Journal of Statistical Software
June 2007, Volume 19, Issue 8. http://www.jstatsoft.org/

SASweave: Literate Programming Using SAS

Russell V. Lenth
The University of Iowa

Søren Højsgaard
Aarhus University

Abstract

SASweave is a collection of scripts that allow one to embed SAS code into a LaTeX document, and automatically incorporate the results as well. **SASweave** is patterned after `Sweave`, which does the same thing for code written in R. In fact, a document may contain both SAS and R code. Besides the convenience of being able to easily incorporate SAS examples in a document, **SASweave** facilitates the concept of "literate programming": having code, documentation, and results packaged together. Among other things, this helps to ensure that the SAS output in the document is in concordance with the code.

Keywords: SAS, **SASweave**, R, `Sweave`, literate programming.

1. Introduction

SASweave is a collection of AWK and shell scripts that provide a similar capability for SAS (SAS Institute Inc. 2003) that `Sweave` (Leisch 2002) does for R (R Development Core Team 2006). That is, **SASweave** provides the ability to embed SAS code into a LaTeX document. By processing the document with **SASweave**'s `sasweave` script, the code is executed and the results are included in the document. This provides a "literate programming" capability (Knuth 1992) for SAS, whereby code, output (including graphics), and documentation are all kept together, and where these elements are guaranteed to be synchronized.

For readers unfamiliar with literate programming and `Sweave`, Figure 1 shows just how easy this is (assuming prior familiarity with LaTeX). The figure displays a **SASweave** source file named `demo.SAStex`. The file is for all practical purposes a LaTeX source file; however, it includes two `SAScode` environments that each contain SAS statements; these are called "code chunks." (The portions that are not code chunks are called "text chunks.") The first code chunk produces printed output, and the second one produces a graph. The `\SASweaveOpts` macro in the preamble, as well as the second `SAScode` environment, specify options for how to format the results. (The data set used in this example is one of the standard data sets

```
\documentclass{article}
\usepackage{mathpazo}

\title{SASweave Demo}
\author{Russ Lenth}

\SASweaveOpts{outputsize=\footnotesize}

\begin{document}
\maketitle

This illustrates how to use \verb"SASweave" to integrate SAS code and output
in a \LaTeX{} document.
\begin{SAScode}            %%% Code chunk 1
proc univariate data = sashelp.shoes;
  var sales;
  ods select moments;
\end{SAScode}

We can also easily include graphics\ldots
\begin{SAScode}{fig=TRUE}  %%% Code chunk 2
proc gplot data=sashelp.shoes;
  plot returns * sales;
\end{SAScode}

\end{document}
```

Figure 1: Simple **SASweave** source file, `demo.SAStex`.

provided in the **sashelp** library; so it should run correctly as-is on any SAS installation.)

When we run the **SASweave** script `sasweave` on `demo.SAStex` in Figure 1, it runs the SAS code, gathers the output, integrates it into a `.tex` file with the other LaTeX markup, runs `pdflatex`, and produces the document `demo.pdf` displayed (with margins cropped) in Figure 2. Note that the SAS code for each chunk is displayed, followed by its output in a different font. The second code chunk produces no printed output, so we see only the resulting graph.

This example illustrates most of what is needed to use **SASweave** effectively. There are, however, a number of options (see Section 2) that allow one to do things like exclude the listing of code or the output, change the way it is displayed, or re-use chunks of code.

SASweave (and `Sweave`) actually provide two different ways to process a source document. The **SASweave** script `sasweave` performs *weaving*, whereby the code, output, and documentation are all packaged together into a `.tex` file. The script `sastangle` performs *tangling*, whereby the SAS code is simply extracted from the source document and saved in a `.sas` file, thereby creating a production version of the code. The `Sweave` analogues of these are implemented in the R functions `Sweave` and `Stangle`, included in R's **utils** package.

The implementation of **SASweave** documented here is inspired by an earlier version by Højsgaard (2006), which, like `Sweave`, was written in R. Both the old and the present **SASweave** provide a means for incorporating *both* SAS and R code in a document. The present version

SASweave Demo

Russ Lenth

May 30, 2007

This illustrates how to use `SASweave` to integrate SAS code and output in a LaTeX document.

```
SAS> proc univariate data = sashelp.shoes;
SAS>   var sales;
SAS>   ods select moments;
```

```
The UNIVARIATE Procedure
Variable:  Sales  (Total Sales)
                            Moments
N                         395    Sum Weights              395
Mean               85700.1671    Sum Observations    33851566
Std Deviation      129107.234    Variance          1.66687E10
Skewness           3.94185882    Kurtosis          24.5888987
Uncorrected SS     9.46854E12    Corrected SS      6.56746E12
Coeff Variation    150.649921    Std Error Mean    6496.08993
```

We can also easily include graphics...

```
SAS> proc gplot data=sashelp.shoes;
SAS>   plot returns * sales;
```

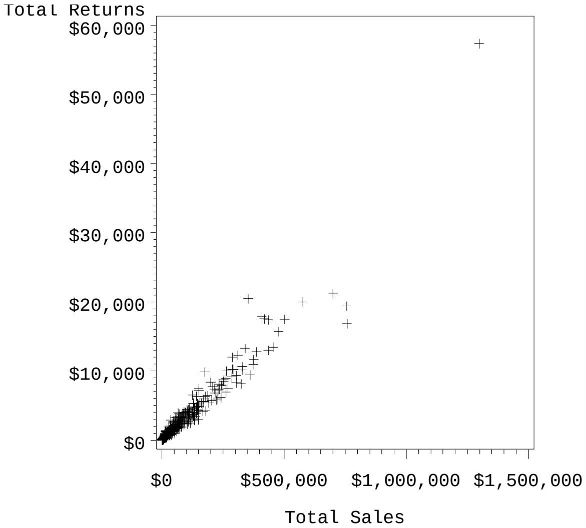


Figure 2: `demo.pdf`—produced by running `sasweave` on the file in Figure 1.

allows control (via the filename extension) over the order in which the SAS and R code is executed. In tangling a source file containing both SAS and R code, two separate code files are created.

SASweave code-chunk specifications are patterned after `Sweave`'s LaTeX-like syntax for delimiting code chunks, similar to `Sweave`'s LaTeX syntax. When a document contains both SAS and R code chunks, either the **noweb** or LaTeX syntax may be used for the R code. We did not attempt to produce an exact equivalent of `Sweave`. There are some extensions, some things that work differently, and some missing capabilities (e.g., in-text evaluation of expressions).

The present version of **SASweave** provides shell scripts `sasweave` and `sastangle` for Unix/Linux or Windows. These scripts in turn execute several AWK scripts; thus, it is necessary for a suitably advanced AWK implementation (GAWK or NAWK) to be installed on the system. These are stadard on Unix systems, and an open-source version of GAWK is available for Windows.

This article is organized as follows. Section 2 details how to prepare the source file, and the various options for controlling how (and whether) code chunks, output, and graphics are displayed. Section 3 describes how to run the shell scripts for **SASweave**. Section 4 provides some examples to illustrate how to handle several typical situations. Finally, a description of each of the shell scripts and AWK scripts is provided in Section 5.

2. Preparing the source file

To use **SASweave**, prepare a text file (hereafter called the "source file") containing standard LaTeX markup, plus one or more `SAScode` environments. The `SAScode` environments contain the SAS statements to be executed and incorporated in the document. Normally, the name of the source file should have the extension `.SAStex` rather than `.tex`. The `sasweave` script processes this file and creates a `.tex` file with the SAS output inserted. Optionally, `sasweave` can also run `pdflatex` to produce a formatted document.

The source file may contain option specifications that control how code chunks are processed. These options are detailed later in this section. A `\SASweaveOpts{}` command, which changes the defaults for all subsequent code chunks, may appear (alone on a line) anywhere in the source file. One-time options for a given code chunk may be given in braces following a `\begin{SAScode}` statement. For example, to change the prompt for all code-chunk listings and put them in a box, we could include this statement in the source file:

```
\SASweaveOpts{prompt=Example: , codefmt = frame=single}
```

To embed a code chunk that is executed but completely invisible in the document, we would use

```
\begin{SAScode}{echo=FALSE, hide}
  ... SAS statements ...
\end{SAScode}
```

In order to be interpreted correctly, all `\begin{SAScode}`, `\end{SAScode}`, and `\SASweaveOpts` statements must start at the beginning of a line of the source file.

Extension(s)	Description
`.SAStex`	SAS code only
`.Rtex` or `.Stex`	R code only (LaTeX syntax)
`.nw` or `.Rnw` or `.Snw`	R code only (**noweb** syntax)
`.SRtex` or `.SASRtex`	Both SAS and R (LaTeX syntax), run `sas` first
`.RStex` or `.RSAStex`	Both R (LaTeX syntax) and SAS, run `R` first
`.SASnw`	Both SAS and R (**noweb** syntax), run `sas` first
`.nwSAS`	Both R (**noweb** syntax) and SAS, run `R` first
`.tex`	Pass file to `pdflatex`

Table 1: Filename extensions for use by **SASweave**.

The SAS code chunks are executed in the order they appear in the source file, and in the context of a single `sas` run. However, because **SASweave** also passes the *text* chunks through SAS statements, each code chunk must be intact. Errors will occur if the statements for a single SAS `PROC` or `DATA` step are split into two or more code chunks. There is one exception: statements in `PROC IML` may be split among several code chunks, and results in one chunk will be available to the next. (**SASweave** accomplishes this by monitoring when the code invokes or leaves `IML`. If an `IML` run is ended by some other means than a `QUIT` statement, a `DATA` step, or another `PROC`, there may be errors in subsequent code chunks.)

SASweave also supports supports source files that contain R code, with or without SAS code. When both are present, it can matter whether `sas` or `R` is run first. For that reason, we have defined standard filename extensions that determine how a file is processed; those extensions are detailed in Table 1. All standard `Sweave` extensions are supported; files having those extensions are passed directly to `Sweave`. Also, a file with a `.tex` extension is passed straight to `pdflatex`. This makes it possible to use the same command to process a very wide variety of LaTeX-based documents.

When the source file contains both SAS and R code, the tangling process produces two independent code files. If the code is interdependent so that it is important that one of those code files be run before the other, it is up to the programmer to document that need.

2.1. Option details

Options are enclosed in braces at the end of a `\begin{SAScode}` or `\SASweaveOpts` statement, and specified as a list of *keyword=value* pairs, separated by commas. Any whitespace in the options list is ignored, except in a `prompt` option (see below). Generally, options will appear on the same line with `\begin{SAScode}` or `\SASweaveOpts`; but to extend them to additional lines, put an ampersand (`&`) at the end of the line. Anything after the closing brace is ignored.

Many options are boolean; these may be specified as `TRUE` or `FALSE`, or simply as `T` or `F`. If a boolean option is specified but not given a value, it is taken as `TRUE`; for example, `\begin{SAScode}{fig}` is equivalent to `\begin{SAScode}{fig=TRUE}`. All keywords and values are case-sensitive. The following five characters are used in parsing options, and hence cannot be used in other ways: `{ } , = &`.

2.2. Options for code and output listings

`echo` (*Type:* boolean *Default value:* `TRUE`)
Determines whether the code chunk is displayed in the document. If `TRUE`, each line is displayed, preceded by the current `prompt` string.

`hide` (*Type:* boolean *Default value:* `FALSE`)
If `TRUE`, the listing output from SAS is not shown.

`results` (*Type:* text *Default value:* `verbatim`)
A setting of `results=verbatim` is equivalent to `hide=FALSE`; and `results=hide` is equivalent to `hide=TRUE`. There is no `results=tex` option like there is in `Sweave`.

`eval` (*Type:* boolean *Default value:* `TRUE`)
If `FALSE`, the code chunk is not actually evaluated; it is simply displayed. This is useful when one wants to display the commands only, and show the results elsewhere in the document rather than immediately following the code listing. When evaluation is suppressed, then obviously there will be no output, and thus `hide` is automatically set to `TRUE` when `eval=FALSE`.

`squeeze` (*Type:* boolean *Default value:* `TRUE`)
When `TRUE`, **SASweave** will reduce the number of blank lines in the SAS output, thus producing more compact results. The top two lines of each page are stripped off regardless of the value of `squeeze`.

`codefmt` (*Type:* Text *Default value:* (null))
This option is used specify how the listing of a code chunk is formatted. Code chunks are put into a verbatim-like environment named `SASinput` derived from the LaTeX package **fancyvrb** (Van Zandt 1998). The value of `codefmt` may be any of the customization commands available for that package. However, one must separate the commands with semicolons instead of commas. Also, remember that braces are illegal within **SASweave** options, so it may be necessary to work around them by defining macros. Here is an example:

```
\newcommand{\red}{\color{red}}
\begin{SAScode}{codefmt += formatcom=\red;fontfamily=courier}
    ... SAS statements ...
\end{SAScode}
```

The "+=" operator (available only here and for `outfmt`) causes the given commands to be *appended* to any formats already in existence (specified in a `\SASweaveOpts` line). Using "=" instead would replace any existing `codefmt`. (The **fancyvrb** command `\RecustomVerbatimEnvironment` may be used to change the default formats for `SASinput` to be used when `codefmt` is null.)

`outfmt` (*Type:* Text *Default value:* (null))
This is the same as `codefmt`, only it sets the format of the output listing environment `SASoutput`.

`codesize` (*Type:* LaTeX command *Default value:* `\small`)

`outsize` (*Type:* LaTeX command *Default value:* `\small`)
These provide less verbose ways to set the font size for code and output listings. They are not true options, in that they just map into `codefmt` and `outfmt` specifications. For example, `codesize=\normalsize` maps to `codefmt+=fontsize=\normalsize`.

`prompt` (*Type:* Text *Default value:* `SAS>`)
The string specified here is added to the beginning of each line of a code chunk. Do not put it in quotation marks. Unlike other options, all whitespace between the "`=`" and the next "`,`" or closing "`}`" is kept as part of the prompt string.

`ls` (*Type:* integer *Default value:* `80`)
This specifies the limit on the number of characters in each line of SAS output (as in the SAS statement `options ls = 80;`). The line size is set to this value before evaluating each code chunk. (For technical reasons, **SASweave** must manage the line size; thus, any `options ls` statement within a code chunk has no effect on subsequent code chunks.)

2.3. Graphics options

`fig` (*Type:* boolean or integer *Default value:* `FALSE`)
If `TRUE` or positive, **SASweave** sets up a `.pdf` file to receive graphical output, and the graph(s) are included in the document. An option of `fig=TRUE` implies that one graph will be created. If, say, `fig=3`, then **SASweave** expects 3 graphs to be generated. The code *must* produce at least the number of graphs specified, or an error will occur. Moreover, use of `fig` requires graphics to be generated by SAS/GRAPH; the newer experimental `ODS` graphics capabilities are not supported.

The remaining options in this section have an effect only if `fig` is not `FALSE`.

`width` (*Type:* number *Default value:* `.6`)
This specifies the actual width of the included graph, as a multiple of `\linewidth`, similar to what is done using `\setkeys{Gin}` in `Sweave`. (This is completely different from the `width` option in `Sweave`.)

`hsize` (*Type:* number *Default value:* `4.0`)
`vsize` (*Type:* number *Default value:* `4.0`)
These options specify the `hsize` and `vsize` values in the `goptions` statement generated by **SASweave**. They set the width and height, in inches, of the plot in the `.pdf` output file. It does not affect the displayed width of the graph in the document (use the `width` option to change that). Changing `hsize` and/or `vsize` will affect the shape of the plot and the apparent font size of labels and symbols.

`striptitle` (*Type:* boolean *Default value:* `TRUE`)
When `TRUE`, the top 30 points of the plot (relative to `vsize`) are clipped off. SAS tends to put extra space at the top of plots, even when no title is given, and this tightens-up the spacing around the plot.

`plotname` (*Type:* LaTeX macro name *Default value:* (null))
If this is null, plots are displayed just below the SAS code and/or output listing. If a

LaTeX macro name is provided here, the plots are not automatically included; instead, macros are defined to be the appropriate `\includegraphics` commands, and these commands may be used later to manually include the graphs at a desired place in the document. The given macro name as-is will produce the first graph. If multiple graphs are created, they may be referenced by appending the macro name with letters `A`, `B`, `C`, etc. For example, the options `fig=3` and `plotname=\myplot` will create the macros `\myplot`, `\myplotA`, `\myplotB`, and `\myplotC`; `\myplot` and `\myplotA` refer to the same graph (the first one). Subsection 4.3 illustrates this feature.

Note that `plotname` creates LaTeX macros. To control the name of the `.pdf` file where the plot is saved, use the `label` option (see Subsection 2.5). Manual graphics inclusion of such a file will prove frustrating, however, because SAS does not set the PDF page size to be the same as that of the graph.

`figdir` (*Type:* string *Default value:* `./`)
This specifies the directory where graphics files are to be stored and retrieved. The directory must already exist; it is not created.

`infigdir` (*Type:* string *Default value:* `figdir`)
This allows the figures to be retrieved from a different directory from where they are stored. This seems contradictory, but it becomes useful when the source file is to be woven into a `.tex` file (using `sasweave -t`), for later inclusion into a main `.tex` document in a different directory. Make `infigdir` match what it needs to be relative to the location of the main document.

2.4. Options for file handling

`split` (*Type:* boolean *Default value:* `FALSE`)
If `FALSE`, the results of weaving the code chunks are all incorporated in the main `.tex` file; if `TRUE`, these results are written to separate `.tex` files and read-in to the main file with an `\input` statement.

`prefix.string` (*Type:* string *Default value:* base filename)
This sets the beginnings of the names of all graphics files, as well as of the `.tex` files generated if `split` is `TRUE`. It may include a directory path, delimited by slashes. A hyphen, a code-chunk label, and the appropriate extension are appended to the prefix string. For example, suppose that `prefix.string` is set to `chunks/myprefix`. If code chunk #3 produces graphics, the associated graphics file is named `chunks/myprefix-swv-003.pdf` (it may have several pages if there are multiple figures); in addition, if `split=TRUE`, the verbatim output for the chunk will be written to `chunks/myprefix-swv-003.tex`. If no `prefix.string` is given and the source file is named `myfile.SAStex`, the defaults are `myfile-swv-003.pdf` and `myfile-swv-003.tex`, respectively. If a `label` (see Subsection 2.5) is also specified, it is used in place of "`swv-003`" wherever it appears in these illustrations.

2.5. Options for code reuse

`label` (*Type:* name *Default value:* `lastchunk`)

This specifies a name under which the current code chunk is saved. In a subsequent code chunk, the same code may be reused via the `\SAScoderef` command:

```
\SAScoderef{label}
```

where *`label`* is the label for the code to be reused. Unlike `Sweave`, the `label` keyword is required. The default label of `lastchunk` is handy for reusing the previous code chunk.

If specified, the label is also used in lieu of the chunk number in naming any files created by that chunk. For example, if the third code chunk in the source file `mysource.SAStex` produces a graph, the graph will be saved to a file named `mysource-swv-003.pdf`. However, if it is given a label of `foo`, then the file name will be `mysource-foo.pdf`.

`showref` (*Type:* boolean *Default value:* `FALSE`)

If `TRUE`, any SAS code recalled using `\SAScoderef` will be displayed in the code listing (as long as `echo` is `TRUE`). If `FALSE`, reused code will be excluded from the listing. This makes it possible to prevent sections of SAS code (perhaps `ODS` statements) from being echoed. See Subsection 4.5 for an illustration.

The `\SAScoderef` command has a starred version `\SAScoderef*` that will force the reused chunk to be displayed regardless of the value of `showref`. This allows one to display some reused code while hiding other code within the same chunk.

2.6. Argument substitution

It is possible to define reusable chunks of SAS code that accept arguments to be provided later in a `\SAScoderef` statement. This is done in much the same ways as a LaTeX macro definition: set up a code chunk that contains the symbols `#1`, `#2`, etc. as placeholders. First, assign this chunk a label, and use options of `eval=FALSE` and (probably) `echo=FALSE`. Then incorporate this chunk in later code chunks using

```
\SAScoderef{label}{arg1}{arg2} ···
```

(or the same with `\SAScoderef*`), where *`label`* is the label of the previously defined code chunk. The contents of *`arg1`* will be substituted for any appearances of `#1`, *`arg2`* will be substituted for any appearances of `#2`, and so forth. No careful checking is done by **SASweave**; if too many arguments are provided, they'll just have no effect, and if there are too few, the code passed to `sas` will contain "`#`" characters, likely producing an error.

3. Running SASweave

The shell commands for tangling and weaving are as follows:

```
sastangle options filename[.SAStex]
sasweave options filename[.SAStex]
```

where *`filename`* is the name of the source file (if an extension is not given, `.SAStex` is assumed). The possible *`options`* can include flags from the list below.

Option for `sastangle`

- `-s` Run `sas` after the `.sas` file is created.

Treatment of intermediate files in `sasweave` (default is `-g`)

- `-c` Clean up the intermediate files that are generated. If errors occur, intermediate files are left anyway. If the creation of the `.tex` file is successful, the `.sas` and `.lst` files are deleted, and the SAS `.log` file is renamed with an extension of `.saslog`. If `pdflatex` processing is requested and it is successful, the `.log` and `.saslog` files and any intermediate graphics files are deleted. (However, only files with standard names are deleted; so the `label`, `figdir`, or `prefix.string` options—see Section 2—may prevent graphics files from being deleted.) The `.tex` and `.aux` files are not deleted.
- `-g` Clean up intermediate files, but do not delete the graphics files.
- `-l` Leave all the intermediate files in place.

Flags to specify the target of `sasweave` (default is `-p`)

- `-p` Run `pdflatex` on the resulting `.tex` file.
- `-t` Terminate after the `.tex` file is produced.
- `-n` Rename the `.tex` file to an extension of `.nw` and stop. This and the `-r` option would be needed only if the source file contains `Sweave` markup and one wants to manually run `Sweave`. If this option is used, the source file should have a `.SAStex` extension; otherwise, `sasweave` will run `Sweave` on its own.
- `-r` Rename the `.tex` file to an extension of `.Rtex` and stop. See also the `-n` option.

4. Examples

The examples in this section illustrate how to use some of **SASweave**'s capabilities.

4.1. Basic use of SASweave

The example in Section 1 illustrates the most basic use of **SASweave** when no options (other than font size) are specified. The first code chunk in Figure 1 is a simple SAS program that produces only listing output.

The second code chunk shows the simplest way to incorporate a figure. The default shape of the plotting region is square, but SAS's formatting of labels causes it to be rather tall because the label for the vertical axis is so long.

4.2. R and SAS together

Here is a simple example where both R and SAS code are incorporated in the same source file. One of the standard datasets in R is summarized, and it is written to a text file, imported into

```
R> table(chickwts$feed)

   casein horsebean   linseed  meatmeal   soybean sunflower
       12        10        12        11        14        12

R> write.table(chickwts, file = "chickwts.txt", row.names = FALSE,
+     quote = FALSE)

SAS> data sasuser.chickwts;
SAS>   infile "chickwts.txt" firstobs = 2;
SAS>   input weight feed $;
SAS> proc freq data=sasuser.chickwts;
SAS>   table feed;

The FREQ Procedure
                                            Cumulative    Cumulative
feed        Frequency     Percent     Frequency      Percent
-------------------------------------------------------------
casein            12       16.90            12        16.90
horsebea          10       14.08            22        30.99
linseed           12       16.90            34        47.89
meatmeal          11       15.49            45        63.38
soybean           14       19.72            59        83.10
sunflowe          12       16.90            71       100.00
```

Figure 3: Results from code in Subsection 4.2

SAS, and summarized there as well. In this example, it is very important that the R code be run first, as it creates the data needed by SAS; hence the filename extension used is `.RSAStex`. By default, SAS statements are formatted in `\small` font. Font sizing is not provided among the options in `Sweave`, so we do it manually. The results of running `sasweave` on the code below are displayed in Figure 3.

```
{\small
\begin{Scode}
table(chickwts$feed)
write.table(chickwts, file="chickwts.txt", row.names=FALSE, quote=FALSE)
\end{Scode}
}

\begin{SAScode}
data sasuser.chickwts;
  infile "chickwts.txt" firstobs = 2;
  input weight feed $;
proc freq data=sasuser.chickwts;
  table feed;
\end{SAScode}
```

4.3. Multiple figures in a float

The following code segment illustrates the use of several options. First, we suppress the code listing (`echo=FALSE`). We ask for two plots (`fig=2`) of reduced width (`width=.45`). Rather than the default placement of plots, we specify that that they be saved as LaTeX macros (`plotname=\chickPlot`) for later inclusion in a `figure` environment. Subsequently, the macros `\chickPlotA` and `\chickPlotB` call up the two plots. Figure 4 shows the results from the code below.

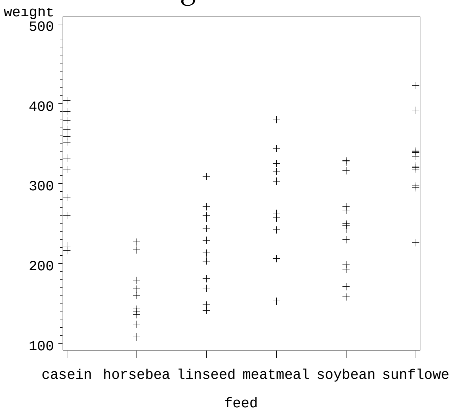
```
\begin{SAScode}{echo=FALSE, fig=2, width=.45, plotname=\chickPlot, &
                outfmt = fontsize=\footnotesize}
proc glm data=sasuser.chickwts;
  class feed;
  model weight = feed / ss1;
  output out=chickfit p=Predicted r=Residual;
  means feed;
  ods exclude NObs ClassLevels;
proc gplot data=chickfit;
  plot weight * feed
       Residual * Predicted;
\end{SAScode}

\renewcommand{\figurename}{Exhibit}

See Exhibit~\ref{chickfig} for some supplementary displays.
\begin{figure}
  \caption{Plots of the \texttt{chickwts} data.}\label{chickfig}
  \begin{center}
    \begin{tabular}{ll}
    Observed weights for each diet   & Residuals versus predicted \\
    \chickPlotA                      & \chickPlotB
    \end{tabular}
  \end{center}
\end{figure}
```

4.4. Separating code and output; hiding code

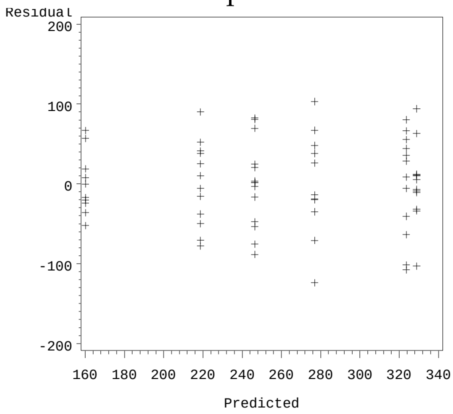
Sometimes we want to put the results in a separate place from the code listing; for example, in a float. The best way to do this is to reuse the same code, via labels. This example shows two code chunks. Chunk 1 contains the code we want to run; but it is only listed, not evaluated (`eval=FALSE`). Code chunk 2 recalls chunk 1 using its default label of `lastchunk`, and adds an `ODS` statement to restrict the output; this time it is executed, but the code listing is suppressed (`echo=FALSE`). Figure 5 displays what is produced by the code below.

Exhibit 1: Plots of the chickwts data.

Observed weights for each diet



Residuals versus predicted




```
The GLM Procedure

Dependent Variable: weight
                                            Sum of
Source                      DF             Squares     Mean Square    F Value    Pr > F
Model                        5     231129.1621      46225.8324      15.36    <.0001
Error                       65     195556.0210       3008.5542
Corrected Total             70     426685.1831

R-Square     Coeff Var      Root MSE    weight Mean
0.541685      20.99052      54.85029       261.3099

Source                      DF         Type I SS     Mean Square    F Value    Pr > F
feed                         5     231129.1621      46225.8324      15.36    <.0001
The GLM Procedure
Level of            ------------weight-----------
feed          N             Mean          Std Dev
casein       12       323.583333       64.4338397
horsebea     10       160.200000       38.6258405
linseed      12       218.750000       52.2356983
meatmeal     11       276.909091       64.9006233
soybean      14       246.428571       54.1290684
sunflowe     12       328.916667       48.8363842
```

See Exhibit 1 for some supplementary displays.

Figure 4: Results from code in Subsection 4.3

```
Here is the SAS code to perform a robust analysis of the chick-weights data.
The output is displayed in Exhibit~\ref{robust-out}.
% Chunk 1
\begin{SAScode}{prompt=, eval=FALSE}
proc robustreg data = sasuser.chickwts  method = M (wf = bisquare);
  class feed;
  model weight = feed;
  Feed_overall: test feed;
\end{SAScode}

\begin{figure}
\caption{Results of \texttt{PROC ROBUSTREG}.}\label{robust-out}
% Chunk 2
\begin{SAScode}{echo=FALSE}
\SAScoderef{lastchunk}
ODS select ParameterEstimates TestsProfile;
\end{SAScode}
\end{figure}
```

4.5. Argument substitution; hiding code

In this example, we set up (but do not evaluate or echo) a code chunk named `import`; it contains the strings `#1`, `#2`, and `#3`, which serve as placeholders for arguments to be supplied later. In the second code chunk, we read a data file and run `PROC REG`; the file-reading part is done by re-using the `import` chunk with appropriate arguments supplied. That part of the code is not displayed in the listing, however, because `showrefs` is `FALSE` by default.

```
\SASweaveOpts{eval=FALSE} %%% suppress all evaluation for this example

\begin{SAScode}{echo=FALSE, eval=FALSE, label=import}
proc import
  datafile = "#1"
  out = #2
  dbms = #3
  replace ;
\end{SAScode}
%
% Secretly read-in a file before an analysis ...
\begin{SAScode}{fig=2}
\SAScoderef{import}{c:\BPSdata\ta05-03.dat}{reactTime}{TAB}
proc reg data=reactTime;
  model Time = Distance;
  plot Time*Distance Residual.*Predicted.;
\end{SAScode}
```

Exhibit 2: Results of `PROC ROBUSTREG`.

```
The ROBUSTREG Procedure
                        Parameter Estimates

                                 Standard   95% Confidence     Chi-
Parameter          DF Estimate    Error        Limits        Square Pr > ChiSq
Intercept           1 329.0835  16.8600 296.0384 362.1286   380.97     <.0001
feed      casein    1  -0.0836  23.8437 -46.8163  46.6492     0.00     0.9972
feed      horsebea  1 -169.863  25.0075 -218.877 -120.850    46.14     <.0001
feed      linseed   1 -110.343  23.8437 -157.076 -63.6106    21.42     <.0001
feed      meatmeal  1 -49.5349  24.3796 -97.3180  -1.7518     4.13     0.0422
feed      soybean   1 -82.8402  22.9764 -127.873 -37.8074    13.00     0.0003
feed      sunflowe  0   0.0000    .         .        .         .         .
Scale               1  52.5603

               Robust Linear Tests

                  FEED_OVERALL

              Test              Chi-
Test     Statistic   Lambda DF  Square Pr > ChiSq
Rho        12.4552   0.7977  5   15.61     0.0080
Rn2        71.1819           5   71.18     <.0001
```

Here is the SAS code to perform a robust analysis of the chick-weights data. The output is displayed in Exhibit 2.

```
proc robustreg data = sasuser.chickwts  method = M (wf = bisquare);
  class feed;
  model weight = feed;
  Feed_overall: test feed;
```

Figure 5: Results from code in Subsection 4.4

```
SAS> proc reg data=reactTime;
SAS>   model Time = Distance;
SAS>   plot Time*Distance Residual.*Predicted.;
```

Note that `import` is effectively a macro for **SASweave**; and we can actually trick **SASweave** into defining new macros based on it. The first code chunk below simply calls up `import` and substitutes appropriate arguments so that it becomes a simplified **SASweave** macro suitable for importing comma-delimited files. It is then used and displayed.

```
% Create a new "macro"
\begin{SAScode}{echo=FALSE, eval=FALSE, label=importCSV}
\SAScoderef{import}{#1.csv}{#1}{CSV}
\end{SAScode}
% Test run...
\begin{SAScode}{showref}
\SAScoderef{importCSV}{newFile}
\end{SAScode}
```

```
SAS> proc import
SAS>   datafile = "newFile.csv"
SAS>   out = newFile
SAS>   dbms = CSV
SAS>   replace ;
```

5. Implementation

This section gives an overview of how the **SASweave** software is structured, and a description of the main tasks of each body of code.

The basic approach in this **SASweave** implementation is rather brute-force in nature: a single SAS program is created that contains everything needed for the final `.tex` file—both code and text chunks. The text chunks and code listings are simply inserted in the right places in the SAS output. The output file is then post-processed and saved as a `.tex` file, which, optionally, is passed to `pdflatex` to produce a `.pdf` file with the formatted document.

For the verbatim listing of code and output, we provide a LaTeX package named `SasWeave.sty` that defines verbatim-like environments `SASinput` and `SASoutput`; these are based on the standard LaTeX package **fancyvrb**. `SasWeave.sty` is similar to the package `Sweave.sty` that is part of `Sweave`. (Originally, it was named `SASweave.sty`, but this had the effect of tricking `Sweave` into thinking that `Sweave.sty` was already loaded.)

The pre- and post-`sas` operations are done as much as possible by means of AWK scripts. AWK is an ideal scripting language for this purpose, because its design focuses on pattern-matching, and there is an implied loop where we go through a file line-by-line. That is exactly what is needed here. Moreover, AWK is quite forgiving (we leave error-checking to `sas` and LaTeX), and an implementation of AWK is available for virtually any platform.

The main workhorse among the AWK scripts is the one named `saswv1.awk` (henceforth called just `saswv1`), which reads the source file and writes the `.sas` file. This script looks for five main conditions: lines that start with "`\begin{SASweaveOpts}`," "`\begin{SAScode}`," and "`\end{SAScode}`", and processing of cases where a flag named `sas` is zero (meaning the current source-file line is in a text chunk) or 1 (it is in a code chunk). By doing appropriate things in response to these five conditions, the script arranges things so that if we are weaving the source file, the output `.sas` file will be organized as follows (and in the order described).

1. Text chunks go into `put` statements within `PROC IML`. (This includes inserting judicious linefeeds to keep these statements from exceeding the line-width limit. For this reason,

SASweave must control SAS's LS option.)

2. If code is to be echoed, the appropriate verbatim environment `SASinput` is set up and included at the end of the preceding text chunk.

3. If output is to be displayed, a `\begin{SASoutput}` statement is added to the text chunk.

4. Appropriate setup code is added to the SAS program. These include setting up the desired line size at `ls`, and if a figure is to be saved, some `goptions` statements to setup an output `.pdf` file.

5. The SAS code itself is added to the SAS program.

6. At the end of a code chunk, `PROC IML` is started (if necessary), and the string `\end{SASoutput}` is added before the subsequent text chunk. (The script monitors whether `PROC IML` is invoked in a code chunk and is still active; if so, `IML` is not restarted. This monitoring allows one to break-up `IML` code into multiple chunks, if desired.)

7. If there are any figures, the needed `\includegraphics` statements are generated. If there is no `plotname`, these are added to the text chunk; otherwise, they are wrapped in LaTeXmacro definitions before adding them to the text chunk.

8. We are now ready for more text from the source file (step 1).

(One can see exactly how the `.sas` file is structured by weaving a file with the `-l` option.)

The `saswv1` script also contains some startup and ending code and a few functions to ease in processing options. It also calls other functions defined in a different AWK script that is loaded at the same time. These externally-supplied functions determine the actions taken at the beginning of the run, at the beginning and end of a text chunk, setting up a graph, and outputting the lines of a text chunk. There are two versions of these functions. The ones in the file `saswsetup.awk` are used for weaving the source file (for eventual creation of a `.tex` file). The alternative functions in `sastsetup.awk` are suitable for tangling. The `sastsetup.awk` function for outputting text chunks does nothing at all, and the others there do very little (for example, graphics are set up with the dimensions specified in the **SASweave** options, but they go to the default device rather than a `.pdf` file). The design decision to provide different output routines for tangling and weaving, while keeping the same basic `saswv1` script, helps with maintainability and consistency; a change made to `saswv1.awk` will appropriately affect both tangling and weaving operations.

In `sasweave`, the script `saswv2.awk` handles post-processing of the `.lst` file generated by `sas`, and creates a `.tex` file. This script is shorter and simpler than `saswv1`, but there are more patterns that need handling. What complexity exists there is due to looking for empty `SASinput` and `SASoutput` environments so that they are not added to the `.tex` file. Beyond that, the main operations are stripping off the top two lines of each page, outputting only one blank line whenever two consecutive blank lines are encountered (when `squeeze` is true), and diverting chunks to other files when `split` is true. Communication of information for `split` and `squeeze` options is done by checking for certain signal lines that `saswv1` outputs.

The same maintainability and portability considerations as described for `saswv1` motivate the design of the command-line interface. For each operating system, we need a shell script that serves as a front end to the AWK scripts. The unix/linux shell scripts `sastangle` and `sasweave`, and the Windows scripts `sastangle.bat` and `sasweave.bat`, are all as minimal as possible. They simply identify and change to the directory where the source file resides, and then call one of the AWK scripts `saswmain.awk` (for weaving) or `sastmain.awk` (for tangling). These two scripts parse the command line for flags and determine the source file's extension. Based on the extension and flags, the source file or one of its derivatives is passed to `saswv1`, `sas`, `saswv2`, `Sweave`, and `pdflatex` as is appropriate and in the correct sequence. The scripts call the AWK `system` function with appropriate arguments to invoke a shell and run `sas`, `R`, and `pdflatex` as needed.

A certain amount of file copying and renaming takes place when both R and SAS code needs processing. For example, with a `.RSAStex` source file, we first copy it to another file with an extension of `.Rtex`, then run `Sweave`; the resulting `.tex` file is renamed with a `.SAStex` extension before passing it to **SASweave**. This management is also done using the `system` function.

The `saswmain` and `sastmain` scripts each require a common script named `saswcfg.awk`, which defines certain variables with system-specific values. This configuration file gives the path where the AWK scripts are installed, and the commands to run `sas`, `R`, `pdflatex`, `Stangle`, and `Sweave`. The Windows installer for **SASweave** creates this file. The one for unix/linux is simply copied and edited, but typically only the AWK-script path needs modification.

6. Discussion

SASweave provides a simple and reliable way of presenting and documenting SAS analyses. We have used it to great benefit in consulting, research and teaching. In research and consulting, one or more **SASweave** source files provide a useful foundation for preparing analyses, simulation studies, etc. One can document the methods used and the associated SAS code; then, when the source file is processed, there is a reliable record of exactly what was done, along with the results.

In teaching how to use SAS, **SASweave** streamlines the preparation of class handouts. Also, if "live" SAS analyses are done in class, it is an easy matter for the instructor to save the `.sas` file, add `SAScode` environments and possibly comments, and use `sasweave` to make a documented form of the class examples with output included.

We have tried to make **SASweave** behave similarly to `Sweave` where that is appropriate and practical. One notable difference between the two arises from the fact that `Sweave` uses R to parse the input statements and simulate an interactive mode, while **SASweave** does not. One code chunk in `Sweave` might produce several sets of code listings interspersed with output listings. In **SASweave**, one code chunk always produces one code listing, followed by one output listing containing all the results. Other `Sweave` features not present in **SASweave** at this time include non-availability of PostScript graphs, no equivalent to `Sweave`'s `\Sexpr{}` capability for incorporating computed results in a text chunk, and no support for the emerging "ODS graphics" provisions in certain SAS procedures.

However, **SASweave** does offer some nice extensions (we think) of `Sweave`. The main ones include control of formatting, support for multiple figures in one code chunk, the provision to assign macro names to plots, argument substitution. Those go on our wish list for future releases of `Sweave`. Future development contemplated for **SASweave** includes extending the same capability to Open Document Format files (used by **OpenOffice**), similar to the way

odfWeave (Kuhn and Coulter 2007) extends `Sweave`.

Acknowledgments

The authors wish to thank two referees, as well as both editors. Their careful reading, helpful comments, and suggestions have greatly improved the article.

References

Højsgaard S (2006). "**SASRweave**: An R Package for Literate Programming with SAS and R at the Same Time." Accessed 2006-10-30, URL http://genetics.agrsci.dk/~sorenh/misc/software/.

Knuth DE (1992). "Literate Programming." *CSLI Lecture Notes 27*, Center for the Study of Language and Information, Stanford, California.

Kuhn M, Coulter N (2007). *The* **odfWeave** *Package*. R package version 0.4.9, URL http://CRAN.R-project.org/.

Leisch F (2002). "Dynamic Generation of Statistical Reports Using Literate Data Analysis." In W Härdle, B Rönz (eds.), "COMPSTAT 2002—Proceedings in Computational Statistics," pp. 575–580. Physika Verlag, Heidelberg, Germany. ISBN 3-7908-1517-9.

R Development Core Team (2006). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

SAS Institute Inc (2003). *SAS/STAT Software, Version 9.1*. Cary, NC. URL http://www.sas.com/.

Van Zandt T (1998). "The **fancyvrb** Package: Fancy Verbatims in LaTeX." LaTeX package version 2.6, URL http://www.CTAN.org/.

Affiliation:

Russell V. Lenth
Department of Statistics and Actuarial Science
The University of Iowa
Iowa City, Iowa 52242, United States of America
E-mail: russell-lenth@uiowa.edu
URL: http://www.stat.uiowa.edu/~rlenth/

Søren Højsgaard
University of Aarhus
Faculty of Agricultural Sciences
Research Centre Foulum
Institute of Genetics and Biotechnology
Blichers Allé 20, P.O. Box 50
8830 Tjele, Denmark
E-mail: Soren.Hojsgaard@agrsci.dk
URL: http://www.agrsci.dk/

Journal of Statistical Software http://www.jstatsoft.org/
published by the American Statistical Association http://www.amstat.org/
Volume 19, Issue 8 *Submitted:* 2007-02-14
June 2007 *Accepted:* 2007-05-27