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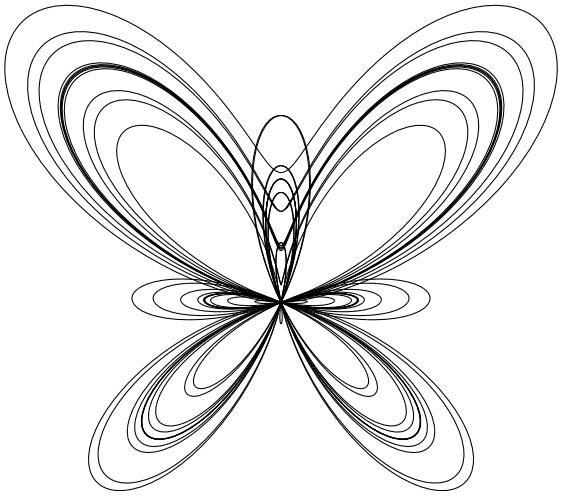
The xpicture package
(http://www.upv.es/~rfuster/xpicture)
Several extensions of the picture standard environment
User Manual



$$x = \sin t \left(\mathrm{e}^{\cos t} - 2\cos 4t + \sin^5 \left(\frac{t}{12} \right) \right)$$
$$y = \cos t \left(\mathrm{e}^{\cos t} - 2\cos 4t + \sin^5 \left(\frac{t}{12} \right) \right)$$

Ex. 1

```
\setlength{\unitlength}{1cm}
\footnotesize
\DIVIDE{1}{12}{\invXII}
\MULTIPLY{12}{\numberTWOPI}{\phione}
\MULTIPLY{12}{64}{\divisions}

\COMPOSITIONfunction{\EXPfunction}{\COSfunction}{\Afunction}
\SCALEVARIABLEfunction{4}{\COSfunction}{\Bfunction}
\SCALEVARIABLEfunction{\invXII}{\SINfunction}{\cfunction}
\POWERfunction{\cfunction}{5}{\Cfunction}
\LINEARCOMBINATIONfunction{1}{\Afunction}{-2}{\Bfunction}{\ABfunction}
\SUMfunction{\ABfunction}{\Cfunction}{\ABCfunction}
\PRODUCTfunction{\SINfunction}{\ABCfunction}{\Xfunction}
   % x=(sin t)(exp(cos t)-2 cos 4t + (sin(t/12))^5)
\PRODUCTfunction{\COSfunction}{\ABCfunction}{\Yfunction}
   % y=(cos t)(exp(cos t)-2 cos 4t + (sin(t/12))^5)
\PARAMETRICfunction{\Xfunction}{\Yfunction}{\butterfly}
\centering
\begin{Picture}(-4,-3)(4,4)
   \PlotParametricFunction[\divisions]\butterfly{0}{\phione}
\end{Picture}
\begin{gather*}
   x=\sin t\left(\mathrm e^{\cos t}-2\cos 4t
               +\sin^5\left(\frac t{12}\right)\right) \\
   y=\cos t\left(\mathrm e^{\cos t}-2\cos 4t
               +\sin^5\left(\frac t{12}\right)\right)
\end{gather*}
```

Contents

The `xpicture` package extends the `picture` standard environment and packages `pict2e` and `curve2e`, adding the ability to work with arbitrary reference systems and with Cartesian or polar coordinates. In addition to other utilities, the greater interest of `xpicture` lies in its capacity to draw function graphs, conic sections and arcs, and parametrically defined curves.

This is the user manual of `xpicture`. Technical documentation and reference manual are contained in file `xpicture.pdf`, distributed together with the package.

1 Introduction. New graphical instructions

The `xpicture` package introduces several new graphical instructions, and some enriched versions of standard instructions used inside the `picture` environment. All these new instructions can be classified as follows:

- Reference systems and coordinates:
  - Declaration and use of different reference systems, with Cartesian or polar coordinates.
  - Instructions to show Cartesian or polar reference systems.
- An alternative to the `picture` environment, compatible with the new reference systems.
- Alternative instructions or extensions of the standard `picture` commands and those defined by the packages `pict2e` and `curve2e`:
  - Enriched versions of marks `\put` and `\multiput`, providing an adequate control of the precise position in which objects are composed (this functionality is especially useful in the composition of not strictly graphical objects, such as formulas or labels).
  - Instructions for drawing straight segments, vectors (in any direction and using any reference system), polygonal lines, and regular and arbitrary polygons.
- Regular curves:
  - Instructions for drawing conic sections (circles, ellipses, hyperbolas and parabolas) and arcs of these curves.
  - Instructions to graph functions and parametrically defined curves (this is the most interesting feature of this package).

The only requeriments for `xpicture` are packages `calculator`, `calculus`, `curve2e` and `xcolor`. Therefore, it works with any TEX extension compatible with these packages. You can compile a document including `xpicture` pictures directly with `pdflatex`, `lualatex`, `xelatex` or indirectly, via `latex/dvips`, `latex/dvips/dvipdfm`, ... Pure `dvi` files are not supported, but some `dvi` previewers may show partially `xpicture` draws included in `dvi` files.

2 A preliminary observation. Compatibility with text composition in color

The `xpicture` package automatically loads the `xcolor` package. So, we can compose our pictures (and the whole document) in various colors. However, when used in the body of the picture environment, marks `\color` and `\colortext` often introduce spurious spaces. For this reason, the `xpicture` package introduces the new command `\pictcolor`.

`\pictcolor{`*color*`}`

This mark behaves like the `\color` command, but does not produces these inappropriate spaces. To change colors inside a picture, instead of `\color` or `\colortext`, use always the `\pictcolor` declaration.

3 Coordinate systems and the `Picture` environment

3.1 Coordinates

The standard `picture` environment establishes a rectangular coordinate system, so that all graphic objects are placed in the picture using the canonical coordinates of the plane. From now on, we will call this reference system *the standard reference system*. Loading the `xpicture` package, we can use any other affine reference system and combine it with the use of polar coordinates.

3.1.1 Reference systems

The `xpicture` package allows us to use other reference systems. For the purpose we are interested, a reference system consists of an origin of coordinates and a pair of linearly independent vectors. Typing

`\referencesystem(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)(`*x2*`,`*y2*`)`

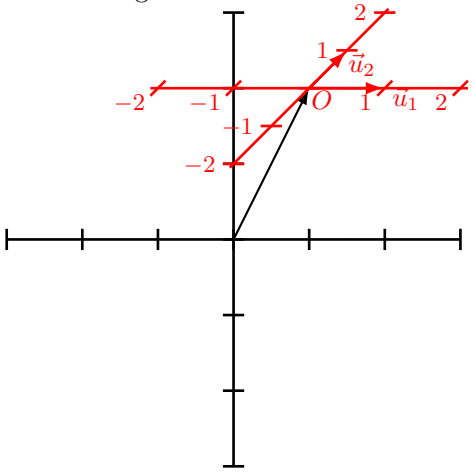
we declare the new reference system with origin at point $(x0, y0)$ and coordinate vectors $(x1, y1)$ and $(x2, y2)$. If the coordinates of the point P with respect to this reference system are $(\bar{x}, \bar{y})$, then the coordinates of P with respect to the standard system, (x, y), are calculated with the formula

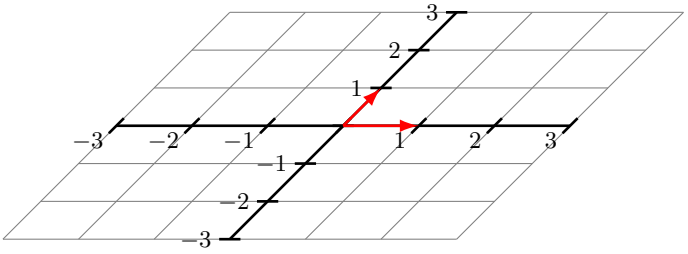
$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} x0 \\ y0 \end{bmatrix} + \begin{bmatrix} x1 & x2 \\ y1 & y2 \end{bmatrix} \begin{bmatrix} \bar{x} \\ \bar{y} \end{bmatrix}$$

For example,

`\referencesystem(1,2)(1,0)(0.5,0.5)`

sets a new reference system that has its origin in the point $O(1, 2)$ and the coordinate vectors $\vec{u}_1 = (1, 0)$ and $\vec{u}_2 = (1/2, 1/2)$. The following pictures show this coordinate system built on the standard reference system and a Cartesian grid refered to the new reference system.





Alternatively, you can use the `\changereferencesystem` declaration: in the instruction

`\changereferencesystem(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)(`*x2*`,`*y2*`)`

point $(x0, y0)$ and vectors $(x1, y1)$ i $(x2, y2)$ are not refered to the standard system, but to the *active* reference system.[1] Moreover, as the more interesting (and frequent) reference system changes consist of translations of the origin, rotations of the axes and symmetries, `xpicture` introduces three specific commands to these special cases:

`\translateorigin(`*x0*`,`*y0*`)`

moves the origin to the specified coordinates.

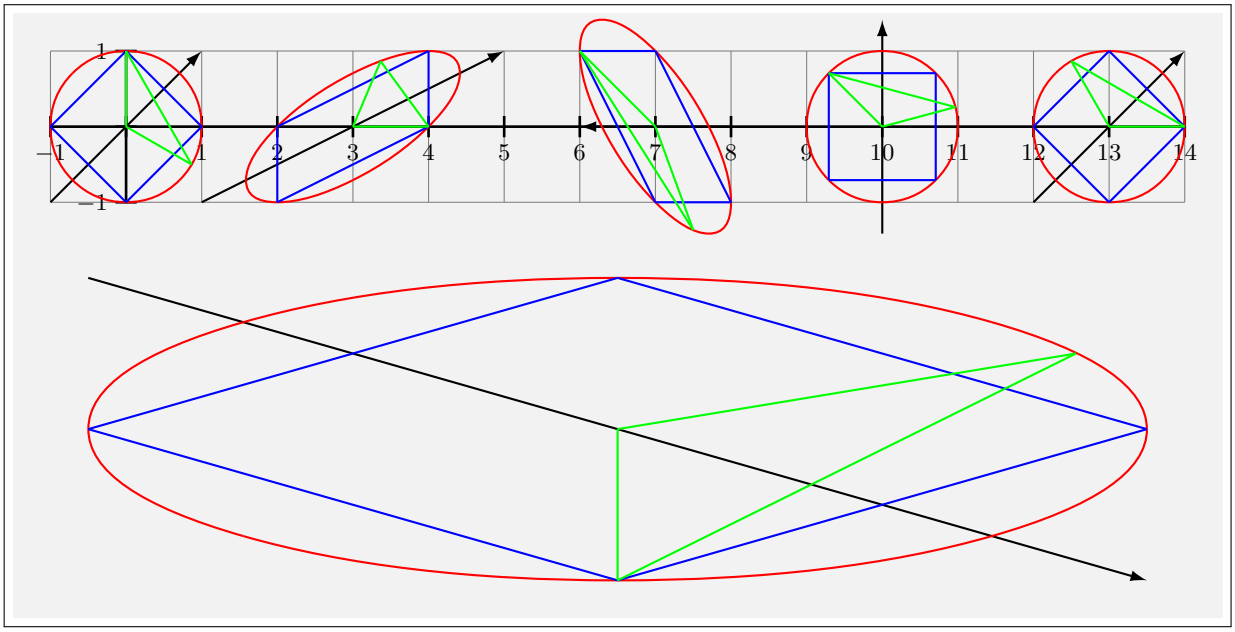
`\rotateaxes{`*angle*`}`

rotates the axes. The *angle* parameter is interpreted as the rotation angle in radians (if the `\radiansangles` declaration is active) or in sexagesimal degrees (if the `\degreesangles` declaration is active). And

`\symmetrize{`*angle*`}`

performs a symmetry, being *angle* the angle between the x axis and the symmetry axis. Also here, the `\radiansangles` and `\degreesangles` declarations determine if angles are interpreted as radians or degrees. These three declarations always apply to the active reference system.

[1] In other words, the instruction `\referencesystem` changes from the standard reference system to the new one, while `\changereferencesystem` changes from the active system.



Ex. 2

```
\newcommand{\mypicture}{%
{\thicklines
\xVECTOR(-1,-1)(1,1)
\pictcolor{red}\Circle{1}
\pictcolor{blue}\regularPolygon{1}{4}
\polarreference\degreesangles
\pictcolor{green}\Polygon(1,90)(0,0)(1,-30)}}
\centering
\setlength{\unitlength}{1cm}
\fbox{\begin{Picture}[black!5!white](-1.5,-6.5)(14.5,1.5)
\cartesiangrid(-1,-1)(14,1)
\mypicture
{\referencesystem(3,0)(1,1)(1,0)
\mypicture
\changereferencesystem(0,4)(-1,1)(1,-2)
\mypicture}
\degreesangles
\translateorigin(10,0)
{\rotateaxes{45}
\mypicture}
\translateorigin(3,0)
\symmetrize{45}
\mypicture
\referencesystem(6.5,-4)(7,0)(0,-2)\mypicture
\end{Picture}}
```

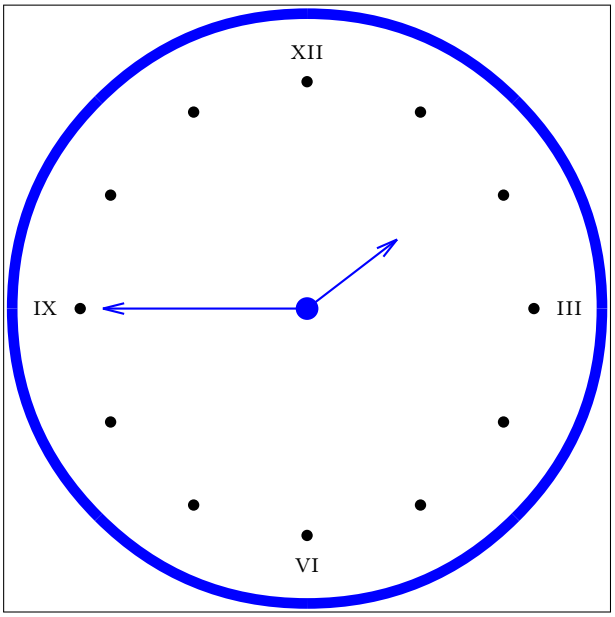
The `\standardreferencesystem` declaration restores the standard reference.

Changes of reference system can be used inside or outside the `Picture` environment. In the next sections we will see what are the effects produced in each case.

3.1.2 Polar coordinates

Instead of Cartesian coordinates, we can refer to a point P using the polar coordinates (r, ϕ) of this point: r is the distance from the origin O and ϕ is the angle between the first coordinate vector and the OP segment. The `\cartesianreference` and `\polarreference` declarations establish the coordinates of one or the other type. By default, the Cartesian coordinates are used, but in some cases is much easier determine polar coordinates. Additionally, the `\radiansangles` and `\degreesangles` declarations sets angle measuring in radians or in degrees, respectively (by default, angles are measured in radians).

The following example shows a typical situation in which it is more appropriate to use polar coordinates: the *natural* way to enter coordinates on a circle is using polar coordinates.



Ex. 3

```
\setlength{\unitlength}{3cm}
\fbox{\begin{Picture}(-1.3,-1.3)(1.3,1.3)
\polarreference
\degreesangles

\renewcommand{\Pictlabelsep}{0.1}

\multiPut(1,0)(0,30){12}{\circle*{0.05}}
    % Put twelve dots, one unit apart,
    % at 0, 30, 60, ..., 330 degrees

\cPut{90}(1,90){\textsc{xii}}
\cPut{0}(1,0){\textsc{iii}}
\cPut{270}(1,270){\textsc{vi}}
\cPut{180}(1,180){\textsc{ix}}

\pictcolor{blue}\thicklines

\arrowsize{8}{2}
\xtrivVECTOR(0,0)(0.5,37.5)
\xtrivVECTOR(0,0)(0.9,180)

\Put(0,0){\circle*{0.1}}
\linethickness{4pt}
\Circle{1.3}
\end{Picture}}
```

The new commands defined in the `xpicture` package and requiring some kind of coordinates support polar coordinates, except the `Picture` and `xpicture` environments and the `\cartesianaxes` and `\cartesiangrid` environments.

3.2 The `Picture` (or `xpicture`) environment

The `xpicture` package supports all drawing commands from standard LaTeX; in particular, you can use the `picture` environment. However, in the expression

`\begin{picture}(`*x*`,`*y*`)(`*x0*`,`*y0*`)`

the pairs of numbers `(`*x*`,`*y*`)` and `(`*x0*`,`*y0*`)` always denote standard coordinates, namely, the `picture` environment only uses the standard reference, thus it defines, as drawing area, the rectangle $[x0,x-x0]\times[y0,y-y0]$, regardless of whether this is the active reference. If we want draw a picture referring coordinates to an alternative reference system, to determine the appropriate drawing area in absolute coordinates is not obvious (and often is difficult). However, the `Picture` environment defines a working area on the active reference system: the

`\begin{Picture}[`*color*`](`*x0*`,`*y0*`)(`*x1*`,`*y1*`)`

instruction fixes the drawing area $[x0,x1]\times[y0,y1]$, refered to the active reference system. Here, the `(`*x0*`,`*y0*`)` i `(`*x1*`,`*y1*`)` coordinates are always rectangular (even when reference in polar coordinates is active). More precisely, this environment defines a `picture` box that circumscribes our drawing area. If the optional argument is used, background is colored in the given *color*.

Very important: note that the syntax of the `picture` *environment is not analogous to the new environment* `Picture`: Here two pairs of coordinates are required, `(`*x0*`,`*y0*`)` and `(`*x1*`,`*y1*`)`, representing two opposite corners of the drawing area.[2] Obviously, if the reference sustem is the standard, expression

`\begin{Picture}(0,0)(`*x*`,`*y*`)`

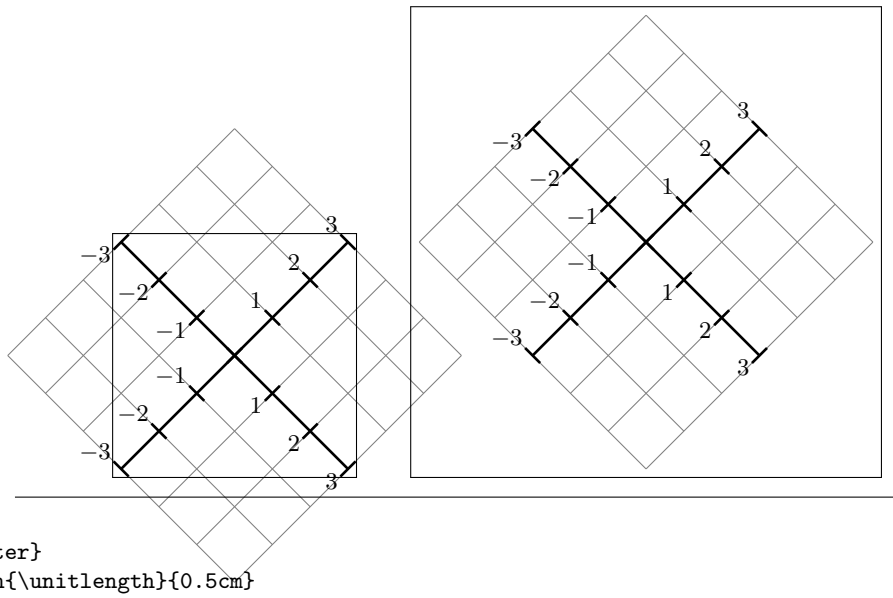
is equivalent to

`\begin{picture}(`*x*`,`*y*`)`

The following example shows the boxes produced by the `picture` and `Picture` environments.

[2] Although it may seem more *logical* preserve the syntax of `picture` environment, it is more natural to define the drawing area in that way.

Ex. 4




```
\begin{center}
 \setlength{\unitlength}{0.5cm}
 \referencesystem(0,0)(1,-1)(1,1)

 \fbox{\begin{picture}(6,6)(-3,-3)
  \cartesiangrid(-3,-3)(3,3)
 \end{picture}}\qquad
 \fbox{\begin{Picture}(-3,-3)(3,3)
  \cartesiangrid(-3,-3)(3,3)
 \end{Picture}}
\end{center}
```

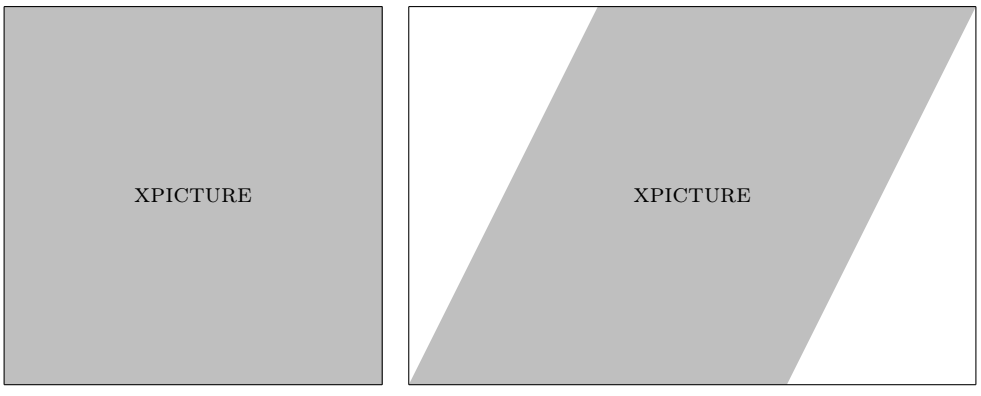
The left picture does not fit the box. In fact, some elementary geometric considerations shown that a square box of 12×12 units of length must be reserved,

```
\begin{picture}(12,12)(-6,-6)
```

The use of the `Picture` environment frees us to determine the actual dimensions of the drawing.

The new environment `xpicture` is an alias to the `Picture` environment. Its sintax and its behavior are identical.

On the other hand, the `\draftPictures` declaration disables all the instructions defined in this package, replacing each picture set in a `Picture` environment by a parallelogram circumscribed by a white rectangle (the box that shows the area reserved for the drawing).[3]



`\standardreferencesystem` `\referencesystem(0,0)(1,0)(0.5,1)`

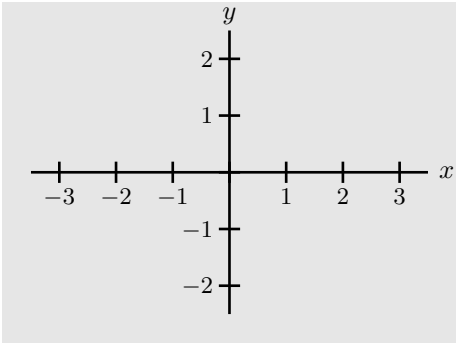
3.3 Coordinate axes

Instruction

`\cartesianaxes(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)`

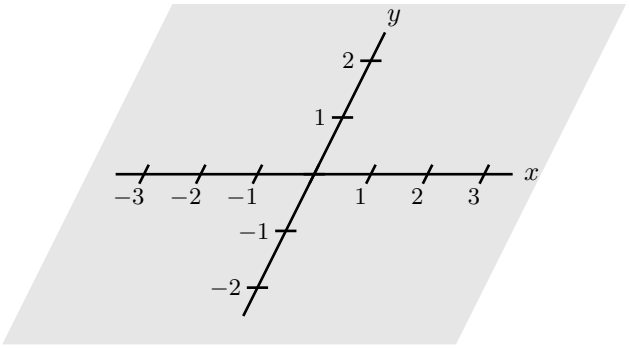
[3] If you use an instruction not directly defined by `xpicture` (inside of a `Picture` environment), this instruction may take effect.

draws the coordinate axes corresponding to the `[x0,x1]`×`[y0,y1]` rectangle. Arguments *x0*, *y0*, *x1* and *y1* must satisfy the conditions *x0*<*x1* and *y0*<*y1*. Here, coordinates `(x0,y0)` and `(x1,y1)` are always rectangular (even when reference in polar coordinates is active).




```
\begin{center}
\setlength{\unitlength}{0.75cm}%
\begin{Picture}[black!10!white](-4,-3)(4,3)
\renewcommand{\Pictlabelsep}{0.2}
\cartesianaxes(-3.5,-2.5)(3.5,2.5)
\Put[r](3.5,0){$x$}
\Put[t](0,2.5){$y$}
\end{Picture}
\end{center}
```

Ex. 5




```
\begin{center}
\referencesystem(0,0)(1,0)(0.5,1)
\setlength{\unitlength}{0.75cm}%
\begin{Picture}[black!10!white](-4,-3)(4,3)
\renewcommand{\Pictlabelsep}{0.2}
\cartesianaxes(-3.5,-2.5)(3.5,2.5)
\Put[r](3.5,0){$x$}
\Put[t](0,2.5){$y$}
\end{Picture}
\end{center}
```

Ex. 6

The following parameters control the style of the axes, the cut marks and labels on the axes:

3.3.1 The style of the axes

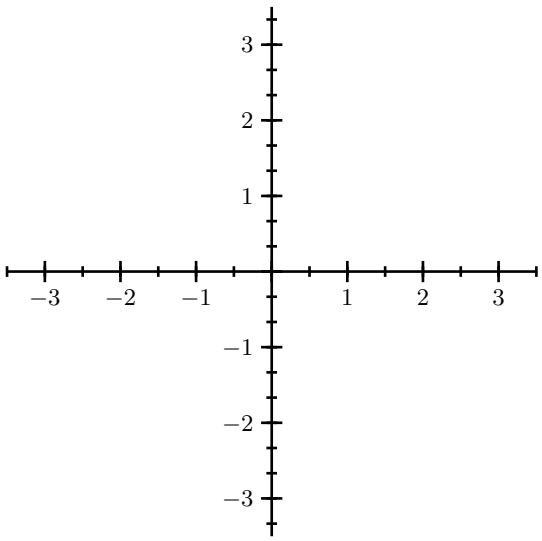
`\axescolor` By default, the axes color is `black`, but we can change it by redefining the `\axescolor` declaration. For example,

```
\renewcommand{\axescolor}{orange}
```

We must use a color name predefined in the package xcolor or defined by the user (for example, using the `\definecolor` command).

`\axesthickness` Length determining the thickness of axes (default `1 pt`). You can modify it using any command that fixes a length (as `\setlength` or `\settowidth`).

`\xunitdivisions, \yunitdivisions` Number of subdivisions of the unit (in each axis). By default, 1. These arguments can also be redefined using the `\renewcommand` command (they must be positive integers).




```
\renewcommand{\xunitdivisions}{2}
\renewcommand{\yunitdivisions}{3}

\begin{center}
\setlength{\unitlength}{1cm}%
\begin{Picture}(-4,-4)(4,4)
\cartesianaxes(-3.5,-3.5)(3.5,3.5)
\end{Picture}
\end{center}
```

Ex. 7

3.3.2 Axes position

The coordinate axes (and also tags and cut marks) are placed by default in the traditional way, on the $y = 0$ (the x axis) and $x = 0$ (the y axis) lines. However, sometimes the fact that labels are inside the graphic can be annoying.[4] Alternatively, we can place axes and tags at the lower and left sides of the coordinate rectangle. To choose between these two options we should use the following declarations:

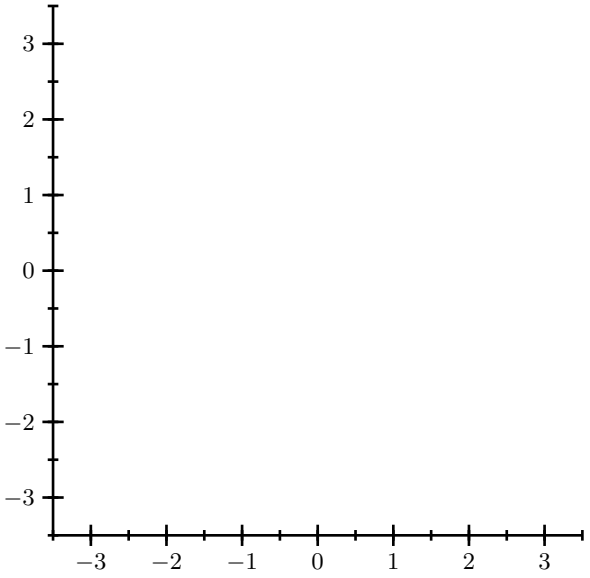
`\internalaxes, \externalaxes` If the `\internalaxes` declaration is active, then axes lies on $y = 0$ and $x = 0$.

However, if we activate the `\externalaxes` declaration, the axes produced by the instruction

`\cartesianaxes(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)`

lies on $y =$ *y0* and $x =$ *x0*.

By default, the `\internalaxes` declaration is active.



Ex. 8

```
\renewcommand{\xunitdivisions}{2}
\renewcommand{\yunitdivisions}{2}

\begin{center}
\externalaxes
\setlength{\unitlength}{1cm}%
\begin{Picture}(-4,-4)(4,4)
\cartesianaxes(-3.5,-3.5)(3.5,3.5)
\end{Picture}
\end{center}
```

3.3.3 Tags style

The numerical tags on the axes are made in math mode. If you need textual labels, put them in a `\mbox` or, using `amsmath`, a `\text` box. We can control the color, attributes and distance to the axes of these tags, redefining (with `\renewcommand`) the following marks:

`\axeslabelcolor` The color of the numerical tags on the axes. By default, this color is identical to the axes color.

`\axeslabelsize` Size of numerical tags. By default, `\small`.

`\axeslabelmathversion` Mathversion of numerical tags. By default, `normal`.[5]

`\axeslabelmathalphabet` Mathalphabet of numerical tags. By default, `\mathrm`.

`\axislabelsep` Distance between tags and cut marks, measured in `\unitlength` units;[6] by default, `0.1` (see later the description of `\makenotics`).

3.3.4 Tags position

Position of tags is controlled by two declarations:

`\xlabelpos{`*position*`}` change the relative position of labels in x axis. Admissible values are those allowed in the *position* argument of command `\Put` (see subsection 4.1). Default is `-90`.

`\ylabelpos{`*position*`}` change the relative position of labels in y axis. Default is `180`.

[4] And produces strange effects when the origin (0.0) is not in the drawing area.
[5] Standard *math versions* are `normal` and `bold`, but some packages define other math versions.
[6] The distance between axes and tags equals `\ticssize`+`\axislabelsep`.

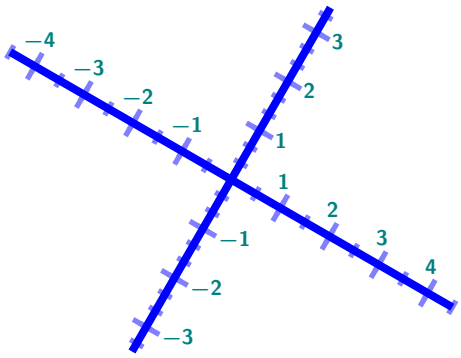
3.3.5 Style of cut marks

Units (and, optionally, unit fractions) are marked over axes with small segments, the style of which is controlled by the following parameters:

`\ticssize, \secundaryticssize` These lengths control the size of the tics: `\ticssize` is half the length of main cuts (by default, `4pt`) and `\secundaryticssize` is half the length of secundary cuts (by default, `2pt`).

`\ticsthickness` Thickness of the marks on axes (by default, `1pt`).

`\ticscolor` Color of the marks on axes (by default, `black`).



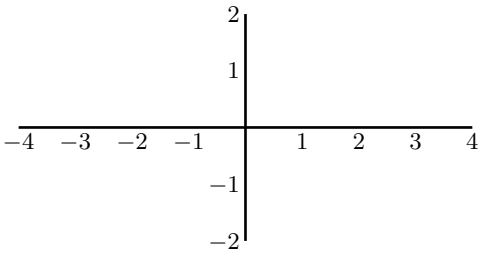

```
\renewcommand{\axescolor}{blue}
\setlength{\axesthickness}{3pt}
\renewcommand{\xunitdivisions}{2}
\renewcommand{\yunitdivisions}{3}

\renewcommand{\axeslabelcolor}{teal}
\renewcommand{\axeslabelsize}{\footnotesize}
\renewcommand{\axeslabelmathversion}{bold}
\renewcommand{\axeslabelmathalphabet}{\mathsf}
\renewcommand{\axislabelsep}{0.05}
\xlabelpos{ttl}
\ylabelpos{r}

\setlength{\ticssize}{0.2cm}
\setlength{\secundaryticssize}{0.1cm}
\setlength{\ticsthickness}{2pt}
\renewcommand{\ticscolor}{blue!50}

\begin{center}
\degreesangles
\rotateaxes{-30}
\setlength{\unitlength}{0.75cm}%
\begin{Picture}(-5,-4)(5,4)
\cartesianaxes(-4.5,-3.5)(4.5,3.5)
\end{Picture}
\end{center}
```

Ex. 9

3.3.6 Removing and directly printing cut marks and labels

`\maketics, \makenotics` These two declarations determine if divisions on the axes should be marked or not. By default the `\maketics` declaration is active.

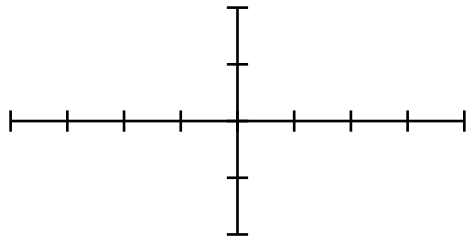
If divisions are not marked, the `\axislabelsep` declaration determines the distance between axes and labels.




```
\begin{center}
\setlength{\unitlength}{0.75cm}%
\begin{Picture}(-4.5,-2.5)(4.5,2.5)
\makenotics
\cartesianaxes(-4,-2)(4,2)
\end{Picture}
\end{center}
```

Ex. 10

`\makelabels, \makenolabels` Two declarations determining whether numerical labels on the axes must appear or not. By default, the `\makelabels` declaration is active.



```
\begin{center}
\setlength{\unitlength}{0.75cm}%
\begin{Picture}(-4.5,-2.5)(4.5,2.5)
\makenolabels
\cartesianaxes(-4,-2)(4,2)
\end{Picture}
\end{center}
```

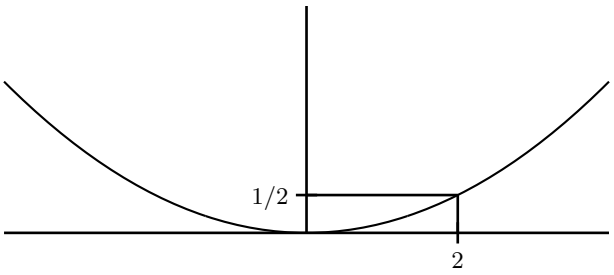
Ex. 11

Declarations `\makenotics` and `\makenolabels` can be useful when you want to show only some specific coordinates, when the points to be highlighted on the axes are not integers and when you need to print labels in some special format. In this cases you can plot tics and/or print labels using the following commands.

`\plotxtic{`*x-coor*`}`, `\plotytic{`*y-coor*`}` plot a tic for the given x or y coordinate.

`\printxlabel{`*x-coor*`}{`*label*`}`, `\printylabel{`*y-coor*`}{`*label*`}` print *label* for the given x or y coordinate. Labels are printed in math mode.

`\printxticlabel{`*x-coor*`}{`*label*`}`, `\printyticlabel{`*y-coor*`}{`*label*`}` plot a tic and print *label* for the given x or y coordinate.




```
\begin{center}
\setlength{\unitlength}{1cm}%
\begin{Picture}(-4.5,-0.5)(4.5,3.5)
\makenolabels
\makenotics
\cartesianaxes(-4,0)(4,3)

\plotytic{0.5}
\printylabel{0.5}{1/2}
\printxticlabel{2}{2}

\Polyline(2,0)(2,0.5)(0,0,5)
\thicklines
\SCALEfunction{0.125}{\SQUAREfunction}{\F}
\PlotFunction[3]{\F}{-4}{4}
\end{Picture}
\end{center}
```

Ex. 12

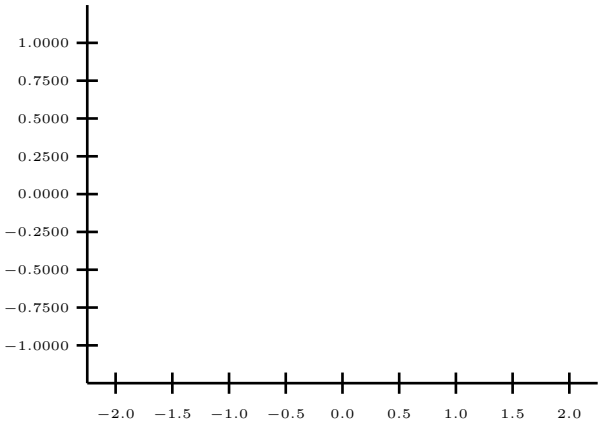
Multiple equally spaced tics and/or labels can be drawn simultaneously:

`\plotxtics{`*firstcoor*`}{`*incr*`}{`*bound*`}`, `\plotytics{`*firstcoor*`}{`*incr*`}{`*bound*`}` plot several (x or y) tics, from the initial coordinate *firstcoor*; *incr* is the distance between consecutive tics, and the last tic is not in a position greater than *bound*.

`\printxlabels[`*digits*`]{`*firstcoor*`}{`*incr*`}{`*bound*`}`, `\printylabels[`*digits*`]{`*firstcoor*`}{`*incr*`}{`*bound*`}` print several labels, from the initial coordinate *firstcoor*; *incr* is the distance between consecutive label positions, and the last position is not greater than *bound*. The optional argument *digits* is the number of decimal digits to be printed (by default, numbers are printed with its natural number of decimals).

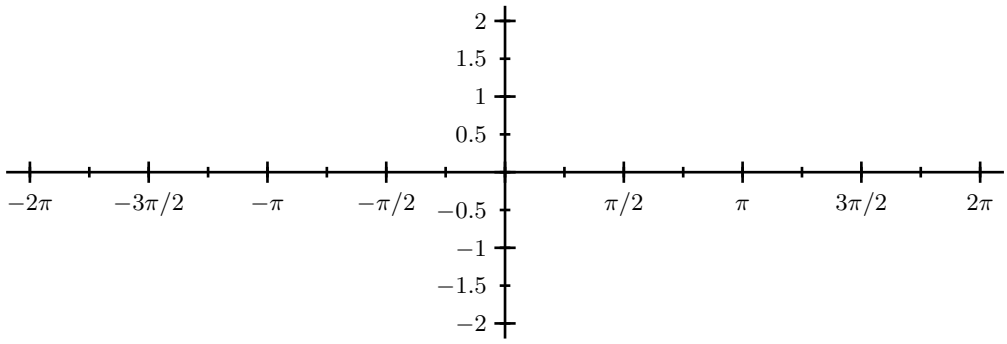
`\printxticslabels[`*digits*`]{`*firstcoor*`}{`*incr*`}{`*bound*`}` plot x tics and labels simultaneously.

`\printyticslabels[`*digits*`]{`*firstcoor*`}{`*incr*`}{`*bound*`}` plot y tics and labels simultaneously.




```
\externalaxes
\setlength{\unitlength}{1cm}
\renewcommand{\axeslabelsize}{\tiny}
\referencesystem(0,0)(1.5,0)(0,2)
\begin{center}
\begin{Picture}(-2.5,-1.5)(2.5,1.5)
\makenotics
\makenolabels
\cartesianaxes(-2.25,-1.25)(2.25,1.25)
\printxticslabels[1]{-2}{0.5}{2.25}
\printyticslabels[4]{-1}{0.25}{1}
\end{Picture}
\end{center}
```

Ex. 13



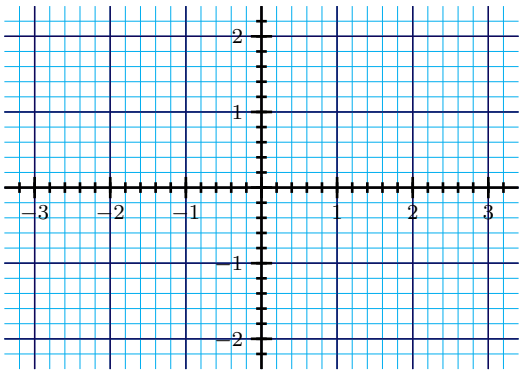

```
\setlength{\unitlength}{1cm}
\begin{center}
\begin{Picture}(-7,-2.5)(7,2.5)
{\referencesystem(0,0)(\numberHALFPI,0)(0,1)
\renewcommand{\xunitdivisions}{2}
\renewcommand{\yunitdivisions}{2}
\makenolabels
\renewcommand{\Pictlabelsep}{0.25}
\cartesianaxes(-4.2,-2.2)(4.2,2.2)

\printylabels{-2}{0.5}{2}

\highestlabel{$-3\pi/2$}
\printxlabel{-4}{-2\pi}
\printxlabel{-3}{-3\pi/2}
\printxlabel{-2}{-\pi}
\printxlabel{-1}{-\pi/2}
\printxlabel{1}{\pi/2}
\printxlabel{2}{\pi}
\printxlabel{3}{3\pi/2}
\printxlabel{4}{2\pi}
}
\end{Picture}
\end{center}
```

Ex. 14

3.4 Cartesian grids

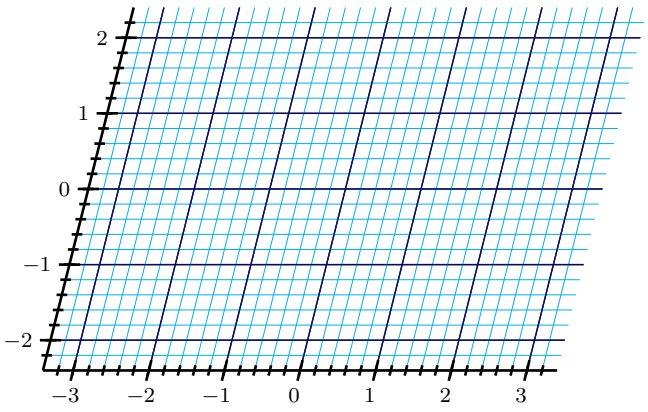
As an alternative to the `\cartesianaxes` command, we can use `\cartesiangrid`, to better visualize the coordinates:

`\cartesiangrid`$(x0, y0)(x1, y1)$




```
\definecolor{myblue}{cmyk}{1,1,0,0.5}
\renewcommand{\gridcolor}{myblue}
\renewcommand{\secundarygridcolor}{cyan}
\setlength{\gridthickness}{0.5pt}
\setlength{\secundarygridthickness}{0.1pt}
\renewcommand{\xunitdivisions}{5}
\renewcommand{\yunitdivisions}{5}
\renewcommand{\axeslabelsize}{\footnotesize}
\begin{center}
\setlength{\unitlength}{1cm}
\begin{Picture}(-3.5,-2.5)(3.5,2.5)
\cartesiangrid(-3.4,-2.4)(3.4,2.4)
\end{Picture}
\end{center}
```

Ex. 15




```
\definecolor{myblue}{cmyk}{1,1,0,0.5}
\renewcommand{\gridcolor}{myblue}
\renewcommand{\secundarygridcolor}{cyan}
\setlength{\gridthickness}{0.5pt}
\setlength{\secundarygridthickness}{0.1pt}
\renewcommand{\xunitdivisions}{5}
\renewcommand{\yunitdivisions}{5}
\renewcommand{\axeslabelsize}{\footnotesize}
\begin{center}
\setlength{\unitlength}{1cm}
\referencesystem(0,0)(1,0)(0.25,1)
\externalaxes
\begin{Picture}(-4,-3)(4,3)
\cartesiangrid(-3.4,-2.4)(3.4,2.4)
\end{Picture}
\end{center}
```

Ex. 16

3.4.1 Grid style

Note that, in addition to the parameters outlined above, there are the following ones, which control the style of the grid (as in previous cases, these parameters are changed by redefining them with the `\renewcommand` declaration, or using the usual instructions when they are lengths).

`\gridcolor` determines the color of main divisions in the grid (regardless of the axes color). By default, this color is `gray`.

`\secundarygridcolor` determines the color of secundary divisions in the grid. By default, `lightgray`).

`\gridthickness` thickness of main divisions (by default, `0.4pt`).

`\secundarygridthickness` thickness of secundary divisions (by default, `0.2pt`).

3.5 Polar grids

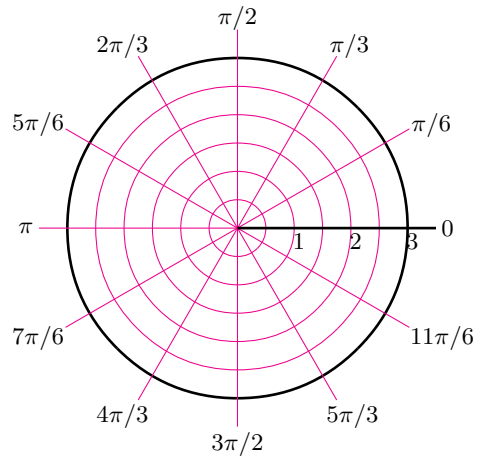
Finally, instead of Cartesian axes, we can construct a polar grid (obviously, this option will be interesting when we use polar coordinates).

`\polargrid{`*radius*`}{`*circledivs*`}`

(*radius* and *circledivs* are, respectively, the radius and the number of divisions of the circle (*circledivs* must be a positive integer).

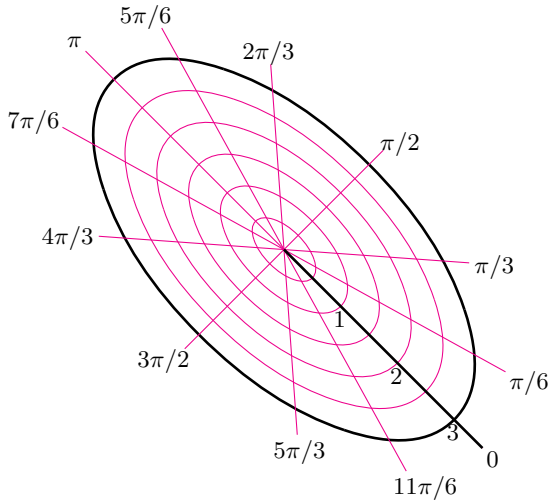
This command supports the same parameters that `\cartesianaxes` and `\cartesiangrid` (when they makes sense), and also the following:

`\runitdivisions` Number of radial subdivisions of the unit. By default, 1 (it must be a positive integer).




```
\renewcommand{\runitdivisions}{2}
\setlength{\unitlength}{0.75cm}
\renewcommand{\gridcolor}{magenta}
\begin{center}
\begin{Picture}(-4,-4)(4,4)
\polargrid{3.5}{12}
\end{Picture}
\end{center}
```

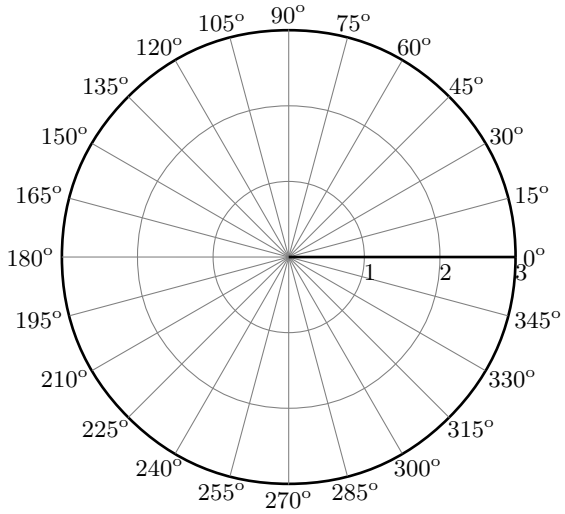
Ex. 17




```
\renewcommand{\runitdivisions}{2}
\setlength{\unitlength}{0.75cm}
\renewcommand{\gridcolor}{magenta}
\referencesystem(0,0)(1,-1)(0.5,0.5)
\begin{center}
\begin{Picture}(-3.5,-3.5)(3.5,3.5)
\polargrid{3.5}{12}
\end{Picture}
\end{center}
```

Ex. 18

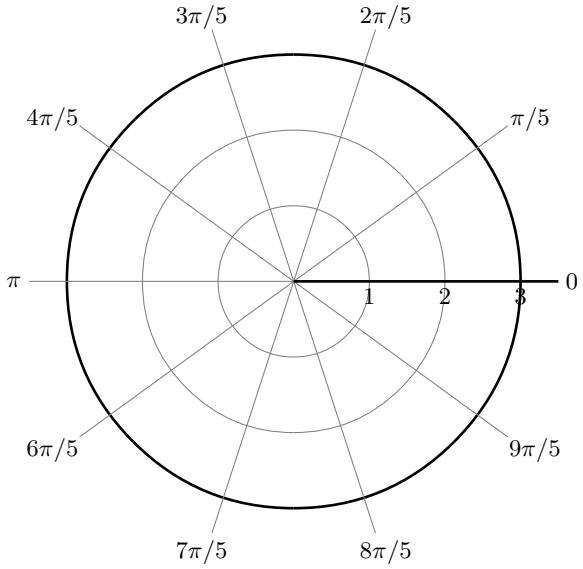
`\degreespolarlabels`, `\radianspolarlabels` Arcs are printed, by default, in radians. If you want angular units mesured in degrees, use the `\degreespolarlabels` declaration (obviously, `\radianspolarlabels` recovers tags in radians).




```
\begin{center}
\degreespolarlabels
\setlength{\unitlength}{1cm}
\begin{Picture}(-4,-4)(4,4)
\polargrid{3}{24}
\end{Picture}
\end{center}
```

Ex. 19

`\rlabelpos` Relative position of labels in polar axis. Admissible values are those allowed in the *position* argument of command `\Put` (see subsection 4.1). Default is `bbr`.




```
\begin{center}
\setlength{\unitlength}{1cm}
\begin{Picture}(-4,-4)(4,4)
\rlabelpos{b}
\polargrid{3.5}{10}
\end{Picture}
\end{center}
```

Ex. 20

To remove tags on the polar axis and angles you can use the `\makenolabels` declaration.

4 Alternatives to standard commands \put,\multiput, \line, and \vector

Standard commands used inside the `picture` environment are not modified by this package (although if we include these commands in the body of a `Picture` environment). In particular, there does not affect the `\referencesystem` declaration. This package introduces similar commands to those which are sensitive to the active reference system and give us a greater control over their behavior. These are the instructions described below.

4.1 Extensions of the \put command

`\Put, \cPut, \rPut`

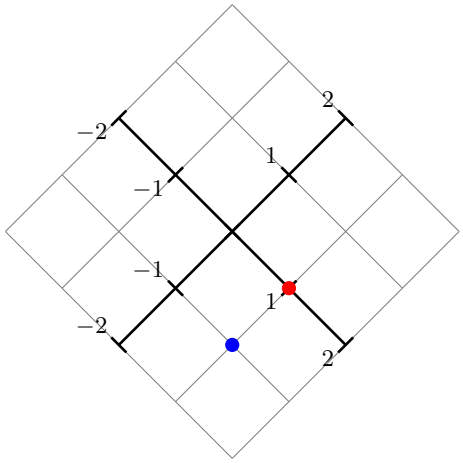
```
\Put[position](x,y){object}
\Put*[position](x,y){object}
\cPut{position}(x,y){object}
\rPut{position}(x,y){object}
\rPut*{position}(x,y){object}
```

place the drawing pointer in the point of coordinates `(x,y)` with respect to the active reference system (which may coincide or not with the standard system). These commands differ in the criteria used to determine the precise position of the object.

Involved parameters are (see below)

```
\Pictlabelsep{distance}
\defaultPut{c}/\defaultPut{r}
\highestlabel{text}
```

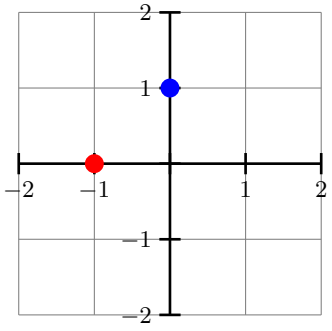
In the following example, the red circle (included as an argument in the `\put` command) is at the point of standard coordinates $(1, -1)$; however, in the case of the blue circle, coordinates $(1, -1)$ refer to the active reference system.




```
\begin{center}
\setlength{\unitlength}{0.75cm}
\referencesystem(0,0)(1,-1)(1,1)
\begin{Picture}(-2.5,-2.5)(2.5,2.5)
\cartesiangrid(-2,-2)(2,2)
\pictcolor{red}
\put(1,-1){\circle*{0.25}}
\pictcolor{blue}
\Put(1,-1){\circle*{0.25}}
\end{Picture}
\end{center}
```

Ex. 21

Recall that coordinates can be rectangular or polar, and angles may be measured in radians or in degrees.

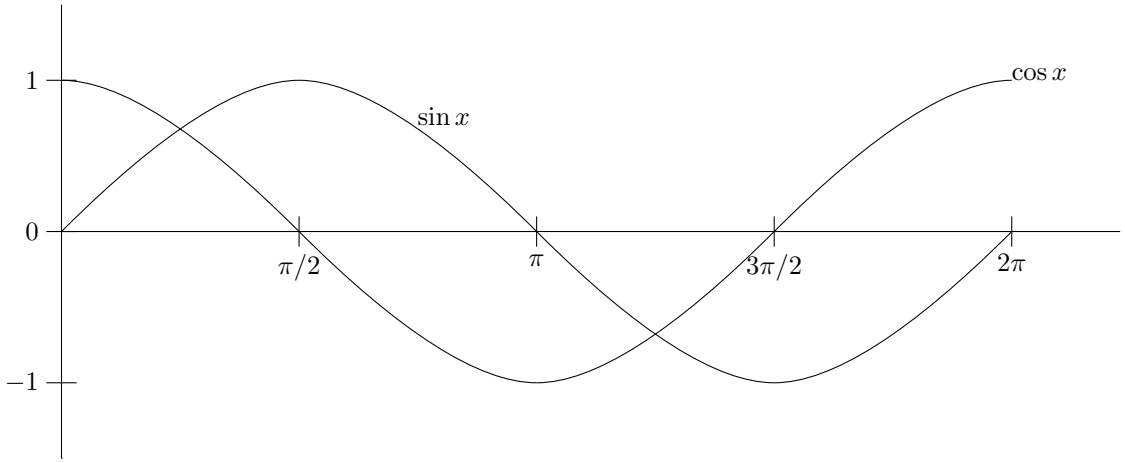



```
\begin{center}
\setlength{\unitlength}{1cm}
\begin{Picture}(-2.5,-2.5)(2.5,2.5)
\cartesiangrid(-2,-2)(2,2)
\polarreference
\pictcolor{blue}
\Put(1,\numberHALFPI){\circle*{0.25}}
\degreesangles
\pictcolor{red}
\Put(1,180){\circle*{0.25}}
\end{Picture}
\end{center}
```

Ex. 22

4.1.1 Accurate positioning of the graphical object

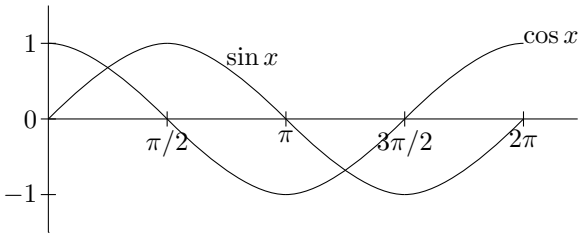
The *position* argument allows us to fix the relative position of *object* respect to point `(x,y)`. Note that this argument is optional in `\Put` and `\Put*`, but mandatory in the other commands we are describing. The purpose of this parameter is to rationalize the disposition of objects, especially when they are not strictly graphical objects (but labels, text boxes or mathematical formulas). In these cases, the appropriate choice of coordinates seems a problem that is not well solved with standard instructions, despite the special syntax of the `\makebox` command in the `picture` environment. For example, in this picture (which we made using only the standard LaTeX commands)



we have located numerical labels (0, 1, $\pi\ldots$) at `0.15\unitlength` of its *natural* position over the axes, while the reference points of tags "$\sin x$" and "$\cos x$" are just in points $(3\pi/4, \sin(3\pi/4))$ and $(2\pi, 1)$, using these instructions:

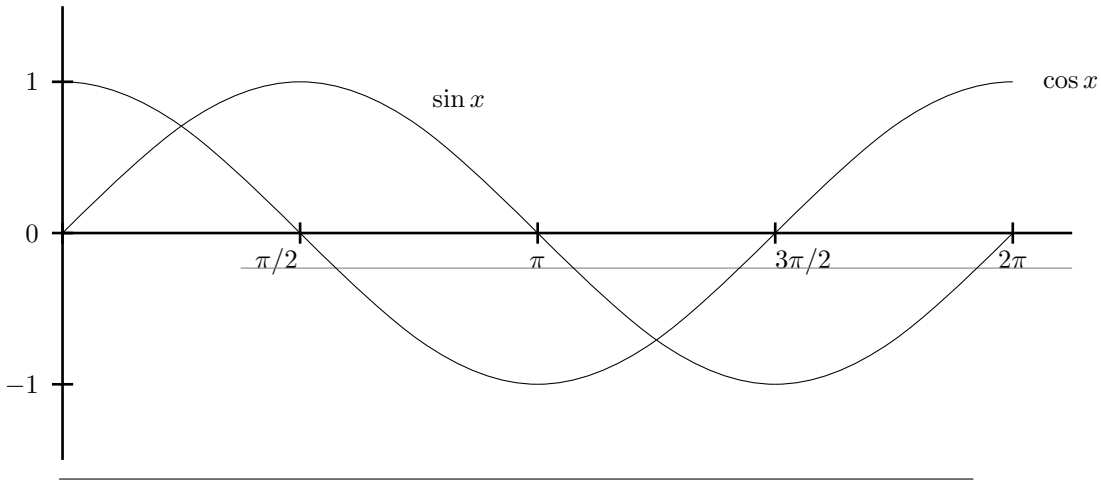
```
\put(2.356194,0.707107){$\sin x$}
\put(6.283185,1){$\cos x$}
\put(-0.15,-1){\makebox(0,0)[r]{$-1$}}
\put(-0.15,0){\makebox(0,0)[r]{$0$}}
\put(-0.15,1){\makebox(0,0)[r]{$1$}}
\put(1.570796,-0.15){\makebox(0,0)[t]{$\pi/2$}}
\put(3.141593,-0.15){\makebox(0,0)[t]{$\pi$}}
\put(4.712389,-0.15){\makebox(0,0)[t]{$3\pi/2$}}
\put(6.283185,-0.15){\makebox(0,0)[t]{$2\pi$}}
```

If we change the value of `\unitlength`, then these values become inappropriate and we need to change several lines of code.



Note that, regarding labels along the x axis, instead of aligning them to a fixed distance of this axis, there would be better to align the baselines (π and 2π should go down); some of these labels should move slightly to the right or to the left to avoid that it cut the graph. Finally, the tag "$\cos x$" should be vertically centered (with respect to the curve) and slightly moved to the right.

Using the `xpicture` package we construct this picture in the following way:




```
\MULTIPLY{3}{\numberQUARTERPI}{\numberTQPI}
\SIN{\numberTQPI}{\sinTQPI}

\begin{center}
\setlength{\unitlength}{2cm}
\begin{Picture}(-0.5,-1.5)(6.5,1.5)
{\referencesystem(0,0)(\numberHALFPI,0)(0,1)
\makenolabels
\renewcommand{\Pictlabelsep}{0.1}
\highestlabel{$-3\pi/2$}
\cartesianaxes(0,-1.5)(4.25,1.5)

\rPut{l}(0,-1){$-1$}                          % put the y-axis labels at left
\rPut{l}(0,0){$0$}
\rPut{l}(0,1){$1$}
\rPut*{bbl}(1,0){$\pi/2$}                     % put "\pi/2" at bbl
\rPut*{b}(2,0){$\pi$}                         % put "\pi" at bottom
\rPut*{bbr}(3,0){$3\pi/2$}                    % put "3\pi/2" at bbr
\rPut*{b}(4,0){$2\pi$}                        % put "2\pi" at bottom

\rPut*{b}(0,0){\pictcolor{gray}\xLINE(0.75,0)(4.25,0)}} % \baseline of x-labels

\PlotFunction[8]{\COSfunction}{0}{\numberTWOPI}
\PlotFunction[8]{\SINfunction}{0}{\numberTWOPI}

\Put[NE](\numberTQPI,\sinTQPI){$\sin x$}      % put "\sin x" at NorthEast
\Put[E](\numberTWOPI,1){$\cos x$}             % put "\cos x" at East
\end{Picture}
\end{center}
```

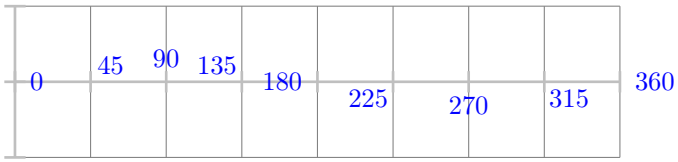
Ex. 23

Here we used several tools to draw the graphs of the functions. But aside from this, commands `\Put`, `\rPut` and `\rPut*` have allowed we to determine the logical position of objects in a much more reasonable way.[7]

Argument *position* supports multiple values:

An integer or decimal number, determining the angle (in degrees) where *object* is placed, with respect to the reference point *(x,y)*.

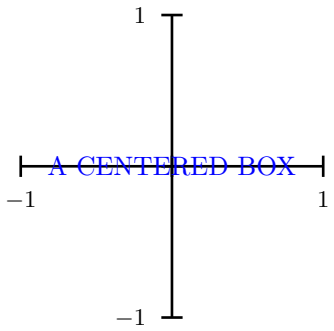
[7] Regarding to labels on coordinated axes a better choice would be to use other specific commands, as `\printxlabels`. Here we have chosen `\rPut` because we are illustrating this instruction.




```
\begin{center}
\setlength{\unitlength}{1cm}
\begin{Picture}(0,-1)(9,1)
\makenolabels
\renewcommand{\axescolor}{lightgray}\renewcommand{\ticscolor}{lightgray}
\cartesiangrid(0,-1)(8,1)
\pictcolor{blue}
\Put[0](0,0){0}
\Put[45](1,0){45}
\Put[90](2,0){90}
\Put[135](3,0){135}
\Put[180](4,0){180}
\Put[225](5,0){225}
\Put[270](6,0){270}
\Put[315](7,0){315}
\Put[360](8,0){360}
\end{Picture}
\end{center}
```

Ex. 24

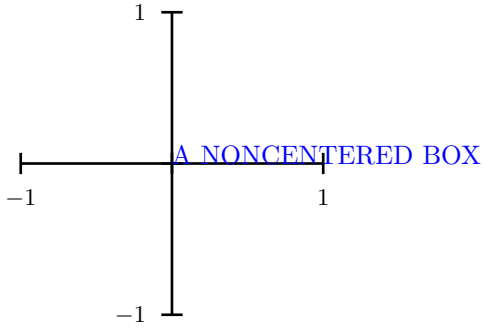
Letter `c` (from *center*), which places the center of *`object`* at point `(`*`x`*`,`*`y`*`)`.




```
\begin{center}
\setlength{\unitlength}{2cm}
\begin{Picture}(-1,-1)(1,1)
\cartesianaxes(-1,-1)(1,1)
\pictcolor{blue}
\Put[c](0,0){A CENTERED BOX}
\end{Picture}
\end{center}
```

Ex. 25

Note that this option is not equivalent to the suppression of the optional argument, because in that case the reference point of *`object`* is located in `(`*`x`*`,`*`y`*`)`.




```
\begin{center}
\setlength{\unitlength}{2cm}
\begin{Picture}(-1,-1)(1,1)
\cartesianaxes(-1,-1)(1,1)
\pictcolor{blue}
\Put(0,0){A NONCENTERED BOX}
\end{Picture}
\end{center}
```

Ex. 26

Letters or letter combinations `N`, `E`, `S`, `W`, `NE`, `SE`, `SW`, `NW`, `NNE`, `ENE`, `ESE`, `SSE`, `SSW`, `WSW`, `WNW`, `NNW`

Abbreviation of *North*, *East*..., *North-East*..., *North-North-East*...

For example, the

`\Put[NE](0,0){A}`

instruction writes "`A`" *at north-east* of point `(0,0)`.

Letters o letter combinations `t`, `r`, `b`, `l`, `tr`, `br`, `bl`, `tl`, `ttr`, `rtr`, `rbr`, `bbr`, `bbl`, `lbl`, `ltl`, `ttl`

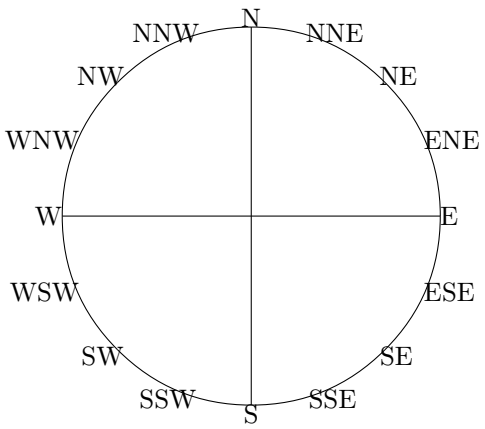
Abbreviation of *top*, *right*..., *top-right*..., *top-top-right*...

For example,

`\Put[tr](0,0){A}`

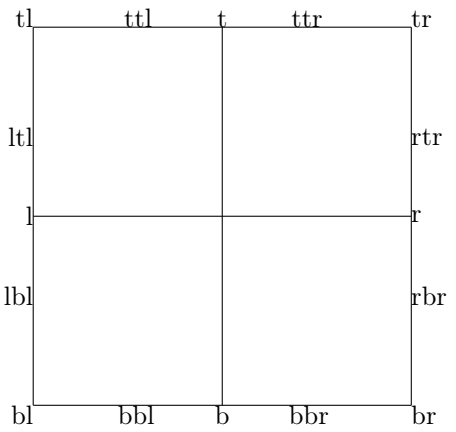
writes "A" *at top and right* of point `(0,0)`.

Parameter `\Pictlabelsep` determines the distance between the graphical object and the given point. In the following examples we have made this argument very big to clearly appreciate the positioning of objects.




```
\renewcommand{\Pictlabelsep}{1}
\begin{center}
\setlength{\unitlength}{2.5cm}%

\begin{Picture}(-1.5,-1.5)(1.5,1.5)
\Put[N](0,0){N}
\Put[S](0,0){S}
\Put[E](0,0){E}
\Put[W](0,0){W}
\Put[NE](0,0){NE}
\Put[SE](0,0){SE}
\Put[SW](0,0){SW}
\Put[NW](0,0){NW}
%
\Put[NNE](0,0){NNE}
\Put[ENE](0,0){ENE}
\Put[ESE](0,0){ESE}
\Put[SSE](0,0){SSE}
\Put[SSW](0,0){SSW}
\Put[WSW](0,0){WSW}
\Put[WNW](0,0){WNW}
\Put[NNW](0,0){NNW}
\Put(0,0){\Circle{1}}
\xLINE(-1,0)(1,0)
\xLINE(0,-1)(0,1)
\end{Picture}
\end{center}
```

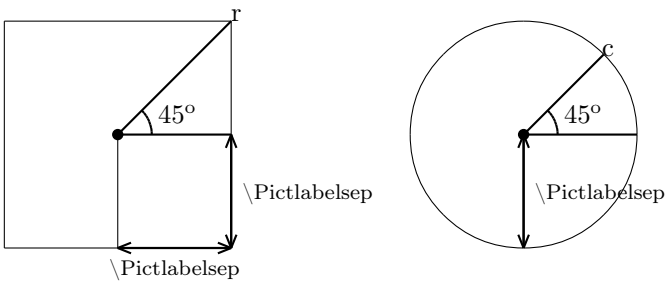
Ex. 27




```
\renewcommand{\Pictlabelsep}{1}
\begin{center}
\setlength{\unitlength}{2.5cm}%

\begin{Picture}(-1.5,-1.5)(1.5,1.5)
\Put[t](0,0){t}
\Put[r](0,0){r}
\Put[b](0,0){b}
\Put[l](0,0){l}
\Put[tr](0,0){tr}
\Put[br](0,0){br}
\Put[bl](0,0){bl}
\Put[tl](0,0){tl}
\Put[ttr](0,0){ttr}
\Put[rtr](0,0){rtr}
\Put[rbr](0,0){rbr}
\Put[bbr](0,0){bbr}
\Put[bbl](0,0){bbl}
\Put[lbl](0,0){lbl}
\Put[ltl](0,0){ltl}
\Put[ttl](0,0){ttl}
\Put(0,0){%
   \regularPolygon[45]{\numberSQRTTWO}{4}}
\xLINE(-1,0)(1,0)
\xLINE(0,-1)(0,1)
\end{Picture}
\end{center}
```

Ex. 28

Rectangular o circular distance? Commands `\rPut` and `\cPut` differ only in the criterion they use to determine the distance between the reference point and the graphical object. Command `\rPut` places the object (outside of) the square centered at the reference point and side `2\Pictlabelsep`, while `\cPut` places it in the cercle of radius `\Pictlabelsep` (letters `r` and `c` mean, respectively, a *rectangular* and *circular* layout).[8] Although, for small values of the `\Pictlabelsep` parameter, the difference is subtle and usually not very significant, it is generally best to use the circular version (because it corresponds to the natural concept of distance) and reserve the rectangular version to objects that are placed on horizontal or vertical lines.



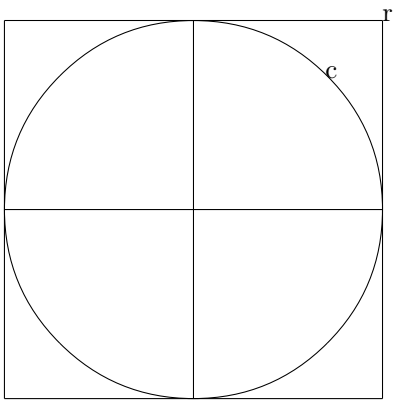

```
\begin{center}
\setlength{\unitlength}{1.5cm}
\renewcommand{\Pictlabelsep}{1}

\begin{Picture}(-1.5,-1.5)(2,1.5)
\regularPolygon[45]{\numberSQRTTWO}{4}
\Put(0,0){\circle*{0.1}}
\rPut{45}(0,0){r}
\xLINE(0,0)(0,-1)
\thicklines
\renewcommand{\Pictlabelsep}{0.1}
\xLINE(0,0)(1,1)
\xLINE(0,0)(1,0)
\xtrivVECTOR(0,-1)(1,-1)
\xtrivVECTOR(1,-1)(0,-1)
\rPut{b}(0.5,-1){\footnotesize\textbackslash Pictlabelsep}
\xtrivVECTOR(1,-1)(1,0)
\xtrivVECTOR(1,0)(1,-1)
\rPut{r}(1,-0.5){\footnotesize\textbackslash Pictlabelsep}
\polarreference\degreesangles
\xArc{0.3}{0}{45}
\degreesangles
\Put[22.5](0.3,22.5){$45^{\mathrm o}$}
\end{Picture}
\begin{Picture}(-1.5,-1.5)(2,1.5)
\Put(0,0){\circle*{0.1}}
\cPut{45}(0,0){c}
\Circle{1}
\thicklines
\xLINE(0,0)(\numberCOSXLV,\numberCOSXLV)
\xLINE(0,0)(1,0)
\xtrivVECTOR(0,0)(0,-1)
\xtrivVECTOR(0,-1)(0,0)
\renewcommand{\Pictlabelsep}{0.1}
\rPut{r}(0,-0.5){\footnotesize\textbackslash Pictlabelsep}
\polarreference\degreesangles
\xArc{0.3}{0}{45}
\degreesangles
\Put[22.5](0.3,22.5){$45^{\mathrm o}$}
\end{Picture}
\end{center}
```

Ex. 29

[8] For the mathematicians: command `\cPut` uses the euclidean norm (or 2-norm), while `\rPut` uses the infinite norm.

Note that if the commands we use are `\rPut` or `\cPut`, then the positioners `t, r, tr`... are equivalent to the corresponding `N, E, NE`... However, the `\Put` command choose between rectangular or circular layout following this criteria:

- Positioners of *compass* type (like `NE`) use the circular layout.
- Positioners `t, tr`, et cetera use the rectangular layout.
- If the positioner is an angle (a number), it uses a default position which is set using the `\defaultPut` declaration: `\defaultPut{c}` determines a circular distance, while `\defaultPut{r}` determines the rectangular alternative.




```
\renewcommand{\Pictlabelsep}{1}
\begin{center}
\setlength{\unitlength}{2.5cm}%

\begin{Picture}(-1.5,-1.5)(1.5,1.5)
\defaultPut{c}
\Put[45](0,0){c}
\defaultPut{r}
\Put[45](0,0){r}
\regularPolygon[45]{\numberSQRTTWO}{4}
\Put(0,0){\Circle{1}}
\xLINE(-1,0)(1,0)
\xLINE(0,-1)(0,1)
\end{Picture}
\end{center}
```

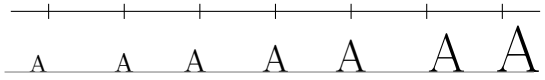
Ex. 30

Alignment by the baseline Starred versions `\Put*` and `\rPut*` allow us to align by the baseline objects positioned below the reference point. To use these commands, user must decide which is the higher object to be positioned, and introduce it as an argument of the `\highestlabel` declaration. For example, typing

```
\highestlabel{\Huge A}
```

we reserve a sufficient vertical space to write the character A.

It should be noted that starred versions behave differently only when the position of the object stands under the reference point, with positioners `bbl`, `b` or `bbr`, or with an appropiate angle (as `-90` or `300`); otherwise (including `S`, `SSW`, et cetera), the `\Put*` and `\rPut*` commands are equivalent to the non-starred commands `\Put` and `\rPut`.




```
\begin{center}
\setlength{\unitlength}{1cm}

\begin{Picture}(-3.5,-1.5)(3.5,1.5)
\xLINE(-3.5,0)(3.5,0)
\multiPut(-3,-0.1)(1,0){7}{\xLINE(0,0)(0,0.2)}
\highestlabel{\Huge A}
\renewcommand{\Pictlabelsep}{0.2}
\Put*[bbl](-3,0){\small A}
\Put*[b](-2,0){\normalsize A}
\Put*[-100](-1,0){\large A}
\Put*[-90](0,0){\Large A}
\Put*[270](1,0){\LARGE A}
\Put*[300](2,0){\huge A}
\Put*[bbr](3,0){\Huge A}
\Put*[bbl](-3.5,0){%
   \pictcolor{gray}\xLINE(0,0)(7,0)}
\end{Picture}
\end{center}
```

Ex. 31

When a `Picture` environment starts, highest label is set to `\normalfont\normalsize$1$` (i.e., the high of a *normal* 1).

4.2 Alternatives to the \multiput command

The xpicture package introduces two families of commands to generalize the \multiput command:

1. The natural generalization, with all versions,

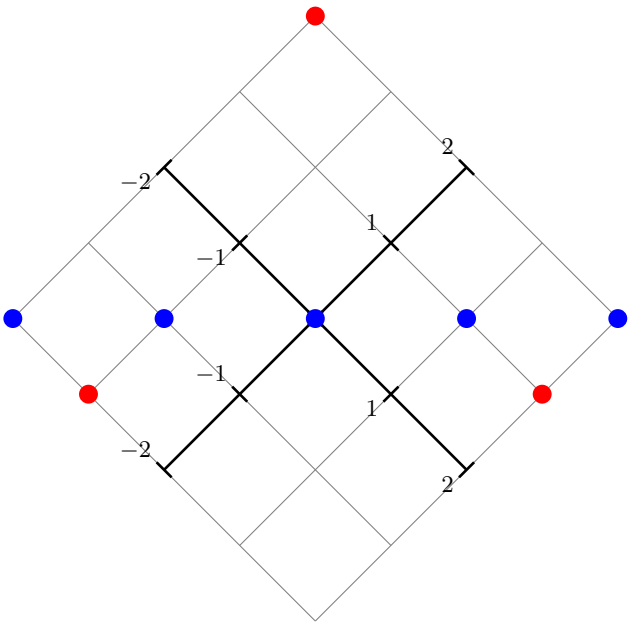
   \multiPut[*position*](*x0*,*y0*)(Δ*x*,Δ*y*){*n*}{*object*}
   \multiPut*[*position*](*x0*,*y0*)(Δ*x*,Δ*y*){*n*}{*object*}
   \multicPut{*position*}(*x0*,*y0*)(Δ*x*,Δ*y*){*n*}{*object*}
   \multirPut{*position*}(*x0*,*y0*)(Δ*x*,Δ*y*){*n*}{*object*}
   \multirPut*{*position*}(*x0*,*y0*)(Δ*x*,Δ*y*){*n*}{*object*}

   These commands compose n copies of *object* in $(x0, y0)$, $(x0+\Delta x, y0+\Delta y)$, $(x0+2\Delta x, y0+2\Delta y)$,..., $(x0+(n-1)\Delta x, y0+(n-1)\Delta y)$.

2. A new command group,

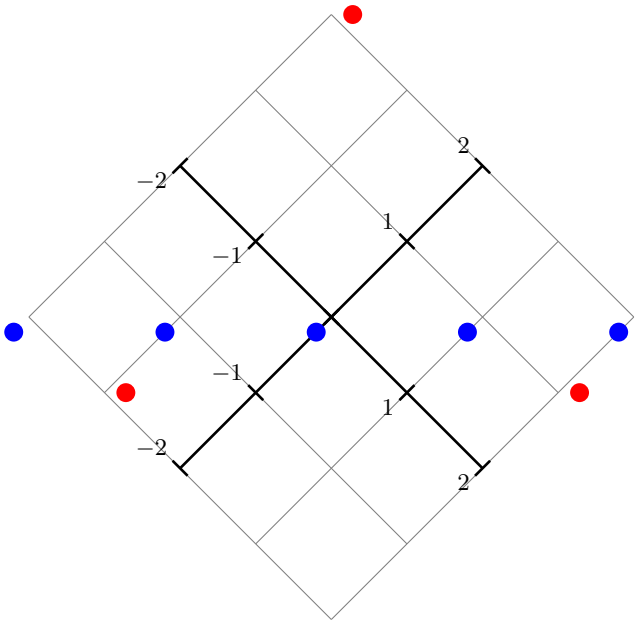
   \multiPlot[*position*]{*object*}(*x0*,*y0*)(*x1*,*y1*)...(*xn*,*yn*)
   \multiPlot*[*position*]{*object*}(*x0*,*y0*)(*x1*,*y1*)...(*xn*,*yn*)
   \multicPlot{*position*}{*object*}(*x0*,*y0*)(*x1*,*y1*)...(*xn*,*yn*)
   \multirPlot{*position*}{*object*}(*x0*,*y0*)(*x1*,*y1*)...(*xn*,*yn*)
   \multirPlot*{*position*}{*object*}(*x0*,*y0*)(*x1*,*y1*)...(*xn*,*yn*)

   These commands compose the done object in several positions, that are freely entered as a list of coordinate pairs.



Ex. 32

```
\begin{center}
\setlength{\unitlength}{1cm}
\referencesystem(0,0)(1,-1)(1,1)
\begin{Picture}(-2.5,-2.5)(2.5,2.5)
\cartesiangrid(-2,-2)(2,2)
\pictcolor{blue}
\multiPut(-2,-2)(1,1){5}{\circle*{0.25}}
\pictcolor{red}
\multiPlot{\circle*{0.25}}(-1,-2)(2,1)(-2,2)
\end{Picture}
\end{center}
```




```
\begin{center}
\setlength{\unitlength}{1cm}
\referencesystem(0,0)(1,-1)(1,1)
\begin{Picture}(-2.5,-2.5)(2.5,2.5)
\cartesiangrid(-2,-2)(2,2)
\pictcolor{blue}
\multiPut[b](-2,-2)(1,1){5}{\circle*{0.25}}
\pictcolor{red}
\multiPlot[NE]{\circle*{0.25}}(-1,-2)(2,1)(-2,2)
\end{Picture}
\end{center}
```

Ex. 33

4.3 Alternatives to `\line` and `\vector`

`\xLINE` This command draws line segments:

`\xLINE(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)`

draws the line segment between the two points (*x0*, *y0*) and (*x1*, *y1*) (Cartesian or polar coordinates, in the active reference system). This allows us to draw any segment in any direction.

`\xVECTOR`, `\xtrivVECTOR` plot arrows:

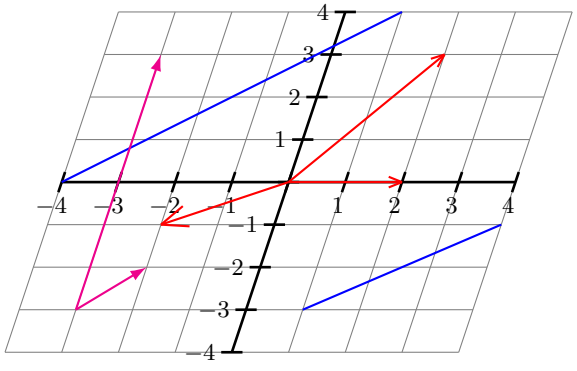
`\xVECTOR(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)`
`\xtrivVECTOR(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)`

draw an arrow between points (*x0*, *y0*) and (*x1*, *y1*). The `\xtrivVECTOR` command draw an arrow the end of which simply consists of a pair of segments (⟶). length and aperture of the end of arrow are controled by the instruction

`\arrowsize{`*xlen*`}{`*ylen*`}`

where the two parameters are non-negative numbers: the first one for the length (in points); second for the half of the aperture. Default is

`\arrowsize{5}{2}`

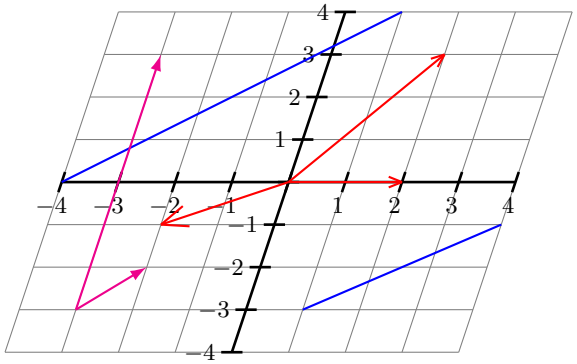


```
\setlength{\unitlength}{0.75cm}
\referencesystem(0,0)(1,0)(0.25,0.75)
\begin{Picture}(-4.5,-4.5)(4.5,4.5)
\cartesiangrid(-4,-4)(4,4)
\thicklines
\pictcolor{blue}
\xLINE(-4,0)(1,4)
\Put(1,-3){\xLINE(0,0)(3,2)}
\pictcolor{red}
\xtrivVECTOR(0,0)(2,3)
\xtrivVECTOR(0,0)(2,0)
\arrowsize{10}{4}
\xtrivVECTOR(0,0)(-2,-1)

\pictcolor{magenta}
\xVECTOR(-3,-3)(-3,3)
\xVECTOR(-3,-3)(-2,-2)
\end{Picture}
```

Ex. 34

`\xline`, `\xvector`, `\xtrivvector` draw lines and vectors using the standard LaTeX syntax (but without any restriction in allowed parameters, that can be integer or decimal numbers, positive, negative or zero).

```
\xline(x,y){size}
\xvector(x,y){size}
\xtrivvector(x,y){size}
```



```
\setlength{\unitlength}{0.75cm}
\referencesystem(0,0)(1,0)(0.25,0.75)
\begin{Picture}(-4.5,-4.5)(4.5,4.5)
\cartesiangrid(-4,-4)(4,4)
\thicklines
\pictcolor{blue}
\Put(-4,0){\xline(5,4){5}}
\Put(1,-3){\xline(3,2){3}}
\pictcolor{red}
\Put(0,0){\xtrivvector(2,3){2}}
\xtrivvector(1,0){2}
\arrowsize{10}{4}
\Put(0,0){\xtrivvector(2,1){-2}}

\pictcolor{magenta}
\Put(-3,-3){\xvector(0,1){6}}
\Put(-3,-3){\xvector(1,1){1}}
\end{Picture}
```

Ex. 35

If you want to draw only an arrowhead (without any line) you can use either the `\zerovector`/`\zerotrivvector` or `\xvector`/`\xtrivvector` commands:

```
\zerovector(x,y)
\zerotrivvector(x,y)
\xvector(x,y){0}
\xtrivvector(x,y){0}
```

4.4 Polygons anf polygonal lines

The `pict2e` and `curve2e` packages include specific instructions for drawing polygonal lines and polygons. We introduce new versions of these commands in order to refer to the active reference system.

`\Polyline` draws polygonal lines. Logically, we must pass the list of vertices:

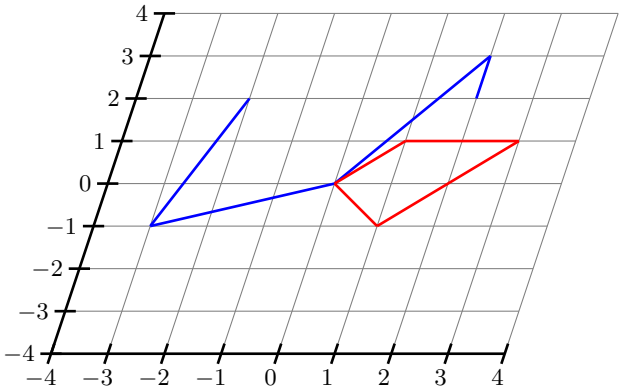
```
\Polyline(x0,y0)(x1,y1)...(xn,yn)
```

`\Polygon` plots polygons, ie, closed polygonal lines:

```
\Polygon(x0,y0)(x1,y1)...(xn,yn)
```

is equivalent to

`\Polyline(`*x0*`,`*y0*`)(`*x1*`,`*y1*`)...(`*xn*`,`*yn*`)(`*x0*`,`*y0*`)`



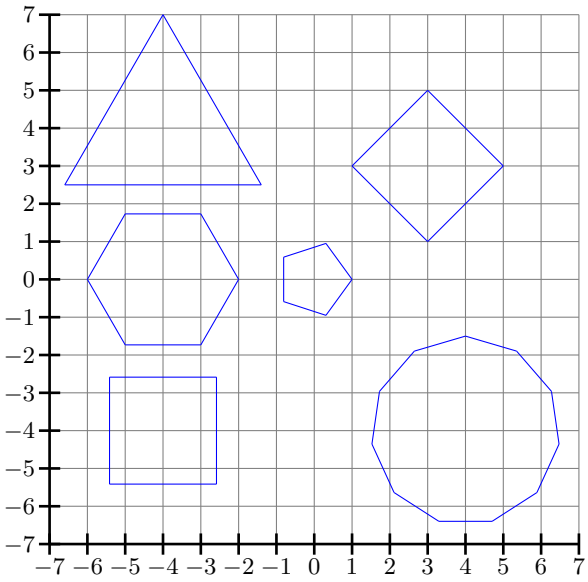
```
\setlength{\unitlength}{0.75cm}
\referencesystem(0,0)(1,0)(0.25,0.75)
\begin{Picture}(-4.5,-4.5)(4.5,4.5)
\externalaxes
\cartesiangrid(-4,-4)(4,4)
\linethickness{1pt}
\pictcolor{blue}
\Polyline(-2,2)(-3,-1)(0,0)(2,3)(2,2)
\pictcolor{red}
\Polygon(0,0)(1,1)(3,1)(1,-1)
\end{Picture}
```

Ex. 36

`\regularPolygon` draws regular polygons:

`\regularPolygon[`*initial angle*`]{`*radius*`}{`*sides*`}`

makes the regular polygon with the given radius and sides. The optional argument (zero, by default) determines the slope of the first vertex, always measured in degrees.



```
\begin{center}
\setlength{\unitlength}{0.5cm}
\begin{Picture}(-7.5,-7.5)(7.5,7.5)
\externalaxes
\cartesiangrid(-7,-7)(7,7)
\pictcolor{blue}
\regularPolygon{1}{5}
\Put(-4,0){\regularPolygon{2}{6}}
\Put(3,3){\regularPolygon{2}{4}}
\Put(-4,-4){\regularPolygon[45]{2}{4}}
\Put(4,-4){\regularPolygon[90]{2.5}{11}}
\Put(-4,4){\regularPolygon[90]{3}{3}}
\end{Picture}
\end{center}
```

Ex. 37

5 Drawing curves

This section highlights the true potentiality of the `xpicture` package. We will describe the instructions that can be used to easily (and effectively) represent several interesting curves: Firstly, conic sections and arcs. Then, any piecewise regular curve (including graphs of real variable functions, in rectangular or polar coordinates, and —in a more general way— curves defined by parametric equations).

5.1 Conic sections

The `xpicture` package defines new commands to draw conic sections: ellipses, circles, hyperbolas and parabolas.

5.1.1 Circles

We can draw the circle of implicit equation $x^2 + y^2 = r^2$ typing

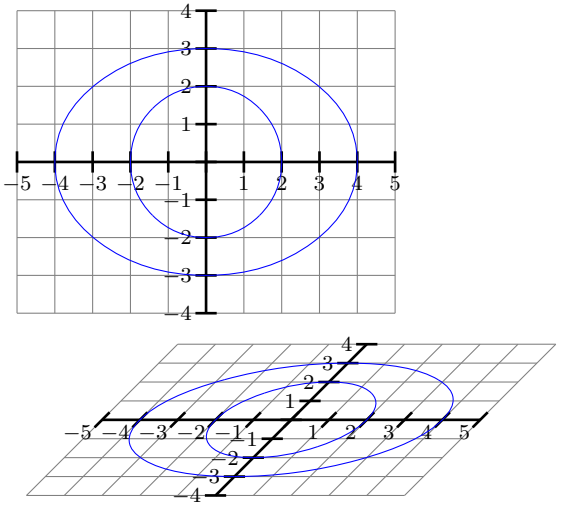
`\Circle{`*r*`}`

Note than the standard command `\circle` requeres the diameter as mandatory argument, while here we must insert the radius.

5.1.2 Ellipses

To draw the ellipse $\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$ enter the following instruction:

`\Ellipse{`*a*`}{`*b*`}`



```
\setlength{\unitlength}{0.5cm}
\renewcommand{\axeslabelsize}{\footnotesize}
\begin{Picture}(-5.5,-4.5)(5.5,4.5)
\cartesiangrid(-5,-4)(5,4)
\pictcolor{blue}
\Ellipse{4}{3}
\Circle{2}
\end{Picture}
```

Ex. 38


```
\referencesystem(0,0)(1,0)(0.5,0.5)
\begin{Picture}(-5.5,-4.5)(5.5,4.5)
\cartesiangrid(-5,-4)(5,4)
\pictcolor{blue}
\Ellipse{4}{3}
\Circle{2}
\end{Picture}
```

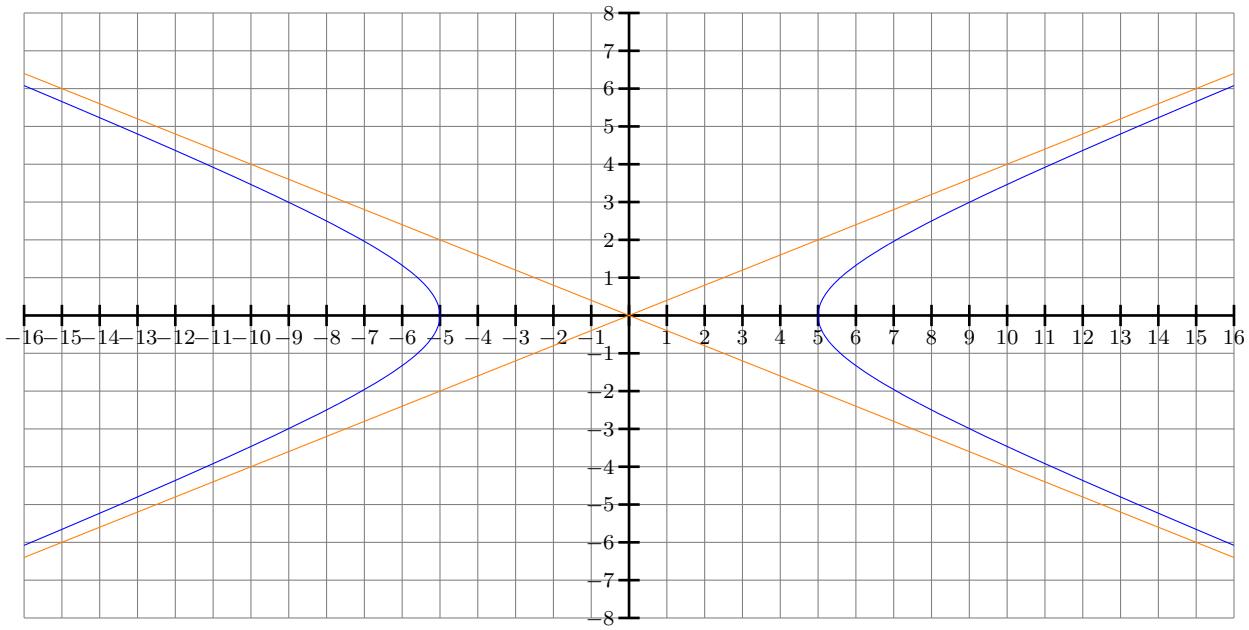
5.1.3 Hyperbolas

Since the hyperbolas and parabolas are not bounded curves, to define the portion of the curve that we want to draw we need to specify the maximum values for the x and y variables.

`\Hyperbola{`*a*`}{`*b*`}{`*xmax*`}{`*ymax*`}`

draws the hyperbola $\frac{x^2}{a^2}-\frac{y^2}{b^2}=1$, where variables x and y are limited, respectively, to the `[-`*xmax*`,`*xmax*`]` and `[-`*ymax*`,`*ymax*`]` intervals. This curve is well defined if the parameter *xmax* is greater than *a*. Otherwise, `xpicture` returns an error message and does not draw any curve.

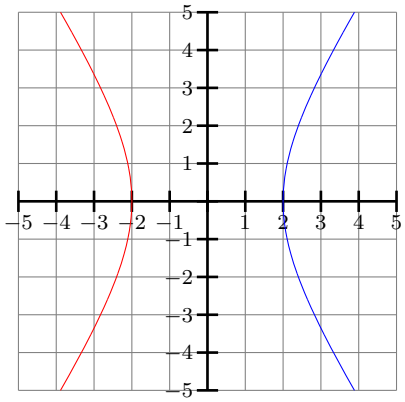
In the following example, we show the hyperbola $\frac{x^2}{5^2}-\frac{y^2}{2^2}=1$ and its asymptotes, using the `\xLINE` command (these asymptotes are lines $2x=\pm 5y$, passing through $(\pm 16,\pm 6.4)$).



Ex. 39

```
\begin{center}
\setlength{\unitlength}{0.5cm}
\begin{Picture}(-17,-9)(17,9)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesiangrid(-16,-8)(16,8)
\pictcolor{blue}
\Hyperbola{5}{2}{16}{8}
\pictcolor{orange}
\xLINE(16,6.4)(-16,-6.4)
\xLINE(-16,6.4)(16,-6.4)
\end{Picture}
\end{center}
```

Instructions `\lHyperbola` and `\rHyperbola` draw, respectively, only the *left* or only the *right* branch of the given hyperbola (here, is interpreted as *right* branch this one that belongs to positive values of variable x).



Ex. 40

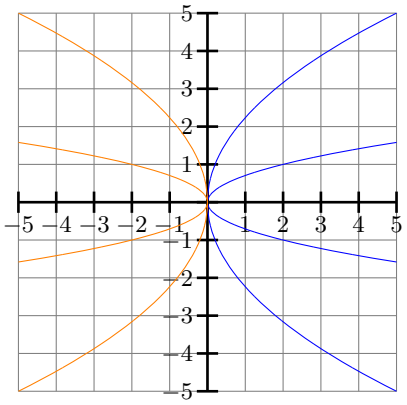
```
\begin{center}
\setlength{\unitlength}{0.5cm}
\begin{Picture}(-5.5,-5.5)(5.5,5.5)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesiangrid(-5,-5)(5,5)
\pictcolor{red}
\lHyperbola{2}{3}{5}{5}
\pictcolor{blue}
\rHyperbola{2}{3}{5}{5}
\end{Picture}
\end{center}
```

5.1.4 Parabolas

Instruction

`\Parabola{`*a*`}{`*xmax*`}{`*ymax*`}`

draw the parabola $x = ay^2$, varying x, at most, in the interval $[0, \mathit{xmax}]$ (if *a* is positive) or in $[-\mathit{xmax}, 0]$ (for negative values of *a*), and y in $[-\mathit{ymax}, \mathit{ymax}]$. Parameters *xmax* and *ymax* must be positive.

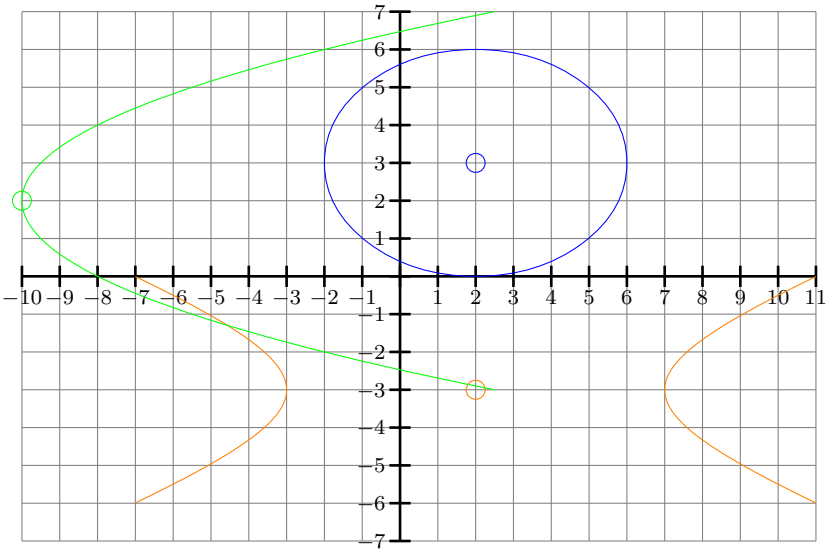


```
\begin{center}
\setlength{\unitlength}{0.5cm}
\begin{Picture}(-5.5,-5.5)(5.5,5.5)
\cartesiangrid(-5,-5)(5,5)
\pictcolor{blue}
\Parabola{2}{5}{5}
\Parabola{0.2}{5}{5}
\pictcolor{orange}
\Parabola{-2}{5}{5}
\Parabola{-0.2}{5}{5}
\end{Picture}
\end{center}
```

Ex. 41

All commands drawing conic sections or arcs divide the curve in `\defaultplotdivs` pieces (8, by default). To obtain a greather accuracy, you can redefine this parameter.

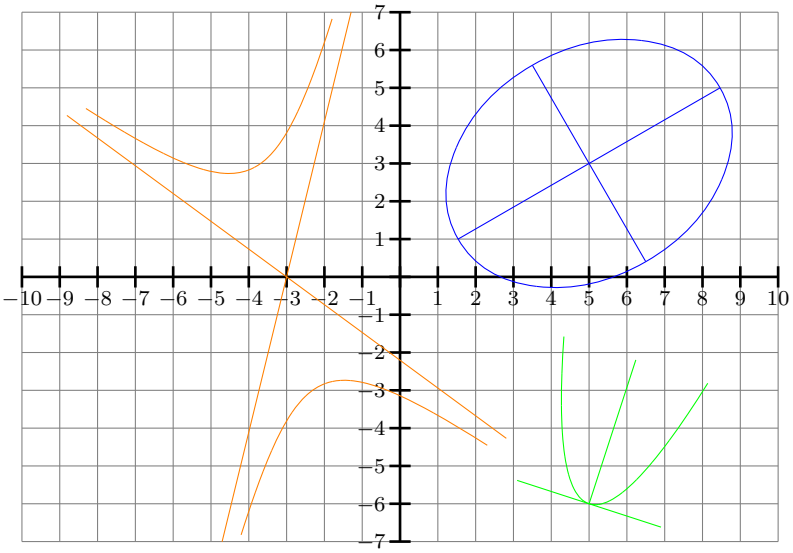
Note that all these commands draw conic sections centered at the coordinate origin, so that their principal axes coincide with the coordinate axes. If we want to move his center to any other point, we can do it moving in advance the origin of coordinates or simply including the command as an argument of the `\Put` command.



Ex. 42

```
\begin{center}
\setlength{\unitlength}{0.5cm}
\begin{Picture}(-11,-8)(11,8)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesiangrid(-10,-7)(11,7)
\pictcolor{blue}
\Put(2,3){\Ellipse{4}{3}}
\Put(2,3){\Circle{0.25}}
\pictcolor{orange}
\Put(2,-3){\Hyperbola{5}{2}{9}{3}}
\Put(2,-3){\Circle{0.25}}
\pictcolor{green}
\translateorigin(-10,2)
\Parabola{0.5}{21}{5}
\Circle{0.25}
\end{Picture}
\end{center}
```

But, if the symmetry axes of our curve are not parallel to the coordinate axes,[9] then we will need a rotation of axes.

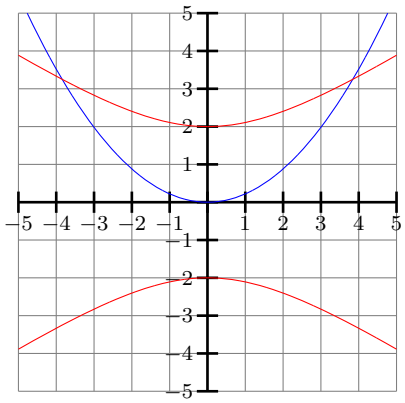


Ex. 43

```
\setlength{\unitlength}{0.5cm}
\begin{center}
\begin{Picture}(-10.5,-7.5)(10.5,7.5)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesiangrid(-10,-7)(10,7)
{%
\pictcolor{blue}
\translateorigin(5,3)
\rotateaxes{\numberSIXTHPI}
\Ellipse{4}{3}
\xLINE(-4,0)(4,0)
\xLINE(0,-3)(0,3)
}
\degreesangles
{%
\pictcolor{orange}
\translateorigin(-3,0)
\rotateaxes{110}
\Hyperbola{3}{2}{6}{4}
\xLINE(-6,-4)(6,4)
\xLINE(6,-4)(-6,4)
}
\pictcolor{green}
\translateorigin(5,-6)
\rotateaxes{72}
\Parabola{1}{4}{3}
\xLINE(0,-2)(0,2)
\xLINE(0,0)(4,0)
\end{Picture}
\end{center}
```

Note that we made a couple of changes of local reference system (one for each curve) within the drawing. We can use the recourse to the change of coordinates also to draw the hyperbola $\frac{y^2}{a^2} - \frac{x^2}{b^2} = 1$ and the parabola $y = ax^2$. Note than `\referencesystem(0,0)(0,1)(1,0)` (or `\symmetrize{\numberQUARTERPI}`) makes vertical the x axis and horizontal the y axis.[10]

[9] That is, in mathematical terms, if the eigenvectors of the underlying quadratic form are not the canonical vectors.
[10] We will use this trick later to plot inverse functions.



```
\setlength{\unitlength}{0.5cm}
\begin{center}
\begin{Picture}(-5.5,-5.5)(5.5,5,5)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesiangrid(-5,-5)(5,5)
\referencesystem(0,0)(0,1)(1,0)
\pictcolor{blue}
\Parabola{0.22}{5}{5}
\pictcolor{red}
\Hyperbola{2}{3}{5}{5}
\end{Picture}
\end{center}
```

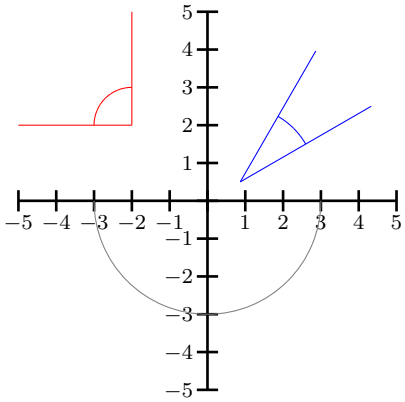
Ex. 44

5.2 Arcs (of conic sections)

The instructions described above allow us to draw whole circles, ellipses hyperbolas and parabolas. More generally, we can represent any portion of these curves, ie, circular, elliptic, hyperbolic and parabolic arcs.

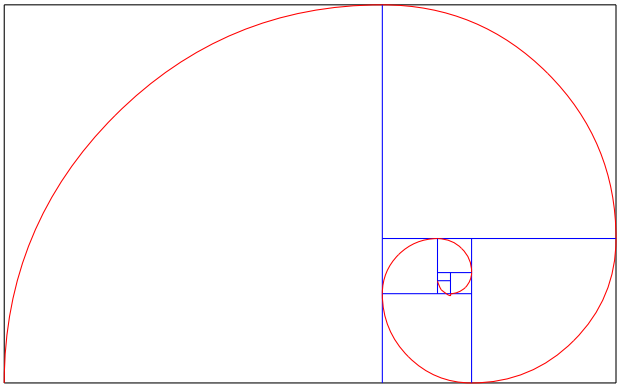
`\xArc{`*r*`}{`*angle1*`}{`*angle2*`}`
`\circularArc{`*r*`}{`*angle1*`}{`*angle2*`}`

These two instructions are equivalent. They draw the arc of the circle centered at $(0,0)$ with radius r and limited by the *angle1* and *angle2* angles.



```
\setlength{\unitlength}{0.5cm}
\begin{center}
\begin{Picture}(-5.5,-5.5)(5.5,5,5)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesianaxes(-5,-5)(5,5)
\pictcolor{gray}
\circularArc{3}{\numberPI}{\numberTWOPI}
\pictcolor{red}
\xLINE(-2,2)(-2,5)
\xLINE(-2,2)(-5,2)
\degreesangles
\Put(-2,2){\circularArc{1}{90}{180}}
\pictcolor{blue}
\polarreference
\Put(1,30){\xLINE(0,0)(4,30)}
\Put(1,30){\xLINE(0,0)(4,60)}
\Put(1,30){\circularArc{2}{30}{60}}
\end{Picture}
\end{center}
```

Ex. 45



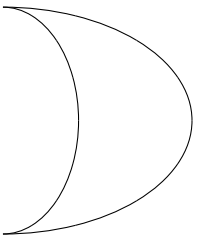
Golden rectangles and spiral

```
\SUBTRACT{\numberGOLD}{1}{\midaB}
\COPY{1}{\midaA}
\ADD{\midaA}{\midaB}{\Mida}
\setlength{\unitlength}{5cm}
\newcommand{\espiral}{%
    \Put(0,0){\begin{Picture}(0,0)(0,0)
      \translateorigin(\midaA,0)
      \pictcolor{red}
      \circularArc{\midaA}{\numberHALFPI}{\numberPI}
      \pictcolor{blue}
      \xLINE(0,0)(0,\midaA)
   \end{Picture}
   }
   \COPY{\midaA}{\Mida}
   \COPY{\midaB}{\midaA}
   \SUBTRACT{\Mida}{\midaA}{\midaB}
   \translateorigin(\Mida,\midaB)
   \changereferencesystem(0,\midaA)(0,-1)(1,0)
}
\renewcommand{\defaultplotdivs}{2}

\begin{center}
\begin{Picture}(0,0)(\numberGOLD,1)
   \Polygon(0,0)(\Mida,0)(\Mida,1)(0,1)
   % Plot 8 circular arcs
   \espiral\espiral\espiral\espiral
   \espiral\espiral\espiral\espiral
\end{Picture}

Golden rectangles and spiral
\end{center}
```

Ex. 46

`\ellipticArc{`*a*`}{`*b*`}{`*angle1*`}{`*angle2*`}`

This instruction draws the arc of the ellipse centered at $(0,0)$ with semiaxes a and b, $\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$, limited by angles ***angle1*** and ***angle2***.

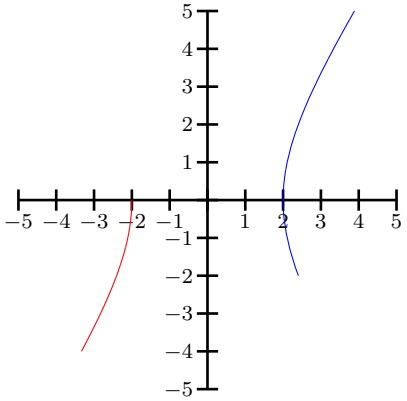


```
\setlength{\unitlength}{0.5cm}
\begin{center}
\begin{Picture}(-0.5,-3.5)(5.5,3.5)
\degreesangles
\ellipticArc{2}{3}{-90}{90}
\ellipticArc{5}{3}{-90}{90}
\end{Picture}
\end{center}
```

Ex. 47

`\rhyperbolicArc{`*a*`}{`*b*`}{`*y1*`}{`*y2*`}`
`\lhyperbolicArc{`*a*`}{`*b*`}{`*y1*`}{`*y2*`}`

Draw the arc (of the right or left branch, respectively) of the hyperbola $\frac{x^2}{a^2}-\frac{y^2}{b^2}=1$ included between $y=$ ***y1*** and $y=$ ***y2***.

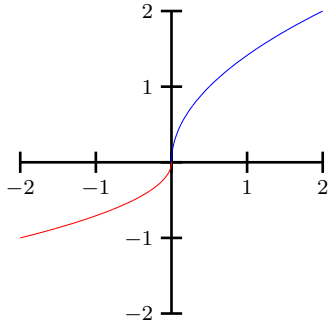



```
\setlength{\unitlength}{0.5cm}
\begin{center}
\begin{Picture}(-5.5,-5.5)(5.5,5,5)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesianaxes(-5,-5)(5,5)
\pictcolor{red}
\lhyperbolicArc{2}{3}{-4}{0}
\pictcolor{blue}
\rhyperbolicArc{2}{3}{-2}{5}
\end{Picture}
\end{center}
```

Ex. 48

`\parabolicArc{`*a*`}{`*y1*`}{`*y2*`}`

Draw the arc of the parabola $x = ay^2$ included between $y =$ *y1* and $y =$ *y2*.




```
\setlength{\unitlength}{1cm}
\begin{center}
\begin{Picture}(-2.5,-2.5)(2.5,2,5)
\renewcommand{\axeslabelsize}{\footnotesize}
\cartesianaxes(-2,-2)(2,2)
\pictcolor{red}
\parabolicArc{-2}{-1}{0}
\pictcolor{blue}
\parabolicArc{0.5}{0}{2}
\end{Picture}
\end{center}
```

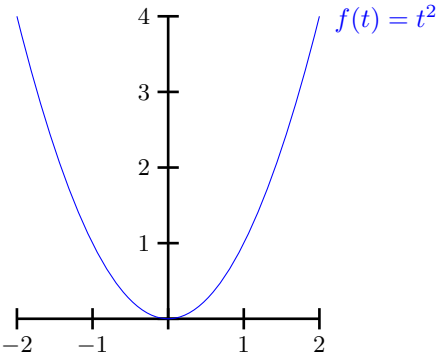
Ex. 49

5.3 Real variable functions

The `xpicture` package provides us two commands to draw the graph of a function: `\PlotFunction` and `\PlotPointsOfFunction`.

`\PlotFunction[`*n*`]{\`*functionname*`}{\`*tzero*`}{\`*tone*`}`
`\PlotPointsOfFunction{`*n*`}{\`*functionname*`}{\`*tzero*`}{\`*tone*`}`

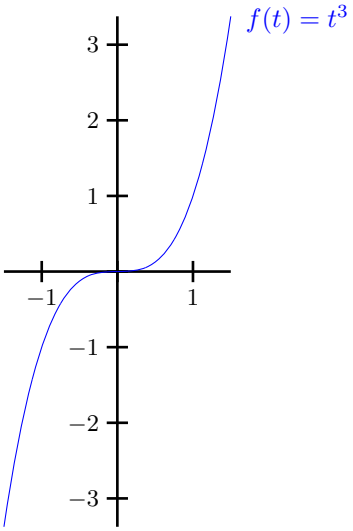
Note that the parameter *n* is optional in one of these instructions and mandatory in the other one. In the case of `\PlotFunction`, if we do not use this optional parameter, a quadratic approximation of the function `\`*functionname* in the $[\backslash tzero, \backslash tone]$ interval is drawn.




```
\setlength{\unitlength}{1cm}
\begin{Picture}(-2.5,-0.5)(3.5,4.5)
\cartesianaxes(-2,0)(2,4)
\pictcolor{blue}
\PlotFunction{\SQUAREfunction}{-2}{2}
\Put[E](2,4){$f(t)=t^2$}
\end{Picture}
```

Ex. 50

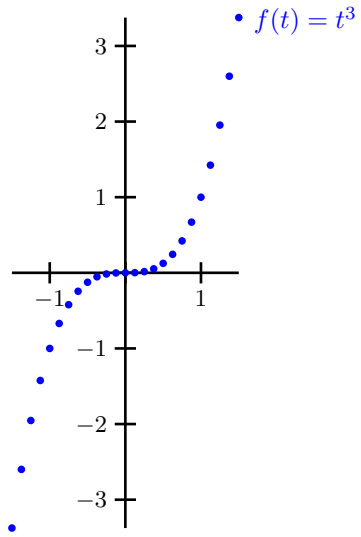
Now, this almost never provides a right graphic. To draw curves with a greater accuracy we should use the parameter, *n*, dividing the interval in *n* subintervals.




```
\setlength{\unitlength}{1cm}
\CUBE{1.5}{\mymax}
\begin{Picture}(-2,-4)(2,4)
\cartesianaxes(-1.5,-\mymax)(1.5,\mymax)
\pictcolor{blue}
\PlotFunction[8]{\CUBEfunction}{-1.5}{1.5}
\Put[E](1.5,\mymax){$f(t)=t^3$}
\end{Picture}
```

Ex. 51

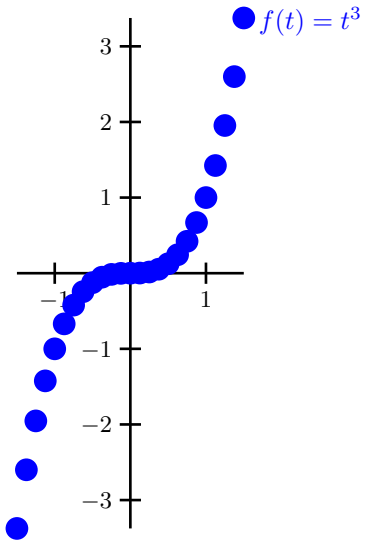
On the other hand, the `\PlotPointsOfFunction` command plots $n+1$ *points*, uniformly distributed about the x-axis.




```
\setlength{\unitlength}{1cm}
\CUBE{1.5}{\mymax}
\begin{Picture}(-2,-4)(2,4)
\cartesianaxes(-1.5,-\mymax)(1.5,\mymax)
\pictcolor{blue}
\PlotPointsOfFunction{24}{\CUBEfunction}{-1.5}{1.5}
\Put[E](1.5,\mymax){$f(t)=t^3$}
\end{Picture}
```

Ex. 52

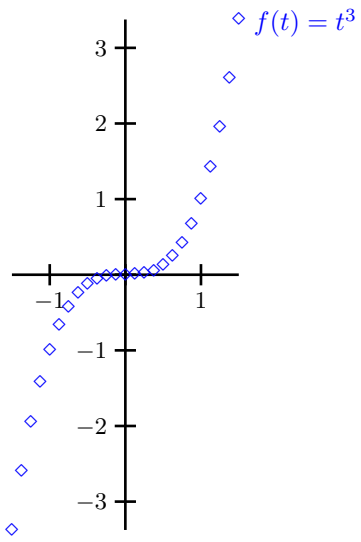
By default, `\PlotPointsOfFunction` plot *points* as a filled circle of diameter `0.1\unitlength`. But you can modifie this diameter, by redefining the `\pointmarkdiam` parameter.




```
\setlength{\unitlength}{1cm}
\CUBE{1.5}{\mymax}
\renewcommand{\pointmarkdiam}{0.3}
\begin{Picture}(-2,-4)(2,4)
\cartesianaxes(-1.5,-\mymax)(1.5,\mymax)
\pictcolor{blue}
\PlotPointsOfFunction{24}{\CUBEfunction}{-1.5}{1.5}
\Put[E](1.5,\mymax){$f(t)=t^3$}
\end{Picture}
```

Ex. 53

Moreover, you can select another symbol for these points, redefining `\pointmark`.

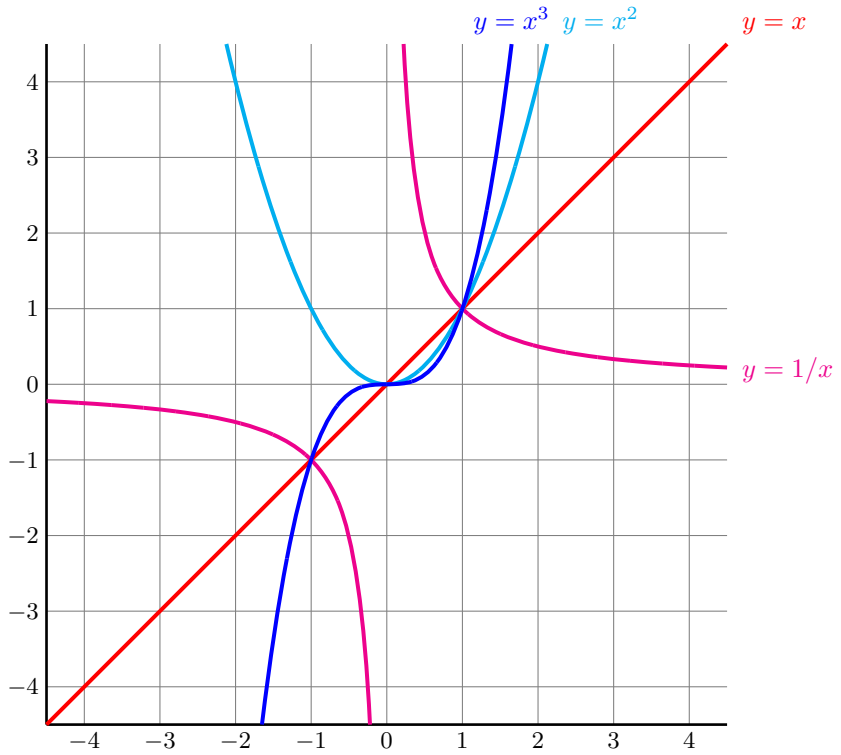



```
\setlength{\unitlength}{1cm}
\CUBE{1.5}{\mymax}
\renewcommand{\pointmark}{$\diamond$}
\begin{Picture}(-2,-4)(2,4)
\cartesianaxes(-1.5,-\mymax)(1.5,\mymax)
\pictcolor{blue}
\PlotPointsOfFunction{24}{\CUBEfunction}{-1.5}{1.5}
\Put[E](1.5,\mymax){$f(t)=t^3$}
\end{Picture}
```

Ex. 54

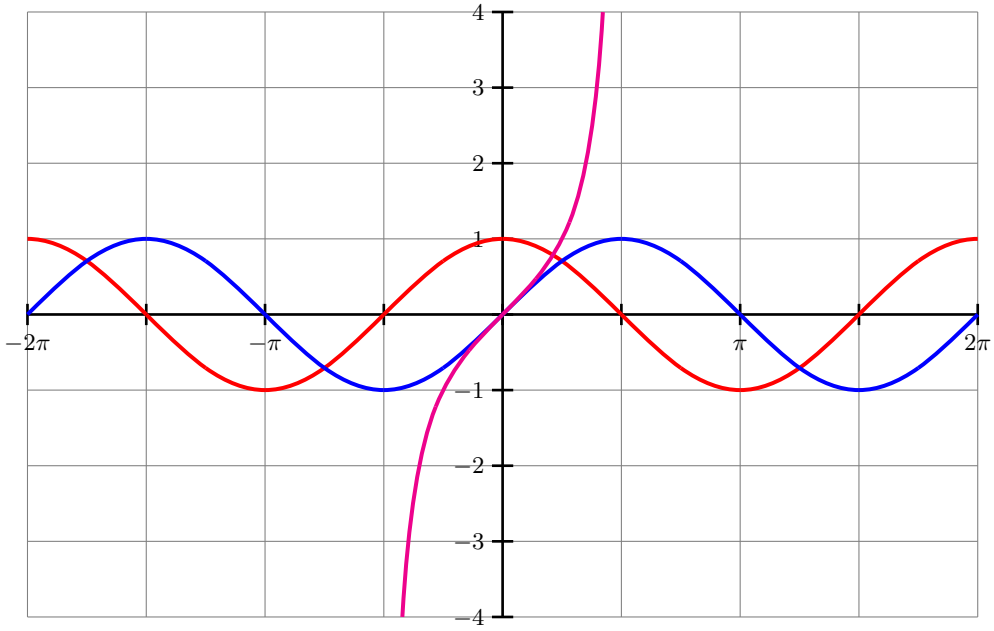
Naturally, in order to apply these commands the function must be defined. `xpicture` loads the `calculus` package, which predefines some of the most common elementary functions and includes several tools to build new ones. The predefined functions are the following:

`\ZEROfunction`	$f(t) = 0$	`\ONEfunction`	$f(t) = 1$
`\IDENTITYfunction`	$f(t) = t$	`\RECIPROCALfunction`	$f(t) = 1/t$
`\SQUAREfunction`	$f(t) = t^2$	`\CUBEfunction`	$f(t) = t^3$
`\SQRTfunction`	$f(t) = \sqrt{t}$		
`\EXPfunction`	$f(t) = \exp t$	`\LOGfunction`	$f(t) = \log t$
`\COSfunction`	$f(t) = \cos t$	`\SINfunction`	$f(t) = \sin t$
`\TANfunction`	$f(t) = \tan t$	`\COTfunction`	$f(t) = \cot t$
`\COSHfunction`	$f(t) = \cosh t$	`\SINHfunction`	$f(t) = \sinh t$
`\TANHfunction`	$f(t) = \tanh t$	`\COTHfunction`	$f(t) = \coth t$
`\HEAVISIDEfunction`	$f(t) = \begin{cases} 0 & \text{si } t < 0 \\ 1 & \text{si } t \geq 0 \end{cases}$		



Ex. 55

```
\setlength{\unitlength}{1cm}
\linethickness{1.5pt}
\centering
\begin{Picture}(-5,-5)(6,5)
\externalaxes\makenotics
\cartesiangrid(-4.5,-4.5)(4.5,4.5)
\pictcolor{red}
\PlotFunction{\IDENTITYfunction}{-4.5}{4.5}
\Put[tr](4.5,4.5){$y=x$}

\DIVIDE{1}{4.5}{\minx}
\pictcolor{magenta}
\PlotFunction[10]{\RECIPROCALfunction}{\minx}{4.5}
\PlotFunction[10]{\RECIPROCALfunction}{-\minx}{-4.5}
\Put[r](4.5,\minx){$y=1/x$}

\SQRT{4.5}{\maxx}
\pictcolor{cyan}
\PlotFunction[10]{\SQUAREfunction}{-\maxx}{\maxx}
\Put[tr](\maxx,4.5){$y=x^2$}

\pictcolor{blue}
\PlotFunction[10]{\CUBEfunction}{-1.6509}{1.6509}
\Put[t](1.6509,4.5){$y=x^3$}
\end{Picture}
```



Ex. 56

```
\setlength{\unitlength}{1cm}
\linethickness{1.5pt}
\centering
\begin{Picture}(-7,-4.5)(7,4.5)
{\makenolabels
\changereferencesystem(0,0)(\numberHALFPI,0)(0,1)
\cartesiangrid(-4,-4)(4,4)
\highestlabel{$2\pi$}
\printylabels{-4}{1}{4}
\printxlabel{-4}{-2\pi}
\printxlabel{-2}{-\pi}
\printxlabel{2}{\pi}
\printxlabel{4}{2\pi}}
\pictcolor{red}
\PlotFunction[16]{\COSfunction}{-\numberTWOPI}{\numberTWOPI}
\pictcolor{blue}
\PlotFunction[16]{\SINfunction}{-\numberTWOPI}{\numberTWOPI}
\pictcolor{magenta}
\PlotFunction[6]{\TANfunction}{-1.3258}{1.3258}
\end{Picture}
```

From these basic functions we can define many others, using the following *operations*:

Constant function:

\CONSTANTfunction{k}{*newfunction*}

Example: defining the $F(t) = 5$ function:

\CONSTANTfunction{5}{\F}

Sum function:

\SUMfunction{*function1*}{*function2*}{*newfunction*}

Example: defining the $F(t) = t^2 + t^3$ function:

\SUMfunction{\SQUAREfunction}{\CUBEfunction}{\F}

Difference function:

\SUBTRACTfunction{*function1*}{*function2*}{*newfunction*}

Example: defining the $F(t) = t^2 - t^3$ function:

\SUBTRACTfunction\SQUAREfunction\CUBEfunction{\F}

Product function:

\PRODUCTfunction{*function1*}{*function2*}{*newfunction*}

Example: defining the $F(t) = \mathrm{e}^t \cos t$ function:

\PRODUCTfunction\EXPfunction\COSfunction{\F}

Quotient function:

\QUOTIENTfunction{*function1*}{*function2*}{*newfunction*}

Example: defining the $F(t) = \mathrm{e}^t / \cos t$ function:

\QUOTIENTfunction\EXPfunction\COSfunction{\F}

Composition of two functions:

\COMPOSITIONfunction{*function1*}{*function2*}{*newfunction*}

Example: defining the $F(t) = \mathrm{e}^{\cos t}$ function:

\COMPOSITIONfunction\EXPfunction\COSfunction{\F}

Scaled function:

\SCALEfunction{k}{*function*}{*newfunction*}

Example: defining the $F(t) = 3\cos t$ function:

\SCALEfunction{3}\COSfunction{\F}

Scaled variable:

\SCALEVARIABLEfunction{k}{*function*}{*newfunction*}

Example: defining the $F(t) = \cos 3t$ function:

\SCALEVARIABLEfunction{3}\COSfunction{\F}

Power function: (exponent enter positiu)

\POWERfunction{*function*}{n}{*newfunction*}

Example: defining the $F(t) = t^5$ function:

\POWERfunction\IDENTITYfunction{5}{\F}

Linear combination:

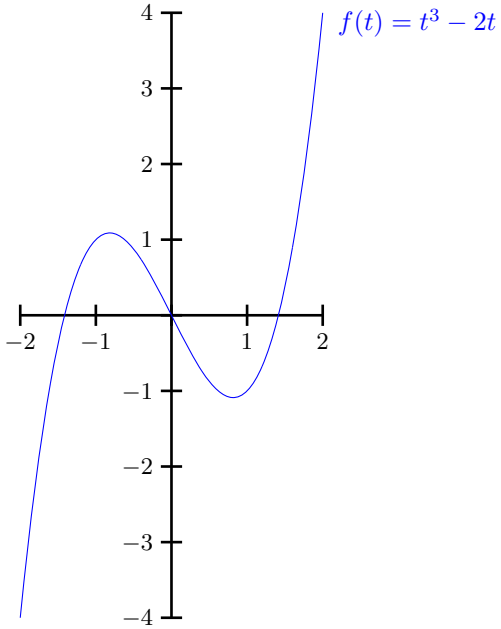
\LINEARCOMBINATIONfunction{a}{*function1*}{b}{*function2*}{*newfunction*}

Example: defining the $F(t) = 2t - 3\cos t$ function:

\LINEARCOMBINATIONfunction{2}\IDENTITYfunction{-3}\COSfunction{\F}

By combining properly these operations, we can draw graphs of many functions. Some examples are shown in next pages.

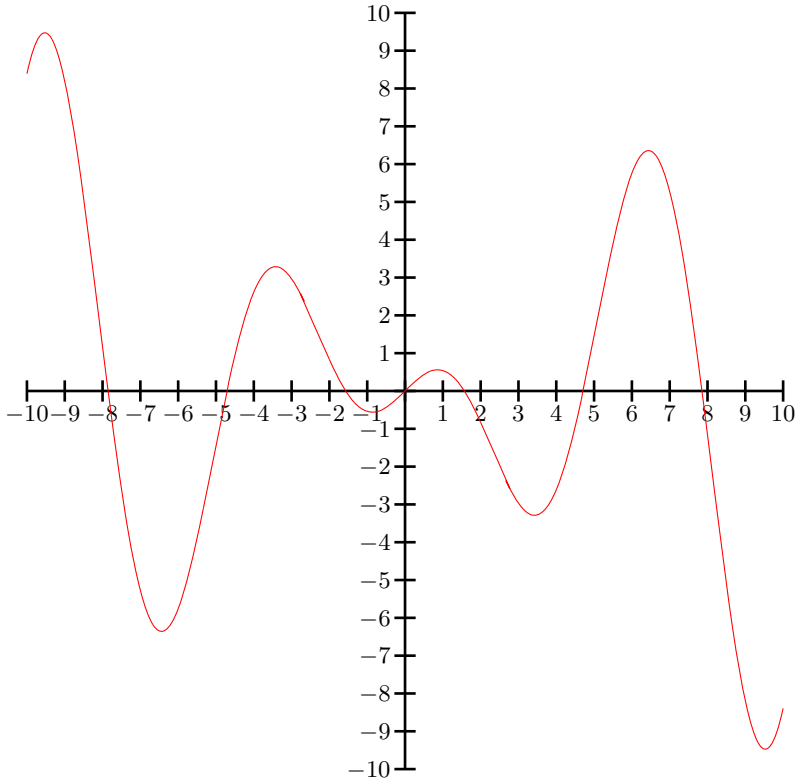
First, we will draw the function $f(t) = t^3 - 2t$, dividing the interval $[-2, 2]$ in ten subintervals. The simplest way to construct this function is as a linear combination of $f_1(t) = t^3$ and $f_2(t) = t$.




```
\LINEARCOMBINATIONfunction
                {1}{\CUBEfunction}
                {-2}{\IDENTITYfunction}
                {\Ffunction}
\begin{center}
\setlength{\unitlength}{1cm}
\begin{Picture}(-2.5,-4.5)(2.5,4.5)
\cartesianaxes(-2,-4)(2,4)
\pictcolor{blue}
\PlotFunction[10]{\Ffunction}{-2}{2}
\Put[rbr](2,4){$f(t)=t^3-2t$}
\end{Picture}
\end{center}
```

Ex. 57

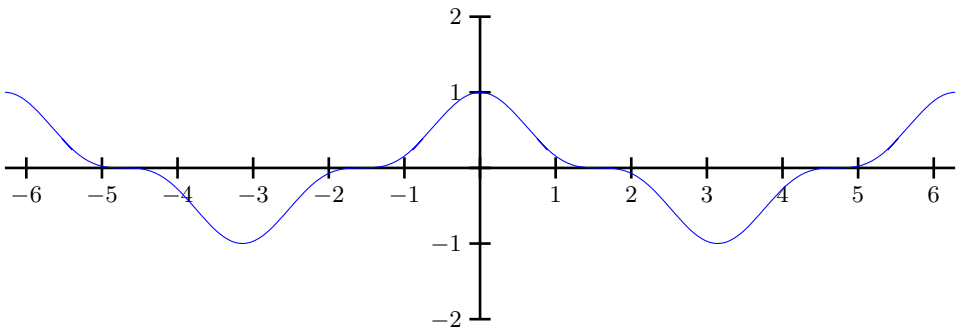
Graph of $g(t) = t \cos t$. We multiply the identity and the cosine functions:



Ex. 58

```
\setlength{\unitlength}{0.5cm}
\begin{center}
\begin{Picture}(-11,-11)(11,11)
\cartesianaxes(-10,-10)(10,10)
\PRODUCTfunction{\IDENTITYfunction}{\COSfunction}{\Gfunction}
\pictcolor{red}
\PlotFunction[30]{\Gfunction}{-10}{10}
\end{Picture}
\end{center}
```

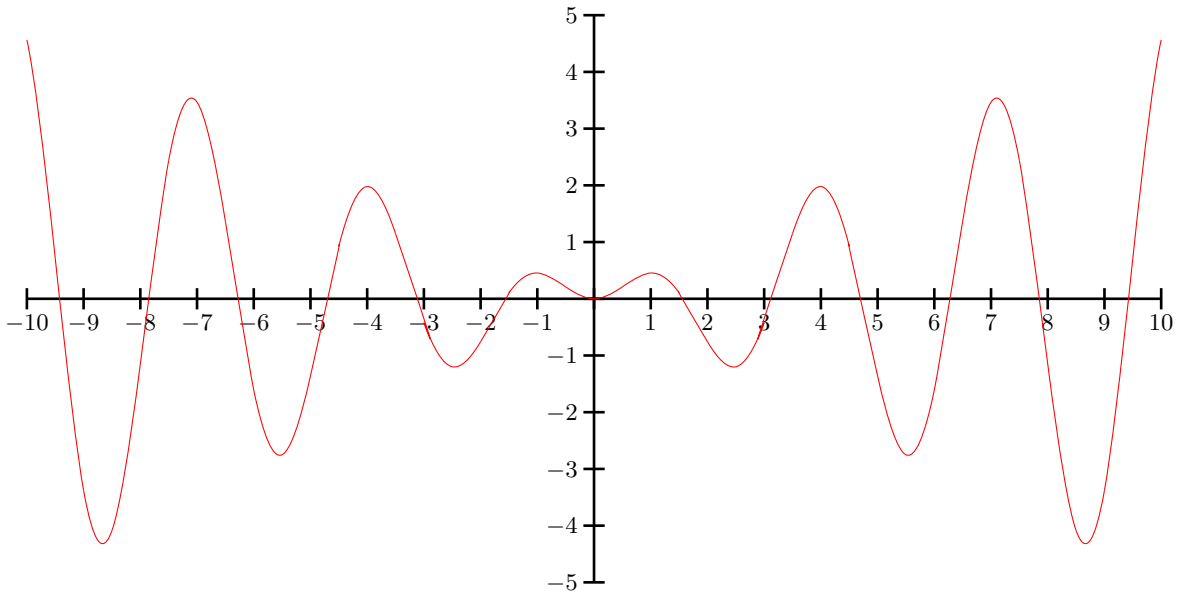
Graph of $f(t) = (\cos t)^3$.



Ex. 59

```
\setlength{\unitlength}{1cm}
\begin{center}
\begin{Picture}(-7,-3)(7,3)
\cartesianaxes(-\numberTWOPI,-2)(\numberTWOPI,2)
\POWERfunction{\COSfunction}{3}{\Ffunction}
\pictcolor{blue}
\PlotFunction[50]{\Ffunction}{-\numberTWOPI}{\numberTWOPI}
\end{Picture}
\end{center}
```

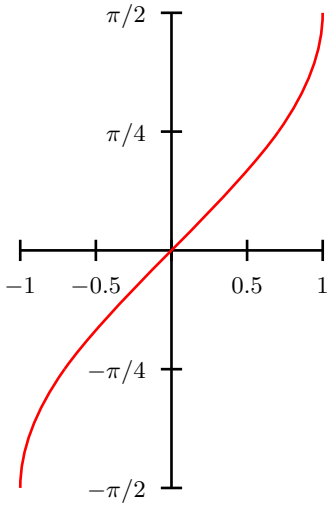
Graph of $g(t) = t\cos t\sin t$. Note that in this case we have two operations: First, we define the $f(t) = t\cos t$, multiplying the identity and cosine functions; then, we multiply by the sine function.



Ex. 60

```
\begin{center}
\setlength{\unitlength}{0.75cm}
 \begin{Picture}(-11,-6)(11,6)
\cartesianaxes(-10,-5)(10,5)
\PRODUCTfunction{\IDENTITYfunction}{\COSfunction}{%
                              \Ffunction}
\PRODUCTfunction{\Ffunction}{\SINfunction}{\Gfunction}
\pictcolor{red}
\PlotFunction[40]{\Gfunction}{-10}{10}
\end{Picture}
\end{center}
```

Graph of $g(t) = \arcsin t$. The `calculus` package not support, for now, the inverse trigonometric functions; but we can plot these functions (or any other inverse function) swapping coordinated axes.



Ex. 61

```
\begin{center}
\setlength{\unitlength}{2cm}
\begin{Picture}(-1.5,-2)(1.5,2)
\makenolabels\makenotics
\cartesianaxes
     (-1,-\numberHALFPI)(1,\numberHALFPI)
\printxticslabels{-1}{0.5}{1}
\printyticlabel{-\numberHALFPI}{-\pi/2}
\printyticlabel{-\numberQUARTERPI}{-\pi/4}
\printyticlabel{\numberQUARTERPI}{\pi/4}
\printyticlabel{\numberHALFPI}{\pi/2}
\pictcolor{red}
\symmetrize{\numberQUARTERPI}
\PlotFunction[4]{\SINfunction}
     {-\numberHALFPI}{\numberHALFPI}
\end{Picture}
\end{center}
```

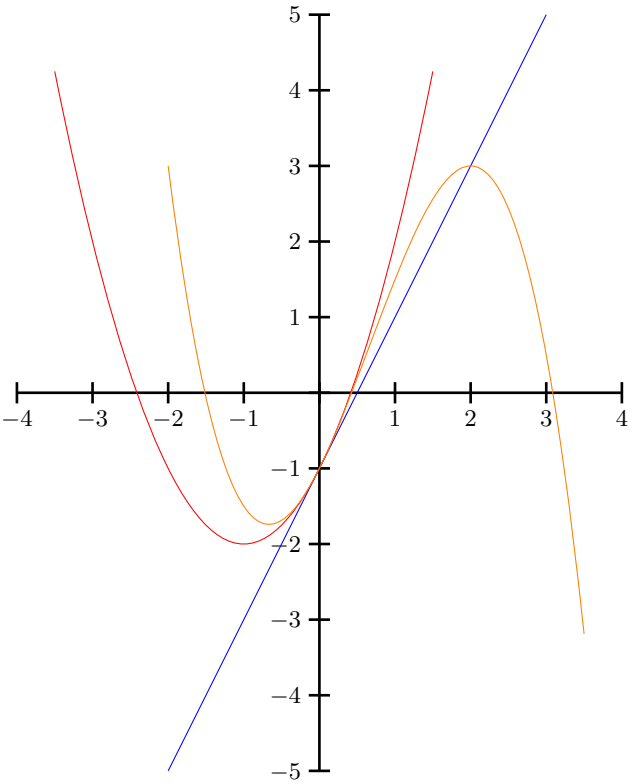
5.3.1 Polynomial functions

Although polynomial functions can be easily defined as linear combinations of power functions, to facilitate our work, the `calculus` package predefines polynomials of 1, 2, and 3 degrees by these commands: `\newlpoly` (new *linear* polynomial), `\newqpoly` (new *quadratic* polynomial), and `\newcpoly` (new *cubic* polynomial):

`\newlpoly{\newfunction}{a}{b}` stores the $p(t) = a + bt$ function in the `\newfunction` command.

`\newqpoly{\newfunction}{a}{b}{c}` stores the $p(t) = a+bt+ct^2$ function in the `\newfunction` command.

`\newcpoly{\newfunction}{a}{b}{c}{d}` stores the $p(t) = a+bt+ct^2+dt^3$ function in the `\newfunction` command.

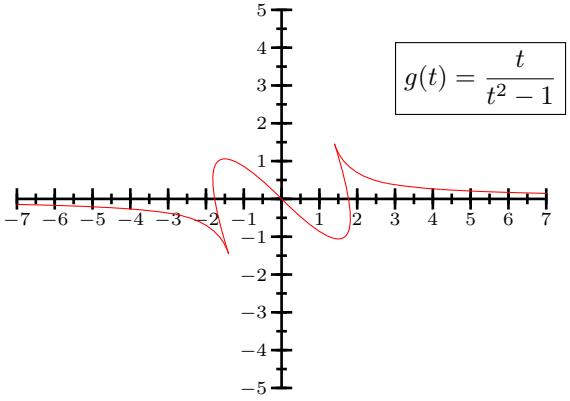



```
% F(t)=-1+2t
   \newlpoly{\poliF}{-1}{2}
% G(t)=-1+2t+t^2
   \newqpoly{\poliG}{-1}{2}{1}
% H(t)=-1+2t+t^2-0,5t^3
   \newcpoly{\poliH}{-1}{2}{1}{-0.5}

\setlength{\unitlength}{1cm}
\begin{Picture}(-4.5,-5.5)(4.5,5.5)
\cartesianaxes(-4,-5)(4,5)
\pictcolor{blue}
\PlotFunction{\poliF}{-2}{3}
\pictcolor{red}
\PlotFunction{\poliG}{-3.5}{1.5}
\pictcolor{orange}
\PlotFunction[10]{\poliH}{-2}{3.5}
\end{Picture}
```

Ex. 62

5.3.2 Possible errors

In many cases you get a fairly accurate graph dividing the domain into several subintervals. But an indiscriminate use of this method can produce erroneous results. For example, if inside a subinterval there is a discontinuity or a point where the function is not differentiable. Look at the following example.




```
\SUBTRACTfunction{\SQUAREfunction}{\ONEfunction}
                                 {\Ffunction}
\QUOTIENTfunction{\IDENTITYfunction}{\Ffunction}
                                 {\Gfunction}

\setlength{\unitlength}{0.5cm}

\begin{Picture}(-8,-6)(8,6)
\def\xunitdivisions{2}
\def\yunitdivisions{2}
\renewcommand{\axeslabelsize}{\scriptsize}
\cartesianaxes(-7,-5)(7,5)
\Put(3,3){%
   $\boxed{\displaystyle g(t)=\frac{t}{t^ 2-1}}$}
\pictcolor{red}
\PlotFunction[10]{\Gfunction}{-7}{7}
\end{Picture}
```

Ex. 63

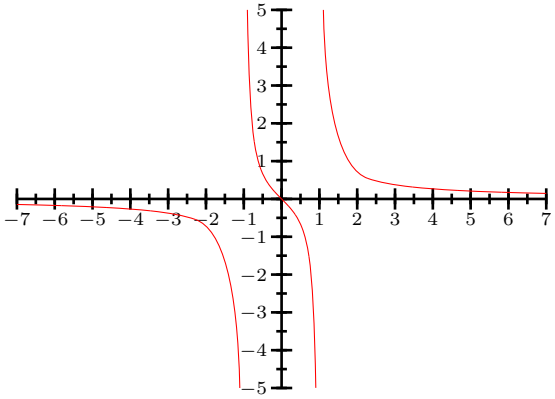
Where is the problem? Our function is $g(t) = t/(t^2 - 1)$; this function has a pair of vertical asymptotes at $t = \pm 1$ (the two zeros of denominator).

We made 10 subdivisions of the $[-7, 7]$ interval. Do, we compute the function in points $-7 + (14/10)k = -7 + (7/5)k$, $0 \leq k \leq 10$, ie,

$$-7 \quad -\frac{28}{5} \quad -\frac{21}{5} \quad -\frac{14}{5} \quad -\frac{7}{5} \quad 0 \quad \frac{7}{5} \quad \frac{14}{5} \quad \frac{21}{5} \quad \frac{28}{5} \quad 7$$

Singularities are between $-7/5$ and 0, and between 0 and $7/5$, So, the graph is not correct in these intervals.

To avoid this problem, we will draw the function in three intervals, excluding the points where it is undefined:




```
\SUBTRACTfunction{\SQUAREfunction}{\ONEfunction}
                                 {\Ffunction}
\QUOTIENTfunction{\IDENTITYfunction}{\Ffunction}
                                 {\Gfunction}
\renewcommand{\axeslabelsize}{\scriptsize}
\setlength{\unitlength}{0.5cm}
\begin{Picture}(-8,-6)(8,6)
\def\xunitdivisions{2}
\def\yunitdivisions{2}
\cartesianaxes(-7,-5)(7,5)
\pictcolor{red}
\PlotFunction[5]{\Gfunction}{-7}{-1.105}
\PlotFunction[5]{\Gfunction}{-0.905}{0}
\PlotFunction[5]{\Gfunction}{0}{0.905}
\PlotFunction[5]{\Gfunction}{1.105}{7}
\end{Picture}
```

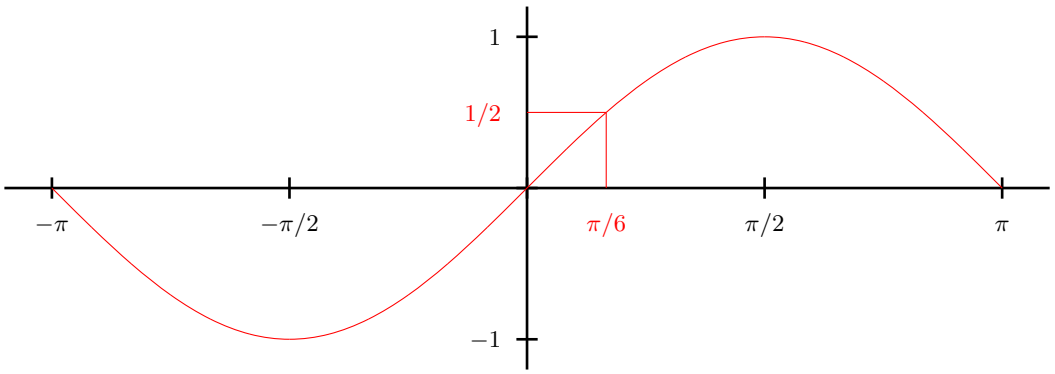
Ex. 64

(To determine the ends of the ranges of variation ± 1.105 and ± 0.905, we solved the equation $g(t) = 5$, to ensure that asymtotic branches are interrupted at the border of the drawing area).

5.3.3 Accurate graphs

In general, to obtain fairly reliable results we must make a careful analysis of the behavior of the function, determining the points where it is undefined or not differentiable, the intervals where it is increasing, its extreme values, points where graph cuts the coordinate axes and, in general, all points where the behavior of function is significant. From this information, we can chose the appropriate drawing intervals. A careful choice of the partition subintervals in the domain ensures us that the graph accurately reflects the behavior of the function.

We will see a couple of examples. First, we draw the sine function in $[-\pi, \pi]$. This function ant its derivative have no discontinuities, but it is convenient to choose a number of partitions being multiple of 4, to carefully draw function at the $k\pi/2$ points. In fact, a good choice are 24 subdivisions, to ensure also the well known values of this function for angles multiple of $\pi/6$ and $\pi/4$.



Ex. 65

```
\setlength{\unitlength}{2cm}%

\highestlabel{\normalfont\normalsize$3\pi/2$}
\begin{center}
\begin{Picture}(-3.5,-1.5)(3.5,1.5)
{\referencesystem(0,0)(\numberHALFPI,0)(0,1)
\makenolabels
\cartesianaxes(-2.2,-1.2)(2.2,1.2)}
\printylabels{-1}{1}{1}
\printxlabel{-\numberPI}{-\pi}
\printxlabel{-\numberHALFPI}{-\pi/2}
\printxlabel{\numberHALFPI}{\pi/2}
\printxlabel{\numberPI}{\pi}
\pictcolor{red}
   \PlotFunction[24]{\SINfunction}{-\numberPI}{\numberPI}
\renewcommand{\axeslabelcolor}{red}
\printxlabel{\numberSIXTHPI}{\pi/6}
\printylabel{0.5}{1/2}
\Polyline(\numberSIXTHPI,0)(\numberSIXTHPI,0.5)(0,0.5)
\end{Picture}
\end{center}
```

Our second example is more complex. Let's graph the function

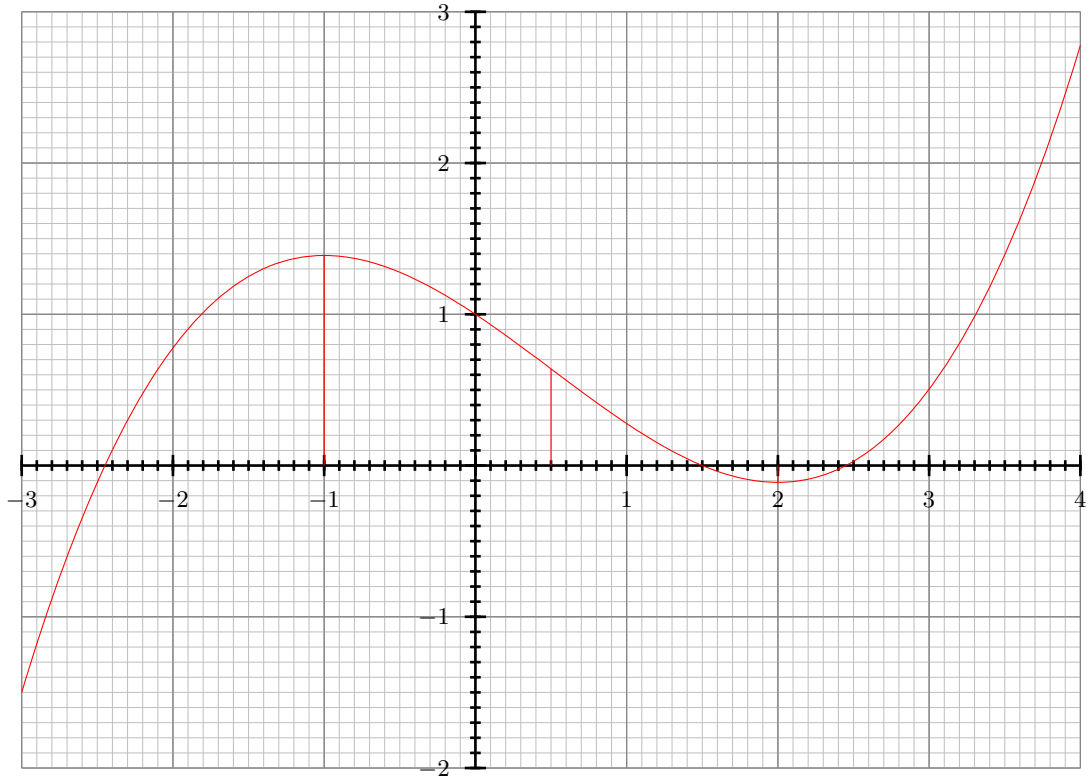
$$f(t) = (t^3/3 - t^2/2 - 2t + 3)/3$$

This function has three roots, at $t = 3/2$ and $t = \pm\sqrt{6}$. Its derivative, $f'(t) = (t^2 - t - 2)/3$, equals zero at $t = -1$ and $t = 2$, where the function has, respectively, a relative maximum and a relative minimum. The second derivative, $f''(t) = (2t - 1)/3$, is zero at $t = 1/2$, which is an inflexion point. Interesting points are, then, the following:

$$-\sqrt{6}, -1, 0, 1/2, 3/2, 2, \sqrt{6}$$

We will plot this function in the $[-3, 4]$ interval (because it includes all these points), but we divide it as

$$[-3, -\sqrt{6}] \cup [-\sqrt{6}, -1] \cup [-1, 0] \cup [0, 1/2] \cup [1/2, 3/2] \cup [3/2, 2] \cup [2, \sqrt{6}] \cup [\sqrt{6}, 4]$$



Ex. 66

```
\SQRT{6}{\SQRTSIX}
\newcpoly{\functionf}{1}{-0.66667}{-0.16667}{0.11111}
\setlength{\unitlength}{2cm}
\begin{center}
 \begin{Picture}(-3.5,-2.5)(4.5,3.5)
\renewcommand{\xunitdivisions}{10}
\renewcommand{\yunitdivisions}{10}
\cartesiangrid(-3,-2)(4,3)
\pictcolor{red}
\PlotFunction{\functionf}{-3}{-\SQRTSIX}
\PlotFunction[4]{\functionf}{-\SQRTSIX}{-1}
\PlotFunction[4]{\functionf}{-1}{0}
\PlotFunction[4]{\functionf}{0}{0.5}
\PlotFunction[4]{\functionf}{0.5}{1.5}
\PlotFunction[4]{\functionf}{1.5}{2}
\PlotFunction[4]{\functionf}{2}{\SQRTSIX}
\PlotFunction{\functionf}{\SQRTSIX}{4}
\functionf{-1}{\tempf}{\tempDf}
\xLINE(-1,0)(-1,\tempf)
\functionf{2}{\tempf}{\tempDf}
\xLINE(2,0)(2,\tempf)
\functionf{0.5}{\tempf}{\tempDf}
\xLINE(0.5,0)(0.5,\tempf)
\end{Picture}
\end{center}
```

5.4 Polar coordinates curves

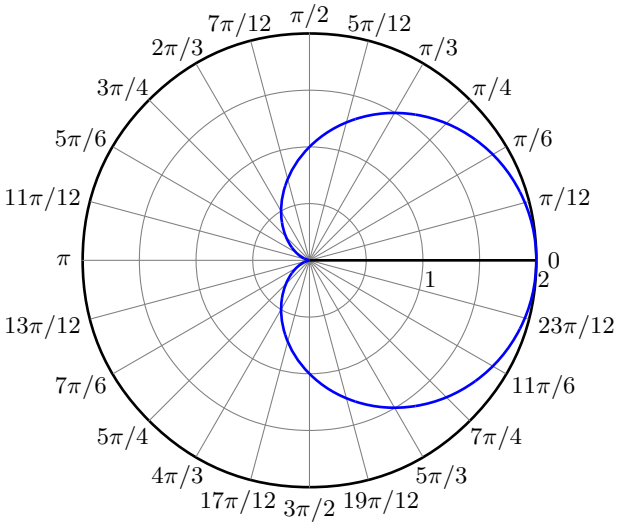
To draw a curve defined in polar form as $\rho = f(t)$, we must declare it as a polar curve, using the `\POLARfunction` declaration: writing

`\POLARfunction{\functionname}{\polarfunction}`

we declare the new polar curve `\polarfunction` $\rho =$ `\functionname`(t). For example, the *cardioide* curve, $\rho = 1 + \cos t$, can be defined in the following way:

```
\SUMfunction{\ONEfunction}{\COSfunction}{\ffunction} % (y=1 + cos t)
\POLARfunction{\ffunction}{\cardioide}
```

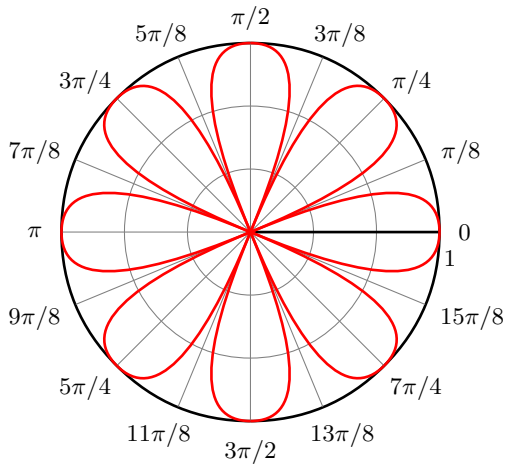
Curves defined in such a way can be plotted using the `\PlotParametricFunction` command, which syntax is analogous to that of `\PlotFunction`.



$\rho = 1 + \cos\phi$

```
% Cardioide: r = 1+cos t
\SUMfunction{\ONEfunction}{\COSfunction}
            {\ffunction}
\POLARfunction{\ffunction}{\cardioide}
\begin{center}
\def\runitdivisions{2}
\setlength{\unitlength}{1.5cm}
\begin{Picture}(-2.5,-2.5)(2.5,2.5)
\polargrid{2}{24}
\pictcolor{blue}\linethickness{1pt}
 \PlotParametricFunction[20]{%
         \cardioide}{0}{\numberTWOPI}
\end{Picture}
$\rho=1+\cos\phi$
\end{center}
```

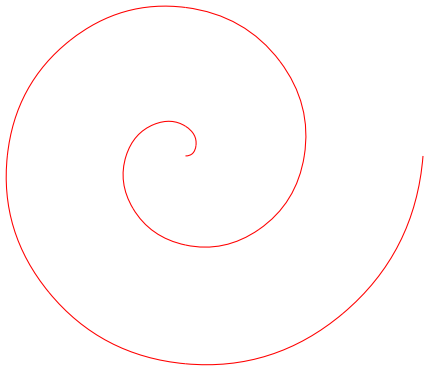
Ex. 67



$\rho = \cos 4\phi$

```
% Eight petal rose: r = cos(4t)
\SCALEVARIABLEfunction{4}{\COSfunction}
                       {\ffunction}
\POLARfunction{\ffunction}{\rose}
\begin{center}
\def\runitdivisions{3}
\MULTIPLY{2}{\numberTWOPI}{\numberFOURPI}
\setlength{\unitlength}{2.5cm}

\begin{Picture}(-1.5,-1.5)(1.5,1.5)
\polargrid{1}{16}
\pictcolor{red}\linethickness{1pt}
\PlotParametricFunction[16]\rose{0}{\numberTWOPI}
\end{Picture}
$\rho=\cos 4\phi$
\end{center}
```

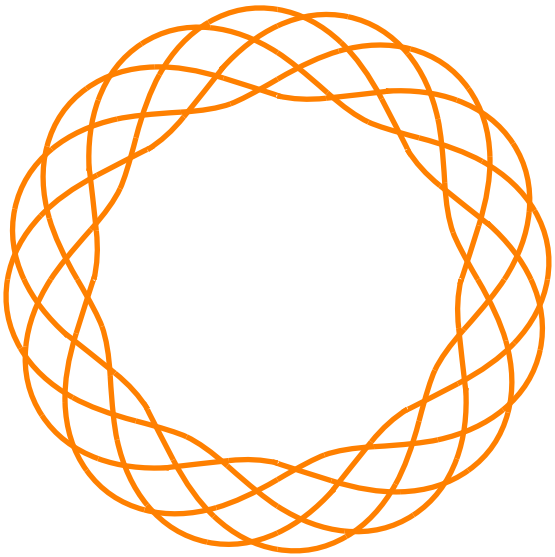
Ex. 68



$2\rho = \phi$

```
% Archimedean spiral: r=0,5t
\SCALEfunction{0.5}{\IDENTITYfunction}{\ffunction}
\POLARfunction{\ffunction}{\archimedes}

\MULTIPLY{2}{\numberTWOPI}{\numberFOURPI}
\setlength{\unitlength}{0.5cm}
\begin{center}
\begin{Picture}(-7,-7)(7,7)
\pictcolor{red}
\PlotParametricFunction[16]{%
                \archimedes}{0}{\numberFOURPI}
\end{Picture}
$2\rho=\phi$
\end{center}
```

Ex. 69



$\rho = 1 + 2\sin 3.2\phi$

```
\SCALEVARIABLEfunction{3.2}{\SINfunction}{\ffunction}
\SCALEfunction{0.2}{\ffunction}{\gfunction}
\SUMfunction{\ONEfunction}{\gfunction}{\myfunction}
\POLARfunction{\myfunction}{\Rfunction}
\MULTIPLY{10}{\numberPI}{\numberTENPI}
\setlength{\unitlength}{3cm}
\linethickness{2pt}
\begin{center}
\begin{Picture}(-1.2,-1.2)(1.2,1.2)
\pictcolor{orange}
\PlotParametricFunction[120]\Rfunction{0}{\numberTENPI}
\end{Picture}
$\rho=1+2\sin 3.2\phi$
\end{center}
```

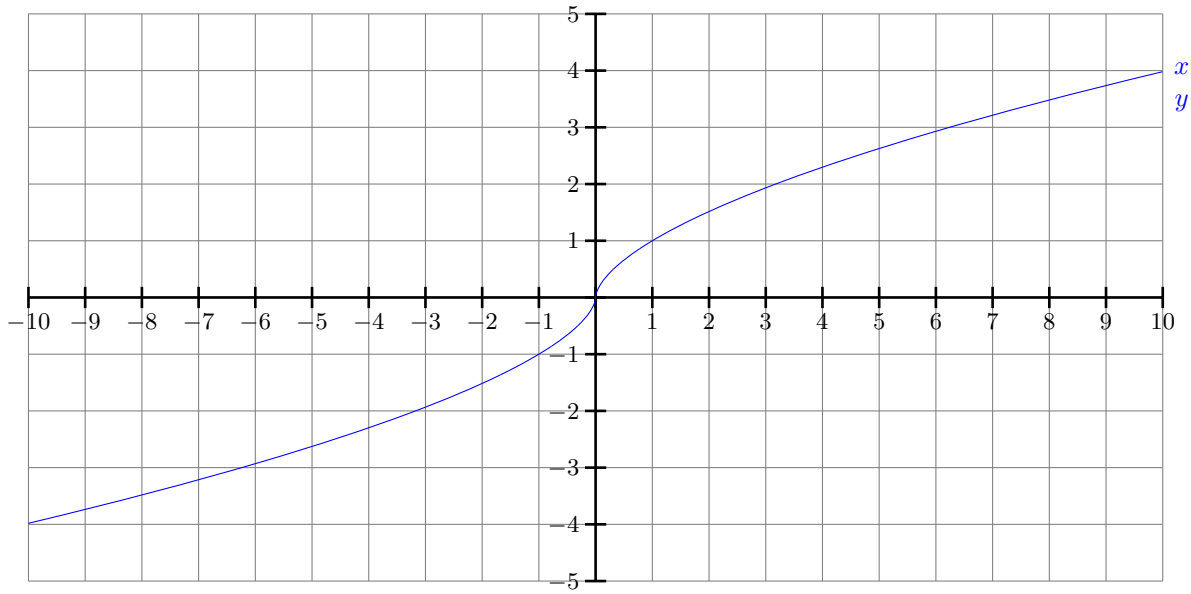
Ex. 70

5.5 Parametrically defined curves

Polar curves are a particular case of parametrically defined curves, $x = f(t), y = g(t)$. These curves are declared by the `\PARAMETRICfunction` command:

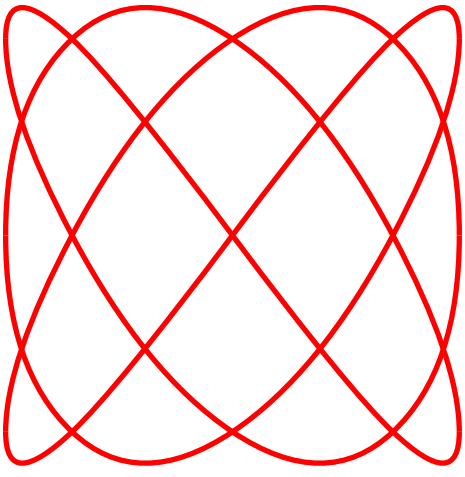
`\PARAMETRICfunction{\`*`Xfunction`*`}{\`*`Yfunction`*`}{\`*`parametricfunction`*`}`

Once we have defined it, to draw this curve, we use the `\PlotParametricFunction` as described above.



Ex. 71

```
\POWERfunction{\IDENTITYfunction}{5}{\xfunction}
\PARAMETRICfunction{\xfunction}{\CUBEfunction}{\myparfunction}
\centering
\setlength{\unitlength}{0.75cm}
\begin{Picture}(-11,-6)(11,6)
\cartesiangrid(-10,-5)(10,5)
\pictcolor{blue}
\PlotParametricFunction[10]{\myparfunction}{-1.5849}{0}
\PlotParametricFunction[10]{\myparfunction}{0}{1.5849}
\Put[E](10,4){$\begin{matrix}x=t^5\\y=t^3\end{matrix}$}
\end{Picture}
```



$x = \sin 3t,\ y = \sin 4t$

```
% A Lissanjous curve: x=sin 3t, y=sin 4t
\SCALEVARIABLEfunction{3}{\SINfunction}{\ffunction}
\SCALEVARIABLEfunction{4}{\SINfunction}{\gfunction}
\PARAMETRICfunction{\ffunction}{\gfunction}{\myfunction}
\MULTIPLY{10}{\numberPI}{\numberTENPI}
\setlength{\unitlength}{3cm}
\linethickness{2pt}
\begin{center}
\begin{Picture}(-1.2,-1.2)(1.2,1.2)
\pictcolor{red}
\PlotParametricFunction[24]\myfunction{0}{\numberTWOPI}
\end{Picture}

$x=\sin 3t,\ y=\sin 4t$
\end{center}
```

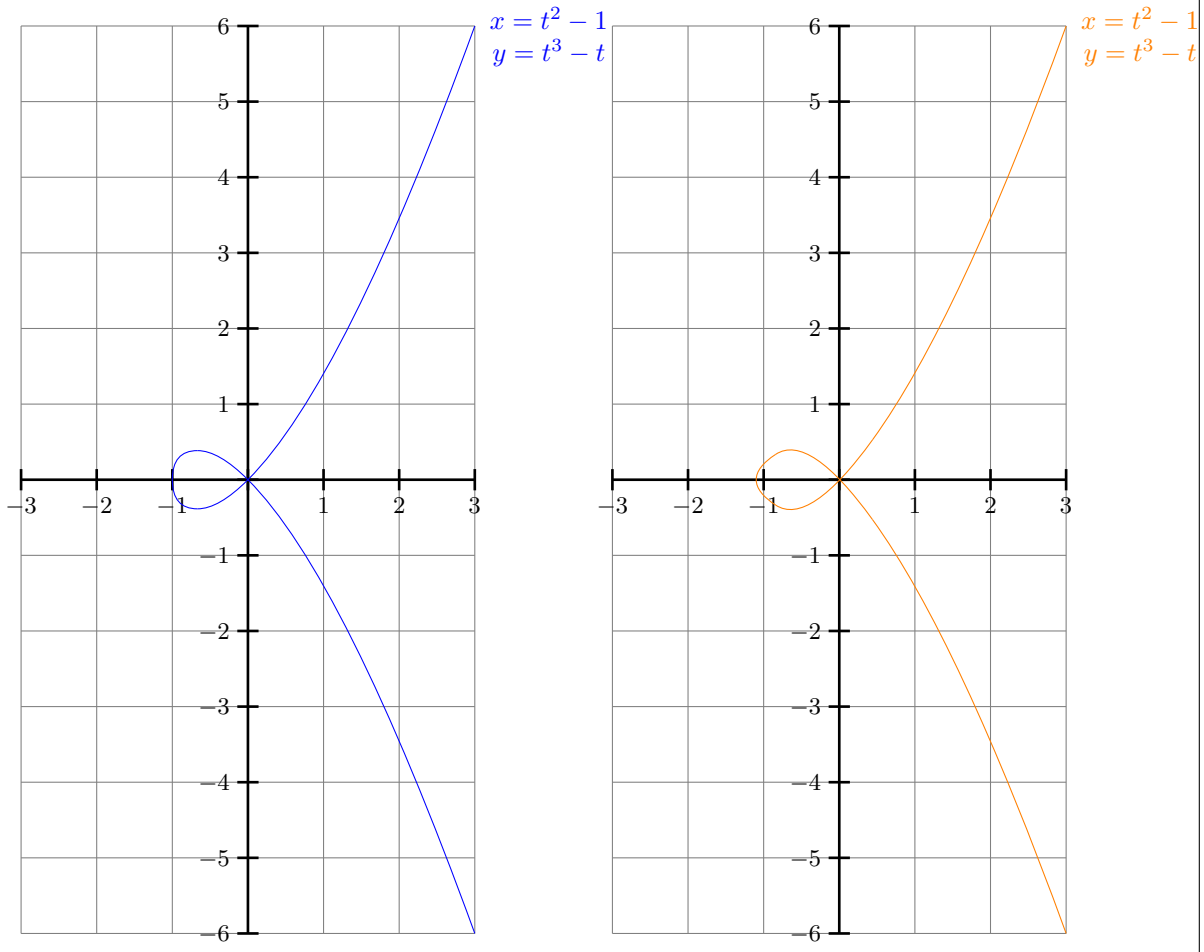
Ex. 72

Here, we should also take into account the characteristics of the curve in order to choose appropriate intervals for the parameter (typically, the points where the function is not defined, singularities, cuts with axes, points where some of the derivatives $x', x'', \ldots$ or $y', y'' \ldots$) is zero... In the following example, to represent the curve $x = t^2 - 1$, $y = t^3 - t$, we see that x or y equals zero when t is 0, 1 or -1; the first derivatives $x' = 2t$, $y' = 3t^2 - 1$, in $t = 0$ and $t = \pm\sqrt{3}/3$, and second derivative of y in $t = 0$. Thus, we choose an interval containing these

values of t, such $[-2.2]$, and this partition of it:

$$[-2,2] = [-2,-1] \cup [-1,-\sqrt{3}/3] \cup [-\sqrt{3}/3,0] \cup [0,\sqrt{3}/3] \cup [\sqrt{3}/3,1] \cup [1,2]$$

This same curve was depicted with a single instruction `\PlotParametricFunction` dividing the interval $[-2.2]$ into five subintervals. Note that the obtained picture is almost identical, but the fact that partition not includes zero conceals the fact that the vertical tangent occurs at the point $(-1,0)$. So, one of the most significant features of the curve is not correctly displayed.



Ex. 73

```
\SUBTRACTfunction{\SQUAREfunction}{\ONEfunction}{\Xpart}
\SUBTRACTfunction{\CUBEfunction}{\IDENTITYfunction}{\Ypart}
\PARAMETRICfunction{\Xpart}{\Ypart}{\myparfunction}
\centering
\setlength{\unitlength}{1cm}
\begin{Picture}(-3.5,-6.5)(3.5,6.5)
\cartesiangrid(-3,-6)(3,6)
\pictcolor{blue}
\PlotParametricFunction\myparfunction{-2}{-1}
\PlotParametricFunction\myparfunction{-1}{-0.57735}
\PlotParametricFunction\myparfunction{-0.57735}{0}
\PlotParametricFunction\myparfunction{0}{0.57735}
\PlotParametricFunction\myparfunction{0.57735}{1}
\PlotParametricFunction\myparfunction{1}{2}
\Put[E](3,6){$\begin{matrix}x=t^2-1\\y=t^3-t\end{matrix}$}
\end{Picture}
\qquad
\begin{Picture}(-3.5,-6.5)(3.5,6.5)
\cartesiangrid(-3,-6)(3,6)
\pictcolor{orange}
\PlotParametricFunction[5]\myparfunction{-2}{2}
\Put[E](3,6){$\begin{matrix}x=t^2-1\\y=t^3-t\end{matrix}$}
\end{Picture}
```

5.5.1 The curve of the front page

To conclude this section we will study in detail the example of the front page of this manual. This example shows the power, while the simplicity of the package `xpicture`.

It is the transcendent curve named *butterfly*,

$$x = \sin t \left(\mathrm{e}^{\cos t} - 2\cos 4t + \sin^5 \left(\frac{t}{12} \right) \right)$$
$$y = \cos t \left(\mathrm{e}^{\cos t} - 2\cos 4t + \sin^5 \left(\frac{t}{12} \right) \right)$$

We analyze step by step the code we used:

- First, we calculated some numbers we'll use later: (a) $1/12$, that appears in the definition of functions x and y; (b) $12 \times 2\pi$, to plot the curve in $[0, 24\pi]$ (twelve laps); and (c) 12×64, the number of subdivisions we will use (64 subintervals for each lap).

```
\DIVIDE{1}{12}{\invXII}
\MULTIPLY{12}{\numberTWOPI}{\phione}
\MULTIPLY{12}{64}{\divisions}
```

- In the next block we do the important work: the curve is defined step by step.
  - Define the function $A(t) = \mathrm{e}^{\cos t}$

```
\COMPOSITIONfunction{\EXPfunction}{\COSfunction}{\Afunction}
```

  - Define $B(t) = \cos 4t$

```
\SCALEVARIABLEfunction{4}{\COSfunction}{\Bfunction}
```

  - Define $c(t) = \sin t/12$

```
\SCALEVARIABLEfunction{\invXII}{\SINfunction}{\cfunction}
```

  - Define $C(t) = \sin^5 t/12$

```
\POWERfunction{\cfunction}{5}{\Cfunction}
```

  - Define $AB(t) = \mathrm{e}^{\cos t} - 2\cos 4t$

```
\LINEARCOMBINATIONfunction{1}{\Afunction}{-2}{\Bfunction}{\ABfunction}
```

  - Define $ABC(t) = \mathrm{e}^{\cos t} - 2\cos 4t + \sin^5 t/12$

```
\SUMfunction{\ABfunction}{\Cfunction}{\ABCfunction}
```

  - Define the x and y functions

```
\PRODUCTfunction{\SINfunction}{\ABCfunction}{\Xfunction}
   % x=(sin t)(exp(cos t)-2 cos 4t + (sin(t/12))^5)
\PRODUCTfunction{\COSfunction}{\ABCfunction}{\Yfunction}
   % y=(cos t)(exp(cos t)-2 cos 4t + (sin(t/12))^5)
```

  - And, finally, we declare the parametric curve:

```
\PARAMETRICfunction{\Xfunction}{\Yfunction}{\butterfly}
```

- Now, the picture composition is trivial (note the use of constants `\divisions` and `\phione` we previously calculated):

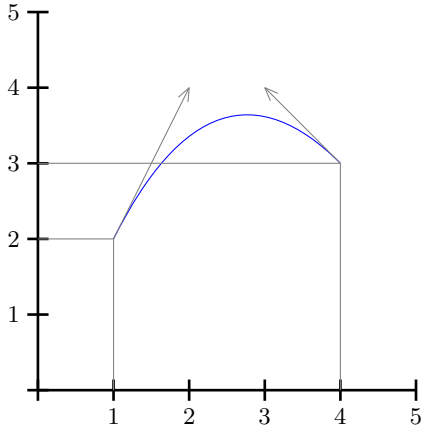
```
\begin{Picture}(-4,-3)(4,4)
   \PlotParametricFunction[\divisions]\butterfly{0}{\phione}
\end{Picture}
```

5.6 Drawing curves from a table of values

All instructions to draw curves described here use the `\qCurve` command, which draws quadratic Bézier curves:

`\qCurve(`*x0*`,`*y0*`)(`*u0*`,`*v0*`)(`*x1*`,`*y1*`)(`*u1*`,`*v1*`)`

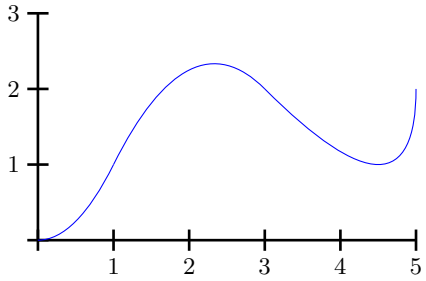
draw a smooth curve between the points (*x0*, *y0*) and (*x1*, *y1*), with tangent vectors (*u0*, *v0*) and (*u1*, *v1*), respectively.




```
\setlength{\unitlength}{1cm}
\begin{Picture}(-0.5,-0.5)(5.5,5.5)
\cartesianaxes(0,0)(5,5)
\pictcolor{blue}
\qCurve(1,2)(1,2)(4,3)(-1,1)
\pictcolor{gray}
\Put(1,2){\xtrivVECTOR(0,0)(1,2)}
\Put(4,3){\xtrivVECTOR(0,0)(-1,1)}
\Polyline(1,0)(1,2)(0,2)
\Polyline(4,0)(4,3)(0,3)
\end{Picture}
```

Ex. 74

The `\PlotQuadraticCurve` command generalizes `\qCurve` to an arbitrary number of points.



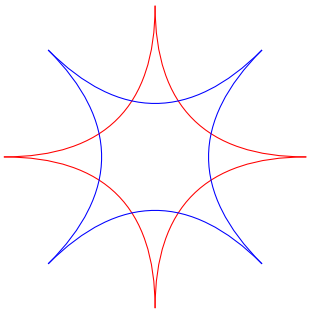

```
\setlength{\unitlength}{1cm}
\begin{Picture}(-0.5,-0.5)(5.5,3.5)
\cartesianaxes(0,0)(5,3)
\pictcolor{blue}
\PlotQuadraticCurve(0,0)(1,0)%
                   (1,1)(1,2)%
                   (3,2)(-1,1)%
                   (5,2)(0,-1)
\end{Picture}
```

Ex. 75

This command supports two alternative syntaxes:

(a) `\PlotQuadraticCurve(`*x0*`,`*y0*`)(`*u0*`,`*v0*`)(`*x1*`,`*y1*`)(`*u1*`,`*v1*`)...(`*xn*`,`*yn*`)(`*un*`,`*vn*`)`

draws a curve through the points $(x0, y0)$, $(x1, y1)\ldots(xn, yn)$ with tangent vectors $(u0, v0)$, $(u1, v1)\ldots(un, vn)$.[11]



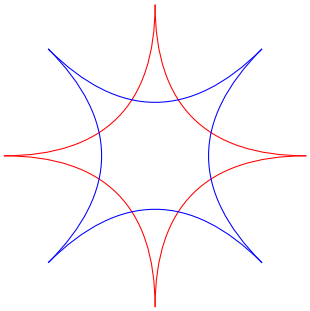
```
\setlength{\unitlength}{2cm}
\begin{center}
\begin{Picture}(1,1)(-1,-1)
\pictcolor{red}
\PlotQuadraticCurve(1,0)(1,0)(0,1)(0,1)%
                   (-1,0)(-1,0)(0,-1)(0,-1)%
                   (1,0)(1,0)
\pictcolor{blue}
\referencesystem(0,0)%
                (\numberCOSXLV,\numberCOSXLV)%
                (-\numberCOSXLV,\numberCOSXLV)
\PlotQuadraticCurve(1,0)(1,0)(0,1)(0,1)%
                   (-1,0)(-1,0)(0,-1)(0,-1)%
                   (1,0)(1,0)
\end{Picture}
\end{center}
```

Ex. 76

(b) `\PlotQuadraticCurve(`*x0*`,`*y0*`){`*angle0*`}(`*x1*`,`*y1*`){`*angle1*`}...(`*xn*`,`*yn*`){`*anglen*`}`

draws a curve through the points $(x0, y0)$, $(x1, y1)\ldots(xn, yn)$ the inclination angles of which, with respect to the x axis, are *angle0*, *angle1*..., *angle0* (always measured in degrees).

[11] This command draws a quadratic curve between each pair of adjacent points.
The `\Curve` command, introduced by the `curve2e` package, does a similar job, but using cubic approximations, instead of quadratic.



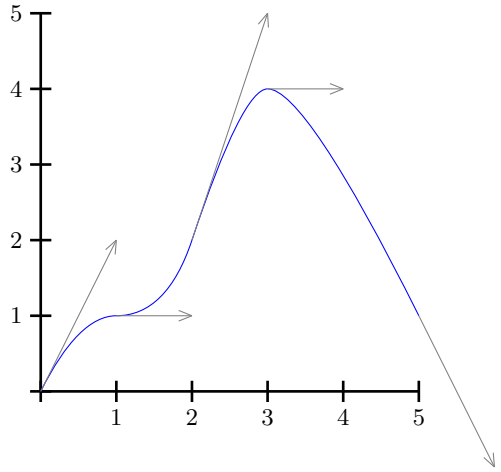
```
\setlength{\unitlength}{2cm}
\begin{center}
\begin{Picture}(1,1)(-1,-1)
\pictcolor{red}
\PlotQuadraticCurve(1,0){0}(0,1){90}
                   (-1,0){180}(0,-1){270}
                   (1,0){360}
\pictcolor{blue}
\referencesystem(0,0)%
                (\numberCOSXLV,\numberCOSXLV)%
                (-\numberCOSXLV,\numberCOSXLV)
\PlotQuadraticCurve(1,0){0}(0,1){90}
                   (-1,0){180}(0,-1){270}
                   (1,0){360}
\end{Picture}
\end{center}
```

Ex. 77

With the `\PlotQuadraticCurve` command you can approximate any smooth curve passing through a list of points when you know the tangent vectors. A particular case, particularly interesting (at least in a calculus course) is the drawing of the graph a function of real variable knowing a table of values of the function and its derivative. To facilitate this work `xpicture` includes the `\PlotxyDyData` command:

`\PlotxyDyData(`*x0*`,`*y0*`,`*Dy0*`)(`*x1*`,`*y1*`,`*Dy1*`)...(`*xn*`,`*yn*`,`*Dyn*`)`

plots the graph of a function $y = f(x)$ passing through points $(x0, y0)$, $(x1, y1)\ldots(xn, yn)$ with derivatives $Dy0$, $Dy1\ldots Dyn$.




```
\setlength{\unitlength}{1cm}
\begin{Picture}(-1,-1)(5.5,5.5)
\cartesianaxes(0,0)(5,5)
\pictcolor{blue}
\PlotxyDyData(0,0,2)(1,1,0)(2,2,3)
                            (3,4,0)(5,1,-2)
\pictcolor{gray}
\Put(0,0){\xtrivVECTOR(0,0)(1,2)}
\Put(1,1){\xtrivVECTOR(0,0)(1,0)}
\Put(2,2){\xtrivVECTOR(0,0)(1,3)}
\Put(3,4){\xtrivVECTOR(0,0)(1,0)}
\Put(5,1){\xtrivVECTOR(0,0)(1,-2)}
\end{Picture}
```

Ex. 78

6 Package options and configuration file

This package is loaded as usual, using the instruction `\usepackage{`*list of options*`}{xpicture}`. Then, packages `pict2e`, `curve2e`, `xcolor`, `calculator`, and `calculus` are automatically loaded. This package is compatible with any system that supports `xcolor` and `pict2e` packages.

The only specific option for this package is `draft`, which disables all the instructions defined in this package, replacing each picture set in a `Picture` environment by a parallelogram circumscribed by a white rectangle (the box that shows the area reserved for the picture).[12] This option is very useful throughout the production of the document, since the composition of the drawings slows considerably the compilation time.

All other options are passed directly to packages `pict2e`, `curve2e`, and `xcolor`. The most interesting option (from package `pict2e`) is `pstarrows`; if used, arrowheads in vectors are drawn in PSTricks style (instead of the standard LaTeX style). Do not use the `hide` or `original` options (from package `pict2e`).

You can include your preferred values for configurable `xpicture` parameters (like axes or labels style, radians or degrees measure for angles, radians or degrees labels in polar grids, et cetera) using the file `xpicture.cfg`, because, if exists, this local configuration file is loaded. If you want to use it, copy the file `xpicture.cfgxmpl` (which is distributed along with package `xpicture`), call your copy as `xpicture.cfg` and put it in your local `texmf` tree. Initially, this file contains the default values for all parameters, but you edit it to modify everything agreed.

[12] This option is equivalent to a global use of the `\draftPictures` declaration.

7 Compatibility with related packages

As mentioned earlier, this package loads packages `pict2e`, `curve2e`, `xcolor`, `calculator`, and `calculus`. Every command defined in these packages works fine within a `Picture` environment. The only restriction to take in account is that colors must be selected with the `\pictcolor` command, because commands `\color` and `\textcolor` may cause the appearance of unwanted spaces. Picture commands defined in `pict2e` and `curve2e` can be freely used (had in mind, however, that in this case coordinates are interpreted as standard), and you can use all the techniques for defining and manipulating colors from `color` and `xcolor` packages.

Although guidelines for defining and operating with functions explained in subsections 5.3–5.5 may be enough to compose a lot of graphics, in order to take full advantage of this package you must known packages `calculator` and `calculus` with certain depth. Package `calculator` will set you free of many tedious calculations.

On the other hand, `xpicture` is widely compatible with other packages related to the graphics inclusion, composition or modification. This fact gives us a lot of flexibility when using them together.

For example, a picture drawn by `xpicture` can include external images loaded with packages `graphics`/`graphicx`, and you can also manipulate the whole picture with the aid of these packages. In a similar way, `pgf/tikz` pictures can be included inside a `xpicture` draw. If you use LaTeX and `dvips` to compile your document, you can combine `xpicture` with `pstricks`.

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