

The bash shell, UNIX utilities, and version control

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Note that it can be difficult to distinguish what is shell-specific and what is just part of UNIX. Some of the material here is not bash-specific but general to UNIX.

Reference: Newham and Rosenblatt, Learning the bash Shell, 2nd ed.

1 Shell basics

The shell is the interface between you and the UNIX operating system. When you are working in a terminal window (i.e., a window with the command line interface), you're interacting with a shell.

There are multiple shells (*sh*, *bash*, *csh*, *tcsh*, *ksh*). We'll assume usage of *bash*, as this is the default for Mac OS X, the BCE VM, and on the SCF machines and is very common for Linux.

1. What is my default shell?

```
> echo $SHELL
```

2. To change to bash on a one-time basis:

```
> bash
```

3. To make it your default:

```
> chsh /bin/bash
```

/bin/bash should be whatever the path to the bash shell is, which you can figure out using `which bash`

Shell commands can be saved in a file (with extension *.sh*) and this file can be executed as if it were a program. To run a shell script called *file.sh*, you would type `./file.sh`. Note that if you just typed `file.sh`, the operating system will generally have trouble finding the script and recognizing that it is executable. To be sure that the operating system knows what shell to use to interpret the script, the first line of the script should be `#!/bin/bash` (in the case that you're using the bash shell). Also, *file.sh* would need to be executable (i.e., to have the 'x' flag set).

2 Tab completion

When working in the shell, it is often unnecessary to type out an entire command or file name, because of a feature known as tab completion. When you are entering a command or filename in the shell, you can, at any time, hit the tab key, and the shell will try to figure out how to complete the name of the command or filename you are typing. If there is only one command in the search path and you're using tab completion with the first token of a line, then the shell will display its value and the cursor will be one space past the completed name. If there are multiple commands that match the partial name, the shell will display as much as it can. In this case, hitting tab twice will display a list of choices, and redisplay the partial command line for further editing. Similar behavior with regard to filenames occurs when tab completion is used on anything other than the first token of a command.

Note that R does tab completion for objects (including functions) and filenames.

3 Command history

By using the up and down arrows, you can scroll through commands that you have entered previously. So if you want to rerun the same command, or fix a typo in a command you entered, just scroll up to it and hit enter to run it or edit the line and then hit enter.

Note that you can use emacs-like control sequences (**C-a**, **C-e**, **C-k**) to navigate and delete characters, just as you can at the prompt in the shell usually.

You can also rerun previous commands as follows:

```
> !-n # runs the nth previous command
> !xt # runs the last command that started with 'xt'
```

If you're not sure what command you're going to recall, you can append **:p** at the end of the text you type to do the recall, and the result will be printed, but not executed. For example:

```
> !xt:p
```

You can then use the up arrow key to bring back that statement for editing or execution.

You can also search for commands by doing **C-r** and typing a string of characters to search for in the search history. You can hit return to submit, **C-c** to get out, or **ESC** to put the result on the regular command line for editing.

4 Wildcards in filenames

The shell will expand certain special characters to match patterns of file names, before passing those filenames on to a program. Note that the programs themselves don't know anything about

Table 1: Wildcards

Syntax	What it matches
<code>?</code>	any single character
<code>*</code>	zero or more characters
<code>[<i>c₁c₂...</i>]</code>	any character in the set
<code>[!<i>c₁c₂...</i>]</code>	anything not in the set
<code>[<i>c₁ - c₂</i>]</code>	anything in the range from <i>c₁</i> to <i>c₂</i>
<code>{<i>string1, string2, ...</i>}</code>	anything in the set of strings

wildcards; it is the shell that does the expansion, so that programs don't see the wildcards. Table 1 shows some of the special characters that the shell uses for expansion:

Here are some examples of using wildcards:

- List all files ending with a digit:

```
> ls *[0-9]
```

- Make a copy of *filename* as *filename.old*

```
> cp filename{,.old}
```

- Remove all files beginning with *a* or *z*:

```
> rm [az]*
```

- List all the R code files with a variety of suffixes:

```
> ls *.{r,q,R}
```

The *echo* command can be used to verify that a wildcard expansion will do what you think it will:

```
> echo cp filename{,.old} # returns cp filename filename.old
```

If you want to suppress the special meaning of a wildcard in a shell command, precede it with a backslash (\). Note that this is a general rule of thumb in many similar situations when a character has a special meaning but you just want to treat it as a character.

5 Basic UNIX utilities

Table 2 shows some basic UNIX programs, which are sometimes referred to as filters. The general syntax for a UNIX program is

```
> command -options argument1 argument2 ...
```

For example, `> grep -i graphics file.txt` looks for *graphics* (argument 1) in *file.txt* (argument2) with the option *-i*, which says to ignore the case of the letters. `> less file.txt`

Table 2: UNIX utilities

Name	What it does
<i>tail</i>	shows last few lines of a file
<i>less</i>	shows a file one screen at a time
<i>cat</i>	writes file to screen
<i>wc</i>	counts words and lines in a file
<i>grep</i>	finds patterns in files
<i>wget or curl</i>	download files from the web
<i>sort</i>	sorts a file by line
<i>nl</i>	numbers lines in a file
<i>diff</i>	compares two files
<i>uniq</i>	removes repeated (sequential) rows
<i>cut</i>	extracts fields (columns) from a file

simply pages through a text file (you can navigate up and down) so you can get a feel for what's in it.

UNIX programs often take options that are identified with a minus followed by a letter, followed by the specific option (adding a space before the specific option is fine). Options may also involve two dashes, e.g., **R --no-save**. Here's another example that tells *tail* to keep refreshing as the file changes:

```
tail -f dat.txt
```

A few more tidbits about *grep*:

```
grep ^read code.r # returns lines that start with 'read'
```

```
grep dat$ code.r # returns lines that end with 'dat'
```

```
grep 7.7 dat.txt # returns lines with two sevens separated by a  
single character
```

```
grep 7.*7 dat.txt # returns lines with two sevens separated by any  
number of characters
```

Note that the first argument to *grep* is the pattern you are looking for. The syntax is different from that used for wildcards in file names. Also, you can use regular expressions in the pattern. We won't see this in detail here, but will see regular expressions in R shortly.

It is sometimes helpful to put the pattern inside double quotes, e.g., if you want spaces in your pattern, e.g.,

```
grep "George .* Bush" dat.txt
```

More generally in UNIX, enclosing a string in quotes is often useful to indicate that it is a single entity.

If you want to explicitly look for one of the special characters used in creating patterns (such as double quote ("), period (.), etc., you can "escape" them by preceding with a back-slash. For

Table 3: Redirection

Syntax	What it does
<code>cmd > file</code>	sends stdout from <i>cmd</i> into <i>file</i> , overwriting <i>file</i>
<code>cmd >> file</code>	appends stdout from <i>cmd</i> to <i>file</i>
<code>cmd < file</code>	execute <i>cmd</i> reading stdin from <i>file</i>
<code>cmd <infile >outfile 2>errors</code>	reads from <i>infile</i> , sending stdout to <i>outfile</i> and stderr to <i>errors</i>
<code>cmd <infile >outfile 2>&1</code>	reads from <i>infile</i> , sending stdout and stderr to <i>outfile</i>
<code>cmd1 cmd2</code>	sends stdout from <i>cmd1</i> as stdin to <i>cmd2</i> (a pipe)

Note that *cmd* may include options and arguments as seen in the previous section.

example to look for *She said, “Hello”*.

```
grep "She said, \"Hello\"\\\".\" dat.txt
```

If you have a big data file and need to subset it by line (e.g., with *grep*) or by field (e.g., with *cut*), then you can do it really fast from the UNIX command line, rather than reading it with R, SAS, Perl, etc.

Much of the power of these utilities comes in piping between them (see Section 6) and using wildcards (see Section 4) to operate on groups of files. The utilities can also be used in shell scripts to do more complicated things.

6 Redirection

UNIX programs that involve input and/or output often operate by reading input from a stream known as standard input (*stdin*), and writing their results to a stream known as standard output (*stdout*). In addition, a third stream known as standard error (*stderr*) receives error messages, and other information that’s not part of the program’s results. In the usual interactive session, standard output and standard error default to your screen, and standard input defaults to your keyboard. You can change the place from which programs read and write through redirection. The shell provides this service, not the individual programs, so redirection will work for all programs. Table 3 shows some examples of redirection.

Operations where output from one command is used as input to another command (via the `|` operator) are known as pipes; they are made especially useful by the convention that many UNIX commands will accept their input through the standard input stream when no file name is provided to them.

Here’s an example of finding out how many unique entries there are in the 2nd column of a data file whose fields are separated by commas:

```
cut -d',' -f2 mileage2009.csv | sort | uniq | wc
```

To see if there are any “S” values in certain fields (fixed width) of a set of files (note I did this on

22,000 files (5 Gb or so) in about 15 minutes on my old desktop; it would have taken much more time to read the data into R):

```
> cut -b29,37,45,53,61,69,77,85,93,101,109,117,125,133,141,149,
157,165,173,181,189,197,205,213,221,229,237,245,253,261,269 USC*.dly
| grep "S" | less
```

A closely related, but subtly different, capability is offered by the use of backticks (`). When the shell encounters a command surrounded by backticks, it runs the command and replaces the backticked expression with the output from the command; this allows something similar to a pipe, but is appropriate when a command reads its arguments directly from the command line instead of through standard input. For example, suppose we are interested in searching for the text *pdf* in the last 4 R code files (those with suffix *.r* or *.R*) that were modified in the current directory. We can find the names of the last 4 files ending in “.R” or “.r” which were modified using

```
> ls -t *.{R,r} | head -4
```

and we can search for the required pattern using *grep*. Putting these together with the backtick operator we can solve the problem using

```
> grep pdf `ls -t *.{R,r} | head -4`
```

Note that piping the output of the *ls* command into *grep* would not achieve the desired goal, since *grep* reads its filenames from the command line, not standard input.

You can also redirect output as the arguments to another program using the *xargs* utility. Here’s an example:

```
> which bash | xargs chsh
```

And you can redirect output into a shell variable (see section 9) by putting the command that produces the output in parentheses and preceding with a *\$*. Here’s an example:

```
> files=$(ls) # NOTE - don't put any spaces around the '='
> echo $files
```

7 Job Control

Starting a job When you run a command in a shell by simply typing its name, you are said to be running in the foreground. When a job is running in the foreground, you can’t type additional commands into that shell, but there are two signals that can be sent to the running job through the keyboard. To interrupt a program running in the foreground, use **C-C**; to quit a program, use **C-^**. While modern windowed systems have lessened the inconvenience of tying up a shell with foreground processes, there are some situations where running in the foreground is not adequate.

The primary need for an alternative to foreground processing arises when you wish to have jobs continue to run after you log off the computer. In cases like this you can run a program in the

background by simply terminating the command with an ampersand (&). However, before putting a job in the background, you should consider how you will access its results, since *stdout* is not preserved when you log off from the computer. Thus, redirection (including redirection of *stderr*) is essential when running jobs in the background. As a simple example, suppose that you wish to run an R script, and you don't want it to terminate when you log off. (Note that this can also be done using R CMD BATCH, so this is primarily an illustration.)

```
> R --no-save <code.R >code.Rout 2>&1 &
```

If you forget to put a job in the background when you first execute it, you can do it while it's running in the foreground in two steps. First, suspend the job using the **C-z** signal. After receiving the signal, the program will interrupt execution, but will still have access to all files and other resources. Next, issue the *bg* command, which will put the stopped job in the background.

Listing and killing jobs Since only foreground jobs will accept signals through the keyboard, if you want to terminate a background job you must first determine the unique process id (PID) for the process you wish to terminate through the use of the *ps* command. For example, to see all the jobs running on a particular computer, you could use a command like:

```
> ps -aux
```

Among the output after the header (shown here) might appear a line that looks like this:

```
USER PID %CPU %MEM VSZ RSS TTY STAT START TIME COMMAND
paciorek 11998 97.0 39.1 1416644 1204824 pts/16 R+ Jul27 1330:01
/usr/lib64/R/bin/exec/R
```

In this example, the *ps* output tells us that this R job has a PID of *11998*, that it has been running for 1330 minutes (!), is using 97% of CPU and 39% of memory, and that it started on July 27. You could then issue the command:

```
> kill 11998
```

or, if that doesn't work

```
> kill -9 11998
```

to terminate the job. Another useful command in this regard is *killall*, which accepts a program name instead of a process id, and will kill all instances of the named program. E.g.,

```
> killall R
```

Of course, it will only kill the jobs that belong to you, so it will not affect the jobs of other users. Note that the *ps* and *kill* commands only apply to the particular computer on which they are executed, not to the entire computer network. Thus, if you start a job on one machine, you must log back into that same machine in order to manage your job.

Monitoring jobs and memory use The *top* command also allows you to monitor the jobs on the system and in real-time. In particular, it's useful for seeing how much of the CPU and how much memory is being used, as well as figuring out a PID as an alternative to *ps*. You can also renice jobs (see below) and kill jobs from within top: just type *r* or *k*, respectively, and proceed from there.

One of the main things to watch out for is a job that is using close to 100% of memory and much less than 100% of CPU. What is generally happening is that your program has run out of memory and is using virtual memory on disk, spending most of its time writing to/from disk, sometimes called *paging* or *swapping*. If this happens, it can be a very long time, if ever, before your job finishes.

Nicing a job The most important thing to remember when starting a job on a machine that is not your personal machine is how to be a good citizen. This often involves 'nicing' your jobs. This is required on the SCF machines, but the compute servers should automatically nice your jobs. Nicing a job puts it at a lower priority so that a user working at the keyboard has higher priority in using the CPU. Here's how to do it, giving the job a low priority of 19, as required by SCF:

```
> nice -19 R CMD BATCH --no-save in.R out.Rout &
```

If you forget and just submit the job without nicing, you can reduce the priority by doing:

```
> renice +19 11998
```

where *11998* is the PID of your job.

On many larger UNIX cluster computers, all jobs are submitted via a job scheduler and enter a queue, which handles the issue of prioritization and jobs conflicting. Syntax varies by system and queueing software, but may look something like this for submitting an R job:

```
> bsub -q long R CMD BATCH --no-save in.R out.Rout # just an example;
this will not work on the SCF network
```

8 Aliases

Aliases allow you to use an abbreviation for a command, to create new functionality or to insure that certain options are always used when you call an existing command. For example, I'm lazy and would rather type **q** instead of **exit** to terminate a shell window. You could create the alias as follow

```
> alias q="exit"
```

As another example, suppose you find the *-F* option of *ls* (which displays */* after directories, *** after executable files and *@* after links) to be very useful. The command

```
> alias ls="ls -F"
```

will insure that the *-F* option will be used whenever you use *ls*. If you need to use the unaliased

version of something for which you've created an alias, precede the name with a backslash (\). For example, to use the normal version of *ls* after you've created the alias described above, just type

```
> \ls
```

The real power of aliases is only achieved when they are automatically set up whenever you log in to the computer or open a new shell window. To achieve that goal with aliases (or any other bash shell commands), simply insert the commands in the file *.bashrc* in your home directory. See the *example.bashrc* file in the repository for some of what's in my *.bashrc* file.

9 Shell Variables

We can define shell variables that will help us when writing shell scripts. Here's an example of defining a variable:

```
> name="chris"
```

The shell may not like it if you leave any spaces around the = sign. To see the value of a variable we need to precede it by \$:

```
> echo $name
```

You can also enclose the variable name in curly brackets, which comes in handy when we're embedding a variable within a line of code to make sure the shell knows where the variable name ends:

```
> echo ${name}
```

There are also special shell variables called environment variables that help to control the shell's behavior. These are generally named in all caps. Type **env** to see them. You can create your own environment variable as follows:

```
> export NAME="chris"
```

The *export* command ensures that other shells created by the current shell (for example, to run a program) will inherit the variable. Without the *export* command, any shell variables that are set will only be modified within the current shell. More generally, if one wants a variable to always be accessible, one would include the definition of a variable with an *export* command in your *.bashrc* file.

Here's an example of modifying an environment variable:

```
> export CDPATH=.:~/research:~/teaching
```

Now if you have a subdirectory *bootstrap* in your *research* directory, you can type **cd bootstrap** no matter what your *pwd* is and it will move you to *~/research/bootstrap*. Similarly for any subdirectory within the *teaching* directory.

Here's another example of an environment variable that puts the username, hostname, and *pwd* in your prompt. This is handy so you know what machine you're on and where in the filesystem

you are.

```
> export PS1="\u@\h:\w> "
```

For me, this is one of the most important things to put in my *.bashrc* file. The `\` syntax tells bash what to put in the prompt string: *u* for username, *h* for hostname, and *w* for working directory.

Finally, a note about using single vs. double quotes in shell code. In general, variables inside double quotes will be evaluated, but variables not inside double quotes will not be:

```
name="chris"
echo "My name is $name"
echo 'My name is $name'
echo "He said, \"My name is $name.\""
```



```
## My name is chris
## My name is $name
## He said, "My name is chris."
```

So we'll generally use double quotes. We can always work with a literal double quote by escaping it as seen above.

10 Functions

You can define your own utilities by creating a shell function. This allows you to automate things that are more complicated than you can do with an alias. One nice thing about shell functions is that the shell automatically takes care of function arguments for you. It places the arguments given by the user into local variables in the function called (in order): *\$1* *\$2* *\$3* etc. It also fills *\$#* with the number of arguments given by the user. Here's an example of using arguments in a function that saves me some typing when I want to copy a file to the SCF filesystem:

```
function putscf() {
    scp $1 paciorek@bilbo.berkeley.edu:~/$2
}
```

To use this function, I just do the following to copy *unit1.pdf* from the current directory on whatever non-SCF machine I'm on to the directory *~/teaching/243* on SCF:

```
> putscf unit1.pdf teaching/243/.
```

Of course you'd want to put such functions in your *.bashrc* file.

11 If/then/else

We can use if-then-else type syntax to control the flow of a shell script. For an example, see *niceR()* in the demo code file *niceR.sh* for this unit.

For more details, look in Newham&Rosenblatt or search online.

12 For loops

for loops in shell scripting are primarily designed for iterating through a set of files or directories. Here's an example:

```
for file in $(ls *txt)
do
    mv $file ${file/.txt/.R}
    # this syntax replaces .txt with .R in $file
done
```

You could also have done that with `for file in `ls *txt``

Another use of *for* loops is automating file downloads: see the demo code file. And, in my experience, *for* loops are very useful for starting a series of jobs: see the demo code files in the repository: *forloopDownload.sh* and *forloopJobs.sh*.

13 How much shell scripting should I learn?

You can do a fair amount of what you need from within R using the *system()* function. This will enable you to avoid dealing with a lot of shell programming syntax (but you'll still need to know how to use UNIX utilities, wildcards, and pipes to be effective). Example: a fellow student in grad school programmed a tool in R to extract concert information from the web for bands appearing in her iTunes library. Not the most elegant solution, but it got the job done.

For more extensive shell programming, it's probably worth learning Python and doing it there rather than using a shell script. In particular iPython makes it very easy to interact with the operating system.

14 Version Control

At a basic level, a simple principle is to have version numbers for all your work: code, datasets, manuscripts. Whenever you make a change to a dataset, increment the version number. For code

and manuscripts, increment when you make substantial changes or have obvious breakpoints in your workflow.

The basic idea of version control software (VCS) is that instead of manually trying to keep track of what changes you've made to code, data, and documents, you use software to help you manage the process. This has several benefits:

- easily allowing you to go back to earlier versions
- allowing you to have multiple version you can switch between
- allowing you to share work easily without worrying about conflicts
- providing built-in backup

The material that follows is borrowed from Jarrod Millman and Fernando Perez.

14.1 Warnings about this demo

1. The demo should work if you just run the demo code 'manually' on your machine. However, when compiled via knitr from the Lyx/Latex document, some of the later output in the branching section seems to be out of sync. So the output in this PDF is not quite right in a few places.
2. Also, note that the output from the embedded bash code chunks below is a bit annoying in that all the output appears in a group after all of the code lines rather than the output appearing after the individual line of code. This is some sort of issue with how knitr processes bash code chunks.

14.2 VCS Overview

There are a number of version control systems (VCS) including CVS and subversion, which use client-server models. Git is a distributed version control system. VCS store your material in a *repository*.

The next couple figures show graphical representations of how a repository is structured.

Recall that we have been using Git in a very simple fashion. We've cloned my class repository onto our local machines and have updated materials from that repository.

```
cd /tmp
git clone https://github.com/berkeley-stat243/stat243-fall-2014
git pull
```

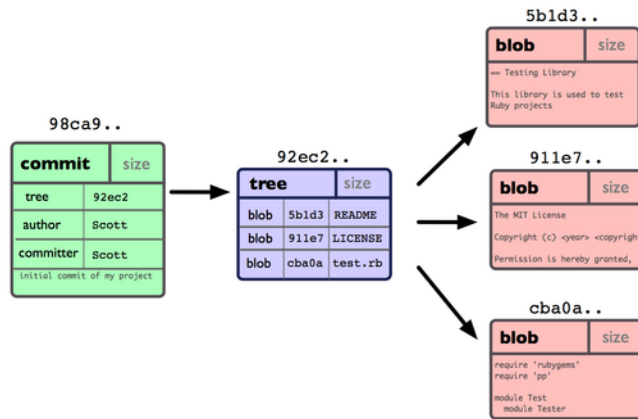


Figure 1: A snapshot of work at a point in time as stored in a 'commit'. Credit: ProGit book, by Scott Chacon, CC License.

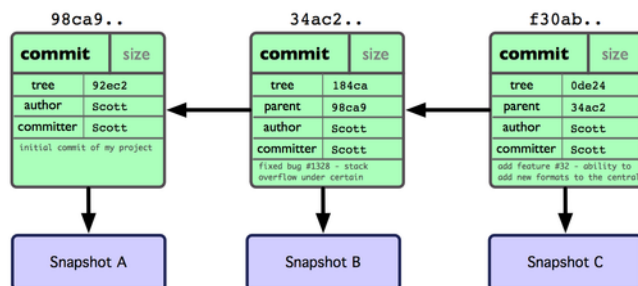


Figure 2: A sequence of commits. Credit: ProGit book, by Scott Chacon, CC License.

The goal of this section is to learn how to do more with Git to actually manage a project of your own.

14.3 Hashing

Hashing provides a way to have a fixed-length identifier for a given set of information, such as a file or set of files. The identifier is not guaranteed to be unique, but if the number of items is small, it will almost always be unique.

A toy "implementation"

```
library("digest")
# first commit
data1 <- "This is the start of my paper2."
meta1 <- "date: 8/20/13"
hash1 <- digest(c(data1, meta1), algo = "sha1")
cat("Hash:", hash1, "\n")

## Hash: 32cff5042299244c8c248f6804bb9756912e5492

# second commit, linked to the first
data2 <- "Some more text in my paper..."
meta2 <- "date: 8/20/13"
# Note we add the parent hash here! q
hash2 <- digest(c(data2, meta2, hash1), algo = "sha1")
cat("Hash:", hash2, "\n")

## Hash: 43925778805d33de28aba5697a967f04613f9153
```

We'll see that Git uses hashes as identifiers for different versions of your work.

14.4 Local, single-user, linear workflow

Simply type `git` (or `git help`) to see a full list of all the 'core' commands. We'll now go through most of these via small practical exercises:

```
git help

## usage: git [--version] [--exec-path[=<path>]] [--html-path] [--man-path]
##          [-p|--paginate|--no-pager] [--no-replace-objects] [--bare]
```

```

##          [--git-dir=<path>] [--work-tree=<path>] [--namespace=<name>]
##          [-c name=value] [--help]
##          <command> [<args>]
##
## The most commonly used git commands are:
##   add          Add file contents to the index
##   bisect       Find by binary search the change that introduced a bug
##   branch       List, create, or delete branches
##   checkout     Checkout a branch or paths to the working tree
##   clone        Clone a repository into a new directory
##   commit       Record changes to the repository
##   diff         Show changes between commits, commit and working tree, etc
##   fetch        Download objects and refs from another repository
##   grep         Print lines matching a pattern
##   init         Create an empty git repository or reinitialize an existing
##   log          Show commit logs
##   merge        Join two or more development histories together
##   mv           Move or rename a file, a directory, or a symlink
##   pull         Fetch from and merge with another repository or a local br
##   push         Update remote refs along with associated objects
##   rebase       Forward-port local commits to the updated upstream head
##   reset        Reset current HEAD to the specified state
##   rm           Remove files from the working tree and from the index
##   show         Show various types of objects
##   status       Show the working tree status
##   tag          Create, list, delete or verify a tag object signed with GPG
##
## See 'git help <command>' for more information on a specific command.

```

14.4.1 Initializing a Git repository

We use *git init* to create an empty repository

```

cd /tmp
rm -rf git-demo
git init git-demo

```

```
## Initialized empty Git repository in /tmp/git-demo/.git/
```

Let's look at what git did:

```
cd /tmp/git-demo
ls -al
ls -al .git

## total 280
## drwxr-xr-x  3 paciorek scfstaff  4096 Aug 28 09:59 .
## drwxrwxrwt 39 root        root    274432 Aug 28 09:59 ..
## drwxr-xr-x  7 paciorek scfstaff  4096 Aug 28 09:59 .git
## total 40
## drwxr-xr-x 7 paciorek scfstaff 4096 Aug 28 09:59 .
## drwxr-xr-x 3 paciorek scfstaff 4096 Aug 28 09:59 ..
## drwxr-xr-x 2 paciorek scfstaff 4096 Aug 28 09:59 branches
## -rw-r--r-- 1 paciorek scfstaff  92 Aug 28 09:59 config
## -rw-r--r-- 1 paciorek scfstaff  73 Aug 28 09:59 description
## -rw-r--r-- 1 paciorek scfstaff  23 Aug 28 09:59 HEAD
## drwxr-xr-x 2 paciorek scfstaff 4096 Aug 28 09:59 hooks
## drwxr-xr-x 2 paciorek scfstaff 4096 Aug 28 09:59 info
## drwxr-xr-x 4 paciorek scfstaff 4096 Aug 28 09:59 objects
## drwxr-xr-x 4 paciorek scfstaff 4096 Aug 28 09:59 refs
```

14.4.2 Adding content to a repository

Now let's edit our first file in the test directory with a text editor... I'm doing it programatically here for automation purposes, but you'd normally be editing by hand

```
cd /tmp/git-demo
echo "My first bit of text" > file1.txt
```

Now we can tell git about this new file using the *add* command:

```
cd /tmp/git-demo
git add file1.txt
```

We can now ask git about what happened with *status*:


```

cd /tmp/git-demo
git status

## # On branch master
## #
## # Initial commit
## #
## # Changes to be committed:
## #   (use "git rm --cached <file>..." to unstage)
## #
## # new file:   file1.txt
## #

```

14.4.3 Committing changes

We now permanently record our changes in git's database.

For now, we are always going to call *git commit* either with the '-a' option or with specific filenames (`git commit file1 file2...`). This avoids discussion of an aspect of git called the *index* (often referred to also as the 'staging area'). Most everyday work in regular scientific practice doesn't require understanding the extra moving parts that the index involves, so we'll bypass it.

```

cd /tmp/git-demo
git commit -am"This is our first commit"
git status

## [master (root-commit) 23d803a] This is our first commit
##   Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
##   Your name and email address were configured automatically based
##   on your username and hostname. Please check that they are accurate.
##   You can suppress this message by setting them explicitly:
##
##       git config --global user.name "Your Name"
##       git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##

```

```
##      git commit --amend --reset-author
##
## 1 file changed, 1 insertion(+)
## create mode 100644 file1.txt
## # On branch master
## nothing to commit (working directory clean)
```

In the commit above, we used the ‘-m’ flag to specify a message at the command line. If we don’t do that, git will open the editor we specified in our configuration above and require that we enter a message. By default, git refuses to record changes that don’t have a message to go along with them (though you can obviously ‘cheat’ by using an empty or meaningless string).

We can use git log to see what has been committed to the repository so far:

```
cd /tmp/git-demo
git log

## commit 23d803a29b92a65bf8ea77c145160f9a77d05488
## Author: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Date: Thu Aug 28 09:59:03 2014 -0700
##
##      This is our first commit
```

Let’s do a little bit more work... Again, in practice you’ll be editing the files by hand, here we do it via shell commands for the sake of automation (and therefore the reproducibility of this tutorial!)

```
cd /tmp/git-demo
echo "And now some more text..." >> file1.txt
```

And now we can ask git what is different:

```
cd /tmp/git-demo
git diff

## diff --git a/file1.txt b/file1.txt
## index ce645c7..4baa979 100644
## --- a/file1.txt
## +++ b/file1.txt
```

```
## @@ -1 +1,2 @@
## My first bit of text
## +And now some more text...
```

So the cycle of work in a git context is: work, commit, work, commit, ...

```
cd /tmp/git-demo
git commit -am"I have made great progress on this critical matter."

## [master 6233fa1] I have made great progress on this critical matter.
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
##
## 1 file changed, 1 insertion(+)
```

Now let's see what the log shows us now:

```
cd /tmp/git-demo
git log

## commit 6233fa12742b26a939ff2b112b29a93a59fb3aca
## Author: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Date: Thu Aug 28 09:59:03 2014 -0700
##
## I have made great progress on this critical matter.
##
## commit 23d803a29b92a65bf8ea77c145160f9a77d05488
## Author: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
```

```
## Date:    Thu Aug 28 09:59:03 2014 -0700
##
##      This is our first commit
```

Sometimes it's handy to see a very summarized version of the log:

```
cd /tmp/git-demo
git log --oneline --topo-order --graph

## * 6233fa1 I have made great progress on this critical matter.
## * 23d803a This is our first commit
```

Git supports *aliases*, new names given to command combinations. Let's make this handy shortlog an alias, so we only have to type `git slog` and see this compact log:

```
cd /tmp/git-demo
# We create our alias (this saves it in git's permanent configuration file)
git config --global alias.slog "log --oneline --topo-order --graph"
# And now we can use it
git slog

## * 6233fa1 I have made great progress on this critical matter.
## * 23d803a This is our first commit
```

14.4.4 Renaming and removing files

Once a file is added to a repository, we need to use git commands to rename and remove files. In familiar Unix fashion, the *mv* and *rm* git commands do precisely this:

```
cd /tmp/git-demo
git mv file1.txt file-newname.txt
git status

## # On branch master
## # Changes to be committed:
## #   (use "git reset HEAD <file>..." to unstage)
## #
## # renamed:    file1.txt -> file-newname.txt
## #
```

Note that these changes must be committed too, to become permanent! In git's world, until something hasn't been committed, it isn't permanently recorded anywhere.

```
cd /tmp/git-demo
git commit -am"I like this new name better"
git slog

## [master be343e2] I like this new name better
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
##
## 1 file changed, 0 insertions(+), 0 deletions(-)
## rename file1.txt => file-newname.txt (100%)
## * be343e2 I like this new name better
## * 6233fa1 I have made great progress on this critical matter.
## * 23d803a This is our first commit
```

Let's see *git rm* in action. First a little setup.

```
cd /tmp/git-demo
echo 'stuff' > test.txt
git add test.txt
git commit -am'added test file'
ls -l test*

## [master bbc3df6] added test file
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
```

```
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
##
## 1 file changed, 1 insertion(+)
## create mode 100644 test.txt
## -rw-r--r-- 1 paciorek scfstaff 6 Aug 28 09:59 test.txt
```

Now let's do the removal.

```
cd /tmp/git-demo
git rm test.txt
ls -l test*
git status
git commit -am'removed test file'
git status

## rm 'test.txt'
## # On branch master
## # Changes to be committed:
## #   (use "git reset HEAD <file>..." to unstage)
## #
## # deleted:    test.txt
## #
## [master b2be590] removed test file
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
```

```
##
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
##
## 1 file changed, 1 deletion(-)
## delete mode 100644 test.txt
## # On branch master
## nothing to commit (working directory clean)
```

Be careful: *git rm* removes the file from the local filesystem as well as the repository. If we want to remove a file from the repository but keep it on the local disk, we can do: `git rm --cached file`

14.4.5 Undoing changes

If we want to make a change before we do a commit, we can do that as follows.

First, let's remove a file.

```
cd /tmp/git-demo
echo 'stuff' > test.txt
git add test.txt
git commit -am'added test file'
git rm test.txt
git status

## [master c583c26] added test file
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
```

```
##      git commit --amend --reset-author
##
## 1 file changed, 1 insertion(+)
## create mode 100644 test.txt
## rm 'test.txt'
## # On branch master
## # Changes to be committed:
## #   (use "git reset HEAD <file>..." to unstage)
## #
## # deleted:    test.txt
## #
```

Now suppose I realize I don't want to remove *test.txt*.

```
cd /tmp/git-demo
git reset -- test.txt # restore file in index (unstage)
git checkout -- test.txt # get a copy of the file back
ls -l test*
git status

## Unstaged changes after reset:
## D test.txt
## -rw-r--r-- 1 paciorek scfstaff 6 Aug 28 09:59 test.txt
## # On branch master
## nothing to commit (working directory clean)
```

Note that if you want to unstage an addition before you've committed it, you can do `git reset -- <file>`. If you want to remove a file from the repository but not the filesystem after you've committed the addition of the file, you can do `git rm --cached` and then a commit.

If you have a bunch of files that have been removed or changed (but not committed) and you want to reset for all of them, you can do: `git reset --hard HEAD`, which should remove working directory changes and changes changed through git, e.g. *git add* and *git rm* changes.

Understanding the difference between the working directory, the index, and HEAD can be confusing and something I'm still wrapping my head around. Fig. 3 helps.

The *working directory* or *working tree* is the state of your local directory on the filesystem. The staging area (or *index*) reflects your *git add*, *git rm*, etc. changes that have been staged but not committed. The repository reflects your commits. HEAD is the last commit on the current branch.

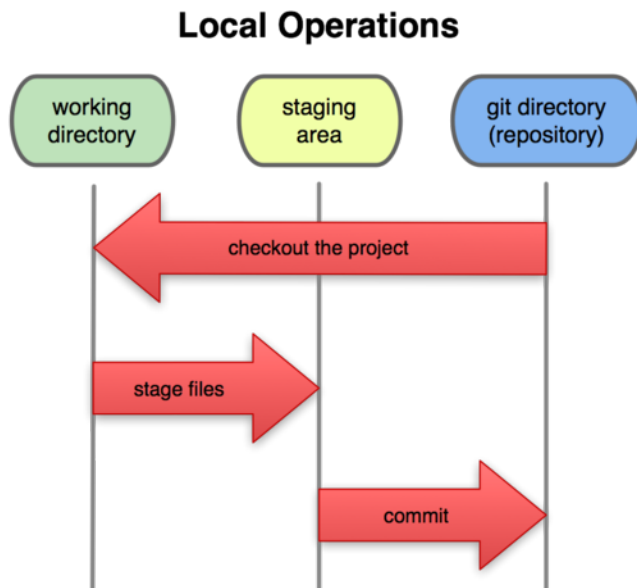


Figure 3: Working tree, staging area, and repository. Credit: ProGit book, by Scott Chacon, CC License.

In our *git reset* and *git checkout* operations above, we had to use *git reset* to restore the file in the index from HEAD (from the commit). We then had to use *git checkout* to check the file back into the working directory (i.e, have the index and the working directory match).

14.5 Branches

What is a branch? It's a label for the 'current' commit in a sequence of ongoing commits.

There can be multiple branches alive at any point in time; the working directory is the state of a special pointer called HEAD.

Let's now illustrate all of this with a concrete example. Let's get our bearings first:

```
cd /tmp/git-demo
git status
ls -l

## # On branch master
## nothing to commit (working directory clean)
## total 8
## -rw-r--r-- 1 paciorek scfstaff 47 Aug 28 09:59 file-newname.txt
## -rw-r--r-- 1 paciorek scfstaff  6 Aug 28 09:59 test.txt
```

We are now going to try two different routes of development: on the *master* branch we will add one file and on the *experiment* branch, which we will create, we will add a different one. We will then merge the experimental branch into *master*.

```
cd /tmp/git-demo
git branch experiment # creating new branch
git checkout experiment # switch to it
echo "Some crazy idea" > experiment.txt
git add experiment.txt
git commit -am"Trying something new"
ls -l
git slog

## [experiment 7ffe039] Trying something new
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
##
## 1 file changed, 1 insertion(+)
## create mode 100644 experiment.txt
## total 12
## -rw-r--r-- 1 paciorek scfstaff 16 Aug 28 09:59 experiment.txt
## -rw-r--r-- 1 paciorek scfstaff 47 Aug 28 09:59 file-newname.txt
## -rw-r--r-- 1 paciorek scfstaff  6 Aug 28 09:59 test.txt
## * 7ffe039 Trying something new
## * c583c26 added test file
## * b2be590 removed test file
## * bbc3df6 added test file
## * be343e2 I like this new name better
```

```
## * 6233fa1 I have made great progress on this critical matter.
## * 23d803a This is our first commit
```

We can see the branches, and which branch we are currently in with `git branch`. We'll switch to the master and notice that *experiment.txt* is not in the master branch.

```
cd /tmp/git-demo
git branch
git checkout master
ls -l # notice the lack of 'experiment.txt'

## * experiment
##   master
## total 8
## -rw-r--r-- 1 paciorek scfstaff 47 Aug 28 09:59 file-newname.txt
## -rw-r--r-- 1 paciorek scfstaff  6 Aug 28 09:59 test.txt
```

Now, let's make a different change to the master branch.

```
cd /tmp/git-demo
echo "All the while, more work goes on in master..." >> progress.txt
git add progress.txt
git commit -am"The mainline keeps moving"
git slog

## [master bc6d8ef] The mainline keeps moving
##   Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
```

```
##
## 1 file changed, 1 insertion(+)
## create mode 100644 progress.txt
## * bc6d8ef The mainline keeps moving
## * c583c26 added test file
## * b2be590 removed test file
## * bbc3df6 added test file
## * be343e2 I like this new name better
## * 6233fa1 I have made great progress on this critical matter.
## * 23d803a This is our first commit
```

Now we'll merge the two together. Git can do this without guidance from us because the differences in the two branches do not conflict with each other.

```
cd /tmp/git-demo
git checkout master
git merge experiment
git slog
ls -l

## Merge made by the 'recursive' strategy.
## experiment.txt | 1 +
## 1 file changed, 1 insertion(+)
## create mode 100644 experiment.txt
## * 6143b98 Merge branch 'experiment'
## |\
## | * 7ffe039 Trying something new
## * | bc6d8ef The mainline keeps moving
## | /
## * c583c26 added test file
## * b2be590 removed test file
## * bbc3df6 added test file
## * be343e2 I like this new name better
## * 6233fa1 I have made great progress on this critical matter.
## * 23d803a This is our first commit
## total 16
## -rw-r--r-- 1 paciorek scfstaff 16 Aug 28 09:59 experiment.txt
```

```
## -rw-r--r-- 1 paciorek scfstaff 47 Aug 28 09:59 file-newname.txt
## -rw-r--r-- 1 paciorek scfstaff 46 Aug 28 09:59 progress.txt
## -rw-r--r-- 1 paciorek scfstaff  6 Aug 28 09:59 test.txt
```

14.6 Using remotes as a single user

We are now going to introduce the concept of a remote repository: a pointer to another copy of the repository that lives on a different location. This can be simply a different path on the filesystem or a server on the internet. Of course we've already used a remote repository a little by cloning the class repository from Github.

For this discussion, we'll be using remotes hosted on the Github.com service, but you can equally use other services like BitBucket (<http://bitbucket.org>) or Gitorious (<http://gitorious.org>). The SCF provides [hosting of git repositories as well](#).

```
cd /tmp/git-demo
# Let's see if we have any remote repositories here
git remote -v
```

Since the `git remote -v` call didn't produce any results, it means we have no remote repositories configured. We will now proceed to do so. We need a Github account. Login to GitHub, and go to the new repository page (<https://github.com/new>). For our demo purposes, we'll make a repository called *test*. Do **not** check the box that says 'Initialize this repository with a README', since we already have an existing repository on our local machine. That option is useful when you're starting first at Github and don't have a repo made already on a local computer.

We can now follow the instructions from the next page:

```
cd /tmp/git-demo
git remote add origin git@github.com:berkeley-stat243/test.git
git push -u origin master
git remote -v

## Branch master set up to track remote branch master from origin.
## origin git@github.com:berkeley-stat243/test.git (fetch)
## origin git@github.com:berkeley-stat243/test.git (push)
```

We can now [see the repository publicly](#).

Let's see how this can be useful for backup and syncing work between two different computers.

```

cd /tmp # Here I clone my 'test' repo but with a different name, test2, to :
# in class we'll actually do this on a separate computer
git clone git@github.com:berkeley-stat243/test.git test2
cd test2
ls -l
git remote -v

## /tmp/test2
## total 16
## -rw-r--r-- 1 paciorek scfstaff 50 Aug 28 09:56 experiment.txt
## -rw-r--r-- 1 paciorek scfstaff 47 Aug 28 09:56 file-newname.txt
## -rw-r--r-- 1 paciorek scfstaff 46 Aug 28 09:56 progress.txt
## -rw-r--r-- 1 paciorek scfstaff  6 Aug 28 09:56 test.txt
## origin git@github.com:paciorek/test.git (fetch)
## origin git@github.com:paciorek/test.git (push)

```

Let's now make some changes in one computer.

```

cd /tmp/test2 # working on computer #2
echo "More new content on my experiment" >> experiment.txt
git commit -am"More work, on machine #2"

## [master 5b20d88] More work, on machine #2
##  Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
##  Your name and email address were configured automatically based
##  on your username and hostname. Please check that they are accurate.
##  You can suppress this message by setting them explicitly:
##
##      git config --global user.name "Your Name"
##      git config --global user.email you@example.com
##
##  After doing this, you may fix the identity used for this commit with:
##
##      git commit --amend --reset-author
##
##  1 file changed, 1 insertion(+)

```

Now we put this new work up on the github server so it's available from the internet

```
cd /tmp/test2
# working on computer #2
git push
```

Now let's fetch that work from machine #1:

```
cd /tmp/git-demo
git pull
cat experiment.txt

## Already up-to-date.
## Some crazy idea
```

14.7 Conflict management

While git is very good at merging, if two different users or two different branches modify the same file in the same location, it simply can't decide which change should prevail. At that point, human intervention is necessary to make the decision. Git will help you by marking the location in the file that has a problem, but it's up to you to resolve the conflict. Let's see how that works by intentionally creating a conflict.

We start by creating a branch and making a change to our experiment file:

```
cd /tmp/git-demo
git branch trouble
git checkout trouble
echo "This is going to be a problem..." >> experiment.txt
git commit -am"Changes in the trouble branch"

## [trouble f6d1860] Changes in the trouble branch
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
```

```
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
##
## 1 file changed, 1 insertion(+)
```

And now we go back to the master branch, where we change the **same** file:

```
cd /tmp/git-demo
git checkout master
echo "More work on the master branch..." >> experiment.txt
git commit -am"Mainline work"

## [master 6a92c17] Mainline work
##  Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
##  Your name and email address were configured automatically based
##  on your username and hostname. Please check that they are accurate.
##  You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"
##     git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
##     git commit --amend --reset-author
##
## 1 file changed, 1 insertion(+)
```

So now let's see what happens if we try to merge the 'trouble' branch into 'master':

```
cd /tmp/git-demo
git merge trouble

## Auto-merging experiment.txt
## CONFLICT (content): Merge conflict in experiment.txt
## Automatic merge failed; fix conflicts and then commit the result.
```

Let's see what git has put into our file:


```

cd /tmp/git-demo
cat experiment.txt

## Some crazy idea
## <<<<<< HEAD
## More work on the master branch...
## =====
## This is going to be a problem...
## >>>>>> trouble

```

At this point, we go into the file with a text editor, decide which changes to keep, and make a new commit that records our decision. To automate my edits, I use the ‘sed’ command.

```

cd /tmp/git-demo
sed -i '/^</d' experiment.txt
sed -i '/^>/d' experiment.txt
sed -i '/^=/d' experiment.txt
cat experiment.txt

## Some crazy idea
## More work on the master branch...
## This is going to be a problem...

```

I’ve now made the edits, in this case I decided that both pieces of text were useful, so I just accepted both additions.

Let’s then make our new commit:

```

cd /tmp/git-demo
git commit -am"Completed merge of trouble, fixing conflicts along the way"
git slog

## [master 5cb98f6] Completed merge of trouble, fixing conflicts along the way
## Committer: Christopher Paciorek <paciorek@scf.Berkeley.EDU>
## Your name and email address were configured automatically based
## on your username and hostname. Please check that they are accurate.
## You can suppress this message by setting them explicitly:
##
##     git config --global user.name "Your Name"

```

```
##      git config --global user.email you@example.com
##
## After doing this, you may fix the identity used for this commit with:
##
##      git commit --amend --reset-author
##
## *    5cb98f6 Completed merge of trouble, fixing conflicts along the way
## |\
## | * f6d1860 Changes in the trouble branch
## * | 6a92c17 Mainline work
## | /
## *    6143b98 Merge branch 'experiment'
## |\
## | * 7ffe039 Trying something new
## * | bc6d8ef The mainline keeps moving
## | /
## * c583c26 added test file
## * b2be590 removed test file
## * bbc3df6 added test file
## * be343e2 I like this new name better
## * 6233fa1 I have made great progress on this critical matter.
## * 23d803a This is our first commit
```

Note: While it's a good idea to understand the basics of fixing merge conflicts by hand, in some cases you may find the use of an automated tool useful. Git supports multiple **merge tools**: a merge tool is a piece of software that conforms to a basic interface and knows how to merge two files into a new one. Since these are typically graphical tools, there are various to choose from for the different operating systems, and as long as they obey a basic command structure, git can work with any of them.

14.8 Collaborating on github with a small team

Single remote with shared access: we are going to set up a shared collaboration with one partner (the person sitting next to you). This will show the basic workflow of collaborating on a project with a small team where everyone has write privileges to the same repository.

We will have two people, let's call them Alice and Bob, sharing a repository. Alice will be the owner of the repo and she will give Bob write privileges.

We begin with a simple synchronization example, much like we just did above, but now between two people instead of one person. Otherwise it's the same:

- Bob clones Alice's repository.
- Bob makes changes to a file and commits them locally.
- Bob pushes his changes to github.
- Alice pulls Bob's changes into her own repository.

Next, we will have both parties make non-conflicting changes each, and commit them locally. Then both try to push their changes:

- Alice adds a new file, *alice.txt* to the repo and commits.
- Bob adds *bob.txt* and commits.
- Alice pushes to github.
- Bob tries to push to github.

What happens here?

The problem is that Bob's changes create a commit that conflicts with Alice's, so git refuses to apply them. It forces Bob to first do the merge on his machine, so that if there is a conflict in the merge, Bob deals with the conflict manually (git could try to do the merge on the server, but in that case if there's a conflict, the server repo would be left in a conflicted state without a human to fix things up). The solution is for Bob to first pull the changes (pull in git is really fetch+merge), and then push again.

14.9 More Git resources

- Git for Scientists: A Tutorial: <http://nyuccl.org/pages/GitTutorial/>
- Gitwash: workflow for scientific Python projects:
http://matthew-brett.github.io/pydagogue/gitwash_build.html
- Git branching demo: <http://pcottle.github.io/learnGitBranching/>