Drawing Block Diagrams in LaTeX

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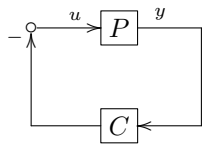
Prerequisites: basic LaTeX commands and some LyX knowledge.
There are multiple ways to generate block diagrams in LaTeX. Here are three most popular approaches.

xyplot using \xymatrix

This tool provides the most natual support for LyX.

Big picture: looking at the block diagram



you can see the following composition:

- two framed blocks $\boxed{P}$ and $\boxed{C}$,
- four points defining the edges of the rectangular diagram,
- arrows and lines connecting different elements,
- comments like the negative sign, u, and y.

When you draw the diagram on a piece of paper, you might use a ruled notebook for better alignment of the elements. XY-plot does the work in exactly the same way. The notebook it uses is called XY-matrix.

Basic commands:

- Outlining: `\xymatrix` generates a matrix where you can fill each entry with items you want (in my case, boxed transfer functions, signals, systems, etc)
- Making connections: `\ar[pos]` places an arrow to [pos], where pos can take the values of: l(eft), r(ight), d(own), u(p)
  - For instance, `\[\xymatrix{B\ar[r] & A}\]` generates a two by one XY-matrix with the entries of B and A. The command `\ar[r]` generates an arrow, starting from the first entry element B, pointing to the right, and ending on the second entry. Overall, the commands typesets

    $$B \longrightarrow A$$

  - Arrows can span multiple cells. For instance, \ar[rr] means "draw an arrow that points to the right and ends two entries away on the right". As an example, `\[\xymatrix{B\ar[rr] & & A}\]` gives

    $$B \longrightarrow\!\!\!\!\!\!\longrightarrow A$$

- Framing a block: `*[F]{contents}` puts contents into frames. The basic usage and common examples are summarized next.
  - default frame: `\[\xymatrix{*[F]{A}}\]` gives

    $$\boxed{A}$$

– Usually the default frame is too tight and must be widened by prefixing with + or ++. Most commonly, I would use a command like `\[\xymatrix{*++[F]{A}}\]`, which gives

$$\boxed{A}$$

– double-line frame: `\[\xymatrix{*++[F=]{A}}\]` typesets

$$\boxed{\boxed{A}}$$

– circular frame: `\[\xymatrix{*+[o][F]{A}}\]` gives

$$\textcircled{A}$$

Similar to the double-line rectangular frame, we can do `\[\xymatrix{*++[o][F=]{A}}\]`, to get

$$\textcircled{\textcircled{A}}$$

- Specifying the arrow formats:

  – use `@{...}` after `\ar` to let LaTeX know the line format of the arrows

    * Dashed arrows can be specified by `\ar@{-->}`. For instance, `\xymatrix{a\ar@{-->}[r]&b}` gives $a \dashrightarrow b$
    * Dotted arrows can be specified by `\ar@{..>}`. E.g., `\xymatrix{a\ar@{..>}[r]&b}` gives $a \cdots\!\!\succ b$
    * Invisible arrows: this is useful for labeling certain graphs. By typing \ar@{}, we can specify null format for the arrow. For instance,
      ```
      \xymatrix{
      A\ar[rrrrr]\ar[d] & & & & & B\\
      C\ar@{}[urrrrr]|{\text{horizontal stretch by more matrix entries}}
      }
      ```
      typesets

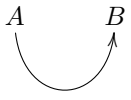
$$\begin{array}{ccc} A & \longrightarrow & B \\ \downarrow & \text{horizontal stretch by more matrix entries} & \\ C & & \end{array}$$

  – use `@()` after `\ar` to specify the start and the end points of the arrow.

    * For instance, `\[\xymatrix{A\ar@(d,u)[r]&B}\]` gives

      The command `\ar@(d,u)[r]` reads: "draw an arrow to reach the next matrix entry on the right (say element B), starting downwards and finishing at the upper side of B."

    * We can do more fancy stuff such as:
      `\[\xymatrix{A\ar@(d,d)[r] &B}\]`,
      `\[\xymatrix{A\ar@(dr,ul)[r] &B}\]`,
      and `\[\xymatrix{A\ar@(d,ul)}\]`, which give, respectively,



      and

- Tips for using XY-matrix in LyX's Math editor (press Ctrl-m or Ctrl-Shift-m and then type \xymatrix)
  - the braces: [] is the same, but {} should be entered by \{,[1] since by default LyX interprets {} as visiable braces to display in math mode (e.g. $\{[A + (B^2 + A)]C\} + A$).
  - shortcuts:
    * Adding a row in XY-matrix: Ctrl-Enter
    * Adding a column in XY-matrix: Alt-m c i
    * Horizontal and vertical scaling: How do we change the spacing between different elements in XY-matrix? In the tutorial "Using XY-pic in LyX," H. Peter Gumm descried using the following macros in the preamble of the LyX document (Layout ▷ Document ▷ Preamble):

      ```
      \newcommand{\xyR}[1]{%
      \xydef@\xymatrixrowsep@{#1}
      } % end of \xyR
      \newcommand{\xyC}[1]{%
      \xydef@\xymatrixcolsep@{#1}
      } % end of \xyC
      ```

    Place the cursor inside the XY-matrix, just before the first entry. Then enter `\xyR\{` and/or `\xyC\{`, followed by the desired values of dimensions in the braces. The default spacing is `2pt`. As an example, see the difference between

    ```
    \xymatrix{
    A\ar[r]\ar[d] & B\\
    C\ar@{}[ur]|{\text{{default}}}
    }
    ```

    and

    ```
    \xyC{9pc}\xyR{2pc}
    \xymatrix{
    A\ar[r]\ar[d] & B\\
    C\ar@{}[ur]|{\text{{horizontal stretch}}}
    }
    ```

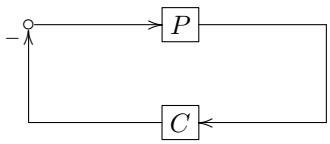
    Results:

    $$\begin{array}{ccc} A & \longrightarrow & B \\ \downarrow & \text{default} & \\ C & & \end{array}$$

    and

    $$\begin{array}{ccc} A & \longrightarrow & B \\ \downarrow & \text{horizontally stretched} & \\ C & & \end{array}$$

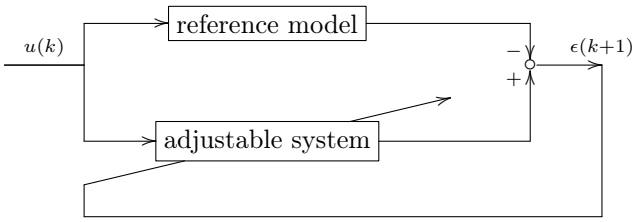
- Placing comments on arrows: In

  we want to put a negative sign near the end of the arrow on the left side. We can do so using `\ar[u]\sp(0.9){-}`, which reads "draw an arrow that points up, and has a superscript (sp) '-' located at 0.9 of the full length of the arrow."
  It is pretty useful to use `>>` to let LaTeX figure out the spacing and automatically locate the arrow comments near the end location. For instance, `A \ar[r]\sp>>+ & B` typesets $A \overset{+}{\longrightarrow} B$.

[1] The closing brace will be automatically supplied by LyX.

- Arrows passing under an element: use \ar'[ur]'[uurr] to go pass the upper right element and then reach the uurr element. For instance



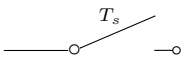
- Defining new arrow types: we can define a new arrow type "|>" by
`\newdir{|>}{%`
`!/4.5pt/@{|}*:(1,-.2)@^{>}*:(1,+.2)@_{>}}`
and use it in arrow formats such as `\ar@{=|>}[r]` and `\ar@{-|>}[r]`, to get

$$A \Longrightarrow\!\!\triangleright B$$

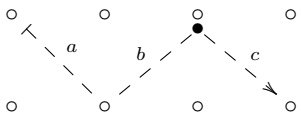
$$A \longrightarrow\!\!\triangleright B$$

Other commands:

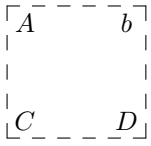
- Drawing a switch: XYpic supports also numerical axis locations. For instance, `\ar@{-}(21,5)*+{}\sp{T_{s}}` typesets a switch



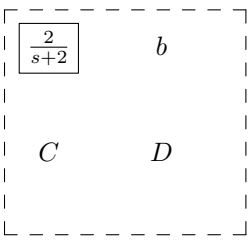
- Arrows passing under: just insert a ' between tha targets on the path
  - example: `\xymatrix{{\circ}\ar@{|-->} '[dr] ^a '[rr]+D*{\bullet}^b [drrr] ^c & {\circ} & {\circ} &{\circ} \\ {\circ}&{\circ}&{\circ}&{\circ}}` typesets



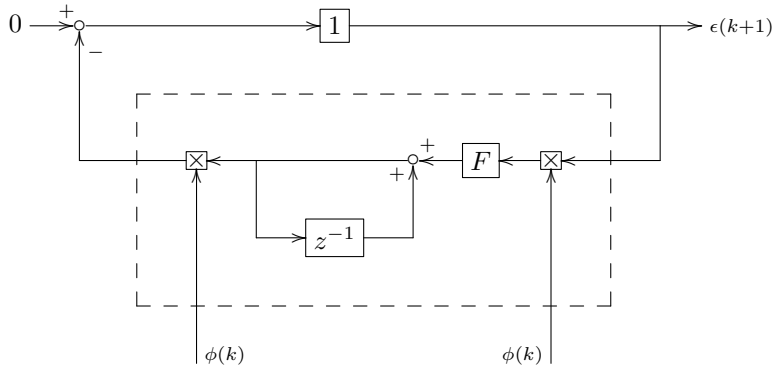
- Framing a group of objects:
`\[ \xymatrix{A & b\save"1,1"."2,2"*[F--]\frm{}\restore\\ C & D } \]`



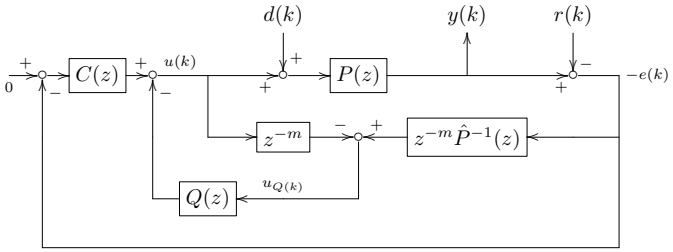
`\[ \xymatrix{*+[F]{\frac{2}{s+2}} & b\save"1,1"."2,2"*++++++[F--]\frm{}\restore\\ C & D } \]`



Using these basic elements can generate more complex block diagrams such as



and



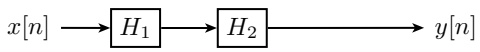
PSTricks and pst-sigsys

pst-sigsys stands for 'additional PSTricks for signal processing'. Below are some brief notes that hopefully illustrate the capabilities of the package. I hope to update more when I get the time.

- Remarks:
  - The lines and arrows generated by the package are more customizable compared to xyplot.
  - The package does not support pdflatex. To obtain the final pdf with correct graphs, one has to compile to dvi first then ultilize the command ps2pdf.
- A basic example:

```
\begin{pspicture}(6,2)
\rput(0,1){\rnode{x}{$x[n]$}}
%\psfblock[framesize =0.75 0.5](2,1){a}{$H_1$}
%\psfblock[framesize =1.5 1](4,1){b}{$H_2$}
\psblock(1.5,1){a}{$H_1$}
\psblock(3,1){b}{$H_2$}
\rput(6,1){\rnode{y}{$y[n]$}}
%-----------------
\psset{style = Arrow }
\ncline[nodesepA =.15]{x}{a}
\ncline{a}{b}
\ncline[nodesepB =.15]{b}{y}
\end{pspicture}
```

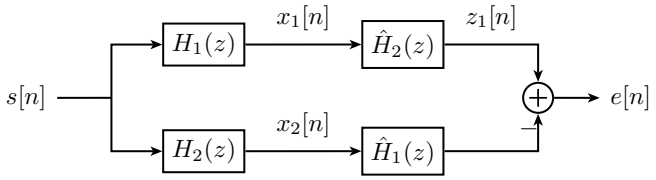
typesets



- More examples

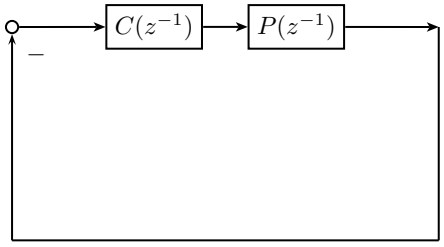
```
\begin{figure}[ht]
\centering %
\begin{pspicture}[showgrid=false](0.5,-1.2)(9,1.55)
%--- Define blocks ---
\rput(0.5,0){\rnode{s}{$s[n]$}}
\dotnode[dotstyle=square*,dotscale=0.001](1.7,0){dot}
\psblock(3,.75){H1}{$H_1(z)$}
\psblock(3,-.75){H2}{$H_2(z)$}
\psblock(5.8,.75){B2}{$\hat H_2(z)$}
\psblock(5.8,-.75){B1}{$\hat H_1(z)$}
\pscircleop(7.7,0){ominus}
\rput(9,0){\rnode{e}{$e[n]$}}
%--- Connect blocks ---
\psset{style=Arrow}
\ncline[nodesepA=.15]{-}{s}{dot}
\ncangle[angleA=90,angleB=180]{dot}{H1}
\ncangle[angleA=-90,angleB=180]{dot}{H2}
\ncline{H1}{B2}
\naput[npos=.5]{$x_1[n]$}
\ncline{H2}{B1}
\naput[npos=.5]{$x_2[n]$}
\ncangle[angleB=90]{B2}{ominus}
\naput[npos=.5]{$z_1[n]$}
\ncangle[angleB=-90]{B1}{ominus}
\naput[npos=.9]{$-$}
\ncline[nodesepB=.15]{ominus}{e}
\end{pspicture}
\end{figure}
```

typesets




```
\begin{pspicture}(6,5)
\cnode(0,4){0.1}{s}
\pnode(6,4){e}
\psblock(2,4){c}{$C(z^{-1})$}
\psblock(4,4){p}{$P(z^{-1})$}
\pnode(6,1){br}
\pnode(0,1){bl}
\nclist[style = Arrow]{ncline}{s,c,p,e}
\ncline{-}{e}{br}
\ncline{-}{br}{bl}
\ncline{->}{bl}{s}
\nbput[npos=.9]{$-$}
\end{pspicture}
```

typesets



tikz

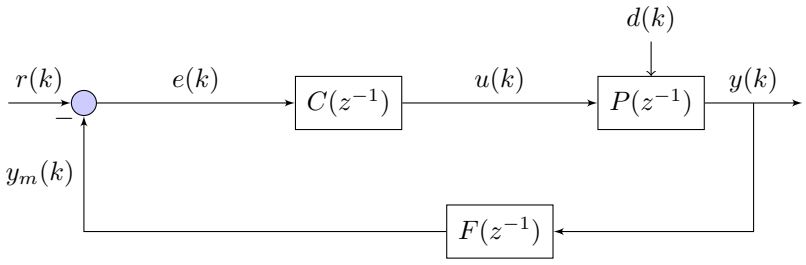
Compared to pst-sigsys, tikz is sometimes more convenient since it supports pdflatex directly. It even supports LyX instant preview, so that we can see the drawings within LyX before compiling them.

To use the package, we will need to add \usepackage{tikz} and \usepackage{pgfplots} at the beginning of the document. Also, it is very useful to define some basic formats at the beginning of the document:

```
\tikzstyle{block} = [draw, rectangle, minimum height=2em, minimum width=4em]
%fill=blue!20
\tikzstyle{sum} = [draw, fill=blue!20, circle, node distance=1cm]
\tikzstyle{input} = [coordinate] \tikzstyle{output} = [coordinate]
\tikzstyle{pinstyle} = [pin edge={to-,thin,black}]
```

The first example[1] uses relative location for each elements:

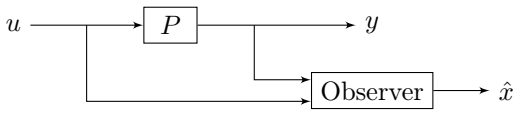
```
\begin{tikzpicture}[auto, node distance=2cm,>=latex']
\node [input, name=input] {};
\node [sum, right of=input] (sum) {};
\node [block, right of=sum, node distance=3.5cm] (controller) {$C(z^{-1})$};
\node [block, right of=controller, pin={[pinstyle]above:$d(k)$}, node distance=4cm] (system) {$P(z^{-1})$};
\draw [->] (controller) -- node[name=u] {$u(k)$} (system);
\node [output, right of=system] (output) {};
\node [block, below of=u] (measurements) {$F(z^{-1})$};
\draw [draw,->] (input) -- node {$r(k)$} (sum);
\draw [->] (sum) -- node {$e(k)$} (controller);
\draw [->] (system) -- node [name=y] {$y(k)$}(output);
\draw [->] (y) |- (measurements);
\draw [->] (measurements) -| node[pos=0.99] {$-$} node [near end] {$y_m(k)$} (sum);
\end{tikzpicture}
```



[1] Modified from an example in http://www.texample.net/tikz/examples/control-system-principles/

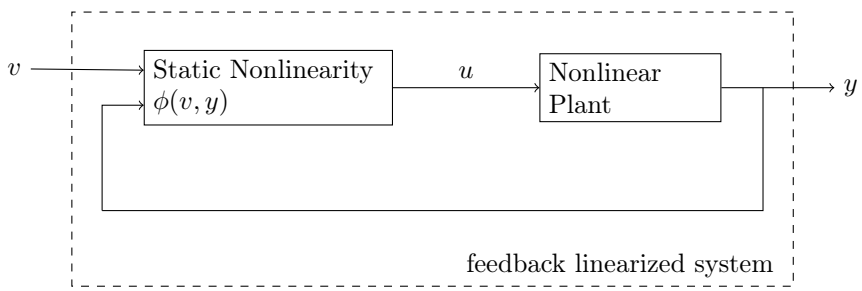
It might be more preferred to construct a matrix and put different nodes there first:

```
\begin{tikzpicture}[auto, node distance=2cm,>=latex']
\matrix[column sep = .75cm, row sep = .375cm]
{
\node (u){$u$}; &
\node [coordinate](d1){}; &
\node [block](plant){$P$}; &
\node [coordinate](d2){}; &
\node (y){$y$}; &
\\
& & & & \node [block](obs){Observer}; & \node (xhat){$\hat{x}$};
\\
};
\draw [->] (u) – (plant);
\draw [->] (plant) – (y);
\draw [->] (obs) – (xhat);
\draw [->] (d1) |- (obs.190);
\draw [->] (d2) |- (obs.170);
\end{tikzpicture}
```

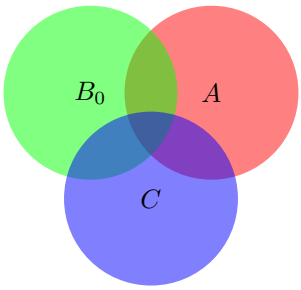


Comments can be very easily added by using relative locations:

```
\begin{tikzpicture}
[
xscale = 1, % to scale horizontally everything but the text
yscale = 1, % to scale vertically everything but the text
]
% NODES DEFINITION
\matrix [ row sep = .375cm, column sep = .75cm, ]
{
% ———————————— row 1
\node (nInputv)[yshift = 0.25cm] {$v$}; &
\node (n22) [coordinate] {}; &
\node (nPhi) [block] {\parbox[c]{1.2in}{Static Nonlinearity \\ $\phi(v,y)$}}; &
\node (nInputu)[above]{$u$}; &
\node (nSystem) [block] {\parbox[c]{.85in}{Nonlinear \\ Plant}}; &
\node (n26) [coordinate, xshift = -0.2cm] {}; &
\node (nOutput) {$y$}; &
\\
& & & & & &
\\
& & & & & &
\\
% ———————————— row 2
\node (n11) [coordinate] {}; &
\node (n12) [coordinate, xshift = 0.2cm] {}; &
\node (n13) [coordinate] {}; &
\node (n14) [coordinate] {}; &
\node (n15) [coordinate] {}; &
\\
};
% ———————————————————————————— % PATHS
\draw [->] (nInputv) – (nPhi.172);
\draw [->] (nPhi) – (nSystem);
\draw [->] (nSystem) – (nOutput);
\draw [-] (n26) |- (n12);
\draw [->] (n12) |- (nPhi.188); %
% auxiliary nodes
\node [coordinate, xshift = 0.4cm, yshift = 1cm] (nAux1) at (n26) {};
\node [coordinate, xshift = -0.4cm, yshift = -1cm] (nAux2) at (n12) {}; %
\draw [dashed] (nAux1) -| (nAux2) -| (nAux1) node [above, pos = 0.38] {feedback linearized system};
\end{tikzpicture}
```

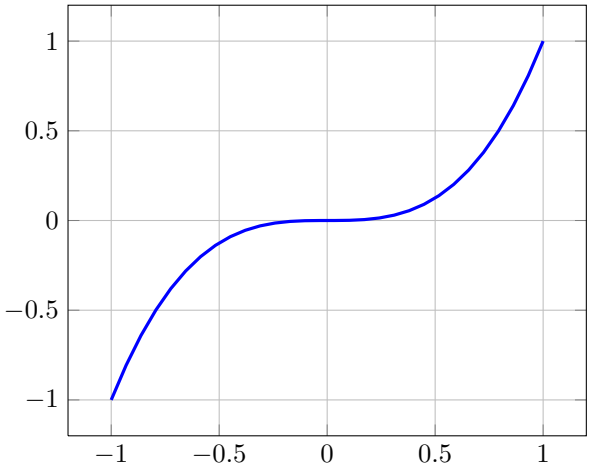


Tikz can also generate simple graphs such as



Several more detailed examples are provided next:

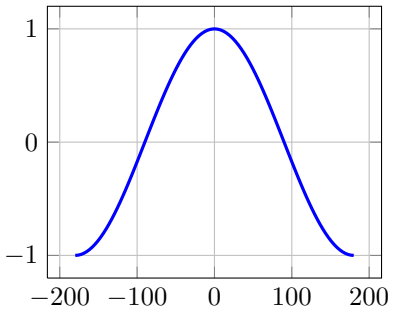
```
\begin{tikzpicture}
\begin{axis}
[grid=major,samples=30,mark=none]
\addplot[blue,very thick,domain=-1:1]
{x^3};
\end{axis}
\end{tikzpicture}
```

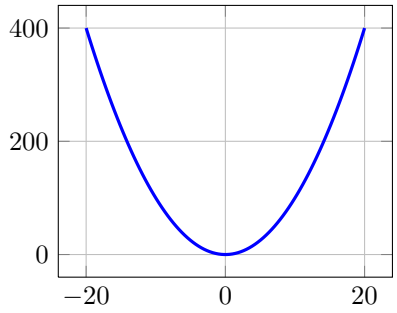


We can actually define a new function to avoid repeated writing the same codes:

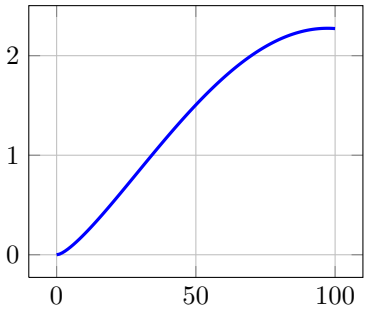
```
\newcommand{\plotfun}[3][6cm]{
\begin{tikzpicture}
\begin{axis}
[width=#1,grid=major,samples=100,mark=none]
\addplot[blue,very thick,domain=#3]
{#2};
\end{axis}
\end{tikzpicture}
}
```

Using now \plotfun{cos(x)}{-180:180} and \plotfun{x^2}{-20:20}, we can get





We can combine different functions. for instance, \plotfun{(sin(x)*ln(x+1))/2}{0:100} typesets



We can even use rnd to generate random numbers. For instance, \plotfun{rnd}{-20:20} typesets