Barriers to Reproducible Research and a Web-Based Solution

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Reproducible Research

- RR is the practice of presenting computational results so that 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

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Origins of RR

- Jon Claerbout; geophysical scientist; 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".

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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]

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Claerbout's Principle Clarified

The scholarship does not only consist of theorems and proofs but also (and perhaps even more importantly) 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]

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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.*

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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
[Hothorn and Leisch, 2011] found better in *Bioinformatics*

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Barriers to RR

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

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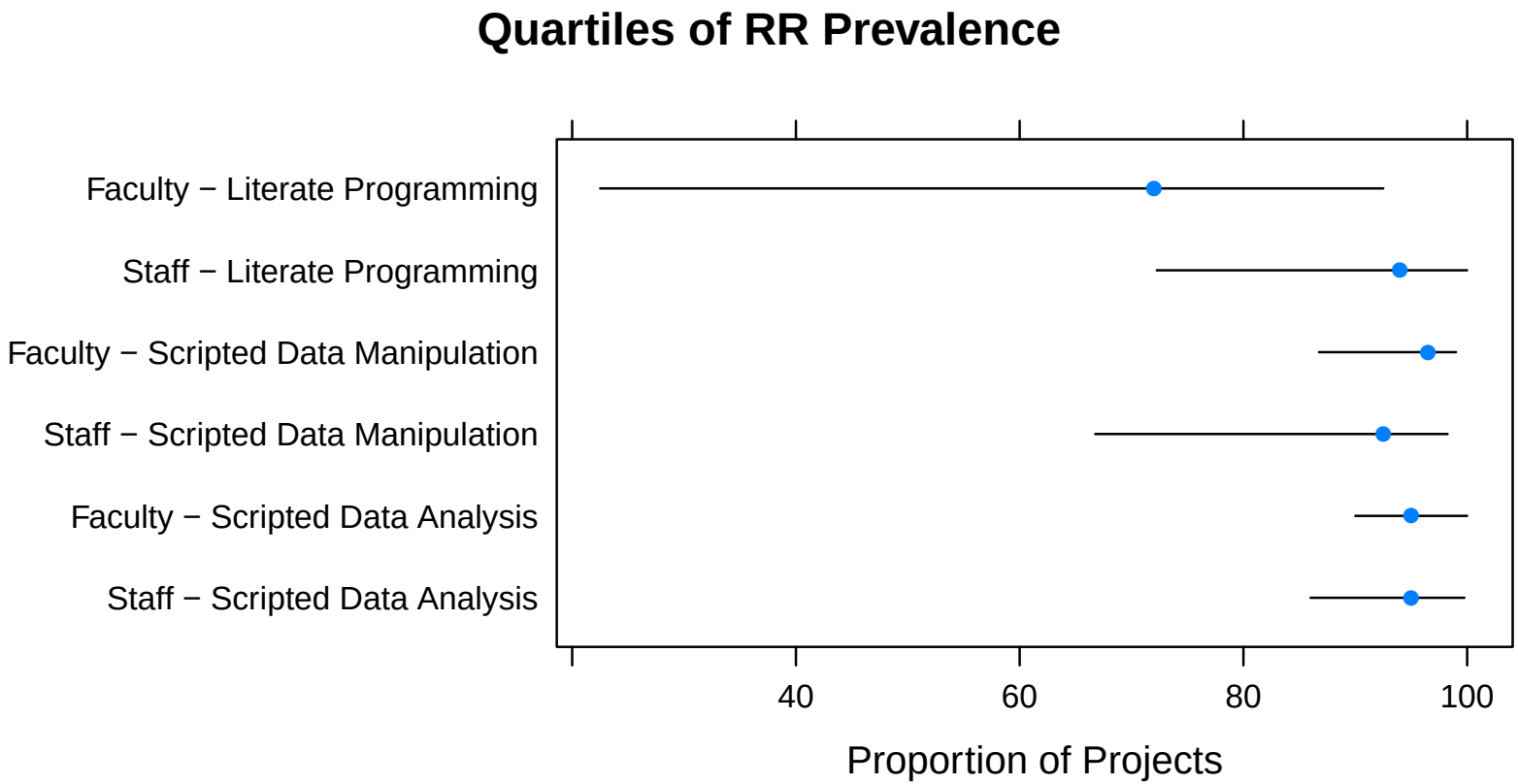
Prevalence of RR



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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 haven't learned how.	0	0
It takes more time.	7	7
It makes collaboration difficult. (software 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

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Other Barriers to RR

- Journals have not incentivized RR (this is changing)
  - *Biostatistics* - 2009 - "kite-mark" D,C,R
  - *Nature* - 2013 - new methods policies
- Proprietary/expensive/incompatible research tools (SAS)
- Scooping/Coattailing (reciprocity/"viral" clause)
- RR software tools (solved?)

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The Reproducible Electronic Document - ReDoc

- Claerbout's lab [Schwab et al., 2009], adopted an RR software 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 instructions
- Targets (outputs) are generated from their dependencies using the associated instructions
- Example

```
target:          dependency
                 instruction1
                 instruction2
```

- ReDoc `make` targets: `build`, `clean`, `view`, `burn`
- use by typing "`make <target>`" at command prompt

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The Reproducible Electronic Document

Example `Makefile`

```
build:          results.pdf

results.pdf:    results.tex
                pdflatex results.tex

clean:
                rm -f results.aux results.log

burn:
                rm -f results.pdf

view:           results.pdf
                gs results.pdf
```

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Sweave ReDoc

- Sweave [Leisch, 2002] is a tool for mixing R output with LaTeX
- Additional ReDoc target:

```
results.tex:    results.Rnw
                R CMD Sweave results.Rnw
```

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Sweave ReDoc

results.Rnw:

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

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Suspendisse elementum
magna et velit molestie lobortis eget eget magna. In quis tincidunt risus.
Mauris congue lacinia augue non varius. Vestibulum posuere nisi vel turpis
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}
```

make build → results.tex → results.pdf:

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Sweave ReDoc

results.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.
Mauris congue lacinia augue non varius. Vestibulum posuere nisi vel turpis
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}
```

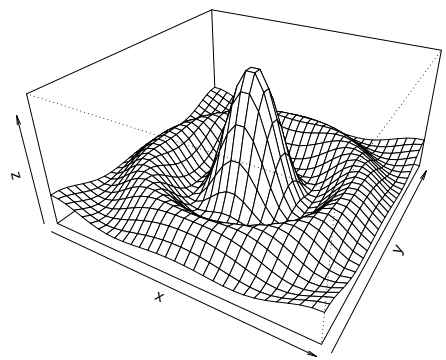
Sweave ReDoc

results.pdf

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Suspendisse elementum magna et velit molestie lobortis eget eget magna. In quis tincidunt risus. Mauris congue lacinia augue non varius. Vestibulum posuere nisi vel turpis consequat at bibendum libero convallis.

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

```
>     # 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.

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Web-based ReDoc

Why web-based?

- Pros:
  - software requirements are a minimal barrier
  - software compatibility and abstraction
  - security (restricted access, encrypted transmission)
  - centralized online storage
  - persistent (keep a record of your work!)
  - images/videos handled more naturally
  - can be interactive (*e.g.* nomogram)
  - mathematical typesetting
- Cons:
  - centralized online storage
  - mathematical typesetting
  - browser variability

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Web-based ReDoc

- Use additional ReDoc target: `make publish`
- Publish output to a web server
- Use HTML rather than LaTeX markup
- Mixing R output with HTML:
  - Sweave (HTML driver)
  - `brew`
  - `yarr`
  - `knitr`

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yarr

- yarr is an R package with facilities for mixing special text (e.g., R code) with plain text (or markup).
- In the yarr framework, special text must be delimited (by default "<<" and ">>"; but this is customizable; comment delimiters!).
- Additional characters that follow the opening delimiter "<<" tell yarr what to do with the delimited text. For example, special text that follows the opening delimiter "<<=" is treated like R code, and the output is inserted in place of the delimited special text.
- yarr is customizable so that special text may be treated in any number of ways (e.g., R code evaluated)

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Simple yarr Example

R -e ‘yarr::yarr(‘‘example.html.R’’)’ → example.html:

```
<html>
<head>
  <script type="text/javascript"
    src="http://cdn.mathjax.org/mathjax/latest/MathJax.js?config=TeX-AMS-MML_HTMLorMML">
  </script>
</head>
<body>
  <p>
    Lorem ipsum dolor sit amet, consectetur adipiscing elit. Suspendisse elementum
    magna et velit molestie lobortis eget eget magna. In quis tincidunt risus.
    Mauris congue lacinia augue non varius. Vestibulum posuere nisi vel turpis
    consequat at bibendum libero convallis. \[ F(b) - F(a) = \int_a^b f(x)dx \]
  </p>
  <pre style="border: 1px solid #aaa;">
    <<&
      perspplot <- expression({
        # 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)
      })
    >>
  </pre>
  <<= html.basegr(perspplot) >>
  <p>
    Ieteger 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.
  </p>
</body>
</html>
```

yarr Code Handlers

```
[[1]]
[[1]]$regex
[1] ""

[[1]]$handler
function (code, envir) {
    capture_handler(code, envir, output = FALSE)
}

[[2]]
[[2]]$regex
[1] "^="

[[2]]$handler
function (code, envir) {
    code <- sub("^=", "", code)
    capture_handler(code, envir, source = FALSE)
}

[[3]]
[[3]]$regex
[1] "^&"

[[3]]$handler
function (code, envir) {
    code <- sub("^&", "", code)
    capture_handler(code, envir, prompt = FALSE)
}
```

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`yarr` Code Handlers

- code handlers
  - may be modified on the fly
  - may handle special text that is not R code
  - add significant extensibility

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yarr Code Handler Extension

```
<<
    # Add a new handler to cite R
    .handlers[[length(.handlers) + 1]] <- list(
        regex = '^citation$',
        handler = function(code, envir) {
            cit <- citation()$textVersion
            paste(strwrap(cit, width=70), sep='', collapse='\n')
        })
>>
This is how R should be cited in publications:

<<citation>>
```

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yarr Code Handler Extension

```
This is how R should be cited in publications:

R Core Team (2013). R: A language and environment for statistical
computing. R Foundation for Statistical Computing, Vienna, Austria.
URL http://www.R-project.org/.
```

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`yarr` ReDoc

- `mkyarr` function creates a directory structure and ReDoc Makefile
- `yarr` at github: `https://github.com/biostatmatt/yarr`
- Example: VU Collaboration Example

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User Friendly Web-Based Alternative

- RStudio/knitr/RMarkdown

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