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Automating Data-analysis Pipelines

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The goal of this activity is to create a pipeline that will

- obtain a large file of English words
- calculate a histogram of word lengths
- determine the most common word length

- generate a figure of this histogram
- render a R Markdown report in HTML and PDF

You will automate this pipeline using `make`!

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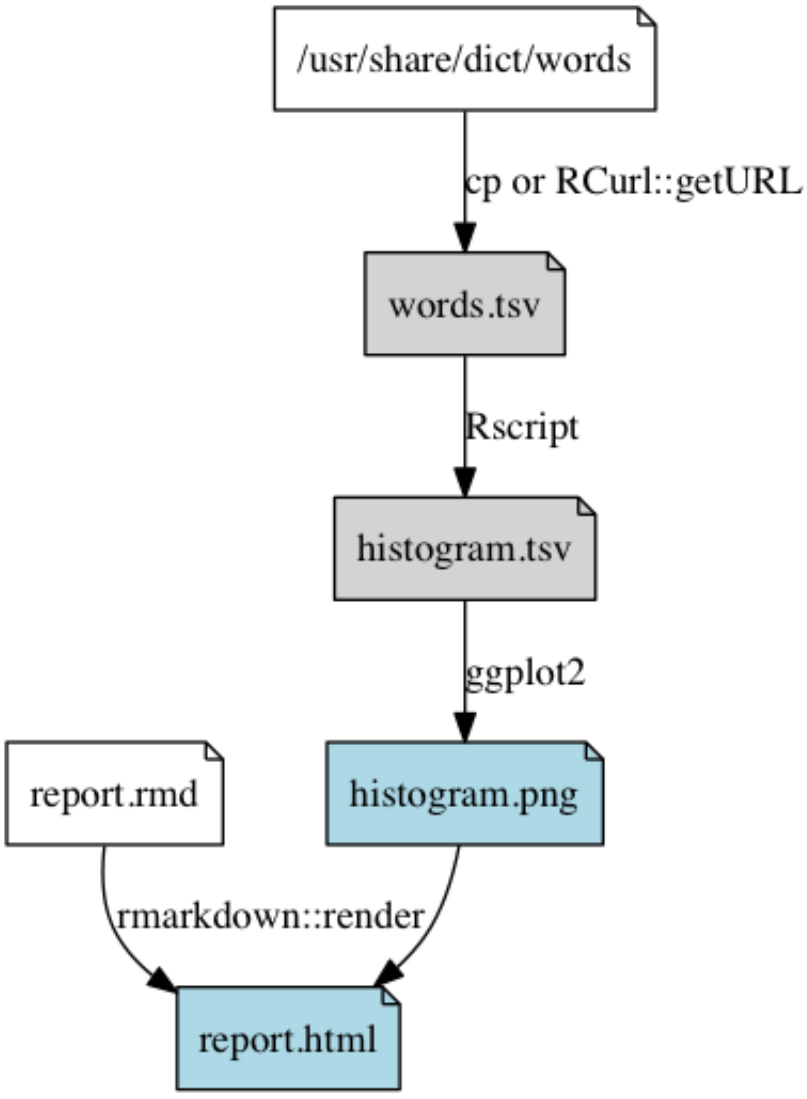
Dependency graph of the pipeline



(automation01_slides/images/activity.gv)

Set up a new RStudio Project (and Git repo)

In RStudio: *File* > *New Project* > *New Directory* > *Empty Project.* If you're a Git user, we strongly encourage you to click on "Create a git repository."

This project will be useful as a reference in the future, so give it an informative name and location. If you're a GitHub user, you may want to push it there as well.

Git(Hub) users: from here on out, we assume you will be committing at regular intervals. At key points, we explicitly prompt you to commit.

Git folks: commit now.

Sample Project and Git repository

We walked through this activity ourselves and this Git repo (https://github.com/STAT545-UBC/make-activity) reflects how our Project evolved.

The Project is set up for use with `make` at this commit (https://github.com/STAT545-UBC/make-activity/tree/5d282f87ec3fd46d13b500be51a74c9df146d283).

Create the Makefile

In RStudio: *File* > *New File* > *Text File.* Save it with the name `Makefile`. Keep adding the rules we write below to this file, saving regularly.

Once you've saved the file with the name `Makefile`, RStudio should indent with tabs instead of spaces. I recommend you display whitespace in order to visually confirm this: *RStudio* > *Preferences* > *Code* > *Display* > *Display whitespace characters*. A more extreme measure is to set Project or Global preferences to NOT replace tabs with spaces, but this will wreak havoc elsewhere.

You also want RStudio to recognize the presence of the `Makefile`. Pick one:

- set Project Build Tools to `Makefile`
- quit and relaunch

You should see a “Build” tab now in the same pane as “Environment”, “History”, and, if applicable, “Git”.

Git folks: commit now.

Get the dictionary of words

Depending on your OS and mood, you can get the file of English words by copying a local file or downloading from the internet.

Download the dictionary

Our first `Makefile` rule will download the dictionary `words.txt`. The command of this rule is a one-line R script, so instead of putting the R script in a separate file, we’ll include the command directly in the `Makefile`, since it’s so short. *Sure, we could download a file without using R at all but humor us: this is a tutorial about `make` and R!*

```
words.txt:
	Rscript -e 'download.file("https://svnweb.freebsd.org/base/head/share/dict/web2?view=co", destfile = "words.txt", quiet = TRUE)'
```

Suggested workflow:

- Git folks: commit anything new/modified. Start with a clean working tree.
- Submit the above `download.file()` command in the R Console to make sure it works.
- Inspect the downloaded words file any way you know how; make sure it’s not garbage. Size should be about 2.4MB.
- Delete `words.txt`.

- Put the above rule into your `Makefile`. From the shell (git09_shell.html), enter `make words.txt` to verify rule works. Reinspect the words file.
- Git folks: commit `Makefile` and `words.txt`.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/c30ecc9c890a2f2261eb94118997f0774012eeb8).

Copy the dictionary

On Mac or Linux systems, rather than download the dictionary, we can simply copy the file `/usr/share/dict/words` that comes with the operating system. In this alternative rule, we use the shell (git09_shell.html) command `cp` to copy the file.

```
words.txt: /usr/share/dict/words
	cp /usr/share/dict/words words.txt
```

This rule copies the input file `/usr/share/dict/words` to create the output file `words.txt`. We then repeat these file names in the command rule, which is redundant and leaves us vulnerable to typos. `make` offers many automatic variables, so the revised rule below uses `$<` and `$@` to represent the input file and output file, respectively.

```
words.txt: /usr/share/dict/words
	cp $< $@
```

Suggested workflow:

- Git folks: commit anything new/modified. Start with a clean working tree.
- Remove `words.txt` if you succeeded with the download approach.
- Submit the above `cp` command in the shell (git09_shell.html) to make sure it works.
- Inspect the copied words file any way you know how; make sure it's not

garbage. Size should be about 2.4MB.
- Delete `words.txt`.
- Put the above rule into your `Makefile`. From the shell (git09_shell.html), enter `make words.txt` to verify rule works. Reinspect the words file.
- Git folks: look at the diff. You should see how your `words.txt` rule has changed and you might also see some differences between the local and remote words files. Interesting! Commit `Makefile` and `words.txt`.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/1131791548e0c5bbc5104eebb19710ed435146e3).

Create rules for all and clean

It would be nice to execute our `make` rules from RStudio. So it's urgent that we create phony targets `all` and `clean`, which are the only targets accessible from RStudio. These targets are phony in the sense that they do not specify an actual file to be made, rather they just make it easy to trigger a certain action. `all` and `clean` are phony targets that appear in most `Makefiles`, which is why RStudio makes it easy to access them from the IDE.

Edit your `Makefile` to look like this (where your `words.txt` rule can be the copy or download version):

```
all: words.txt

clean:
	rm -f words.txt

words.txt: /usr/share/dict/words
	cp /usr/share/dict/words words.txt
```

Since our only output so far is `words.txt`, that's what we associate with the `all` target. Likewise, the only product we can re-make so far is `words.txt`, so it's the only thing we delete via `clean`.

Suggested workflow:

- Use `make clean` from the shell and/or *RStudio* > *Build* > *More* > *Clean All* to delete `words.txt`.
  - Does it go away?
  - Git folks: does the deletion of this file show up in your Git tab?
- Use `make all` from the shell and/or *RStudio* > *Build* > *Build All* to get `words.txt` back.
  - Does it come back?
  - Git folks: does the restoration of `words.txt` cause it to drop off your radar as a changed/deleted file? See how this stuff all works together?
- Git folks: Commit.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/9e1a556adc602ffce91b5c8edccd223237080c54).

Create a table of word lengths

This rule will read the list of words and generate a table of word length frequency, stored in a tab-separated-values (TSV) file. This R script is a little longer, so we'll put it in its own file, named `histogram.r`. If either the script `histogram.r` or the data file `words.txt` were to change, we'd need to rerun this command to get up-to-date results, so both files are dependencies of this rule. The input-file variable `$<` refers to the *first* dependency, `histogram.r`.

```
histogram.tsv: histogram.r words.txt
	Rscript $<
```

FYI: `Rscript` allows you to execute R scripts from the shell (git09_shell.html). It is a more modern replacement for `R CMD BATCH` (don't worry if you've never heard of that).

Create the R script `histogram.r` that reads the list of words from `words.txt` and writes the table of word length frequency to `histogram.tsv`. It should be a tab-delimited TSV file with a header and two columns, named `Length` and `Freq`. Hint: you can accomplish this task using four functions: `readLines`, `nchar`, `table` and `write.table`. Here's one solution (https://raw.githubusercontent.com/STAT545-UBC/STAT545-UBC.github.io/master/automation10_holding-area/activity/histogram.r), but try not to peek until you've attempted this task yourself.

Suggested workflow:

- Develop your `histogram.r` script interactively. Make sure it works when you step through it line-by-line. Debugging only gets harder once you're running entire scripts at arm's length via `make`!
- Remove `histogram.tsv`. Clean out the workspace and restart R. Run `histogram.r` via `source()` or using RStudio's Source button. Make sure it works!
- Add the `histogram.tsv` rule to your `Makefile`.
- Remove `histogram.tsv` and regenerate it via `make histogram.tsv` from the shell (git09_shell.html).
- Git folks: Commit.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/889e01a3d610e900c7e58ebd32a0506c61543fd9).

Update rules for all and clean

The new output `histogram.tsv` can replace `words.txt` as our most definitive output. So it will go in the `all` rule. Likewise, we should add `histogram.tsv` to the `clean` rule. Edit your `all` and `clean` rules to look like this:

```
all: histogram.tsv

clean:
	rm -f words.txt histogram.tsv
```

Suggested workflow:

- Use `make clean` from the shell and/or *RStudio* > *Build* > *More* > *Clean All*.
  - Do `words.txt` and `histogram.tsv` go away?
  - Git folks: does the deletion of these files show up in your Git tab?
- Use `make all` from the shell and/or *RStudio* > *Build* > *Build All* to get `words.txt` back.
  - Does it come back?
  - Git folks: does the restoration of the files cause them to drop off your radar as changed/deleted files?
- Git folks: Commit.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/4f392d0e20bb7e4bfcdc00a812190e40e27ae3d4).

Plot a histogram of word lengths, update all and clean

This rule will read the table of word lengths and plot a histogram using `ggplot2::qplot()`. The R snippet is three lines long, but we'll still include the script in the `Makefile` directly, and use semicolons `;` to separate the R commands. The variable `$@` refers to the output file, `histogram.png`.

```
histogram.png: histogram.tsv
	Rscript -e 'library(ggplot2); qplot(Length, Freq, data=read.delim("$<")); ggsave("$@")'
```

Suggested workflow:

- Test the histogram-drawing code in the R Console to make sure it works.
- Inspect the resulting PNG to make sure it's good.
- Clean up after yourself.
- Add the above rule to your `Makefile`.
- Test that new rule works.
- If you get an unexpected empty plot `Rplots.pdf`, don't worry about it yet.
- Update the `all` and `clean` targets in light of this addition to the pipeline.
- Test the new definitions of `all` and `clean`.
- Git folks: commit.

NOTE: Why are we writing this PNG to file when, by the end of the activity, we are writing an R Markdown report? We could include this figure-making code in an R chunk there. We're doing it this way to demonstrate more about R and `make` workflows. Plus sometimes we do work this way in real life, if a figure has a life outside one specific R Markdown report.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/221c2d66fe9fd7a359835492db6557e258178780).

Use `make` to deal with an annoyance

The code used above to create `histogram.png` usually leaves an empty `Rplots.pdf` file behind. You can read this thread on stackoverflow (http://stackoverflow.com/questions/17348359/how-to-stop-r-from-creating-empty-rplots-pdf-file-when-using-ggsave-and-rscript) if you'd like to know more.

We'll just use this as a teachable moment to demonstrate how handy an automated pipeline is for dealing with such annoyances and to show a multi-line `make` rule.

Update the `histogram.png` rule like so:

```
histogram.png: histogram.tsv
	Rscript -e 'library(ggplot2); qplot(Length, Freq, data=read.delim("$<")); ggsave("$@")'
	rm Rplots.pdf
```

Suggested workflow:

- Remove `Rplots.pdf` manually
- Add the `rm Rplots.pdf` command to the `histogram.png` rule.
- Test that new rule works.
- Test that behavior of `all` and `clean` still good.
- Git folks: commit.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/3b75dac0d0cd8dd7e7cd3c2e66799a65d90b9fff).

Render an HTML report

Finally, we'll use `rmarkdown::render()` to generate an HTML report. If we think narrowly, we might say that the HTML report depends only on its Markdown predecessor, which would lead to a rule like this:

```
report.html: report.md
	Rscript -e 'rmarkdown::render("$<")'
```

But we really shouldn't hard-wire statements about word length in Markdown; we should use inline R code to compute that from the word length table. Similarly, if the plotted histogram were to change, we'd need to remake the HTML report. Here is a better rule that captures all of these dependencies:

```
report.html: report.rmd histogram.tsv histogram.png
	Rscript -e 'rmarkdown::render("$<")'
```

Create the R Markdown file `report.rmd` that reads the table of word lengths `histogram.tsv`, reports the most common word length, and displays the pre-made histogram `histogram.png`. Here's one solution (https://raw.githubusercontent.com/STAT545-UBC/STAT545-UBC.github.io/master/automation10_holding-area/activity/report.rmd), but try not to peek until you've attempted this task yourself.

Suggested workflow:

- Develop `report.rmd`, running the R chunks often, from a clean workspace and fresh R session. Debugging only gets harder once you're rendering entire reports at arm's length via `make`!
- Render the report using `rmarkdown::render()` in the Console or RStudio's Preview HTML button.
- Clean up after yourself.
- Add the above rule for `report.html` to your `Makefile`.
- Test that new rule works.
- Update the `all` and `clean` targets in light of this addition to the pipeline.
- Test the new definitions of `all` and `clean`.
- Git folks: commit.

See the sample Project at this point in this commit (https://github.com/STAT545-UBC/make-activity/tree/91ebcfc7d25743ebd8d6c9684ed7923ad4758585).

The Final Makefile

At this point, your `Makefile` should look something like this:

```
all: report.html

clean:
	rm -f words.txt histogram.tsv histogram.png report.md report.
html

words.txt: /usr/share/dict/words
	cp /usr/share/dict/words words.txt

histogram.tsv: histogram.r words.txt
	Rscript $<

histogram.png: histogram.tsv
	Rscript -e 'library(ggplot2); qplot(Length, Freq, data=read.d
elim("$<")); ggsave("$@")'
	rm Rplots.pdf

report.html: report.rmd histogram.tsv histogram.png
	Rscript -e 'rmarkdown::render("$<")'
```

Remember, you can review the entire activity via the commit history of the sample Project: https://github.com/STAT545-UBC/make-activity (https://github.com/STAT545-UBC/make-activity).

And that's how a data analytical pipeline gets built using `make`, the shell, R, RStudio, and optionally Git.

Appendix

Here are some additions (https://www.gnu.org/software/make/manual/html_node/Special-Targets.html) you might like to include in your `Makefile`:

```
.PHONY: all clean
.DELETE_ON_ERROR:
.SECONDARY:
```

The `.PHONY` line is where you declare which targets are *phony*, i.e. are not actual files to be made in the literal sense. It's a good idea to explicitly tell `make` which targets are phony, instead of letting it try to deduce this. `make` can get confused if you create a file that has the same name as a phony target. If for example you create a directory named `clean` to hold your clean data and run `make clean`, then `make` will report `'clean' is up to date`, because a directory with that name already exists.

`.DELETE_ON_ERROR` causes `make` to "delete the target of a rule if it has changed and its recipe exits with a nonzero exit status". In English, this means that – if a rule starts to run but then exits due to error – any outputs written in the course of that fiasco will be deleted. This can protect you from having half-baked, erroneous files lying around that will just confuse you later.

`.SECONDARY` tells `make` not to delete intermediate files of a chain of pattern rules. Consider creating a `Makefile` with two pattern rules, `%.md: %.rmd` and `%.html: %.md`, and then running `make report.html`. After `make` has created `report.md` and `report.html`, it will delete the intermediate file `report.md`. Adding `.SECONDARY` to your `Makefile` prevents the intermediate file from being deleted.

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