

Tikz in mathematics: pgfplots and tikz-cd

권현우

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공주대학교 문서작성워크숍 2017

- 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

- `\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)
```

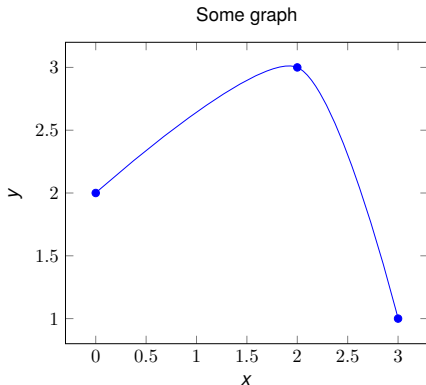
```
(2,3)
```

```
(3,1)
```

```
};
```

```
\end{axis}
```

```
\end{tikzpicture}
```



```
\usepackage{pgfplots}
```

```
\begin{tikzpicture}
```

```
\begin{axis}[
```

```
title=Some graph
```

```
xlabel={ $x$ },
```

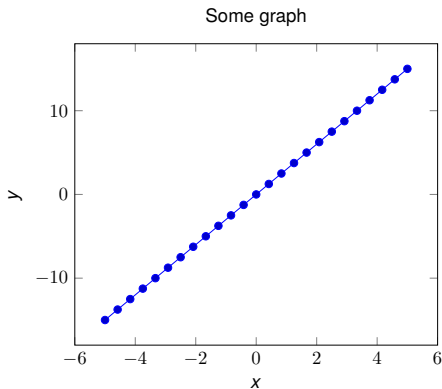
```
ylabel={ $y$ },
```

```
]
```

```
\addplot {3x};
```

```
\end{axis}
```

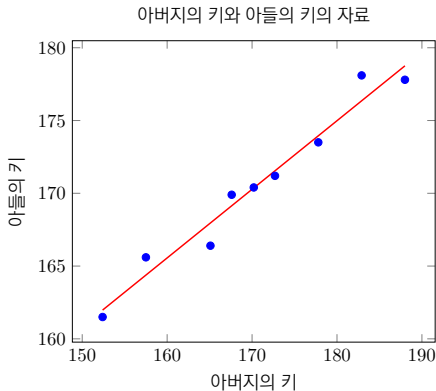
```
\end{tikzpicture}
```



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}
```

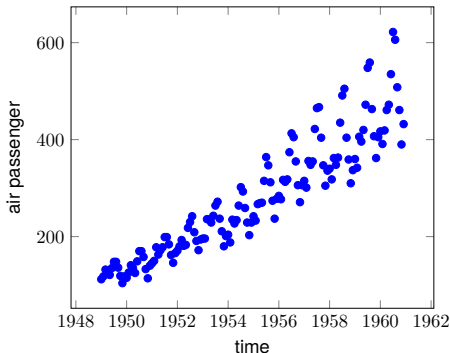


pgfplots: 기본사용법 (dat file)

```
\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={}}
]

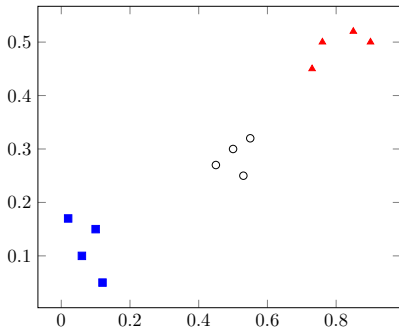
\addplot[only marks,blue] table
[x=time,y=AirPassengers]
{airpassenger.dat};
\end{axis}

\end{tikzpicture}
```



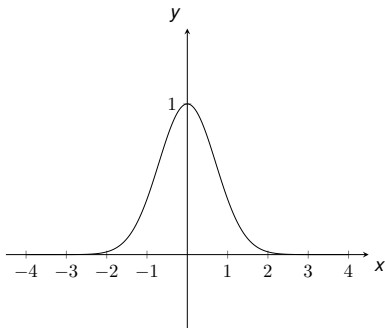
pgfplots: Scatter Plot

```
\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}
```

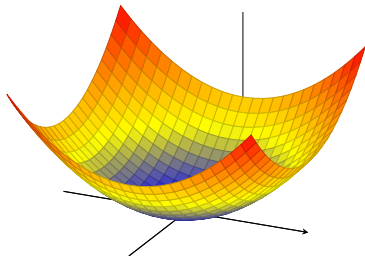


pgfplots: plotting some graph

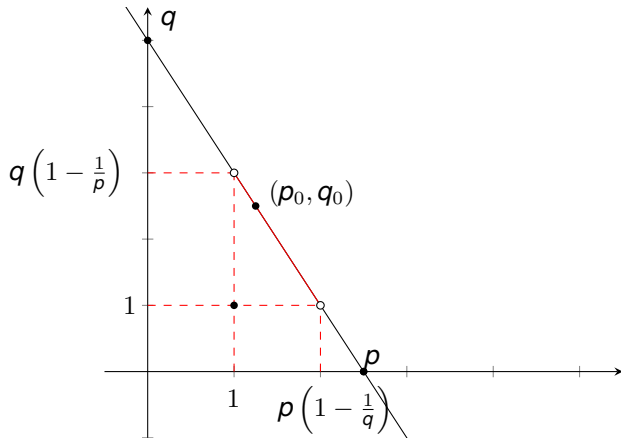
```
\begin{tikzpicture}[>=latex]
\begin{axis}[
  axis x line=center,
  axis y line=center,
  xtick={-5,-4,...,5},
  ytick={0,1},
  xlabel={ $x$ },
  ylabel={ $y$ },
  xlabel style={below right},
  ylabel style={above left},
  xmin=-4.5,
  xmax=4.5,
  ymin=-0.5,
  ymax=1.5]
\addplot [mark=none,domain=-4:4,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



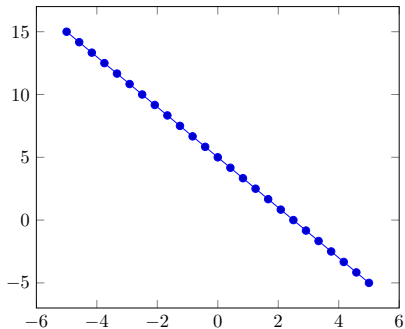

```
\begin{tikzpicture}[>=latex]
\begin{axis}[
axis x line=center,
axis y line=center,
ticks=none,
xlabel style={below right},
ylabel style={above left},
]
\addplot3 [mark=none,domain=-4:4,surf]
{x^2+y^2};
\end{axis}
\end{tikzpicture}
```



출판 수준으로 다듬어보기 step by step!

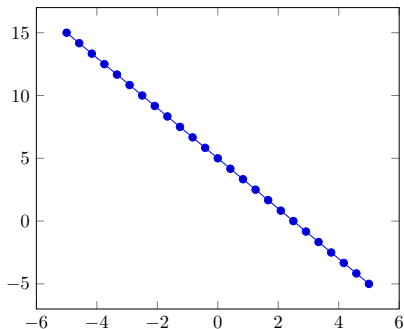


```
\begin{axis}  
\addplot {-2*x+5};  
\end{axis}
```

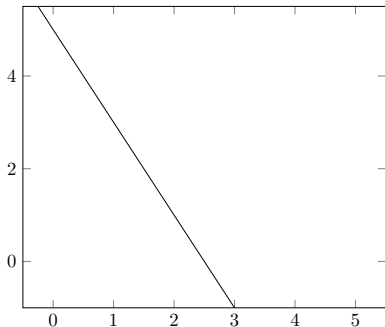


```
\begin{axis}  
\addplot {-2*x+5};  
\end{axis}
```

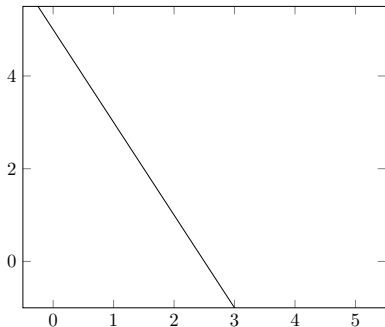
- 점이 안 나왔으면 좋겠어요.
- x의 양의 축만 관심이 있어요.



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

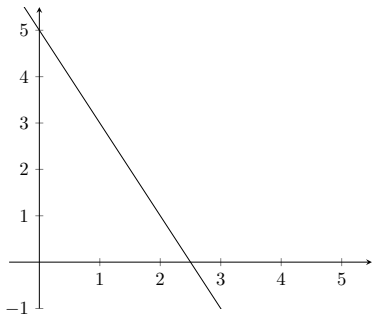


```
\begin{axis}[  
  xmin=-0.5,  
  xmax=5.5,  
  ymin=-1,  
  ymax=5.5]  
\addplot[mark=none] {-2*x+5};  
\end{axis}
```

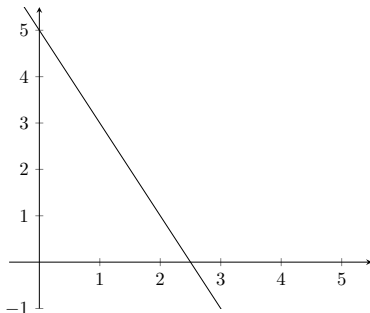


- 상자로 가두는거 마음에 안들어요.
- x축과 y축 숫자 표시간격을 같게 만들고 싶어요.


```
\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}
```



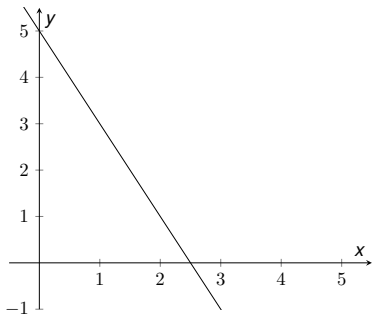
```
\begin{axis}[  
  axis x line=center,  
  axis y line=center,  
  xtick={-5,-4,...,5},  
  ytick={-5,-4,...,5},  
  xmin=-0.5,  
  xmax=5.5,  
  ymin=-1,  
  ymax=5.5]  
\addplot[mark=none] {-2*x+5};  
\end{axis}
```



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

```
\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}
```

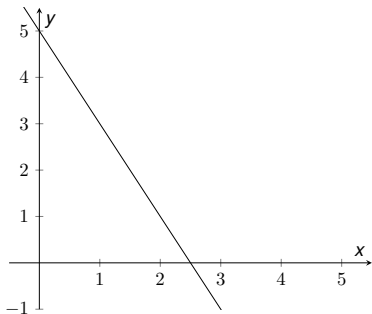
* xlabel style 위치 중요



```
\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

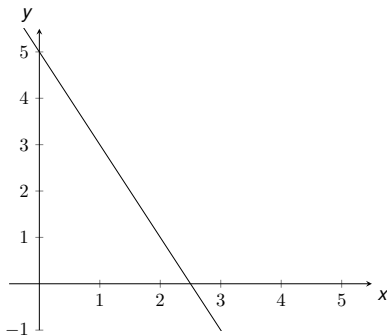
- x,y축 위치가 마음에 안들어요.



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}
```

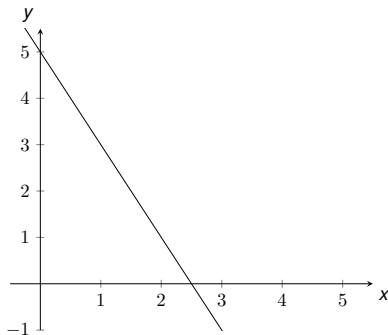
* xlabel style 위치 중요



```
\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}
```

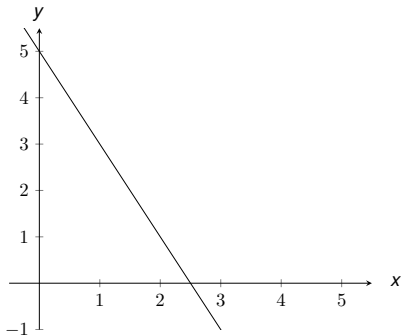
* xlabel style 위치 중요

- 축 종류 표시하는거 내 마음대로 놓고 싶어요.

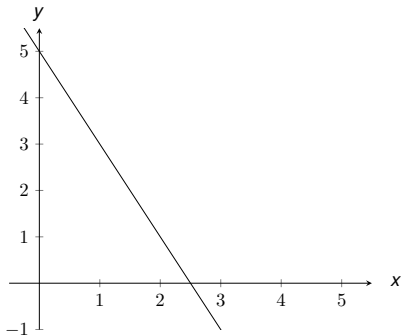


pgfplots: step by step

```
\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}
```

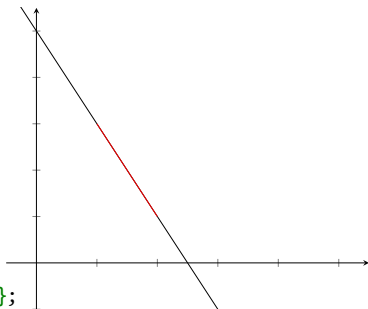


```
\begin{axis}[  
  axis x line=center,  
  axis y line=center,  
  xlabel={ $x$ },  
  ylabel={ $y$ },  
  xtick={-5,-4,...,5},  
  ytick={-5,-4,...,5},  
  x label style=  
{at={(axis cs:6.1,-0.2)}},  
  y label style=  
{at={(axis cs:-0.2,6.1)}},  
  xmin=-0.5,  
  xmax=5.5,  
  ymin=-1,  
  ymax=5.5]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

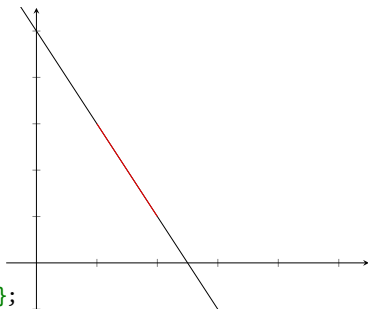


- 그냥 숫자를 다 없애고 싶어요.
- 선분을 덧대고 싶어요.


```
\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}
```



```
\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}
```

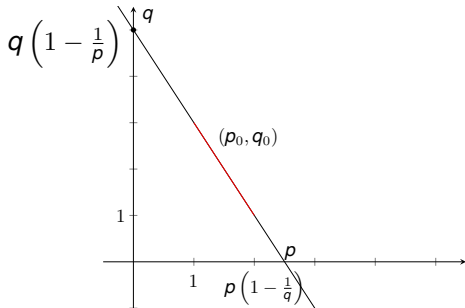


- 좌표 표시를 하고 싶어요.

```

...
\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) {};

```

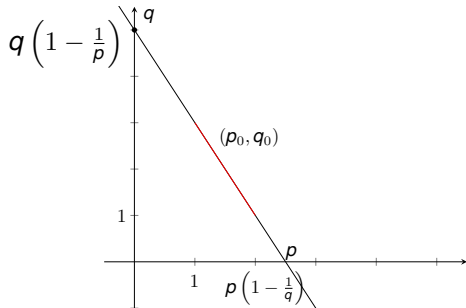


```

...
\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) {};

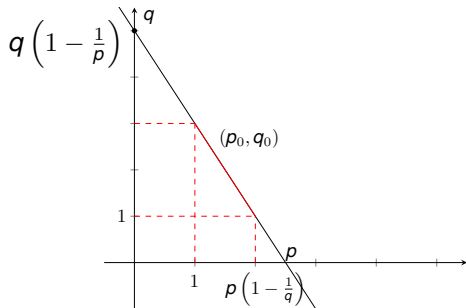
```

- 보조선도 넣고 싶어요.



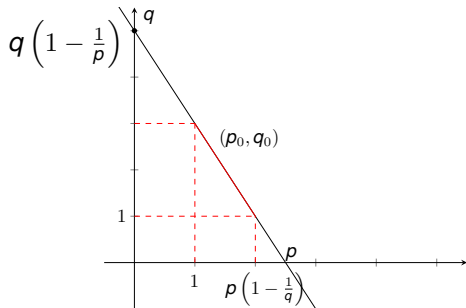
...

```
\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)};
```



...

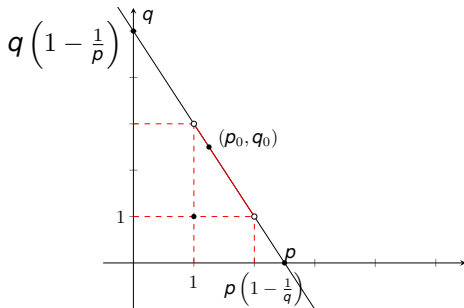
```
\addplot [red,dashed] coordinates
{(0,3) (1,3)};
\addplot [red,dashed] coordinates
{(2,0) (2,1)};
\addplot [red,dashed] coordinates
{(0,1) (2,1)};
\addplot [red,dashed] coordinates
{(1,0) (1,3)};
```



- 점도 표시하는게 좋지 않을까요?

...

```
\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) {}
```



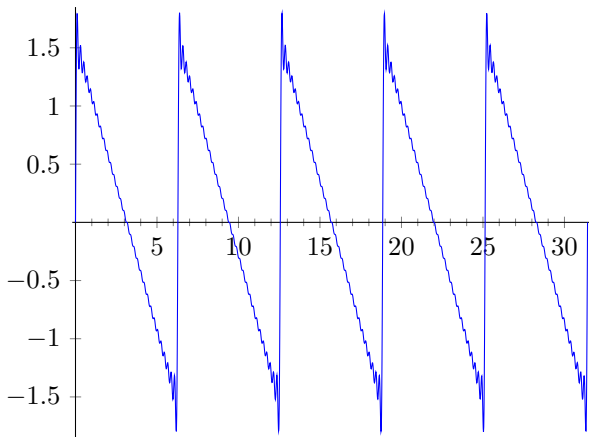


Figure: Gibbs' phenomenon

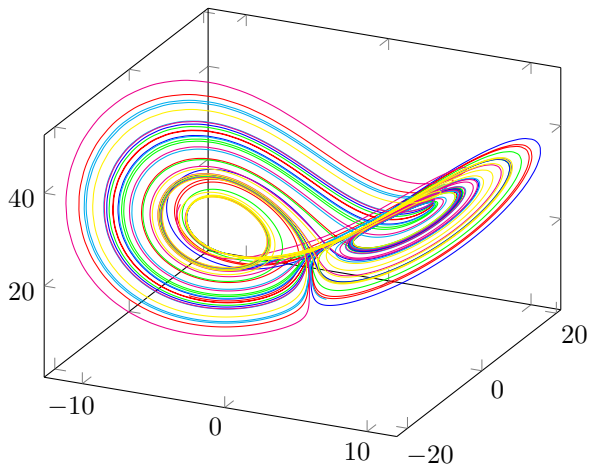


Figure: The Lorenz attractor

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

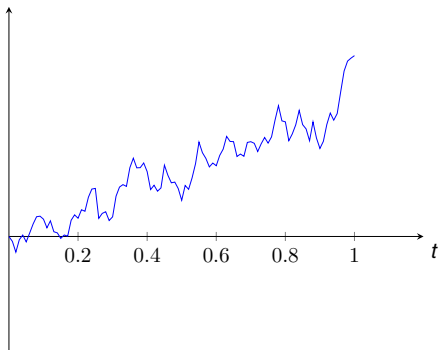
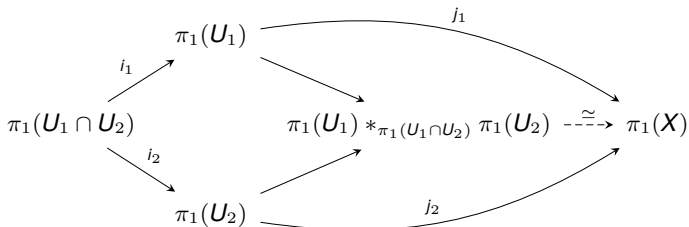
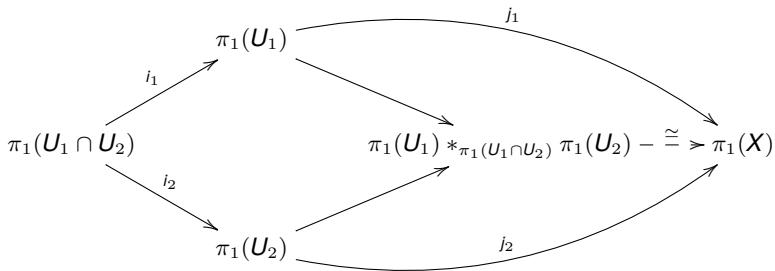


Figure: Brownian motion

- 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



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

$$\begin{array}{ccc}
 G & \xrightarrow{\varphi} & \varphi(G) \\
 \downarrow \pi & \nearrow \tilde{\varphi} & \\
 G/\ker(\varphi) & &
 \end{array}$$

```

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

```

$$\begin{array}{ccc}
 A & \xrightarrow{\phi} & B \\
 \downarrow & & \downarrow \psi \\
 C & \xrightarrow{\eta} & D
 \end{array}$$

```

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

```

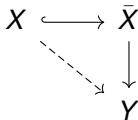
$$A \xrightarrow{\phi} B$$

$$A \xrightarrow[\phi]{} B$$

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

$$A \xrightarrow[\eta]{\phi} B$$

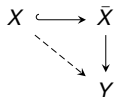
```
\begin{tikzcd}
A \arrow[rrr, "\phi" near start, "\eta" near end] &&& B
\end{tikzcd}
```



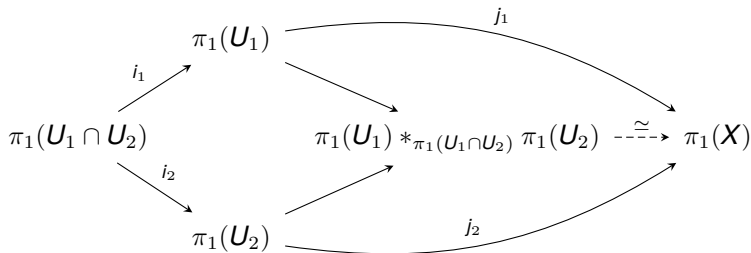
```
\begin{tikzcd}
X \arrow[r, hook] \arrow[dr, dashrightarrow]
& \bar{X} \\
& \downarrow \\
& Y
\end{tikzcd}
```

* tikz-cd 설명서 p.3 – p.4 참조

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



tikz-cd example 1

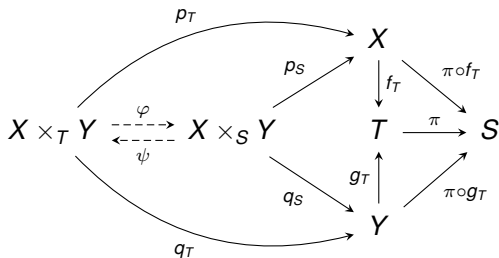


```

\begin{tikzcd}[column sep=tiny]
& \pi_1(U_1) & & & \\
\pi_1(U_1 \cap U_2) & \arrowrightarrow{i_1} & & & \\
& & \pi_1(U_1) *_{\pi_1(U_1 \cap U_2)} \pi_1(U_2) & \dashrightarrow[\simeq] & \pi_1(X) \\
& & \arrowleftarrow{} & & \\
& \pi_1(U_2) & & & \\
& \arrowleftarrow{i_2} & & & \\
& & \arrowleftarrow{j_1} & & \\
& & & \arrowleftarrow{j_2} & \\
& & & & 
\end{tikzcd}

```

tikz-cd example 2

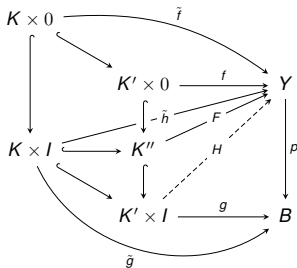


```

\begin{tikzcd}
& & X & & \\
& & \downarrow f_T & & \searrow \pi \circ f_T \\
X \times_T Y & \xrightarrow{\varphi} & X \times_S Y & & T & \xrightarrow{\pi} & S \\
& & \downarrow q_S & & \uparrow g_T & & \nearrow \pi \circ g_T \\
& & Y & & & & \\
& & \uparrow q_T & & & & \\
& & X & & & & \\
& & \downarrow p_T & & & & \\
& & Y & & & & 
\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}

```

-  PGFplots project, <http://pgfplots.sourceforge.net/>
-  F. Neves, *tikzcd: commutative diagrams with TikZ*
-  C. Feuers'anger, *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 Lua \LaTeX TUGboat*, Volume 35 (2014), No. 1, <https://www.tug.org/TUGboat/tb35-1/tb109montijano.pdf>