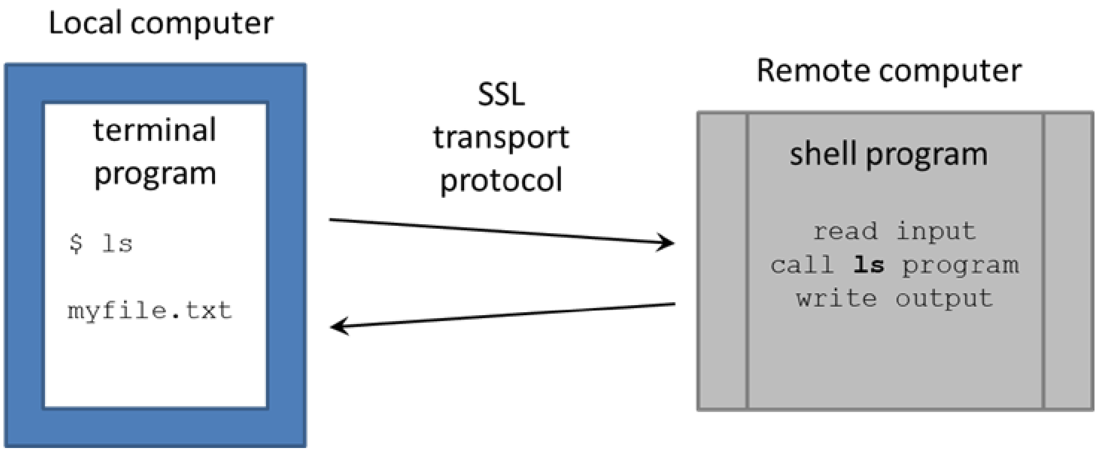
Linux fundamentals

This page should serve as a reference for the many "things Linux" we use in this course. It is by no means complete – Linux is *****huge***** – but offers introductions to many important topics.

Terminal programs, shells and commands

You need a **Terminal** program in order to **ssh** to a remote computer.



- Macs and Linux have a **Terminal** program built-in
- Windows options:
  - Windows 10+
    - **Command Prompt** and **PowerShell** programs have **ssh** and **scp** (may require latest Windows updates)
      - Start menu Search for **Command**
    - **Putty** – http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html
      - simple Terminal and file copy programs
      - download either the Putty installer or just **putty.exe** (Terminal) and **pscp.exe** (secure copy client)
    - **Windows Subsystem for Linux** – Windows 10 Professional includes a Ubuntu-like **bash** shells
      - See https://docs.microsoft.com/en-us/windows/wsl/install-win10
      - We recommend the Ubuntu Linux distribution, but any Linux distribution will have an SSH client

Use **ssh** (**s**ecure **sh**ell) to login to a remote computers.

SSH to a remote computer

```
# General form:
ssh <user_name>@<full_host_name>

# For example
ssh abattenh@ls6.tacc.utexas.edu
```

The bash shell REPL and commands

When you type something in at a **bash** ***command-line prompt***, it ***Reads*** the input, ***Evaluates*** it, then ***Prints*** the results, then does this over and over in a ***Loop***. This behavior is called a ***REPL*** – a ***Read, Eval, Print Loop***.

The input to the **bash** REPL is a ***command***, which consists of:

- The ***command name***
- One or more (optional) ***options***, usually noted with a leading **dash** (**-**) or **double-dash** (**--**).
  - ***short (1-character) options*** can be provided separately, prefixed by a single **dash** (**-**)
    - or can be combined with the combination prefixed by a single dash
  - ***long (multi-character*** or ***"word") options*** are prefixed with a **double dash** (**--**) and must be supplied separately.
  - Both long and short options can be assigned a value
- One or more command-line ***arguments***, which are often (but not always) file names

Some examples using the **ls** (**lis**t files) command:

```
ls                # example 1 - no options or arguments
ls -l             # example 2 - one "short" (single character) option only (-l)
ls --help         # example 3 - one "long" (word) option (--help)
ls .profile       # example 4 - one argument, a file name (.profile)
ls --width=20     # example 5 - a long option that has a value (--width is the option, 20 is the value)
ls -w 20          # example 6 - a short option w/a value, as above, where -w is the same as --width
ls -l -a -h       # example 7 - three short options entered separately (-l -a -h)
ls -lah           # example 8 - three short options that can be combined after a dash (-lah)
```

- The ***arguments*** to **ls** are one or more file or directory names. If no arguments are provided, the contents of the ***current directory*** are listed.
  - If an argument is a directory name, the contents of that directory are listed.

- Some handy ***options*** for **ls**:
  - **-l** shows a **l**ong listing, including file permissions, ownership, size and last modified date.
  - **-a** shows **a**ll files, including ***dot files*** whose names start with a period (**.**) which are normally not listed
  - **-h** says to show file sizes in **h**uman readable form (e.g. 12M instead of 12201749)

Getting help

How do you find out what options and arguments a command uses?

1. In the **Terminal**, type in the command name then the **--help** long option (e.g. **ls --help**)
   - Works for most Linux commands; 3rd party tools may use **-h** or **-?** or even **/?** instead
   - May produce a lot of output, so you may need to scroll up quite a bit, or pipe the output to a ***pager***
     - e.g. **ls --help | more**
       - a **space** advances the output by one screen/"page", and typing **Ctrl-C** will exit **more**
2. Use the built-in **man**ual system (e.g. type **man ls**)
   - This system uses the **less** ***pager*** described below
   - For now, just know that a **space** advances the output by one screen/"page", and typing **q** will exit the display.
3. Ask the **Google**, e.g. search for **ls man page**
   - Can be easier to read

Literal characters and metacharacters

In the **bash** shell, and in most tools and programming environment, there are two kinds of input:

- ***literal*** characters, that just represent (and print as) themselves
  - e.g. **alphanumeric** characters **A-Z**, **a-z**, **0-9**
- ***metacharacters*** - these are special characters that are associated with an operation in the environment
  - e.g. the **pound sign** (**#**) ***comment character*** that tells the shell to ignore everything after the **#**

There are ***many metacharacters*** in **bash**: **# \ $ | ~ [ ]** to name a few.

Pay attention to the different ***metacharacters*** and their usages – which ***can depend on the context*** where they're used.

About command line input

You know the command line is ready for input when you see the ***command line prompt***. The shell executes command line input when it sees a **linefeed** c haracter (**\n**, also called a **newline**), which happens when you press **Enter** after entering the command.

Note: The Unix **linefeed** (**\n**) line delimiter is different from Windows, where the default line ending is **carriage-return + linefeed** (**\r\n**), and some Mac text editors that just use a **carriage return** (**\r**).

More than one command can be entered on a single line – just separate the commands with a **semi-colon** (**;**).

Multiple command on a line

```
cd; ls -lh
```

A single command can also be split across multiple lines by adding a backslash (****) at the end of the line you want to continue, before pressing **Enter**.

Split a command across multiple lines

```
ls6:~$ ls ~/.bashrc \
> ~/.profile
```

Notice that the shell indicates that it is not done with command-line input by displaying a **greater than sign** (**>**). You just enter more text then **Enter** when done.

Use Ctrl-C to exit the current command input

At any time during command input, whether on the 1st command line prompt or at a **>** continuation, you can press **Ctrl-c** (**Cont**ro**l** key and the **c** key at the same time) to get back to the command prompt.

Text lines and the Terminal

Sometimes a line of text is longer than the width of your Terminal. In this case the text is ***wrapped***. It can appear that the output is multiple lines, but it is not. For example, **FASTQ** files often have long lines:

```
head $CORENGS/misc/small.fq
```

Note that most **Terminals** let you increase/decrease the width/height of the **Terminal** window. But there will always be single lines too long for your **Terminal** width (and too many lines of text for its height).

So how long is a line? So how many lines of output are there really? And how long is a line? The **wc** (**w**ord **c**ount) command can tell us this.

- **wc -l** reports the number of ***lines*** in its input
- **wc -c** reports the number of ***characters*** in its input (including invisible ***linefeed*** characters)

And when you give **wc -l** multiple files, it reports the line count of each, then a total.

```
wc -l $CORENGS/misc/small.fq           # Reports the number of lines in the small.fq file
cat $CORENGS/misc/small.fq | wc -l     # Reports the number of lines on its standard input
wc -l $CORENGS/misc/*.fq               # Reports the number of lines in all matching *.fq files
tail -1 $CORENGS/misc/small.fq | wc -c # Reports the number of characters of the last small.fq line
```

Command input errors

You don't always type in commands, options and arguments correctly – you can misspell a command name, forget to type a space, specify an unsupported option or a non-existent file, or make all kinds of other mistakes.

What happens? The shell attempts to guess what kind of error it is and reports an appropriate error message as best it can. Some examples:

```
# You type the name of a command that is not installed on your system
ls6:~$ lz
Command 'lz' not found, but can be installed with:
apt install mtools
Please ask your administrator.

# You enter something that is close to an existing, or known, command
ls6:~$ catt
Command 'catt' not found, did you mean:
  command 'cat' from deb coreutils (8.30-3ubuntu2)
  command 'catty' from deb node-catty (0.0.8-1)
  command 'ratt' from deb ratt (0.0~git20180127.c44413c-2)
Try: apt install <deb name>

# You try to use an unsupported option
ls6:~$ ls -z
ls: invalid option -- 'z'
Try 'ls --help' for more information.

# You specify the name of a file that does not exist
ls6:~$ ls xxx
ls: cannot access 'xxx': No such file or directory
```

Basic Linux commands

One of the steepest Unix/Linux learning curves is the ***sheer number of built-in commands***, all of which have ***many options – most of which you'll never use***, and the more advanced commands are ***extremely complex.***

To help address this, this section introduces a number of built-in Linux utilities along with some of their common options, by category.

> **Command line arguments can be replaced by standard input**
>
> Most built-in Linux commands that obtain data from a file can also accept the data ***piped in*** on their ***standard input***.

And here's a Linux commands cheat sheet you may find useful:

Displaying file contents

- **cat** outputs all the contents of its input (one or more files and/or ***standard input***) or the specified file
  - **cat -n** prefixes each line of output with its line **n**umber

    - CAUTION – only use on small files!
- **zcat <file.gz>** like **cat**, but understands the **gzip** (**.gz**) format, and decompresses the data before writing it to ***standard output***
    - CAUTION – only use on small files!
    - Another CAUTION – does not understand **.zip** or **.bz2** compression formats
- **more** and **less** ***pagers***
    - both display their (possibly very long) input one Terminal "page" at a time
    - in **more**:
        - use **spacebar** to advance a page
        - use **q** or **Ctrl-c** to exit **more**
    - in **less**:
        - **q** – quit
        - **Ctrl-f** or **space** – page forward
        - **Ctrl-b** – page backward
        - **/<pattern>** – search for <pattern> in ***forward*** direction
            - **n** – next match
            - **N** – previous match
        - **?<pattern>** – search for <pattern> in ***backward*** direction
            - **n** – previous match going back
            - **N** – next match going forward
    - use **less -N** to display line numbers
    - **less -I** says to do pattern matching ignoring case
    - can be used directly on **.gz** format files
- **head** and **tail**
    - show you the first or last 10 lines (by default) of their input
    - **head -n 20** or just **head -20** shows the first 20 lines
    - **tail -n 2** or just **tail -2** shows the last 2 lines
    - **tail -n +100** shows lines starting at line 100
    - **tail -n +100 | head -20** shows 20 lines starting at line 100
    - **tail -f** shows the last lines of a file, then **f**ollows the output as more lines are written (**Ctrl-c** to quit)
- **gunzip -c <file.gz> | more** (or **less**) – like **zcat**, un-compresses lines of **<file.gz>** and outputs them to ***standard output***
    - **<file.gz>** is not altered on disk
    - always ***pipe*** the output to a ***pager***!

File system navigation

- **ls** - list the contents of the specified directory
    - **-l** says produce a **l**ong listing (including file permissions, sizes, owner and group)
    - **-a** says show **a**ll files, even normally-hidden ***dot files*** whose names start with a **period** (**.**)
    - **-h** says to show file sizes in **h**uman readable form (e.g. 12M instead of 12201749)
    - **-t** says to sort files on last modification **t**ime
    - **-r** says to **r**everse the current sort order
    - **-d** says to show directory listing information only, instead of directory contents
        - usually combined with **-l**, e.g.: **ls -ld <dirname>**
- **cd <whereto>** - change the current working directory to **<whereto>**. Some special **<wheretos>**:
    - **..** (**period**, **period**) means "***up one directory level***"
    - **~** (**tilde**) means "***my Home directory***"
    - **-** (**dash**) means "***the last directory I was in***"
- **find <in_directory> [operators] -name <expression> [tests]**
    - looks for files matching **<expression>** in **<in_directory>** and its sub-directories
    - **<expression>** can be a double-quoted string ***including pathname wildcard***s (e.g. "**[a-g]*.txt**")
    - there are ***tons*** of **operators** and **tests**:
        - **-type f** (**file**) and **-type d** (**d**irectory) are useful **tests**
        - **-maxdepth NN** is a useful **operator** to limit the depth of recursion.
- **file <file>** tells you what kind of file **<file>** is
- **df** shows you the top level directory structure of the system you're working on, along with how much disk space is available
    - **-h** says to show sizes in **h**uman readable form (e.g. 12G instead of 12318201749)
- **pwd** - display the **p**resent **w**orking **d**irectory
    - **-P** says to display the full ***absolute path***, resolving any symbolic links or relative path syntax
- **tree <directory>** - shows the file system hierarchy of the specified directory
    - **tree** is not always available on all Linux systems

Create, rename, link to, delete files

- **touch <file>** – create an empty file, or update the modification timestamp on an existing file
- **mkdir -p <dirname>** – create directory **<dirname>**.
    - **-p** says to create any needed sub-directories also
- **mv <file1> <file2>** – renames **<file1>** to **<file2>**
    - **mv <file1> <file2> ... <fileN> <to_dir>/** – moves files **<file1> <file2> ... <fileN>** into directory **<to_dir>**
    - **mv -t <dir> <file1> <file2> ... <fileN>** – same as above, but specifies the **t**arget directory as an option (**-t <to_dir>**)
- **ln -s <path>** creates a ***symbolic*** (**-s**) ***link*** (a.k.a ***symlink***) to **<path>** in the current directory
    - default link name corresponds to the last name component in **<path>**
    - ***always*** change into (**cd**) the directory where you want the link before executing **ln -s**
    - a symbolic link can be deleted without affecting the linked-to file
    - **ln -sf -t <target_dir> <file1> <file2> ... <fileN>** – creates symbolic links to **<file1> <file2> ... <fileN>** in **t**arget directory **<target_dir>**
- **rm <file>** deletes a file. This is ***permanent*** - not a "trash can" deletion.
    - **rm -rf <dirname>** deletes an entire directory – be careful!

Copying files and directories

- **cp <source> [<source>...] <destination>** copies the file(s) **<source> [<source>...]** to the directory and/or file name **<destination>**.
    - using **.** (period) as the destination means "here, with the same name"
    - **-p** option says to **p**reserve file modification timestamps
    - **cp -r <dirname>/ <destination>/** will **r**ecursively copy the directory **<dirname>/** and all its contents to the directory **<destination>/**.
- **scp <user>@<host>:<remote_source_path> <local_destination_path>**
    - Works just like **cp** but copies **<remote_source_path>** ***from the remote host*** machine to the **<local_destination_path>**
    - **-p** (**p**reserve file times) and **-r** (**r**ecursive) options work the same as **cp**
    - **scp <local_source_path> <user>@<host>:<remote_destination_path>** is similar, but copies the **<local_source_path>** to the **<remote_destination_path>** on the ***remote host machine***.
    - A nice **scp** syntax resource is located here.
- **wget <url>** fetches a file from a valid URL (e.g. **http**, **https**, **ftp**).
    - **-O <file>** specifies the name for the local file (defaults to the last component of the URL)
- **rsync -arvW <source_directory>/ <target_directory>/**
  rsync -ptlrvP <source_directory>/ <target_directory>/
    - Recursively copies <source_directory> contents to **<target_directory>**, but only if **<source_directory>** files are newer or don't yet exist in **<target_directory>**
    - Remote path syntax (**<user>@<host>:<absolute_or_home-relative_path>**) can be used for either source or target (but not both).
    - ***Always*** include a trailing slash (**/**) after the source and target directory names!
    - **-a** means "archive" mode (equivalent to **-ptl** and some other options)
    - **-r** means **r**ecursively copy sub-directories
    - **-v** means **v**erbose
    - **-W** means **W**hole file only
        - Normally the **rsync** algorithm compares the contents of files that need to be copied and only transfers the different portions. This option disables file content comparisons, which are not appropriate for large and/or binary files.
    - **-p** means preserve file **p**ermissions
    - **-t** means preserve file **t**imes
    - **-l** means copy symbolic links as **l**inks (vs **-L** which means ***dereference*** the link and copy the file it refers to)
    - **-P** means show transfer **P**rogress (useful when large files are being transferred)

Miscellaneous commands

- **echo <text>** prints the specified text on ***standard output***
    - evaluation of ***metacharacters*** (***special characters***) inside the text may be performed first
    - **-e** says to enable conversion of ***backslash escapes*** such as **\t Tab** and **\n newline** to their ASCII character
    - **-n** says not to output the trailing **newline**
- **wc -l** reports the number of **l**ines (**-l**) in its input
    - **wc -c** reports the number of **c**haracters (**-c**) in its input
    - **wc -w** reports the number of **w**ords (**-w**) in its input
- **history** lists your command history to the terminal
    - redirect to a file to save a history of the commands executed in a shell session
    - pipe to **grep** to search for a particular command
- **which <pgm>** searches all **$PATH** directories to find the program/command **<pgm>** and reports its full pathname
- **du <file_or_directory><file_or_directory>..**
    - shows the **d**isk **u**sage (size) of the specified files/directories
    - **-h** says report the size in **h**uman-readable form (e.g. 12M instead of 12201749)
    - **-s** says **s**ummarize the directory size for directories
    - **-c** says print a grand total when multiple items are specified
- **seq N** generates a set of **N** numbers, 1 through N
- **groups** - lists the ***Unix groups*** you belong to

Advanced commands

cut, sort, uniq

- **cut** command lets you isolate ***ranges*** of data from its input lines
    - **cut -f <field_number(s)>** extracts one or more **f**ields (**-f**) from each line of its input
        - use **-d <delim>** to change the field **d**elimiter (**Tab** by default)
    - **cut -c <character_number(s)>** extracts one or more **c**haracters (**-c**) from each line of input
    - the **<numbers>** can be
        - a comma-separated list of numbers (e.g. **1,4,7**)
        - a **hyphen*-separated*** range (e.g. **2-5**)
        - a ***trailing*** **hyphen** says "and all items after that" (e.g. **3,7-**)
    - **cut *does not re-order fields***, so **cut -f 5,3,1** acts like **-f 1,3,5**
- **sort** sorts its input lines using an efficient algorithm
    - by default sorts each line ***lexically*** (as strings), low to high
        - use **-n** sort **n**umerically (**-n**)
        - use **-V** for **V**ersion sort (numbers with surrounding text)
        - use **-r** to **r**everse the sort order
    - use one or more **-k <start_field_number>,<end_field_number>** options to specify a range of "**k**eys" (fields) to sort on
        - e.g. **-k1,1 -k2,2nr** to sort field **1** lexically and field **2** as a number high-to-low
        - by default, fields are delimited by **whitespace** -- one or more **spaces** or **Tabs**
            - use **-t <delim>** to change the field delimiter (e.g. **-t "\t"** for **Tab** only; ignore spaces)

- **uniq -c** counts groupings of its input (which must be sorted) and reports the text and count for each group
  - use **cut | sort | uniq -c** for a quick-and-dirty histogram

awk

awk is a powerful scripting language that is easily invoked from the command line. Its field-oriented capabilities make it the go-to tool for manipulating table-like delimited lines of text.

- **awk '<script>'** - the **'<script>'** is applied to each ***line*** of input (generally piped in)
- ***always*** enclose **'<script>'** in **single quotes** to inhibit shell evaluation, because **awk** has its own set of ***metacharacters*** that are different from the shell's

Example that prints the average of its input numbers (**echo -e** converts ***backslash escape characters*** like **newline \n** to the ASCII **newline** character so that the numbers appear on separate lines)

```
echo -e "1\n2\n3\n4\n5" | awk '
BEGIN{sum=0; ct=0}
{ sum = sum + $1
  ct = ct + 1 }
END{print sum/ct}'
```

General structure of an **awk** script:

- **BEGIN {<expressions>}** – use to initialize variables before any script body lines are executed
  - e.g. **BEGIN {FS=":"; OFS="\t"; sum=0; ct=0}**
    - says use **colon (:)** as the ***input field separator*** (**FS**), and **Tab (\t)** as the ***output field separator*** (**OFS**)
      - the default ***input field separator*** (**FS**) is **whitespace**
        - one or more **spaces** or **Tabs**
      - the default ***output field separator*** **(OFS)** is a **single space**
    - initializes the variables **sum** and **ct** to **0**
- **{<body expressions>}** – expressions to apply to each line of input
  - use **$1**, **$2**, etc. to pick out specific input fields of each line
    - e.g. **{sum = sum + $4}** adds field 4 of the input to the variable **sum**
  - the built-in variable **NF** is the number of fields in the current line
  - the built-in variable **NR** is the record (line) number of the current line
- **END {<expressions>}** – executed after all input is complete
  - e.g. **END {print sum,ct}** prints the final value of the **sum** and **ct** variables, separated by the ***output field separator***.

Here is an excellent awk tutorial, very detailed and in-depth

cut versus awk

The basic functions of **cut** and **awk** are similar – both are field oriented. Here are the main differences:

- Default field separators
  - **Tab** is the default field separator for **cut**
  - **whitespace** (one or more **spaces** or **Tabs**) is the default field separator for **awk**
- Re-ordering
  - **cut** cannot re-order fields
  - **awk** can re-order fields, based on the order you specify
- **awk** is a full-featured programming language while **cut** is just a single-purpose utility.

grep and regular expressions

- **grep -P '<pattern>'** searches for **<pattern>** in its input, and only outputs ***lines*** containing it
  - ***always*** enclose **'<pattern>'** in single quotes to inhibit shell evaluation!
    - pattern-matching ***metacharacters*** in **grep** are very different from those in the shell
  - **-P** says to use **Perl** patterns, which are much more powerful (and standard) than default **grep** patterns
  - **-v** (in**v**erse match) – only print lines with ***no match***
  - **-n** (line **n**umber) – prefix output with the line number of the match
  - **-i** (case **i**nsensitive) – ignore case when matching
  - **-l** says return only the ***names of files*** that ***do contain*** the pattern match
  - **-L** says return only the ***names of files*** that ***do not contain*** the pattern match
  - **-c** says just return a **c**ount of line matches
  - **-A <n>** (**A**fter) and **-B <n>** (**B**efore) – output **<n>** number of lines after or before a match

A ***regular expression*** (***regex***) is a ***pattern*** of ***literal characters*** to search for and ***metacharacters*** that control and modify how matching is done.

A ***regex*** **<pattern>** can contain special ***match metacharacters*** and ***modifiers***. The ones below are **Perl** ***metacharacters***, which are the "gold standard", supported by most languages (e.g. **grep -P**)

- **^** – matches ***beginning*** of line
- **$** – matches ***end*** of line
- **.** – (period) matches any ***single*** character

- ***** – modifier; place after an expression to match ***0 or more*** occurrences
- **+** – modifier, place after an expression to match ***1 or more*** occurrences
- **?** – modifier, place after an expression to match ***0 or 1*** occurrences
- **\s** – matches any **whitespace** character (**\S** any ***non*-whitespace**)
- **\d** – matches **d**igits **0-9**
- **\w** – matches any **w**ord character: **A-Z**, **a-z**, **0-9** and **_** (**underscore**)
- **\t** matches **Tab**;
- **\n** matches **linefeed**; **\r** matches **carriage return**
- **[xyz123]** – matches any ***single character*** (including special characters) among those listed between the brackets **[ ]**
  - this is called a ***character class***.
  - use **[^xyz123]** to match any single character ***not*** listed in the class
- **(Xyz|Abc)** – matches either **Xyz** or **Abc** or any text or expressions inside parentheses separated by **|** characters
  - note that parentheses **( )** may also be used to ***capture matched sub-expressions*** for later use

Regular expression modules are available in nearly every programming language (**Perl**, **Python**, **Java**, **PHP**, **awk**, even **R**)

- each "flavor" is slightly different
- even **bash** has multiple regex commands: **grep**, **egrep**, **fgrep**.

There are many good online regular expression tutorials, but be sure to pick one tailored to the language you will use.

- here are some good ones:
  - a good general one: https://www.regular-expressions.info/
  - Ryan's tutorials on Regular Expressions: http://ryanstutorials.net/regular-expressions-tutorial/
  - RegexOne: http://regexone.com
- and a **perl** regex tutorial: http://perldoc.perl.org/perlretut.html
  - **perl** regular expressions are the "gold standard" used in most other languages

perl pattern matching

If **grep** pattern matching isn't behaving the way I expect, I turn to **perl**. While Perl, like awk, is a fully functional programming language, Here's how to invoke regex pattern matching from a command line using **perl**:

perl -n -e 'print $_ if $_=~/<pattern>/'

sed pattern substitution

The **sed** (**s**tring **ed**itor) command can be used to ***edit text*** using ***pattern substitution***.

sed 's/<search pattern>/<replacement>/'

While **sed** is very powerful, the ***regex*** syntax for its more advanced features is quite different from "standard" **grep** or **perl** regular expressions. As a result, I tend to use it only for ***very simple substitutions***, usually as a component of a multi-pipe expression.

perl pattern substitution

If I have a more complicated pattern, or if **sed** pattern substitution is not working as I expect (which happens frequently!), I again turn to **perl**. Here's how to invoke **perl** pattern substitution from a command line:

perl -p -e '~s/<search pattern>/<replacement>/'

Parentheses ( ) around one or more text sections in the **<search pattern>** will cause matching text to be ***captured*** in built-in **perl** variables **$1**, **$2**, etc., following the order of the parenthesized text. The ***capture variables*** can then be used in the **<replacement>**.

Field delimiter summary

Be aware of the ***default field delimiter for*** the various **bash** utilities, and how to change them:

utility	default delimiter	how to change	example
cut	**Tab**	**-d** or **--delimiter** option	`cut -d ':' -f 1 /etc/passwd`
sort	**whitespace** (one or more **spaces** or **Tabs**)	**-t** or **--field-separator** option	`sort -t ':' -k1,1 /etc/passwd`
awk	**whitespace** (one or more **spaces** or **Tabs**) Note: some older versions of **awk** do not treat **Tab** **s** as field separators.	• In the BEGIN { } block ◦ **FS=** (***input field separator***) ◦ **OFS=** (***output field separator***) • **-F** or **--field-separator** option	`cat /etc/fstab | grep -v '^#' | awk 'BEGIN{OFS="\t"} {print $2,$1}'` `cat /etc/passwd | awk -F ":" '{print $1}'`

join	one or more **spaces**	**-t** option	`join -t $'\t' -j 2 file1 file12`
perl	**whitespace** (one or more **spaces** or **Tabs**) when auto-splitting input with **-a**	**-F'/<pattern>/'** option	`cat /etc/fstab | grep -v '^#' | perl -F'/\s+/' -a -n -e 'print "$F[1]\t$F[0]\n";'`
read	**whitespace** (one or more **spaces** or **Tabs**)	**IFS=** (***input field separator***) option	Note that a bare **IFS=** ***removes any field separator***, so whole lines are read each loop iteration.

Getting around in the shell

Type as little and as accurately as possible by using keyboard shortcuts!

Command line history and editing

Sometimes you want to repeat a command you've entered before, possibly with some changes.

- The built-in **history** command lists the commands you've entered, each with a number.
  - You can re-execute any command in the history by typing an **exclamation point** (**!**) then the number
  - e.g. **!15** re-executes the 15th command in your history.

- Use **Up arrow** to retrieve any of the last 50+ commands you've typed, going backwards through your history.
  - You can then edit the retrieved line, and hit **Enter** (even in the middle of the command), and the shell will use that command.
- The **Down arrow** "scrolls" forward from where you are in the command history.

The command line ***cursor*** (small thick bar on the command line) marks where you are on the command line.

- **Right arrow** and **Left arrow** move the cursor forward or backward on the current command line.
- Use **Ctrl-a** (holding down the **Con**t**r**o**l** key and **a**) to jump the cursor to the ***beginning*** of the line.
- Use **Ctrl-e** to jump the cursor to the ***end*** of the line.
- Arrow keys are also modified by **Ctrl-** (Windows) or **Option-** (Mac)
  - **Ctrl-right-arrow** (Windows) or **Option-right-arrow** (Mac) will skip by "word" forward
  - **Ctrl-left-arrow** (Windows) or **Option-left-arrow** (Mac) will skip by "word" backward

Once the ***cursor*** is positioned where you want it:

- Just type in any additional text you want
- To delete text ***after*** the cursor, use:
  - **Delete** key on Windows
  - **Function-Delete** keys on Macintosh
- To delete text ***before*** the cursor, use:
  - **Backspace** key on Windows
  - **Delete** key on Macintosh
- Use **Ctrl-k** (**k**ill) to delete everything on the line ***after*** the cursor
- Use **Ctrl-y** (**y**ank) to copy the last killed text to where the cursor is

Tab key completion

Hitting **Tab** when entering command line text invokes ***shell completion***, instructing the shell to try to ***guess*** what you're doing and finish the typing for you. It's almost magic!

On most modern Linux shells you use **Tab** completion by pressing:

- ***single*** **Tab** – completes file or directory name up to any ambiguous part
  - if nothing shows up, there is no unambiguous match
- **Tab** ***twice*** – display all possible completions
  - you then decide where to go next
- shell completion works for commands too (like **python**)

Absolute and relative pathname syntax

An ***absolute pathname*** lists all components of the full ***file system hierarchy*** that describes a file. ***Absolute paths*** always start with the **forward slash** (**/**), which is the ***root*** of the file system hierarchy. Directory names are separated by the **forward slash** (**/**) .

You can also specify a directory ***relative*** to where you are using one of the ***special directory names***:

1. **single period** (.) means "***the current directory***"
2. **two periods** (**. .**) means "***directory above the current***"
3. **tilde** (**~**) means "***my Home directory***"

Avoid special characters in filenames

While it is possible to create file and directory names that have embedded spaces, that creates problems when manipulating them.

To avoid headaches, it is best not to create file/directory names with embedded spaces, or with special characters such as **+ & # ( )**

Pathname wildcards

The shell has shorthand to refer to groups of files by allowing ***wildcards*** in file names.

Using these ***wildcards*** is sometimes called ***filename globbing***, and the pattern a ***glob***.

- **asterisk** (*****) is the most common filename wildcard. It matches ***any length of any characters***
- **brackets** (**[ ]**) match ***any character between the brackets***
    - and you can use a **hyphen** (**-**) to specify a range of characters (e.g. **[A-G]**)
- **braces** (**{ }**) enclose a list of comma-separated strings to match (e.g. **{dog,pony}**)

For example:

- **ls *.bam** – lists all files in the current directory that end in **.bam**
- **ls [A-Z]*.bam** – does the same, but only if the first character of the file is a capital letter
- **ls [ABcd]*.bam** – lists all **.bam** files whose 1st letter is **A**, **B**, **c** or **d**.
- **ls *.{fastq,fq}.gz** – lists all **.fastq.gz** and **.fq.gz** files.

More Linux concepts

Standard streams and redirection

Most Linux commands write their results to ***standard output***, a built-in stream that is mapped to your **Terminal**, but that data can be ***redirected*** to a file instead.

In fact every Linux command and program has three ***standard Unix streams***: ***standard input***, ***standard output*** and ***standard error***. Each has a number, a name, and ***redirection*** syntax:

- ***standard output*** is stream **1**
    - redirect ***standard output*** to a file with a the **>** or **1>** redirection operator
        - a single **>** or **1>** ***overwrites*** any existing data in the target file
        - a double **>>** or **1>>** ***appends*** to any existing data in the target file
- ***standard error*** is stream **2**
    - redirect ***standard error*** to a file with a the **2>** redirection operator
        - a single **2>** ***overwrites*** any existing data in the target file
        - a double **2>>** ***appends*** to any existing data in the target file

It is easy to not notice the difference between ***standard output*** and ***standard error*** when you're in an interactive **Terminal** session – because both outputs are sent to the **Terminal** window. But they are separate streams, with different meanings. In particular, programs write error and/or diagnostic messages to ***standard error***, not to ***standard output***.

Here's a command that shows the difference between ***standard error*** and ***standard output***:

```
ls /etc/fstab xxx.txt
```

Produces this output in your **Terminal**:

```
ls: cannot access 'xxx.txt': No such file or directory
/etc/fstab
```

What is not obvious, since both streams are displayed on the **Terminal**, is that:

- the diagnostic text "**ls: cannot access 'xxx.txt': No such file or directory**" is being written to ***standard error***
- the listing of the existing file ("**/etc/passwd**") is being written to ***standard output***

To see this, redirect ***standard output*** and ***standard error*** to different files and look at their contents:

```
ls /etc/fstab xxx.txt 1> stdout.txt 2>stderr.txt
cat stdout.txt   # Displays "/etc/fstab"
cat stderr.txt   # Displays "ls: cannot access 'xxx.txt': No such file or directory"
```

What if you want both ***standard output*** and ***standard error*** to go to the same file? You use this somewhat odd **2>&1** redirection syntax:

```
# Redirect both standard output and standard error to the out.txt file
ls /etc/fstab xxx.txt > out.txt 2>&1

# Display the contents of the out.txt file
cat out.txt

# produces output like this:
ls: cannot access 'xxx.txt': No such file or directory
/etc/fstab
```

Two final notes.

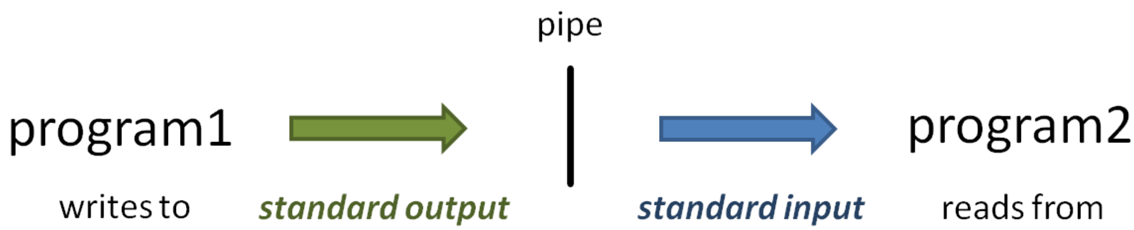
- When ***standard output*** is redirected to a file, the data is ***not*** displayed on the **Terminal**
  - If you want the data written to both ***standard output*** (the **Terminal**) and a file, use the **tee** command
  - e.g. **ls -l ~ | tee home_dir_listing.log**
- There is a special Linux file called **/dev/null** that serves as a "***global trash can***" – it just throws away anything you write to it.
  - So you can direct ***standard output*** and/or ***standard error*** to **/dev/null** to ignore it completely.

When running batch programs and scripts you will want to manipulate ***standard output*** and ***standard error*** from programs appropriately – especially for 3rd party programs that often produce both results data and diagnostic/progress messages.

Piping

Most programs/commands ***read input*** data from some ***source***, then ***write output*** to some ***destination***. A data ***source*** can be a file, but can also be ***standard input***. Similarly, a data ***destination*** can be a file but can also be a ***stream*** such as ***standard output***.

The power of the Linux command line is due in no small part to the power of ***piping***. The ***pipe operator*** (**|**) connects one program's ***standard output*** to the next program's ***standard input***.



A simple example is piping uncompressed data "on the fly" to count its lines using **wc -l** (**w**ord **c**ount command with the **l**ines option).

Pipe uncompressed output to a pager

```
# zcat is like cat, except that it understands the gz compressed format,
# and uncompresses the data before writing it to standard output.
# So, like cat, you need to be sure to pipe the output to a pager if
# the file is large.
zcat big.fq.gz | wc -l
```

piping a histogram

But the real power of piping comes when you stitch together a string of commands with pipes – it's incredibly flexible, and fun once you get the hang of it.

For example, here's a simple way to make a histogram of mapping quality values from a subset of **BAM** file records.

The power of chaining pipes

```
# create a histogram of mapping quality scores for the 1st 1000 mapped bam records
samtools view -F 0x4 small.bam | head -1000 | cut -f 5 | sort -n | uniq -c
```

- **samtools view** converts the binary **small.bam** file to text and writes alignment record lines one at a time to ***standard output***.
  - **-F 0x4** option says to filter out any records where the **0x4** flag bit is **0** (not set)
  - since the **0x4** flag bit is set (1) for ***unmapped*** records, this says to only report records where the query sequence did map to the reference
- **| head -1000**
  - the pipe connects the ***standard output*** of **samtools view** to the ***standard input*** of **head**
  - the **-1000** option says to only write the first 1000 lines of input to ***standard output***
- **| cut -f 5**
  - the pipe connects the ***standard output*** of **head** to the ***standard input*** of **cut**
  - the **-f 5** option says to only write the 5th field of each input line to ***standard output*** (input fields are tab-delimited by default)
    - the 5th field of an alignment record is an integer representing the alignment mapping quality
    - the resulting output will have one integer per line (and 1000 lines)
- **| sort -n**
  - the pipe connects the ***standard output*** of **cut** to the ***standard input*** of **sort**
  - the **-n** option says to sort input lines according to ***numeric*** sort order
  - the resulting output will be 1000 numeric values, one per line, sorted from lowest to highest
- **| uniq -c**
  - the pipe connects the ***standard output*** of **sort** to the ***standard input*** of **uniq**
  - the **-c** option option says to just ***count*** groups of lines with the same value (that's why they must be sorted) and report the total for each group
  - the resulting output will be one line for each group that **uniq** sees
  - each line will have the text for the group (here the unique mapping quality values) and a count of lines in each group

Environment variables

Environment variables are just like variables in a programming language (in fact **bash** ***is*** a complete programming language), they are "pointers" that reference data assigned to them. In **bash**, you assign an environment variable as shown below:

Set an environment variable

```
export varname="Some value, here it's a string"
```

Careful – ***do not put spaces around the equals sign*** when assigning environment variable values.

Also, always surround the value with **double quotes** (**" "**) if it contains (or might contain) **spaces**.

You ***set*** environment variables using the bare name (**varname** above).

You then ***refer to*** or ***evaluate*** an ***environment variable*** using a **dollar sign** (**$**) ***evaluation operator*** before the name:

Refer to an environment variable

```
echo $varname
```

The **export** keyword when you're setting ensures that any sub-processes that are invoked will inherit this value. Without the **export** only the current shell process will have that variable set.

Use the **env** command to see all the environment variables you currently have set.

Quoting in the shell

What different quote marks mean in the shell and when to use can be quite confusing.

When the shell processes a command line, it first ***parses*** the text into ***tokens*** ("***words***"), which are groups of characters separated by **whitespace** (one or more **space** characters). ***Quoting*** affects how this parsing happens, including how ***metacharacters*** are treated and ***how text is grouped***.

There are three types of quoting in the shell:

1. ***single quoting*** (e.g. **'some text'**) – this serves two purposes
   - It ***groups*** together all text inside the quotes into a ***single token***
   - It tells the shell not to "look inside" the quotes to perform ***any*** evaluations
     - ***all metacharacters*** inside the single quotes are ***ignored***
     - in particular, any ***environment variables*** in single-quoted text are ***not evaluated***
2. ***double quoting*** (e.g. **"some text"**) – also serves two purposes
   - it ***groups*** together all text inside the quotes into a ***single token***
   - it allows ***environment variable*** evaluation, but inhibits some ***metacharcters***
     - e.g. asterisk (*****) ***pathname globbing*** and some other ***metacharacters***
   - ***double quoting*** also ***preserves any special characters*** in the text
     - e.g. **newlines** (**\n**) or **Tabs** (**\t**)
3. ***backtick quoting*** (e.g. **`date`**)
   - ***evaluates*** the expression inside the ***backtick*** marks (**` `**)
   - the ***standard output*** of the expression replaces the text inside the ***backtick*** marks (**` `**)
   - the syntax **$(date)** is equivalent

The quote characters themselves (**' " `**) are ***metacharacters*** that tell the shell to "***start a quoting process***" then "***end a quoting process***" when the matching quote is found. Since they are part of the processing, the ***enclosing quotes are not included in the output***.

If you see the **greater than** (**>**) character after pressing **Enter**, it can mean that your ***quotes are not paired***, and the shell is waiting for more input to contain the missing quote of the pair (either single or double). Just use **Ctrl-c** to get back to the prompt.

single and double quotes

The ***first rule of quoting*** is: ***always enclose a command argument in quotes if it contains spaces*** so that the command sees the quoted text as ***one item***. In particular, always use **single** (**'**) or **double** (**"**) **quotes** when you define an ***environment variable*** whose value contains **spaces**.

```
foo='Hello world'   # correct - defines variable "foo" to have value "Hello world"
foo=Hello world     # error - no command called "world"
```

These two expressions using **double quotes** or **single quotes** are different because the **single quotes** tell the shell to treat the quoted text as a literal, and not to look inside it for ***metacharacter*** processing.

```
# Inside double quotes, the text "$USER" is evaluated and its value substituted
echo "my account name is $USER"

# Inside single quotes, the text "$USER" is left as-is
echo 'the environment variable storing my account name is $USER'
```

To display a ***metacharacter*** as a literal inside double quotes, use the **backslash** (****) character to ***escape*** the following character.

```
# Inside double quotes, use a backslash ( \ ) to escape the dollar sign ( $ ) metacharacter
echo "the environment variable storing my account name is \$USER"
```

backtick quoting and sub-shell evaluation

backtick (**` `**) ***evaluation quoting*** is one of the underappreciated wonders of Unix. The shell:

- ***evaluates*** the expression/command inside the **backtick** marks (**` `**)
- the ***standard output*** of the expression replaces the text inside the **backticks**

An example, using the **date** function that just writes the current date and time to ***standard output***, which appears on your **Terminal**.

```
date          # Calling the date command just displays date/time information
echo date     # Here "date" is treated as a literal word, and written to standard output
echo `date`   # The date command is evaluated and its standard output replaces `date`
```

A slightly different syntax, called ***sub-shell evaluation***, also evaluates the expression inside **$( )** and replaces it with the expression's ***standard output***.

```
today=$( date );           echo $today  # environment variable "today" is assigned today's date
today="Today is: `date`"; echo $today  # "today" is assigned a string including today's date
```

What is text?

So what exactly ***is*** text? That is, what is stored in files that the shell interprets as text?

On standard Unix systems, each text character is stored as ***one byte*** – ***eight binary bits*** – in a format called ***ASCII*** (**A**merican **S**tandard **C**ode for **I**nformation **I**nterchange). Eight bits can store $2^{\wedge 8}$ = 256 values, numbered 0 - 255.

In its original form values 0 - 127 were used for standard ASCII characters. Now values 128 - 255 comprise an Extended set. See https://www.asciitable.com/

However ***not all ASCII "characters" are printable*** -- in fact the "printable" characters start at **ASCII** 32 (**space**).

ASCII values 0 - 31 have special meanings. Many were designed for use in early modem protocols, such as EOT (end of transmission) and ACK (acknowledge), or for printers, such as VT (vertical tab) and FF (form feed).

The ***non-printable ASCII characters*** we care most about are:

- **Tab** (decimal 9, hexadecimal **0x9**, octal 0o011)
  - backslash escape: **\t**
- **Linefeed/Newline** (decimal 10, hexadecimal **0xA**, octal 0o012)
  - backslash escape: **\n**
- **Carriage Return** (decimal 13, hexadecimal **0xD**, octal 0o015)
  - backslash escape: **\r**

Let's use the **hexdump** command (really an ***alias***, defined in your **~/.bashrc** login script) to look at the actual **ASCII** codes stored in a file:

```
tail ~/.bashrc | hexdump
```

This will produce output something like this:

```
000000 23 61 6c 69 61 73 20 6c 73 3d 22 6c 73 20 2d 2d  >#alias ls="ls --<
000010 63 6f 6c 6f 72 3d 61 6c 77 61 79 73 22 0a 61 6c  >color=always".al<
000020 69 61 73 20 6c 6c 3d 22 6c 73 20 2d 6c 61 22 0a  >ias ll="ls -la".<
000030 61 6c 69 61 73 20 6c 61 68 3d 22 6c 73 20 2d 6c  >alias lah="ls -l<
000040 61 68 22 0a 61 6c 69 61 73 20 6c 63 3d 22 77 63  >ah".alias lc="wc<
000050 20 2d 6c 22 0a 61 6c 69 61 73 20 68 65 78 64 75  > -l".alias hexdu<
000060 6d 70 3d 27 6f 64 20 2d 41 20 78 20 2d 74 20 78  >mp='od -A x -t x<
000070 31 7a 20 2d 76 27 0a 75 6d 61 73 6b 20 30 30 32  >1z -v'.umask 002<
000080 0a 23 23 23 23 23 23 23 23 23 23 0a 23 20 4f 70  >.##########.# Op<
000090 74 69 6f 6e 61 6c 20 53 74 61 72 74 75 70 20 53  >tional Startup S<
0000a0 63 72 69 70 74 20 74 72 61 63 6b 69 6e 67 0a 69  >cript tracking.i<
0000b0 66 20 5b 20 2d 6e 20 22 24 53 48 45 4c 4c 5f 53  >f [ -n "$SHELL_S<
0000c0 54 41 52 54 55 50 5f 44 45 42 55 47 22 20 5d 3b  >TARTUP_DEBUG" ];<
0000d0 20 74 68 65 6e 20 44 42 47 5f 45 43 48 4f 20 22  > then DBG_ECHO "<
0000e0 24 7b 44 42 47 5f 49 4e 44 45 4e 54 7d 7d 22 3b  >${DBG_INDENT}}";<
0000f0 20 66 69 0a 0a                                   > fi..<
```

Each line here describes 16 characters, in three display areas:

- The numeric offset of the 16-character line, in hexadecimal (base 16)
  - 16 decimal is 0x10 hex
- The numeric value (**ASCII** code) for each character, again in hexadecimal
  - each 2-digit hex number represents one 8-bit byte/character
- The translated text, written between a **greater than** (**>**) and **less than** (**<**) sign
  - The display character associated with each **ASCII** code, or a **period** (**.**) for non-printable characters

Notice that ***spaces*** are **ASCII 0x20** (decimal 32), and the **newline** characters appear as **0x0a** (decimal 10).

Why hexadecimal? Programmers like hexadecimal (base 16) because it is easy to translate hex digits to binary, which is how everything is represented in computers. And it can sometimes be important to know which binary bits are 1s and which are 0s. (Read more about **Decimal and Hexadecimal**)

Writing multiple text lines

There are several ways to output ***multi-line text***. You can:

- Start the text with a **single quote** or a **double quote**
  - press **Enter** when you want to start a new line
  - keep entering text and **Enter** until you're satisfied
  - supply the matching **single quote** or a **double quote** then **Enter**

- example:

```
echo 'My
name is
Anna'
```

- Use **echo -e**
  - The **-e** option tells **echo** to replace some special ***backslash escapes*** characters that represent non-printable characters with their associated ASCII codes
    - So **\n** will be replaced by a **newline** (**linefeed**) character and **\t** will be replaced by a **Tab**.
  - example:

```
echo -e "My\nname is\nAnna"
```

heredoc

Another method for writing multi-line text that can be useful for composing a large block of text in a script, is the ***heredoc*** syntax, where a block of text is specified between two user-supplied ***block delimiters***, and that text block is sent to a command. The general form of a ***heredoc*** is:

```
COMMAND << DELIMITER
..text...
..text...
DELIMITER
```

The 2nd (ending) ***block delimiter*** you specify for a ***heredoc*** must appear at the ***start*** of a new line.

For example, using the (arbitrary) delimiter **EOF** and the **cat** command:

```
cat << EOF
This text will be output
And this USER environment variable will be evaluated: $USER
EOF
```

Here the block of text provided to **cat** is just displayed on the **Terminal**. To write it to a file just use the **1>** or **>** redirection syntax in the **cat** command:

```
cat 1> out.txt << EOF
This text will be output
And this USER environment variable will be evaluated: $USER
EOF
```

The **out.txt** file will then contain this text:

```
This text will be output
And this USER environment variable will be evaluated: student01
```

Bash control flow

the bash for loop

As in many programming languages, a ***for loop*** performs a series of expressions on one or more item in the **for**'s ***argument list***.

The **bash for** loop has the general structure:

> **for <variable_name> in <list of space-separated items>**
do <something>
  <somthing else>
done

The **<items>** should be (or evaluate to) **for**'s ***argument list***: a **space*-separated*** list of items (e.g. **1 2 3 4** or **`ls -1 *.gz`**).

for loop example

```
for num in `seq 4`
do
  echo $num
done

# or, since bash lets you put multiple commands on one line
# if they are each separated by a semicolon ( ; )
for num in `seq 4`; do echo $num; done
```

Gory details:

- The **`seq 4`** expression uses ***backtick evaluation*** to generate a set of 4 numbers: **1 2 3 4**.
- The **do**/**done** block expressions are executed once for each of the items in the list
- Each time through the loop (the **do**/**done** block) the variable named **num** is assigned one of the values in the list
  - Then the value can be used by referencing the variable using **$num**
  - The variable name **num** is arbitrary – it can be any name we choose

processing multiple files in a for loop

One common use of **for** loops is to process multiple files, where the set of files to process is obtained by pathname ***wildcarding***. For example, the code below counts the number of reads in a set of compressed **FASTQ** files:

For loop to count sequences in multiple FASTQs

```
for fname in *.gz; do
   echo "$fname has $((`zcat $fname | wc -l` / 4)) sequences"
done
```

quotes matter

We saw how ***double quotes*** allow the shell to evaluate certain ***metacharacters*** in the quoted text.

But more importantly when ***assigning multiple lines of text*** to a variable, quoting the evaluated variable ***preserves any special characters in the variable value's text*** such as **Tab** or **newline** characters.

Consider this case where a captured string contains **newlines**, as illustrated below.

```
txt=$( echo -e "aa\nbb\ncc" )
echo "$txt"   # inside double quotes, newlines preserved
echo $txt     # without double quotes, newlines are converted to spaces
```

This difference is very important!

- you ***do want to preserve newlines*** when ***processing one line of text at a time***
- you ***do not want to preserve newlines*** when ***specifying the list of values*** a **for** loop processes (which must all be on one line)

See the difference:

```
nums=$( seq 5 )
echo $nums
echo "$nums"

echo $nums| wc -l     # newlines converted to spaces, so only one line
echo "$nums" | wc -l  # newlines preserved, so reports 5

# This loop prints a line for each of the files
for n in $nums; do
  echo "the number is: '$n'"
done

# But this loop prints only one line
for n in "$nums"; do
  echo "the number is: '$n'"
done
```

the if statement

The general form of an **if**/**then**/**else** statement in **bash** is:

> **if [<test expression>]**
> **then <expression> [expression...]**
> **else <expression> [expression...]**
> **fi**

Where

- The **<test expression>** is any expression that evaluates to **true** or **false**
  - In the shell, the number 0 (or an empty value) is **false**
  - Anything else is **true**
  - There must be ***at least one space*** around the **<test expression>** separating it from the enclosing bracket **[ ]**.
  - Double brackets **[[ ]]** can also be used to enclose the **<test expression>**
- When the **<test expression>** is **true** the **then** expressions are evaluated.
- When the **<test expression>** is **false** the **else** expressions are evaluated.

A simple example:

```
for val in 5 0 "27" "$emptyvar" abc '0'; do
  if [ "$val" ]
    then echo "Value '$val' is true"
    else echo "Value '$val' is false"
  fi
done
```

A good reference on the many built-in **bash** conditionals: https://www.gnu.org/software/bash/manual/html_node/Bash-Conditional-Expressions.html

reading file lines with while

The **read** function can be used to read input one line at a time, in a **bash while** loop.

While the full details of the **read** commad are complicated (see https://unix.stackexchange.com/questions/209123/understanding-ifs-read-r-line) this read-a-line-at-a-time idiom works nicely.

```
while IFS= read line; do
  echo "Line: '$line'"
done < ~/.bashrc
```

- The **IFS=** clears all of **read**'s default input field separators, which is normally **whitespace** (one or more **spaces** or **Tabs**).
  - This is needed so that **read** will set the **line** variable to ***exactly*** the contents of the input line, and not strip leading **whitespace** from it.
- The lines are redirected from **~/.bashrc** to the ***standard input*** of the **while** loop by the **< ~/.bashrc** expression after the **done** keyword.

If the input data is well structured, its fields can be read directly into variables. Notice we can pipe all the output to **more** – or could redirect it to a file.

```
tail /etc/passwd | while IFS=':' read account x uid gid name shell
do
  echo $account $name
done | more
```

File attributes

Consider a long listing of our ***Home directory***.

```
-rw-r----- 1 abattenh G-801021 11563 Jun  5 12:05 .bash_history
-rw------- 1 abattenh G-801021  2016 Jun  5 10:40 .bashrc
drwx------ 3 abattenh G-801021    27 Jun  6 21:03 .config
-rwx------ 1 abattenh G-801021  2636 Nov 19  2021 .cshrc
-rwx------ 1 abattenh G-801021   381 Nov 19  2021 .login
-rwx------ 1 abattenh G-801021   717 Nov 19  2021 .profile
lrwxrwxrwx 1 abattenh G-801021    56 Jun  5 10:56 CoreNGS -> /work/projects/BioITeam/projects/courses/Core_NGS_Tools/
drwxr-x--- 3 abattenh G-801021    25 Jun  5 11:00 local
lrwxrwxrwx 1 abattenh G-801021    23 Jun  5 10:54 scratch -> /scratch/01063/abattenh
drwxr-x--- 5 abattenh G-801021    57 Jun  6 21:05 tmp
lrwxrwxrwx 1 abattenh G-801021    24 Jun  5 10:54 work -> /work/01063/abattenh/ls6
```

There are 9 **whitespace**-separated columns in this long listing:

1. ***file permissions*** - a 10-character field
2. number of ***sub-components*** associated with a directory - rarely important
3. ***account*** name of the file ***owner***
4. Unix ***group*** associated with the file
5. ***file size***
6. ***last modification month***
7. ***last modification day***
8. ***last modification year***, or ***last modification hour/minute*** if within the last year
9. ***file name***

Notice I call everything a ***file***, even directories. That's because ***directories are just a special kind of file*** – one that contains information about the directory's contents.

Owner and Group

A file's ***owner*** is the ***Unix account*** that created the file (here **abattenh**, me). That ***account*** belongs to one or more ***Unix groups***, and the ***group*** associate d with a file is listed in field 4.

The ***owner*** will always be a member of the ***Unix group*** associated with a file, and other accounts may also be members of the same group. **G-801021** is one of the ***Unix groups*** I belong to at TACC. To see the ***Unix groups*** you belong to, just type the **groups** command.

Permissions

File permissions and information about the ***file type*** are encoded in that 1st 10-character field. Permissions govern ***who can access a file***, and what ***acti ons they are allowed***.

- **character 1** describes the ***file type*** (**d** for ***directory***, **-** for ***regular file***, **l** for ***symbolic link***)
- the **remaining 9 characters** are 3 sets of 3-character designations
  - **characters 2-4**: what the ***owning user account*** can do
  - **characters 5-7**: what other members of the associated ***Unix group*** can do
  - **characters 8-19**: what ***other*** non-group members (***everyone***) can do

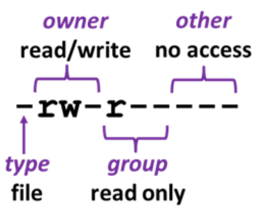
Each of the 3-character sets describes if **read** (**r**) **write** (**w**) and **execute** (**x** or **s**) actions are allowed, or **not allowed** (**-**).

- **read** (**r**) access means file contents can be read, and copied
- **write** (**w**) access means a file's contents can be changed, and directory contents can be modified (files added or deleted)
- **execute** (**x** or **s**)
  - for ***files***, **execute** (**x**) means it is ***a program that can be called/executed***
    - e.g. **/usr/bin/ls**, the file that performs the **ls** command
  - for ***directories***, **execute** (**x**) means ***directory operations*** may be performed/executed
    - the directory can be ***listed*** and ***changed into***

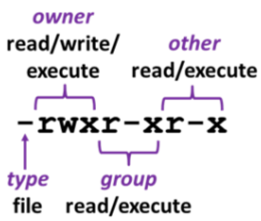
Examples:

ls -l ~/.bash_history

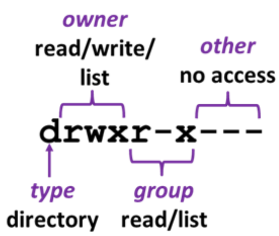
haiku.txt	description

	• **dash** (**-**) in position one signifies this is a ***regular file*** • **rw-** for ***owner*** allows read and write access • **r--** for ***group*** permits only read access • **---** for ***everyone*** means no access allowed

ls -l /usr/bin/ls

/usr/bin/ls	description
	• **/usr/bin/ls** is the ***program*** that performs the **ls** command ◦ **root** (the master admin account) is the owner, in the **root** group • **dash** (**-**) in position one signifies this is a ***regular file*** • **rwx** for ***owner*** allows read, write and execute • **r-x** for ***group*** permits read and execute • **r-x** for ***everyone*** permits read and execute

ls -l -d ~/local (**-d** says to list directory information, not directory contents)

docs	description
	• **d** in position one signifies this is a ***directory*** • **rwx** for ***owner*** allows read, write and "execute" (list for directories) • **r-x** for ***group*** permits read and "execute" (list) • **---** for ***everyone*** means no access allowed

Copying files between TACC and your laptop

Assume you want to copy the TACC file **$SCRATCH/core_ngs/fastq_prep/small_fastqc.html** back to your laptop/local computer. You must ***initiate the copy operation from your local computer*** rather than at TACC. Why? because the TACC servers have host names and IP addresses that are public in the Internet's ***Distributed Name Service*** (***DNS***) directory. But your local computer (in nearly all cases) does not have a published name and address.

First, on the TACC server figure out what the appropriate ***absolute path*** (a.k.a. ***full pathname***) is.

Execute this at TACC

```
cd $SCRATCH/core_ngs/fastq/prep
pwd -P
```

This will display something like **/scratch/01063/abattenh/core_ngs/fastq_prep**

For folks with Mac or Linux laptops or Windows 10+ users with **scp** available in the **Command Prompt** program (or Windows subsystem for Linux):

- Open a **Terminal** window on your local computer
- **cd** to the directory where you want the files
- Type something like the following, substituting your user name and absolute path:

Execute this on your laptop

```
scp abattenh@ls6.tacc.utexas.edu:/scratch/01063/abattenh/core_ngs/fastq_prep/small_fastqc.html .
```

Windows users can use the free WinSCP program (https://winscp.net/eng/index.php) if their Windows version does not support **scp**.

Editing files

There are three main approaches to editing Unix files:

1. Use a command-line program that lets you enter/edit text in a Terminal window (e.g. **nano**, **vi**/**vim**, **emacs**)
    a. **nano** is extremely simple and is a good choice as a first local text editor
        - ***warning***: **nano** has a tendency to break long single lines into multiple lines
    b. **vi** and **emacs** are ***extremely*** powerful but also quite complex
        - **emacs** reference sheet: https://www.gnu.org/software/emacs/refcards/pdf/refcard.pdf
        - **vi** reference sheet: http://www.atmos.albany.edu/daes/atmclasses/atm350/vi_cheat_sheet.pdf
2. Use a text editor or IDE (Integrated Development Environment) program that runs on your local computer but has an SFTP (secure FTP) interface that lets you connect to a remote computer
    - E.g., **Komodo IDE** (Windows & Mac) or **Notepad++** (Windows). Both are no-cost.
    - Once you connect to the remote host, you can navigate its directory structure and edit files.
    - When you open a file, its contents are brought over the network into the text editor's edit window, then saved back when you save the file.
3. Use software or protocols that allow you to "mount" remote server directories
    - Once mounted, the remote storage appears as a local volume/drive.
        - Then, you can use any text editor or IDE on your local computer to open/edit/save remote files.
    - Software programs that can mount remote data include **ExpanDrive** for Windows or Mac (costs $$, but has a free trial), **TextWrangler** for Mac.
    - Remote file system protocols include **Samba** (Windows, Mac) and **NFS** (Linux)

Knowing the basics of at least one Linux command-line text editor is useful for creating/editing small files, and we'll explore **nano** in this class. For editing larger files, you may find options #2 or #3 more useful.

nano

nano is a very simple editor available on most Linux systems. If you are able to **ssh** into a remote system, you can use **nano** there.

To invoke **nano** to edit a new or existing file just type **nano <filename>**. For example:

Start the nano text editor

```
nano newfile.txt
```

You'll see the name of the file (if you supplied one) on the top line of the **Terminal** window.

Navigation and operations in **nano** are similar to those we discussed in Command line editing

You can just type in text, and navigate around using ***arrow keys*** (up/down/left/right). A couple of other navigation shortcuts:

- **Ctrl-a** - go to start of line
- **Ctrl-e** - go to end of line
- Arrow keys are also modified by **Ctrl-** (Windows) or **Option-** (Mac)
    - **Ctrl-right-arrow** (Windows) or **Option-right-arrow** (Mac) will skip by "word" forward
    - **Ctrl-left-arrow** (Windows) or **Option-left-arrow** (Mac) will skip by "word" backward

Once you've positioned the ***cursor*** where you want it, just type in your text.

> Be careful with long lines – sometimes **nano** will split long lines into more than one line, which can cause problems in a commands file where each task must be specified on a single line.

To remove text:

- To delete text ***after*** the cursor, use:
    - **Delete** key on Windows
    - **Function-Delete** keys on Macintosh
- To delete text ***before*** the cursor, use:
    - **Backspace** key on Windows
    - **Delete** key on Macintosh
- Use **Ctrl-k** (**k**ill) to ***delete everything on the line***
    - This is different from **Ctrl-k** on the command line where it deletes everything after the cursor
- Use **Ctrl-u** (**u**ncut) to ***paste*** the just-killed text at the cursor
    - Recall this operation is **Ctrl-y** (**y**ank) for command line editing

Once you're satisfied with your edits:

- use **Ctrl-o** - write **o**ut the file

- use **Ctrl-x** - exit **nano**

These and other important **nano** ***operations*** are displayed in a menu at the bottom of the Terminal window. Note that the **^** character means **Ctrl-** in this menu.

emacs

emacs is a complex, full-featured editor available on most Linux systems.

To invoke **emacs** to edit a new or existing file just type:

Start the emacs text editor

```
emacs <filename>
```

Here's a reference sheet that list many commands: https://www.gnu.org/software/emacs/refcards/pdf/refcard.pdf. The most important are:

- **Ctrl-x/Ctrl-s** - write out the file
- **Ctrl-x/Ctrl-c** - exit **emacs**

You can just type in text, and navigate around using arrow keys. A couple of other navigation shortcuts:

- **Ctrl-a** - go to start of line
- **Ctrl-e** - go to end of line

> Be careful when pasting text into an **emacs** buffer – it takes a few seconds before **emacs** is ready to accept pasted text.
>
> Double-check that the 1st line of pasted test is correct – **emacs** can clip the 1st few characters if the paste is done too soon.

Line ending nightmares

The dirty little secret of the computer world is that the three main "families" of computers – Macs, Windows and Linux/Unix – use different, mutually incompatible line endings.

- Linux/Unix uses **linefeed** (**\n**)
- Windows uses **carriage return** followed by **linefeed** (**\r\n**)
- some Mac programs use **carriage return** only (**\r**)

And guess what? Most Linux programs don't work with files that have Windows or Mac line endings, and what's worse they give you bizarre error messages that don't give you a clue what's going on!

So whatever non-Linux text editor you use, be sure to adjust its "line endings" setting – and it better have one somewhere!

Komodo Edit for Mac and Windows

Komodo Edit is a free, full-featured text editor with syntax coloring for many programming languages and a remote file editing interface. It has versions for both Macintosh and Windows. Download the appropriate install image here.

Once installed, start **Komodo Edit** and follow these steps to configure it:

- Configure the default line separator for Unix
  - On the **Edit** menu select **Preferences**
  - Select the **New Files** Category
  - For **Specify the end-of-line (EOL) indicator for newly created files** select **UNIX (\n)**
  - Select OK
- Configure a connection to TACC
  - On the **Edit** menu select **Preferences**
  - Select the **Servers** Category
  - For **Server type** select **SFTP**
  - Give this profile the **Name** of **lonestar6**
  - For **Hostname** enter **ls6.tacc.utexas.edu**
  - Enter your TACC user ID for **Username**
  - Leave **Port** and **Default path** blank
  - Select OK

When you want to open an existing file at **lonestar6**, do the following:

- Select the **File** menu -> **Open** -> **Remote File**
  - Select your **lonestar6** profile from the top **Server** drop-down menu
  - Once you log in, it should show you all the files and directories in your **lonestar6** **$HOME** directory
- Navigate to the file you want and open it

    - Often you will use your **~/work** or **~/scratch** directory links to help you here

To create and save a new file, do the following:

- From the Komodo Edit **Start Page**, select **New File**
    - Select the file type (**Text** is good for commands files)
- Edit the contents
- Select the **File** menu -> **Save As Other** -> **Remote File**
    - Select your **lonestar6** profile from the **Server** drop-down menu
    - Once you log in, it should show you all the files and directories in your **lonestar6** **$HOME** directory
- Navigate to where you want the put the file and save it
    - Often you will use your **~/work** or **~/scratch** directory links to help you here

Rather than having to navigate around TACC's complex file system tree, it helps to use the symbolic links to those areas that we created in your **Home** directory.

Notepad++ for Windows

Notepad++ is an open source, full-featured text editor for Windows PCs (not Macs). It has syntax coloring for many programming languages (**python**, **perl**, **bash**), and a remote file editing interface.

If you're on a Windows PC download the installer here.

Once it has been installed, start **Notepad++** and follow these steps to configure it:

- Configure the default line separator for Unix
    - In the **Settings** menu, select **Preferences**
    - In the **Preferences** dialog, select the **New Document/Default Directory** tab.
    - Select **Unix** in the **Format** section
    - **Close**
- Configure a connection to TACC
    - In the **Plugins** menu, select **NppFTP**, then select **Focus NppFTP Window**. The top bar of the **NppFTP** panel should become blue.
    - Click the **Settings** icon (looks like a gear), then select **Profile Settings**
    - In the **Profile settings** dialog click **Add new**
    - Call the new profile **lonestar6**
    - Fill in **Hostname** (**ls6.tacc.utexas.edu**) and your TACC user ID
    - **Connection type** must be **SFTP**
    - Close

To open the connection, click the blue **(Dis)connect** icon then select your **lonestar6** connection. It should prompt for your password. Once you've authenticated, a directory tree ending in your **Home** directory will be visible in the **NppFTP** window. You can click the the **(Dis)connect** icon again to Disconnect when you're done.

Rather than having to navigate around TACC's complex file system tree, it helps to use the symbolic links to those areas that we created in your **Home** directory (**~/work** or **~/scratch**).

Other bash resources

- Greg's Bash Guide
    - The Guide: http://mywiki.wooledge.org/BashGuide
    - FAQ: http://mywiki.wooledge.org/BashFAQ
    - Pitfalls: http://mywiki.wooledge.org/BashPitfalls
- Ryan's Tutorials on Bash Scripting: http://ryanstutorials.net/bash-scripting-tutorial/
- CBRS short course workshop wikis (developed by Anna)
    - Introduction to Unix: https://wikis.utexas.edu/display/CbrsIntroUnix
    - Intermediate Unix: https://wikis.utexas.edu/display/CbrsIntermUnix
    - You won't have access to the small compute cluster they use, but you can download the example files and manipulate them in your own Linux or Unix environment.