Tikz in mathematics: pgfplots and tikz-cd

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공주대학교 문서작성워크숍 **2017**

Tikz in mathematics

- 발표자는 수학 문서를 작성할 때 tikz를 쓰는 일이 거의 없음. (세부전공 특성상 그림을 그릴 일이 거의 없음)
- 가끔 과제를 제출하거나 알바를 할 때 사용

수학과 관련된 다양한 패키지들이 있지만, 오늘은

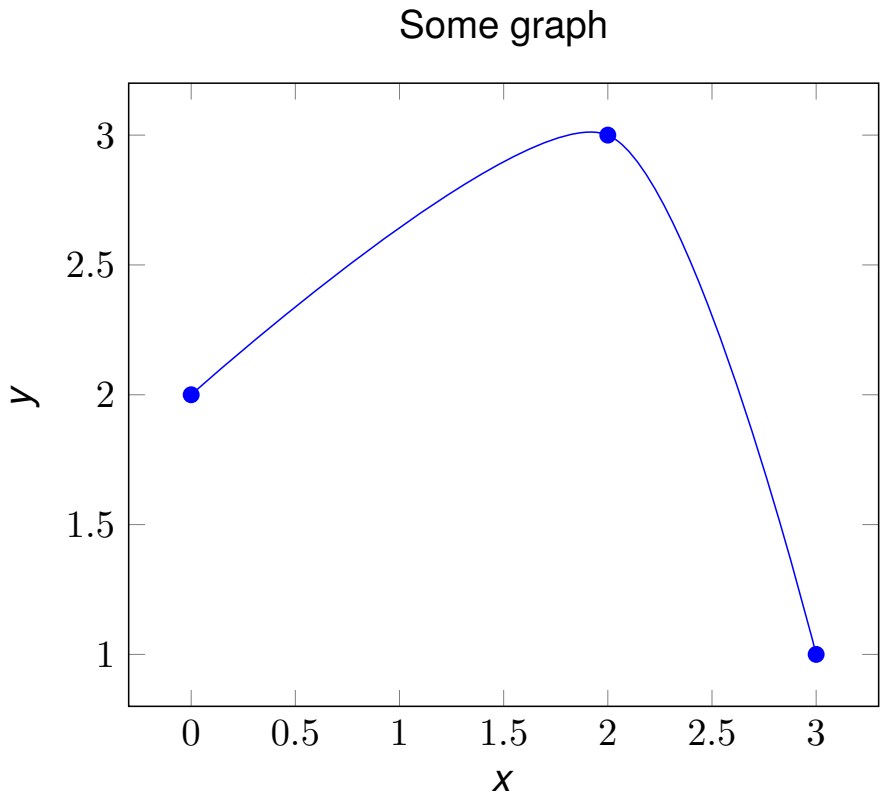
pgfplots / tikz-cd

위주로

pgfplots: 기본사용법

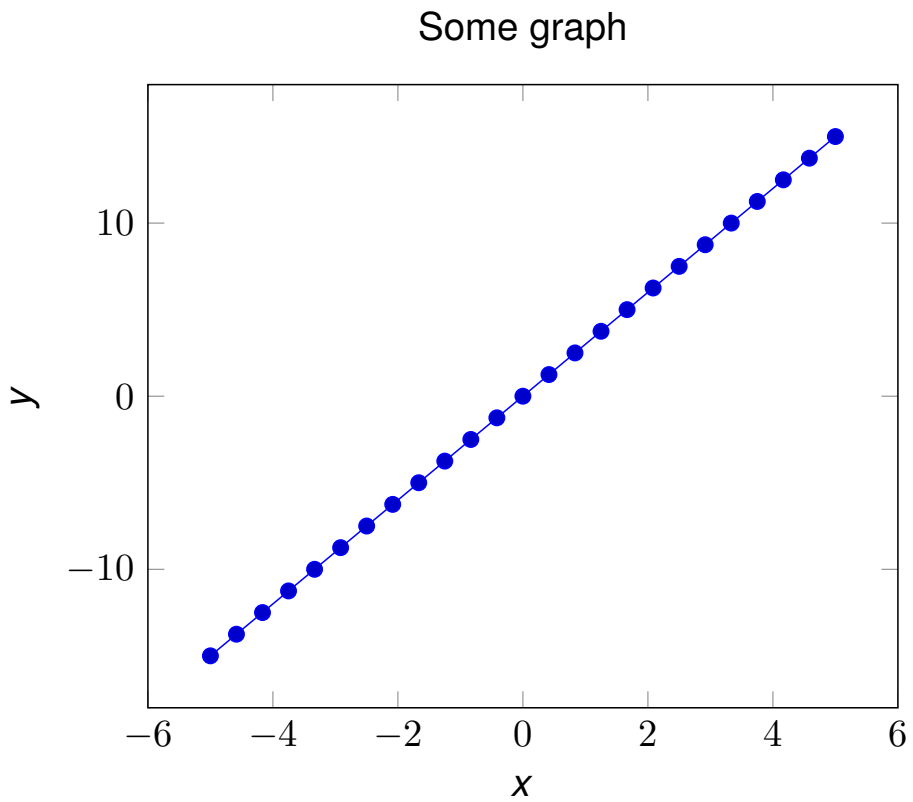
- \usepackage{pgfplots}
- data analysis를 한 것을 표현할 때 유용

```
\usepackage{pgfplots}

\begin{tikzpicture}
\begin{axis}[
title=Some graph
xlabel={$x$},
ylabel={$y$},
]
\addplot[smooth,blue] plot
 coordinates {
        (0,2)
        (2,3)
        (3,1)
    };
\end{axis}
\end{tikzpicture}
```



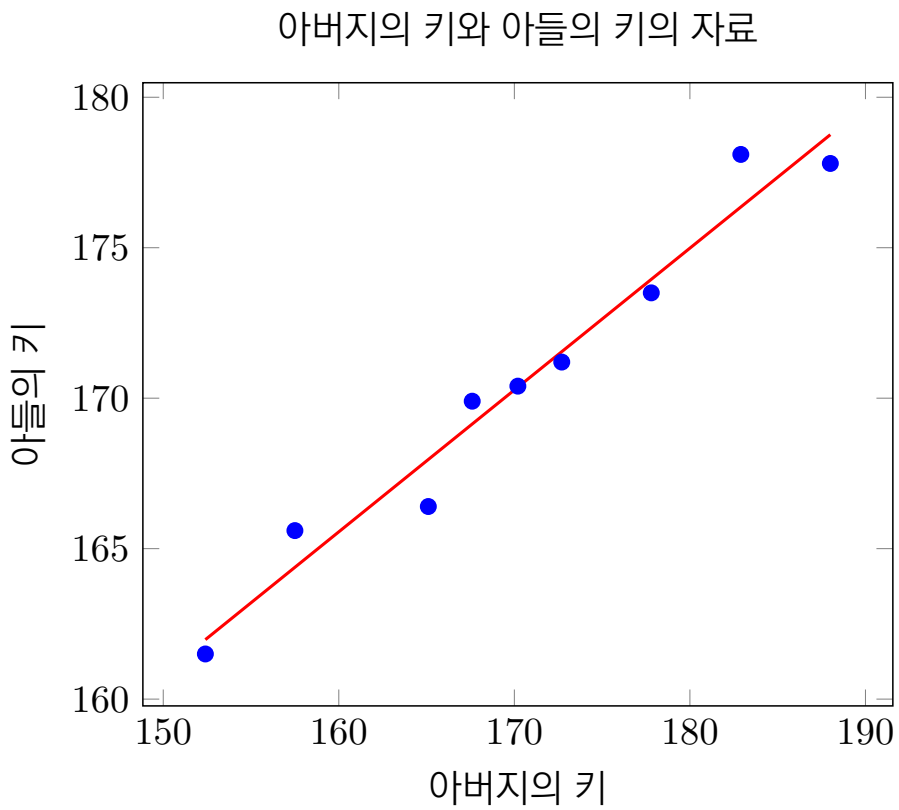
pgfplots: 기본사용법

```
\usepackage{pgfplots}

\begin{tikzpicture}
\begin{axis}[
title=Some graph
xlabel={$x$},
ylabel={$y$},
]
\addplot {3x};
\end{axis}
\end{tikzpicture}
```



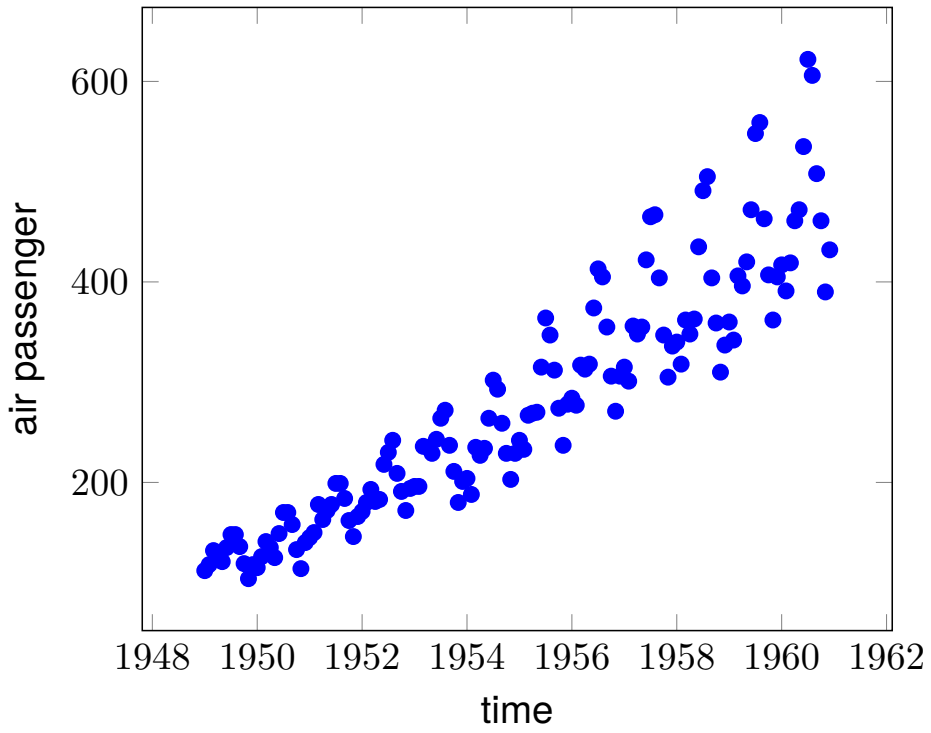
pgfplots: 기본사용법 (dat file)

```
\usepackage{pgfplotstable}

\begin{axis}[
title=아버지의 키와 아들의 키의 자료,
xlabel={아버지의 키},
ylabel={아들의 키},
]
\addplot [blue] table {height.dat};
\addplot [no markers, thick, red]
table [y={create col/linear
regression={y=y}}] {height.dat}
node [anchor=west] {};
\end{axis}
```



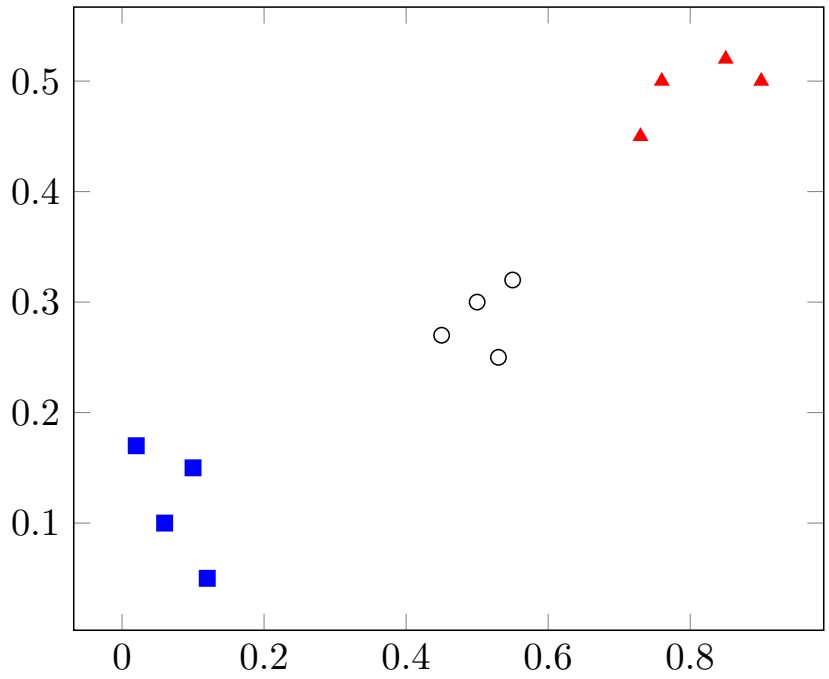
pgfplots: 기본사용법 (dat file)

```
\begin{tikzpicture}
\begin{axis}[
title=비행기 승객 수 추이,
xlabel={time},
ylabel={air passenger},
x tick label style ={/pgf/number
format/.cd,
set thousands separator={}}
]

\addplot[only marks,blue] table
[x=time,y=AirPassengers]
{airpassenger.dat};
\end{axis}

\end{tikzpicture}
```



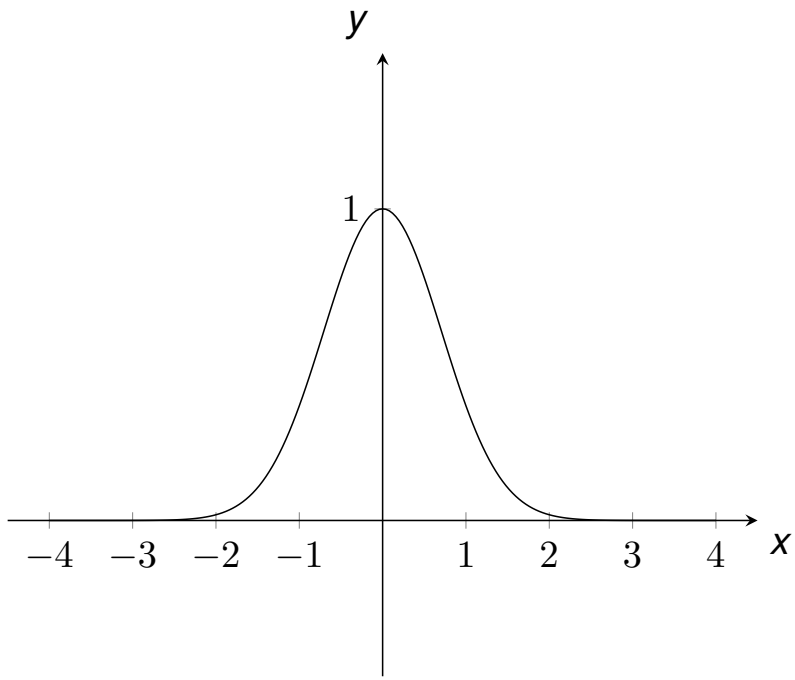
pgfplots: Scatter Plot

```
\begin{tikzpicture}
\begin{axis}
\addplot[scatter, only marks,
point meta=explicit symbolic, scatter/classes
={ a={mark=square*,blue},
b={mark=triangle*,red},
c={mark=o,draw=black}}]
table[meta=label] {
x        y        label
0.1        0.15        a
0.45        0.27        c
0.02        0.17        a
0.06        0.1        a
0.9        0.5        b
0.5        0.3        c
0.85        0.52        b
0.12        0.05        a
0.73        0.45        b
0.53        0.25        c
0.76        0.5        b
0.55        0.32        c
};
\end{axis}
\end{tikzpicture}
```



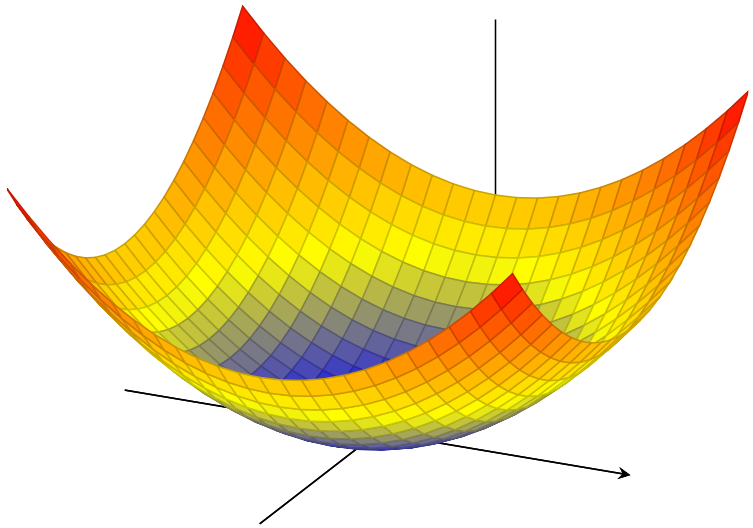
pgfplots: plotting some graph

```
\begin{tikzpicture}[>=latex]
\begin{axis}[
  axis x line=center,
  axis y line=center,
  xtick={-5,-4,...,5},
  ytick={0,1},
  xlabel={$x$},
  ylabel={$y$},
  xlabel style={below right},
  ylabel style={above left},
  xmin=-4.5,
  xmax=4.5,
  ymin=-0.5,
  ymax=1.5]
\addplot [mark=none,domain=-4:4,
samples=201] {exp(-x^2)};
\end{axis}
  \end{tikzpicture}
```



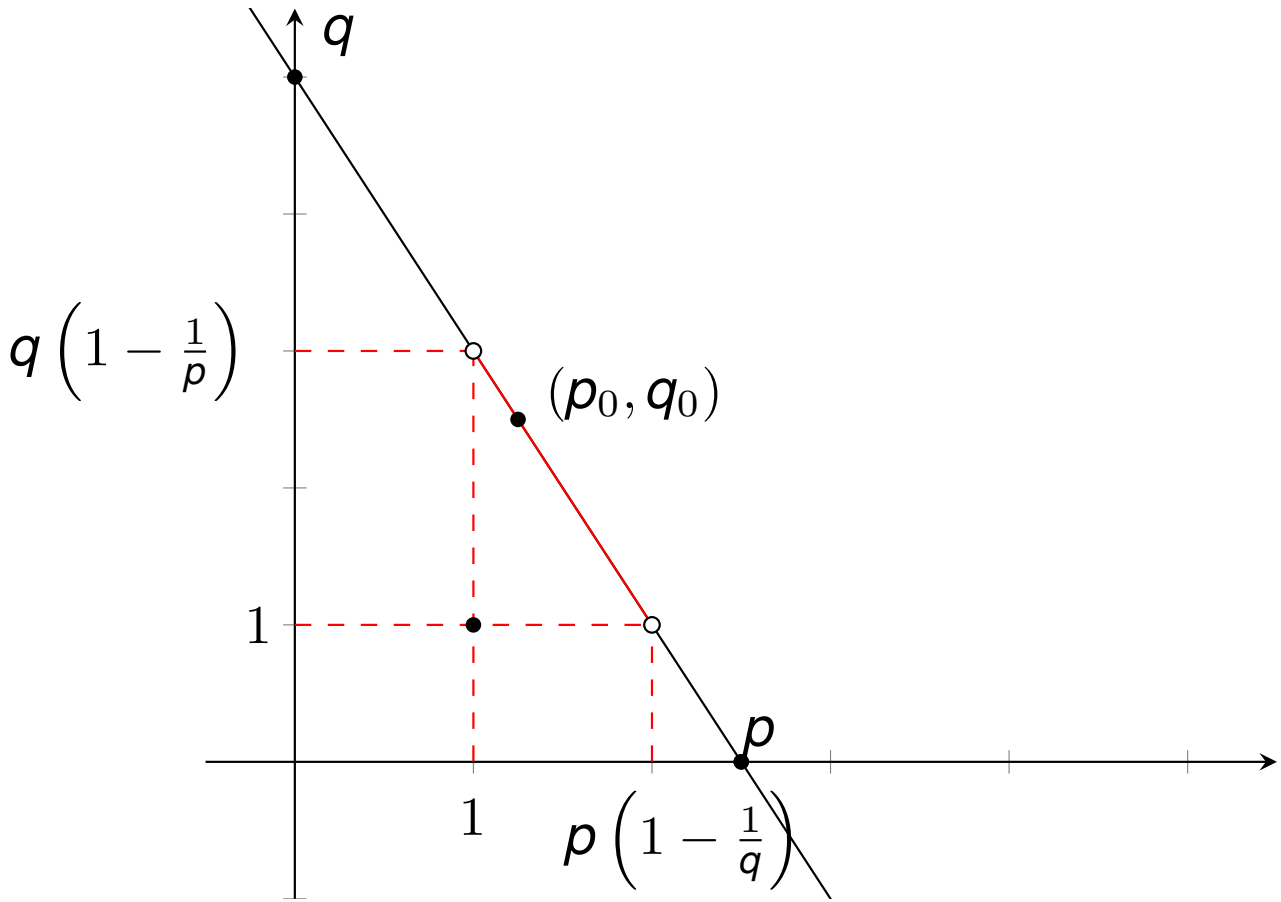
pgfplots: 3D graph

```
\begin{tikzpicture}[>=latex]
\begin{axis}[
  axis x line=center,
  axis y line=center,
  ticks=none,
  xlabel style={below right},
  ylabel style={above left},
]
\addplot3 [mark=none,domain=-4:4,surf]
 {x^2+y^2};
\end{axis}
\end{tikzpicture}
```



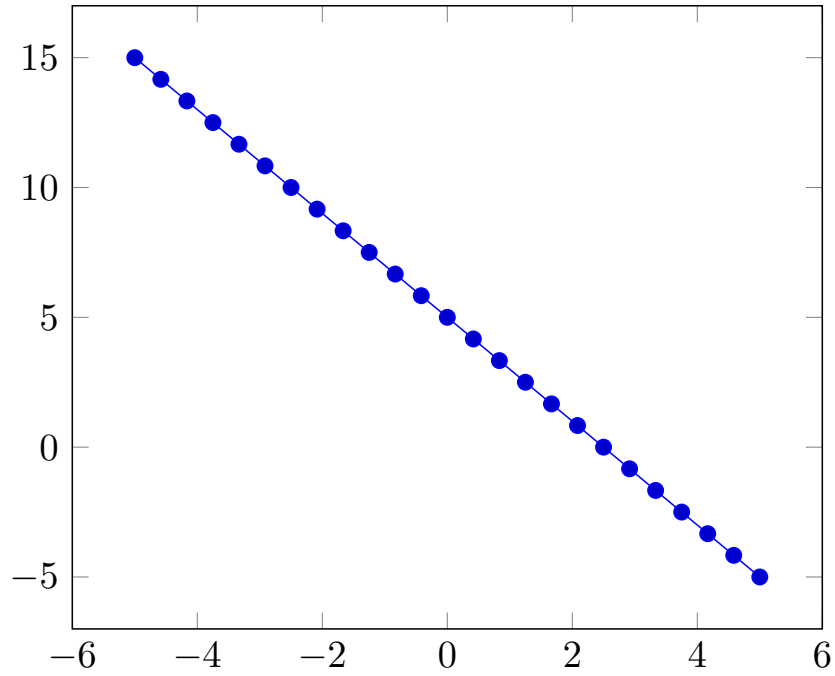
출판 수준으로 다듬어보기 step by step!

pgfplots: step by step



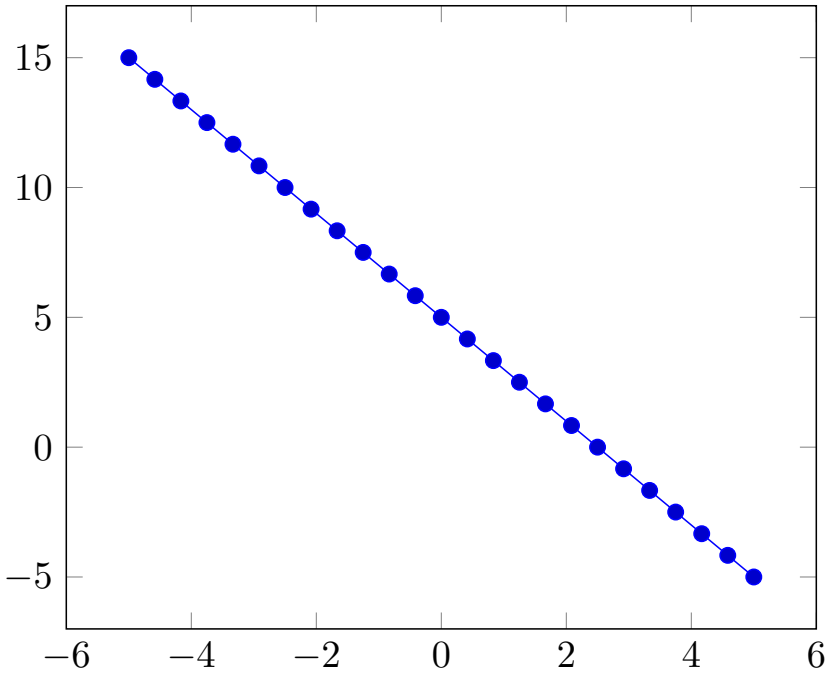
pgfplots: step by step

```
\begin{axis}
\addplot {-2*x+5};
\end{axis}
```



pgfplots: step by step

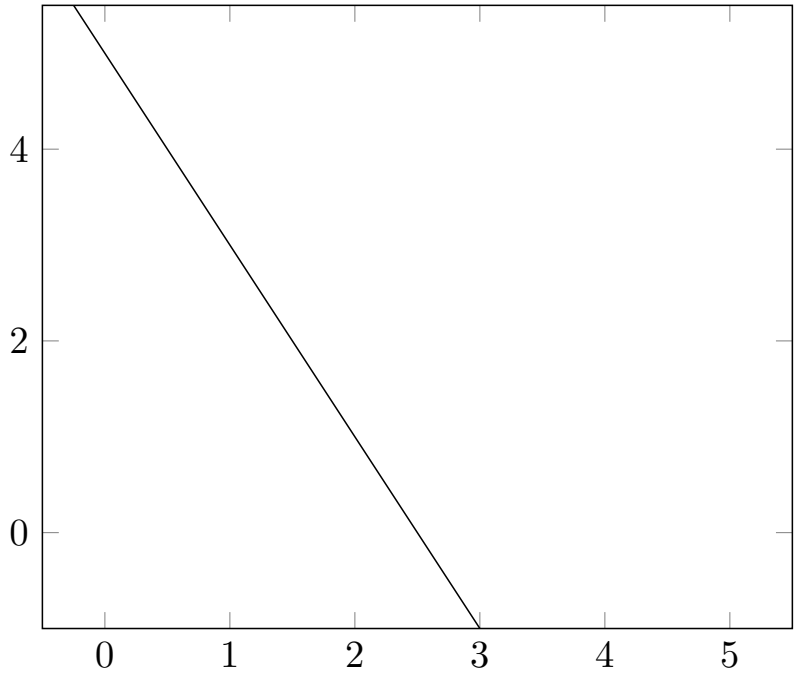
```
\begin{axis}
\addplot {-2*x+5};
\end{axis}
```



- 점이 안 나왔으면 좋겠어요.
- x의 양의 축만 관심이 있어요.

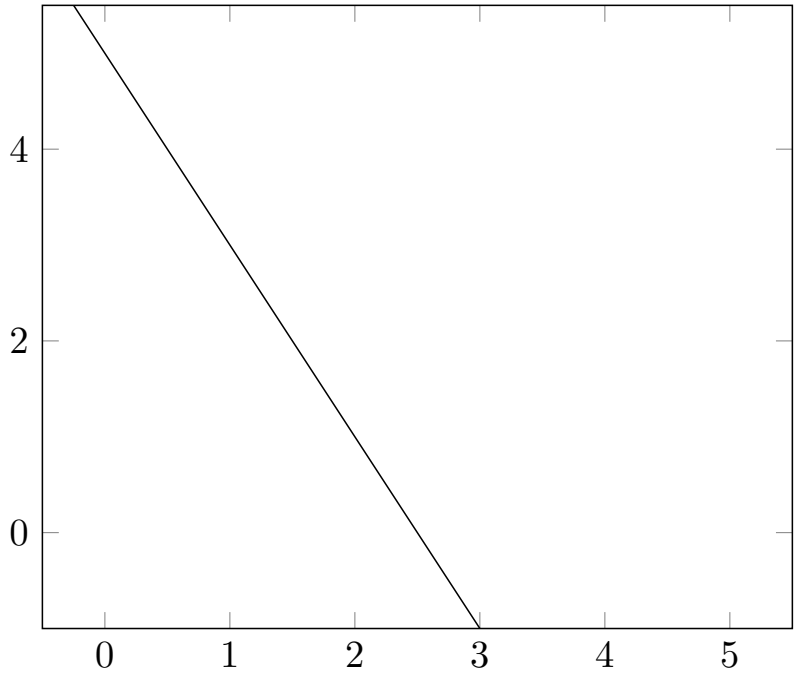
pgfplots: step by step

```
\begin{axis}[
  xmin=-0.5,
  xmax=5.5,
  ymin=-1,
  ymax=5.5]
\addplot[mark=none] {-2*x+5};
\end{axis}
```



pgfplots: step by step

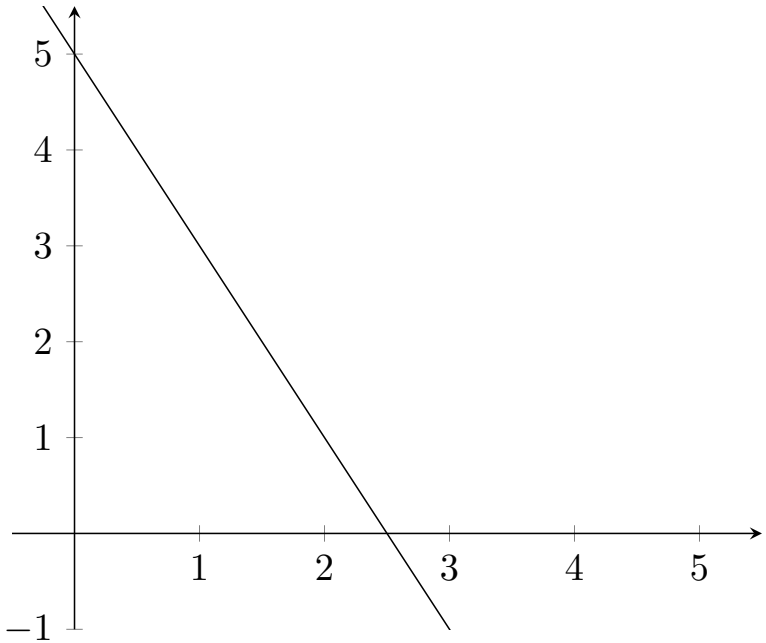
```
\begin{axis}[
  xmin=-0.5,
  xmax=5.5,
  ymin=-1,
  ymax=5.5]
\addplot[mark=none] {-2*x+5};
\end{axis}
```



- 상자로 가두는거 마음에 안들어요.
- x축과 y축 숫자 표시간격을 같게 만들고 싶어요.

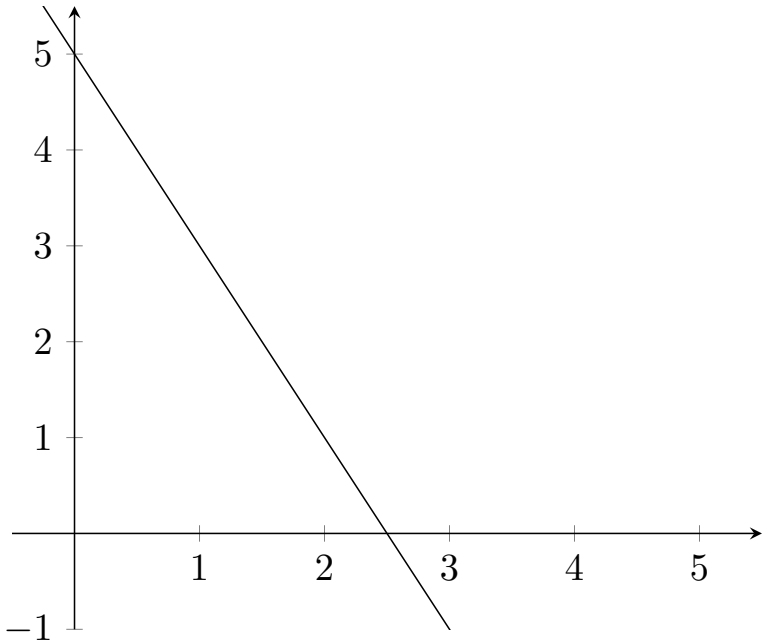
pgfplots: step by step

```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```



pgfplots: step by step

```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```

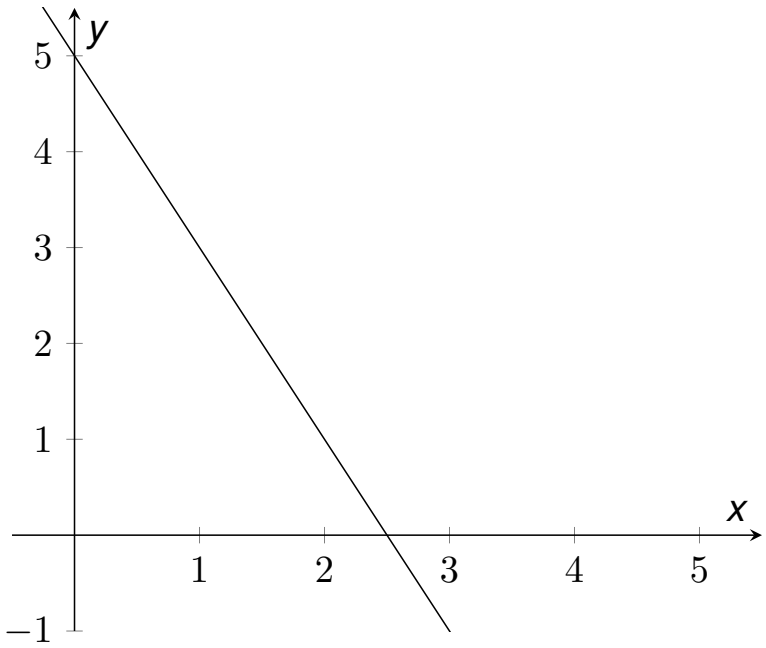


- x축, y축 표시 '수능 그래프처럼' 하려면 어떻게 해야 하나요?

pgfplots: step by step

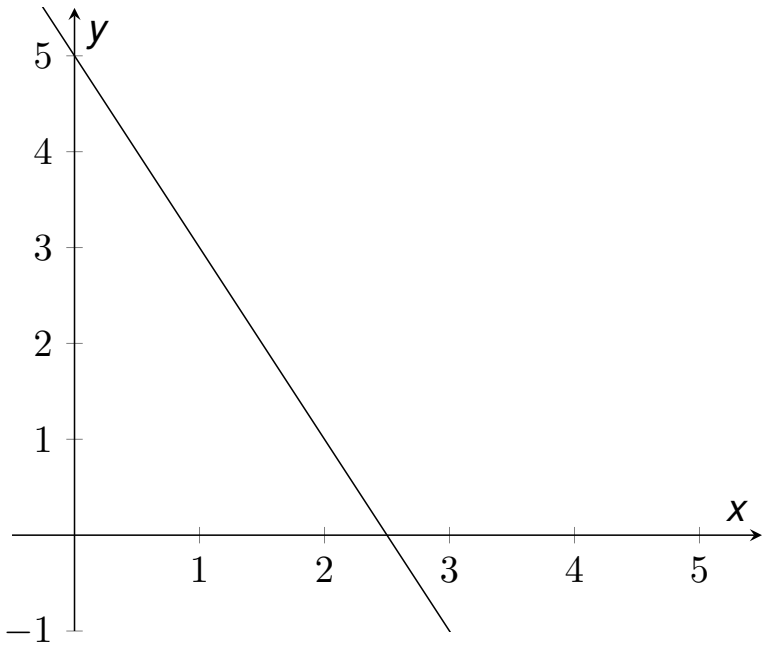
```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
 xlabel={$x$},
 ylabel={$y$},
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```

* xlabel style 위치 중요



pgfplots: step by step

```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
 xlabel={$x$},
 ylabel={$y$},
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```



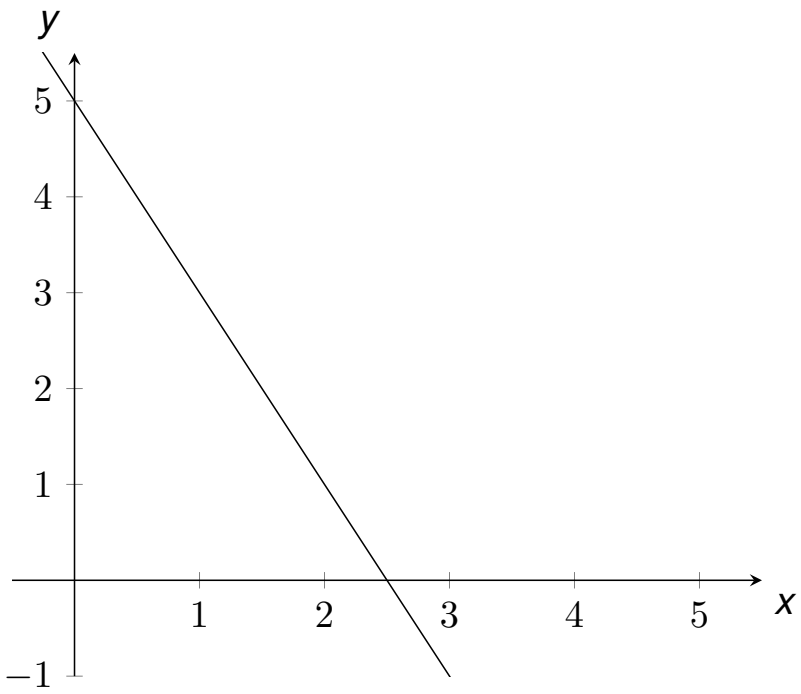
* xlabel style 위치 중요

- x,y축 위치가 마음에 안들어요.

pgfplots: step by step

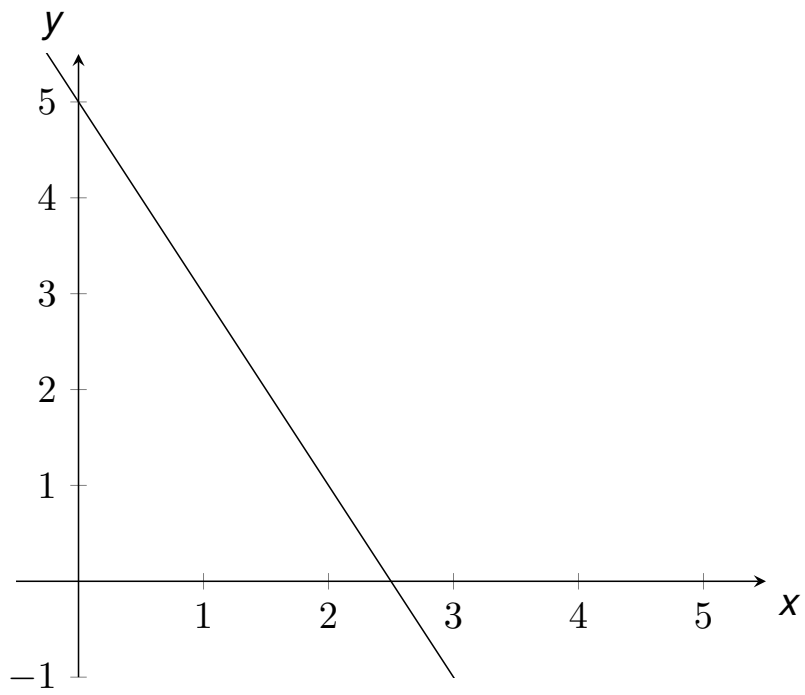
```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
 xlabel={$x$},
 ylabel={$y$},
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
  xlabel style={below right},
  ylabel style={above left},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```

* xlabel style 위치 중요



pgfplots: step by step

```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
 xlabel={$x$},
 ylabel={$y$},
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
  xlabel style={below right},
  ylabel style={above left},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```

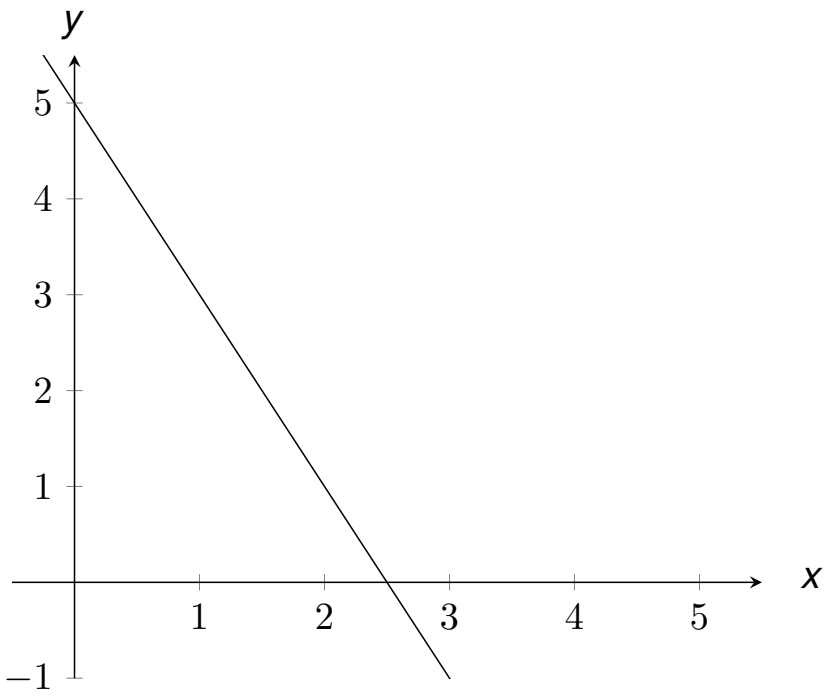


* xlabel style 위치 중요

- 축 종류표시하는거 내 마음대로 놓고 싶어요.

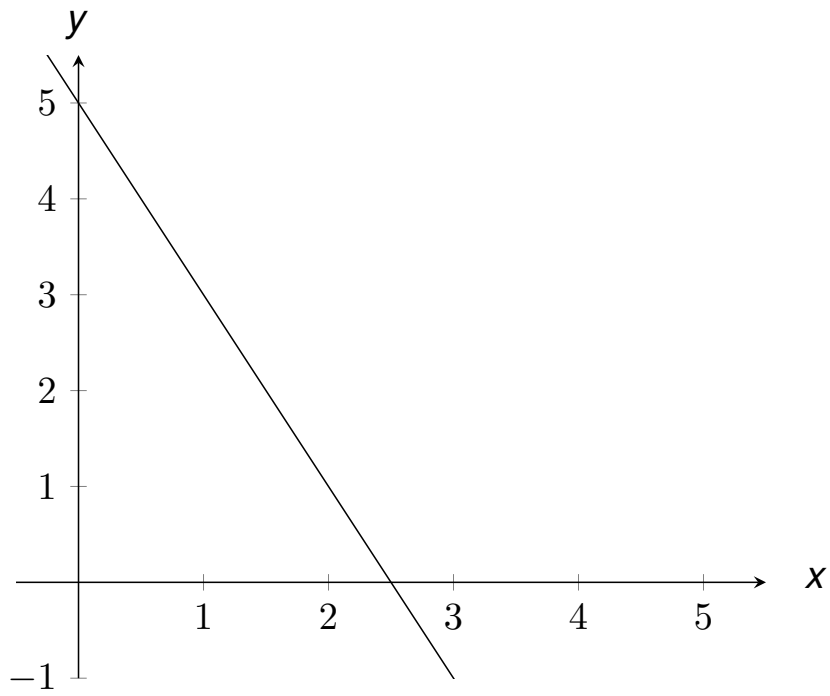
pgfplots: step by step

```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
 xlabel={$x$},
 ylabel={$y$},
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
  x label style=
{at={(axis cs:6.1,-0.2)}},
  y label style=
{at={(axis cs:-0.2,6.1)}},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```



pgfplots: step by step

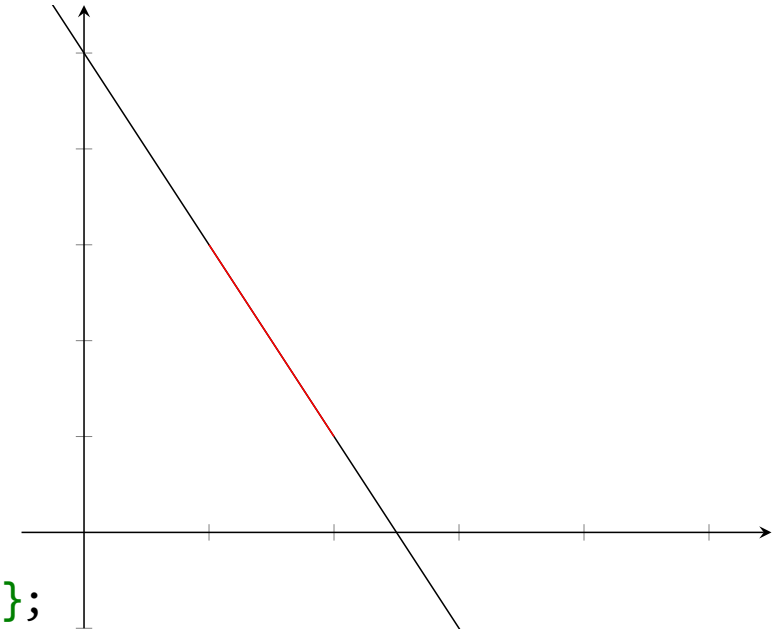
```
  \begin{axis}[
    axis x line=center,
    axis y line=center,
 xlabel={$x$},
 ylabel={$y$},
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
  x label style=
{at={(axis cs:6.1,-0.2)}},
  y label style=
{at={(axis cs:-0.2,6.1)}},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \end{axis}
```



- 그냥 숫자를 다 없애고 싶어요.
- 선분을 덧대고 싶어요.

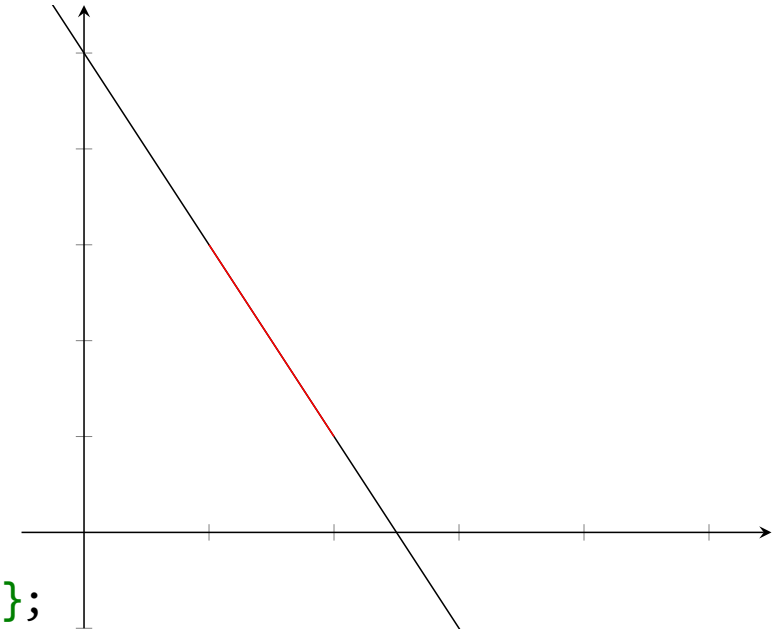
pgfplots: step by step

```
  \begin{axis}[
  yticklabels={,,}, xticklabels={,,},
    axis x line=center,
    axis y line=center,
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \addplot [red] coordinates {(2,1) (1,3)};
  \end{axis}
```



pgfplots: step by step

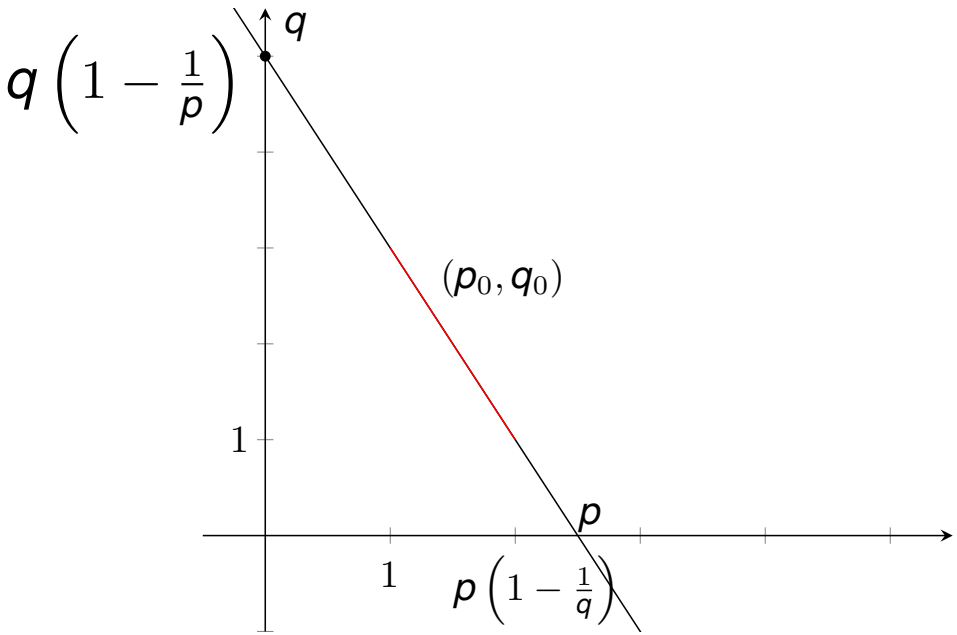
```
  \begin{axis}[
  yticklabels={,,}, xticklabels={,,},
    axis x line=center,
    axis y line=center,
  xtick={-5,-4,...,5},
  ytick={-5,-4,...,5},
xmin=-0.5,
    xmax=5.5,
    ymin=-1,
    ymax=5.5]
  \addplot[mark=none] {-2*x+5};
  \addplot [red] coordinates {(2,1) (1,3)};
  \end{axis}
```



- 좌표 표시를 하고 싶어요.

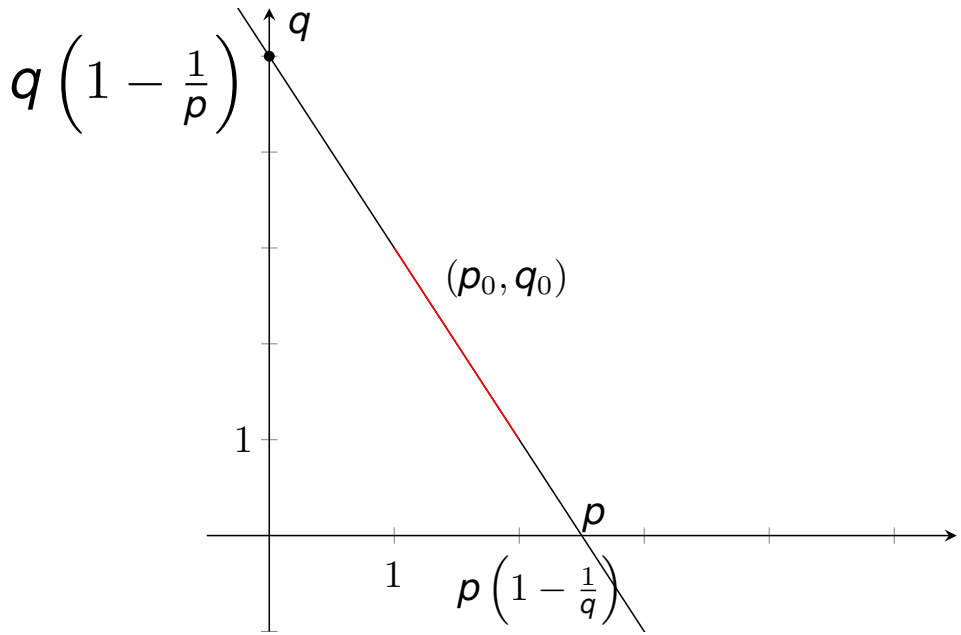
pgfplots: step by step

```
...
\node[label={-10:{$p$}}] at
(axis cs:2.3,0.5) {};
\node[label={10:{$q$}},circle,
fill,inner sep=1pt] at
(axis cs:0,5) {};
\node[label={10:
{$p\left(1-\frac{1}{q}\right)$}}] at
(axis cs:1.3,-1.1) {};
\node[label={10:{$1$}}] at
(axis cs:0.7,-0.7) {};
\node[label={10:{$1$}}] at
(axis cs:-0.5,0.7) {};
\node[label={$(p_0,q_0)$}] at
(axis cs:1.9,2.2) {};
```



pgfplots: step by step

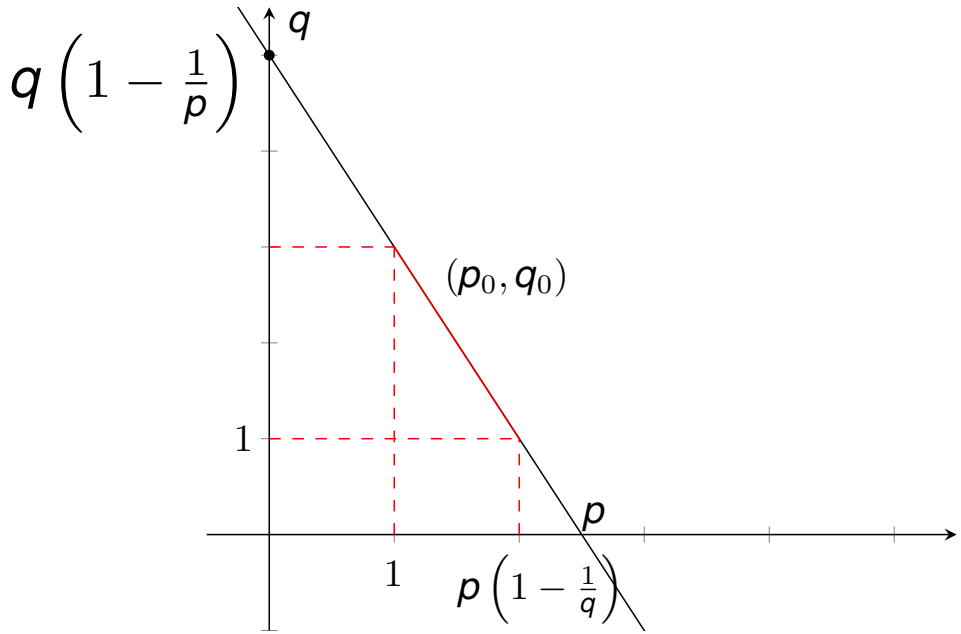
```
...
\node[label={-10:{$p$}}] at
(axis cs:2.3,0.5) {};
\node[label={10:{$q$}},circle,
fill,inner sep=1pt] at
(axis cs:0,5) {};
\node[label={10:
{$p\left(1-\frac{1}{q}\right)$}}] at
(axis cs:1.3,-1.1) {};
\node[label={10:{$1$}}] at
(axis cs:0.7,-0.7) {};
\node[label={10:{$1$}}] at
(axis cs:-0.5,0.7) {};
\node[label={$(p_0,q_0)$}] at
(axis cs:1.9,2.2) {};
```



- 보조선도 넣고 싶어요.

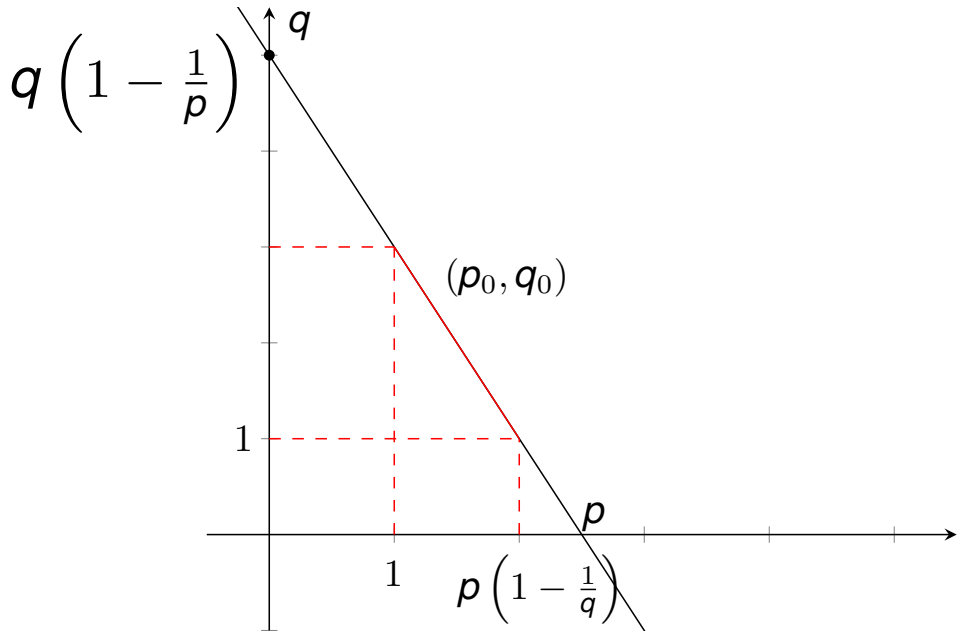
pgfplots: step by step

```
...
\addplot [red,dashed] coordinates
{(0,3) (1,3)};
\addplot [red,dashed] coordinates
{(2,0) (2,1)};
\addplot [red,dashed] coordinates
{(0,1) (2,1)};
\addplot [red,dashed] coordinates
{(1,0) (1,3)};
```



pgfplots: step by step

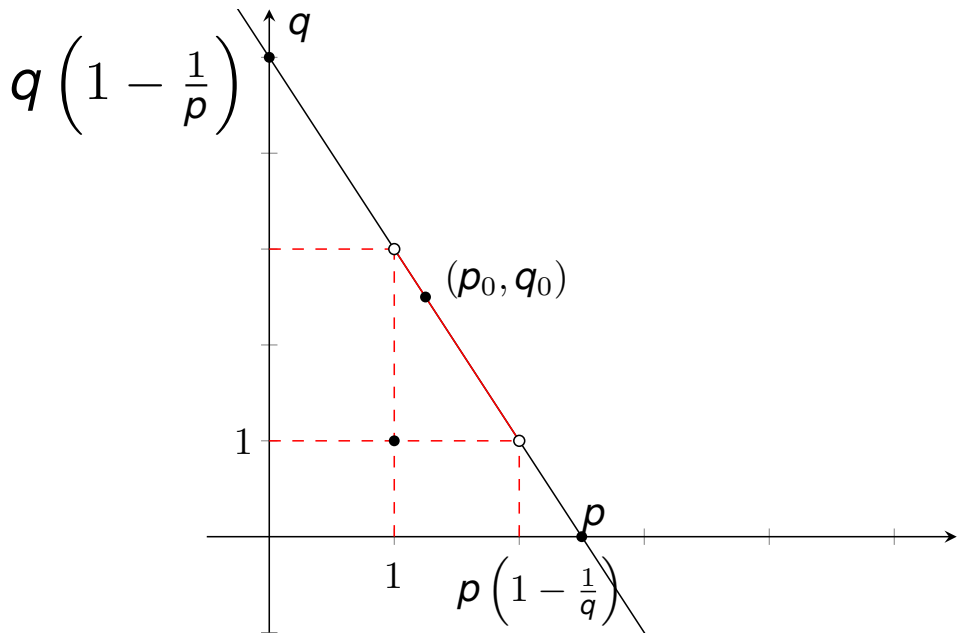
```
...
\addplot [red,dashed] coordinates
{(0,3) (1,3)};
\addplot [red,dashed] coordinates
{(2,0) (2,1)};
\addplot [red,dashed] coordinates
{(0,1) (2,1)};
\addplot [red,dashed] coordinates
{(1,0) (1,3)};
```



- 점도 표시하는게 좋지 않을까요?

pgfplots: step by step

```
...
\node[circle,fill,inner sep=1pt] at
(axis cs:2.5,0) {};
\node[circle,draw=black,fill=white,
inner sep=1pt] at (axis cs:1,3) {};
\node[circle,draw=black,fill=white,
inner sep=1pt] at (axis cs:2,1) {};
\node[circle,fill,inner sep=1pt] at
(axis cs:1,1) {};
\node[circle,fill,inner sep=1pt] at
(axis cs:1.25,2.5) {}
```



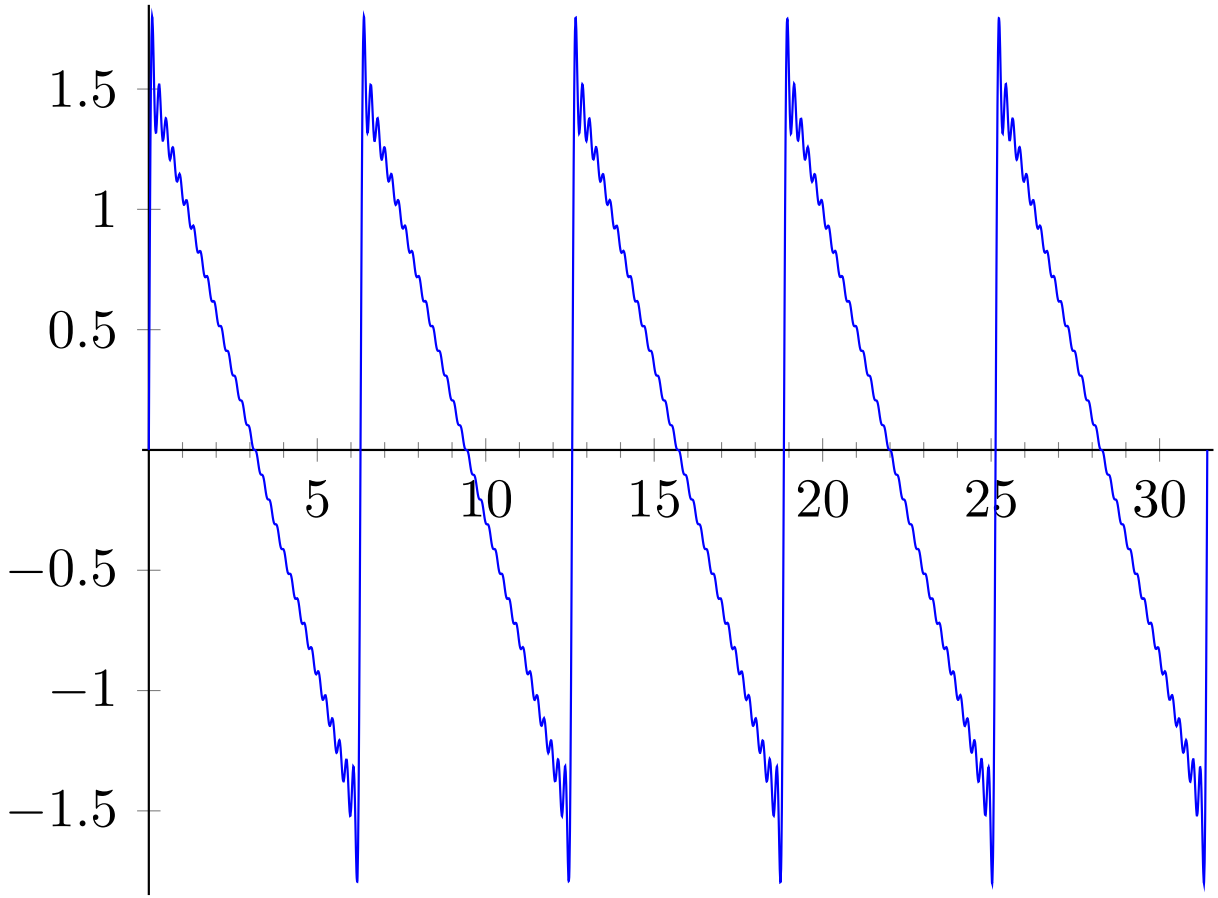


Figure: Gibb's phenomenon

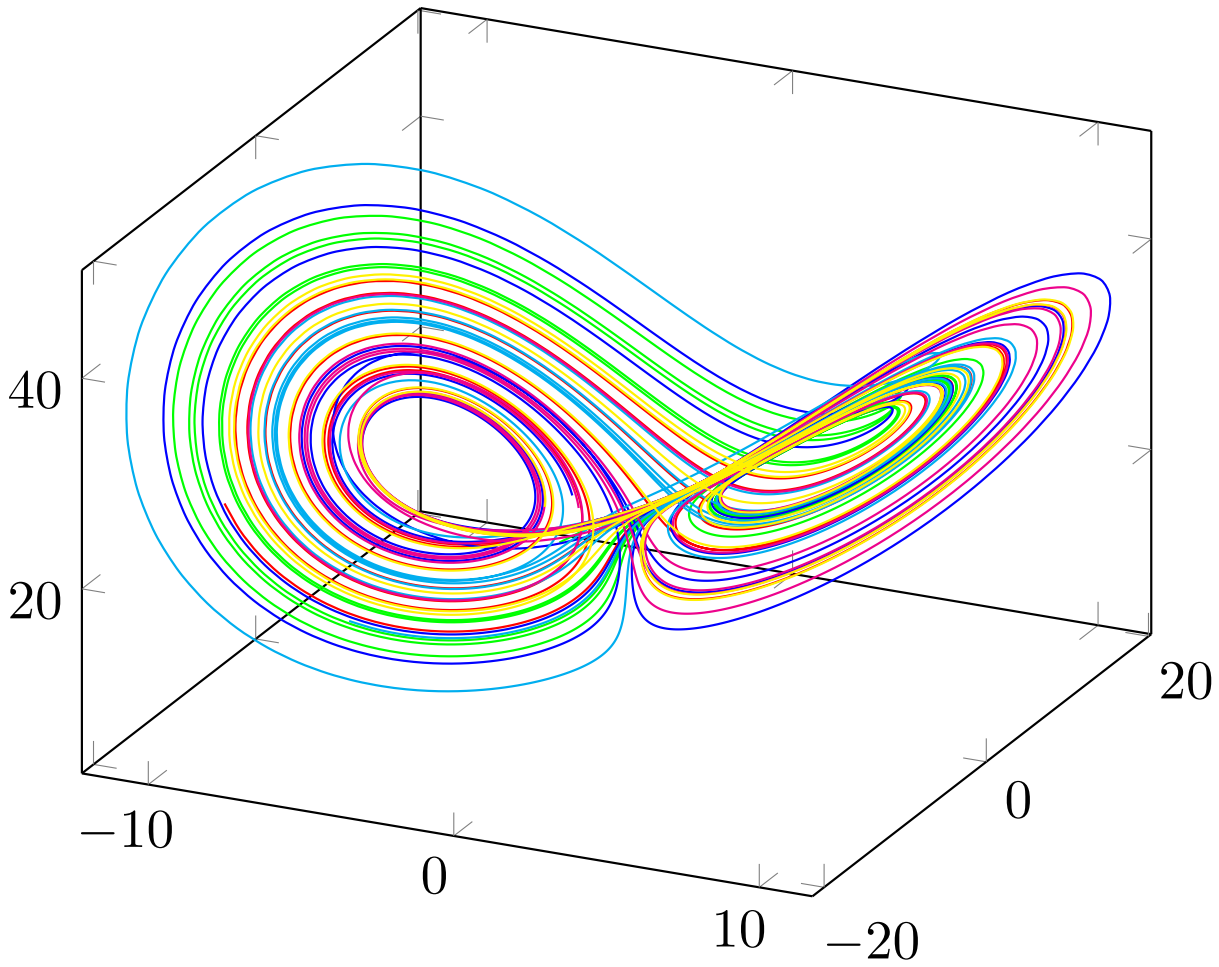


Figure: The Lorentz attractor

pgfplots: Mathematica, R, Sage, MATLAB

- 복잡한 계산이 있는 경우는 텍으로 그림을 그리는 것이 만만치 않음.
- 다른 수학 프로그램을 이용해서 계산한 데이터를 인풋하는 방법을 취하는 것이 합리적.

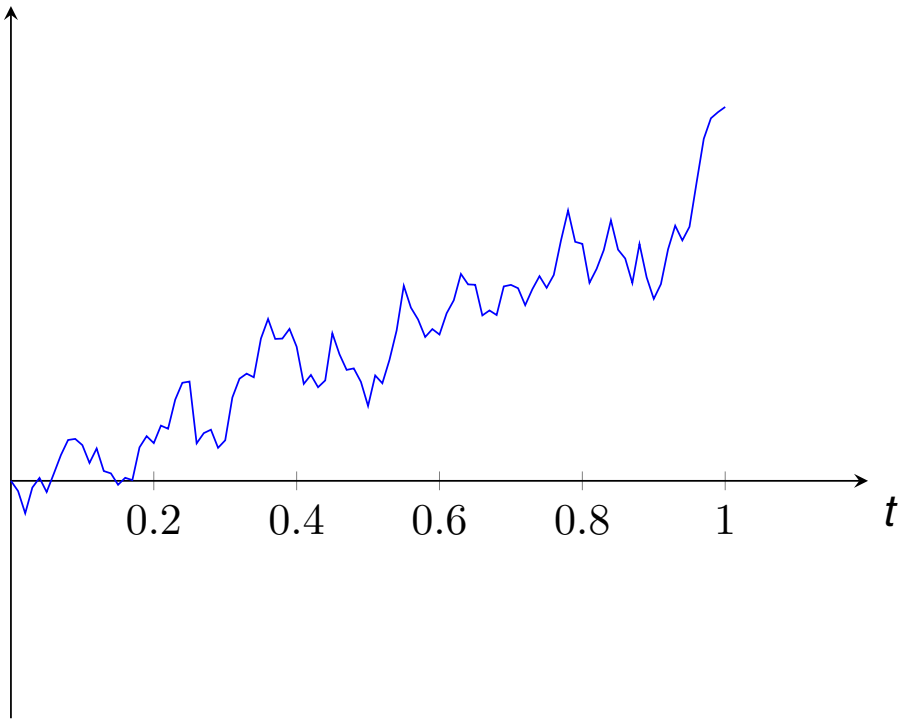


Figure: Brownian motion

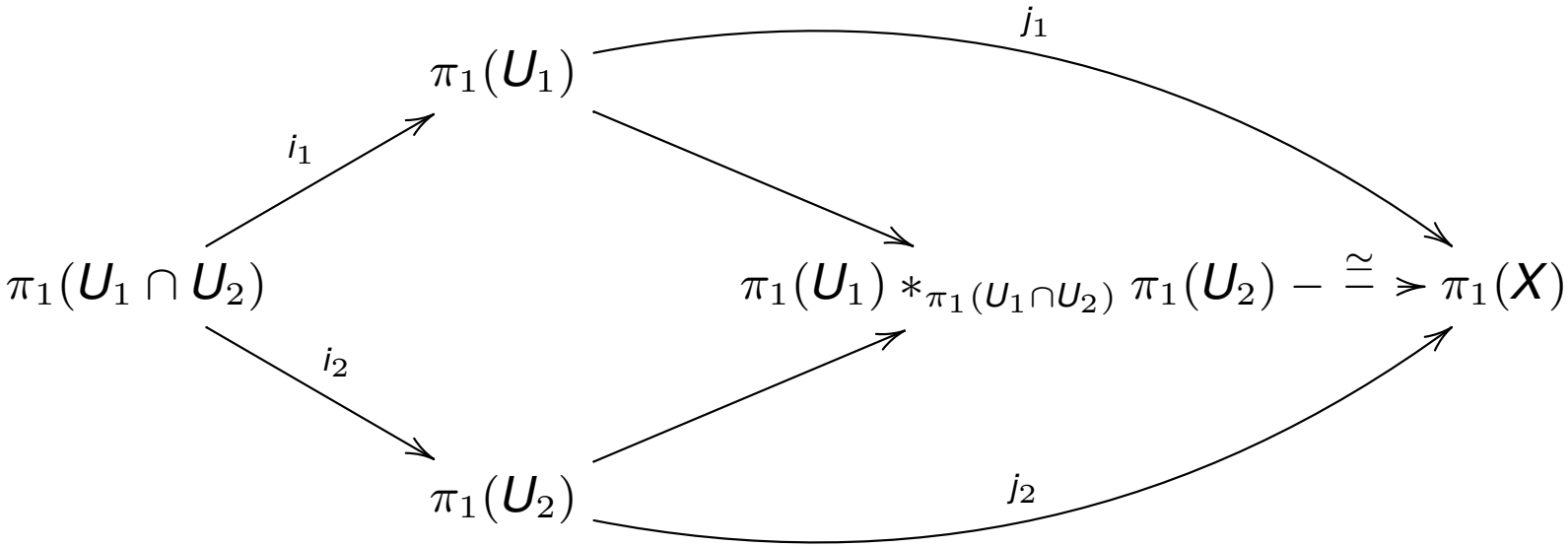
drawing commutative diagram

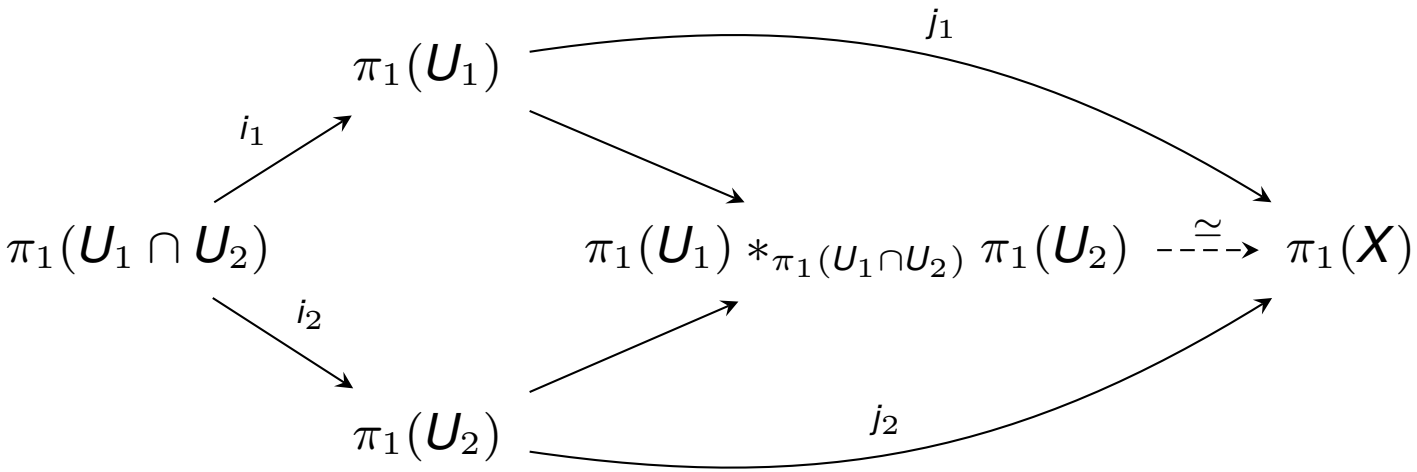
- Commutative diagram을 그릴 때 xy 패키지를 사용하는 사람들이 많다.
- tikz-cd를 이용하면 보다 직관적이며, 이쁘게 그릴 수 있다.

주의

- package name: tikz-cd
- environment name: tikzcd

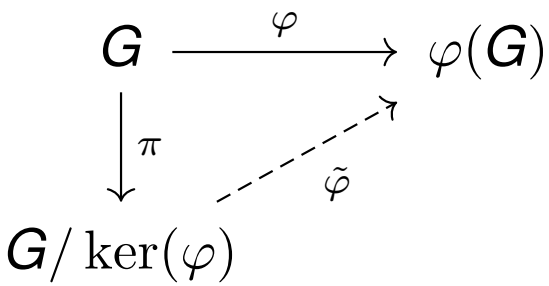
xy-pic vs tikz-cd





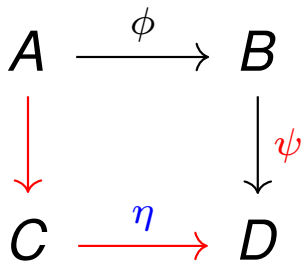
tikz-cd 기초문법

- 행렬을 만들 때랑 비슷함
- `\arrow[r,l,d,u]` (rr,dd,ru,rd, ...)



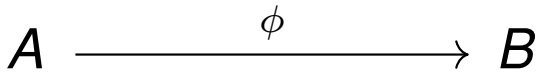

```
\begin{tikzcd}
G \arrow[r,"\varphi"]\arrow[d,"\pi"] &  \varphi (G)  \\
G/\ker(\varphi)\arrow[ru,"\tilde{\varphi}",dashed,swap] &
\end{tikzcd}
```

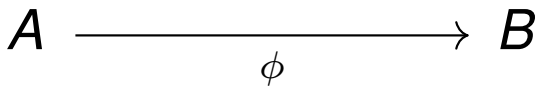
tikz-cd 기초문법 - 색칠




```
\begin{tikzcd}
A \arrow[r, "\phi"] \arrow[d, red] & B \arrow[d, "\psi" red] \\
C \arrow[r, red, "\eta" blue] & D
\end{tikzcd}
```

tikz-cd 기초문법 - label 위치

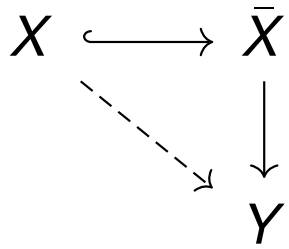





```
\begin{tikzcd}
A \arrow[rrr, "\phi"] &&& B
\end{tikzcd}
\begin{tikzcd}
A \arrow[rrr, "\phi",swap] &&& B
\end{tikzcd}
```


```
\begin{tikzcd}
A \arrow[rrr, "\phi" near start, "\eta" near end] &&& B
\end{tikzcd}
```

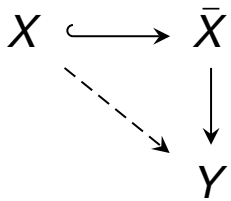
tikz-cd 기초문법 - 화살표 모양에 관하여



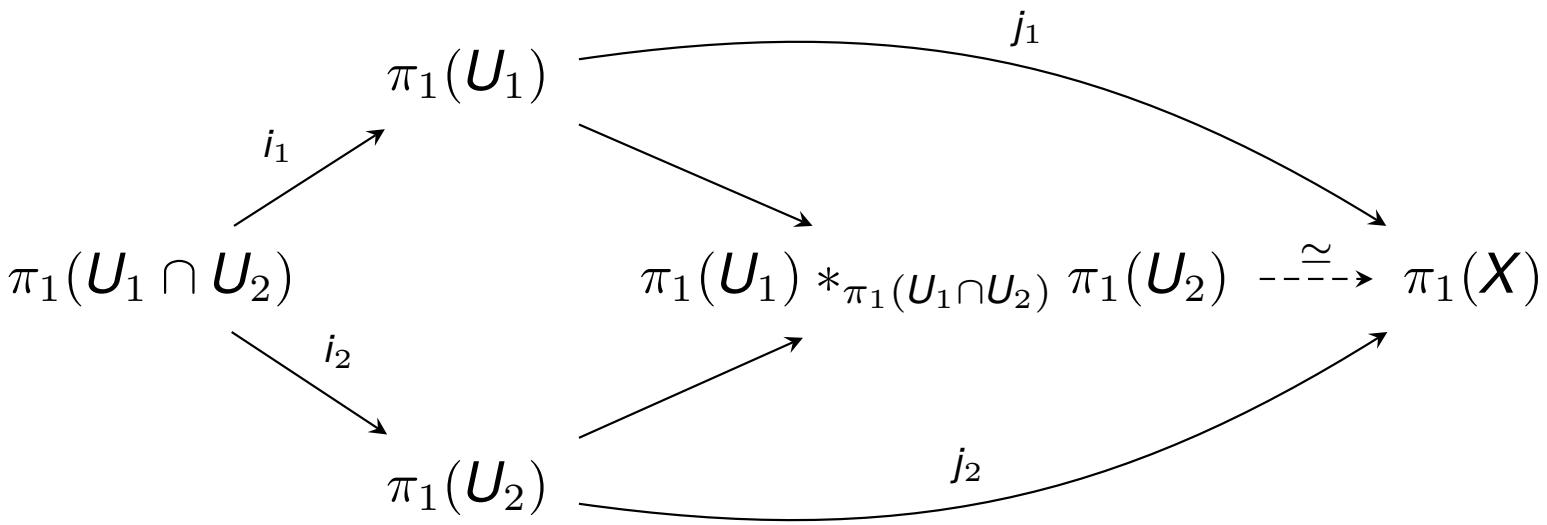

```
\begin{tikzcd}
X \arrow[r, hook] \arrow[dr, dashrightarrow]
& \bar{X} \arrow[d]\\
& Y
\end{tikzcd}
```

* tikz-cd 설명서 p.3 – p.4 참조

```
\tikzcdset{arrow style=tikz, diagrams={>=stealth}}
```

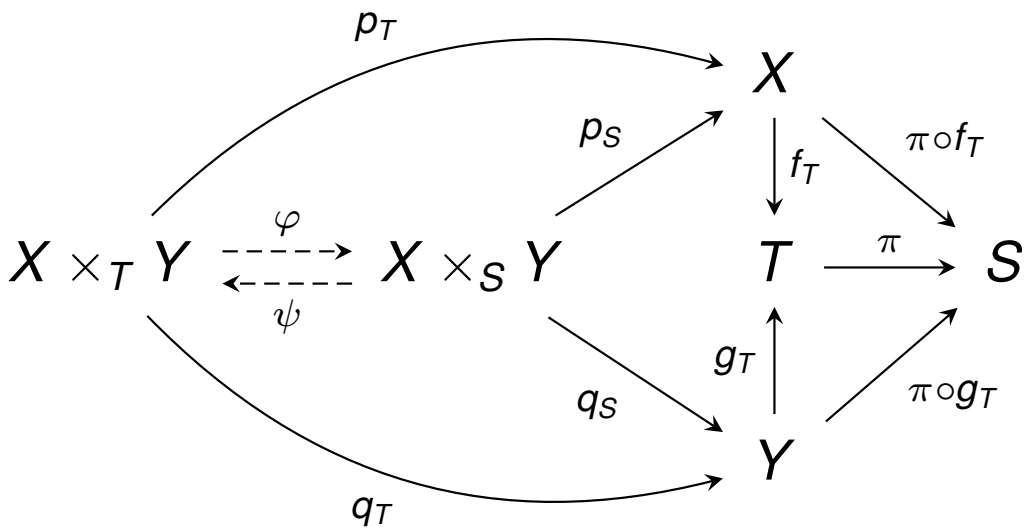


tikz-cd example 1



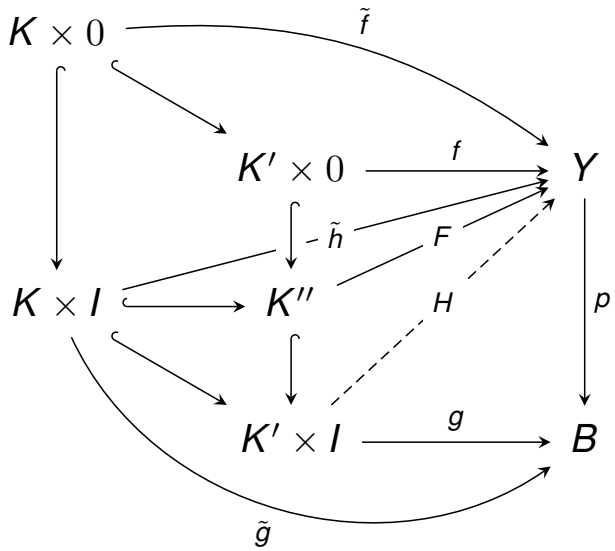

```
\begin{tikzcd}[column sep=tiny]
& \pi_1(U_1)\arrow[dr] \arrow[drr, "j_1", bend left=20]  & &[1.5em] \\
\pi_1(U_1\cap U_2) \arrow[ur, "i_1"] \arrow[dr, "i_2"] & &
\pi_1(U_1) \ast_{ \pi_1(U_1\cap U_2)} \pi_1(U_2)
 \arrow[r, dashed, "\simeq"] & \pi_1(X) \\
& \pi_1(U_2) \arrow[ur]\arrow[urr, "j_2", bend right=20]&&
\end{tikzcd}
```

tikz-cd example 2




```
\begin{tikzcd}
& &X\arrow{d}{f_T} \arrow{dr}{\pi \circ f_T} & \\
X\times_T Y \arrow[bend left]{urr}{p_T} \arrow[bend right, swap]{drr}{q_T}
\arrow[shift left, dashed]{r}{\varphi} & X\times_S Y \arrow{ur}{p_S}
 \arrow[swap]{dr}{q_S} \arrow[shift left, dashed]{l}{\psi} & T
 \arrow{r}{\pi} & S \\
&&Y \arrow{u}{g_T} \arrow[swap]{ur}{\pi \circ g_T}
\end{tikzcd}
```

tikz-cd example 3




```
\begin{tikzcd}
K\times 0 \arrow[bend left=20]{drrr}{\tilde f} \arrow[hookrightarrow]{dd}
\arrow[hookrightarrow]{dr}& && \\
& K'\times 0 \arrow{rr}{f} && Y \arrow{dd}{p} \\
K\times I \arrow[hookrightarrow]{r} \arrow["\tilde h" description]{urrr}
\arrow[hookrightarrow]{dr} \arrow[bend right=50,swap]{drrr}{\tilde g} & K''
\arrow[from=u,hookrightarrow,crossing over] \arrow[swap,"F" description]{urr}
\arrow[hookrightarrow]{d} && \\
&K'\times I \arrow[dashed,swap,"H" description]{uurr} \arrow{rr}{g}&& B
\end{tikzcd}
```

References

- PGFplots project, http://pgfplots.sourceforge.net/
- F. Neves, *tikzcd: commutative diagrams with TikZ*
- C. Feuersänger, *Manual for Package pgfplots*
- J. Wright, *Plotting experimental data using pgfplots*, TUGboat, Volume 31 (2010), No. 1, https://www.tug.org/TUGboat/tb31-1/tb97wright-pgfplots.pdf
- J. I. Montijano, M. Pérez, L. Rández and J. L. Varona, Numerical methods with LuaLaTeX TUGboat, Volume 35 (2014), No. 1, https://www.tug.org/TUGboat/tb35-1/tb109montijano.pdf