

# 그림과 함수 플로팅

In-Sung Cho

Economics, Kongju National University

2018/11/17

공주대학교 문서작성워크숍 2018

한국텍학회 · 한국텍사용자그룹 (<http://ktug.org>)

# Table of Contents

1	Introduction to graphics in L <sup>A</sup> T <sub>E</sub> X . . . . .	1
1.1	<code>\includegraphics</code> . . . . .	2
1.2	<code>pstricks</code> vs. <code>tikz</code> . . . . .	4
1.3	environments: <code>pspicture</code> vs. <code>tikzpicture</code> . . . . .	5
1.4	<code>\useasboundingbox</code> (not for beginners) . . . . .	6
1.5	<code>\tikz</code> and <code>tikzpicture</code> environment . . . . .	7
2	Path, stroke and fill . . . . .	8
2.1	<code>path</code> and <code>draw</code> . . . . .	9
2.2	<code>path</code> and <code>fill</code> . . . . .	10
2.3	abbreviations: <code>\fill</code> , <code>\filldraw</code> . . . . .	11
3	Lines . . . . .	12
3.1	lines and <code>line width</code> . . . . .	13
3.2	line styles . . . . .	14
3.3	colors and shifts ( <code>xshift</code> , <code>yshift</code> , <code>shift</code> ) . . . . .	15
3.4	axes . . . . .	16
4	Grids and <code>help lines</code> . . . . .	17
4.1	grids . . . . .	18
4.2	<code>help lines</code> . . . . .	19
5	Dots and circles . . . . .	20
5.1	dots and circles . . . . .	21
5.2	<code>node dots</code> . . . . .	22
5.3	making your life easier . . . . .	23
6	Adding texts and repeating . . . . .	25

6.1	node	26
6.2	dots vs. <code>node dots</code>	27
6.3	axes with labels	28
7	Repeating: <code>\foreach</code>	29
7.1	<code>\foreach</code>	30
7.2	<code>\foreach</code> : axes	31
8	Coordinates: basics	32
8.1	Cartesian coordinates	33
8.2	polar coordinates	34
9	Relative coordinates	35
9.1	relative coordinates	36
9.2	turn	37
9.3	example: when can I go home?	38
10	Curves	40
10.1	basic curves	41
10.2	plot coordinates	42
10.3	example: utility maximization (a tangent curve to a line)	43
11	Plotting functions	44
11.1	plotting your own functions	45
11.2	some internal functions	47
11.3	example: utility maximization	50

# 1 Introduction to graphics in L<sup>A</sup>T<sub>E</sub>X

```
\usepackage{graphicx}  
\includegraphics[width=...]{filename}  
  
\usepackage{pstricks}  
  
\usepackage{tikz}
```

## 1.1 `\includegraphics`

```
\includegraphics[width=.7\linewidth]{isc1}
```

```
\includegraphics[width=.7\linewidth]{isc1}
```

## 1.2 pstricks vs. tikz

```
%% \usepackage{pstricks} % dvi -> ps -> pdf
\psline(-1,0)(1,0)
\pscircle(0,0){2pt}
```

~~first~~ try of drawing

first try of drawing

~~first~~ try of drawing

first\pscircle(0,0){2pt} of drawing

~~first~~ try of drawing

first\tikz{\draw (0,0) circle (2pt);} of drawing

~~first~~ try of drawing

first\tikz[baseline]{\draw (0,0) circle (2pt);} of drawing

~~first~~ try of drawing

first\tikz[overlay]{\draw (0,0) circle (2pt);} of drawing

```
%%\usepackage{tikz}
```

```
\tikz { \draw (0,0) circle (2pt) ; }
```

```
\tikz[overaly]{ \draw (0,0) circle (2pt) ; }
```

```
\begin{tikzpicture}[overlay] < tikz codes > \end{tikzpicture}
```

### 1.3 environments: pspicture vs. tikzpicture


#### pspicture

---

```
모든 날이\psframe(0,0)(1,.5)
        \psline(0,0)(1,0)\ 좋았다.
```

너와 함께한 시간 모두 눈부셨다. 날이  
좋아서 날이 ~~좋지~~ 않아서 날이 적당해서  
모든 날이 ~~좋았다~~.

```
모든 날이\begin{pspicture}(0,0)(1,.5)
        \psline(0,0)(1,0)
        \end{pspicture} 좋았다.
```

너와 함께한 시간 모두 눈부셨다. 날이  
좋아서 날이 ~~좋지~~ 않아서 날이 적당해서  
모든 날이  좋았다.

#### tikz

---

```
모든 날이\begin{tikzpicture}
        \draw (0,0) rectangle (1,.5);
        \draw (0,0) -- (1,1);
        \end{tikzpicture} 좋았다.
```

너와 함께한 시간 모두 눈부셨다. 날이  
좋아서 날이 ~~좋지~~ 않아서 날이 적당해서

모든 날이  좋았다.


```
모든 날이\begin{tikzpicture}[overlay]
        ...
        \end{tikzpicture} 좋았다.
```

너와 함께한 시간 모두 눈부셨다. 날이  
좋아서 날이 ~~좋지~~ 않아서 날이 적당해서  
모든 날이 ~~좋았다~~.

#### \useasboundingbox

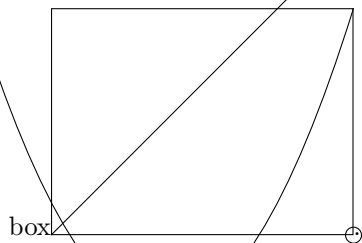
---

```
모든 날이\begin{tikzpicture}
        \useasboundingbox (0,0) rectangle (1,.5);
        ...
        \end{tikzpicture} 좋았다.
```

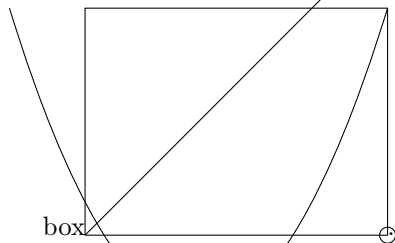
너와 함께한 시간 모두 눈부셨다. 날이  
좋아서 날이 ~~좋지~~ 않아서 날이 적당해서  
모든 날이  좋았다.



## 1.4 `\useasboundingbox` (not for beginners)



```
%% pstricks codes
box\begin{pspicture}(4,3)
\psset{linewidth=.4pt}
\psframe(4,3)
\psline(0,0)(5,5)
\parabola(-1,3)(1.5,-1)
\pscircle(4,0){3pt}
\end{pspicture}.
```



```
%% tikz codes
box\begin{tikzpicture}
\useasboundingbox (0,0) rectangle (4,3);
\draw (0,0) rectangle (4,3);
\draw (0,0) -- (5,5);
\draw (-1,3) parabola bend (1.5,-1) (4,3);
\draw (4,0) circle (3pt);
\end{tikzpicture}.
```

Remark: `\useasboundingbox` is an abbreviation of `\path[use as bounding box]`.

# TikZ from now on

## 1.5 `\tikz` and `tikzpicture` environment

```
%% package load
\usepackage{tikz}

%% command
\tikz[<option>]{<tikz codes>}

%% environment
\begin{tikzpicture}[<option>]
  <tikz codes>
\end{tikzpicture}
```

Do not forget ; at the end of every path.

## 2 Path, stroke and fill

```
\path (0,0) -- (0,1) -- (1,1) -- (1,0) -- (0,0);
```

```
\path [draw] (0,0) -- (0,1) -- (1,1) -- (1,0) -- (0,0);
```

```
\path [fill] (0,0) -- (0,1) -- (1,1) -- (1,0) -- (0,0);
```

## 2.1 path and draw

`\path`: a sequence of straight lines and curves connected

---

`\path`

```
\begin{tikzpicture}
% \path [use as bounding box] (0,0) rectangle (1,1);
\path (0,0) -- (0,1) -- (1,1) -- (1,0) -- (0,0);
\end{tikzpicture}
```

---

`\path[draw]`

```
\begin{tikzpicture}
\path [draw] (0,0) -- (0,1) -- (1,1) -- (1,0) -- (0,0);
\end{tikzpicture}
```



---

`\draw`

```
%% cycle
\begin{tikzpicture}
\draw (0,0) -- (0,1) -- (1,1) -- (1,0) -- cycle;
\end{tikzpicture}
```



## 2.2 path and fill

`\path[fill]`

```
\begin{tikzpicture}
\path [fill] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```



`\path[fill=<color>]`

```
\begin{tikzpicture}
\path [fill=green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```



`\path[draw,fill=<color>]`

```
\begin{tikzpicture}
\path [draw,fill=green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```



`\path[draw=<color>,fill=<color>]`

```
\begin{tikzpicture}
\path [draw=blue,fill=green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```



## 2.3 abbreviations: `\fill`, `\filldraw`

`\fill = \path[fill]`

```
\begin{tikzpicture}
\fill [green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```



`\fill[draw]`

```
\begin{tikzpicture}
\fill [draw,green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```



`\filldraw = \fill[draw] = \path[fill,draw]`

```
\begin{tikzpicture}
\filldraw [green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```



`\filldraw`

```
\begin{tikzpicture}
\filldraw [blue,fill=green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```

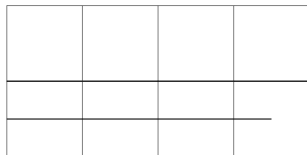









### 3 Lines

```
\draw (0,0) -- (4,0);
```

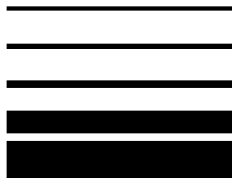
### 3.1 lines and line width

```
\begin{tikzpicture}
\draw [help lines] (0,-1) grid (4,1);
\draw (0,0) -- (4,0);
\draw [thin] (0,-.5) -- (3.5,-.5);
\end{tikzpicture}
```



ultra thin		0.1pt
very thin		0.2pt
thin		0.4pt (default)
semithick		0.6pt
thick		0.8pt
very thick		1.2pt
ultra thick		1.6pt

```
\begin{tikzpicture}
\draw [ultra thick] (0,0) -- (3,0);
\draw [line width=2pt] (0,-.5) -- (3,-.5);
\draw [line width=1mm] (0,-1) -- (3,-1);
\draw [line width=3mm] (0,-1.5) -- (3,-1.5);
\draw [line width=5mm] (0,-2) -- (3,-2);
\end{tikzpicture}
```





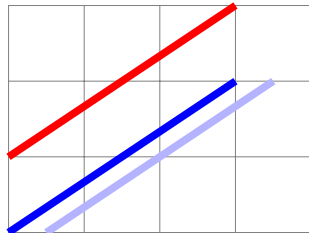


### 3.3 colors and shifts (xshift, yshift, shift)

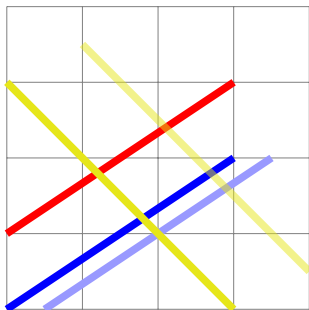
```
\begin{tikzpicture}
\draw [blue] (0,0) -- (4,0);
\draw [red,yshift=-5mm] (0,0) -- (4,0);
\end{tikzpicture}
```



```
\begin{tikzpicture}[line width=1mm]
\draw [help lines] (0,0) grid (4,3);
\draw [blue] (0,0) -- (3,2);
\draw [red,yshift=10mm] (0,0) -- (3,2);
\draw [blue!30,xshift=.5cm] (0,0) -- (3,2);
\end{tikzpicture}
```

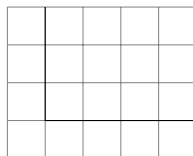


```
%% shift, opacity
\begin{tikzpicture}[line width=1mm]
\draw [help lines] (0,0) grid (4,4);
\draw [blue] (0,0) -- (3,2);
\draw [red,yshift=10mm] (0,0) -- (3,2);
\draw [blue!40,xshift=.5cm] (0,0) -- (3,2);
\draw [blue!10!yellow] (0,3) -- (3,0);
\draw [blue!10!yellow,shift={(1,.5)},opacity=.5]
(0,3) -- (3,0);
\end{tikzpicture}
```

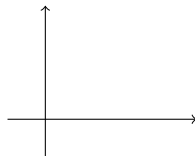


### 3.4 axes

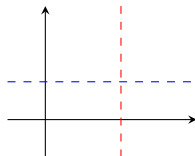
```
\begin{tikzpicture}[scale=.5]
\draw [help lines] (-1,-1) grid (4,3);
\draw (0,3) -- (0,0) -- (4,0);
\end{tikzpicture}
```



```
%% arrows
\begin{tikzpicture}[scale=.5]
%\draw [help lines] (-1,-1) grid (4,3);
\draw [->] (-1,0) -- (4,0);
\draw [->] (0,-1) -- (0,3);
\end{tikzpicture}
```



```
%% >=stealth/latex
\begin{tikzpicture}[scale=.5,>=stealth]
%\draw [help lines] (-1,-1) grid (4,3);
\draw [->] (-1,0) -- (4,0);
\draw [->] (0,-1) -- (0,3);
\draw [dashed,blue,yshift=1cm] (-1,0) -- (4,0);
\draw [dashed,red,xshift=20mm] (0,-1) -- (0,3);
\end{tikzpicture}
```



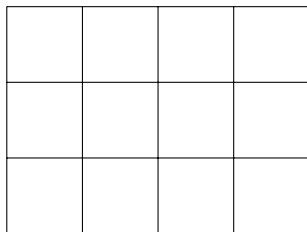
## 4 Grids and help lines

```
\draw (0,0) grid (4,3);
```

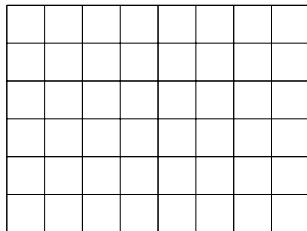
```
\draw [help lines] (0,0) grid (1cm);
```

## 4.1 grids

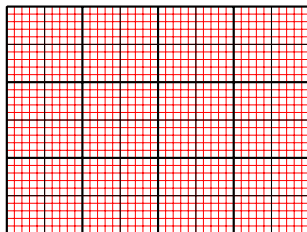
```
\begin{tikzpicture}  
\draw (0,0) grid (4,3);  
\end{tikzpicture}
```



```
\begin{tikzpicture}  
\draw [step=.5cm,very thin] (0,0) grid (4,3);  
\draw (0,0) grid (4,3);  
\end{tikzpicture}
```

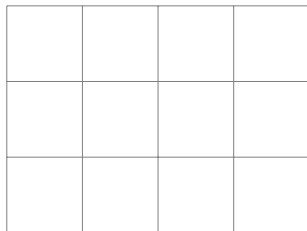


```
\begin{tikzpicture}  
\draw [step=1mm,red,ultra thin] (0,0) grid (4,3);  
\draw [step=.5cm] (0,0) grid (4,3);  
\draw [thick] (0,0) grid (4,3);  
\end{tikzpicture}
```



## 4.2 help lines

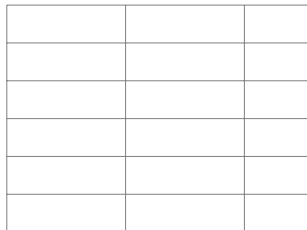
```
\begin{tikzpicture}  
\draw [help lines] (0,0) grid (4,3);  
\end{tikzpicture}
```



```
\begin{tikzpicture}  
\draw [help lines,step=5mm,densely dotted,blue]  
      (0,0) grid (4,3);  
\end{tikzpicture}
```



```
\begin{tikzpicture}  
\draw [help lines,xstep=.5*pi,ystep=5mm]  
      (0,0) grid (4,3);  
\end{tikzpicture}
```



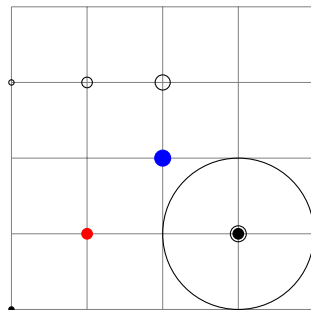
## 5 Dots and circles

```
\draw (0,0) circle (2pt);
```

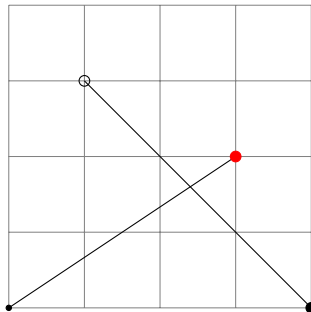
```
\draw (0,0) node [draw,circle] {};
```

## 5.1 dots and circles

```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,4);
\draw (0,3) circle (1pt);
\draw (1,3) circle (2pt);
\draw (2,3) circle (1mm);
\filldraw (0,0) circle (1pt);
\filldraw [red] (1,1) circle (2pt);
\filldraw [blue] (2,2) circle (3pt);
\filldraw (3,1) circle (2pt);
\draw (3,1) circle (3pt);
\draw (3,1) circle (1cm);
\end{tikzpicture}
```



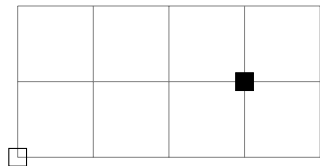
```
\begin{tikzpicture}
\filldraw [help lines] (0,0) grid (4,4);
\draw (0,0) -- (3,2);
\filldraw (0,0) circle (1pt);
\filldraw [red] (3,2) circle (2pt);
\draw (1,3) -- (4,0);
\draw (1,3) circle (2pt);
\filldraw (4,0) circle (2pt);
\end{tikzpicture}
```



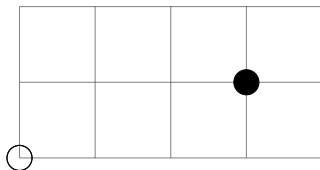


## 5.2 node dots

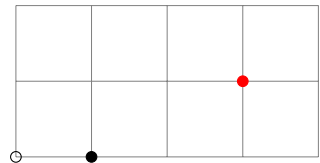
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,2);
\draw (0,0) node [draw] {};
\draw (3,1) node [draw,fill] {};
\end{tikzpicture}
```



```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,2);
\draw (0,0) node [draw,circle] {};
\draw (3,1) node [draw,fill,circle] {};
\draw (0,0) node [draw,circle,minimum size=4pt] {};
\end{tikzpicture}
```



```
%%\tikzset{my node dot/.style=
%% {draw,circle,minimum size=4pt,inner sep=0pt}}
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,2);
\draw (0,0) node [my node dot] {};
\draw (1,0) node [my node dot,fill] {};
\draw (3,1) node [my node dot,fill,red] {};
\end{tikzpicture}
```



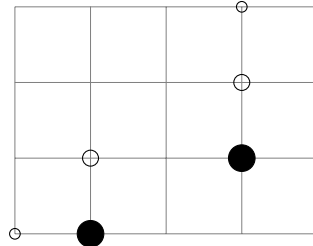
## 5.3 making your life easier

### Using my own styles

```
\tikzset{my style/.style={my options}}
```

### Using my own macros

```
%% predefined macros:  
%% \mydot,\mydotfill,\mynodedot,\mynodedotfill  
\begin{tikzpicture}  
\draw[help lines] (0,0) grid (4,3);  
\mydot(0,0);  
\mydot(1,1)(3pt);  
\mydotfill(1,0)(5pt);  
\mynodedot(3,3);  
\mynodedot(3,2)(3pt);  
\mynodedotfill(3,1)(5pt);  
\end{tikzpicture}
```



## Defining my own macros

```
%% \usepackage{xparse}
\NewDocumentCommand\mydot{ r() D(){2pt} }
{ \draw (#1) circle (#2)
}

\NewDocumentCommand\mydotfill{ r() D(){2pt} }
{ \draw [fill] (#1) circle (#2)
}

\NewDocumentCommand\mynodedot{ r() D(){2pt} }
{ \draw (#1)
    node [draw,circle,inner sep=0pt,minimum size=2*#2] {}
}

\NewDocumentCommand\mynodedotfill{ r() D(){2pt} }
{ \draw (#1)
    node [draw,circle,inner sep=0pt,black,fill=black,
    minimum size=2*#2] {}
}
```

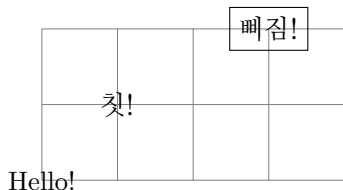
## 6 Adding texts and repeating

```
\draw (0,0) node {Hello!};
```

```
\node at (0,0) {Hello!};
```

## 6.1 node

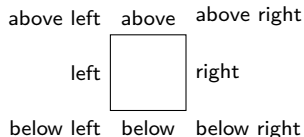
```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,2);
\draw (0,0) node {Hello!};
\node at (1,1) { 찻! };
\draw (3,2) node [draw] { 빼짐! };
\end{tikzpicture}
```



```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,2);
\draw (0,0) circle (2pt);
\draw (0,0) node [above right] {A};
\draw (3,1) circle (2pt) node [above] {B};
\end{tikzpicture}
```

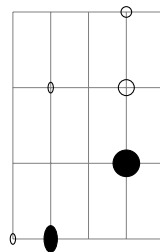


```
\begin{tikzpicture}[font={\sffamily\footnotesize}]
\draw (0,0) rectangle (1,1);
\draw (0,0) node [below left] {below left};
\draw (1,1) node [above right] {above right};
\draw (1,.5) node [right] {right};
<...codes...>
\end{tikzpicture}
```



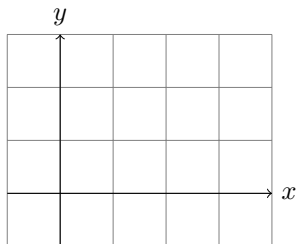
## 6.2 dots vs. node dots

```
%%\usepackage{tikz}
%%\tikzset{my node dot/.style=
%% {draw,circle,minimum size=4pt,inner sep=0pt}}
\begin{tikzpicture}[xscale=.5]
\draw[help lines] (0,0) grid (4,3);
\draw (0,0) circle (2pt);
\draw (1,2) circle (2pt);
\filldraw (1,0) circle (5pt);
\draw (3,3) node
[my node dot,minimum size=2*2pt] {};
\draw (3,2) node
[my node dot,minimum size=2*3pt] {};
\draw (3,1) node
[my node dot,minimum size=2*5pt,fill] {};
\end{tikzpicture}
```

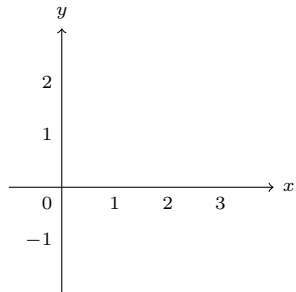


## 6.3 axes with labels

```
%% arrows
\begin{tikzpicture}[scale=.7]
\draw [help lines] (-1,-1) grid (4,3);
\draw [->] (-1,0) -- (4,0) node [right] {$x$};
\draw [->] (0,-1) -- (0,3) node [above] {$y$};
\end{tikzpicture}
```



```
%% arrows
\begin{tikzpicture}[scale=.7,font=\scriptsize]
%\draw [help lines] (-1,-3) grid (4,3);
\draw [->] (-1,0) -- (4,0) node [right] {$x$};
\draw [->] (0,-2) -- (0,3) node [above] {$y$};
\draw (0,0) node [below left] {0};
\draw (1,0) node [below] {1};
\draw (2,0) node [below] {2};
\draw (3,0) node [below] {3};
\draw (0,1) node [left] {1};
\draw (0,2) node [left] {2};
\draw (0,-1) node [left] {$-1$};
\end{tikzpicture}
```



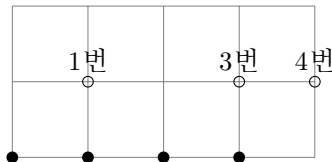
## 7 Repeating: `\foreach`

```
\foreach \myx in {1,2,3}
{
  \filldraw (\myx,0) circle (2pt);
}
```



## 7.1 \foreach

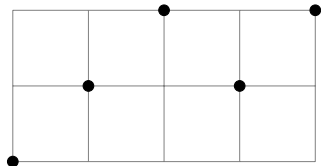
```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,2);
\foreach \x in {0,1,3,2}
  \filldraw (\x,0) circle (2pt);
\foreach \x in {1,3,4}
  \draw (\x,1) circle (2pt) node [above] {\x 번};
\end{tikzpicture}
```



```
\begin{tikzpicture}
\draw [help lines,shift={(.5,.5)}]
(0,0) grid (4,3);
\foreach \x in {1,2,3,4}
  \foreach \y in {1,2,3}
    \draw (\x,\y) node {\x,\y};
\end{tikzpicture}
```

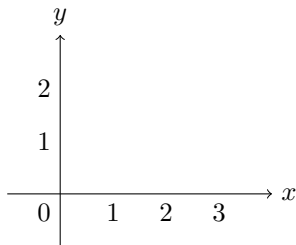
1,3	2,3	3,3	4,3
1,2	2,2	3,2	4,2
1,1	2,1	3,1	4,1

```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,2);
\foreach \x in {(0,0),(1,1),(2,2),(3,1),(4,2)}
  \filldraw \x circle (2pt);
\end{tikzpicture}
```

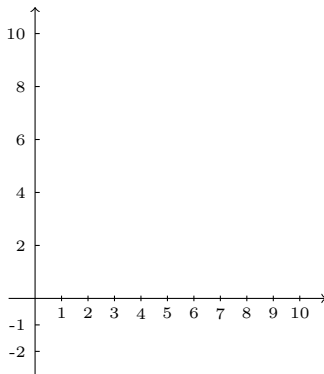


## 7.2 \foreach: axes

```
\begin{tikzpicture}[scale=.7]
\draw [->] (-1,0) -- (4,0) node [right] {$x$};
\draw [->] (0,-1) -- (0,3) node [above] {$y$};
\draw (0,0) node [below left] {0};
\foreach \x in {1,2,3}
  \draw (\x,0) node [below] {\x};
\foreach \x in {1,2}
  \draw (0,\x) node [left] {\x};
\end{tikzpicture}
```



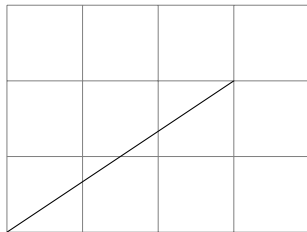
```
\begin{tikzpicture}[scale=.35,font=\tiny]
\draw [->] (-1,0) -- (11,0);
\draw [->] (0,-3) -- (0,11);
\foreach \x in {1,2,...,10}
  { \draw (\x,0) node [below] {\x};
    \draw (\x,-3pt) -- (\x,3pt);
  }
\foreach \x in {-2,-1,2,4,...,10}
  { \draw (0,\x) node [left] {\x};
    \draw (0,\x) -- (5pt,\x);
  }
\end{tikzpicture}
```



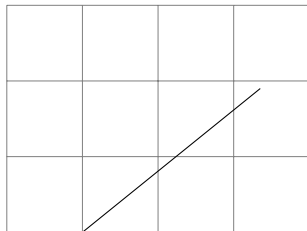
## 8 Coordinates: basics

## 8.1 Cartesian coordinates

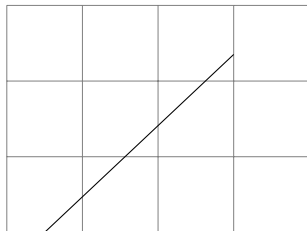
```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\coordinate (A) at (0,0);
\coordinate (B) at (3,2);
\draw (A) -- (B);
\end{tikzpicture}
```



```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\coordinate (A) at (-1+2,0);
\coordinate (B) at (3cm+10pt,2cm-1mm);
\draw (A) -- (B);
\end{tikzpicture}
```

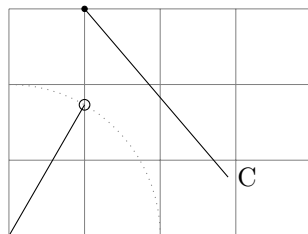


```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\coordinate (A) at ([xshift=5mm]0,0);
\coordinate (B) at ([yshift=10pt]3,2);
\draw (A) -- (B);
\end{tikzpicture}
```



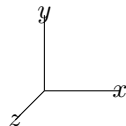
## 8.2 polar coordinates

```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\draw [dotted,gray] (2,0) arc (0:90:2);
\coordinate (A) at (60:2);
\draw (0,0) -- (A);
\draw (A) circle (2pt);
\filldraw (1,3) circle (1pt);
\draw (1,3) -- (15:3) node [right] {C};
\end{tikzpicture}
```



## 3D coordinates

```
\begin{tikzpicture}
\draw (0,0,0) -- (1,0,0) node {$x$};
\draw (0,0,0) -- (0,1,0) node {$y$};
\draw (0,0,0) -- (0,0,1) node {$z$};
\end{tikzpicture}
```



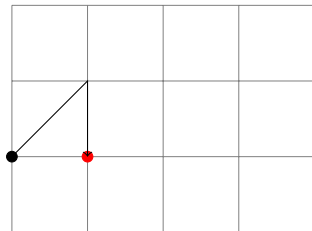
## 9 Relative coordinates

```
\draw (0,0) -- (1,1) - (1,1);+
```

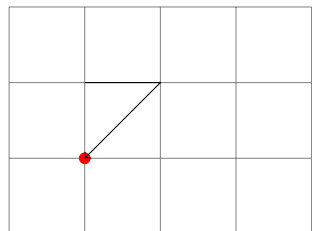
```
\draw (0,0) -- +(1,1) - (1,1);+
```

## 9.1 relative coordinates

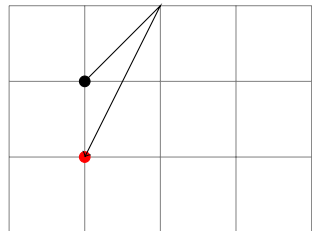
```
\begin{tikzpicture}
\draw[help lines](0,0) grid (4,3);
\filldraw[red] (1,1) circle (2pt);
\draw [->] (1,1) (0,1) -- +(1,1) -- (1,1);
\mydotfill(0,1); % liftpen, moveto, lineto
\end{tikzpicture}
```



```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\filldraw[red] (1,1) circle (2pt);
\draw [->] (1,1) +(0,1) -- +(1,1) -- (1,1);
\end{tikzpicture}
```

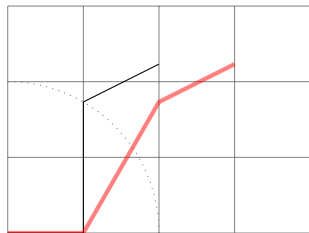


```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\filldraw[red] (1,1) circle (2pt);
\draw [->] (1,1) ++(0,1) -- +(1,1) -- (1,1);
\mydotfill(1,2);
\end{tikzpicture}
```

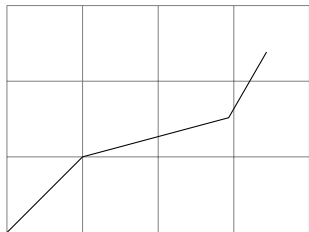


## 9.2 turn

```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw [dotted,gray] (2,0) arc (0:90:2);
\draw (0,0) -- (1,0) -- (60:2cm) -- +(1,.5);
\draw [ultra thick,red,opacity=.5]
      (0,0) -- (1,0) -- ([turn]60:2cm) -- +(1,.5);
\end{tikzpicture}
```

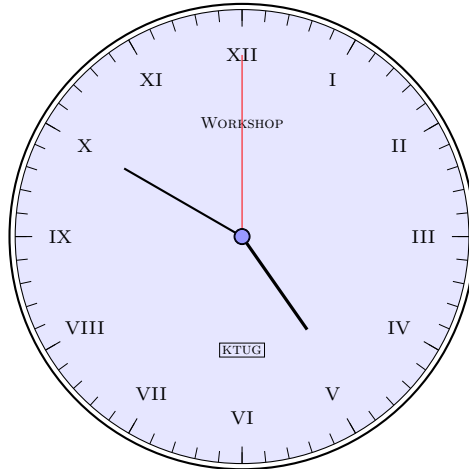


```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw (0,0) -- (1,1) --
      ([turn]-30:2cm) --
      ([turn]45:1);
\end{tikzpicture}
```





### 9.3 example: when can I go home?



```

\begin{tikzpicture}
\def\Romantime#1{%
  \scriptsize\MakeUppercase{\romannumeral #1}
}
\draw [thick] (0,0) circle (2.05cm);
\draw [fill=blue!10] (0,0) circle (2cm);
\draw (90:1) node {\tiny\textsc{Workshop}};
\draw (-90:1) node [draw,ultra thin,inner sep=1pt] {\tiny\textsc{ktug}};
\draw [very thick] (0,0) -- (-55:1);      % hour hand
\draw [thick] (0,0) -- (150:1.2);        % minute hand
\draw [very thin,red] (0,0) -- (90:1.6); % second hand
\draw [fill=blue] (0,0) circle (2pt);
\draw [fill=blue!40] (0,0) circle (1.8pt);
%% minutes
\foreach \ang in {90,84,78,...,-264}
  \draw [ultra thin] (\ang:2) -- (\ang:1.9);
%% hours
\foreach \ang [count=\t] in {60,30,0,...,-270}
{ \draw (\ang:2) -- (\ang:1.85);
  \draw (\ang:1.6) node {\Romantime \t};
}
\end{tikzpicture}

```

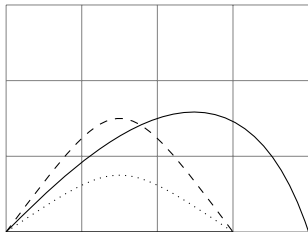
## 10 Curves

```
\draw (0,0) .. controls (1,1) and (2,0) .. (4,3);
```

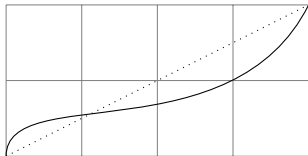
```
\draw (0,0) -- +(1,1) - (1,1);+
```

## 10.1 basic curves

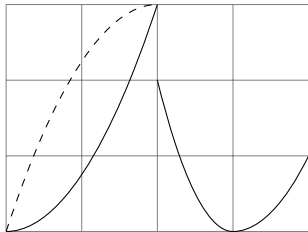
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw      (0,0) -- (3,0);
\draw [dotted] (0,0) .. controls (1.5,1) .. (3,0);
\draw [dashed] (0,0) .. controls (1.5,2) .. (3,0);
\draw (0,0) .. controls (1,1) and (3,3) .. (4,0);
\end{tikzpicture}
```



```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,2);
\draw [dotted] (0,0) -- (4,2);
\draw (0,0) .. controls (0,1) and (3,0) .. (4,2);
\end{tikzpicture}
```

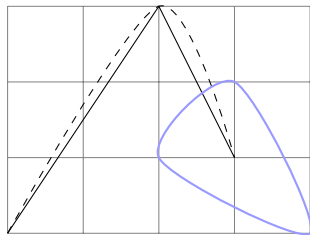


```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw (0,0) parabola (2,3);
\draw [dashed] (0,0) parabola [bend at end] (2,3);
\draw (2,2) parabola bend (3,0) (4,1);
\end{tikzpicture}
```

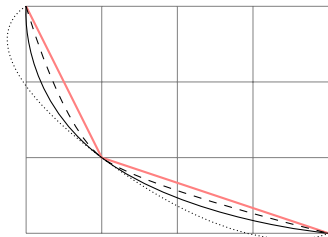


## 10.2 plot coordinates

```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw plot coordinates {(0,0) (2,3) (3,1)};
\draw [dashed] plot [smooth]
coordinates {(0,0) (2,3) (3,1)};
\draw [blue!40,thick] plot [smooth cycle]
coordinates {(2,1) (3,2) (4,0)};
\end{tikzpicture}
```

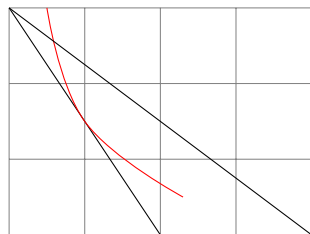


```
%% smooth, tension
\begin{tikzpicture}
\useasboundingbox (0,0) rectangle (4,3);
\draw [help lines] (0,0) grid (4,3);
\draw [red!50,thick] plot [smooth,tension=0]
coordinates {(0,3) (1,1) (4,0)};
\draw [dashed] plot [smooth]
coordinates {(0,3) (1,1) (4,0)};
\draw plot [smooth,tension=1]
coordinates {(0,3) (1,1) (4,0)};
\draw [densely dotted] plot [smooth,tension=1.8]
coordinates {(0,3) (1,1) (4,0)};
\end{tikzpicture}
```

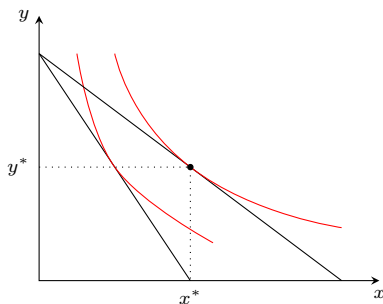


## 10.3 example: utility maximization (a tangent curve to a line)

```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw (0,3) -- (2,0);
\draw [red] plot [smooth,tension=.7]
  coordinates {(.5,3) (1,1.5) (2.3,.5)};
\draw (0,3) -- (4,0);
\end{tikzpicture}
```



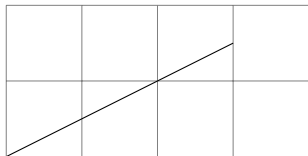
```
\begin{tikzpicture}[>=stealth,font=\scriptsize]
\useasboundingbox (0,0) rectangle (4,3);
\draw [<->] (0,3.5) node [left] {$y$} --
  (0,0) -- (4.5,0) node [below] {$x$};
\draw (0,3) -- (2,0);
\draw [red] plot [smooth,tension=.7]
  coordinates {(.5,3) (1,1.5) (2.3,.5)};
\draw (0,3) -- (4,0);
\draw [red] plot [smooth,tension=1]
  coordinates {(1,3) (2,1.5) (4,.7)};
\draw [dotted] (0,1.5) node [left] {$y^*$} --
  (2,1.5) -- (2,0) node [below] {$x^*$};
\filldraw (2,1.5) circle (1pt);
\end{tikzpicture}
```



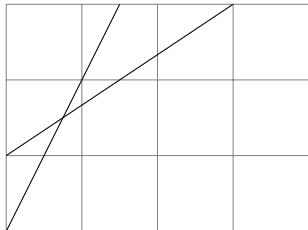
## 11 Plotting functions

## 11.1 plotting your own functions

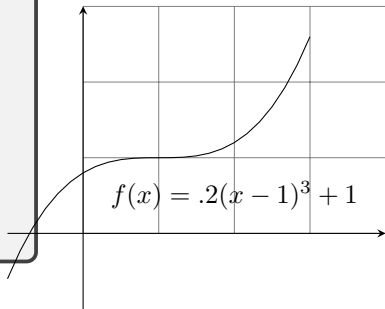
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,2);
\draw plot [domain=0:3] (\x,{.5*\x});
\end{tikzpicture}
```



```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw plot [domain=0:3] (\x,{(2/3)*\x+1});
\draw plot [domain=0:1.5,variable=\var] (\var,2*\var);
\end{tikzpicture}
```



```
\begin{tikzpicture}[>=stealth]
\useasboundingbox (0,0) rectangle (4,3);
\draw [help lines] (0,0) grid (4,3);
\draw [->] (-1,0) -- (4,0);
\draw [->] (0,-1) -- (0,3);
\draw plot [domain=-1:3] (\x,{.2*(\x-1)^3+1});
\draw (2,.5) node {$f(x)=.2(x-1)^3+1$};
\end{tikzpicture}
```

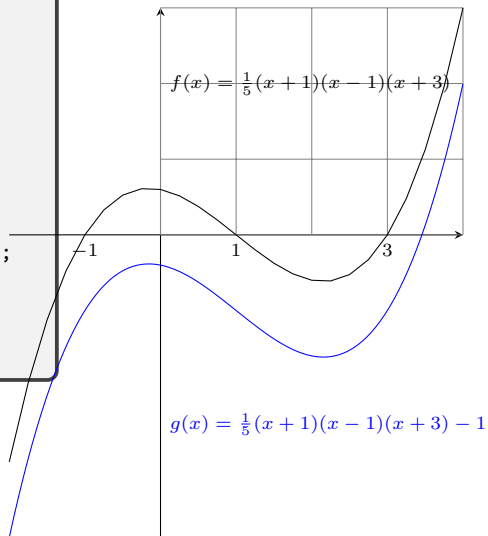




```

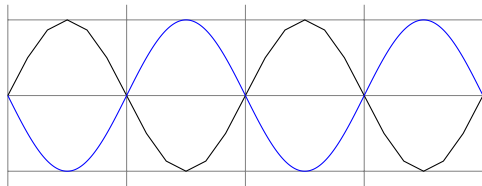
\begin{tikzpicture}[>=stealth,font=\scriptsize]
\useasboundingbox (0,0) rectangle (4,3);
\draw [->] (-2,0) -- (4,0);
\draw [->] (0,-4) -- (0,3);
\def\Fx{.2*(\x+1)*(\x-1)*(\x-3)}
\draw [help lines] (0,0) grid (4,3);
\draw plot [domain=-2:4] (\x,{\Fx});
\foreach \x in {-1,1,3}
  \draw (\x,0) node [below] {\$ \x \$};
\draw (0,2) node [right]
  {\$f(x)=\frac{1}{5}(x+1)(x-1)(x+3)\$};
\draw [blue] plot
  [domain=-2:4,samples=100] (\x,{\Fx-1});
\draw (0,-2.5) node [right,blue]
  {\$g(x)=\frac{1}{5}(x+1)(x-1)(x+3)-1\$};
\end{tikzpicture}

```

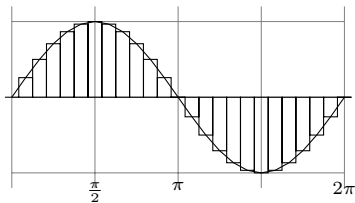


## 11.2 some internal functions

```
\begin{tikzpicture}
\draw[help lines,xstep=.5*pi] (0,-1.2) grid
(2*pi,1.2);
\def\Fx{\sin(2*\x r)}
\def\Gx{-\sin(deg(2*\x))}
\draw plot [domain=0:2*pi] (\x,{\Fx});
\draw [blue] plot
[domain=0:2*pi,samples=500] (\x,{\Gx});
\end{tikzpicture}
```

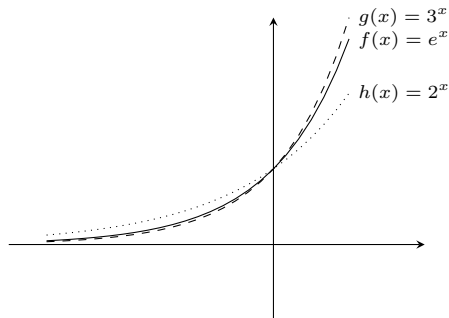


```
\begin{tikzpicture}[xscale=.7,font=\scriptsize]
\draw[help lines,xstep=.5*pi] (0,-1.2) grid
(2*pi,1.2);
\def\Fx{\sin(\x r)}
\draw [domain=0:2*pi] plot
[ybar,bar width=7.4pt] (\x,{\Fx});
\draw plot [domain=0:2*pi] (\x,{\Fx});
\draw (.5*pi,-1)
node [below] {$\frac{\pi}{2}$};
\draw (pi,-1) node [below] {$\pi$};
\draw (2*pi,-1) node [below] {$2\pi$};
\end{tikzpicture}
```



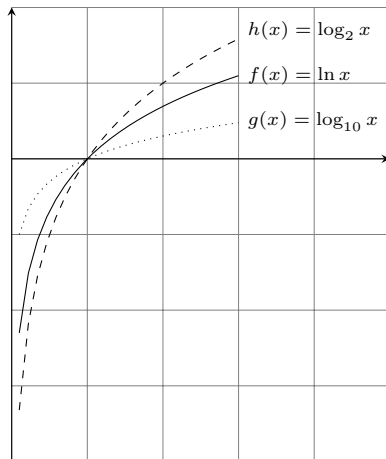
## exponential function

```
\begin{tikzpicture}[>=stealth,font=\scriptsize]
\draw [->] (-3.5,0) -- (2,0);
\draw [->] (0,-1) -- (0,3);
\def\Fx{exp(\x)}
\def\Gx{2^\x}
\def\Hx{3^\x}
\draw plot [domain=-3:1] (\x,{\Fx});
\draw [dotted] plot [domain=-3:1] (\x,{\Gx});
\draw [dashed] plot [domain=-3:1] (\x,{\Hx});
\draw (1,3) node [right] {$g(x)=3^x$};
\draw (1,2.7) node [right] {$f(x)=e^x$};
\draw (1,2) node [right] {$h(x)=2^x$};
\end{tikzpicture}
```



## logarithmic function

```
\begin{tikzpicture}[>=stealth,font=\scriptsize]
\draw [help lines] (0,-4) grid (5,2);
\draw [->] (0,0) -- (5,0);
\draw [->] (0,-4) -- (0,2);
\def\Fx{\ln(\x)}
\def\Gx{\log10(\x)}
\def\Hx{\log2(\x)}
\draw plot [domain=.1:3] (\x,{\Fx});
\draw [dotted] plot [domain=.1:3] (\x,{\Gx});
\draw [dashed] plot [domain=.1:3] (\x,{\Hx});
\draw (3,.5) node [right]
    {$g(x)=\log_{10}x$};
\draw (3,1.1) node [right] {$f(x)=\ln x$};
\draw (3,1.7) node [right] {$h(x)=\log_2 x$};
\end{tikzpicture}
```



### 11.3 example: utility maximization

Consider a consumer whose preference relation is represented by the utility function  $u(x, y) = xy$ . Suppose that prices and income are  $p_x = 2$ ,  $p_y = 3$ , and  $m = 60$ , respectively. What is the consumer's utility maximizing consumption? Now suppose that the price of  $y$  decreases by 1. What is the new utility maximizing consumption?

