Approaches and Barriers to Reproducible Practices in Biostatistics

Matthew S. Shotwell and JoAnn M. Álvarez

Vanderbilt University
Department of Biostatistics

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Reproducible Research

- RR is the practice of presenting computational research such that members of a scientific community may easily reproduce and verify the results.
- Distinct from “scientific replication”
- Reproducibility *i.e. RR* verifies an experimental result
- Replication strengthens evidence about a scientific theory

Origins of RR

- Jon Claerbout; geophysical image/signal processing; Stanford, mid 1980's:
- "a few months after completing a project, the researchers at our laboratory were usually unable to reproduce their own work without considerable agony".
- [Schwab et al., 2009]
- Reviewing published results were no help (no code, no data)!
- Led to reverse engineering a colleague's, even one's own work!
- In biomedical research, [Baggerly and Coombes, 2009] call this "forensic bioinformatics".

Claerbout's Principle

> *An article about computational science in a scientific publication is not the scholarship itself, it is merely advertising of the scholarship. The actual scholarship is the complete software development environment and the complete set of instructions which generate the figures.*

[Buckheit and Donoho, 1995]
[de Leeuw, 2001]

Claerbout's Principle Clarified

> *The scholarship does not only consist of theorems and proofs but also (and perhaps even more important) of data, computer code and a runtime environment which provides readers with the possibility to reproduce all tables and figures in an article.*

[Hothorn et al., 2009]

The Beneficiaries of RR

Quoting Schwab and Claerbout:

> *It takes some effort to organize your research to be reproducible. We found that although the effort seems to be directed to helping other people stand up on your shoulders, the principal beneficiary is generally the author herself. This is because time turns each one of us into another person, and by making effort to communicate with strangers, we help ourselves to communicate with our future selves.*

Timeliness of RR (and sessions like this)

- As research becomes more technical, RR is more important
  - Journal page requirements haven't increased
  - Online suppliments help
- The barriers to RR are not philosophical, but practical
  - Few incentives from journals (but this is changing)
  - Perception of effort
  - Software tools (solved?)
  - Survey evidence

Prevalence of RR

[Hothorn et al., 2009]: Considered v.50 Biometrical Journal:

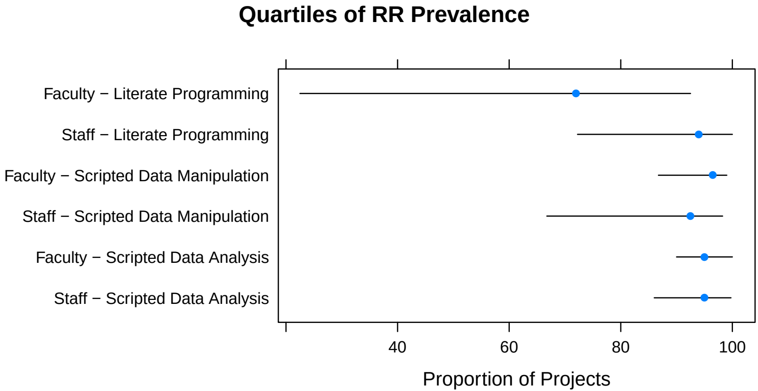
- Among 53 articles with simulations:
    - 17 provide data
    - 8 provide code
    - 6 “contain the whole scholarship” (data + code)

[Ioannidis et al., 2008] found similar in gene microarray articles

Barriers to RR

- In conversation, statisticians often admit the benefits of RR.
- So, why isn't reproducible research more prevalent?
- What are the barriers to adopting reproducible practices?
- We polled biostatisticians of VUMC Dept. of Biostatistics to assess:
    - the prevalence of fully scripted data analyses
    - the prevalence of literate programming practices
    - the perceived barriers to reproducible research

Prevalence of RR



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Barriers to RR

The biggest obstacle to always reproducibly scripting your work?

Barrier	Staff	Faculty
No significant obstacles.	8	10
I havent learned how.	0	0
It takes more time.	7	7
It makes collaboration difficult. (e.g. file compatibility)	4	2
The software I use doesnt facilitate reproducibility.	0	0
Its not always necessary for my work to be reproducible.	2	0
Other	2	1

The Reproducible Electronic Document - ReDoc

- Claerbout's lab [Schwab et al., 2009], adopted an RR framework centered around the `make` utility.
- GNU `make`: `http://www.gnu.org/software/make/`
- `make` synchronizes the generation of output from source files
- `make` is configured using a `Makefile` with *targets*, *dependencies* and commands.
- Targets are generated from their dependencies using the associated commands
- Example

```
target:          dependency
                 command1
                 command2
```

- ReDoc `make` targets: `build`, `clean`, `burn`, `view`
- File naming conventions.

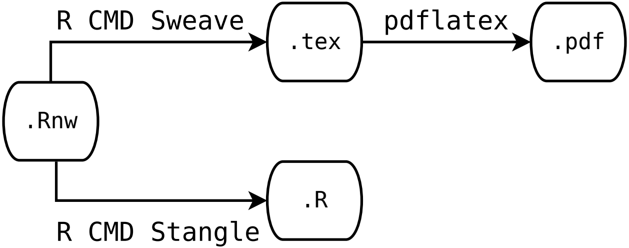
The RR Compendium

[Gentleman and Temple Lang, 2007]

- RR Compendium: a dynamic document containing text, code, and data.
- The complete scholarship, a la Claerbout's principle.
- *Transformations* are applied to the compendium to view its various aspects (*e.g.* convert raw data into a graphic).
- Recommend using `make` to synchronize transformations.

Sweave

- Sweave [Leisch, 2002] is a tool for working with RR compendia in R
- Compendium: a LaTeX file mixed with R code + data
- Transformations: weaving + tangling [Knuth, 1984]



Simple Sweave Example

example.Rnw:

```
\documentclass{article}
\begin{document}

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consequat at bibendum libero convallis. \[ F(b) - F(a) = \int_a^b f(x)dx \]

<<fig=TRUE, keep.source=TRUE>>=
     # From ?persp
     y <- x <- seq(-10, 10, length= 30)
     f <- function(x,y) { r <- sqrt(x^2+y^2); 10 * sin(r)/r }
     z <- outer(x, y, f)
     z[is.na(z)] <- 1
     persp(x, y, z, theta = 30, phi = 30, expand = 0.5)
@

Integer eu purus non mi sagittis venenatis. Integer venenatis, nulla ac
scelerisque volutpat, ante felis consectetur enim, vitae fringilla purus lorem
et elit. Curabitur congue facilisis ipsum, non cursus tortor dignissim eu.
Donec convallis feugiat eros et vestibulum.

\end{document}
```

Simple Sweave Example

`R CMD Sweave example.Rnw` → `example.tex`:

```
\documentclass{article}
\usepackage{Sweave}
\begin{document}

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Suspendisse elementum
magna et velit molestie lobortis eget eget magna. In quis tincidunt risus.
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consequat at bibendum libero convallis. \[ F(b) - F(a) = \int_a^b f(x)dx \]

\begin{Schunk}
\begin{Sinput}
>       # From ?persp
>       y <- x <- seq(-10, 10, length= 30)
>       f <- function(x,y) { r <- sqrt(x^2+y^2); 10 * sin(r)/r }
>       z <- outer(x, y, f)
>       z[is.na(z)] <- 1
>       persp(x, y, z, theta = 30, phi = 30, expand = 0.5)
\end{Sinput}
\end{Schunk}
\includegraphics{example-001}

Integer eu purus non mi sagittis venenatis. Integer venenatis, nulla ac
scelerisque volutpat, ante felis consectetur enim, vitae fringilla purus lorem
et elit. Curabitur congue facilisis ipsum, non cursus tortor dignissim eu.
Donec convallis feugiat eros et vestibulum.

\end{document}
```
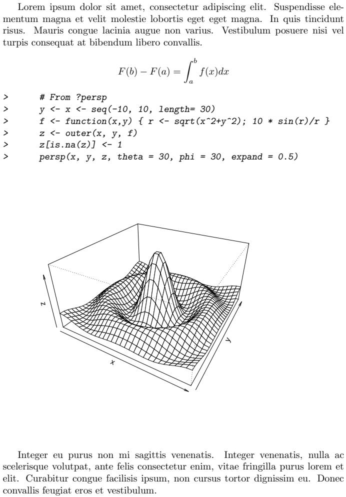

Simple Sweave Example

pdflatex example.tex → example.pdf



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$$F(b) - F(a) = \int_a^b f(x)dx$$

```
>       # From ?persp
>       y <- x <- seq(-10, 10, length= 30)
>       f <- function(x,y) { r <- sqrt(x^2+y^2); 10 * sin(r)/r }
>       z <- outer(x, y, f)
>       z[is.na(z)] <- 1
>       persp(x, y, z, theta = 30, phi = 30, expand = 0.5)
```

Integer eu purus non mi sagittis venenatis. Integer venenatis, nulla ac scelerisque volutpat, ante felis consectetur enim, vitae fringilla purus lorem et elit. Curabitur congue facilisis ipsum, non cursus tortor dignissim eu. Donec convallis feugiat eros et vestibulum.

Web-based RR Compendia

Why web-based?

- Pros:
  - nearly universal compatibility
  - security (restricted access, encryption)
  - centralized storage and backup
  - persistent (keep a record of your work!)
  - images handled more naturally
  - can be interactive (*e.g.* nomogram)
  - easy compendium download
- Cons:
  - mathematical typesetting
  - browser variability

Web-based RR Compendia

- Use HTML rather than LaTeX markup
- Use Sweave HTML *driver* rather than default LaTeX driver
- Use additional `make` target: `make publish`
- Publish the entire compendia (a link to itself)

Revision Control Systems

- Keep a record of changes to RR compendia
- Useful for modeling decisions (which aren't often documented)
- Modern RCSs: Subversion, Git, Mercurial

Baggerly, K. A. and Coombes, K. R. (2009). Deriving chemosensitivity from cell lines: Forensic bioinformatics and reproducible research in high-throughput biology. *The Annals of Applied Statistics*, 3(4):1309–1334.

Buckheit, J. B. and Donoho, D. L. (1995). WaveLab and reproducible research. In Antoniadis, A. and Oppenheim, G., editors, *Wavelets and statistics*, pages 55–81. Springer-Verlag Inc.

de Leeuw, J. (2001). Reproducible research: the bottom line. Technical report, Department of Statistics, UCLA, http://repositories.cdlib.org/uclastat/papers/2001031101.

Gentleman, R. and Temple Lang, D. (2007). Statistical Analyses and Reproducible Research. *Journal of Computational and Graphical Statistics*, 16(1):1–23.

Hothorn, T., Held, L., and Friede, T. (2009). Biometrical Journal and reproducible research. *Biometrical Journal*, 51(4):553–555.

Ioannidis, J. P., Allison, D. B., Ball, C. A., Coulibaly, I., Cui, X., Culhane, A. C., Falchi, M., Furlanello, C., Game, L., Jurman, G., Mangion, J., Mehta, T., Nitzberg, M., Page, G. P., Petretto, E., and van Noort, V. (2008). Repeatability of published microarray gene expression analyses. *Nature Genetics*, 41(2):149–155.

Knuth, D. (1984). Literate programming. *The Computer Journal*, 27(2):97–111.

Leisch, F. (2002). Sweave: Dynamic generation of statistical reports using literate data analysis. In *COMPSTAT 2002. Proceedings of the 15th symposium on computational statistics, Berlin, Germany, August 24–28, 2002.*, pages 575–580.

Schwab, M., Karrenbach, M., and Claerbout, J. (2009). Making scientific computations reproducible. *Computing in Science & Engineering*, 2(6):61–67.