LaTeX Lectures for Mathematicians

TikZ: from beginer

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Ti*k*Z: basic things

- "**T**i*k*Z **i**st **k**ein **Z**eichenprogramm"
  - "Ti*k*Z is not a drawing program"
  - "Drawing a picture without mouse and tablet!"

- "**T**ikZ **i**st **k**ein **Z**eichenprogramm"
    - "Ti*kZ* is not a drawing program"
    - "Drawing a picture without mouse and tablet!"

Why is it useful?

- it is easy to draw a diagram

So, what is TikZ?

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- if you know how to use illustrator, it is okay but.. (expensive)

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    - "Drawing a picture without mouse and tablet!"

Why is it useful?

- it is easy to draw a diagram
- if you know how to use illustrator, it is okay but.. (expensive)
- but it is free!

xymatrix $\Rightarrow$ tikz-cd

Drawing a diagram by xymatrix

$$
\begin{array}{ccc}
HF(L,L) & \xrightarrow{\quad OC \quad} & QH^*(M) \\
\downarrow{\scriptstyle \mathcal{F}^{\mathbb{L}}} & \searrow^{B} & \downarrow{\scriptstyle \mathfrak{ks}} \\
 & & Jac(W_{\mathbb{L}}) \\
 & & \downarrow{\scriptstyle I} \\
MF(\mathcal{F}^{\mathbb{L}}(L),\mathcal{F}^{\mathbb{L}}(L)) & \xrightarrow[\text{boundary-bulk}]{\quad\quad} & Jac(W_{\mathbb{L}})dx_1 \cdots dx_n
\end{array}
\tag{1}
$$

```
\begin{equation}\label{diagram7}
\xymatrix{
HF(L,L) \ar[dd]^{\mathcal{F}^\mathbb{L}}  \ar[rr]^-{OC} \ar@{-->}[ddrr]^-{B} &
  \;\;\;\;   &  QH^*(M) \ar[d]^{\mathfrak{ks}}  \\
& & Jac(W_\mathbb{L}) \ar[d]^-{I} \\
MF(\mathcal{F}^\mathbb{L}(L),\mathcal{F}^\mathbb{L}(L))
  \ar[rr]_-{\textrm{boundary-bulk}} &  \;\;\;\;   &   \;\;\;\;
  Jac(W_\mathbb{L})dx_1 \cdots dx_n}
\end{equation}
```

Drawing a diagram by xymatrix (* use 'gathered' environment to fix a numbering problem)

$$
\begin{array}{ccc}
HF(L,L) & \xrightarrow{\quad OC \quad} & QH^*(M) \\
\downarrow{\scriptstyle \mathcal{F}^{\mathbb{L}}} & {\scriptstyle B} & \downarrow{\scriptstyle \mathfrak{l}_\mathfrak{s}} \\
& & Jac(W_{\mathbb{L}}) \\
& & \downarrow{\scriptstyle I} \\
MF(\mathcal{F}^{\mathbb{L}}(L), \mathcal{F}^{\mathbb{L}}(L)) & \xrightarrow[\text{boundary-bulk}]{} & Jac(W_{\mathbb{L}})dx_1 \cdots dx_n
\end{array}
\tag{1}
$$

```
\begin{equation}
\begin{gathered}
\xymatrix{ ...}
\end{gathered}
\end{equation}
```

xymatrix ⇒ tikz-cd

```
\usepackage{tikz-cd}
```

$$
\begin{array}{ccc}
HF(L,L) & \xrightarrow{\;\;OC\;\;} & QH^*(M) \\
\Big\downarrow{\scriptstyle \mathcal{F}^{\mathbb{L}}} & \searrow{\scriptstyle B} & \Big\downarrow{\scriptstyle \mathfrak{ks}} \\
& & Jac(W_{\mathbb{L}}) \\
& & \Big\downarrow{\scriptstyle I} \\
MF(\mathcal{F}^{\mathbb{L}}(L), \mathcal{F}^{\mathbb{L}}(L)) & \xrightarrow[\text{boundary-bulk}]{} & Jac(W_{\mathbb{L}})\,dx_1 \cdots dx_n
\end{array}
\tag{2}
$$

```
\tikzcdset{arrow style=tikz, diagrams={>=stealth}}
\begin{tikzcd}[row sep={large},column sep={huge}]
HF(L,L)\arrow[r,"OC"]\arrow[ddr,"B",dashed]\arrow[dd,"\mathcal{F}^{\mathbb{L}}"]
↪ &[20pt] QH^*(M)\arrow[d,"\mathfrak{ks}"]  \\
&Jac(W_{\mathbb{L}})\arrow[d,"I"] \\
MF(\mathcal{F}^{\mathbb{L}}(L),\mathcal{F}^{\mathbb{L}}(L))
\arrow[r,"\textrm{boundary-bulk}",swap]&Jac(W_{\mathbb{L}})  dx_1\cdots dx_n
\end{tikzcd}
```

Drawing a diagram via tikz-cd

```
\usetikzlibrary{arrows,arrows.meta} %preamble
\tikzcdset{arrow style=tikz, diagrams={>=stealth}}
\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}
```
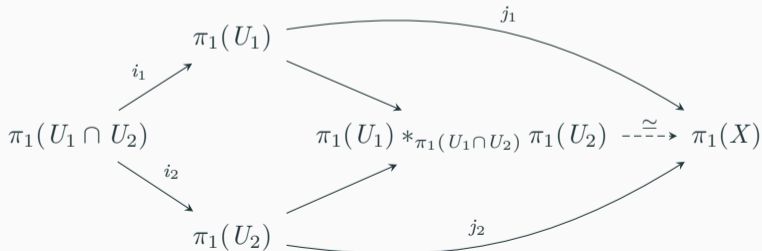
$$\begin{array}{ccccccc}
\ker a & \longrightarrow & \ker b & \longrightarrow & \ker c & \dashrightarrow & \\
\downarrow & & \downarrow & & \downarrow & & \\
A & \xrightarrow{f} & B & \xrightarrow{g} & C & \longrightarrow & 0 \\
\downarrow{a} & & \downarrow{b} & & \downarrow{c} & & \\
& & & & d & & \\
0 & \longrightarrow & A' & \xrightarrow{f'} & B' & \xrightarrow{g'} & C' \\
& & \downarrow & & \downarrow & & \downarrow \\
& \dashrightarrow & \operatorname{coker} a & \longrightarrow & \operatorname{coker} b & \longrightarrow & \operatorname{coker} c
\end{array}$$

`https://tikzcd.yichuanshen.de/`

- See the manual of tikz-cd (or if you are Korean
  `http://wiki.ktug.org/wiki/wiki.php/LaTeXWorkshop/2017` 에서 "Ti*k*Z와
  수학" 참고)

standalone class

- If you are in trouble when you compile every picture (e.g. Ti*k*Z-Feynman), it is better to use the standalone class.
- Useful when you use Ti*k*Z
- Automatically crop

Load it as a picture

```
\documentclass[tikz]{standalone}
```
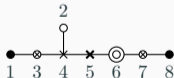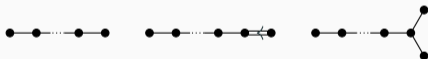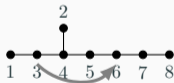
...

Example:
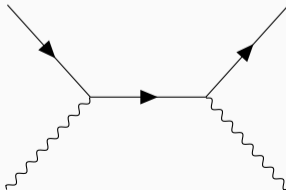
```latex
\usepackage{dynkin-diagrams}

...
\[    \dynkin{A}{}\quad \dynkin{C}{}\quad  \dynkin{D}{}\]
\[ \dynkin[label]{E}{*otxXOt*} \]
```

```
\begin{tikzpicture}
\dynkin[label]{E}{8}
\draw[very thick, black!50,-latex]
(root 3.south) to [out=-45, in=-135] (root 6.south);
\end{tikzpicture}
```

So the goal of this lecture is

- Study the basic command on Ti*k*Z
- Drawing some typical examples in Calculus and research articles

Basic one (basic-one.tex)

```latex
\documentclass[tikz]{standalone}

\usepackage{tikz}

\begin{document}
\begin{tikzpicture}
        \draw (0,0) -- (1,1);
        \draw (0,0) rectangle (2,1);
        \draw (0,0) circle [radius=0.5];
        \node at (0,0) {Some text};
        \draw (0,0) -- (120:2); %polar coordinate
\end{tikzpicture}
\end{document}
```

- When you end some command in TikZ, you must end it via semicolon.
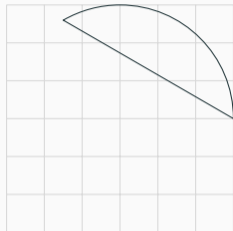- \draw, \node

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Drawing a shape (shape.tex)


```
\draw (0,0) -- (1,1);
\draw (0,0) -- (1,-1) -- (2,-2);
\draw (0,0) -- (2,0) -- (2,3) -- (0,3) -- cycle;
\draw (3,0) arc (0:120:3) -- cycle;%(start angle:end angle:radius)
```

- cycle: make a closed path
- See chapter 2 of visualtikz (>texdoc visualtikz)

Drawing a shape (shape.tex)


```
\draw (0,0) -- (1,1);
\draw (0,0) -- (1,-1) -- (2,-2);
\draw (0,0) -- (2,0) -- (2,3) -- (0,3) -- cycle;
\draw (3,0) arc (0:120:3) -- cycle;%(start angle:end angle:radius)
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\draw (3,0) arc (0:120:3) -- cycle;%(start angle:end angle:radius)
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Drawing a shape (shape.tex)


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\draw (0,0) -- (1,1);
\draw (0,0) -- (1,-1) -- (2,-2);
\draw (0,0) -- (2,0) -- (2,3) -- (0,3) -- cycle;
\draw (3,0) arc (0:120:3) -- cycle;%(start angle:end angle:radius)
```

- cycle: make a closed path
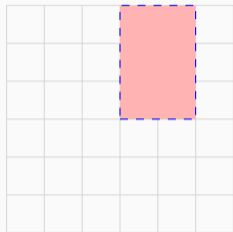- See chapter 2 of visualtikz (>texdoc visualtikz)

Color a face or line(decoration.tex)
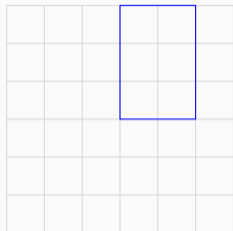

```
\draw[draw=blue] (0,0) -- (2,0) -- (2,3) -- (0,3) -- cycle;
```

- line (draw=color), face (fill=color)
- width: line width = 2pt, thick,...
- shape: dashed, dotted,...
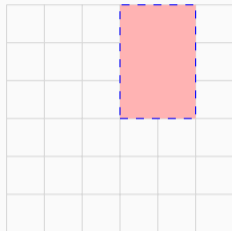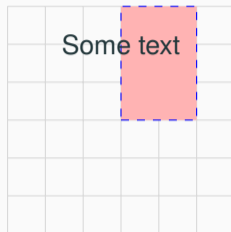- tip of arrow: ->, <->, ... (See visualtikz 4.10)

Color a face or line(decoration.tex)
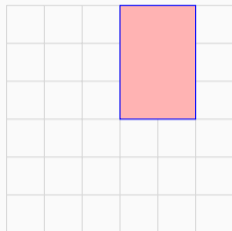

```
\draw[draw=blue,fill=red!30] (0,0) -- (2,0) -- (2,3) -- (0,3) -- cycle;
```
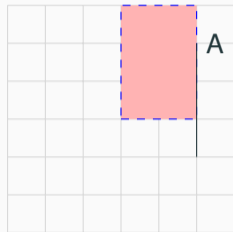
- line (draw=color), face (fill=color)
- width: line width = 2pt, thick,...
- shape: dashed, dotted,...
- tip of arrow: ->, <->, ... (See visualtikz 4.10)

Color a face or line(decoration.tex)


```
\draw[draw=blue,fill=red!30,dashed] (0,0) -- (2,0) -- (2,3) -- (0,3) --
```

- line (draw=color), face (fill=color)
- width: line width = 2pt, thick,...
- shape: dashed, dotted,...
- tip of arrow: ->, <->, ... (See visualtikz 4.10)

```
\filldraw[draw=blue,fill=red!30,dashed] (0,0) -- (2,0) -- (2,3) --
↪  (0,3) -- cycle;
```

- line (draw=color), face (fill=color)
- width: line width = 2pt, thick,...
- shape: dashed, dotted,...
- tip of arrow: ->, <->, ... (See visualtikz 4.10)

Write a text (decoration-text.tex)
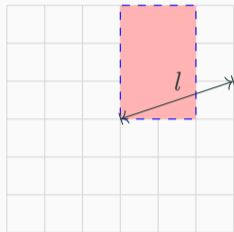

```
\filldraw[draw=blue,fill=red!30,dashed] (0,0) -- (2,0) -- (2,3) --
→  (0,3) -- cycle;
\node at (0,2) {Some text};
\draw (2,-1) -- (2,2) node[right] {A};
\draw[|<->|] (0,0) -- node[midway, above] {$ l $} (3,1);
```

```
\filldraw[draw=blue,fill=red!30,dashed] (0,0) -- (2,0) -- (2,3) --
→ (0,3) -- cycle;
\node at (0,2) {Some text};
\draw (2,-1) -- (2,2) node[right] {A};
\draw[|<->|] (0,0) -- node[midway, above] {$ l $} (3,1);
```

```
\filldraw[draw=blue,fill=red!30,dashed] (0,0) -- (2,0) -- (2,3) --
↪ (0,3) -- cycle;
\node at (0,2) {Some text};
\draw (2,-1) -- (2,2) node[right] {A};
\draw[|<->|] (0,0) -- node[midway, above] {$ l $} (3,1);
```

Relative positions

All of these yield same one

```
\draw (10,10) -- (10,11) -- (11,11);
\draw (10,10) -- +(0,1) -- +(1,1);
\draw (10,10) -- ++(0,1) -- ++(1,0);
```

- '+' 1개: temporary
- '+' 2개: not temporary

relative position (text-relative.tex)

above left •   • above   • above right

left •   • right

• below left   • below   • below right

```
It can be drawn above the text
\begin{tikzpicture}[overlay]
\draw (0,10) -- (5,-20);
\end{tikzpicture}
```

It can be drawn above the text

Example: overlay

```
\usepackage{tikz}
\usetikzlibrary{shapes.callouts}
\begin{tikzpicture}[overlay]
\node[fill=red!50, rectangle callout, callout relative pointer={(-2,-1)}] at (12,1)
{Nonlinear Schr\"odinger equation};
\node[fill=red!50, rectangle callout, callout relative pointer={(-2,1)}] at (12,-3)
{Hartree equation};
\end{tikzpicture}
```

Nonlinear Schrödinger equation

$$i\partial_t u + \triangle u = |u|^{p-1}u$$

$$i\partial_t u + \triangle u = V(u)u$$

where $V(u) = |x|^{-n} * |u|^2$.

Hartree equation

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Readable references

- ~~pgfmanual (1161 pages..)~~
- VisualTi*k*Z
- Texample.net (a lot of examples on Ti*k*Z)

Drawing a graph via Ti*k*Z
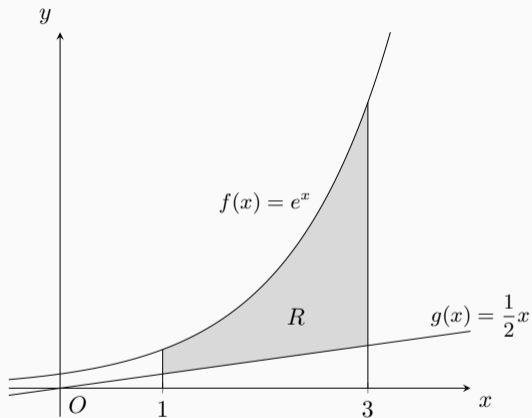
김현석, 이영란, 조성희 저 / "대학수학", 청문각

First example: Calculus / Step 1. Coordinate axis
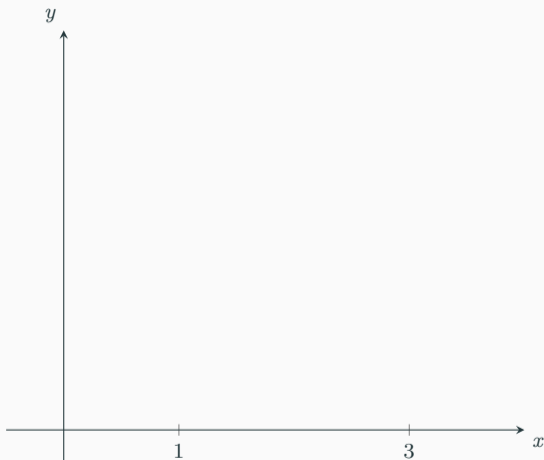

```latex
\usepackage{tikz,pgfplots,amssymb}

\begin{tikzpicture}[>=stealth]
\begin{axis}[
axis x line=center,
axis y line=center,
xlabel={$x$},
ylabel={$y$},
xtick={1,3},
ytick={.},
xlabel style={below right},
ylabel style={above left},
xmin=-0.5,
xmax=4,
ymin=-2,
ymax=25]
\end{axis}
\end{tikzpicture}
```

First example: Calculus / Step 2. Drawing a graph
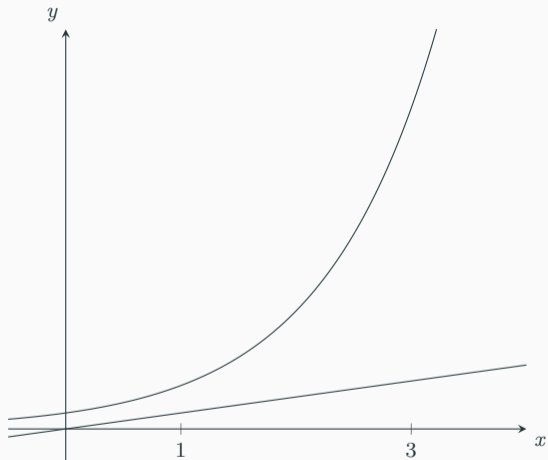

```
\begin{axis}
....
\addplot [mark=none,domain=-
↪ 0.5:4,samples=201]
↪ {e^x};
\addplot [mark=none,domain=-
↪ 0.5:4,samples=201]
↪ {x};
\end{axis}
```
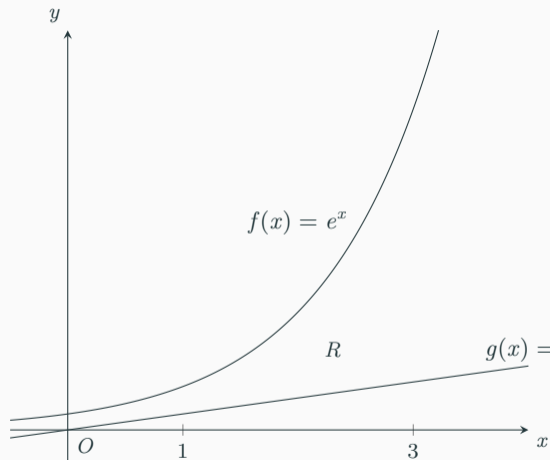
```latex
\begin{axis}
....
\node at (axis cs:2.3,5) {$R$};
\node[below right] at (axis cs:0,0)
↪ {$O$};

\node at (axis cs:2,13) {\small
↪ $f(x)=e^x$};
\end{axis}
\node at (7,1.5) {\small
↪ $\displaystyle
↪ g(x)=\frac{1}{2}x$};
```
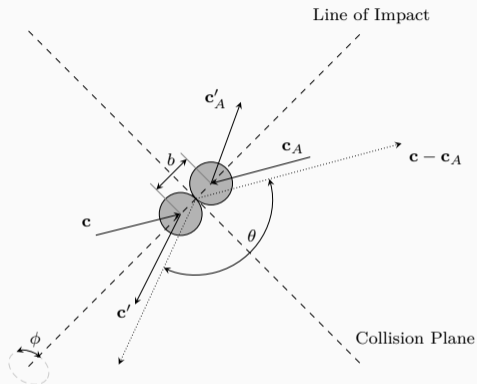
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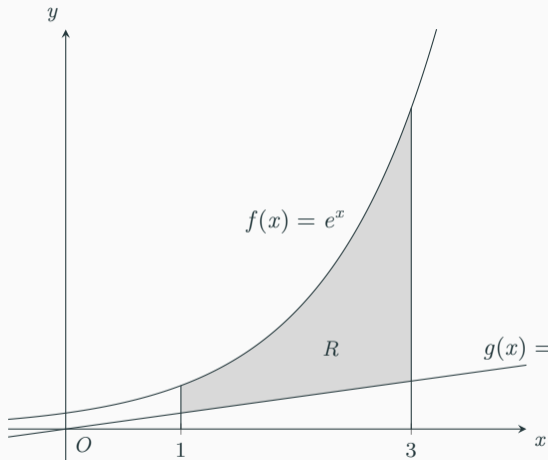
```
\begin{axis}
....

\addplot [mark=none,domain=-
↪  0.5:4,samples=201,name path=f]
↪  {e^x};
\addplot [mark=none,domain=-
↪  0.5:4,samples=201,name path=l]
↪  {x};

\addplot[gray!30] fill between[of=f
↪  and l,soft clip={(axis cs:1,0)
↪  rectangle (axis cs:3,e^3)}];
\draw (axis cs:1,0) -- (axis
↪  cs:1,e^1);
\draw (axis cs:3,0) -- (axis
↪  cs:3,e^3);
\end{axis}
```
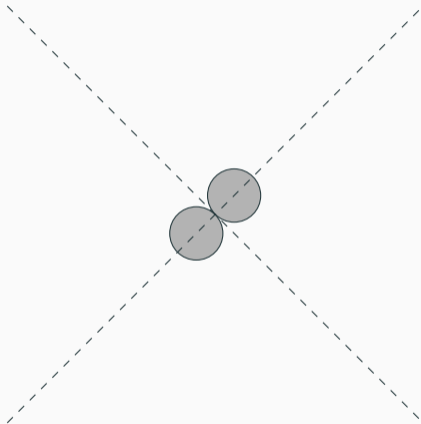
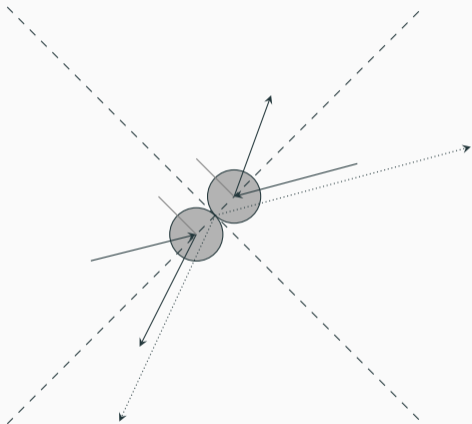## Second example: Elastic Collision of Two Particles

https://thermalfluidscentral.org/encyclopedia/index.php/Boltzmann_
Equation

Step 1: drawing dashed lines and two particles

```latex
\begin{tikzpicture}[>=stealth]
\draw[fill=black!30] (-0.25,-0.25)
↪ circle (10pt);
\draw[fill=black!30] (0.25,0.25)
↪ circle (10pt);
\draw[dashed] (-2.75,-2.75) --
↪ (2.75,2.75);
\draw[dashed] (-2.75,2.75) --
↪ (2.75,-2.75);
\end{tikzpicture}
```
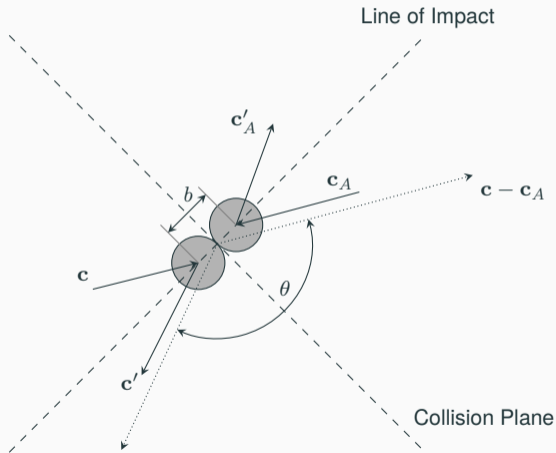
Step 2: momentum path


```
\begin{tikzpicture}[>=stealth]
\draw[<-] (-0.25,-0.25) --
↪ (-160:1.75cm);
\draw[->] (-0.25,-0.25) --
↪ (-120:2cm);
\draw[<-] (0.25,0.25) -- (20:2cm);
\draw[->] (0.25,0.25) -- (65:1.75cm);

\draw[->,densely dotted] (0,0) --
↪ (15:3.5cm);
\draw[->,densely dotted] (0,0) --
↪ (-115:3cm);
\draw[gray] (-0.25,-0.25) --
↪ (-0.75,0.25);
\draw[gray] (0.25,0.25) --
↪ (-0.25,0.75);
\end{tikzpicture}
```

```
\draw[<->] (-0.65,0.15) --
↪  ++(0.5,0.5) node[below
↪  left,xshift=-2pt,yshift=6pt]
↪  {\footnotesize $b$};

\draw[<->] (15:1.25cm) arc
↪  (15:-115:1.25cm) node[below
↪  right,xshift=1.25cm,yshift=0.75cm]
↪  {\footnotesize $\theta$};

\node[above right] at (2.5,-2.5)
↪  {\footnotesize Collision Plane};
\node[above right] at (1.8,2.75)
↪  {\footnotesize Line of Impact};
\node[below right] at (15:3.5cm)
↪  {\footnotesize
↪  $\mathbf{c}-\mathbf{c}_{A}$};
\node[above left] at (18:2cm)
↪  {\footnotesize $\mathbf{c}_{A}$};
...
```
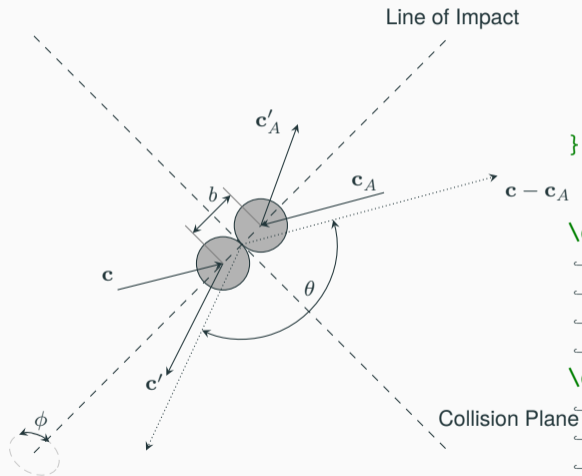
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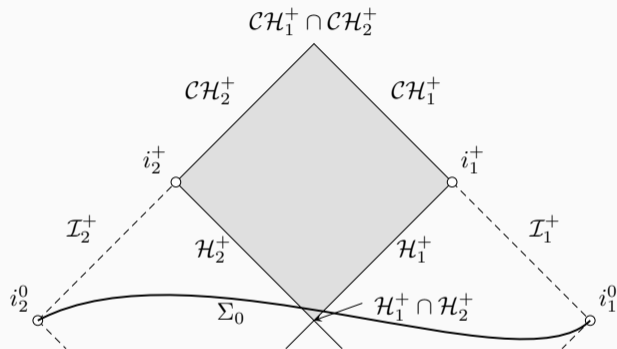
```
\tikzset{
    partial ellipse/.style
    ↪ args={#1:#2:#3}{
        insert path={+ (#1:#3) arc
        ↪ (#1:#2:#3)}
    }
} %found on stackexchange
```

```
\draw[densely
↪ dashed,black!20,rotate=-
↪ 30,xshift=50pt,yshift=-29pt]
↪ (-2.75,-2.75) [partial
↪ ellipse=0:360:10pt and 7pt];
\draw[<->,rotate=-
↪ 30,xshift=50pt,yshift=-29pt]
↪ (-2.75,-2.75) [partial
↪ ellipse=75:150:10pt and 7pt];
\node[above right] at (-2.85,-2.55)
↪ {\footnotesize $\phi$};
```

Third example: Penrose diagram of Reissner-Nordström spacetime

J. Luk and S.-J. Oh, arXiv:1702.05715 (originally drawn by inkscape)

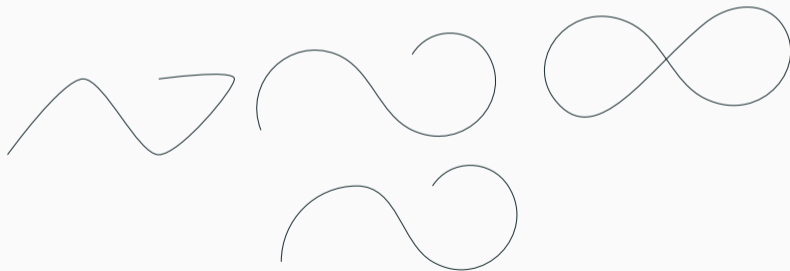See RN-tikz.tex for further information.

An interesting things

```
\usetikzlibrary{hobby}

\tikz[smooth] \draw plot coordinates {(0,0) (1,1) (2,0) (3,1) (2,1)};
\tikz[hobby] \draw plot coordinates {(0,0) (1,1) (2,0) (3,1) (2,1)};
\tikz[closed hobby] \draw plot coordinates {(0,0) (1,1) (2,0) (3,1) (2,1)};
\tikz[quick hobby] \draw plot coordinates {(0,0) (1,1) (2,0) (3,1) (2,1)};
```
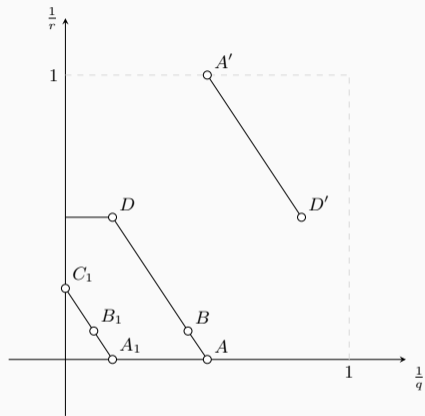
Homework! (I know you won't do it..)

Figure 1: The Strichartz "game board" for Schrödinger equations in $\dot{H}^1(\mathbb{R}^3)$ (T. Tao, Nonlinear dispersive equations)

- Do pratice many times!
- Ask questions on ktug (with Minimal Working Example!)
- If you have in trouble which should be confidential, ask me (willkwon@sogang.ac.kr)

References

📄 권현우, Ti*k*Z와 수학, 2017 문서작성워크숍

📄 박승원, Ti*k*Z기초, 2017 문서작성워크숍

📄 PGFplots project, `http://pgfplots.sourceforge.net/`

📄 F. Neves, tikzcd: commutative diagrams with Ti*k*Z

📄 Overleaf, `https://www.overleaf.com/learn/latex/TikZ-Feynman`