Guiding student work in modeling using reproducible statistical analysis tools

Nicholas J. Horton

Smith College, Northampton, MA, USA

July 2, 2010

nhorton@smith.edu
http://www.math.smith.edu/~nhorton

Plan for talk

- background on literate programming
- goals and motivation
- history of application to statistics
- example
- more details
- conclusions and future work (Statdocs as the holy grail)

Background on literate programming

- integrate code and documentation
- automate documentation and report generation
- (particularly) useful to students to facilitate appropriate and correct statistical analysis
- helps minimize the pain of iterative analyses
- leaves behind a clear online trail
- helps to structure analysis

Background on literate programming

Let us change our traditional attitude to the construction of programs: Instead of imagining that our main task is to instruct a computer what to do, let us concentrate rather on explaining to humans what we want the computer to do. (Donald E. Knuth, 1984).

Background on reproducible analysis

The purpose of Sweave (Statweave) is to create dynamic reports, which can be updated automatically if data or analysis change. Instead of inserting a prefabricated graph or table into the report, the master document contains the code necessary to obtain it. When run through a statistics package, all data analysis output (tables, graphs, . . .) is created on the fly and inserted into a final LaTeX (Open Office) document. The report can be automatically updated if (when!) data or analysis change, which allows for truly reproducible research. (Leisch, R-News 2002)

Reproducible statistical analysis

- document details of derived variables and subsetting
- facilitate re-running analyses with updated datasets
- goal: avoid cut and paste errors
- goal: single document (compendium) to generate different views for different audiences (Gentleman and Temple Lang, 2004)
- useful for collaborative work as well as teaching (Nolan and Temple Lang, 2007)

History of reproducible statistical analysis

- noweb (Ramsay, 1994) [support for programming language]
- R and XML (Temple Lang, 2001) [specialized]
- Sweave (Leisch, 2002) [S-plus and R only and LaTeX, quite popular]
- odfWeave (Kuhn, 2007) [extends Sweave to open document format, .odt]
- SASweave (Lenth and Hojsgaard, 2007) [added Sweave-like support for SAS]

StatWeave

- builds and generalizes prior systems
- supports multiple output formats (tex, dvi, pdf, odt)
- supports many languages/engines (R, S-plus, Stata, SAS, IML, Maple, Linux)
- plans for support for Matlab, Mathematica, GenStat (, SAGE?)
- runs under Windows, Mac OS X and Linux
- downloadable from `http://www.stat.uiowa.edu/~rlenth/StatWeave`
- sample files in `http://www.math.smith.edu/~nhorton/statweave`

Running StatWeave

- code chunks for each engine are collected
- code file are run (in order)
- output is collected and embedded
- similar in spirit to Mathematica notebooks, but more flexible

Example

```
suitable header, then

\begin{Rcode}
lmres <- lm(logfev~age+loght+initage+loginitht, data=ds)
summary(lmres)
\end{Rcode}
```

Output of regression

```
R> lmres <- lm(logfev~age+loght+initage+loginitht, data=ds)
R> summary(lmres)

Call:
lm(formula = logfev ~ age + loght + initage + loginitht, data = ds)

Residuals:
     Min       1Q   Median       3Q      Max
-0.46501 -0.07267  0.00192  0.07922  0.37385

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.33289    0.02071  -16.07  < 2e-16
age          0.02868    0.00208   13.81  < 2e-16
loght        2.04343    0.06880   29.70  < 2e-16
initage     -0.01498    0.00396   -3.78  0.00016
loginitht    0.39223    0.08263    4.75  2.2e-06

Residual standard error: 0.114 on 1988 degrees of freedom
Multiple R-squared: 0.88,       Adjusted R-squared: 0.88
F-statistic: 3.64e+03 on 4 and 1988 DF,  p-value: <2e-16
```

Execute a block of code

```
At this point we can access particular values, for example,
the age of the subject in row \Rexpr{i} is \Rexpr{age[i]}.
```

generates:

At this point we can access particular values, for example, the age of the subject in row 4 is 12.46.

Format regression results

```
\begin{Rcode}{results=tex}
library(xtable)
lmtab <- xtable(lmres,digits=c(0,3,3,2,4),
      caption="Better formatted results")
print(lmtab)
\end{Rcode}
```

Formatted output of regression

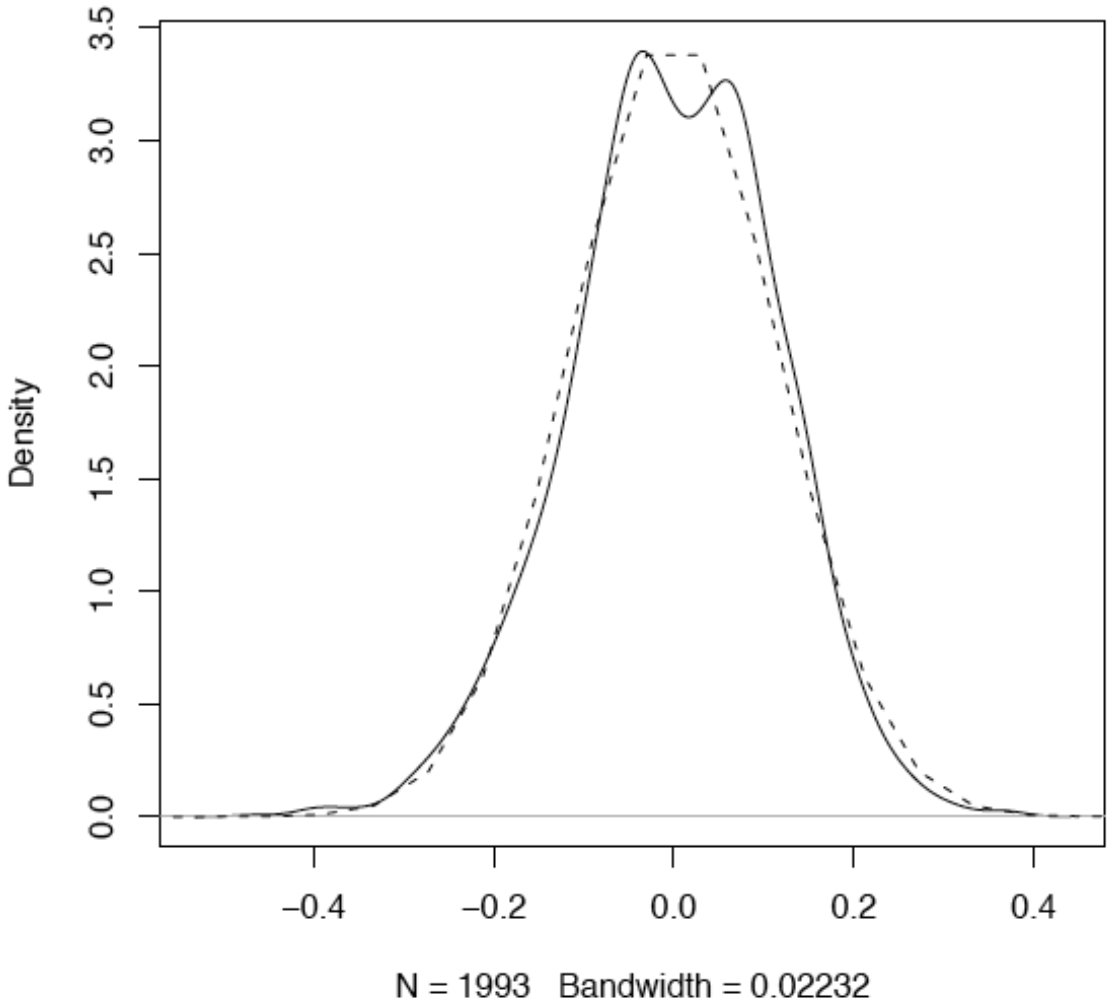
	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	−0.333	0.021	−16.07	0.0000
age	0.029	0.002	13.81	0.0000
loght	2.043	0.069	29.70	0.0000
initage	−0.015	0.004	−3.78	0.0002
loginitht	0.392	0.083	4.75	0.0000

Table 1: Better formatted results

Create a plot

```
Figure \ref{bplot} displays  the empirical density
of the residuals.
\begin{figure}[tbph]
\caption{Empirical density of residuals}
\label{bplot}
\begin{center}
\begin{Rcode}{fig,label=bplot}
plot(density(resid),main="")
x <- seq(from=-3,to=3,length=100)
lines(x,dnorm(x,0,sd(resid)),lty=2)
\end{Rcode}
\end{center}
\end{figure}
```

Plot of residuals



Open Office (.odt)

- slightly different syntax
- examples on my website
- can be saved as Microsoft Word (.doc) format

Open Office

R:

```
options(digits=3)
options(show.signif.stars=FALSE)
ds <- read.csv("http://www.math.smith.edu/~nhorton/statweave/fev.csv")
attach(ds)
i <- 4
ds[i,]
```

At this point we can access particular values, for example, the age of the subject in row R

Open Office

```
R> options(digits=3)
R> options(show.signif.stars=FALSE)
R> ds <- read.csv("http://www.math.smith.edu/~nhorton/statw
R> attach(ds)
R> i <- 4
R> ds[i,]

  id height  age initht initage logfev loght loginitht
4  1   1.42 12.5    1.2    9.34  0.751 0.351     0.182
```

Example

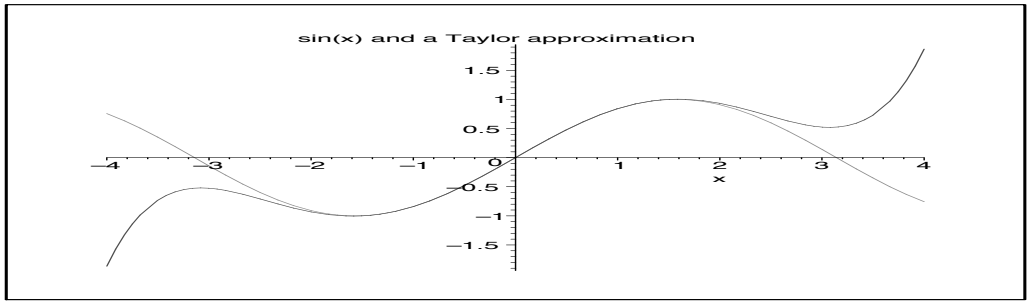
```
suitable header, then

Here is some Maple code to do a plot:
\begin{Maplecode}{fig, width=400, height=300, dispw=10cm, di
plot({sin(x), x-x^3/6+x^5/120}, x=-4..4,
title=`sin(x) and a Taylor approximation`);
\end{Maplecode}
```

Output of plot

Here is some Maple code to do a plot:

```
Maple> plot({sin(x), x-x^3/6+x^5/120}, x=-4..4, title=`sin(x)
```



Some other output

```
Maple> a := sin(x) * x^(x^x);
Maple> diff(a, x);
```

```
                                      x
                                    (x )
                     a := sin(x) x

         x                x   /                               x \
       (x )             (x )  | x                           x   |
cos(x) x      + sin(x) x      |x  (ln(x) + 1) ln(x) + ----|
                              \                             x   /
```

We can display these results in a more refined way: Suppose that $a = \sin(x)x^{x^x}$; then

$$\partial a/\partial x = \cos(x)x^{x^x} + \sin(x)x^{x^x}\left(x^x(\ln(x)+1)\ln(x) + \frac{x^x}{x}\right)$$

Projects in Intro and Intermediate Stat

- projects an effective way to implement many of the GAISE recommendations
  - use real data
  - stress conceptual understanding rather than mere knowledge of procedures
  - use technology for ... analysing data
- generally done in groups of 3-4
- need for audit trail is key
- many deliverables throughout the semester
- culminates in a final report

Group project from intro course in Stata

- data entry and cleaning
- creation of derived variables
- data summaries
- data analysis
- model assessment

Summary

- reproducible statistical analyses are a (very) good thing
- integrating documentation and output is helpful
- ability to rerun analyses with different datasets or analytic decisions is a big win
- StatWeave is portable and extensible

Future work and closing thoughts

- Statweave creates static documents, which can be extremely helpful
- particularly useful for statisticians in training or starting to work on collaborative research
- Creative people are working on extensions (DynDocs and StatDocs, Temple Lang and Nolan) that have even more potential