

# TikZ Figures

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This file is a collection of most of the TikZ figures I made

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## TikZ preamble

```
\usepackage{tikz}
\usepackage{xcolor}

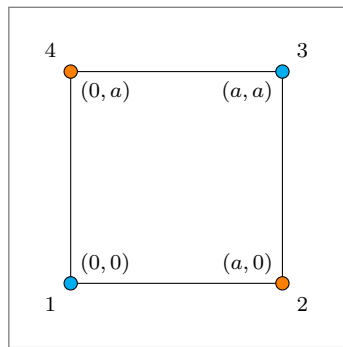
% TikZ
\usetikzlibrary{
    arrows.meta,
    decorations.markings,
    patterns,
    fit,
    intersections,
    positioning
}
\tikzset{
    % Main settings
    font=\footnotesize,
    >={Latex},
    % Phase diagrams
    nota/.style={align=center, fill=Grey10, inner sep=0.5cm, font=\normalsize},
    titolo nota/.style={align=center, color=Blue50, font=\normalsize},
    etichetta/.style = {fill=white, fill opacity=0.9, text opacity=1, text=black, rounded
    corners, inner sep=2pt},
    freccia/.style = {arrows = {-Stealth}},
    % Ribbons styles
    direct vertex/.style={circle, inner sep=0pt, minimum size=3pt, draw=black, fill=black
    },
    dual vertex/.style={circle, inner sep=0pt, minimum size=3pt, draw=black, fill=white},
    ribbon site/.style={very thick, dashed, black},
    direct edge/.style={very thick, black},
    dual edge/.style={very thick, dotted, black},
    ribbon/.style={green, opacity=0.3},
    direct ribbon/.style={red, opacity=0.3},
    dual ribbon/.style={blue, opacity=0.3}
}

% IBM Carbon Colors
\definecolor{Foreground}{RGB}{22, 22, 22}
\definecolor{Background}{RGB}{244, 244, 244}
\definecolor{Blue100}{RGB}{0, 17, 65}
\definecolor{Blue90}{RGB}{0, 29, 108}
\definecolor{Blue80}{RGB}{0, 45, 156}
\definecolor{Blue70}{RGB}{0, 67, 206}
\definecolor{Blue60}{RGB}{15, 95, 254}
\definecolor{Blue50}{RGB}{69, 137, 255}
\definecolor{Blue40}{RGB}{120, 169, 255}
\definecolor{Blue30}{RGB}{166, 200, 255}
\definecolor{Blue20}{RGB}{208, 226, 255}
\definecolor{Blue10}{RGB}{237, 245, 255}
\definecolor{Red}{RGB}{218, 30, 40}
\definecolor{Orange}{RGB}{255, 131, 43}
\definecolor{Yellow}{RGB}{253, 220, 105}
\definecolor{Green}{RGB}{25, 128, 56}
\definecolor{Grey05}{RGB}{240, 240, 240}
\definecolor{Grey10}{RGB}{224, 224, 224}
\definecolor{Grey15}{RGB}{211, 211, 211}
\definecolor{Grey20}{RGB}{198, 198, 198}
\definecolor{Grey30}{RGB}{168, 168, 168}
\definecolor{Grey40}{RGB}{141, 141, 141}
\definecolor{Grey50}{RGB}{111, 111, 111}
\definecolor{Grey60}{RGB}{82, 82, 82}
\definecolor{Grey70}{RGB}{57, 57, 57}
\definecolor{Grey80}{RGB}{38, 38, 38}
\definecolor{Grey90}{RGB}{22, 22, 22}
\definecolor{White}{RGB}{255, 255, 255}
\definecolor{Black}{RGB}{0, 0, 0}
```

```
\colorlet{Blue}{Blue60}  
\colorlet{Gray}{Grey40}
```

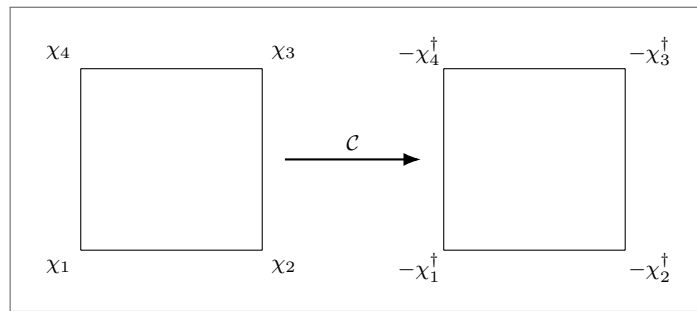
plus maybe some macros for math commands

## Staggered spinor components



```
\begin{tikzpicture}[scale=0.7,
  dot/.style = {circle, minimum size=5pt, inner sep=0pt, draw=black},
  even/.style = {dot, fill=cyan},
  odd/.style = {dot, fill=orange}
]
\draw[step=4.0,black,thin] (0,0) grid (4,4);
\draw (0,0) node [even, label=below left:{$1$}] {} node [black, above right] {$$(0,0)$$};
\draw (4,0) node [odd, label=below right:{$2$}] {} node [black, above left] {$$(a,0)$$};
\draw (4,4) node [even, label=above right:{$3$}] {} node [black, below left] {$$(a,a)$$};
\draw (0,4) node [odd, label=above left:{$4$}] {} node [black, below right] {$$(0,a)$$};
\end{tikzpicture}
```

## Charge conjugation of a plaquette

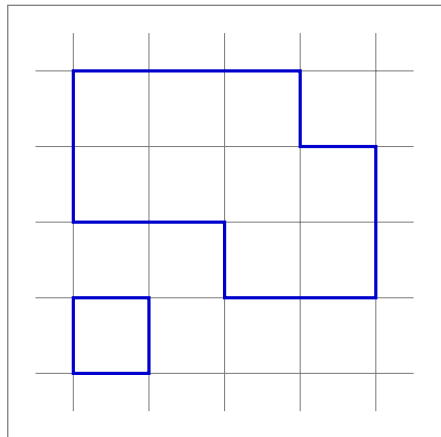


```
\begin{tikzpicture}[scale=0.6]
  \draw[step=4, black] (0,0) grid (4,4);
  \node[below left] at (0,0) {$\chi_1$};
  \node[below right] at (4,0) {$\chi_2$};
  \node[above right] at (4,4) {$\chi_3$};
  \node[above left] at (0,4) {$\chi_4$};

  \begin{scope}[xshift=8cm, inner sep=1pt]
    \draw[step=4, black] (0,0) grid (4,4);
    \node[below left] at (0,0) {$-\chi_1^\dagger$};
    \node[below right] at (4,0) {$-\chi_2^\dagger$};
    \node[above right] at (4,4) {$-\chi_3^\dagger$};
    \node[above left] at (0,4) {$-\chi_4^\dagger$};
  \end{scope}

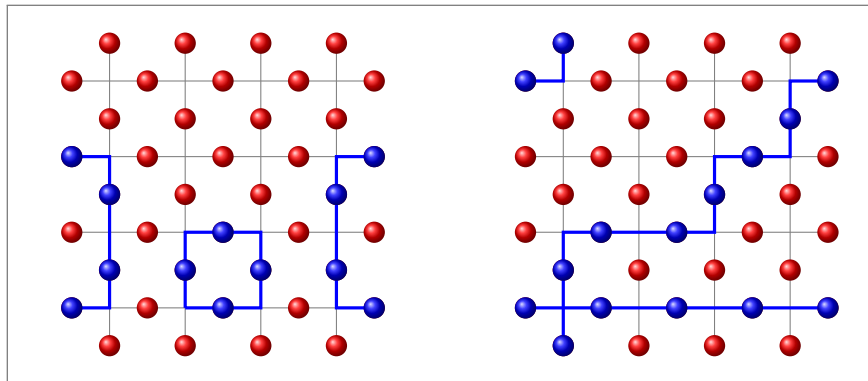
  \draw[thick, ->] (4.5,2) -- +(3,0) node[pos=0.5, above] {$\mathcal{C}$};
\end{tikzpicture}
```

## Closed loops on a square lattice



```
\begin{tikzpicture}
% Grid
\draw[step=1.0,gray,thin] (-0.5,-0.5) grid (4.5,4.5);
% Small loop
\draw[black!20!blue, very thick]
  (0,0) -- (1,0) -- (1,1) -- (0,1) -- cycle;
% Big loop
\draw[black!20!blue, very thick]
  (2,1) -- (4,1) -- (4,3) -- (3,3) -- (3,4) -- (0,4) -- (0,2) -- (2,2) -- cycle;
\end{tikzpicture}
```

## Gauge invariant configurations



```
% Draw horizontal line of nodes
\newcommand{\DrawHoriz}[2]{
  \draw[gray, thin] (-0.5, #1)
  -- ++(0.5, 0) node [pos=0.0, #2] {}
  -- ++(1.0, 0) node [pos=0.5, #2] {}
  -- ++(1.0, 0) node [pos=0.5, #2] {}
  -- ++(1.0, 0) node [pos=0.5, #2] {}
  -- ++(0.5, 0) node [pos=1.0, #2] {};
}

% Draw vertical line of nodes
\newcommand{\DrawVert}[2]{
  \draw[gray, thin] (#1, -0.5)
  -- ++(0, 0.5) node [pos=0.0, #2] {}
  -- ++(0, 1.0) node [pos=0.5, #2] {}
  -- ++(0, 1.0) node [pos=0.5, #2] {}
  -- ++(0, 1.0) node [pos=0.5, #2] {}
  -- ++(0, 0.5) node [pos=1.0, #2] {};
}

% Draw grid
\newcommand{\DrawGrid}[1]{
  \foreach \x in {0,...,3} \DrawHoriz{\x}{#1};
  \foreach \y in {0,...,3} \DrawVert{\y}{#1};
}

\begin{tikzpicture}[
  ball/.style={shade, shading=ball, circle, minimum size=8pt, inner sep=0pt},
  zero/.style={ball, ball color=red},
  one/.style={ball, ball color=blue},
  loopline/.style={blue, very thick},
  loopdot/.style={pos=0.5, one},
  loopstart/.style={pos=0, one},
  loopend/.style={pos=1, one}
]

%% First grid
% Draw a grid of red dots
\DrawGrid{zero};
% Draw over loops of blue dots
\draw[loopline]
(1,0) foreach \x / \y in {1/0, 0/1, -1/0, 0/-1} { -- ++(\x, \y) node [loopdot] {} } ;
\draw[loopline]
(-0.5,0) -- (0,0) node [loopstart] {}
  foreach \y in {1, 1} { -- ++(0, \y) node [loopdot] {} }
  -- ++(-0.5, 0) node [loopend] {};
\draw[loopline]
(3.5,0) -- (3,0) node [loopstart] {}
  foreach \y in {1, 1} { -- ++(0, \y) node [loopdot] {} }
  -- ++(0.5, 0) node [loopend] {};

%% Second grid, shifted
```

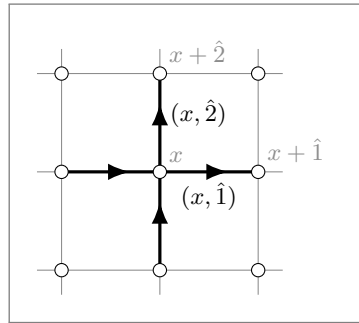
```

\begin{scope}[xshift=6cm]
  % Grid of red dots
  \DrawGrid{zero};
  % Loop
  \draw[loopleft]
    (-0.5,0) -- (0,0) node [loopstart] {}
    foreach \x in {1, 2, 3} { -- (\x, 0) node [loopdot] {} }
    -- (3.5,0) node [loopend] {}];
  \draw[loopleft]
    (0,-0.5) -- (0,0) node [loopstart] {}
    foreach \x / \y in {0/1, 1/0, 1/0, 0/1, 1/0, 0/1} { -- ++(\x, \y) node [loopdot
] {} }
    -- ++(0.5,0) node [loopend] {}];
  \draw[loopleft]
    (-0.5,3) -- (0,3) node [loopstart] {}
    -- (0,3.5) node [loopend] {}];
\end{scope}
\end{tikzpicture}

```

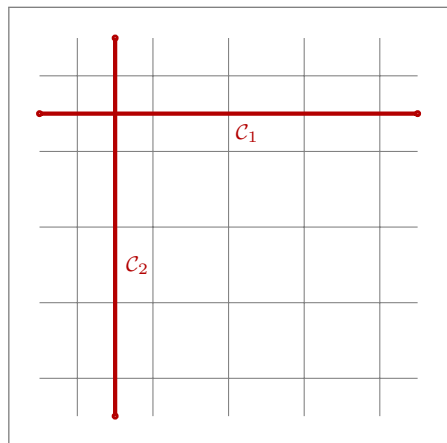


## Lattice links labels



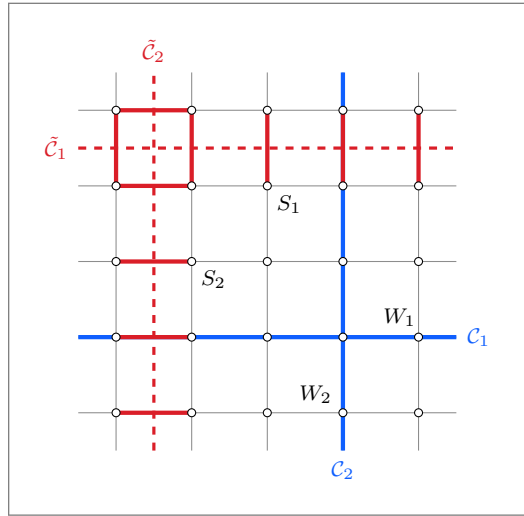
```
\begin{tikzpicture}[
  font=\small,
  scale=1.3,
  site/.style = {circle, inner sep=0 pt, minimum size=5pt, draw=black, fill=white},
  decoration={
    markings,
    mark=at position 0.35 with {\arrow{>}},
    mark=at position 0.85 with {\arrow{>}}
  }
]
% Lattice
\draw[Gray, thin] (-1.25, -1.25) grid (1.25, 1.25);
% links
\draw[very thick, postaction={decorate}]
  (-1, 0) -- (1, 0)
  node [pos=0.75, below] {$(x, \hat{1})$}
  % node [pos=0.25, below] {$(x, -\hat{1})$}
;
\draw[very thick, postaction={decorate}]
  (0, -1) -- (0, 1)
  node [pos=0.8, right] {$(x, \hat{2})$}
  % node [pos=0.15, right] {$(x, -\hat{2})$}
;
% sites
\foreach \x in {-1,...,1}
  \foreach \y in {-1,...,1}
    \draw (\x, \y) node [site] {};
\draw (0, 0) node [Gray, above right] {$x$};
\draw (1, 0) node [Gray, above right] {$x + \hat{1}$};
\draw (0, 1) node [Gray, above right] {$x + \hat{2}$};
\end{tikzpicture}
```

## Non contractible loops



```
\begin{tikzpicture}
\draw[step=1.0,gray,thin] (-0.5,-0.5) grid (4.5,4.5);
\draw[black!30!red, ultra thick] (0.5,-0.5) circle (0.5 pt) -- (0.5,4.5) node[pos=0.4,
  right] {$\mathcal{C}_2$} circle (0.5pt);
\draw[black!30!red, ultra thick] (-0.5,3.5) circle (0.5 pt) -- (4.5,3.5) node[pos=0.55,
  below] {$\mathcal{C}_1$} circle (0.5pt);
\end{tikzpicture}
```

## Non local operators

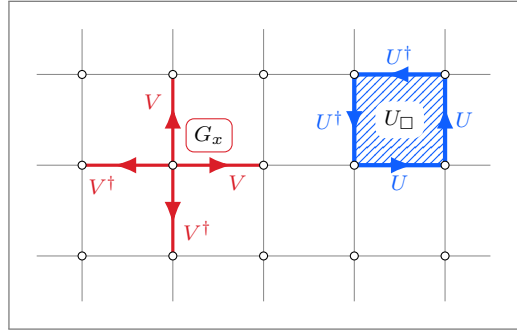


```
\begin{tikzpicture}[
  site/.style = {circle, inner sep=0 pt, minimum size=3pt, draw=black, fill=white},
]
% lattice grid
\draw[Gray,thin] (-0.5,-0.5) grid (4.5,4.5);

% Wilson loops
\draw[Blue, ultra thick]
  (-0.5, 1) -- (4.5, 1)
  node [pos=1, right] {\mathcal{C}_1}
  node [pos=0.85, above, black] {W_1}
  ;
\draw[Blue, ultra thick]
  (3, -0.5) -- (3, 4.5)
  node [pos=0, below] {\mathcal{C}_2}
  node [pos=0.15, left, black] {W_2}
  ;

% 't Hooft strings
\draw[Red, very thick, dashed]
  (-0.5,3.5) -- (4.5,3.5)
  node[pos=0, left] {\tilde{\mathcal{C}}_1}
  ;
\foreach \x in {0,...,4} { \draw[Red, ultra thick] (\x, 3) -- +(\x, 1); }
\draw (2,3) node [below right] {S_1};
\draw[Red, very thick, dashed]
  (0.5,-0.5) -- (0.5,4.5)
  node[pos=1, above] {\tilde{\mathcal{C}}_2}
  ;
\foreach \y in {0,...,4} { \draw[Red, ultra thick] (0, \y) -- +(1, 0); }
\draw (1,2) node [below right] {S_2};
\foreach \y in {0,...,4} \foreach \x in {0,...,4} \draw (\x,\y) node [site] {};
\end{tikzpicture}
```

## Gauss and plaquette operators



```
\begin{tikzpicture}[
  scale=1.2,
  site/.style = {circle, inner sep=0 pt, minimum size=3pt, draw=black, fill=white},
  decoration={
    markings,
    mark=at position 0.65 with {\arrow{>}}
  },
  plaq/.style={Blue, very thick, postaction={decorate}},
  gauss/.style={Red, very thick, postaction={decorate}}
]
% Lattice
\draw[Gray,thin] (-0.5,-0.5) grid (4.5,2.5);

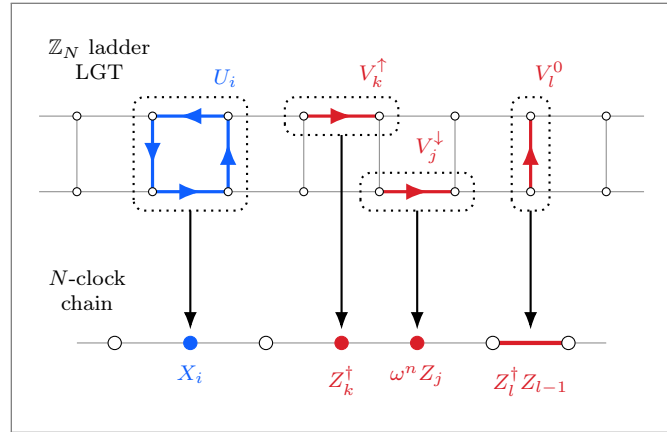
% Plaquette operator
\draw[plaq] (3,1) -- (4,1) node [pos=0.5, below] {$U$};
\draw[plaq] (4,1) -- (4,2) node [pos=0.5, right] {$U$};
\draw[plaq] (4,2) -- (3,2) node [pos=0.5, above] {$U^\dagger$};
\draw[plaq] (3,2) -- (3,1) node [pos=0.5, left] {$U^\dagger$};
\draw[Blue, ultra thick, pattern=north east lines, pattern color=Blue] (3,1)
rectangle (4,2);
\draw (3.5,1.5) node [fill=white, rounded corners] {$U_\square$};

% Gauss operator
\draw[gauss] (1, 1) -- (2, 1) node [pos=0.5, below right] {$V$};
\draw[gauss] (1, 1) -- (1, 2) node [pos=0.5, above left] {$V$};
\draw[gauss] (1, 1) -- (0, 1) node [pos=0.5, below left] {$V^\dagger$};
\draw[gauss] (1, 1) -- (1, 0) node [pos=0.5, below right] {$V^\dagger$};

\foreach \y in {0,1,2} \foreach \x in {0,1,...,4} \draw (\x,\y) node [site] {};

\draw (1,1) node [above right, outer sep=5pt, inner sep=3pt, draw=Red, rounded
corners=3pt] {$G_x$};
\end{tikzpicture}
```

## Duality map on a ladder



```

\begin{tikzpicture}[
  scale=1,
  site/.style = {circle, inner sep=0 pt, minimum size=3pt, draw=black, fill=white},
  site2/.style = {circle, inner sep=0 pt, minimum size=5pt, draw=black, fill=white},
  decoration={
    markings,
    mark=at position 0.65 with {\arrow{>}}
  },
  plaq/.style={Blue, very thick, postaction={decorate}},
  elec/.style={Red, very thick, postaction={decorate}},
  arr/.style={->, thick, shorten >=5pt},
  box/.style={dotted, rounded corners, thick}
]
% ladder
\draw[Gray, thin] (-0.5,0) grid (7.5,1);

% plaquette operator
\draw[plaq] (1,0) -- (2,0);
\draw[plaq] (2,0) -- (2,1);
\draw[plaq] (2,1) -- (1,1);
\draw[plaq] (1,1) -- (1,0);
\draw[box] (0.75,-0.25) rectangle (2.25, 1.25) node [above left, Blue] {$U_i$};

% horizontal electric operators
\draw[elec] (4,0) -- (5,0);
\draw[elec] (3,1) -- (4,1);
\draw[box] (3.75,-0.25) rectangle (5.25, 0.25) +(-0.25,0) node [above left, Red] {$\Vdown_j$};
\draw[box] (2.75, 0.75) rectangle (4.25, 1.25) node [above left, Red] {$\Vup_k$};

% vertical electric operator
\draw[elec] (6,0) -- (6,1);
\draw[box] (5.75,-0.25) rectangle (6.25, 1.25) node [above, Red] {$V_l^0$};

% ladder sites
\foreach \y in {0,1} \foreach \x in {0,...,7} \draw (\x,\y) node [site] {};

% chain
\draw[Gray, thin] (-0,-2) -- (7,-2);

% clock operators
\draw (1.5,-2) node [site2, draw=Blue, fill=Blue] {} node [text=Blue, below=5pt] {$X_i$};
\draw (3.5,-2) node [site2, draw=Red, fill=Red] {} node [text=Red, below=5pt] {$Z_k^\dagger$};
\draw (4.5,-2) node [site2, draw=Red, fill=Red] {} node [text=Red, below=5pt] {$\omega^n Z_j$};
\draw (6.5,-2) node [site2, draw=Red, fill=Red] {} node [text=Red, below=5pt] {$Z_l^\dagger Z_{l-1}$};

```

```

\draw [ultra thick, Red] (5.5,-2) -- (6.5,-2) node [pos=0.5, below=5pt] {$Z^\dagger_{l-1}$};

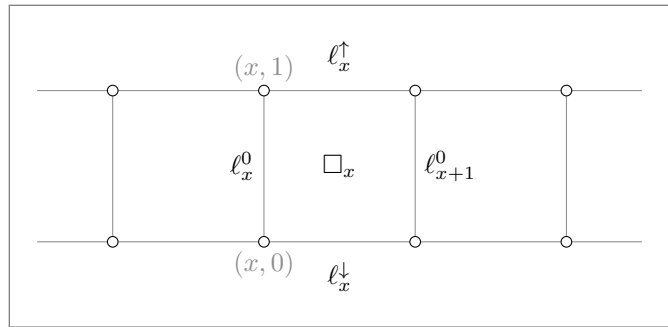
% chain sites
\foreach \x in {0,2,5,6} \draw (\x+0.5,-2) node [site2] {};

% arrows
\draw[arr] (1.5,-0.25) -- (1.5, -2);
\draw[arr] (3.5, 0.75) -- (3.5, -2);
\draw[arr] (4.5,-0.25) -- (4.5, -2);
\draw[arr] (6.0,-0.25) -- (6.0, -2);

% labels
\draw (-0.5,1.75) node [right, align=center] {$\backslash Z_N$ ladder \\\ LGT};
\draw (-0.5,-1.3) node [right, align=center] {$\backslash N$-clock \\\ chain};
\end{tikzpicture}

```

## Ladder geometry



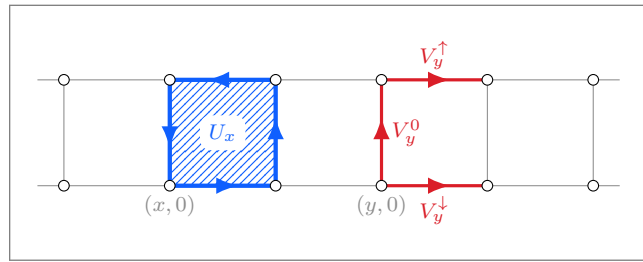
```
\begin{tikzpicture}[
  scale=1,
  font=\normalsize,
  site/.style = {circle, inner sep=0 pt, minimum size=4pt, draw=black, fill=white},
]
\draw[step=2, Gray, thin] (-1,0) grid (7,2);

\foreach \y in {0,2} \foreach \x in {0,2,...,6} \draw (\x,\y) node [site] {};

\draw[Gray] (2,0) node [below] {$(x, 0)$};
\draw[Gray] (2,2) node [above] {$(x, 1)$};

\draw (2,1) node [left] {$\text{\runlink\_x}$};
\draw (4,1) node [right] {$\text{\runlink\_}{x+1}$};
\draw (3,0) node [below=4pt] {$\text{\botlink\_x}$};
\draw (3,2) node [above=4pt] {$\text{\toplink\_x}$};
\draw (3,1) node {$\text{\square\_x}$};
\end{tikzpicture}
```

## Ladder operators



```
\begin{tikzpicture}[
  scale=0.7,
  site/.style = {circle, inner sep=0 pt, minimum size=4pt, draw=black, fill=white},
  decoration={
    markings,
    mark=at position 0.65 with {\arrow{>}}
  },
  plaq/.style={Blue, very thick, postaction={decorate}},
  elec/.style={Red, very thick, postaction={decorate}}
]
% ladder
\draw[Gray, step=2, thin] (-0.5,0) grid (10.5,2);

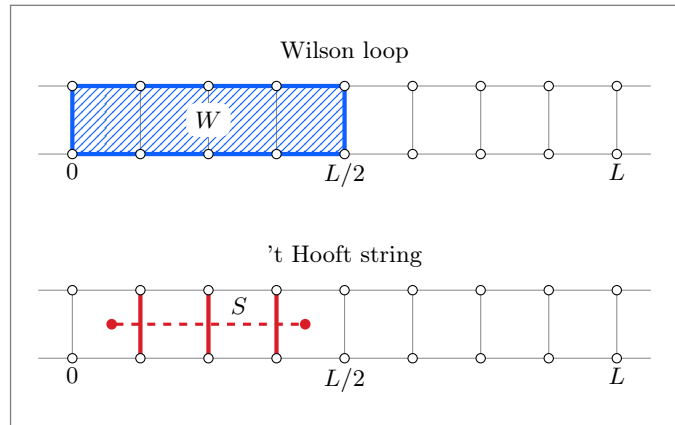
% Plaquette operator
\draw[Gray] (2,0) node [below] {$(x,0)$};
\draw[Blue, ultra thick, pattern=north east lines, pattern color=Blue] (2,0)
rectangle +(2,2);
\draw[plaq] (2,0) -- (4,0);
\draw[plaq] (4,0) -- (4,2);
\draw[plaq] (4,2) -- (2,2);
\draw[plaq] (2,2) -- (2,0);
\node at (3,1) [fill=white, rounded corners, text=Blue] {$U_x$};

% Electric field operators
\draw[Gray] (6,0) node [below] {$(y,0)$};
\draw[elec] (6,0) -- (6,2) node [pos=0.5, right] {$V_y^0$};
\draw[elec] (6,2) -- (8,2) node [pos=0.5, above] {$V_y^{\uparrow}$};
\draw[elec] (6,0) -- (8,0) node [pos=0.5, below] {$V_y^{\downarrow}$};

\foreach \y in {0,2} \foreach \x in {0,2,...,10} \draw (\x,\y) node [site] {};
\end{tikzpicture}
```



## Order parameters on a ladder

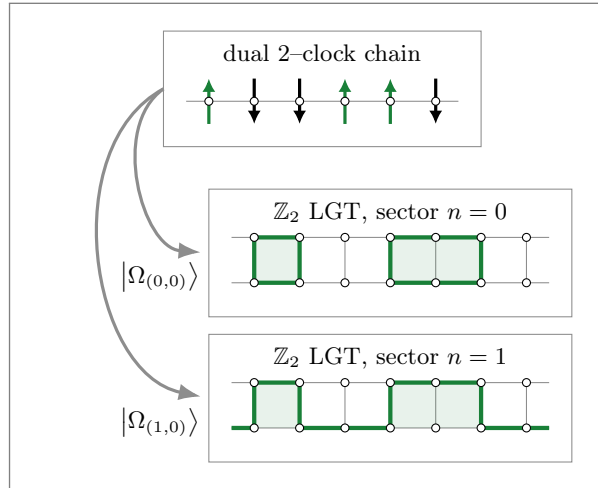


```
\begin{tikzpicture}[
  scale=0.9,
  font=\small,
  site/.style = {circle, inner sep=0 pt, minimum size=3.5pt, draw=black, fill=white},
  string/.style={Circle[length=4pt, width=4pt]}-{Circle[length=4pt, width=4pt]}, very
  thick, dashed, Red}
]
%% Wilson loop

% Lattice
\draw[Gray, thin] (-0.5,0) grid (8.5,1);
% Loop interior
\draw[Blue, ultra thick, pattern=north east lines, pattern color=Blue] (0,0)
rectangle (4,1);
% Labels
\draw (2,0.5) node [fill=white, rounded corners] {$W$};
\draw (0,0) node [below] {$0$};
\draw (4,0) node [below] {$L/2$};
\draw (8,0) node [below] {$L$};
\draw (4,1.5) node {Wilson loop};
\foreach \y in {0,1} \foreach \x in {0,...,8} \draw (\x,\y) node [site] {};

%% 't Hooft string
\begin{scope}[yshift=-3cm]
  % Lattice
  \draw[Gray, thin] (-0.5,0) grid (8.5,1);
  % String
  \draw [string] (0.5,0.5) -- (3.5,0.5) node [black, above, pos=0.65] {$S$};
  \foreach \x in {1,2,3} \draw [Red, ultra thick] (\x,0) -- (\x,1);
  % Labels
  \draw (0,0) node [below] {$0$};
  \draw (4,0) node [below] {$L/2$};
  \draw (8,0) node [below] {$L$};
  \draw (4,1.5) node {'t Hooft string};
  \foreach \y in {0,1} \foreach \x in {0,...,8} \draw (\x,\y) node [site] {};
\end{scope}
\end{tikzpicture}
```

## $\mathbb{Z}_2$ duality map



```

\newcommand{\UpArrow}[2]{\draw[up] (#1,#2) ++(0,-0.5) -- ++(0,1);}
\newcommand{\DownArrow}[2]{\draw[down] (#1,#2) ++(0,-0.5) -- ++(0,1);}
\begin{tikzpicture}[
  font=\small,
  scale=0.6,
  site/.style = {circle, inner sep=0 pt, minimum size=3pt, draw=black, fill=white},
  on/.style = {ultra thick, Green},
  flux/.style = {fill=Green, fill opacity=0.1},
  up/.style = {-{Latex[length=5pt, width=5pt]}, very thick, Green},
  down/.style = {-{Latex[length=5pt, width=5pt]}-, very thick}
]

% Clock chain
\begin{scope}[xshift=-1cm, yshift=4cm, local bounding box=chain]
  \draw[Gray, thin] (-0.5, 0) -- (5.5,0) node [pos=0.5, above=10pt, inner sep=5pt,
  black] {dual 2--clock chain};
  \foreach \x/\arr in {0/\UpArrow, 1/\DownArrow, 2/\DownArrow, 3/\UpArrow, 4/\
  UpArrow, 5/\DownArrow} {
    \arr{\x}{0};
    \draw (\x, 0) node [site] {};
  }
  \useasboundingbox (-1, 0) -- (6,0) -- +(0,-1);
\end{scope}

% LGT sector (0,0)
\begin{scope}[local bounding box=trivial]
  \node at (3,1) [above, inner sep=5pt] {\$Z_2\$ LGT, sector \$n=0\$};
  \draw[Gray, thin] (-0.5,0) grid (6.5,1);
  \draw[on, flux] (0,0) rectangle (1,1);
  \draw[on, flux] (3,0) rectangle (5,1);
  % sites
  \foreach \y in {0,1} \foreach \x in {0,1,...,6} \draw (\x,\y) node [site] {};
  \useasboundingbox (-1, 0) -- (7,0) -- +(0,-0.75);
\end{scope}

% LGT sector (1,0)
\begin{scope}[yshift=-3.2cm, local bounding box=topological]
  \node at (3,1) [above, inner sep=5pt] {\$Z_2\$ LGT, sector \$n=1\$};
  \draw[Gray, thin] (-0.5,0) grid (6.5,1);
  \draw[on] (-0.5, 0) -- (0,0) -- (0,1) -- (1,1) -- (1,0) -- (3,0) -- (3,1) --
  (5,1) -- (5,0) -- (6.5,0);
  \fill[flux] (0,0) rectangle (1,1);
  \fill[flux] (3,0) rectangle (5,1);
  % sites
  \foreach \y in {0,1} \foreach \x in {0,1,...,6} \draw (\x,\y) node [site] {};

```

```

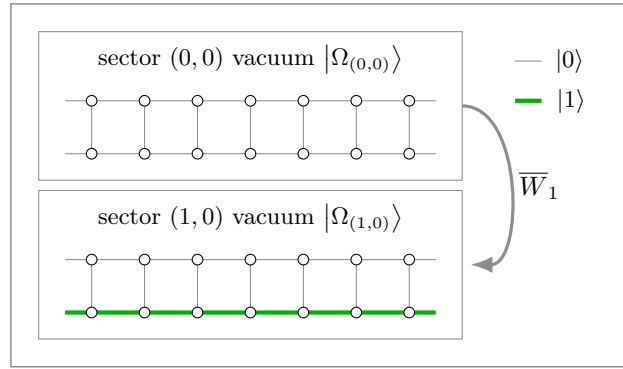
\useasboundingbox (-1, 0) -- (7,0) -- +(0,-0.75);
\end{scope}

% Bounding boxes
\draw [thin, Gray] (chain.north west) rectangle (chain.south east);
\draw [thin, Gray] (trivial.north west) rectangle (trivial.south east);
\draw [thin, Gray] (topological.north west) rectangle (topological.south east);

% Arrows between the bounding boxes
\draw [thick, Gray, shorten >= 3pt] (chain.west)
  edge [bend right=70, -{Latex}, Gray, very thick]
  % node [pos=0.8, below=6pt, text=black] {$\ket{\Omega_{(0,0)}}$}
  (trivial.west);
\draw [thick, Gray, shorten >= 3pt] (chain.west)
  edge [bend right=70, -{Latex}, Gray, very thick]
  % node [pos=0.85, below=10pt, text=black] {$\ket{\Omega_{(1,0)}}$}
  (topological.west);
\draw (trivial.west) node [below left] {$\ket{\Omega_{(0,0)}}$};
\draw (topological.west) node [below left] {$\ket{\Omega_{(1,0)}}$};
\end{tikzpicture}

```

## $\mathbb{Z}_2$ vacuum states



```
\begin{tikzpicture}[
  font=\small,
  scale=0.7,
  site/.style = {circle, inner sep=0 pt, minimum size=4pt, draw=black, fill=white},
  up/.style = {ultra thick, green!70!black},
  legend/.style = {text=black, inner sep=5pt}
]

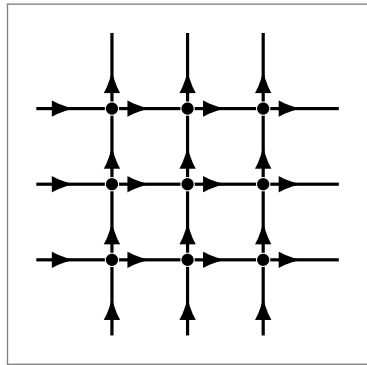
%%% Sector (0,0) vacuum
\begin{scope}[local bounding box=trivial]
  \node at (3,1) [above=5pt, legend] {sector  $(0,0)$  vacuum  $|\ket{\Omega_{(0,0)}}\rangle$ ;
  % ladder
  \draw[Gray, thin] (-0.5,0) grid (6.5,1);
  % sites
  \foreach \y in {0,1} \foreach \x in {0,1,...,6} \draw (\x,\y) node [site] {};
  \useasboundingbox (-1,0) -- (7,0) -- +(0,-0.5);
\end{scope}

%%% Sector (1,0) vacuum
\begin{scope}[yshift=-3cm, local bounding box=topol]
  \node at (3,1) [above=5pt, legend] {sector  $(1,0)$  vacuum  $|\ket{\Omega_{(1,0)}}\rangle$ ;
  % ladder
  \draw[Gray, thin] (-0.5,0) grid (6.5,1);
  % Wilson loop
  \draw[up] (-0.5, 0) -- (6.5, 0);
  % sites
  \foreach \y in {0,1} \foreach \x in {0,1,...,6} \draw (\x,\y) node [site] {};
  \useasboundingbox (-1,0) -- (7,0) -- +(0,-0.5);
\end{scope}

\begin{scope}[xshift=8cm, yshift=1cm, local bounding box=legend]
  \draw [Gray, thin] (0,0.75) -- +(0.5,0) node [right, legend] { $|\ket{0}\rangle$ ;
  \draw [up] (0,0) -- +(0.5,0) node [right, legend] { $|\ket{1}\rangle$ ;
  \useasboundingbox (-0.25,0);
\end{scope}

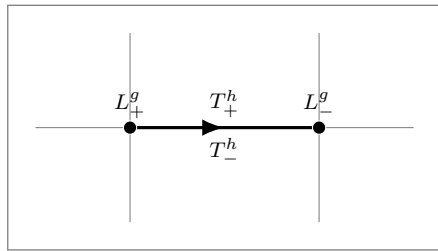
\draw[thin, Gray] (trivial.south west) rectangle (trivial.north east);
\draw[thin, Gray] (topol.south west) rectangle (topol.north east);
% \draw[thin, Gray] (legend.south west) rectangle (legend.north east);
\draw [shorten >= 3pt] (trivial.east)
  edge [-{Latex}, Gray, very thick, out=0, in=0]
  node [font=\normalsize, right, text=black] { $\overline{W}_1$ }
  (topol.east);
\end{tikzpicture}
```

## Orientation of a 2d lattice



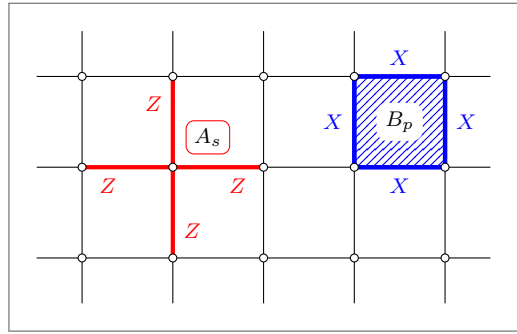
```
%
% Picture of the orientation of the 2d square lattice
%
\begin{tikzpicture}[
  decoration={
    markings,
    mark=at position 0.5 with {\arrow{>}}
  },
  link/.style={postaction={decorate}, very thick},
  site/.style={circle, inner sep=0pt, minimum size=5pt, draw=white, fill=black}
]
\foreach \x in {0,...,2} \draw [link] (\x, -1) -- +(0, 1);
\foreach \y in {0,...,2} \draw [link] (-1, \y) -- +(1, 0);
\foreach \x in {0,...,2}
\foreach \y in {0,...,2}
{
  \draw[link] (\x, \y) -- +(1, 0);
  \draw[link] (\x, \y) -- +(0, 1);
  \draw (\x, \y) node[site] {};
}
\end{tikzpicture}
```

## Orientation of link operators



```
%
% Picture of the orientation of the link operators  $L^g$  and  $T^h$ 
%
\begin{tikzpicture}[
  scale=2.5,
  decoration={
    markings,
    mark=at position 0.5 with {\arrow{>}}
  },
  link/.style={postaction={decorate}, very thick},
  site/.style={circle, inner sep=0pt, minimum size=5pt, draw=white, fill=black}
]
\draw[gray] (-0.5, 0) -- (1.5, 0);
\draw[gray] (0, -0.5) -- (0, 0.5);
\draw[gray] (1, -0.5) -- (1, 0.5);
\draw[link] (0,0) -- (1, 0)
  node [pos=0.5, above] {$T^h_+$}
  node [pos=0.5, below] {$T^h_-$}
  ;
\draw (0,0) node [site] {} node [above] {$L^g_+$};
\draw (1,0) node [site] {} node [above] {$L^g_-$};
\end{tikzpicture}
```

## Toric code operators



```
\begin{tikzpicture}[
    scale=1.2,
    site/.style = {circle, inner sep=0 pt, minimum size=3pt, draw=black, fill=white},
    plaq/.style={blue, ultra thick},
    gauss/.style={red, ultra thick}
]
% Lattice
\draw[thin] (-0.5,-0.5) grid (4.5,2.5);

% Plaquette operator
\draw[plaq] (3,1) -- (4,1) node [pos=0.5, below] {$X$};
\draw[plaq] (4,1) -- (4,2) node [pos=0.5, right] {$X$};
\draw[plaq] (4,2) -- (3,2) node [pos=0.5, above] {$X$};
\draw[plaq] (3,2) -- (3,1) node [pos=0.5, left] {$X$};
\draw[blue, ultra thick, pattern=north east lines, pattern color=blue] (3,1)
rectangle (4,2);
\draw (3.5,1.5) node [fill=white, rounded corners] {$B_p$};

% Gauss operator
\draw[gauss] (1, 1) -- (2, 1) node [pos=0.5, below right] {$Z$};
\draw[gauss] (1, 1) -- (1, 2) node [pos=0.5, above left] {$Z$};
\draw[gauss] (1, 1) -- (0, 1) node [pos=0.5, below left] {$Z$};
\draw[gauss] (1, 1) -- (1, 0) node [pos=0.5, below right] {$Z$};

\foreach \y in {0,1,2} \foreach \x in {0,1,...,4} \draw (\x,\y) node [site] {};

\draw (1,1) node [above right, outer sep=5pt, inner sep=3pt, draw=red, rounded
corners=3pt] {$A_s$};
\end{tikzpicture}
```

## Operators of a quantum double model

$$A_g(s, p) = \begin{array}{c} L_+^g \\ \rightarrow \quad \bullet \quad \rightarrow L_-^g \\ \uparrow \quad \bullet \quad \downarrow \\ L_+^g \end{array} \quad B_h(s, p) = \sum_{h_1 \dots h_4} T_-^{h_4} \begin{array}{c} T_-^{h_3} \\ \bullet \quad \bullet \\ \uparrow \quad \downarrow \\ \bullet \quad \bullet \\ T_+^{h_1} \end{array} T_+^{h_2}$$

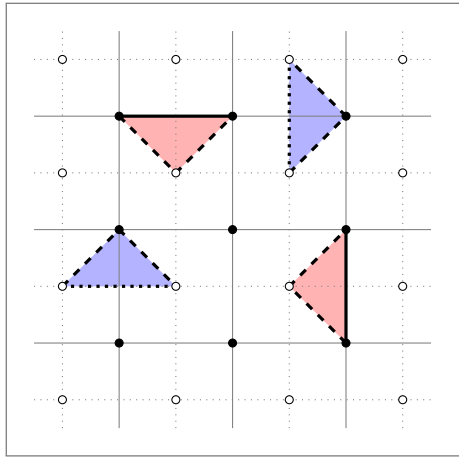
```
%
% Pictorial representations of the operators A_g and B_h
%
\begin{tikzpicture}[
  decoration={
    markings,
    mark=at position 0.5 with {\arrow{>}}
  },
  link/.style={postaction={decorate}, very thick},
  site/.style={circle, inner sep=0pt, minimum size=5pt, draw=white, fill=black},
  font=\small
]
\draw (-1.2, 0) node[font=\normalsize, anchor=east] {$A_g(s,p) = $};

\draw[link] (-1, 0) -- (0, 0) node [pos=0.3, above] {$L^g_+$};
\draw[link] (0, 0) -- (1, 0) node [pos=0.7, below] {$L^g_-$};
\draw[link] (0, -1) -- (0, 0) node [pos=0.3, left] {$L^g_+$};
\draw[link] (0, 0) -- (0, 1) node [pos=0.7, right] {$L^g_-$};
\draw (0, 0) node [site] {};
\draw (0, 0) node [above right, black!70] {$s$};

\begin{scope}[xshift=7cm]
\draw (-1.2, 0) node[font=\normalsize, anchor=east] {$B_h(s,p) = \sum_{h_1 \dots h_4}$};
\draw[link] (-0.5, -0.5) -- (+0.5, -0.5) node [pos=0.5, below] {$T^{h_4}_-$};
\draw[link] (+0.5, -0.5) -- (+0.5, +0.5) node [pos=0.5, right] {$T^{h_2}_+$};
\draw[link] (-0.5, +0.5) -- (+0.5, +0.5) node [pos=0.5, above] {$T^{h_3}_-$};
\draw[link] (-0.5, -0.5) -- (-0.5, +0.5) node [pos=0.5, left] {$T^{h_1}_+$};
\draw[>] (0, -0.25) arc (-90:180:0.25);
\draw[black!70] (0,0) node {$p$};
\draw[black!70] (-0.5,-0.5) node [below left] {$s$};
\foreach \x in {-0.5,0.5} \foreach \y in {-0.5,0.5} \draw (\x,\y) node [site] {};
\end{scope}
\end{tikzpicture}
```



## Triangles on a lattice



```
\begin{tikzpicture}[scale=1.5]
  % direct ribbons fill
  \fill [direct ribbon] (0, 2) -- ++(1, 0) -- ++(-0.5, -0.5) -- cycle;
  \fill [direct ribbon] (2, 0) -- ++(0, 1) -- ++(-0.5, -0.5) -- cycle;

  % dual ribbons fill
  \fill [dual ribbon] (-0.5, 0.5) -- ++(1, 0) -- ++(-0.5, 0.5) -- cycle;
  \fill [dual ribbon] (1.5, 1.5) -- ++(0, 1) -- ++(0.5, -0.5) -- cycle;

  % lattice grid
  \draw[gray, thin] (-0.75, -0.75) grid (2.75, 2.75);

  % dual lattice grid
  \draw[gray, dotted, xshift=-0.5cm, yshift=-0.5cm] (-0.25, -0.25) grid (3.25, 3.25);

  % direct ribbon draw
  \draw [direct edge] (0, 2) -- ++(1, 0);
  \draw [direct edge] (2, 0) -- ++(0, 1);
  \draw [ribbon site] (0, 2) -- ++(0.5, -0.5) -- ++(0.5, 0.5);
  \draw [ribbon site] (2, 0) -- ++(-0.5, 0.5) -- ++(0.5, 0.5);

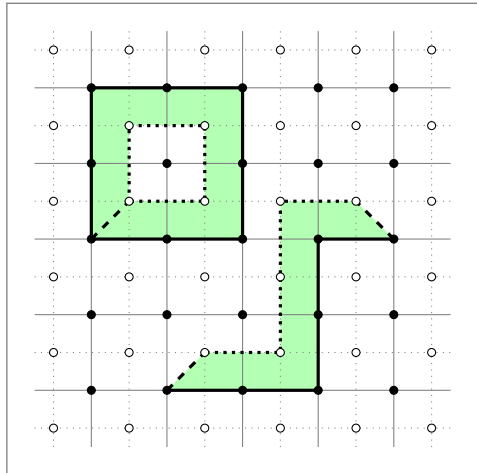
  % dual ribbon draw
  \draw [dual edge] (-0.5, 0.5) -- ++(1, 0);
  \draw [dual edge] (1.5, 1.5) -- ++(0, 1);
  \draw [ribbon site] (-0.5, 0.5) -- ++(0.5, 0.5) -- ++(0.5, -0.5);
  \draw [ribbon site] (1.5, 1.5) -- ++(0.5, 0.5) -- ++(-0.5, 0.5);

  % lattice sites
  \foreach \x in {0,...,2} \foreach \y in {0,...,2} \node at (\x, \y) [direct vertex] {};

  % dual lattice sites
  \begin{scope}[xshift=-0.5cm, yshift=-0.5cm]
    \foreach \x in {0,...,3} \foreach \y in {0,...,3} \node at (\x, \y) [dual vertex] {};
  \end{scope}

\end{tikzpicture}
```

## Examples of ribbons



```
\begin{tikzpicture}
  % first ribbon fill
  \fill[ribbon]
  (1,0) -- ++(2, 0) -- ++(0, 2) -- ++(1, 0) -- ++(-0.5, 0.5)
  -- ++(-1, 0) -- ++(0, -2) -- ++(-1, 0) -- cycle;

  % second ribbon fill
  \fill[ribbon] (0,2) rectangle ++(2, 2);
  \fill[white] (0.5, 2.5) rectangle ++(1, 1);

  % lattice grid
  \draw[gray, thin] (-0.75, -0.75) grid (4.75, 4.75);

  % dual lattice grid
  \draw[gray, dotted, xshift=-0.5cm, yshift=-0.5cm] (-0.25, -0.25) grid (5.25, 5.25);

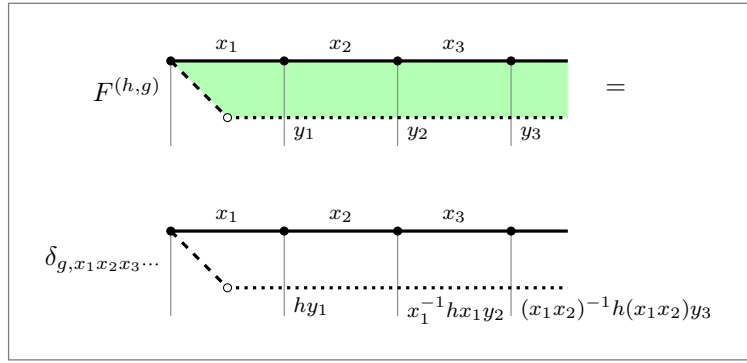
  % first ribbon draw
  \draw[ribbon site] (1, 0) -- ++(0.5, 0.5); % starting ribbon site
  \draw[direct edge] (1,0) -- ++(2, 0) -- ++(0, 2) -- ++(1,0);
  \draw[ribbon site] (4, 2) -- ++(-0.5, 0.5); % ending ribbon site
  \draw[dual edge] (3.5, 2.5) -- ++(-1, 0) -- ++(0, -2) -- ++(-1, 0);

  % second ribbon draw
  \draw[ribbon site] (0, 2) -- ++(0.5, 0.5);
  \draw[direct edge] (0, 2) rectangle ++(2, 2);
  \draw[dual edge] (0.5, 2.5) rectangle ++(1, 1);

  % lattice sites
  \foreach \x in {0,...,4} \foreach \y in {0,...,4} \node at (\x, \y) [direct vertex]
  {};

  % dual lattice sites
  \begin{scope}[xshift=-0.5cm, yshift=-0.5cm]
    \foreach \x in {0,...,5} \foreach \y in {0,...,5} \node at (\x, \y) [dual vertex]
    {};
  \end{scope}
\end{tikzpicture}
```

## Action of a ribbon operator



```
\begin{tikzpicture}[scale=1.5, font=\footnotesize]
% ribbon fill
\fill [ribbon] (0, 0) -- ++ (3.5, 0) -- ++(0, -0.5) -- ++(-3, 0) -- cycle;

% lattice grid
\draw[thin, gray] (0,0) grid (3.5, -0.75);

% ribbon edges
\draw[ribbon site] (0, 0) -- ++(0.5, -0.5);
\draw[direct edge] (0, 0) -- ++(3.5, 0);
\draw[dual edge] (0.5, -0.5) -- ++(3, 0);

% lattice vertices
\foreach \x in {0,...,3} \node at (\x, 0) [direct vertex] {};
\node at (0.5, -0.5) [dual vertex] {};

% labels
\node at (0.5, 0) [above] {$x_1$};
\node at (1.5, 0) [above] {$x_2$};
\node at (2.5, 0) [above] {$x_3$};

\node at (1, -0.5) [below right] {$y_1$};
\node at (2, -0.5) [below right] {$y_2$};
\node at (3, -0.5) [below right] {$y_3$};

\node at (0, -0.25) [left, font=\normalsize] {$F^{(h,g)}$};
\node at (3.75, -0.25) [right, font=\normalsize] {$ = $};

% transformed grid
\begin{scope}[yshift=-1.5cm]

% lattice grid
\draw[thin, gray] (0,0) grid (3.5, -0.75);

% ribbon edges
\draw[ribbon site] (0, 0) -- ++(0.5, -0.5);
\draw[direct edge] (0, 0) -- ++(3.5, 0);
\draw[dual edge] (0.5, -0.5) -- ++(3, 0);

% lattice vertices
\foreach \x in {0,...,3} \node at (\x, 0) [direct vertex] {};
\node at (0.5, -0.5) [dual vertex] {};

% labels
\node at (0.5, 0) [above] {$x_1$};
\node at (1.5, 0) [above] {$x_2$};
\node at (2.5, 0) [above] {$x_3$};

\node at (1, -0.5) [below right] {$hy_1$};
\node at (2, -0.5) [below right] {$x_1^{-1} h x_1 y_2$};
\node at (3, -0.5) [below right] {(x_1 x_2)^{-1} h (x_1 x_2) y_3};

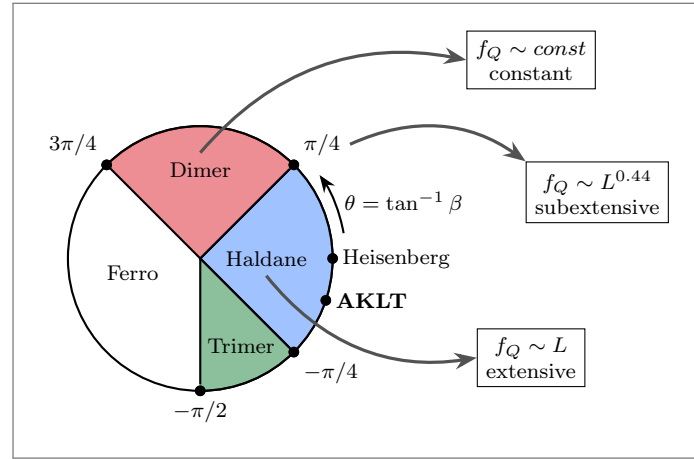
\end{scope}
\end{tikzpicture}
```

```

\begin{tikzpicture}
  \node at (3, -0.5) [below right] {$ (x_1 \ x_2)^{-1} h (x_1 \ x_2) y_3 $};
  \node at (0, -0.25) [left, font=\normalsize] {$ \delta_{g, x_1 \ x_2 \ x_3 \ \cdots} $};
\end{tikzpicture}

```

## Phases of the Bilinear-Biquadratic model



```
\begin{tikzpicture}[
  scale=1.75,
  font=\footnotesize,
  dot/.style = {circle, inner sep=0pt, minimum size=4pt, fill=black},
  thick,
  etichetta grafico/.style = {above=0.1cm, font=\normalsize, fill=Grey10, fill
opacity=0.9, text opacity=1, rounded corners, inner sep=2pt},
  nota grafico/.style = {below=0.2cm, font=\small, fill=Grey10, fill opacity=0.9,
text opacity=1, rounded corners, inner sep=2pt, align=center},
  sfondo grafico/.style = {fill=white, draw=black, thin, inner sep=2pt}
]
\node (A) at (45:1) [dot] {};
\node (C) at (-45:1) [dot] {};
\node (D) at (-90:1) [dot] {};
\node (E) at (135:1) [dot] {};
\node (H) at (0:1) [dot] {};
\node (K) at (-18.44:1) [dot] {};
\node[above right] (critical) at (A) {\pi/4};
\node[below right] at (C) {-\pi/4};
\node[below] at (D) {-\pi/2};
\node[above left] at (E) {3 \pi / 4};
\node[right] at (H) {Heisenberg};
\node[right] at (K) {\textbf{AKLT}};

\draw (0,0) circle [radius=1];

\draw[fill=Blue40, fill opacity=0.7] (0,0) -- (C) arc (-45:45:1) -- (0,0);
\draw[fill=Green, fill opacity=0.5] (0,0) -- (D) arc (-90:-45:1) -- (0,0);
\draw[fill=Red, fill opacity=0.5] (0,0) -- (A) arc (45:135:1) -- (0,0);

\node at (45:1) [dot] {};
\node at (-45:1) [dot] {};
\node at (-90:1) [dot] {};
\node at (135:1) [dot] {};
\node at (0:1) [dot] {};
\node at (-18.44:1) [dot] {};

\path (A) arc (45:135:1) node (dimer) [below=10pt, midway] {Dimer};
\path (C) arc (-45:45:1) node (Haldane) [left=6pt, midway] {Haldane};
\path (D) arc (-90:-225:1) node (above right=10pt, midway) {Ferro};
\path (C) arc (-45:-90:1) node (above=8pt, pos=0.6) {Trimer};

\draw[freccia] (10:1.1) arc (10:35:1.1) node (midway, right) {\theta = \tan^{-1} \beta};

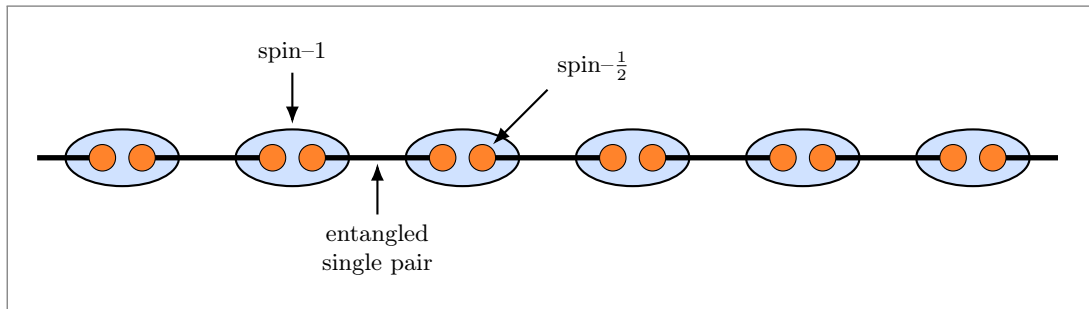
\node[align=center, draw=black, thin] (const) at (2.5, 1.5) {\$f_Q \sim const\$ \\\
constant};
```

```

\draw[very thick] (Haldane.south) edge[Grey60, freccia, bend right] (ext.west);
\draw[very thick] (critical.east) edge[Grey60, freccia, bend left] (subext.north west);
\draw[very thick] (dimer.north) edge[Grey60, freccia, bend left] (const.west);
\end{tikzpicture}

```

## AKLT state



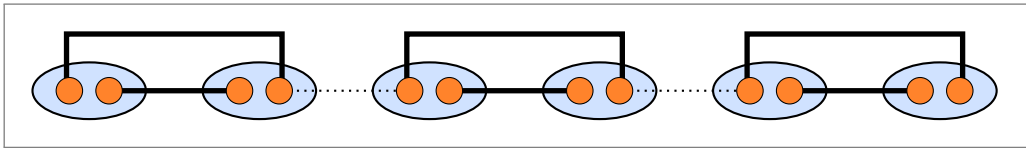
```
\begin{tikzpicture}[
  scale=0.75,
  spin one/.style={fill=Blue20, fill opacity=1, draw=black, thin, inner sep=0cm,
  minimum size=0.5cm, thick},
  spin half/.style={circle, fill=Orange, draw=black, inner sep=0cm, minimum size
  =0.35cm},
  entangled/.style={line width=2pt},
  nonentangled/.style={dotted, thick},
  font=\small
]
% spin 1 sites
\foreach \x in {0, 3, ..., 15}
\draw [spin one] (\x, 0) ellipse [ x radius=1cm, y radius=0.5cm ];

% entanglement lines
\foreach \x/\y in {0/3, 3/6, 6/9, 9/12, 12/15}
\draw[entangled] (\x+0.4,0 ) -- (\y-0.4,0);
\draw[entangled] (-1.5, 0) -- (-0.4, 0);
\draw[entangled] (15.4, 0) -- (16.5, 0);

% spin one half lines
\foreach \x in {0, 3, ..., 15} {
  \draw (\x+0.35, 0) node [anchor=center, spin half] {};
  \draw (\x-0.35, 0) node [anchor=center, spin half] {};
}

% labels
\draw[<-, shorten <=2pt, thick] (3, 0.5) -- +(0, 1) node [above] {spin--$1$};
\draw[<-, shorten <=1pt, thick] (6.5, 0.2) -- +(1, 1) node [above right] {spin--$\frac{1}{2}$};
\draw[<-, shorten <=2pt, thick] (4.5, 0) -- +(0, -1) node [below, align=center] {
entangled\ single pair};
\end{tikzpicture}
```

## Dimer state



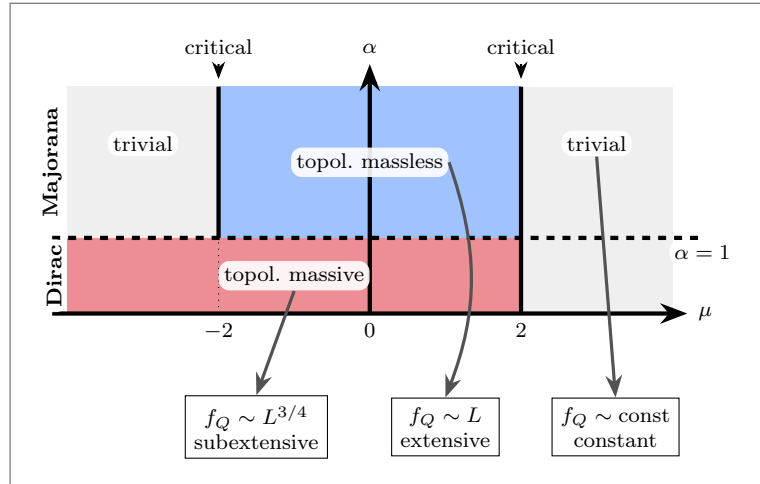
```
\begin{tikzpicture}[
  scale=0.75,
  spin one/.style={fill=Blue20, fill opacity=1, draw=black, thin, inner sep=0cm,
  minimum size=0.5cm, thick},
  spin half/.style={circle, fill=Orange, draw=black, inner sep=0cm, minimum size
  =0.35cm},
  entangled/.style={line width=2pt},
  nonentangled/.style={dotted, thick},
  font=\footnotesize
]
% spin 1 sites
\foreach \x in {0, 3, ..., 15}
\draw [spin one] (\x, 0) ellipse [ x radius=1cm, y radius=0.5cm ];

% entanglement lines
\foreach \x/\y in {0/3, 6/9, 12/15} {
  \draw[entangled] (\x+0.4, 0 ) -- (\y-0.4,0);
  \draw[entangled] (\x-0.4, 0 ) -- ++(0, 1) -- ++(3.8, 0) -- ++(0, -1);
}
\draw[nonentangled] (3.4, 0) -- (5.6,0);
\draw[nonentangled] (9.4, 0) -- (11.6,0);

% spin one half
\foreach \x in {0, 3, ..., 15} {
  \draw (\x+0.35, 0) node [anchor=center, spin half] {};
  \draw (\x-0.35, 0) node [anchor=center, spin half] {};
}
\end{tikzpicture}
```



## Phases of the long-range Kitaev model



```
\begin{tikzpicture}[
  scale=1.,
  font=\footnotesize,
  punto/.style = {circle, inner sep=0pt, minimum size=2pt, fill=black},
  massless/.style = {fill=Blue40, fill opacity=0.7},
  trivial/.style = {fill=Grey10, fill opacity=0.5},
  massive/.style = {fill=Red, fill opacity=0.5},
  etichetta spettro/.style = {above=-0.25cm, font=\normalsize, fill=Grey10, fill
  opacity=0.9, text opacity=1, rounded corners, inner sep=2pt}
]

%% Phases
% massless
\path[massless] (-2,1) rectangle (2,3);
% massive
\path[massive] (-4,1) rectangle (2,0);
% trivial
\path[trivial] (-4,1) rectangle (-2,3);
\path[trivial] (2,0) rectangle (4,3);

% sector separator
\draw[dashed, ultra thick] (-4.2,1) -- (4.4,1) node [below, etichetta] {$\alpha = 1$};

% critical line
\draw[ultra thick] (2,0) -- (2,3);
\draw[dotted] (-2,0) -- (-2,1);
\draw[ultra thick] (-2,1) -- (-2,3);

%% Axis
\draw[ultra thick, freccia] (0,0) -- (0,3.3) node [above] {$\alpha$};
\draw[ultra thick, freccia] (-4.2,0) -- (4.2,0) node [right] {$\mu$};
\draw (2,0) node [below] {2};
\draw (-2,0) node [below] {-2};
\draw (0,0) node [below] {0};

% labels
\node [etichetta] (massless) at (0,2) {topol.~massless};
\node [etichetta] (trivial1) at (-3,2.25) {trivial};
\node [etichetta] (trivial2) at (3,2.25) {trivial};
\node [etichetta] (massive) at (-1,0.5) {topol.~massive};

\draw[Stealth-, thick] (2,3.1) -- (2,3.3) node [above] {critical};
\draw[Stealth-, thick] (-2,3.1) -- (-2,3.3) node [above] {critical};
```

```

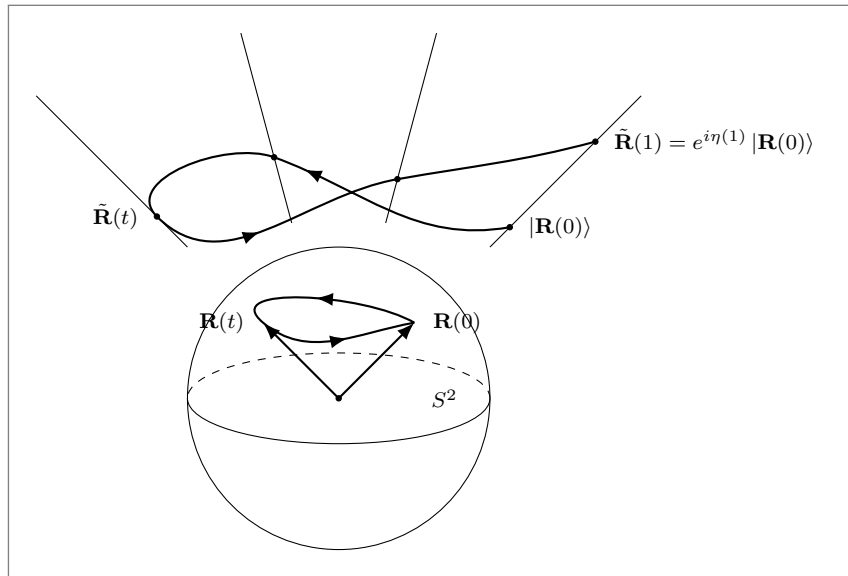
\draw (-4, 2) node [anchor=south, etichetta, rotate=90] {\textbf{Majorana}};
\draw (-4, 0.5) node [anchor=south, etichetta, rotate=90] {\textbf{Dirac}};

\node[align=center, draw=black] (subext) at (-1.5, -1.5) {\mathfrak{f}_Q \sim L^{3/4} \\\subextensive};
\node[align=center, draw=black] (ext) at ( 1.0, -1.5) {\mathfrak{f}_Q \sim L \\\ extensive};
\node[align=center, draw=black] (const) at ( 3.25, -1.5) {\mathfrak{f}_Q \sim \text{const} \\\ constant};

\draw[very thick] (massive.south) edge[Grey60, freccia] (subext.north);
\draw[very thick] (massless.east) edge[Grey60, freccia, bend left=20] (ext.north);
\draw[very thick] (trivial2.south) edge[Grey60, freccia] (const.north);
\end{tikzpicture}

```

## Adiabatic phase



```
\begin{tikzpicture}[scale=2]
% Sphere
\draw (1,0) arc (0:360:1);
\draw (1,0) arc [x radius=1, y radius=0.3, start angle=0, end angle=-180] {};
\draw[dashed] (1,0) arc [x radius=1, y radius=0.3, start angle=0, end angle=180] {};

\draw (0.7, 0) node {\$S^2\$};

\draw[fill] (0,0) circle [radius=0.5pt] ;

\begin{scope}[thick,decoration={
    markings,
    mark=at position 0.3 with {\arrow{>}},
    mark=at position 0.8 with {\arrow{>}}}
]
\draw[postaction={decorate}] (0.5,0.5)
    to [out=150, in=140] (-0.5,0.5)
    to [out=-40, in=190] (0.5, 0.5)
;
\end{scope}
\draw (0.5,0.5) node [label=right:{ \$ \mathbf{R}(0) \$ }] {};
\draw (-0.5,0.5) node [label=left:{ \$ \mathbf{R}(t) \$ }] {};

% Arrows from the origin
\draw[thick, ->] (0,0) -- (0.5, 0.5 );
\draw[thick, ->] (0,0) -- (-0.5, 0.5);

% Fibers
\draw (1,1) -- (2,2);
\draw (-1,1) -- (-2,2);
\draw (75:1.2) -- (75:2.5);
\draw (105:1.2) -- (105:2.5);

\coordinate (R0) at (45:1.6);
\coordinate (R1) at (45:2.4);
\coordinate (R2) at (75:1.5);
\coordinate (R3) at (105:1.65);
\coordinate (Rt) at (135:1.7);

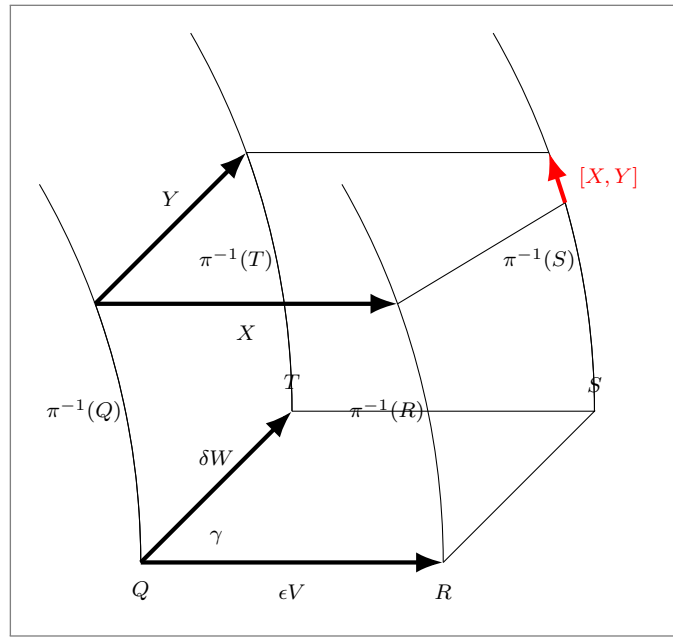
\draw[fill] (R0) circle [radius=0.5pt] node[label=right:{\$ \ket{\mathbf{R}(0)} \$}] {};
\draw[fill] (R1) circle [radius=0.5pt] node[label=right:{\$ \tilde{\mathbf{R}}(1) = e^{i\eta(1)} \ket{\mathbf{R}(0)} \$}] {};
\draw[fill] (R2) circle [radius=0.5pt] ;
```

```

\draw[fill] (R3) circle [radius=0.5pt] ;
\draw[fill] (Rt) circle [radius=0.5pt] node[label=left:{$\tilde{\mathbf{R}}(t)$}] {};

\begin{scope}[thick,decoration={
    markings,
    mark=at position 0.25 with {\arrow{>}},
    mark=at position 0.6 with {\arrow{>}}}
]
\draw[postaction={decorate}]
(R0) to [out=190, in=-20] (R3)
to [out=160, in=135] (Rt)
to [out=-45, in=190] (R2)
to [out=10, in=195] (R1)
;
\end{scope}
\end{tikzpicture}

```



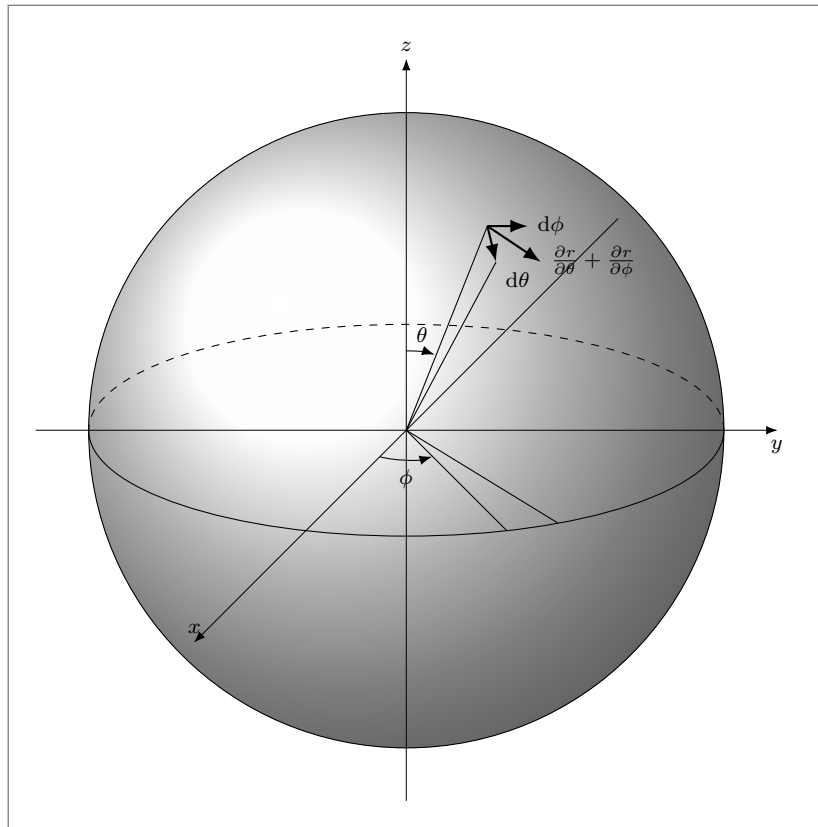
```
\begin{tikzpicture}[scale=2]
  \draw (0.5,0) node [label={\gamma}] {};
  \draw (0,0) node [label=below:{Q}] {};
  \draw[->, ultra thick] (0,0) -- (2,0) node [label=below:{R}] {} node [midway, label=below:{\epsilon V}] {}; % segmento Q-R
  \draw[->, ultra thick] (0,0) -- (1,1) node [label=above:{T}] {} node [midway, label={\delta W}] {}; % segmento Q-T
  \draw (1,1) -- (3,1) node [label=above:{S}] {} -- (2,0);

  % Fibers
  \draw (0,0) arc (0:30:5);
  \draw (2,0) arc (0:30:5);
  \draw (1,1) arc (0:30:5);
  \draw (3,1) arc (0:30:5);

  \draw (0,1) node [label=left:{\pi^{-1}(Q)}] {};
  \draw (2,1) node [label=left:{\pi^{-1}(R)}] {};
  \draw (1,2) node [label=left:{\pi^{-1}(T)}] {};
  \draw (3,2) node [label=left:{\pi^{-1}(S)}] {};

  \draw (0,0) arc (0:20:5) coordinate (pQ);
  \draw[->, ultra thick] (pQ) -- ++ (2,0) coordinate (x) node [midway, label=below:{X}] {};
  \draw[->, ultra thick] (pQ) -- ++ (1,1) node [midway, label=above:{Y}] {};
  \draw (1,1) arc (0:20:5) -- ++ (2,0) coordinate (z);
  \draw (3,1) arc (0:16:5) coordinate (y) ;
  \draw (x) -- (y);
  \draw[->,red,ultra thick] (y) -- (z) node [midway, label=right:{[X, Y]}] {};
\end{tikzpicture}
```

## Sphere



```
\begin{tikzpicture}[scale=0.7]
  \pgfmathsetmacro{\Rx}{6}
  \pgfmathsetmacro{\Ry}{2}
  \pgfmathsetmacro{\Rr}{3}

  \filldraw[ball color=black!01] (0,0) circle (\Rx);

  % Axis
  \draw[very thin,->] (-7,0) -- (7,0) node [below] {$y$};
  \draw[very thin,->] (0,-7) -- (0,7) node [above] {$z$};
  \draw[very thin,->] (4,4) -- (-4,-4) node [above] {$x$};

  % Equator
  \draw[name path=equatore] (\Rx,0) arc (0:-180:\Rx) and \Ry;
  \draw[dashed] (\Rx,0) arc (0:180:\Rx) and \Ry;

  % Reference meridians (not drawn)
  \path[name path=meridiano1] (0,\Rx) arc (90:-90:\Ry) and \Rx;
  \path[name path=meridiano2] (0,\Rx) arc (90:-90:\Rr) and \Rx;

  % Polar angle
  \path (0,\Rx) arc (90:40:\Ry) and \Rx coordinate (P1);
  \path (0,\Rx) arc (90:32:\Ry) and \Rx coordinate (P2);

  % Azimuthal angle
  \path[name intersections={of=equatore and meridiano1, name=x}] (x-1) coordinate (Q1);
  \path[name intersections={of=equatore and meridiano2, name=x}] (x-1) coordinate (Q2);

  % Variations
  \path (0,\Rx) arc (90:40:\Rr) and \Rx coordinate (P1Q2);
  \path (0,\Rx) arc (90:32:\Rr) and \Rx coordinate (P2Q2);

  % Segments from the origins
  \draw (0,0) -- (P1);
  \draw (0,0) -- (P2);
```

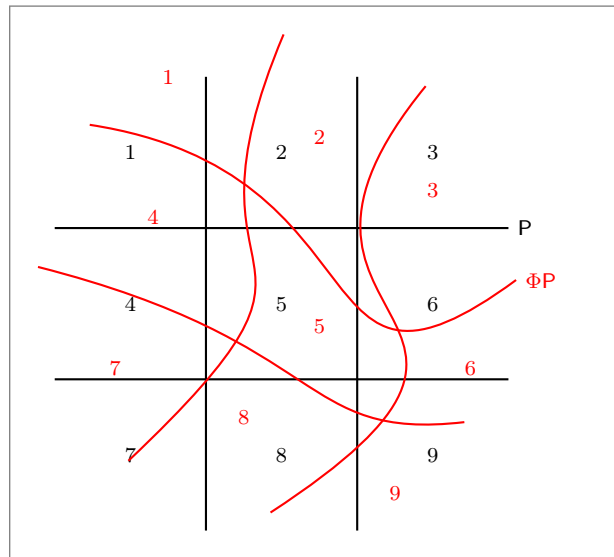
```

\draw (0,0) -- (Q1);
\draw (0,0) -- (Q2);
\draw[thick,->] (P1) -- (P2) node [below right] {$\dd \theta$};
\draw[thick,->] (P1) -- (P1Q2) node [right] {$\dd \phi$};
\draw[thick,->] (P1) -- (P2Q2) node [right] {$\pdv{r}{\theta} + \pdv{r}{\phi}$};

% Arcs
\draw[->] (0,1.5) arc (90:40:0.7 and 0.2) node [midway,above] {$\theta$} ;
\draw[->] (-0.5,-0.5) arc (225:315:0.7 and 0.2) node [midway,below] {$\phi$} ;
\end{tikzpicture}

```

## Partition



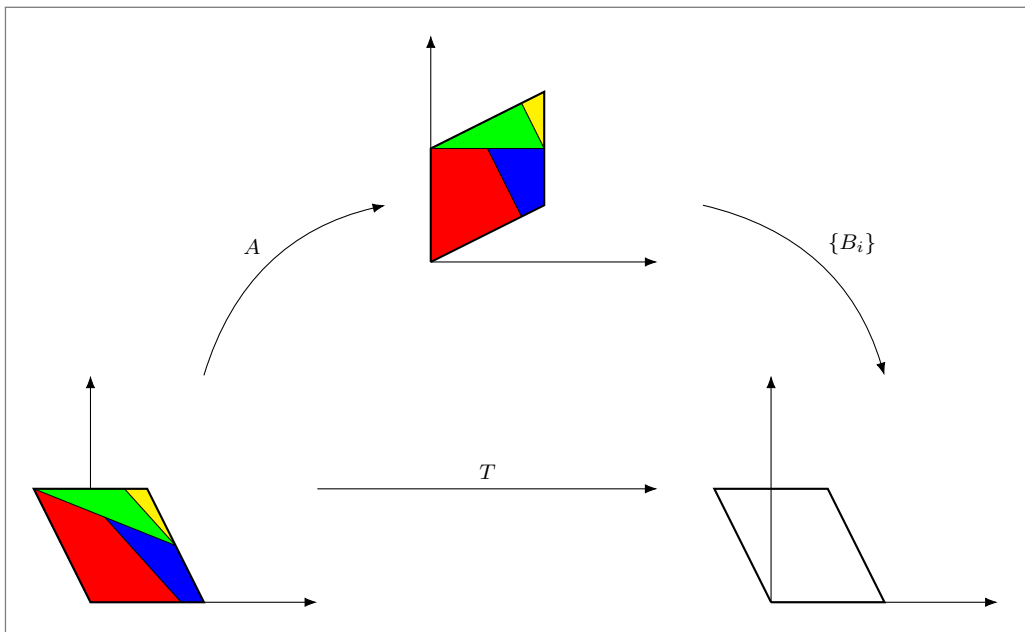
```
\begin{tikzpicture}
% Non-transformed grid
\foreach \t in {2,4} \draw[thick] (\t,0) -- (\t,6);
\foreach \t in {2,4} \draw[thick] (0,\t) -- (6,\t);
% Name each cells
\draw (1,5) node {1}
      (3,5) node {2}
      (5,5) node {3}
      (1,3) node {4}
      (3,3) node {5}
      (5,3) node {6}
      (1,1) node {7}
      (3,1) node {8}
      (5,1) node {9};

% Transformed grid
\begin{scope}[red, thick, rotate=-20, yshift=1.2cm, xshift=-1.4cm]
\foreach \t in {2,4} \draw (\t,0) .. controls ({1 + 1.5*\t},4) and ({1+0.4*\t},2)
.. (\t,6);
\foreach \t in {2,4} \draw (0,\t) .. controls (4,{0 + 1.2*\t}) and (4,1) .. (6,\t);
\end{scope}
% Name each new cells
\draw[red] (1.5,6) node {1}
           (3.5,5.2) node {2}
           (5,4.5) node {3}
           (1.3,4.15) node {4}
           (3.5,2.7) node {5}
           (5.5,2.15) node {6}
           (0.8,2.15) node {7}
           (2.5,1.5) node {8}
           (4.5,0.5) node {9};

% Labels
\draw (6,4) node [right] { $ \mathsf{P} $ };
\draw[red] (6.1,3.3) node [right] { $ \Phi \mathsf{P} $ };
\end{tikzpicture}
```



## Ergodic map



```
\begin{tikzpicture}[scale=1.5]
  % Parallelogram 1

  % initial axis
  \draw[<->, thin] (2,0) -- (0,0) -- (0,2);

  \coordinate (a1) at (0,0);
  \coordinate (b1) at (1,0);
  \coordinate (c1) at (0.5,1);
  \coordinate (d1) at (-0.5,1);

  \coordinate (a1b1) at (4/5, 0);
  \coordinate (x1) at (1/8, 3/4);
  \coordinate (b1c1) at (3/4, 1/2);
  \coordinate (c1d1) at (3/10, 1);

  \fill[red] (a1) -- (a1b1) -- (x1) -- (d1) -- cycle;
  \fill[blue] (a1b1) -- (b1) -- (b1c1) -- (x1) -- cycle;
  \fill[green] (b1c1) -- (c1d1) -- (d1) -- cycle;
  \fill[yellow] (b1c1) -- (c1) -- (c1d1) -- cycle;

  % cuts
  \draw (a1b1) -- (x1) (b1c1) -- (c1d1) (b1c1) -- (d1);

  % contour
  \draw[thick] (a1) -- (b1) -- (c1) -- (d1) -- cycle;

  % Environment for parallelogram 2
  \begin{scope}[xshift=3cm,yshift=3cm]
    \draw[<->, thin] (2,0) -- (0,0) -- (0,2); % assi

    \coordinate (a2) at (0,0);
    \coordinate (b2) at (1,0.5);
    \coordinate (c2) at (1,1.5);
    \coordinate (d2) at (0,1);

    \coordinate (a2b2) at (4/5, 2/5);
    \coordinate (x2) at (1/2, 1);
    \coordinate (b2c2) at (1, 1);
    \coordinate (c2d2) at (4/5, 7/5);
  \end{scope}
\end{tikzpicture}
```

```

\fill[red] (a2) -- (a2b2) -- (x2) -- (d2) -- cycle;
\fill[blue] (a2b2) -- (b2) -- (b2c2) -- (x2) -- cycle;
\fill[green] (b2c2) -- (c2d2) -- (d2) -- cycle;
\fill[yellow] (b2c2) -- (c2) -- (c2d2) -- cycle;

% cuts
\draw (a2b2) -- (x2) (b2c2) -- (c2d2) (b2c2) -- (d2);

% contour
\draw[thick] (a2) -- (b2) -- (c2) -- (d2) -- (a2);
\end{scope}

% Environment for parallelogram 3
\begin{scope}[xshift=6cm]
\draw[<->, thin] (2,0) -- (0,0) -- (0,2); % assi

\coordinate (a3) at (0,0);
\coordinate (b3) at (1,0);
\coordinate (c3) at (0.5,1);
\coordinate (d3) at (-0.5,1);

\draw[thick] (a3) -- (b3) -- (c3) -- (d3) -- (a3);
\end{scope}

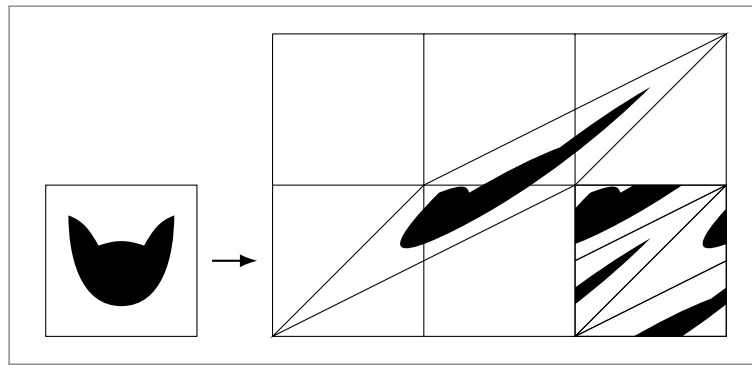
% arrow 1 -> 2
\draw[->] (1,2) to [bend left] node [midway, above left] { $ A $ } (2.6, 3.5);

% arrow 2 -> 3
\draw[->] (5.4,3.5) to [bend left] node [midway, above right] { $ \{B_i\} $ } (7,2);

% arrow 3 -> 1
\draw[<-] (5,1) to [] node [midway, above] { $ T $ } (2,1);
\end{tikzpicture}

```

## Arnold cat



```
% macro for drawing the cat
\newcommand{\Cat}{
  \draw[thin] (0,0) rectangle (2,2);
  \fill (1,0.4)
    to [in=270, out=0] ++( 0.7, 1.2)
    to [out=200, in=60] ++(-0.4, -0.4)
    to [out=160, in=20] ++( -0.6, 0)
    to [out=120, in=-20] ++( -0.4, 0.4)
    to [in=180, out=270] cycle;
}

\begin{tikzpicture}[deform/.style={ yslant=0.5, xslant=2, yscale=0.5, xscale=2}]
  % non-deformed cat
  \Cat

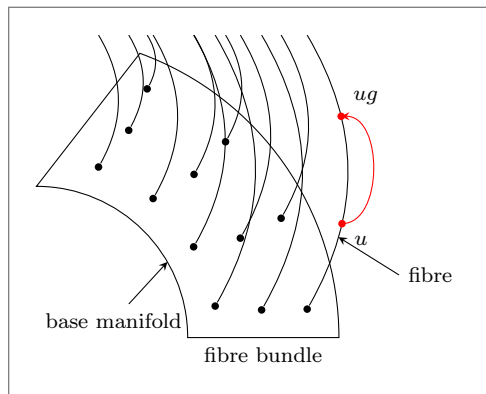
  % grid 3x2
  \draw[xshift=3cm, step=2cm, thin] (0,0) grid (6,4);

  % arrow
  \draw[->, thick] (2.2, 1) -- (2.8,1);

  % deformed cat full
  \begin{scope}[xshift=3cm, deform]
    \Cat
  \end{scope}

  % deformed cat cut
  \clip[draw] (7,0) rectangle ++(2,2);
  \begin{scope}[xshift=5cm, deform]
    \Cat
  \end{scope}
  \begin{scope}[xshift=5cm, yshift=-2cm, deform]
    \Cat
  \end{scope}
  \begin{scope}[xshift=3cm, yshift=-2cm, deform]
    \Cat
  \end{scope}
  \begin{scope}[xshift=7cm, deform]
    \Cat
  \end{scope}
\end{tikzpicture}
```

## Principal bundle



```
\begin{tikzpicture}[>=stealth, every node/.style={font=\footnotesize}]
% manifold
\draw(2,0)--(4,0)node[midway,below]{fibre bundle}arc(0:70:4)--(90:2)arc(90:0:2)--
cycle;
\draw[->] (20:1.3)node[below,xshift=-2mm]{base manifold}--(30:2);

% fibres
\begin{scope}[bend right]
\foreach \i[count=\x] in {10,30,50,70}
{\node(a\x)[circle,fill,inner sep=1pt]at (\i:2.4){};
\draw(a\x)to(a\x|-0,4);}

\foreach \i[count=\x] in {7,26,46,66}
{\node(b\x)[circle,fill,inner sep=1pt]at (\i:3){};
\draw(b\x)to(b\x|-0,4);}

\foreach \i[count=\x] in {6,26,46,66}
{\node(c\x)[circle,fill,inner sep=1pt]at (\i:3.6){};
\draw(c\x)to(c\x|-0,4);}

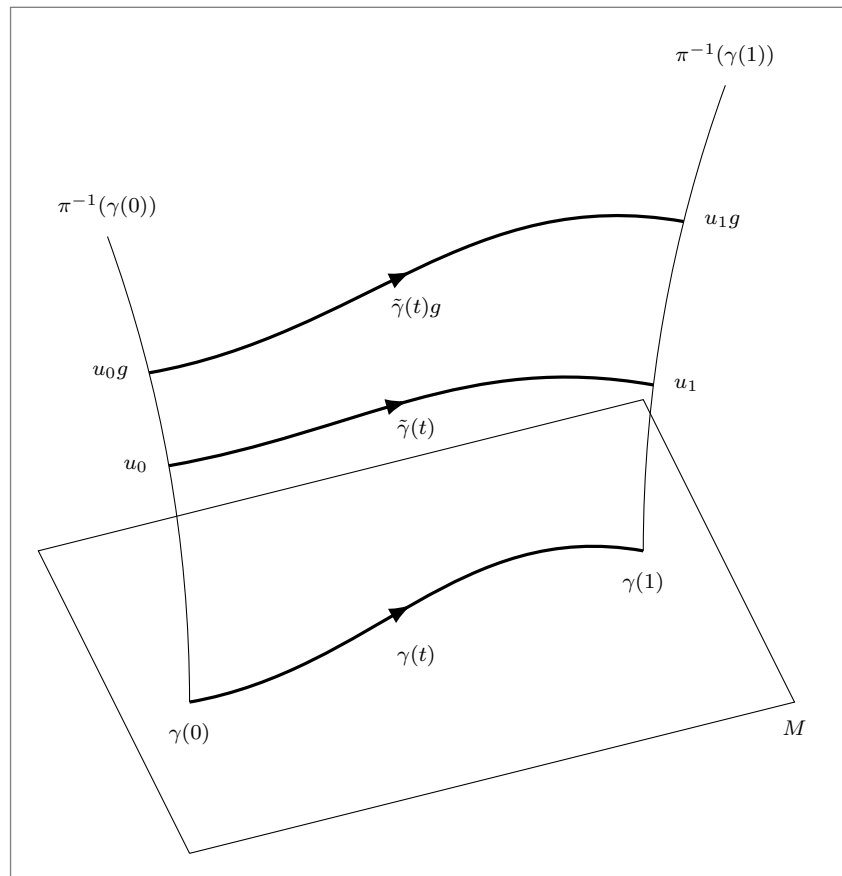
\path(c1)to coordinate[near start](d)(c1|-0,4);

\path(c1) to coordinate[ pos=0.3 ](x)(c1 |- -0,4);
\path(c1) to coordinate[ pos=0.7 ](y)(c1 |- -0,4);
\end{scope}

\draw[<-](d)--+(0.8,-0.5)node[right]{fibre};

% u and ug
\draw (x) node [red, circle, fill, inner sep=1pt, label=below right:{ $u$ }] {};
\draw (y) node [red, circle, fill, inner sep=1pt, label=above right:{ $u g$ }] {};
\draw[->, red] (x) to [ bend right=90 ] (y);
\end{tikzpicture}
```

## Parallel transport



```
\begin{tikzpicture}[scale=2]
  % rectangle
  \draw (0,0) -- ++(4,1) -- ++(-1,2) -- ++(-4,-1) -- ++(1,-2);
  \draw (4,1) node [label=below:{$M$}] {};

  \draw (0,1) arc (0:20:9) node [label={$\pi^{-1}(\gamma(0))$}] {};
  \draw (3,2) arc (180:160:9) node [label={$\pi^{-1}(\gamma(1))$}] {};

  \path (0,1) arc (0:10:9) coordinate (u0);
  \path (0,1) arc (0:14:9) coordinate (u0g);
  \path (3,2) arc (180:173:9) coordinate (u1);
  \path (3,2) arc (180:166:9) coordinate (u1g);

  % various gamma
  \begin{scope}[very thick,decoration={
    markings,
    mark=at position 0.5 with {\arrow{>}}}
  ]
  % gamma
  \draw[postaction={decorate}] (0,1)
  node [label=below:{$\gamma(0)$}] {}
  to [ out=10, in=170] ++(3,1)
  node (g1) [label=below:{$\gamma(1)$}] {}
  ;
  \draw[postaction={decorate}] (u0)
  node [label=left:{$u_0$}] {}
  to [ out=10, in=170] (u1)
  node [label=right:{$u_1$}] {}
  ;
  \draw[postaction={decorate}] (u0g)
  node [label=left:{$u_0 g$}] {}
  to [ out=10, in=170] (u1g)
  ;
  \end{scope}
\end{tikzpicture}
```

```

        node [label=right:{$u_1 g$}] {}
    ;
\end{scope}

\draw (1.5,1.5) node [label=below:{$\gamma(t)$}] {};
\draw (1.5,3) node [label=below:{$\tilde{\gamma}(t)$}] {};
\draw (1.5,3.8) node [label=below:{$\tilde{\gamma}(t)g$}] {};
\end{tikzpicture}

```