Makefiles

Originally designed for compiling large software projects, Makefiles can automate the dependencies between data analysis steps, enabling **reproducible research**.[1] Taking a little time early on to precisely record and understand your steps in a Makefile will pay big dividends when it comes time to reproduce that analysis.

To create this pdf, navigate to the directory containing the Makefile and type `make`. Note that you will need LaTeX, R, and Python installed for this example. The Makefile contains a list of dependencies and commands that act as a recipe for building the final product, in this case a pdf. Later, if you change any step in the analysis you can issue the `make` command again and the make program will run the appropriate commands to refresh the results.

Makefiles consist of rules that follow this pattern:

```
target: dependencies
[tab] system command
```

Note that it **must** have a tab character, spaces will not work. You may need to change your text editor settings. This is one of the only times that tab characters are a good idea when programming. The Makefile below generates this pdf.

Makefile

```
paper.pdf : paper.tex figure.pdf make_graph.pdf plot.R Makefile
        pdflatex paper.tex

# Running vanilla means that R won't save or use .RData files
figure.pdf : data.csv plot.R
        R CMD BATCH --vanilla plot.R

data.csv : get_data.py
        python get_data.py

make_graph.pdf : make_graph.dot
        dot -Tpdf make_graph.dot -o make_graph.pdf

make_graph.dot : make_graph.py Makefile
        python make_graph.py > make_graph.dot

clean :
        rm *.Rout *.aux *.log
```

[1] For more on reproducible research, check out the chapter on Open Source Scientific Practice by K. Jarrod Millman and Fernando Perez available at `https://osf.io/h9gsd/`.

The first line describes our final target, `paper.pdf`. It says that `paper.pdf` depends on the TEX source `paper.tex`, `figure.pdf`, `make_graph.pdf`, `plot.R`, and `Makefile`. If any of these files change then the corresponding command `pdflatex paper.tex` will run, which makes a new `paper.pdf`. It's a little strange that it directly depends on all these source files but the reason is that LATEX actually pulls in the source code of `Makefile` and `plot.R` and renders it in the pdf!

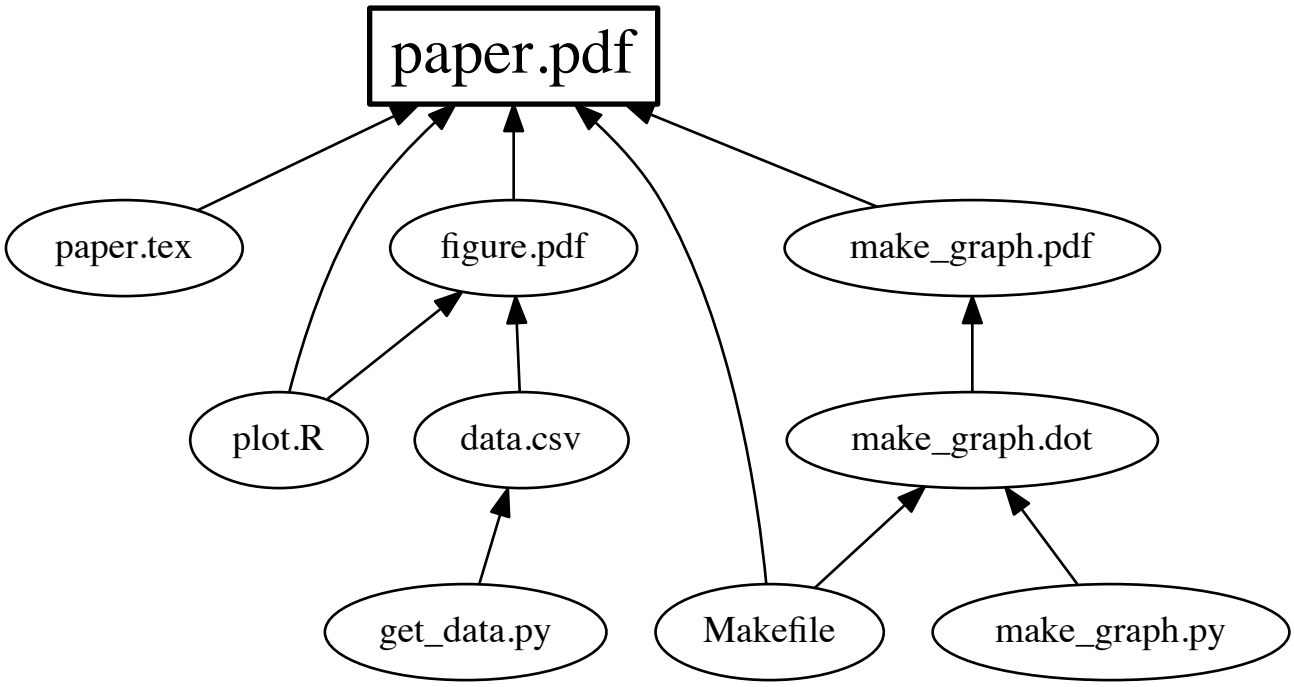
The line with `figure.pdf` as the target has dependencies `data.csv` and `plot.R`. If the data or the R script changes then `make` needs to create a new figure.

`data.csv` is a target with dependency `get_data.py`. If the Python script that produces the data changes and we run `make` again then the command `python get_data.py` will run, updating `data.csv`. This will cause `figure.pdf` to be plotted again, which will in turn cause the final pdf to be recreated.

The final target is `clean`. Issuing the command `make clean` runs the line beginning with `rm`, removing the byproducts of R and LATEX.

`make` is great because it's lazy. Good programmers always look out for a chance to be lazy. That means that if you only change `paper.tex`, then `make` won't plot the figure or do anything with the python script.

Below is a visualization of the Makefile. It was automatically created using Python to generate the dot language, aka Graphviz.



Use the `listings` package with LaTeX to include source code. For example, the R file shown below generates the corresponding plot.

plot.R

```
ru <- read.csv('data.csv')

pdf('figure.pdf', height=5, width=5)
plot(ru$x, ru$y, xlab='x', ylab='f(x)', col='red')
dev.off()
```

R saved this plot as a PDF. PDF's are vector graphics, which means that they'll look good no matter how much you zoom. Use them for professional results. Mathematical expressions are always beautiful in LaTeX.

$$f(x) = x^2 + 5x + \pi$$