그림과 함수 플로팅

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1 Introduction to graphics in LaTeX

```
\usepackage{graphicx}
\includegrpahics[width=...]{filename}

\usepackage{pstricks}

\usepackage{tikz}
```

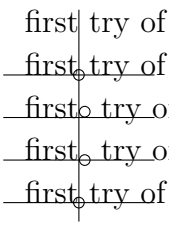
1.1 \includegraphics

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

```
%%\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

pstricks

```
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.
```

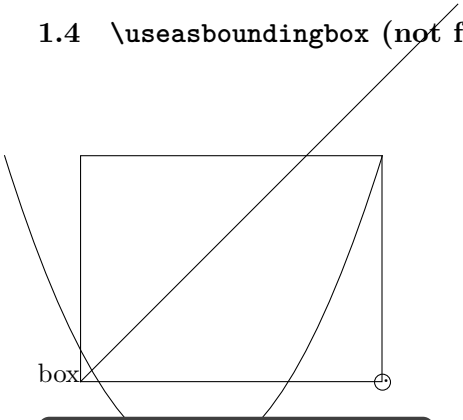
너와 함께한 시간 모두 눈부셨다. 날이 좋아서 날이 좋지 않아서 날이 적당해서 모든 날이 좋았다.

\useasboundingbox

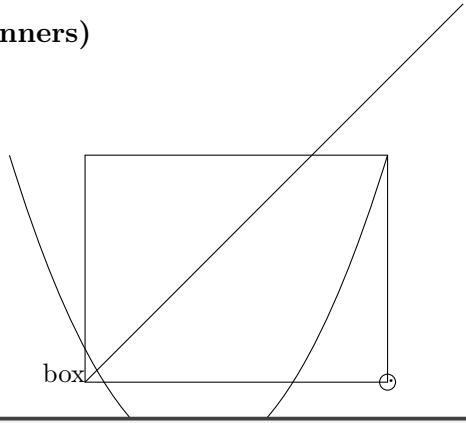
```
모든 날이\begin{tikzpicture}
        \useasboundingbox (0,0) rectangle (1,.5);
        ...
        \end{tikzpicture} 좋았다.
```

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]`.

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

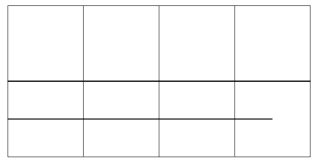
```
\begin{tikzpicture}
\filldraw [blue,fill=green] (0,0) -- (0,1) -- (1,1) -- (1,.5);
\end{tikzpicture}
```

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}
```

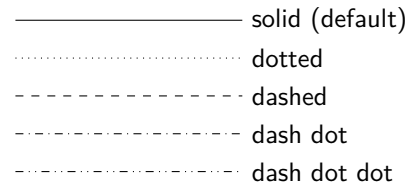


ultra thin — 0.1pt
very thin — 0.2pt
thin — 0.4pt (default)
semithick — 0.6pt
thick — 0.8pt
very thick — 1.2pt
ultra thick — 1.6pt

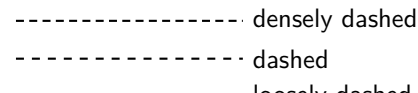
```
\begin{tikzpicture}
\draw [ultra thick]     (0,0)    -- (3,0);
\draw [line width=2pt] (0,-.5)  -- (3,-.5);
\draw [line width=1mm] (0,-1)   -- (3,-1);
\draw [line width=3mm] (0,-1.5) -- (3,-1.5);
\draw [line width=5mm] (0,-2)   -- (3,-2);
\end{tikzpicture}
```

3.2 line styles

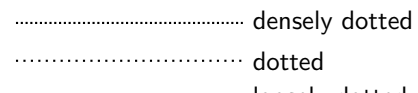
```
\begin{tikzpicture}
\draw [solid]         (0,0)  -- (3,0);
\draw [dotted]        (0,-.5) -- (3,-.5);
\draw [dashed]        (0,-1) -- (3,-1);
\draw [dash dot]      (0,-1.5) -- (3,-1.5);
\draw [dash dot dot] (0,-2) -- (3,-2);
\end{tikzpicture}
```




```
%% densely, loosely
\begin{tikzpicture}[line width=.8pt]
\draw [densely dashed] (0,.5)  -- (3,.5);
\draw [dashed]         (0,0)   -- (3,0);
\draw [loosely dashed] (0,-.5) -- (3,-.5);
\end{tikzpicture}
```

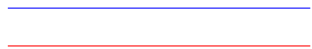



```
%% densely, loosely
\begin{tikzpicture}[line width=.8pt]
\draw [densely dotted] (0,.5)  -- (3,.5);
\draw [dotted]         (0,0)   -- (3,0);
\draw [loosely dotted] (0,-.5) -- (3,-.5);
\end{tikzpicture}
```

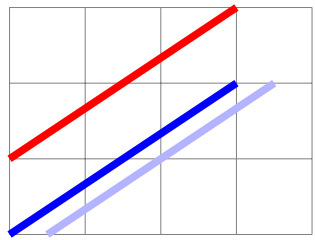


3.3 colors and shifts (xshift, yshift, shift)

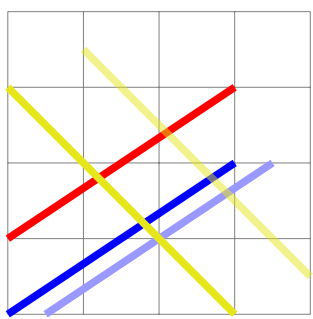
```
\begin{tikzpicture}
\draw [blue] (0,0) -- (4,0);
\draw [red,yshift=-5mm] (0,0) -- (4,0);
\end{tikzpicture}
```



```
\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}
```

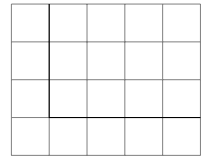


```
%% shift, opacity
\begin{tikzpicture}[line width=1mm]
\draw [help lines] (0,0) grid (4,4);
\draw [blue] (0,0) -- (3,2);
\draw [red,yshift=10mm] (0,0) -- (3,2);
\draw [blue!40,xshift=.5cm] (0,0) -- (3,2);
\draw [blue!10!yellow] (0,3) -- (3,0);
\draw [blue!10!yellow,shift={(1,.5)},opacity=.5]
    (0,3)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

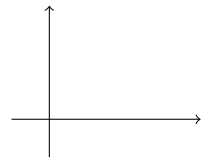


3.4 axes

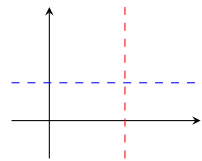
```
\begin{tikzpicture}[scale=.5]
\draw [help lines] (-1,-1) grid (4,3);
\draw (0,3) -- (0,0) -- (4,0);
\end{tikzpicture}
```



```
%% 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}
```

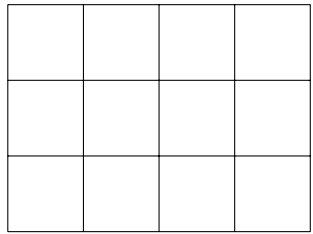


4 Grids and `help lines`

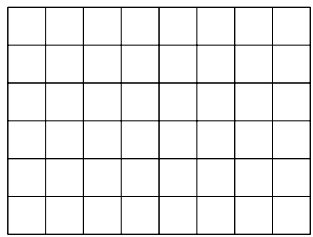
```
\draw (0,0) grid (4,3);

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

4.1 grids

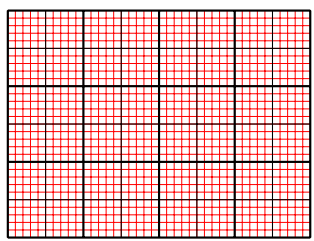
```
\begin{tikzpicture}
\draw (0,0) grid (4,3);
\end{tikzpicture}
```



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

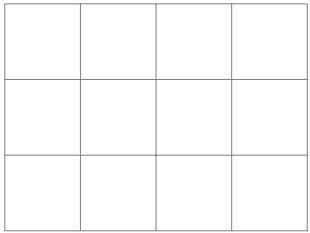


```
\begin{tikzpicture}
\draw [step=1mm,red,ultra thin] (0,0) grid (4,3);
\draw [step=.5cm] (0,0) grid (4,3);
\draw [thick] (0,0) grid (4,3);
\end{tikzpicture}
```



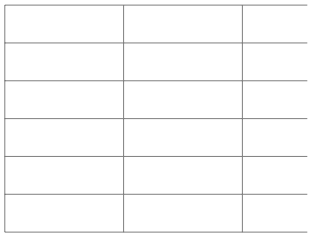
4.2 help lines

```
\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}
```



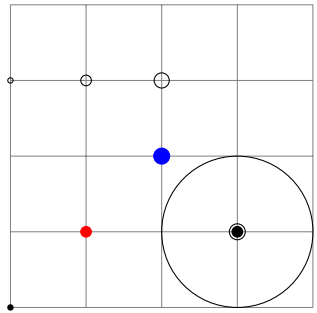
5 Dots and circles

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

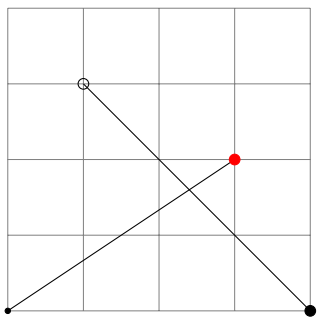
```
\draw (0,0) node [draw,circle] {};
```

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}
```

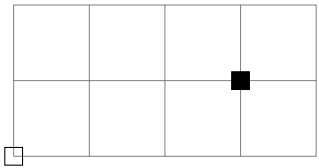


```
\begin{tikzpicture}
\filldraw [help lines] (0,0) grid (4,4);
\draw (0,0) -- (3,2);
\filldraw        (0,0) circle (1pt);
\filldraw [red]  (3,2) circle (2pt);
\draw     (1,3)     -- (4,0);
\draw     (1,3) circle (2pt);
\filldraw (4,0) circle (2pt);
\end{tikzpicture}
```

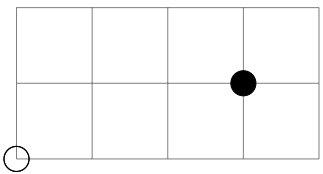


5.2 node dots

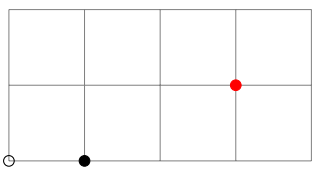
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,2);
\draw (0,0) node [draw] {};
\draw (3,1) node [draw,fill] {};
\end{tikzpicture}
```



```
\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}
```



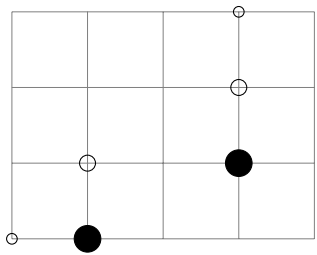
5.3 making your life easier

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

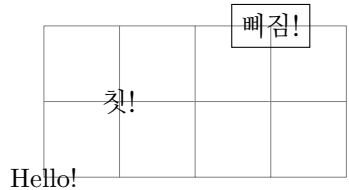
```
%% \usepackage{xparse}
\NewDocumentCommand\mydot{ r() D(){2pt} }
{ \draw (#1) circle (#2)
}

\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

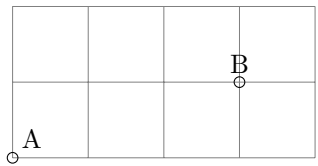
```
\draw (0,0) node {Hello!};

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

6.1 node

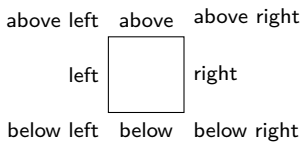
```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,2);
\draw (0,0) node {Hello!};
\node at (1,1) { 칫! };
\draw (3,2) node [draw] { 삐짐! };
\end{tikzpicture}
```




```
\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}
```

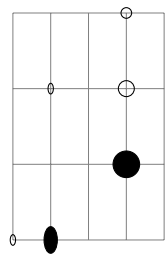



```
\begin{tikzpicture}[font={\sffamily\footnotesize}]
\draw (0,0) rectangle (1,1);
\draw (0,0) node [below left] {below left};
\draw (1,1) node [above right] {above right};
\draw (1,.5) node [right] {right};
<...codes...>
\end{tikzpicture}
```



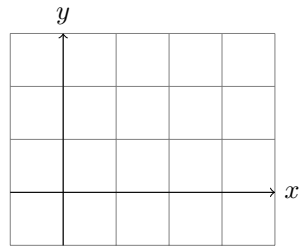
6.2 dots vs. node dots

```
%%\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}
```

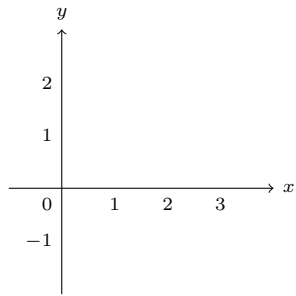


6.3 axes with labels

```
%% 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}
```

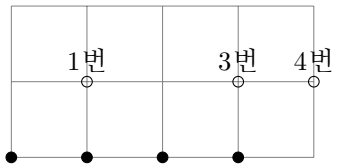


7 Repeating: \foreach

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

7.1 \foreach

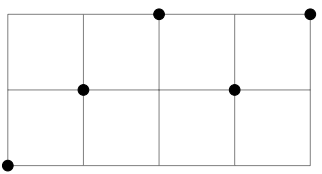
```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,2);
\foreach \x in {0,1,3,2}
  \filldraw (\x,0) circle (2pt);
\foreach \x in {1,3,4}
  \draw (\x,1) circle (2pt) node [above] {\x 번};
\end{tikzpicture}
```




```
\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}
```

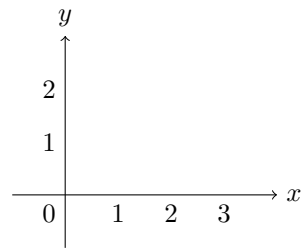
1,3	2,3	3,3	4,3
1,2	2,2	3,2	4,2
1,1	2,1	3,1	4,1

```
\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}
```

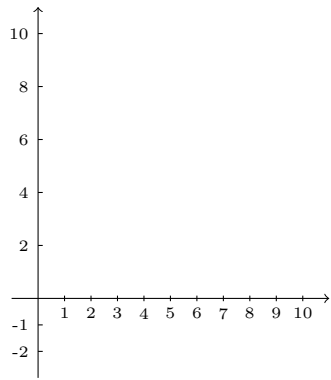


7.2 \foreach: axes

```
\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}
```



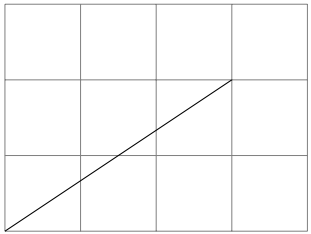

```
\begin{tikzpicture}[scale=.35,font=\tiny]
\draw [->] (-1,0) -- (11,0);
\draw [->] (0,-3) -- (0,11);
\foreach \x in {1,2,...,10}
  { \draw (\x,0) node [below] {\x};
    \draw (\x,-3pt) -- (\x,3pt);
  }
\foreach \x in {-2,-1,2,4,...,10}
  { \draw (0,\x) node [left] {\x};
    \draw (0,\x) -- (5pt,\x);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



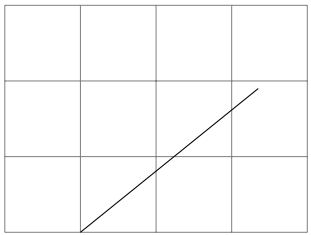
8 Coordinates: basics

8.1 Cartesian coordinates

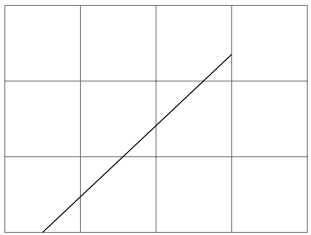
```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\coordinate (A) at (0,0);
\coordinate (B) at (3,2);
\draw (A) -- (B);
\end{tikzpicture}
```



```
\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}
```

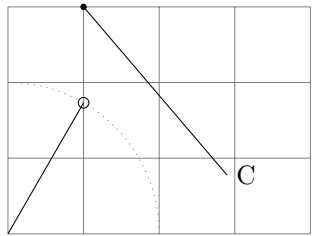


```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\coordinate (A) at ([xshift=5mm]0,0);
\coordinate (B) at ([yshift=10pt]3,2);
\draw (A) -- (B);
\end{tikzpicture}
```



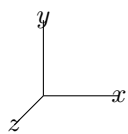
8.2 polar coordinates

```
\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}
```



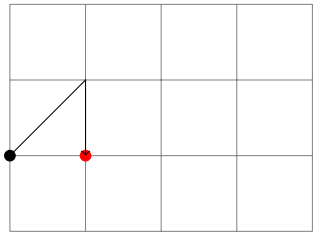
9 Relative coordinates

`\draw (0,0) --` (1,1) – (1,1);+

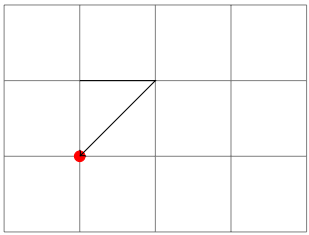
`\draw (0,0) --` +(1,1) – (1,1);+

9.1 relative coordinates

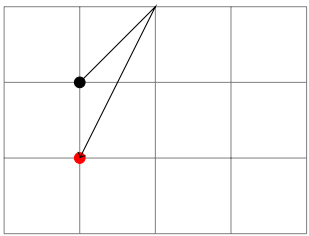
```
\begin{tikzpicture}
\draw[help lines](0,0) grid (4,3);
\filldraw[red] (1,1) circle (2pt);
\draw [->] (1,1)  (0,1) -- +(1,1) -- (1,1);
\mydotfill(0,1); % liftpen, moveto, lineto
\end{tikzpicture}
```



```
\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}
```

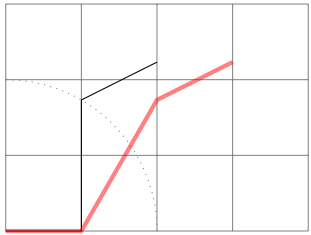


```
\begin{tikzpicture}
\draw[help lines] (0,0) grid (4,3);
\filldraw[red] (1,1) circle (2pt);
\draw [->] (1,1)  ++(0,1) -- +(1,1) -- (1,1);
\mydotfill(1,2);
\end{tikzpicture}
```

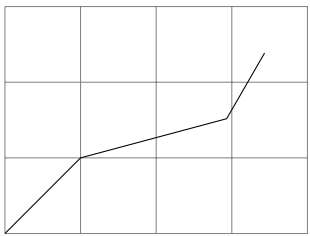


9.2 turn

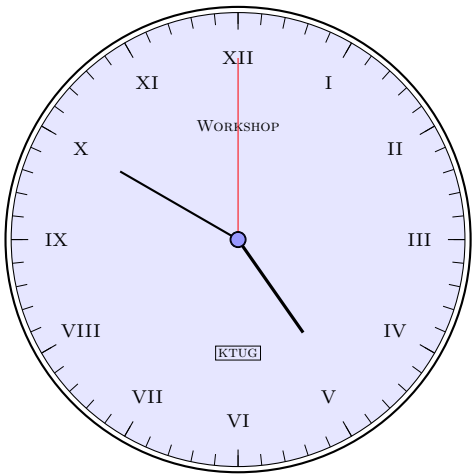
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw [dotted,gray] (2,0) arc (0:90:2);
\draw (0,0) -- (1,0) -- (60:2cm) -- +(1,.5);
\draw [ultra thick,red,opacity=.5]
    (0,0) -- (1,0) -- ([turn]60:2cm) -- +(1,.5);
\end{tikzpicture}
```



```
\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}
```

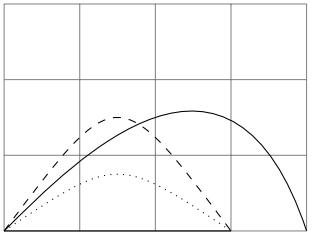
10 Curves

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

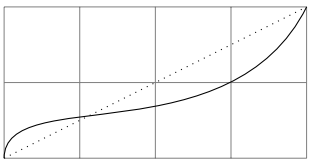
```
\draw (0,0) -- +(1,1) – (1,1);+
```

10.1 basic curves

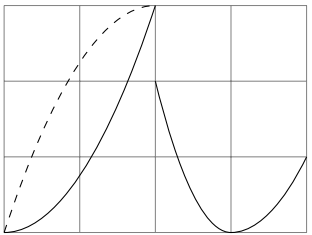
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw          (0,0) -- (3,0);
\draw [dotted] (0,0) .. controls (1.5,1) .. (3,0);
\draw [dashed] (0,0) .. controls (1.5,2) .. (3,0);
\draw (0,0) .. controls (1,1) and (3,3) .. (4,0);
\end{tikzpicture}
```



```
\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}
```

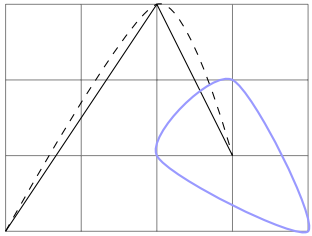


```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw (0,0) parabola (2,3);
\draw [dashed] (0,0) parabola [bend at end] (2,3);
\draw (2,2) parabola bend (3,0) (4,1);
\end{tikzpicture}
```

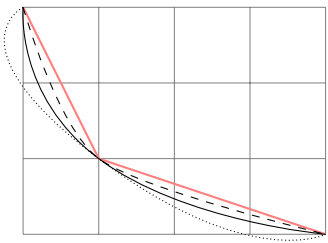


10.2 plot coordinates

```
\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}
```

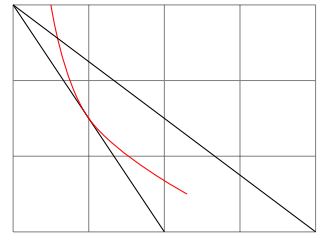


```
%% smooth, tension
\begin{tikzpicture}
\useasboundingbox (0,0) rectangle (4,3);
\draw [help lines] (0,0) grid (4,3);
\draw [red!50,thick] plot [smooth,tension=0]
      coordinates {(0,3) (1,1) (4,0)};
\draw [dashed] plot [smooth]
      coordinates {(0,3) (1,1) (4,0)};
\draw plot [smooth,tension=1]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

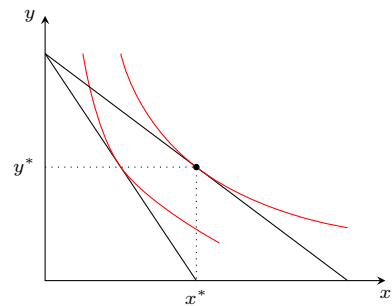


10.3 example: utility maximization (a tangent curve to a line)

```
\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}
```



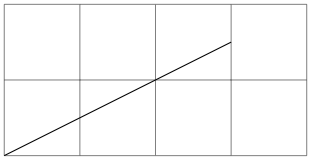
```
\begin{tikzpicture}[>=stealth,font=\scriptsize]
\useasboundingbox (0,0) rectangle (4,3);
\draw [<->] (0,3.5) node [left] {$y$} --
      (0,0) -- (4.5,0) node [below] {$x$};
\draw (0,3) -- (2,0);
\draw [red] plot [smooth,tension=.7]
      coordinates {(.5,3) (1,1.5) (2.3,.5)};
\draw (0,3) -- (4,0);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



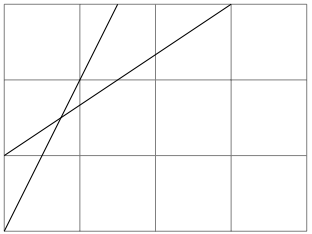
11 Plotting functions

11.1 plotting your own functions

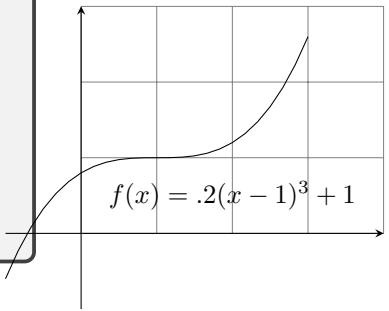
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,2);
\draw plot [domain=0:3] (\x,{.5*\x});
\end{tikzpicture}
```



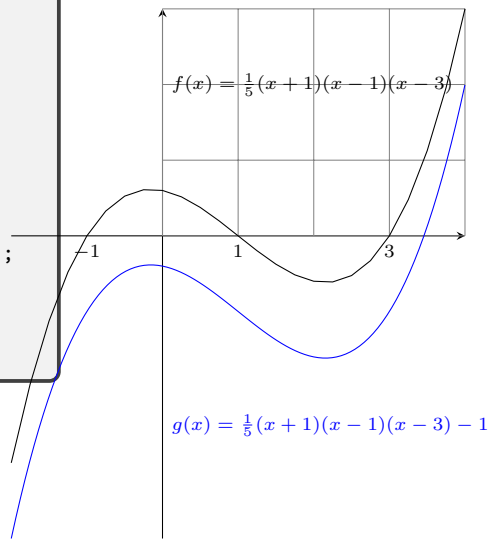
```
\begin{tikzpicture}
\draw [help lines] (0,0) grid (4,3);
\draw plot [domain=0:3] (\x,{(2/3)*\x+1});
\draw plot [domain=0:1.5,variable=\var] (\var,2*\var);
\end{tikzpicture}
```



```
\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}
```

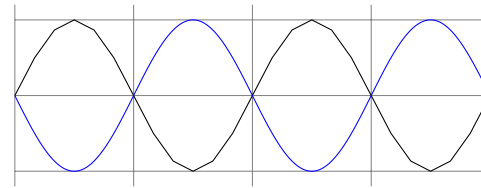


```
\begin{tikzpicture}[>=stealth,font=\scriptsize]
\useasboundingbox (0,0) rectangle (4,3);
\draw [->] (-2,0) -- (4,0);
\draw [->] (0,-4) -- (0,3);
\def\Fx{.2*(\x+1)*(\x-1)*(\x-3)}
\draw [help lines] (0,0) grid (4,3);
\draw plot [domain=-2:4] (\x,{\Fx});
\foreach \x in {-1,1,3}
  \draw (\x,0) node [below] {$\x$};
\draw (0,2) node [right]
      {$f(x)=\frac15(x+1)(x-1)(x-3)$};
\draw [blue] plot
      [domain=-2:4,samples=100] (\x,{\Fx-1});
\draw (0,-2.5) node [right,blue]
      {$g(x)=\frac15(x+1)(x-1)(x-3)-1$};
\end{tikzpicture}
```

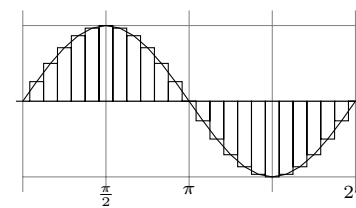


11.2 some internal functions

```
\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}
```

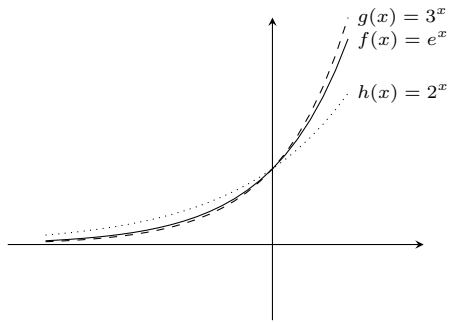


```
\begin{tikzpicture}[xscale=.7,font=\scriptsize]
\draw[help lines,xstep=.5*pi] (0,-1.2) grid
    (2*pi,1.2);
\def\Fx{sin(\x r))}
\draw [domain=0:2*pi] plot
      [ybar,bar width=7.4pt] (\x,{\Fx});
\draw plot [domain=0:2*pi] (\x,{\Fx});
\draw (.5*pi,-1)
      node [below] {$\frac{\pi}{2}$};
\draw (pi,-1)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



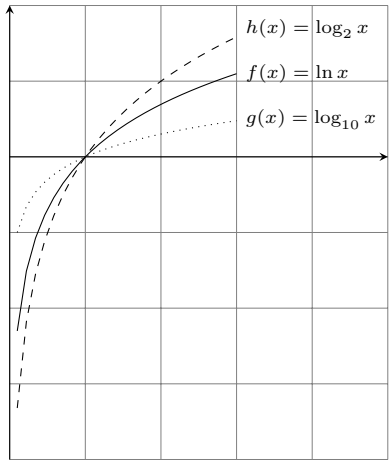
exponential function

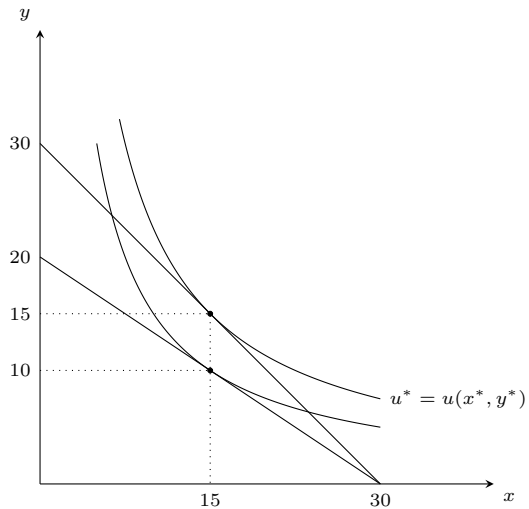
```
\begin{tikzpicture}[>=stealth,font=\scriptsize]
\draw [->] (-3.5,0) -- (2,0);
\draw [->] (0,-1) -- (0,3);
\def\Fx{exp(\x)}
\def\Gx{2^\x}
\def\Hx{3^\x}
\draw plot [domain=-3:1] (\x,{\Fx});
\draw [dotted] plot [domain=-3:1] (\x,{\Gx});
\draw [dashed] plot [domain=-3:1] (\x,{\Hx});
\draw (1,3) node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