TikZ Is All You Need

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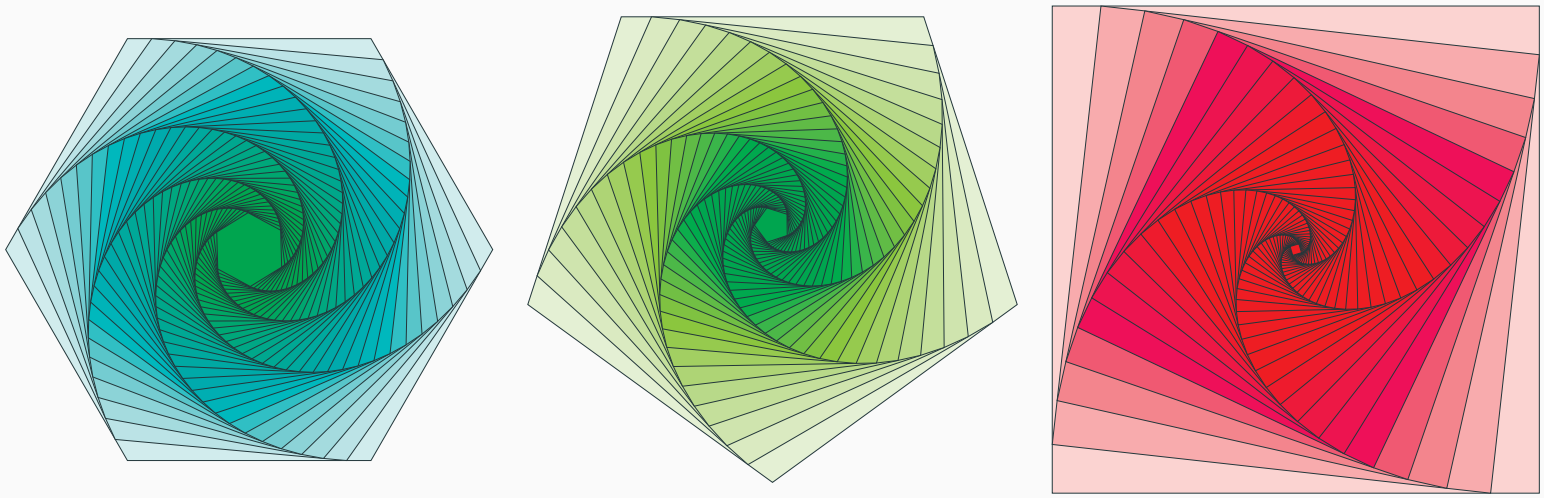
What is PGF/TikZ?

- Author: Till Tantau (University of Lübeck)
- PGF: “Portable Graphics Format” (backend)
- TikZ: “TikZ ist *kein* Zeichenprogramm” (frontend)
  (German for ”TikZ is *not* a drawing program”)
- Current version: 3.1.9a, *1321 page manual*,
  https://pgf-tikz.github.io/pgf/pgfmanual.pdf

Showcase - Example #1

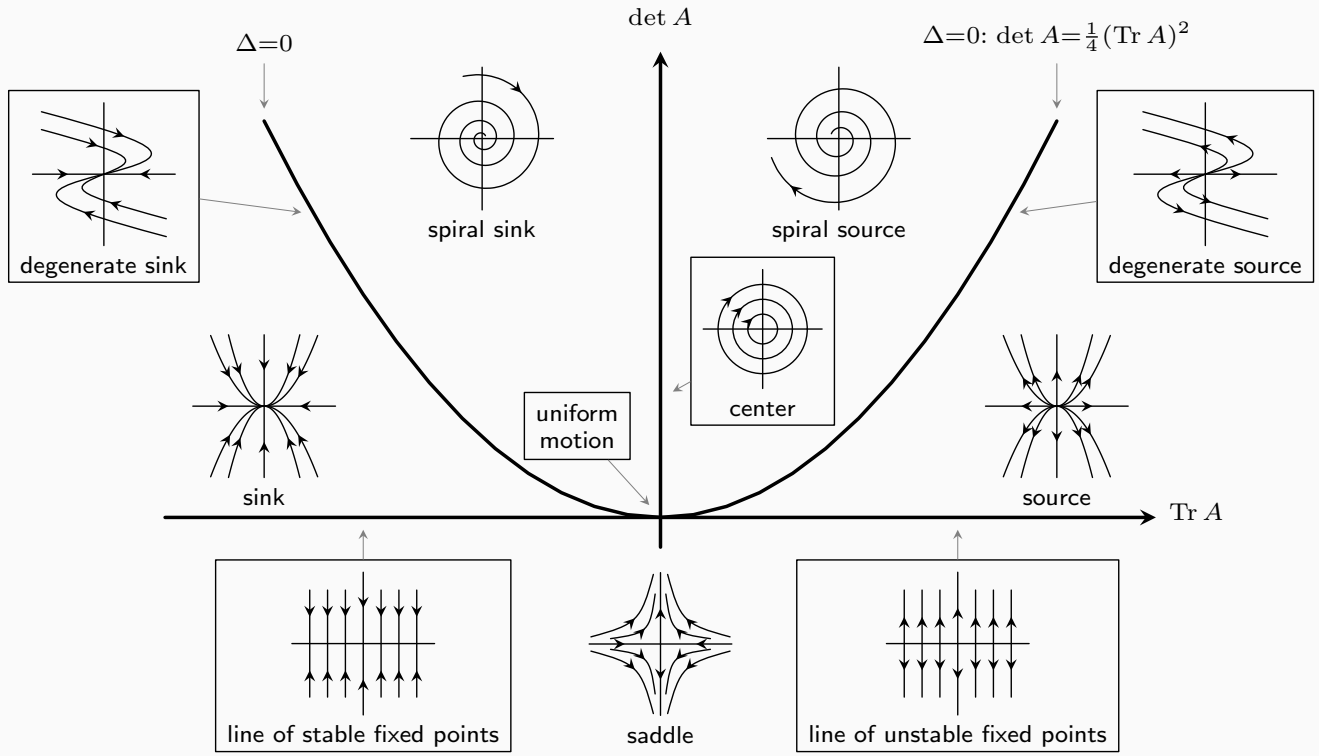


Source: https://texample.net/tikz/examples/rotated-polygons/

Size: 76 lines of code

Showcase - Example #2

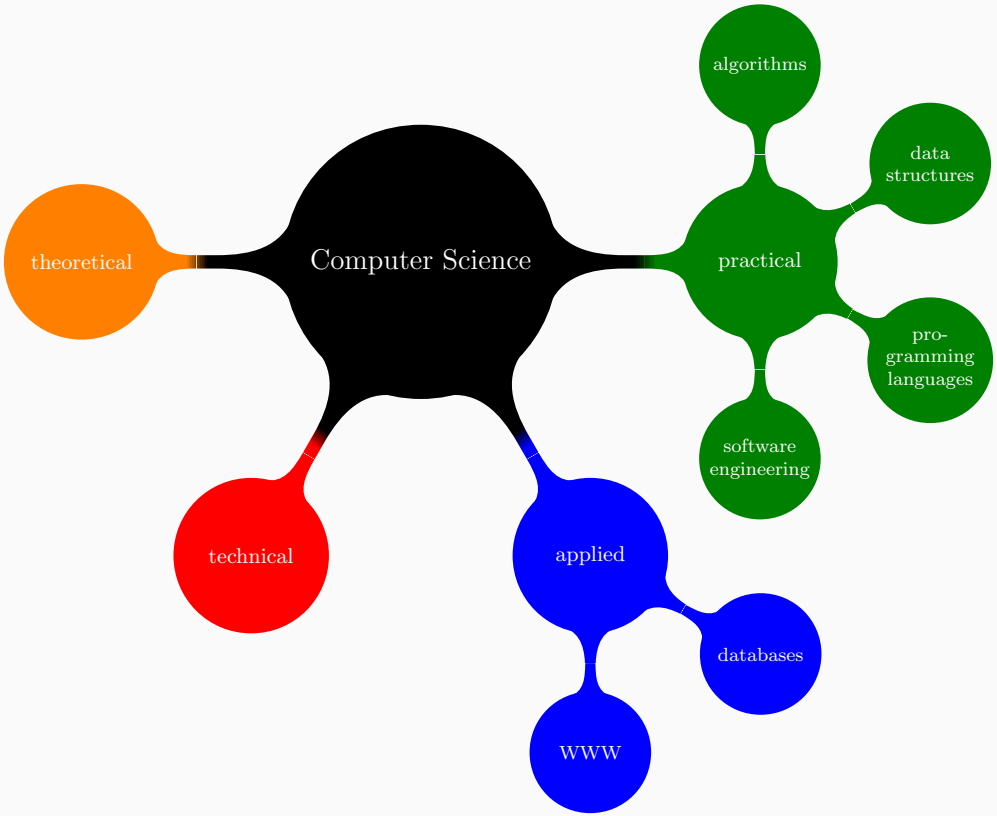
Poincaré Diagram: Classification of Phase Portraits in the $(\det A, \operatorname{Tr} A)$-plane



Source: https://texample.net/tikz/examples/poincare/

Size: 168 lines of code

Showcase - Example #3



Source: https://texample.net/tikz/examples/computer-science-mindmap/

Size: 29 lines of code

TikZ - Pros and Cons

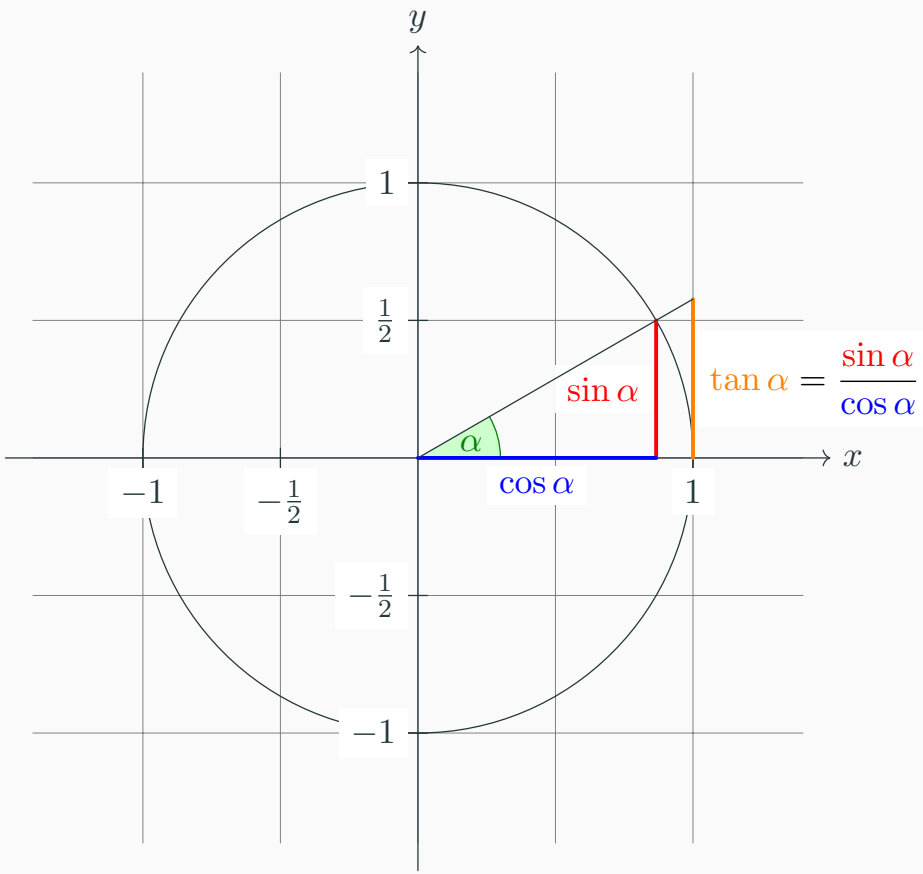
With TikZ you get all the **advantages** of the "TEX-approach to typesetting" for your graphics:

+ Quick creation of simple graphics
+ Precise positioning
+ Use of macros
+ Often superior typography
+ *Code suggestions from CoPilot!*

You also inherit all the **disadvantages**:

– Steep learning curve
– No WYSIWYG
– Small changes require a long recompilation time
– The code does not really "show" how things will look like

Hello World++: A Picture for Karl's Students



The angle α is $30°$ in the example ($\pi/6$ in radians). The sine of α, which is the height of the red line, is

$$\sin \alpha = 1/2.$$

By the Theorem of Pythagoras we have $\cos^2 \alpha + \sin^2 \alpha = 1$. Thus the length of the blue line, which is the cosine of α, must be

$$\cos \alpha = \sqrt{1 - 1/4} = \frac{1}{2}\sqrt{3}.$$

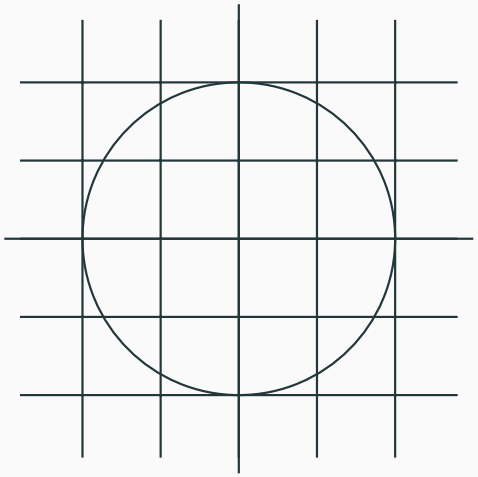
This shows that $\tan \alpha$, which is the height of the orange line, is

$$\tan \alpha = \frac{\sin \alpha}{\cos \alpha} = 1/\sqrt{3}.$$

Source: https://texample.net/tikz/examples/tutorial/

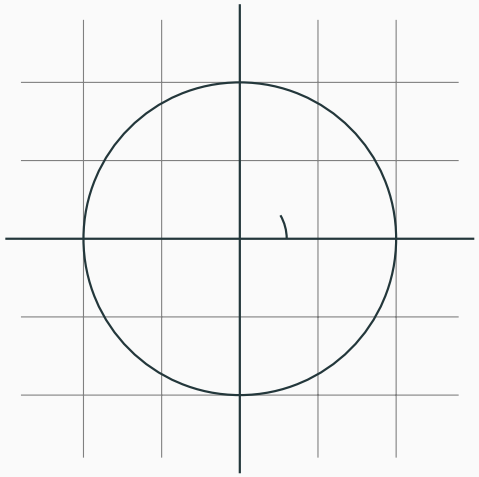
Size: 46 lines of code

Hello World (1) - Drawing



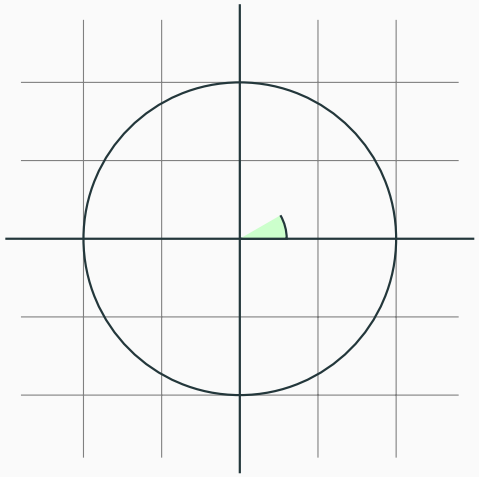
```latex
\documentclass{article}
\usepackage{tikz}

\begin{document}
  \begin{tikzpicture}
    \draw (-1.5,0) -- (1.5,0);
    \draw (0,-1.5) -- (0,1.5);
    \draw (0,0) circle [radius=1];
    \draw[step=0.5] (-1.4,-1.4) grid (1.4,1.4);
  \end{tikzpicture}
\end{document}
```

Hello World (2) - Arguments



```
6       \draw[step=.5cm,gray,very thin] (-1.4,-1.4) grid
        ↪  (1.4,1.4);
7       \draw (-1.5,0) -- (1.5,0);
8       \draw (0,-1.5) -- (0,1.5);
9       \draw (0,0) circle [radius=1cm];
10      \draw (3mm,0mm) arc [start angle=0, end angle=30,
        ↪  radius=3mm];
```

Hello World (3) - Styles



```
5   \begin{tikzpicture}[
6     help lines/.style={very thin, gray},
7   ]
8     \draw[help lines, step=0.5cm] (-1.4,-1.4) grid
      ↪  (1.4,1.4);
9     \draw (-1.5,0) -- (1.5,0);
10    \draw (0,-1.5) -- (0,1.5);
11    \draw (0,0) circle [radius=1cm];
12    \filldraw[fill=green!20,draw] (0,0) -- (3mm,0pt)
      ↪  arc [start angle=0, end angle=30, radius=3mm];
13  \end{tikzpicture}
```

Hello World++: A Picture for Karl's Students

```
\begin{tikzpicture}[
  scale=3, line cap=round,
  % Styles
  axes/.style=,
  important line/.style={very thick},
  information text/.style={rounded corners, fill=red!10, inner sep=1ex}
]
  % Colors
  \colorlet{anglecolor}{green!50!black}
  \colorlet{sincolor}{red}
  \colorlet{tancolor}{orange!80!black}
  \colorlet{coscolor}{blue}

  % The graphic
  \draw[help lines,step=0.5cm] (-1.4,-1.4) grid (1.4,1.4);
  \draw (0,0) circle [radius=1cm];
  \begin{scope}[axes]
    \draw[->] (-1.5,0) -- (1.5,0) node[right] {$x$} coordinate(x axis);
    \draw[->] (0,-1.5) -- (0,1.5) node[above] {$y$} coordinate(y axis);
    \foreach \x/\xtext in {-1, -.5/-\frac{1}{2}, 1}
      \draw[xshift=\x cm] (0pt,1pt) -- (0pt,-1pt) node[below,fill=white] {$\xtext$};
    \foreach \y/\ytext in {-1, -.5/-\frac{1}{2}, .5/\frac{1}{2}, 1}
      \draw[yshift=\y cm] (1pt,0pt) -- (-1pt,0pt) node[left,fill=white] {$\ytext$};
  \end{scope}

  \filldraw[fill=green!20,draw=anglecolor] (0,0) -- (3mm,0pt) arc [start angle=0, end
  ↪  angle=30, radius=3mm];
```

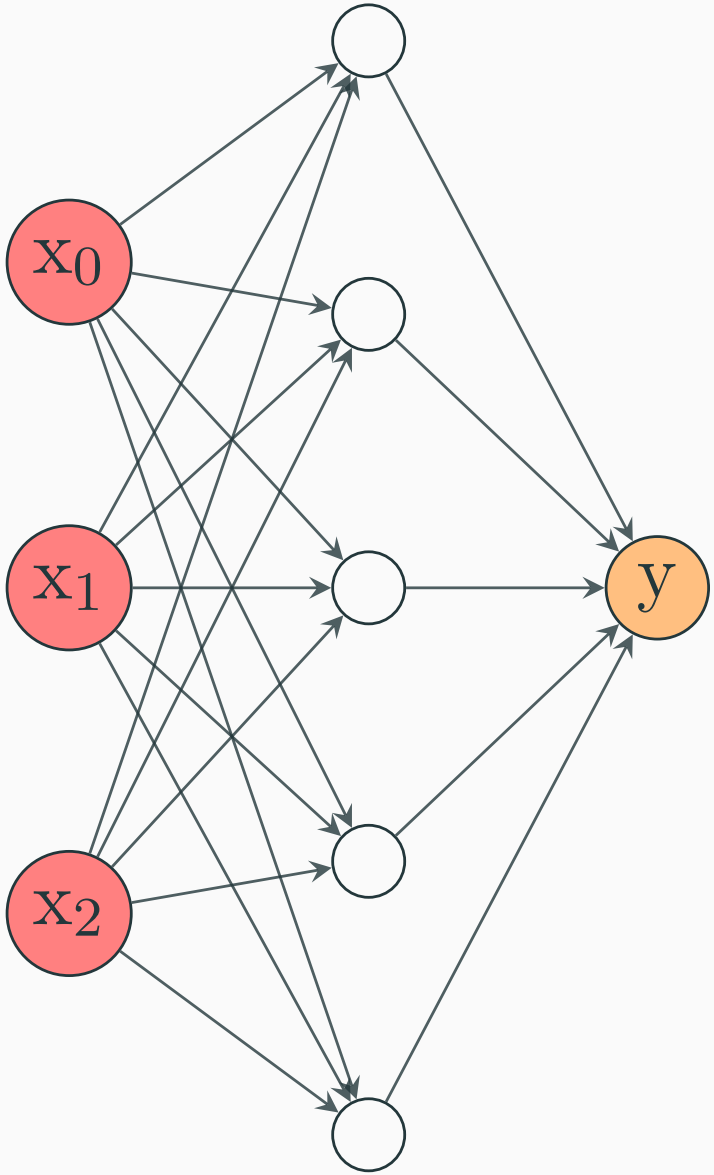
Hello World++: A Picture for Karl's Students

```
27      \draw (15:2mm) node[anglecolor] {$\alpha$};
28      \draw[important line,sincolor] (30:1cm) -- node[left=1pt,fill=white] {$\sin
        ↪  \alpha$} (30:1cm |- x axis);
29      \draw[important line,coscolor] (30:1cm |- x axis) -- node[below=2pt,fill=white]
        ↪  {$\cos \alpha$} (0,0);
30      \path [name path=upward line] (1,0) -- (1,1);
31      \path [name path=sloped line] (0,0) -- (30:1.5cm);
32      \draw [name intersections={of=upward line and sloped line, by=t}]
33        [very thick,orange] (1,0) -- node [right=1pt,fill=white]
34        {$\displaystyle \tan \alpha \color{black}=\frac{{\color{sincolor}\sin
          ↪  \alpha}}{\color{coscolor}\cos \alpha}$} (t);
35      \draw (0,0) -- (t);
36      \draw[xshift=1.85cm] node[right,text width=6cm,information text]
37      {The {\color{anglecolor} angle $\alpha$} is $30^\circ$ in the example ($\pi/6$ in
        ↪  radians).
38       The {\color{sincolor}sine of $\alpha$}, which is the height of the red line, is
39       \[{\color{sincolor} \sin \alpha} = 1/2.\]
40       By the Theorem of Pythagoras we have ${\color{coscolor}\cos^2 \alpha} +
         ↪  {\color{sincolor}\sin^2 \alpha} = 1$.
41       Thus the length of the blue line, which is the {\color{coscolor} cosine of
         ↪  $\alpha$}, must be
42       \[{\color{coscolor}\cos \alpha} = \sqrt{1 - 1/4} = \frac{1}{2}\sqrt{3}.\]
43       This shows that ${\color{tancolor}\tan \alpha}$, which is the height of the orange
         ↪  line, is
44       \[{\color{tancolor}\tan \alpha} = \frac{{\color{sincolor}\sin
         ↪  \alpha}}{{\color{coscolor}\cos \alpha}} = 1/\sqrt{3}.\]
45      };
46    \end{tikzpicture}
```

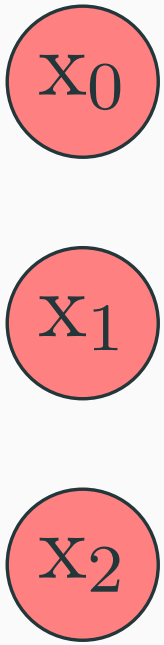
TikZ for Neural Networks

- A simple MLP
- Transformers
- Graph Networks

A simple MLP

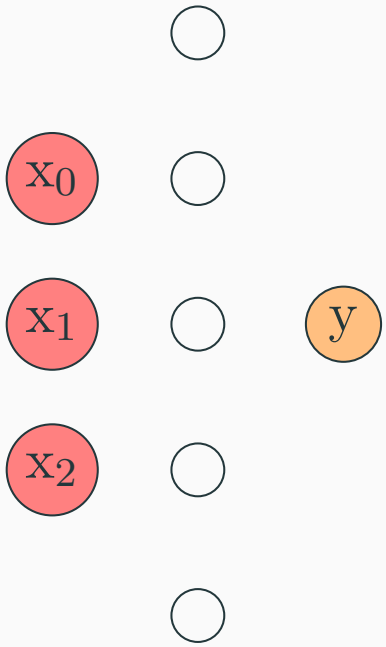


A simple MLP



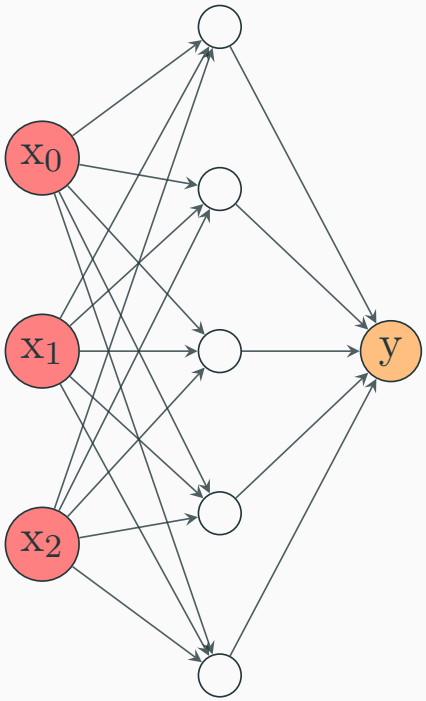

```latex
\begin{tikzpicture}[
  inputnode/.style={draw, circle, fill=red!50, inner sep=2pt},
]
  \node[inputnode] (x0) at (0, 1) {$\mathrm{x}_0$};
  \node[inputnode] (x1) at (0, 0) {$\mathrm{x}_1$};
  \node[inputnode] (x2) at (0, -1) {$\mathrm{x}_2$};
\end{tikzpicture}
```

A simple MLP



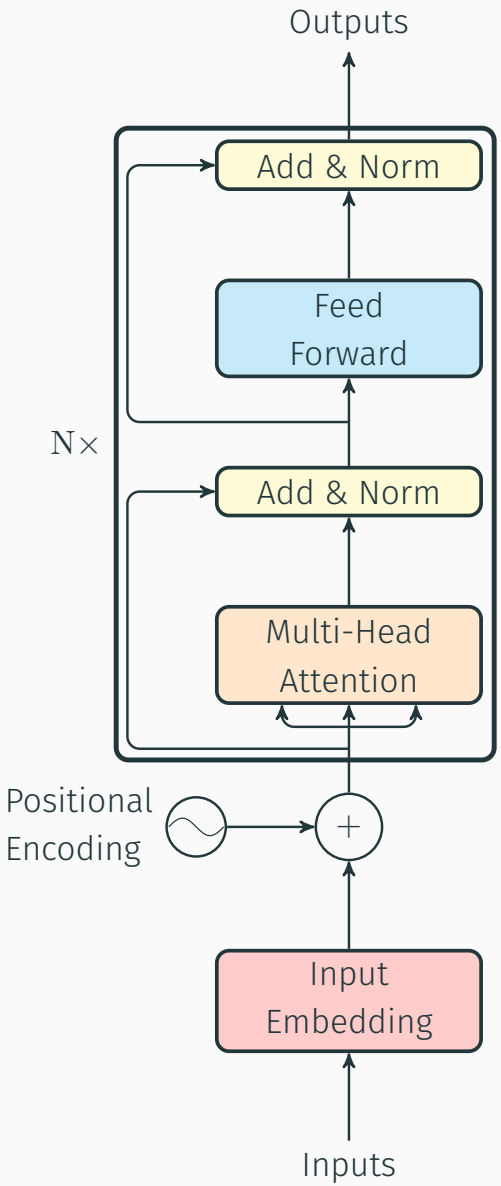

```latex
\begin{tikzpicture}[
  inputnode/.style={draw, circle, fill=red!50, inner sep=2pt},
  hiddenunit/.style={draw, circle, minimum size=10pt},
  outnode/.style={draw, circle, fill=orange!50, inner sep=2pt},
]
  \node[inputnode] (x0) at (0, 1) {$\mathrm{x}_0$};
  \node[inputnode] (x1) at (0, 0) {$\mathrm{x}_1$};
  \node[inputnode] (x2) at (0, -1) {$\mathrm{x}_2$};

  \node[hiddenunit] (h2) at (1, 2) {};
  \node[hiddenunit] (h1) at (1, 1) {};
  \node[hiddenunit] (h0) at (1, 0) {};
  \node[hiddenunit] (h3) at (1, -1) {};
  \node[hiddenunit] (h4) at (1, -2) {};

  \node[outnode] (y0) at (2, 0) {$\mathrm{y}$};
\end{tikzpicture}
```

A simple MLP




```
\begin{tikzpicture}[
  inputnode/.style={draw, circle, fill=red!50, inner sep=2pt},
  outnode/.style={draw, circle, fill=orange!50, inner sep=2pt},
  hiddenunit/.style={draw, circle, minimum size=10pt},
  weights/.style={-stealth, thin, opacity=0.8},
]
  \node[inputnode] (x1) {$\mathrm{x}_1$};
  \node[inputnode, above=of x1] (x0) {$\mathrm{x}_0$};
  \node[inputnode, below=of x1] (x2) {$\mathrm{x}_2$};

  \node[hiddenunit, right=of x1] (h2) {};
  \node[hiddenunit, above=of h2] (h1) {};
  \node[hiddenunit, above=of h1] (h0) {};
  \node[hiddenunit, below=of h2] (h3) {};
  \node[hiddenunit, below=of h3] (h4) {};

  \node[outnode, right=of h2] (y0) {$\mathrm{y}$};

  \foreach \x in {x0, x1, x2} {
    \foreach \h in {h0, h1, h2, h3, h4} {
      \draw[weights] (\x) -- (\h);
    }
  }
  \foreach \h in {h0, h1, h2, h3, h4} {
    \foreach \y in {y0} {
      \draw[weights] (\h) -- (\y);
    }
  }
\end{tikzpicture}
```

~~Attention~~TikZ Is All You Need



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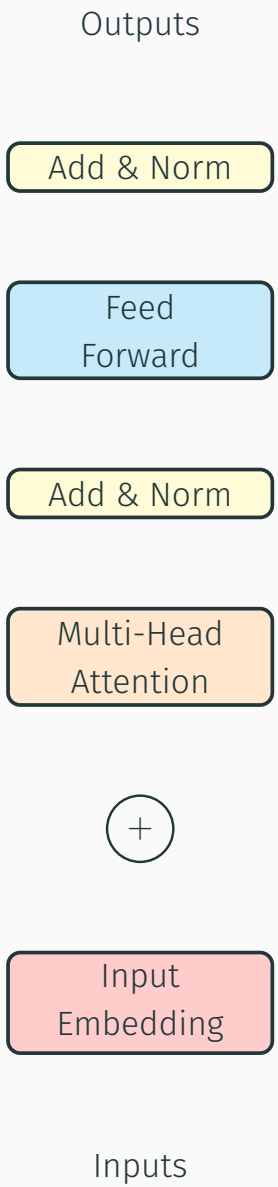
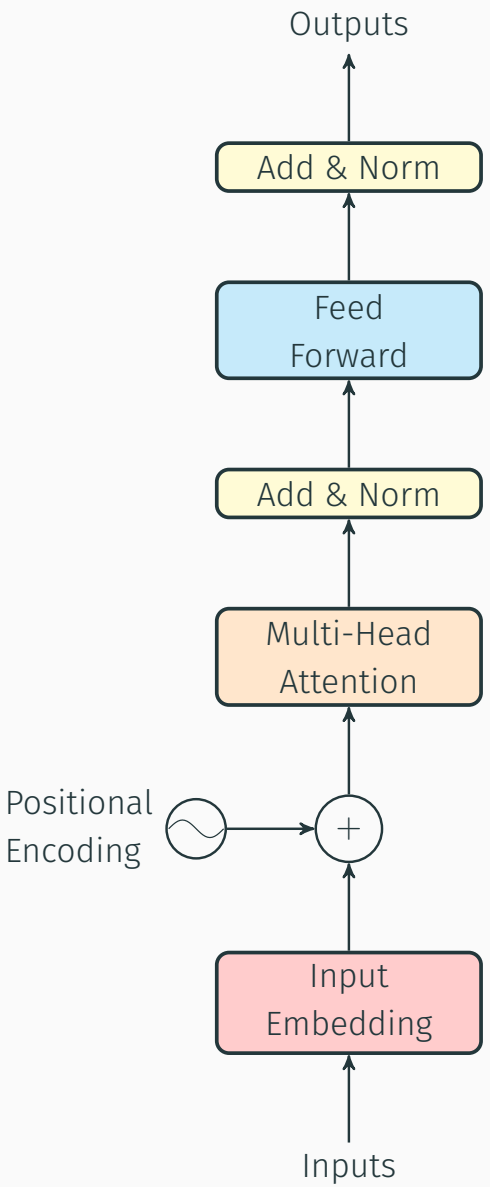


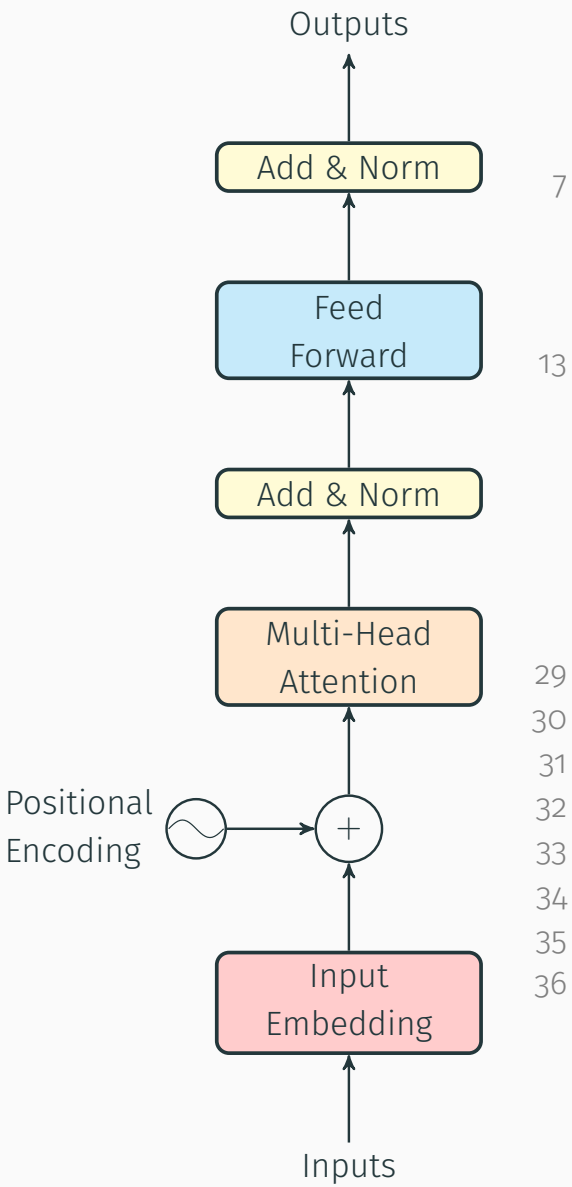

```latex
\begin{tikzpicture}[
  module/.style={draw, very thick, rounded corners, minimum width=15ex},
  embmodule/.style={module, fill=red!20},
  mhamodule/.style={module, fill=orange!20},
  lnmodule/.style={module, fill=yellow!20},
  ffnmodule/.style={module, fill=cyan!20},
  arrow/.style={-stealth', thick, rounded corners},
]
  \node (inputs) {Inputs};
  \node[above=of inputs, embmodule, align=center] (inputemb) {Input\\Embedding};
  \node[above=of inputemb, draw, thick, circle] (embplus) {$+$};
  \node[above=of embplus, mhamodule, align=center] (mha) {Multi-Head\\Attention};
  \node[above=of mha, lnmodule, align=center] (addnorm1) {Add \& Norm};
  \node[above=of addnorm1, ffnmodule, align=center] (ffn) {Feed\\Forward};
  \node[above=of ffn, lnmodule, align=center] (addnorm2) {Add \& Norm};
  \node[above=of addnorm2] (outputs) {Outputs};
\end{tikzpicture}
```

~~Attention~~TikZ Is All You Need



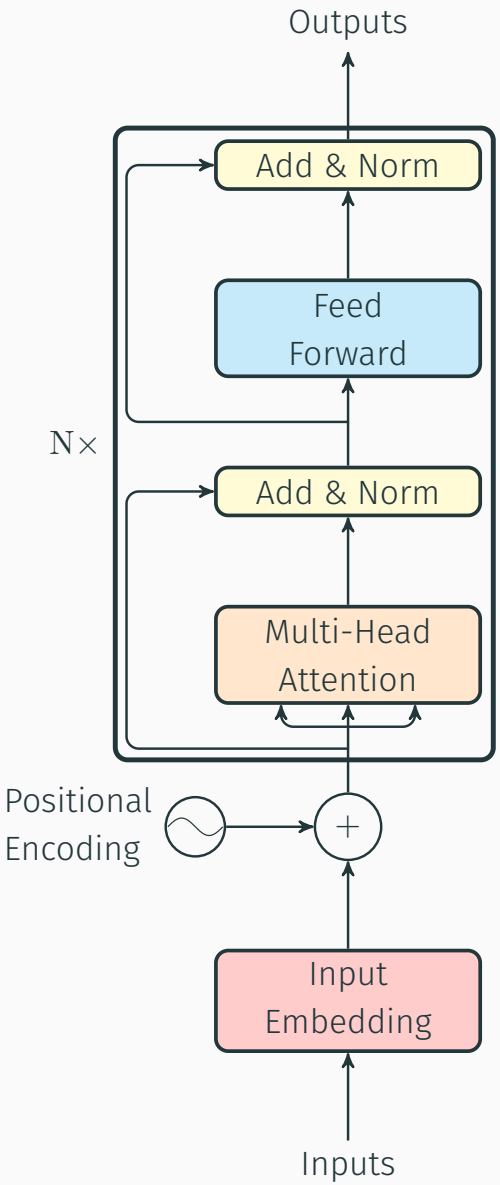

```
7     arrow/.style={-stealth', thick, rounded corners},
⋮
13    \node[left=of embplus, draw, thick, circle, inner
↪     sep=0pt,label={[align=left]left:Positional\\Encoding}]
↪     (pe) {\tikz \draw[scale=0.1] plot[domain=0.0:6.28]
↪     (\x,{sin(\x r)});};
⋮
29    \draw[arrow] (inputs) -- (inputemb);
30    \draw[arrow] (inputemb) -- (embplus);
31    \draw[arrow] (pe) -- (embplus);
32    \draw[arrow] (embplus) -- (mha);
33    \draw[arrow] (mha) -- (addnorm1);
34    \draw[arrow] (addnorm1) -- (ffn);
35    \draw[arrow] (ffn) -- (addnorm2);
36    \draw[arrow] (addnorm2) -- (outputs);
```

~~Attention~~TikZ Is All You Need



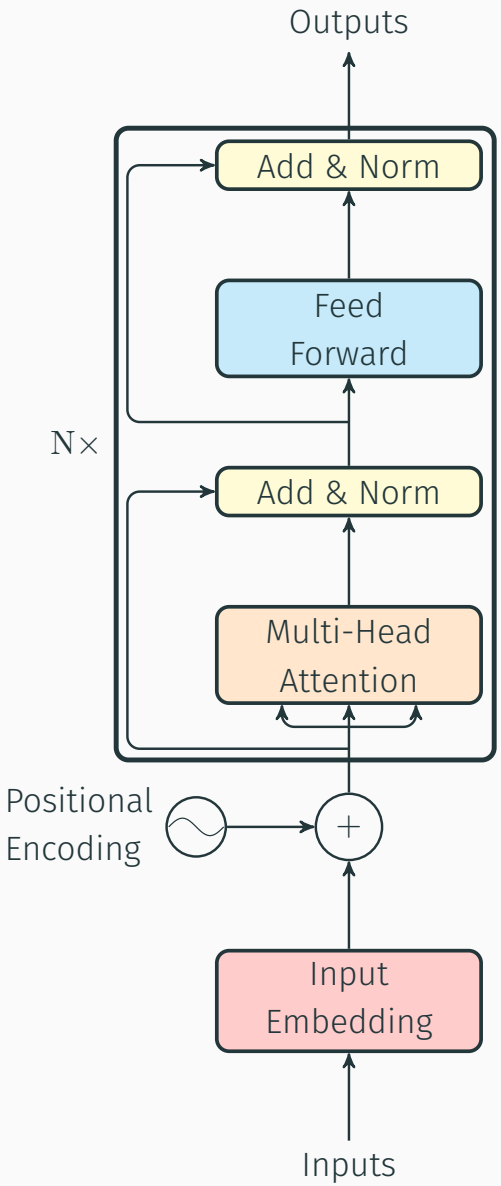

```
7   arrow/.style={-stealth', thick, rounded corners},
    ⋮ ⟵ This is inline TikZ!
13  \node[left=of embplus, draw, thick, circle, inner
↪   sep=0pt,label={[align=left]left:Positional\\Encoding}]
↪   (pe) {\tikz \draw[scale=0.1] plot[domain=0.0:6.28]
↪   (\x,{sin(\x r)});};
    ⋮ ⟵ This is inline TikZ!
29  \draw[arrow] (inputs) -- (inputemb);
30  \draw[arrow] (inputemb) -- (embplus);
31  \draw[arrow] (pe) -- (embplus);
32  \draw[arrow] (embplus) -- (mha);
33  \draw[arrow] (mha) -- (addnorm1);
34  \draw[arrow] (addnorm1) -- (ffn);
35  \draw[arrow] (ffn) -- (addnorm2);
36  \draw[arrow] (addnorm2) -- (outputs);
```

~~Attention~~TikZ Is All You Need

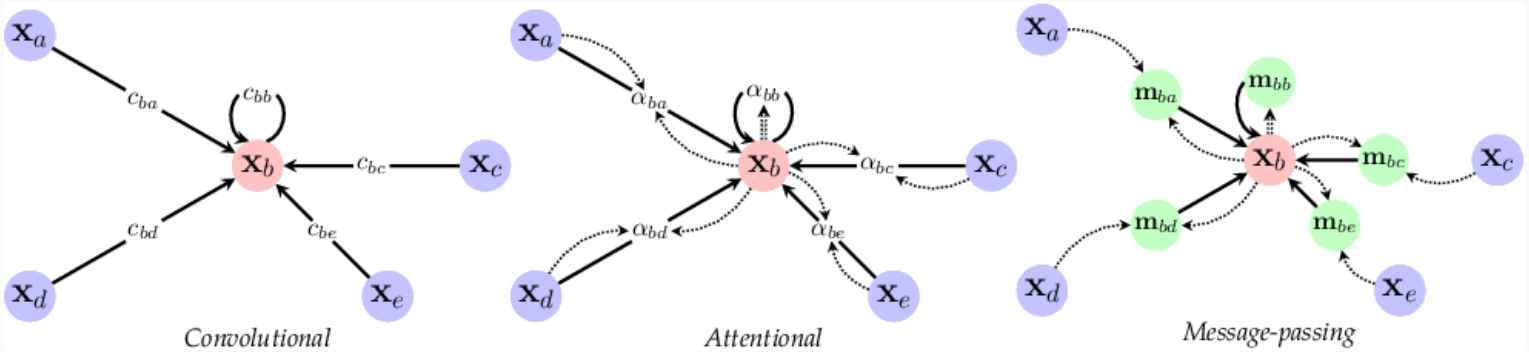



```
21  \coordinate (mharesidual) at
↪   ($(mha.south)!0.5!(embplus.north)$);
22  \coordinate (ffnresidual) at
↪   ($(ffn.south)!0.5!(addnorm1.north)$);
23  \coordinate (mhafork) at
↪   ($(mha.south)!0.5!(mharesidual)$);
24  \coordinate[left=of addnorm1] (ln1residualleft);
25  \coordinate[left=of addnorm2] (ln2residualleft);

    ⋮

27  \node[fit={(mha)(addnorm2)(mharesidual)(ln1residualleft)
↪   draw, ultra thick, rounded corners,
↪   label=left:$\mathrm{N\times}$] (encoder) {};

    ⋮

38  \draw[arrow]
↪   (mharesidual)-|(ln1residualleft)--(addnorm1);
39  \draw[arrow]
↪   (ffnresidual)-|(ln2residualleft)--(addnorm2);
40  \draw[arrow] (mhafork)-|($(mha.south)!0.5!(mha.south
↪   west)$);
41  \draw[arrow] (mhafork)-|($(mha.south)!0.5!(mha.south
↪   east)$);
```

~~Attention~~TikZ Is All You Need



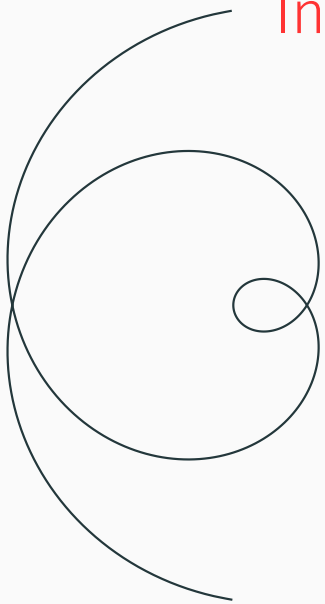
Graph Network Flavours



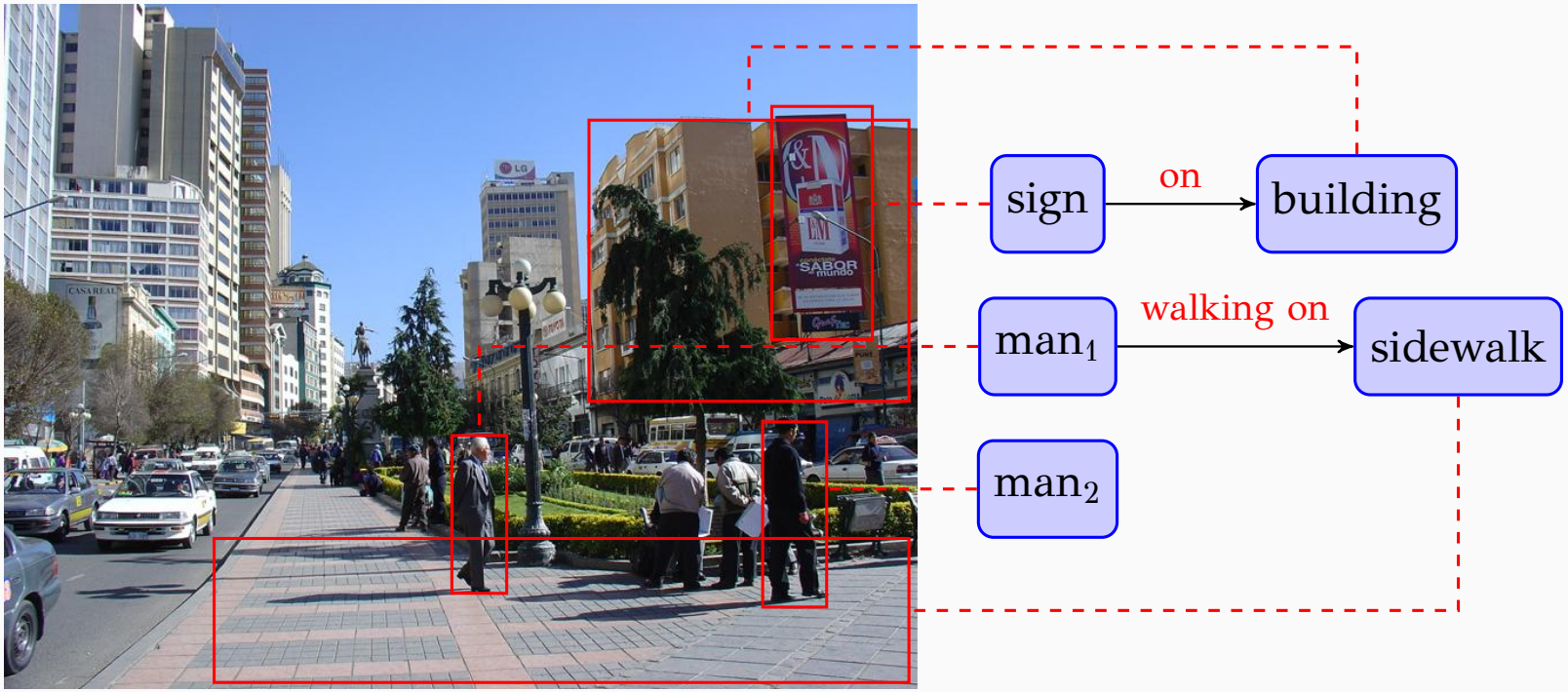
Final notes

- You can use TikZ inline!
- You can export Matplotlib to pgf!
  - https://matplotlib.org/stable/tutorials/text/pgf.html
- Same with programming: Learn-by-doing!

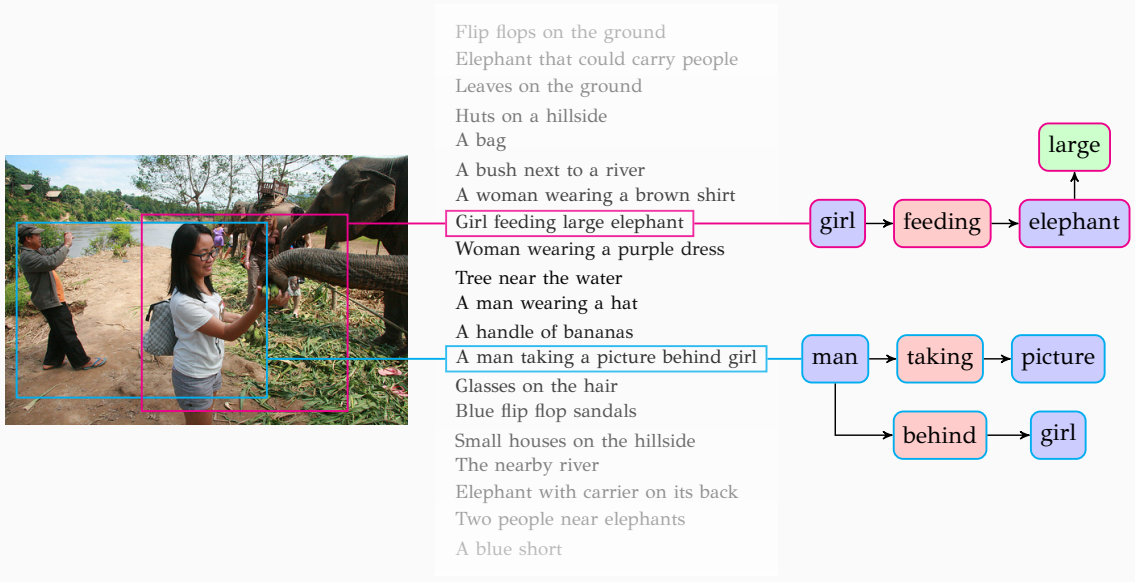
Inline TikZ



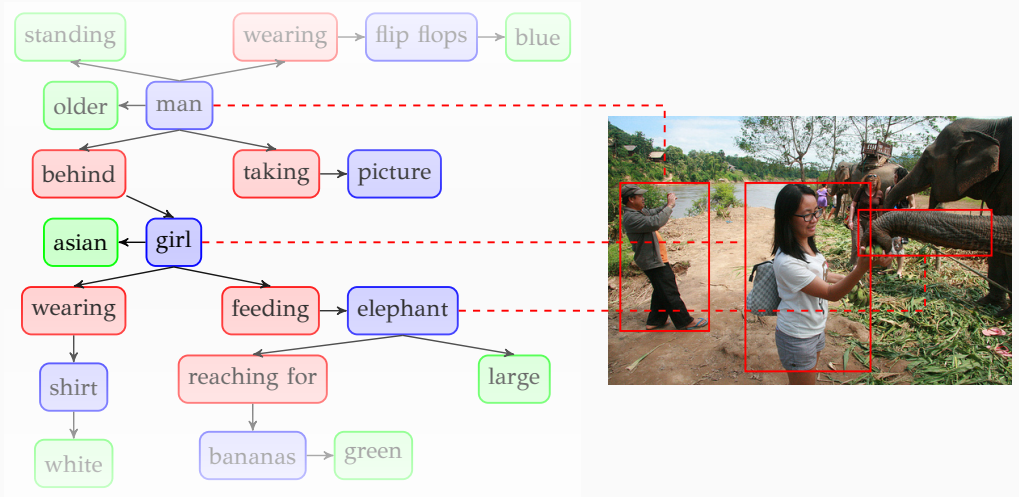
Personal portfolio collage



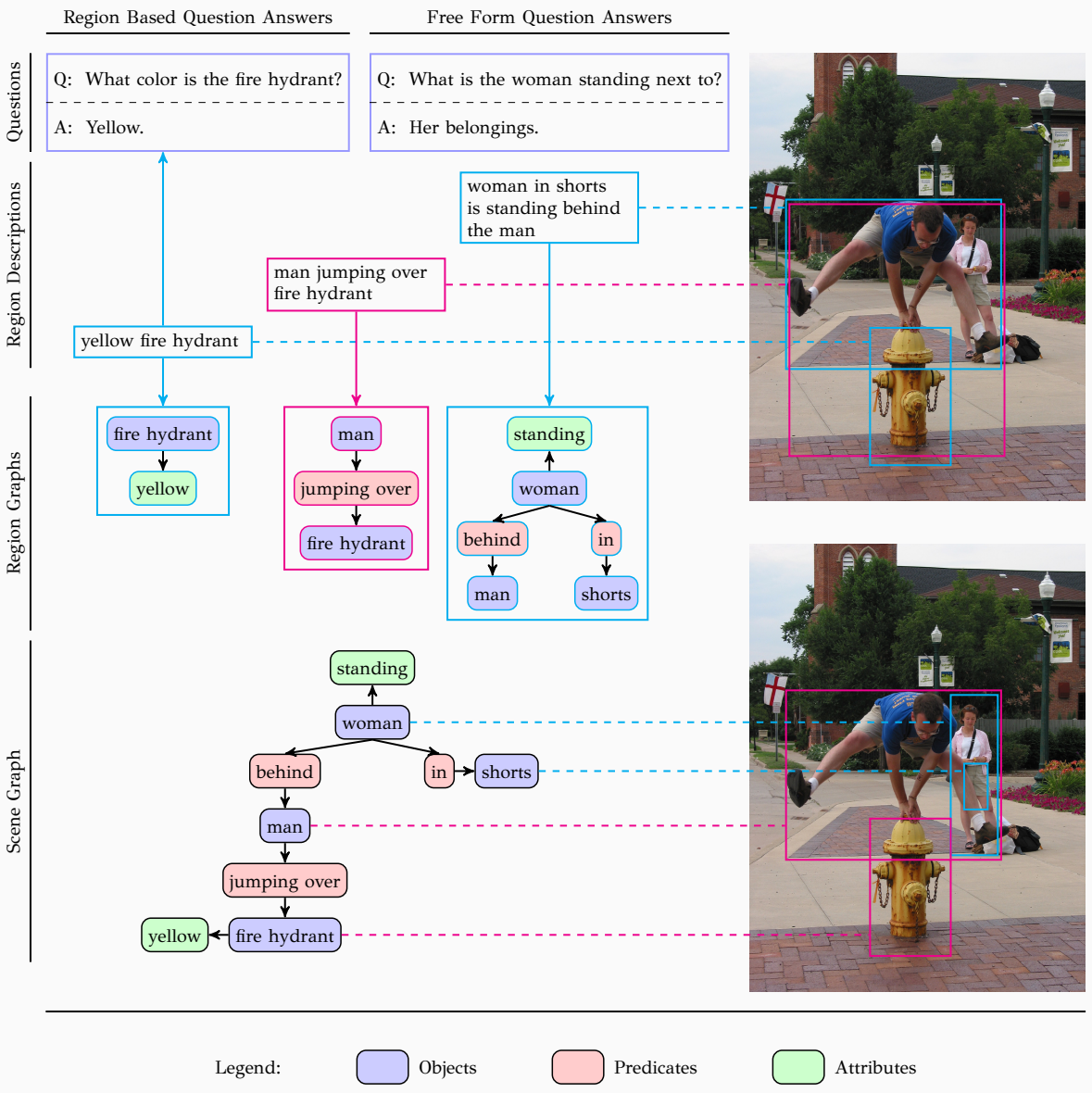
Personal portfolio collage



(α')



Personal portfolio collage



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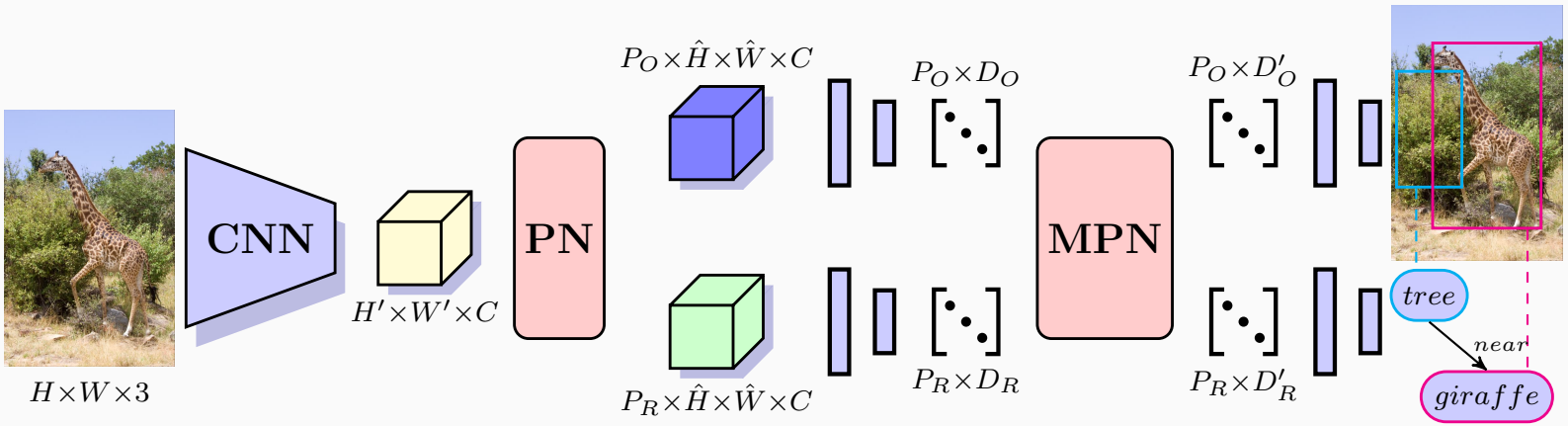

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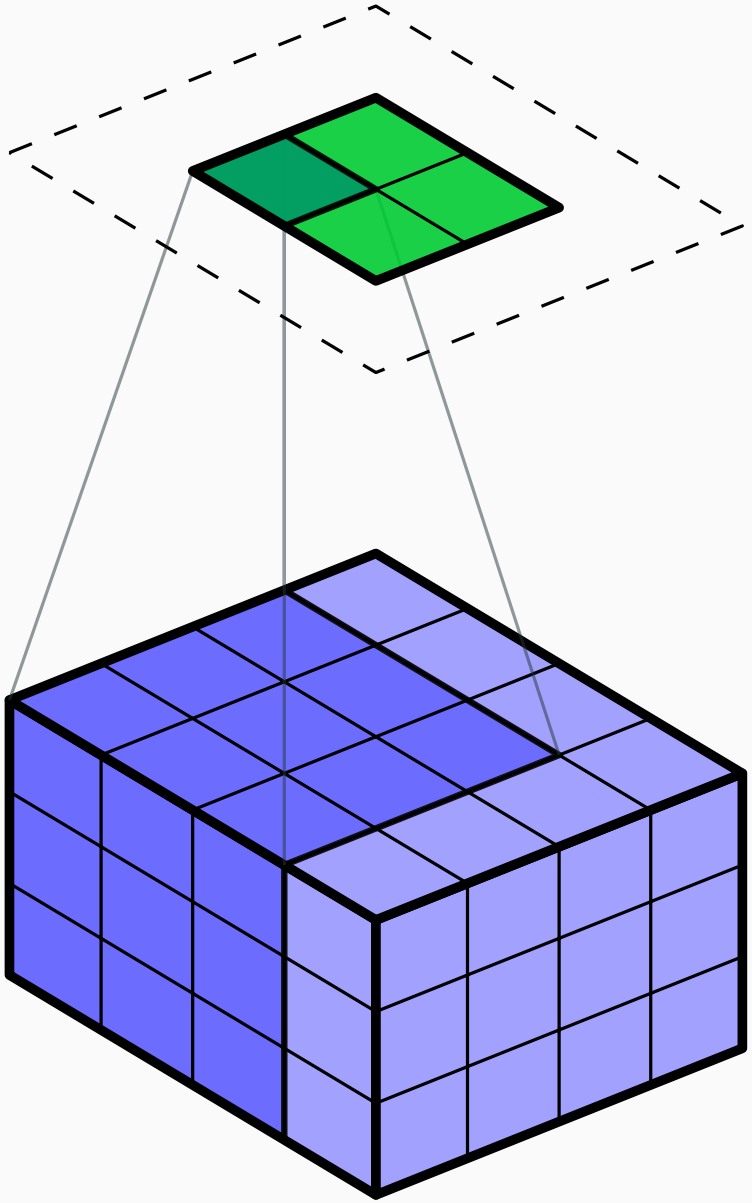

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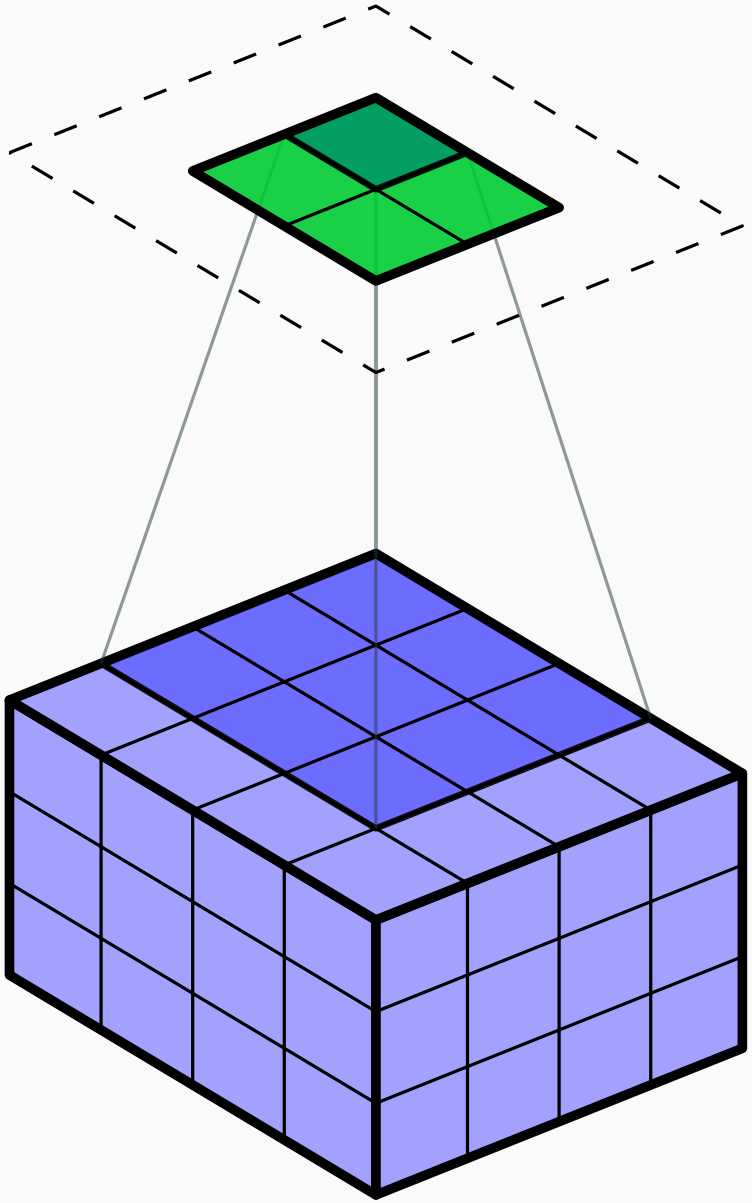

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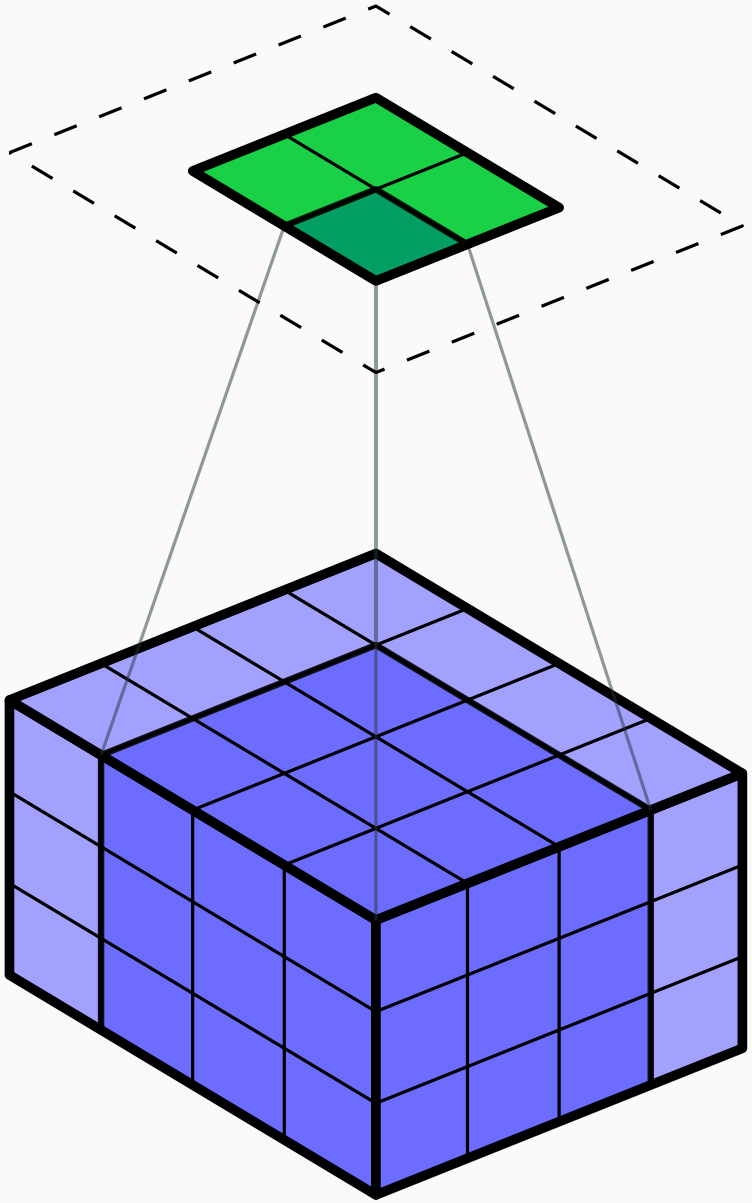
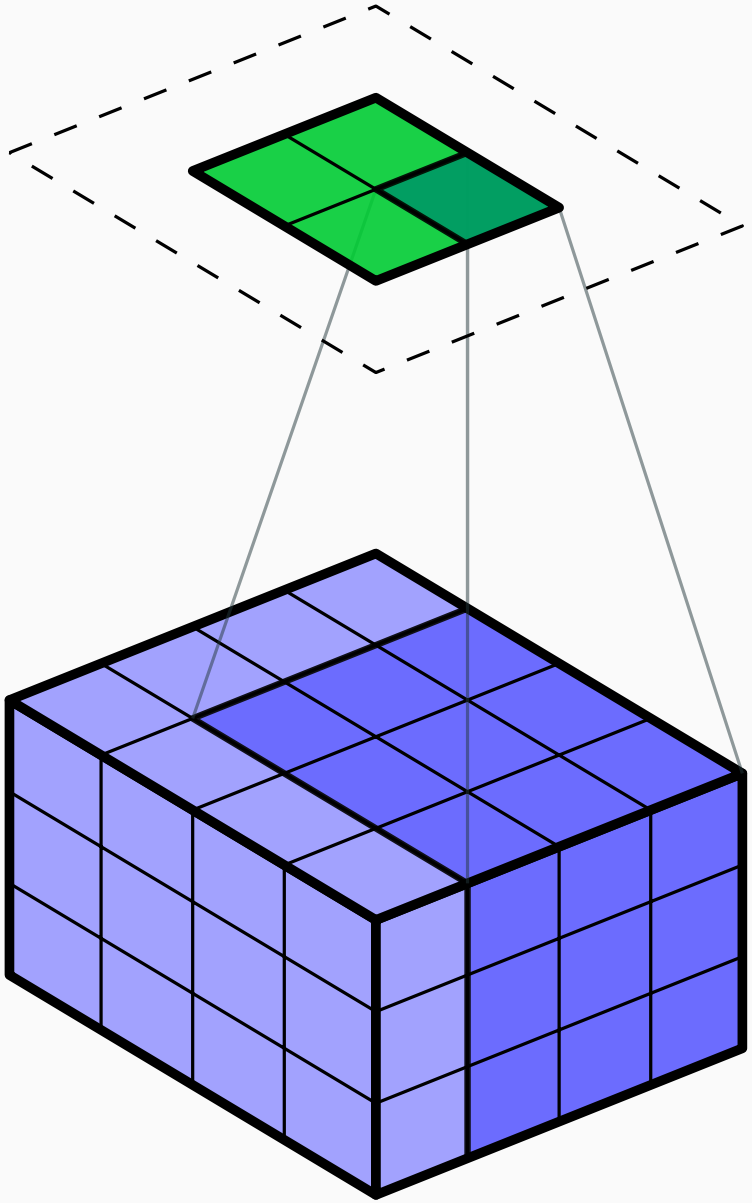
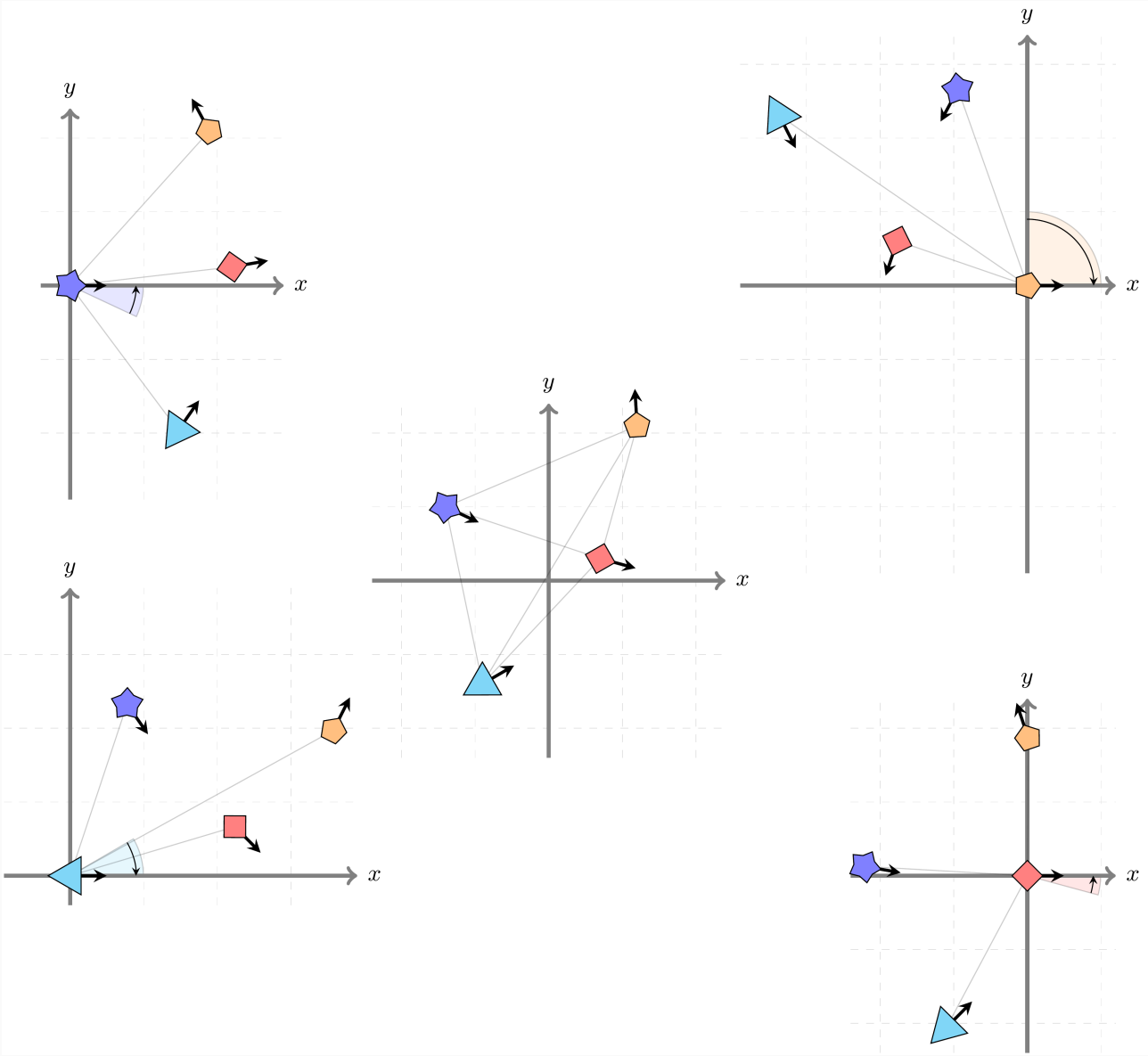


Personal portfolio collage



Personal portfolio collage



References i

[1] Till Tantau. *TikZ and PGF. Manual for version 3.1.9a*. URL: https://github.com/pgf-tikz/pgf.