. The length of the separator used in fractions (the horizontal line) varies automatically, according to the size of the fraction. The superscript size is smaller than the normal size.

## 4.3 Case statement

In maths, one often needs to enumerate cases. Here is an example (using `cases` environment):

$$P_{(r-j)} = \begin{cases} 0 & \text{if } r-j \text{ is odd,} \\ r! & \text{if } r-j \text{ is even,} \\ 1 & \text{if } r-j \text{ is } 0 \end{cases} \tag{8}$$

Notice that the above is given a single equation number (automatically).

That is not all !

## 4.4 Equations

Equations form the heartbeat of many mathematical narrations. LaTeX offers many facilities for displaying equations.

### 4.4.1 Plain equations, with or without numbering

Equations are numbered automatically. You can turn ON or turn OFF equation numbering. The numbering is useful when equations are cross-referenced later on in the text.

Write a numbered equation ::

$$\sin^2(x) + \cos^2(x) = 1 \tag{9}$$

..and an equation without number :

$$\sin(x+y) = \sin(x)\cos(y) + \cos(x)\sin(y)$$

When you put equations just behind one another (with or without equation numbers), remember to align them with each other. Use the `align` environment:

$$\begin{align}
\sin^2(x) + \cos^2(x) = 1 \tag{10}\\
\sin(x+y) &= \sin(x)\cos(y) + \cos(x)\sin(y) \tag{11}\\
\cos(x+y) &= cos(x)cos(y) - sin(x)sin(y) \tag{12}
\end{align}$$

### 4.4.2 Boxed equations

You can display plain equations like above (with or without equation numbers), or put them in boxes (to highlight some of them).

Put the equation in a box (and numbering outside) ::

$$\boxed{x^2 + y^2 = z^2} \tag{13}$$

Put the equation in a box (and NO numbering outside) ::

$$\boxed{x^2 + y^2 = z^2}$$

Or put a whole line (with numbering) in the box ::

$$x^2 + y^2 = z^2 \tag{14}$$

A boxed equation without numbers ...

$$x^2 + y^2 = z^2$$

Now put two equations in the box :

Solution of a quadratic equation : $m_1x^2 + m_2x + m_3 = 0$

$$\begin{align}
x_1 &= - {}^1/_2\ \frac{m_2}{m_1} + \frac{\sqrt{(m_2 + 2\sqrt{m_1.m_3}).(m_2 - 2\sqrt{m_1.m_3})}}{2.m_1} \tag{15}\\
x_2 &= - {}^1/_2\ \frac{m_2}{m_1} - \frac{\sqrt{(m_2 + 2\sqrt{m_1.m_3}).(m_2 - 2\sqrt{m_1.m_3})}}{2.m_1} \tag{16}
\end{align}$$

### 4.4.3 Aligned equations

Here is a sample of aligned mathematical expressions :

$$
\begin{aligned}
y &= y_0 + v_{0y}t + \frac{1}{2}a_y t^2 && (17)\\
&= v_0\sin(\theta)\frac{v_0\sin(\theta)}{g} - \frac{g}{2}\left(\frac{v_0\sin(\theta)}{g}\right)^2 && (18)\\
&= \frac{1}{2}\frac{v_0^2\sin^2(\theta)}{g} && (19)
\end{aligned}
$$

And one more sample:

$$
\begin{gathered}
a = b = c \quad (20)\\
\alpha = \beta = \gamma \quad (21)\\
D = B \quad (22)\\
C + G/H = K \quad (23)
\end{gathered}
$$

## 4.5 Definitions, underbrace, overbrace

Here are some tools to emphasise or annotate portions of mathematical expressions.

### 4.5.1 stackrel

It is often necessary to define certain entities in mathematics. Use the `\stackrel` command to put "def" on top of an equal sign to denote equal-by-definition:

$$LHS \stackrel{\text{def}}{=} RHS$$

For instance,

$$\sum_{i=0}^{\infty} a_i \stackrel{\text{def}}{=} \lim_{n\to\infty} \sum_{i=0}^{n} a_i$$

### 4.5.2 underset

The `\underset{bottomtext}{toptext}` command puts a text under another text (without braces or any separator) like this :

$$\underset{bottomtext}{toptext}$$

### 4.5.3 underbrace, overbrace

Use `\underbrace{text-above}_{text-below}` to get :

$$\underbrace{text-above}_{text-below}$$

You can also use `\overbrace` to get something like :

$$z = \overbrace{\underbrace{x}_{\text{real}} + \underbrace{iy}_{\text{imaginary}}}^{\text{complex number}}$$

## 4.6 Permutations and combinations

Permutation of r objects out of n objects is the same as selecting r objects out of n (in any order), and then arranging these r objects (out of r objects) in all possible sequences.

$$^{n}P_{r} = \frac{n!}{(n-r)!} \tag{24}$$

$$^{n}P_{r} = {}^{n}C_{r}.{}^{r}P_{r} \tag{25}$$

$$= {}^{n}C_{r}.r! \tag{26}$$

$$^{n}C_{r} = \frac{n!}{r!.(n-r)!} \tag{27}$$

$$\because {}^{n}P_{r} = \frac{n!}{(n-r)}! \tag{28}$$

Now, let us see what ${}^nC_{(n-r)}$ is :

$$
\begin{aligned}
{}^nC_{(n-r)} &= \frac{n!}{(n-r)!.(n-(n-r))!} && (29)\\
&= \frac{n!}{(n-r)!.(n-n+r)!} && (30)\\
&= \frac{n!}{(n-r)!.r!} && (31)\\
&= {}^nC_r && (32)\\
\therefore {}^nC_{(n-r)} &= {}^nC_r && (33)
\end{aligned}
$$

In other words,

$$
\begin{aligned}
\binom{n}{r} &= \binom{n}{n-r} && (34)\\
&= {}^nC_r && (35)
\end{aligned}
$$

Typesetting maths is different from typesetting normal text. You have identify the parts which should be typeset using maths mode. Math modes are indicated by using
`\( some stuff \)` or
`\[ some stuff \]` or
`$ some stuff $`

This is what you get in each of these cases :

- `\(a^p-b_q \)` gives $a^p - b_q$ (in line).
- `\[ a^p-b_q \]` gives (centered on a new line)

$$a^p - b_q$$

- `$ a^p-b_q $` gives $a^p - b_q$ (in line).

You can also use a `\begin{equation}... \end{equation}` environment as a global delimiter.

$$\therefore x = y \qquad (36)$$

$$\because z + j + g \neq (x + y)/k \tag{37}$$

Notice that the equations are numbered (and centered).

You can also use a `\begin{equation*}... \end{equation*}` environment, if you want to avoid the numbering.

A stack of multi-line equations will look like this :

$$\begin{aligned}
e^x &\approx 1 + x + x^2/2! + \quad (38)\\
& x^3/3! + x^4/4! + \quad (39)\\
& x^5/5! \quad (40)\\
x + v^3 - g/h &= a + b + c + d + e +\\
& f + g + h + \cos\beta \quad (41)\\
x^2 - y^2 &= (x + y)(x - y) \quad (42)\\
(x + y)(x - y) &= x^2 - y^2 \quad (43)
\end{aligned}$$

By default, all fragments of a multi-line equation are numbered. You can selectively suppress numbering of any fragment , by using the `\nonumber` command.
You can also align the = marks vertically, regardless of the length of LHS or RHS of each equation, using the `\align` command.

$$\therefore x * (z + j + g)/b_p^g = y \tag{44}$$

$$\because z + j + g \neq (x + y)/k \tag{45}$$

## 4.7 A pot-pourri of pictures, tables and text paras

Mathematicians use non-textual matter e.g. figures, graphs, diagrams, tables etc. along with textual matter in the same documment. Creating a document with only plain text is easy. Trying to put text, figures, tables, and maths, in the same document, requires some expertise in using LaTeX . Here is a sample of how you can do this yourself. Feel free to hack the LaTeX source of this document.

This part uses the picinpar package by Friedhelm Sowa. [3]

[3] Some portions of this material have been hacked shamelessly from the picinpar.tex document of Friedhelm Sowa, Heinrich–Heine–Universität Düsseldorf, Universitätsrechenzentrum

Parthasarathy, is an experienced and an internationally respected scientist from India. When he is not teaching discrete mathematics to undergrad students of computer science, he loves to explore and discover LaTeX mysteries, on his Linux machine. This is an example of the things LaTeX can do for you. This para begins with an extra large letter. The rest of the text behaves like normal text, and is placed all around the first letter.

Now, try to stick a picture at a specific place, relative to a paragraph of text. Like this. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. You can decide if you want the picture at right, left or centre. Or, a picture, with or without caption. There must be enough text to go around the picture, or the picture should be small enough to have enough text around it. Or else, you get some ugly results.

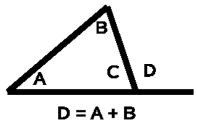


**Figure 1:** *External angle of a triangle*

Now, try to stick a picture at a specific place, relative to a paragraph of text. Like this. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text.

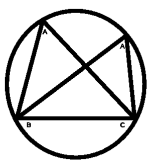

**Figure 2:** *Angle subtended on a circle*

You can decide if you want the picture at right, left or centre. Or, a picture, with or without caption.

Now, try to stick a picture at a specific place, relative to a paragraph of text. Like this. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. Now, try to stick a picture at a place, relative to a paragraph of text. vxvxvxvx bxbxbxbx bxv12345 vxvxvvx ggxxgxgxgx

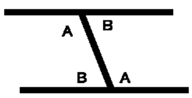


**Figure 3:** *Alternate angles*

You can decide if you want the picture at right, left or centre. Or, a picture, with or without caption.

You can do the same thing with tables too ! You can do the same thing with tables too ! You can do the same thing with tables too ! You can do the same thing with tables too !You can do the same thing with tables too ! You can do the same thing with tables too ! But you should be careful about the size and length of the table.

| | | |
|---|---|---|
| 1 | HSV | 12:0 |
| 2 | MSV | 11:1 |
| 3 | VfB | 10:2 |
| 4 | SVW | 9:3 |
| 5 | King-queen | 8:4 |

**Table 1:** Table trick#1

You can do more tricks with tables ! You can do the same thing with tables too ! You can do the same thing with tables too ! But you should be careful about the size and length of the table. Make sure you do not bump into the next paragraph. This is possbile if you space out your txt carefully. Blah blah blah....Blah blah blah....Blah blah blah

| | | |
|---|---|---|
| 1 | HSV | 12:0 |
| 2 | MSV | 11:1 |
| 3 | VfB | 10:2 |
| 4 | SVW | 9:3 |
| 5 | King-queen | 8:4 |

**Table 2:** Table trick#2

The table which you see here is plunk in the middle of the text paragraph. Mary had a little lamb, which knew nothing about LaTeX ... blah blah blah blih blih blih Mary had a little lamb, which knew nothing about LaTeX ... blah blah blah blih blih blih Mary had a little lamb, which knew nothing about LaTeX ... blah blah blah blih blih blih The table is plunk in the middle of the text paragraph. blah blah blah blih blih blih The table is plunk in the middle of the text paragraph. blah blah blah blih blih blih The table is plunk in the middle of the text paragraph. blah blah blah blih blih blih This table will be visible only if the text around it is bigger than the table. If there is not enough text, you will not see the table at all.

| | | | | |
|---|---|---|---|---|
| 1 | HSV | 12:0 | 14:1 | blue |
| 2 | MSV | 11:1 | 10:4 | pink |
| 3 | VfB | 10:2 | 12:9 | red |
| 4 | SVW | 9:3 | 11:9 | green |
| 5 | HYG | 8:4 | 10:10 | gray |

**Table 3:** Table trick#3

And here is one more test table which will be cross-referenced later in this aricle.

| | | | |
|---|---|---|---|
| a | b | c | d |
| 9 | 8 | 7 | 6 |

Table 4: my test table

## 4.8 Math related fonts

Sometimes we need a special font for denoting maths related terms (all these fonts must be used in math mode only).

Now, for some math related font styles (in Large size):

$\mathfrak{QED}\ mathfrac + \mathcal{QED}\ mathcal + \mathsf{QED}\ mathsf + \mathbb{QED}\ mathbb + \mathrm{QED}\ mathrm$

$\mathsf{QED}$ : $\mathsf{quod\ erat\ demonstrandum}$ Made with `mathsf`
$\mathrm{QED}$ : $\mathrm{quod\ erat\ demonstrandum}$ Made with `mathrm`

This is a Large size text using default font of LaTeX: QED

## 4.9 Therefore, because, degree, angles and dots

**Therefore-because**

$\therefore x = y$
$\because z + j + g \neq (x + y)/k$

**On the dot...like this**

Dots are useful in many places.

xyz … pqr (dots , made with `\dots`, is on the lower edge of the line)

zxzxzx … cvcvcv (low dots, made with `\ldots`, same as dots)

abc $\cdots$ def (dots on the v-center of the line , made with `\cdots`)

qwer
$\vdots$
vbnm (vertical dots, made with `\vdots`)

zxcv $\ddots$ vbnm (slanted line dots, made with `\ddots`)

asdf .................................. hjkl (fillup with dots using `\dotfill`)

Here is an easy way to divide a line into one, two, three, four, or n equal parts (with `\dotfill`).

|.................................................................|
|................................|..................................|
|................|................|................|................|
|.....................|.....................|.....................|

**Angles**
In a right angled triangle there is one angle which is exactly 90°(made with `\textdegree`)

In an equilateral triangle, all angles are equal to $60^\circ$ (made with `\degree`)

If ABC is an equlateral triangle

$\angle ABC = \angle BCA = \angle CAB = 60^\circ$and

$AB = BC = CA$

The *textdegree* command works only if you have "usepackage[latin1]{inputenc}" in the Preamble of your document. The `\degree` command was defined in the Preamble of this document.

LaTeX offers two other styles of denoting an angle:

**Spherical angle :** `\sphericalangle ABC` gives: $\sphericalangle ABC$

**Measured angle :** `\measuredangle ABC` gives: $\measuredangle ABC$

# 5 Mat-tricks

Mathematicians use matrices and arrays frequently. It is also common to embed such matrices within other matrices, as shown in the example below.

$$\begin{bmatrix} a & b & \begin{pmatrix} g & h \\ i & j \end{pmatrix} \\ d & e & f \end{bmatrix}$$

Notice how the f is centred horizontally, just below the ghij matrix and the a b is centred vertically, by the side of ghij matrix. The sizes of the bounding brackets are also just perfect for the size of the matrix they cover. All this is done automagically by LaTeX . It would be a major exercise, if you try to do this using ordinary wordprocessors.

Let us take a little more elaborate example.

$$\begin{bmatrix} \frac{\theta}{\alpha+\beta+\gamma} & \frac{\omega+\delta}{\psi-(\chi*\pi)} & \begin{pmatrix} g & h \\ i & j \end{pmatrix} \\ d & e & f \end{bmatrix}$$

Notice, how all the centring, positioning and sizes are maintained accurately, **without any effort by the user**. You can appreciate the true power of LaTeX better, if you try to set the above matrix using any popular word-processor.

They can also be numbered, like equations.

$$\begin{bmatrix} \alpha & \beta^* \\ \gamma^* & \delta \end{bmatrix} \tag{46}$$

$$\begin{Bmatrix} \alpha & \beta^* \\ \gamma^* & \delta \end{Bmatrix} \tag{47}$$

And here is a small-sized $\left(\begin{smallmatrix} \alpha & \beta^* \\ \gamma^* & \delta \end{smallmatrix}\right)$ in-line matrix you may need some time.

Matrices can be delimited in different ways and styles.

$$\begin{pmatrix} \alpha & \beta^* \\ \gamma^* & \delta \end{pmatrix}$$

$$\begin{vmatrix} \alpha & \beta^* \\ \gamma^* & \delta \end{vmatrix}$$

$$\begin{Vmatrix} \alpha & \beta^* \\ \gamma^* & \delta \end{Vmatrix}$$

Or,

$$\left\{ \begin{array}{lll} a & b & c \\ aa & b & c \end{array} \right\}$$

Or,

$$\left[ \begin{array}{lll} a & b & c \\ aa & b & c \\ aaa & b & c \\ aaaa & b & c \end{array} \right]$$

Or, if you *really* don't want any delimiter on one side, use '.' in place of a delimiter, as in `\( \left. ... \right\} \)`

$$\left.\begin{array}{ll} a & \text{blah bla bla} \\ d & \text{blah bla bla} \\ g & \text{blah bla bla} \end{array}\right\} \text{ga gagaa ggaffagagaffa ttyytt}$$

Notice that the delimiter size and positioning get adjusted automatically.

Write matrices which are side by side to each other

$$\begin{pmatrix} 1 & 0 \\ 0 & e^{i\pi} \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} u \\ -v \end{pmatrix}$$

# 6 Other goodies

## 6.1 Theorems

Theorems are an integral part of mathematics. LaTeX has a wider meaning for the term: "theorem". LaTeX gives you a whole lot of possibilities to define your own categories of theorems. You can make – theorems, lemmas, corollaries, conjectures, example, remark, definitions, hunches etc. , just about anything. You can use a wide choice of styles in which these "theorems" will be visually presented. Use `\newtheorem` and `\theoremstyle` in the Preamble, to create your own categories of theorems, lemmas, hunches etc. LaTeX keeps a separate counter for each of these categories, so you can use them in crossreferencing.

**The law of wild-hunches 1**
*All hunches do not become theorems. But, all theorems started out as hunches.*

**Non-theorem 1** *Sometimes, theorems turn out to be fakes, and then, they become plain hunches.*

**The law of wild-hunches 2**
*This is a dummy wild-hunch 2, just to show you how theorem numbers get incremented automatically.*

**Non-theorem 2** *This is a dummy nontheorem 2. All hunches are not theorems, and all theorems are not just hunches.*

This is the celebrated theorem ascribed to the great **Pythagoras** by his followers: *The square of the length of the hypotenuse (c) of a right angled triangle equals the sum of the squares of the lengths of the other two sides (a,b).* In other words,:

$$c^2 = a^2 + b^2 \tag{48}$$

Poor **Louis Fermat** was not so lucky. He could'nt go beyond three in the famous equation. Thus spake Louis Fermat : *There are no integral solutions for the equation :*

$$x^n + y^n = z^n for\ n\ \geq 3 \tag{49}$$

Pythogoras made a positive statement about something. There are a hundred ways to prove Pythagoras right. Fermat had a negative statement to make. Fermat had to wait 200 years to prove his theorem. Is this proof of the power of positive thinking ?

## 6.2 Tombstone (aka halmos)

**QED** A `\blacksquare` marks the QED of a proof.

The black square is sometimes called as a tombstone. You can use a tombstone or a classic QED, to mark the end of a proof : It is sometimes called a halmos after the mathematician Paul Halmos, who first used it in mathematical context. He got the idea of using it from seeing it was being used to indicate the end of articles in magazines.

| **Proof1** | **Proof2** |
|---|---|
| First line of Proof1 | First line of Proof2 |
| ⋮ | ⋮ |
| Last line of Proof1 ■ | Last line of Proof2 QED |

Here is an example of proof, with a halmos symbol (notice that in LaTeX the symbol name is written with a lower case h) :

$$\therefore a^2 + b^2 = c^2 \quad \blacksquare$$

This was made with:

```
 \[
\therefore a^2 + b^2 = c^2 \quad\blacksquare
\]
```

In AMS-LaTeX, the tombstone is automatically appended at the end of a proof environment `\begin{proof} ... \end{proof}`. It can also be obtained from the commands `\qedsymbol or \qed` (the latter causes the symbol to be right aligned).

## 6.3 Margin notes

You can also add some informal notes on the margin, using LaTeX , just like the great mathematician Louis de Fermat did. His margin madness, set mathematicians on a 200-year adventure, to prove his last theorem (popularly known as Fermat's last theorem).

Louis de Fermat is said to have made an enigmatic margin note like this.

To your right, in the margin, you see some margin notes. the size and positioning is also done by LaTeX, for free !

## 6.4 Footnotes

Footnotes [4] like this one, and like this one [5], are easy to add, and manage.

You can make cross references to any part of the document. The corresponding numbers (page number, section number, equation number, figure number) are **automatically** computed and inserted for you. these numbers are also automatically re-computed whenever their location in the document changes.

If you want to write beautiful mathematics, like the ones shown above, you have to learn, and get using LaTeX immediately. But, that is not enough, as you will see soon.

# 7 Cross referencing – LaTeX style

**The power of cross referencing :** You can make cross references to any part of the document. The corresponding numbers (page number, section number, equation number, figure number) are **automatically** computed and

[4] Footnotes are numbered automatically
[5] and this one ...

inserted for you. these numbers are also automatically re-computed whenever their location in the document changes.

- **Cross-referencing a Section** :

  Read about Louis Fermat in Section 6.1 (this section number is automatically inserted by LaTeX).

- **Cross-referencing a page** : The author's bio is in page 26. You can also refer to the page where an equation occurs - like this. In page 19 we have the enigmatic theorem attributed to Louis de Fermat (aka Fermat's last theorem).

- **Cross-referencing an equation :** Equation 49 shows what Fermat wanted to say (but did not prove).

  Use `\eqref` if you want a numbered cross-reference with parantheses, plain `\ref` will give you a cross-reference without the parantheses. See the example below :

  $$a^2 + b^2 = c^2 \tag{50}$$

  Note: I used the label eq:1 above. You can use any other text as label.

  `\eqref{eq:1} vs \ref{eq:1}` gives : (50) vs 50

  `\textit{\eqref{eq:1} vs \ref{eq:1}}` gives : (50) *vs 50*

  Equation 50 is a famous theorem in Euclidean geometry.

- **Cross-reference to a figure/picture :** In Figure 3 we see an illustration of the geometric theorem about alternate angles.

- **Cross referencing a theorem, lemma, corollary, hunch etc.**

  Hunch# 2 is my second wild-hunch.

  Ahunch# 2 is my second nontheorem

- **Cross-reference to a table :** You can cross-reference to a table, or the page containing a given table. This feature is very useful if you are writing a long report, or a thesis. Here is an example:

  Table 4 on page 14 was a test table given earlier in this article (it is usually not a good idea to refer to something which will appear later, also called as forward-referencing) ...

## 8 What LaTeX won't do for you

We have seen above, that LaTeX is exceptionally good in presenting your mathematics, in a visually appealing way. That is all that LaTeXcan do. It is so easy to get carried away by the beauty of LaTeX . What LaTeX cannot do, or will not do, is improve your mathematics.

Of course, LaTeX will not correct your maths. You can, for instance, say, $5 + 3 = 53$, and get away with it. It will not undo badly designed expressions, either. That is, it cannot repair, shabbily presented expressions. Even good mathematicans have a tendency to write maths shabbily [4] .

Here is an example, inspired from [6]. Every student of high school algebra will recognise the following two equations:

$$x_1 = \frac{-b \ + \ \sqrt{b^2 - 4ac}}{2.a}$$

$$x_2 = \frac{-b \ - \ \sqrt{b^2 - 4ac}}{2.a}$$

Now, we will be a little mischievous and make some simple modifications. We will replace the constants a, b, c by $m_1, m_2, m_3$. We will replace the discriminant $\sqrt{b^2 - 4ac}$ by an equivalent expression. This is what we get :

$$x_1 = -\ {}^1/_2\ \frac{m_2}{m_1} + \frac{\sqrt{(m_2 + 2\sqrt{m_1.m_3}).(m_2 - 2\sqrt{m_1.m_3})}}{2.m_1}$$

$$x_1 = -\ {}^1/_2\ \frac{m_2}{m_1} - \frac{\sqrt{(m_2 + 2\sqrt{m_1.m_3}).(m_2 - 2\sqrt{m_1.m_3})}}{2.m_1}$$

Mathematically, you are still correct. You have used LaTeX and created impressive expressions. But, your students will call you a criminal, and curse you for messing up a simple formula. (This is a warning for all teachers of mathematics)

The message here is simple. It is not enough to own a good dictionary, to avoid writing bad English. Similarly, it is not enough to use LaTeX , to avoid writing maths shabbily.

Donald Knuth, and Leslie lamport, the two main inventors of TeX and LaTeX have some advise for using LaTeX for mathematics. Knuth's paper [3] is available as a pdf file, and is invaluable for writing maths. It is a summary of a course of the same name given at Stanford University during autumn quarter, 1987. Lamport's paper [5] is also available as a pdf file, and is a description of how to write long and complex mathematical expressions (especially proofs and derivations). The reader must study these two papers carefully, if he/she wants to use LaTeX wisely.

When you use LaTeX you must observe a few simple rules of writing maths (there are many more, not listed here. Read [3] and [5] for more details.):

**Write simple expressions** – Do not use complicated nested-expressions of the kind : $\log \sin x^{2*sec(y!)}$. Adding appropriately placed parentheses helps, but only in a limited way. Nested parentheses only end up confusing the reader. Subscripted superscripts of the type: $x^{y_2}$ are the oxymorons of mathematics. You can simplify this clutter, by making smaller subexpressions, and then stringing the subexpressions together. Define simpler variables, to eliminate combinations of subscripts and superscripts.

**Make shorter equations** – Sometimes equations tend to become unusually long. Of course the LaTeX command : `\multiline` can help you handle long equations which span multiple lines. But, `\multiline` sometimes breaks a line in unusual or illogical places. It would thus be a better idea, to avoid `\mutiline` equations altogether. You can break the equation, by defining smaller expressions. Then, use a single-line, top-level equation which chains all these subexpressions together.

**Break the monotony** Sometimes we see whole pages of text, filled with just mathematical expressions. It may look impressive, but that's usually not a good idea. You should intersperse your maths with short English-language text, which narrates what you are doing. This breaks the monotony, and makes your document much more pleasant to read. When the reader loses his way somewhere, the short narrations will help him (or her) recover and find his (or her) way.

**Cross referencing** Cross-referencing to other equations helps the reader maintain a mental thread. LaTeX gives you many facilities for cross-referencing. But do not overdo this. And in any case, $s$trictly avoid forward referencing i.e. referencing to text or equations which will show up later than the current position.

**Pay attention to definitions, terminology, abbreviations, nomenclature, symbols** – It is a good practice to clearly define and describe all definitions, abbreviations and terminology used in the text. In any case, make this list, as small as possible. And also make sure that you use universally defined and accepted symbols, in their most natural way. For instance, all the world knows that the equation $A = \pi * (r^2)$ gives the area of a circle whose radius is r. It would be crazy to use other symbols (even if you define them explicitly), like $V = \lambda(\gamma * \gamma)$ Or, you could be more treacherous, and express the area of a circle as: $\pi = A * (r^2)$ . All you have to do is redefine the meanings of A and $\pi$. That may be mathematically correct, but many people won't appreciate the joke. It is always a good idea to respect conventions. LaTeX will not stop you from being mischievous.

**Numbering your equations** – It is not a good idea to number all equations, recklessly. Number your equations, only if you intend to cross-reference them. Otherwise, you can easily run into frighteningly large numbers for your equations. With LaTeX you can easily inhibit numbering of equations, whenever you want, and restart numbering, whenever you choose.

# 9 Closing remarks

LaTeX can be used for producing very elegant looking documents, especially when they involve mathematical expressions. However, you should also obey some commonsense rules, to make the exercise worthwhile. Maths is more than just skin-deep beauty. In short, use of commonsense, and LaTeX can help you create wonderful documents, especially if you indulge in mathematics.

The examples given above, show you how, unconventional and complex mathematically-rich text can be created using LaTeX . Using traditional word-processors for such text, can prove to be painful or futile. There are lots of things things like this which LaTeX can do for you. It usually needs a few hours of patient study and experimentation, to produce such typographically complex material.

This paper, predictably, was made using LaTeX . It used the Kile front-end provided by Suse Linux. It uses the AMSmath package, downloaded from the CTAN site.

source of this text, as well as the rendered version (pdf file), by sending a request by email, to the author, at: drpartha@gmail.com. Please mention the Reference code and date mentioned at the top of this article. This paper, is updated/improved regularly. You can get the latest version of this paper, and a whole lot of similar tutorial material on LaTeX , from the web, at :

http:://www.freewebs.com/profpartha/publications/downloadables.htm.

Feel free to hack this article itself. You can get the LaTeX source of this article, from the author (email: drpartha@gmail.com). Hacking and experimenting, is the best way to learn LaTeX . You too can write mathematically-rich documents like this. Have fun !

As always, your constructive comments and suggestions are always welcome.

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[12] https://www.economics.utoronto.ca/osborne/latex/LTXERR.HTM

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# 10 About the author

*This part uses the floatflt package for displaying a figure along with text.*

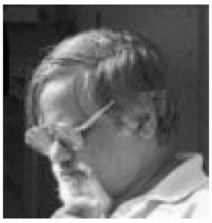

Figure 4: The pensive Professor

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