

Shells

- Shells are command interpreters
 - they allow interactive users to execute the commands.
 - typically a command causes another program to be run
 - shells may have a graphical (point-and-click) interface
 - much easier for naive users
 - much less powerful & not covered in this course
- command-line shells are programmable, powerful tools for expert users
- **bash** is the most popular used shell for unix-like systems
 - other significant unix-like shells include : **dash, ash, zsh, fish**
- we will cover the core features provided by most shells
 - essentially the POSIX standard shell features
- we use **dash** for scripts in this course
 - **dash** implements essentially the POSIX standard shell features
 - **bash & zsh** implement superset of POSIX shell features
 - **ash**, part of **busybox**, implements more-or-less the POSIX standard shell features
 - so scripts written for **dash** usually compatible with with **bash & zsh, ash**

What Shells Do

- Unix shells have the same basic mode of operation:

loop

```
if (interactive) print a prompt
read a line of user input
apply transformations to line
split line into words using whitespace
use first word in line as command name
execute command, passing other words as arguments
```

end loop

- shells can also be run with commands in a file
- shells are programming languages
- shells have design decisions to suit interactive use
 - e.g. variables don't have to be initialized or declared
 - these decisions not ideal for programming in Shell
 - in other words there have to be design compromises

- a series of **transformations** are applied to Shell input lines
 - 1 tilde expansion, e.g. `~z1234567` → `/home/z1234567`
 - 2 parameter and variable expansion, e.g. `$HOME` → `/home/z1234567`
 - 3 arithmetic expansion, e.g. `$((6 * 7))` → `42`
 - 4 command substitution, e.g. `$(whoami)` → `z1234567`
 - 5 word splitting - line is broken up on white-space
 - 6 filename expansion (globbing), e.g. `*.c` → `main.c i.c`
 - 7 I/O redirection e.g. `<i.txt` → stdin replaced with stream from `i.txt`
 - 8 first word used as program name, other words passed as arguments
- order of these transformation is important!
- not understanding order is a common source of bugs & security holes
 - shell is better-avoided if security is significant concern
- directories in **PATH** searched for program name

echo: print arguments to stdout

- **echo** prints its arguments to stdout
- mainly used in scripts, but also useful when exploring shell behaviour
- **echo** is often built in to shells for efficiency, but also provided by `/bin/echo`
- see also `/usr/bin/printf`
- Two useful **echo** options:

-n do not output a trailing newline
-e enable interpretation of backslash escapes (on by default in dash)

```
$ echo Hello Andrew
Hello Andrew
$ echo '\n'
\n
$ echo -e '\n'

$ echo -n Hello Andrew
Hello Andrew$
```

echo: implemented in Python

```
import sys
def main():
    """
    print arguments to stdout
    """
    print(' '.join(sys.argv[1:]))
```

source code for echo.py

```
// print arguments to stdout
int main(int argc, char *argv[]) {
    for (int i = 1; i < argc; i++) {
        if (i > 1) {
            fputc(' ', stdout);
        }
        fputs(argv[i], stdout);
    }
    fputc('\n', stdout);
    return 0;
}
```

source code for echo.c

Shell Variables

- shell variables are untyped - consider them as strings
 - note that **1** is equivalent to “**1**”
- shell variables are not declared
- shell variables do not need initialization
 - initial value is the empty string
- one scope - no local variables
 - except sub-shells & functions (sort-of)
 - changes to variables in sub-shells have no effect outside sub-shell
 - components of pipeline executed in sub-shell
- **\$name** replaced with value of variable **name**
- **name=value** assigns **value** to variable **name**
 - note: no spaces around =

\$(command) - command expansion:

- **\$(command)** is evaluated by running **command**
- stdout is captured from **command**
- **\$(command)** is replaced with the entire captured stdout
- **'command'** (backticks) is equivalent to **\$(command)**
 - backticks is original syntax, so widely used
 - nesting of backticks is problematic

For example:

```
$ now=$(date)
$ echo $now
Sun 23 Jun 1912 02:31:00 GMT
$
```

' ' - Single Quotes

- single quotes ' ' group the characters within into a single word
 - no characters interpreted specially inside single quotes
 - variables, commands and arithmetic are not expanded inside single quotes
 - globbing and word-splitting does not occur inside double quotes
 - a single quote can not occur within single quotes
 - you can put a double quote between single-quotes

For example:

```
$ echo '*** !@#%$^&*(){}[]:;<>?,./` ***'
*** !@#%$^&*(){}[]:;<>?,./` ***
$ echo 'this is "normal"'
this is "normal"
```

"" - Double Quotes

- double quotes "" group the characters within into a single word
 - variables, commands and arithmetic are expanded inside double quotes
 - backslash can be used to escape \$ " ' " \
 - other characters not interpreted specially inside double quotes
 - globbing and word-splitting does not occur inside double quotes
 - you can put a single quote between double-quotes

For example:

```
$ answer=42
$ echo "The answer is $answer."
The answer is 42.
$ echo 'The answer is $answer.'
The answer is $answer.
$ echo "time's up"
time's up
$ echo "*   *"
*   *
```

<< - here documents

- <<**word** called a here document
- following lines until **word** specify multi-line string as command input
- variables and commands expanded - same as double quotes
- <<'**word**' variables and commands not expanded - same as single quotes
- <<-**word** removes leading tabs from each line, allowing indentation within scripts

```
$ name=Andrew
$ tr a-z A-Z <<END-MARKER
Hello $name
How are you
Good bye
END-MARKER
HELLO ANDREW
HOW ARE YOU
GOOD BYE
```

- `$(expression)` is evaluated as an arithmetic expression
 - **expression** is evaluated as C-like integer arithmetic
 - and is replaced with the result
 - the `$` on variables can be omitted in expressions
- shell arithmetic implementation slow compared to e.g. C
 - significant overhead converting to/from strings
- older scripts may use the separate program **expr** for arithmetic

For example:

```
$ x=8
$ answer=$((x*x - 3*x + 2))
$ echo $answer
42
```

- Note that variables in arithmetic expressions are recursively evaluated

word splitting

- coders not understanding how shells split words is a frequent source of bugs

```
# inspect how shell splits lines into program arguments (argv)
import sys
print(f'sys.argv = {sys.argv}')
```

source code for print_argv.py

```
$ v=' '
$ ./print_argv.py $v
sys.argv = ['./print_argv.py']
$ ./print_argv.py "$v"
sys.argv = ['./print_argv.py', ' ']
$ w=' xx   yyy       zzzz   '
$ ./print_argv.py $w
sys.argv = ['./print_argv.py', 'xx', 'yyy', 'zzzz']
$ ./print_argv.py "$w"
sys.argv = ['./print_argv.py', ' xx   yyy       zzzz   ']
```

*?[]! - pathname globbing

- `*?[]!` characters cause a word to be matched against pathnames
 - confusingly similar to regexes - but much less powerful
- `*` matches 0 or more of **any** character - equivalent to regex `.*`
- `?` matches any **one** characters - equivalent to regex `.`
- `[characters]` matches **1** of **characters** - same as regex `[]`
- `[!characters]` matches **1** character not in **characters** - same as regex `[^]`
- if no pathname matches the word is unchanged
- aside: globbing also available in Python, Perl, C & other languages

```
$ echo *.c[h]
functions.c functions.h i.h main.c
$ ./print_argv.py *.c[h]
['./print_argv.py', 'functions.c', 'functions.h', 'i.h', 'main.c']
$ ./print_argv.py '*.c[h]'
['./print_argv.py', '*.c[h]']
$ ./print_argv.py "*.c[h]"
['./print_argv.py', '*.c[h]']
$ ./print_argv.py *.zzzzz
['./print_argv.py', '*.zzzzz']
```

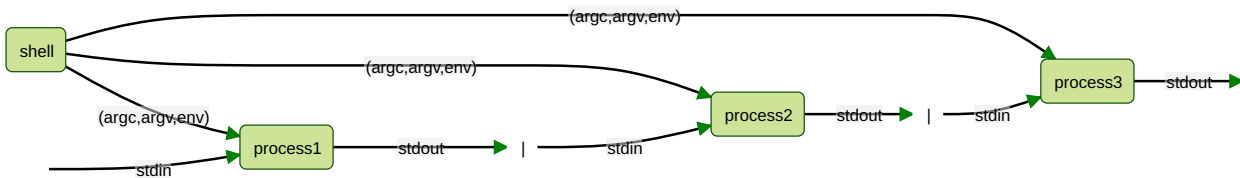
- stdin, stdout & stderr for a command can be directed to/from files

< infile	connect stdin to the file infile
> outfile	send stdout to the file outfile
>> outfile	append stdout to the file outfile
2> outfile	send stderr to the file outfile
2>> outfile	append stderr to the file outfile
> outfile 2>&1	send stderr+stdout to outfile
1>&2	send stdout to stderr (handy for error messages)
«word	here-document - previously discussed
«< string	(in bash) here-string - a single line here-document
&> outfile	(in bash) send stdout+stderr to outfile

- beware: > truncates file before executing command.
- always have backups!

Pipelines

- **command₁ | command₂ | command₃ | ...**
- stdout of **command_{n-1}** connected to stdin of **command_n**
- beware changes to variables in pipeline are lost
- some non-filter style Unix programs given a filename – read from stdin
 - allows them to be used in a pipeline



searching PATH for the program

- first word on line specifies command to be run
- if first word is not the full (absolute) pathname of a file the colon-separated list of directory specified by the variable PATH is searched
- for example if **PATH=/bin/:usr/bin:/home/z1234567/bin** and the command is **kitten** the shell will check (stat) these files in order:
 - **/bin/kitten /usr/bin/kitten /home/z1234567/bin**
 - the first that exists and is executable will be run
 - if none exist the shell will print an error message
- or **.** in PATH causes the current directory to be checked
 - this can be convenient - but make it last not first, e.g.:
PATH=/bin/:usr/bin:/home/z1234567/bin:.
 - definitely do not include the current directory in PATH if you are root
 - an empty entry in PATH is equivalent to **.**

danger of having `.` in your PATH

- if `.` is not last in PATH then programs in the current directory may be unexpectedly run
- this can also happen inside run shell scripts or other programs you run
- robust shell scripts often set PATH to ensure this doesn't happen, e.g.: **PATH=/bin/#!/usr/bin/:\$PATH**

```
# equivalent to PATH=./bin:/usr/bin:/home/z1234567/bin
$ PATH=./bin:/usr/bin:/home/z1234567/bin
$ cat >cat <<eof
#!/bin/dash
echo miaou
eof
$ chmod 755 cat
$ cat /home/cs2041/public_html/index.html
miaou
$
```

Problem: `./cat` is being run rather `/bin/cat`

Shell Scripts

We can execute shell commands in a file:

```
$ cat hello
echo Hello, John Connor - the time is $(date)
$ dash hello
Hello, John Connor - the time is Fri 29 Aug 1997 02:14:00 EST
```

- Unix-like systems allow an interpreter to be specified in a `#!` line
- allows program to be executed directly without knowing it is shell

```
$ cat hello
#!/usr/bin/env dash
echo Hello, John Connor - the time is $(date)
$ chmod 755 hello
$ ./hello
Hello, John Connor - the time is Fri 29 Aug 1997 02:14:00 EST
```

- use **#!/bin/bash** if you want bash

Shell Built-in Variables

Some shell built-in variables with pre-assigned values:

\$0	the name of the command
\$1	the first command-line argument
\$2	the second command-line argument
...	...
\$#	count of command-line arguments
"\$@"	command-line arguments as separate word
\$?	exit status of the most recent command
\$\$	process ID of this shell

- **\$\$** is useful for generating (somewhat) unique names in scripts.
- see also the **shift** command

Example - Shell Script using Built-in Variables

```
#!/bin/dash
# A simple shell script demonstrating access to arguments.
# written by andrewt@unsw.edu.au as a COMP(2041|9044) example
echo My name is "$0"
echo My process number is $$
echo I have $# arguments
echo My command-line arguments are "$@"
echo My 5th argument is "$5"
echo My 10th argument is "${10}"
```

source code for args.sh

Example - Simple Shell Script

```
#!/bin/sh
# l [file|directories...] - list files
#
# written by andrewt@unsw.edu.au as a COMP(2041|9044) example
#
# Short shell scripts can be used for convenience.
#
# It is common to put these scripts in a directory
# such as /home/z1234567/scripts
# then add this directory to PATH e.g in .bash_login
# PATH=$PATH:/home/z1234567/scripts
#
# Note: "$@" expands to the arguments to the script,
# but preserves whitespace in arguments.
ls -las "$@"
```

source code for l

Example - Putting a Pipeline in a Shell Script

```
#!/bin/dash
# Count the number of time each different word occurs
# in the files given as arguments, or stdin if no arguments,
# e.g. word_frequency.sh dracula.txt
# written by andrewt@unsw.edu.au as a COMP(2041|9044) example
cat "$@" |                               # tr doesn't take filenames as arguments
tr 'A-Z' 'a-z' |                          # map uppercase to lower case, better - tr '[:upper:]'
tr ' ' '\n' |                             # convert to one word per line
tr -cd "a-z" |                             # remove all characters except a-z and '
grep -E -v '^$' |                         # remove empty lines
sort |                                     # place words in alphabetical order
uniq -c |                                  # count how many times each word occurs
sort -rn |                                 # order in reverse frequency of occurrence
# notes:
# - first 2 tr commands could be combined
# - sed 's/ /\n/g' could be used instead of tr ' ' '\n'
# - sed "s/[^a-z]//g" could be used instead of tr -cd "a-z"
```

source code for word_frequency.sh

Tip: debugging for shell scripts

- test parts of shell script from command line
- use **echo** to print the value of variables
- add **set -x** to see commands being executed
 - or equivalently run **/bin/dash -x script.sh**
 - shell transforms commands
 - useful to see exactly what is being executed

Exit Status and Control

- when Unix-like programs finish they give the operating system an **exit status**
 - the return value of 'main' becomes the **exit status** of a C program
 - or if `exit` is called, its argument is the **exit status**
 - in Python **exit status** is supplied as an argument to `sys.exit`
- an **exit status** is a (usually small) integer
 - by convention a zero exit status indicated normal/successful execution
 - a non-zero exit status indicates an error occurred
 - which non-zero integer might indicate the nature of the problem
- program exit status is often ignored
 - not important writing single programs (COMP1511/COMP9021)
 - very important when combining multiple programs COMP(2041|9044)
- flow of execution in Shell scripts based on exit status
 - `if/while` statement conditions use exit status
- two weird utilities
 - `/bin/true` does nothing and always exits with status 0
 - `/bin/false` does nothing and always exits with status 1

The test command

- The **test** command performs a test or combination of tests and:
 - does/prints nothing
 - returns a zero exit status if the test succeeds
 - returns a non-zero exit status if the test fails
- Provides a variety of useful operators:
 - string comparison: `=` `!=`
 - numeric comparison: `-eq` `-ne` `-lt`
 - test if file exists/is executable/is readable: `-f` `-x` `-r`
 - boolean operators (and/or/not): `-a` `-o` `!`
- also available as `[]` instead of `test` - which many programmers prefer
- builtin to some shell (e.g. bash) but available as **/bin/test** or **/bin/[]**

The test command examples

```
# does the variable msg have the value "Hello"?
test "$msg" = "Hello"

# does x contain a numeric value larger than y?
test "$x" -gt "$y"

# Error: expands to "test hello there = Hello"?
msg="hello there"
test $msg = Hello

# is the value of x in range 10..20?
test "$x" -ge 10 -a "$x" -le 20

# is the file xyz a readable directory?
test -r xyz -a -d xyz

# alternative syntax; requires closing ]
[ -r xyz -a -d xyz ]
```

If Statements - syntax

```
if command1
then
    then-commands
elif command2
then
    elif-commands
else
    else-commands
fi
```

- the execution path depends on the exit status of *command₁* and *command₂*
- **command₁** is executed and if its exit status is 0, the **then-commands** are executed
- otherwise **command₂** is executed and if its exit status is 0, the **elif-commands** are executed
- otherwise the **else-commands** are executed

If Statements - Example

```
if gcc main.c; then
    echo your C compiles
elif python3 main.c; then
    echo you have written Python not C
else
    echo program broken - send help
fi
```

```
if gcc a.c
then
# you can not have an empty body
# use a : statement which does nothing
:
else
    rm a.c
fi
```

shell **while** statements have this form:

```
while command
do
    body-commands
done
```

- the execution path depends on the exit status of *command*
- **command** is executed and if its exit status is 0, the **body-commands** are executed and then **command** is executed and if its exit status is 0 the **body-commands** are executed and ...
- if the exit status of **command~** is not 0, execution of the loop stops

example - seq - simple version

```
#!/bin/dash
# simple emulation of /usr/bin/seq for a COMP(2041|9044) example
# andrewt@unsw.edu.au
# Print the integers 1..n with no argument checking
last=$1
number=1
while test $number -le "$last"
do
    echo $number
    number=$((number + 1))
done
```

source code for seq.v0.sh

```
$ ./seq.v0.sh 3
1
2
3
```

example - seq - argument handling added

```
# Print the integers 1..n or n..m
if test $# = 1
then
    first=1
    last=$1
elif test $# = 2
then
    first=$1
    last=$2
else
    echo "Usage: $0 <last> or $0 <first> <last>" 1>&2
    exit 1
fi
number=$first
while test $number -le "$last"
do
    echo $number
    number=$((number + 1))
done
```

source code for seq.v1.sh

example - seq - using [] instead of test

```
if [ $# = 1 ]
then
    first=1
    last=$1
elif [ $# = 1 ]
then
    first=$1
    last=$2
else
    echo "Usage: $0 <last> or $0 <first> <last>" 1>&2
    exit 1
fi
number=$first
while [ $number -le $last ]
do
    echo $number
    number=$((number + 1))
done
```

source code for seq.v2.sh

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example - watching a website - argument checking

```
# Repeatedly download a specified web page
# until a specified regexp matches its source
# then notify the specified email address.
#
# For example:
# watch_website.sh http://ticketek.com.au/ '[Tt]ayl(a|or) *[Ss]wift' andrewt@unsw
repeat_seconds=300 #check every 5 minutes
if test $# = 3
then
    url=$1
    regexp=$2
    email_address=$3
else
    echo "Usage: $0 <url> <regexp> <email-address>" 1>&2
    exit 1
fi
```

source code for watch_website.sh

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example - watching a website - main loop

```
while true
do
    if curl --silent "$url"|grep -E "$regexp" >/dev/null
    then
        # the 2nd echo is for testing, remove to really send email
        echo "Generated by $0" |
        echo mail -s "website '$url' now matches regex '$regexp'" "$email_address"
        exit 0
    fi
    sleep $repeat_seconds
done
```

source code for watch_website.sh

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shell **for** statements have this form:

```
for var in word1 word2 word3
do
    body-commands
    ...
done
```

- the loop executes once for each *word* with *var* set to the *word*
- **break** & **continue** statements can be in used inside for & while loops with the same effect as C/Python
- keywords such **for**, **if**, **while**, ... are only recognised at the start of a command, e.g.:

```
$ echo when if else for
when if else for
```

Example - Shell Script accessing Command-line Arguments

```
echo "$a"
done
```

source code for accessing_args.sh

Example - Shell Script accessing Command-line Arguments

```
$ ./accessing_args.sh one two "three four"
one
two
three four
```

Using Exit Status for Conditional Execution

- all commands are executed if separated by **;** or newline, e.g:
 $cmd_1 ; cmd_2 ; \dots ; cmd_n$
- when commands are separated by **&&**
 $cmd_1 \&\& cmd_2 \&\& \dots \&\& cmd_n$
execution stops if a command has non-zero exit status
 cmd_{n+1} is executed only if cmd_n has zero exit status
- when commands are separated by **||**
 $cmd_1 || cmd_2 || \dots || cmd_n$
execution stops if a command has zero exit status
 cmd_{n+1} is executed only if cmd_n has non-zero exit status
- **{ }** can be used to group commands
- **()** also can be used to group commands - but executes them in a subshell
 - changes to variables and current working directory have no effect outside the subshell
- exit status of group or pipeline of commands is exit status of last command

```
# run a.out if it exists and is executable
test -x a.out && ./a.out

# if directory tmp doesn't exist create it
test -d tmp || mkdir tmp

# if directory tmp doesn't exist create it
{test -d tmp || mkdir tmp;} && chmod 755 tmp

# but simpler is
mkdir -p tmp && chmod 755 tmp
```

{ } versus () - example

```
$ cd /usr/share
$ x=123
$ ( cd /tmp; x=abc; )
$ echo $x
123
$ pwd
/usr/share
$ { cd /tmp; x=abc; }
$ echo $x
abd
$ pwd
/tmp
```

- changes to variables and current working directory have no effect outside a subshell
- pipelines also executed in subshell, but variables and directory not usually changed in a pipeline

shellcheck - shell static analysis tool

- shellcheck <https://www.shellcheck.net/> statically analyzes shell scripts
 - finds possible bugs without running script
 - highly-recommended because it picks up many common shell coding mistakes
- static analysis tools highly valuable because they give another way of checking for errors
 - faster/easier than testing
 - may find errors testing will miss
- static analysis tools available for many languages
 - e.g. pyflakes, pylint, prospector for Python
 - compilers (e.g. gcc/clang) use static analysis to produce faster/smaller code and report possible bugs

example - renaming files - argument checking

```
# Change the names of the specified files to lower case.
# (simple version of the perl utility rename)
#
# Note use of test to check if the new filename is unchanged.
#
# Note the double quotes around $filename so filenames
# containing spaces are not broken into multiple words
# Note the use of mv -- to stop mv interpreting a
# filename beginning with - as an option
# Note files named -n or -e still break the script
# because echo will treat them as an option,
if test $# = 0
then
    echo "Usage $0: <files>" 1>&2
    exit 1
fi
```

source code for tolower.sh

example - renaming files- main loop

```
for filename in "$@"
do
    new_filename=$(
        echo "$filename" |
        tr '[:upper:]' '[:lower:]'
    )
    test "$filename" = "$new_filename" &&
        continue
    if test -r "$new_filename"
    then
        echo "$0: $new_filename exists" 1>&2
    elif test -e "$filename"
    then
        mv -- "$filename" "$new_filename"
    else
        echo "$0: $filename not found" 1>&2
    fi
done
```

source code for tolower.sh

read - shell builtin

- **read** is a shell builtin which reads a line of input into variable(s)
 - non-zero exit status on EOF
 - newline is stripped
 - leading and trailing whitespace stripped unless variable IFS unset
 - note **-r** option if input might contain backslashes
- if more than one variable specified, line is split into fields on white space
 - 1st variable assigned 1st field, 2nd variable assigned 2nd field ...
 - last variable entire remainder of line
 - if insufficient fields variables assigned empty strings
- if more than one variable specified, line is split into fields on white space

```
$ read v
hello world
$ echo "$v"
hello world
$ read a b c
1 2 3 4 5
$ echo "a='$a' b='$b' c='$c'"
a='1' b='2' c='3 4 5'
```

read - simple example

```
echo -n "Do you like learning Shell? "  
read answer  
# get first letter of answer converted to lower case  
answer="$(  
    echo "$answer" |  
    cut -c1 |  
    tr A-Z a-z  
)"  
if test "$answer" = "y"  
then  
    response=":)"  
elif test "$answer" = "n"  
then  
    response=":( "  
else  
    response="??"  
fi  
echo "$response"
```

source code for read_response_if.sh

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emulating cat with read

```
#!/bin/dash  
# written by andrewt@unsw.edu.au for COMP(2041|9044)  
# over-simple /bin/cat emulation using read  
# setting the special variable IFS to the empty string  
# stops trailing white space being stripped  
for file in "$@"  
do  
    while IFS= read -r line  
    do  
        echo "$line"  
    done <$file  
done
```

source code for read_cat.sh

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case statements - syntax

```
case word in  
pattern1)  
    commands1  
    ;;  
pattern2)  
    commands2  
    ;;  
patternn)  
    commandsN  
esac
```

- **word** is compared to each **pattern**, in turn.
- for the first **pattern**, that matches the corresponding **commands**, is executed and the case statement finishes.

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- case patterns use the same language as filename expansion (globbing)
 - in other words the special characters are `* ? []`
 - patterns are not interpreted as regexes
- shell programmer used to use **case** statements heavily for efficiency
 - much less important now and many shell programmers don't use case
 - but use of case can still make shell code more readable

case statement - examples

```
# Checking number of command line args
case $# in
0) echo "You forgot to supply the argument" ;;
1) filename=$1 ;;
*) echo "You supplied too many arguments" ;;
esac

# Classifying a file via its name
case "$file" in
*.c) echo "$file looks like a C source-code file" ;;
*.h) echo "$file looks like a C header file" ;;
*.o) echo "$file looks like an object file" ;;
...
?) echo "$file's name is too short to classify" ;;
*) echo "I have no idea what $file is" ;;
esac
```

case - simple example

```
echo -n "Do you like learning Shell? "
read answer
case "$answer" in
[Yy]*)
    response=":)"
    ;;
[Nn]*)
    response=":(("
    ;;
*)
    response="???"
esac
echo "$response"
```

source code for read_response_case.sh

creating a 1001 file C program - getting started

```
# this programs creates 1000 files f0.c .. f999.c
# file f$i.c contains function f$i which returns $i
# for example file42.c contains function f42 which returns 42
# main.c is created with code to call all 1000 functions
# and print the sum of their return values
#
# first add the initial lines to main.c
# note the use of quotes on eof to disable variable interpolation
# in the here document
cat >main.c <<'eof'
#include <stdio.h>
int main(void) {
    int v = 0 ;
eof
```

source code for create_1001_file_C_program.sh

creating a 1001 file C program - creating the files

```
i=0
while test $i -lt 1000
do
    # add a line to main.c to call the function f$i
    cat >>main.c <<eof
    int f$i(void);
    v += f$i();
eof
    # create file$i.c containing function f$i
    cat >file$i.c <<eof
int f$i(void) {
    return $i;
}
eof
    i=$((i + 1))
done
```

source code for create_1001_file_C_program.sh

creating a 1001 file C program - compiling & running the program

```
cat >>main.c <<'eof'
    printf("%d\n", v);
    return 0;
}
eof
# compile and run the 1001 C files
time clang main.c file*.c
./a.out
```

source code for create_1001_file_C_program.sh

shell functions have this form:

```
name () {
    commands
}
```

- function arguments passed in: `$@ $1 $2 ...`
- use **return** to stop function execution and return exit status
 - beware: **exit** in a function still terminates entire program
- **local** keyword can be used to limit scope of variables to function
 - **local** is not POSIX, but is widely supported although exact semantics vary
 - **ksh** does not support **local**, it has a similar keyword **typeset**

example - shell function

```
#!/bin/dash
# written by andrewt@unsw.edu.au for COMP(2041|9044)
# demonstrate simple use of a shell function
favourite_command() {
    name=$1
    command=$2
    echo "My name is $name, my favourite Unix command is $command."
}
favourite_command Andrew "uniq"
favourite_command Dylan "jq"
favourite_command Grace "sed"
```

source code for favourite_command.sh

example - local variables in a shell function

```
# print numbers < 1000
# note use of local Shell builtin to scope a variable
# without the local declaration
# the variable i in the function would be global
# and would break the bottom while loop
# local is not (yet) POSIX but is widely supported
is_prime() {
    local n i
    n=$1
    i=2
    while test $i -lt $n
    do
        test $((n % i)) -eq 0 &&
            return 1
        i=$((i + 1))
    done
    return 0
}
i=0
while test $i -lt 1000
do
    is_prime $i &&
        echo $i
    i=$((i + 1))
done
```

source code for local.sh

```
# Note use of diff -iw so changes in white-space or case are ignored
for file1 in "$@"
do
  for file2 in "$@"
  do
    test "$file1" = "$file2" &&
      break # avoid comparing pairs of assignments twice
    if diff -iBw "$file1" "$file2" >/dev/null
    then
      echo "$file1 is a copy of $file2"
    fi
  done
done
```

source code for plagiarism_detection.simple_diff.sh

plagiarism detection - ignoring changes to comments

```
# The substitution s/\/\./.*// removes // style C comments.
# This means changes in comments won't affect comparisons.
# Note use of temporary files is insecure - an attacker can anticipate the filename
TMP_FILE1=/tmp/plagiarism_tmp1$$
TMP_FILE2=/tmp/plagiarism_tmp2$$
for file1 in "$@"
do
  for file2 in "$@"
  do
    test "$file1" = "$file2" &&
      break # avoid comparing pairs of assignments twice
    sed 's/\/\./.*//' "$file1" >$TMP_FILE1
    sed 's/\/\./.*//' "$file2" >$TMP_FILE2
    if diff -i -w $TMP_FILE1 $TMP_FILE2 >/dev/null
    then
      echo "$file1 is a copy of $file2"
    fi
  done
done
rm -f $TMP_FILE1 $TMP_FILE2
```

source code for plagiarism_detection.comments.sh

robust creation & removal of temporary files

- our code can be more robust and more secure by using `mktemp` to generate temporary file names
- we can also use the builtin shell `trap` command to ensure temporary files are removed however the script exits
- temporary file creation is major source of security holes be very careful creating temporary files
- in all languages, use existing robust & well-tested code such as `mktemp`
 - don't write your own code
- `mktemp` is not (yet) standardized by POSIX
 - simple uses are portable to many platforms

plagiarism detection - ignoring changes to variable names #1

```
# change all C strings to the letter 's'
# and change all identifiers to the letter 'v'.
# Hence changes in strings & identifiers will be ignored.
# mktemp provide suitable temporary filename, robustly & securely
TMP_FILE1=$(mktemp)
TMP_FILE2=$(mktemp)
# trap allows use to remove temporary files if program interrupted
trap 'rm -f $TMP_FILE1 $TMP_FILE2' EXIT
# s/"["]*"/s/g changes strings to the letter 's'
# It won't match a few C strings which is OK for our purposes
# s/[a-zA-Z_][a-zA-Z0-9_]*/v/g changes variable names to 'v'
# It will also change function names, keywords etc. which is OK for our purposes.
transform() {
    sed '
        s/\\//.*//
        s/"[^"]"/s/g
        s/[a-zA-Z_][a-zA-Z0-9_]*/v/g
        ' $1
}
```

source code for plagiarism_detection.identifiers.sh

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plagiarism detection - ignoring changes to variable names #2

```
for file1 in "$@"
do
    for file2 in "$@"
    do
        test "$file1" = "$file2" &&
            break # avoid comparing pairs of assignments twice
        transform "$file1" >$TMP_FILE1
        transform "$file2" >$TMP_FILE2
        if diff -iBw $TMP_FILE1 $TMP_FILE2 >/dev/null
        then
            echo "$file1 is a copy of $file2"
        fi
    done
done
```

source code for plagiarism_detection.identifiers.sh

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plagiarism detection - ignoring changes in code order

```
TMP_FILE1=$(mktemp)
TMP_FILE2=$(mktemp)
trap 'rm -f $TMP_FILE1 $TMP_FILE2' EXIT
# Note the use of sort so line reordering won't prevent detection of plagiarism.
transform() {
    sed '
        s/\\//.*//
        s/"[^"]"/s/g
        s/[a-zA-Z_][a-zA-Z0-9_]*/v/g
        ' $1 |
    sort
}
```

source code for plagiarism_detection.reordering.sh

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Example - creating a temporary directory

```
# securely & robustly create a new temporary directory
temporary_directory=$(mktemp -d)
# ensure temporary directory + all its contents removed on exit
trap 'rm -rf "$temporary_directory"; exit' INT TERM EXIT
# change working directory to the new temporary directory
cd "$temporary_directory" || exit 1
# we are now in an empty directory
# and create any number of files & directories
# which all will be removed by the trap above
# e.g. create one thousand empty files
seq 1 1000|xargs touch
# print current directory and list files
pwd
ls -l
```

source code for create_temporary_directory.sh

Cryptographic hash function

- algorithm maps byte sequence of any length to certain number of bits
- e.g sha256 input: any number of bytes, output 256 bits (= 8 bytes) hash
- one way function - not feasible to reverse
- given a hash, not feasible to compute an input which produces that hash
- collisions (different inputs producing the same hash) occur but are vanishingly rare
- small change to input changes hash completely
- many applications:
 - hashes of passwords stored rather than password itself
 - integrity check on set of files
 - fingerprint a file

plagiarism detection - using hashing

```
# Improved version of plagiarism_detection.reordering.sh
# Note use sha256sum to calculate a Cryptographic hash of the modified file
# https://en.wikipedia.org/wiki/SHA-2
# and use of sort && uniq to find files with the same hash
# This allows execution time linear in the number of files
# We could use a faster less secure hashing function instead of sha2
sha2hash() {
    sed '
        s/\\/\./g
        s/"[^"]"/s/g
        s/[a-zA-Z_][a-zA-Z0-9_]*/v/g
        ' $1|
    sort|
    sha256sum
}
for file in "$@"
do
    echo "$(sha2hash $file) $file"
done|
sort|
uniq -w32 -d --all-repeated=separate
```

source code for plagiarism_detection.hash.sh

```

my_process_id=$((
# launch a asynchronous sub-shell that will kill
# this process in a second
(sleep 1; kill $my_process_id) &
i=0
while true
do
    echo $i
    i=$((i + 1))
done

```

source code for `async.v0.sh`

- **command &** executes *command* but does not wait for it to finish
- **sleep 1** suspends execution for a second
- **kill** sends a signal to a process, which by default causes it to exit

intercepting signals with trap

- **trap** specifies commands to be executed if a signal is received, e.g.:

```

# count slowly and laugh at interrupts (ctrl-C)
# catch signal SIGINT and print message
trap 'echo ha ha' INT
n=0
while true
do
    echo "$n"
    sleep 1
    n=$((n + 1))
done

```

source code for `laugh.sh`

- **trap** is useful for cleaning up temporary files before termination, e.g.

```
trap 'rm -f "$TMP_FILE";exit' INT TERM EXIT
```

example - catching a signal with trap

```

# catch signal SIGTERM, print message and exit
trap 'echo loop executed $n times in 1 second; exit 0' TERM
# launch a sub-shell that will terminate
# this process in 1 second
my_process_id=$((
(sleep 1; kill $my_process_id) &
n=0
while true
do
    n=$((n + 1))
done

```

source code for `async.v1.sh`

example - compiling in parallel

```
# compile the files of a muti-file C program in parallel
# use create_1001_file_C_program.sh to create suitable test data
# On a CPU with n cores this can be (nearly) n times faster
# If there are large number of C files we
# may exhaust memory or operating system resources
for f in "$@"
do
    clang -c "$f" &
done
# wait for the incremental compiles to finish
# and then compile .o files into single binary
wait
clang -o binary -- *.o
```

source code for parallel_compile.v0.sh

example - compiling in parallel

```
# compile the files of a muti-file C program in parallel
# use create_1001_file_C_program.sh to create suitable test data
# on Linux getconf will tell us how many cores the machine has
# otherwise assume 8
max_processes=$(getconf _NPROCESSORS_ONLN 2>/dev/null) ||
    max_processes=8
# NOTE: this breaks if a filename contains whitespace or quotes
echo "$@" |
xargs --max-procs=$max_processes --max-args=1 clang -c
clang -o binary -- *.o
```

source code for parallel_compile.v1.sh

example - compiling in parallel

```
$ ./create_1001_file_C_program.sh
$ echo *.c
file0.c file1.c file10.c file100.c file101.c file102.c ...
$ echo *.c|wc -w
1001
# compiling 1 file at a time
$ time clang *.c
real    0m20.875s
user    0m13.016s
sys     0m7.835s
# compiling all 1001 files simultaneously
$ time ./parallel_compile.v0.sh *.c
real    0m2.335s
user    0m9.066s
sys     0m8.788s
# compiling 24 files at time
$ time ./parallel_compile.v1.sh *.c
real    0m1.971s
user    0m18.694s
sys     0m18.428s
$ grep 'model name' /proc/cpuinfo|sed 1q
model name : AMD Ryzen 9 3900X 12-Core Processor
```


example - compiling in parallel

```
# compile the files of a multi-file C program in parallel
# use create_1001_file_C_program.sh to create suitable test data
# find's -print0 option terminates pathnames with a '\0'
# xargs's --null option expects '\0' terminated input
# as '\0' can not appear in file names this can handle any filename
# on Linux getconf will tell us how many cores the machine has
# if getconf assume 8
max_processes=$(getconf _NPROCESSORS_ONLN 2>/dev/null) ||
    max_processes=8
find "$@" -print0 |
xargs --max-procs=$max_processes --max-args=1 --null clang -c
clang -o binary -- *.o
```

source code for parallel_compile.v2.sh

example - compiling in parallel

```
# compile the files of a muti-file C program in parallel
# use create_1001_file_C_program.sh to create suitable test data
parallel clang -c '{}' ::: "$@"
clang -o binary -- *.o
```

source code for parallel_compile.v3.sh

Shell Variable Expansion - More Syntax

```
$ x=1
$ y=fred
$ echo $x$y
1fred
$ echo $xy      # the aim is to display "1y"

$ echo "$x"y
1y
$ echo ${x}y
1y
$ echo ${j-10}   # give value of j or 10 if no value
10
$ echo ${j=33}   # set j to 33 if no value (and give $j)
33
$ echo ${x:?No Value} # display "No Value" if $x not set
1
$ echo ${xx:?No Value} # display "No Value" if $xx not set
-bash: xx: No Value
```

Bash arithmetic (()) extension example

```
# print print numbers < 1000
# Rewritten to use bash arithmetic extension (( ))
# This makes the program more readable but less portable.
is_prime() {
    local n i
    n=$1
    i=2
    while ((i < n))
    do
        if ((n % i == 0))
        then
            return 1
        fi
        i=$((i + 1))
    done
    return 0
}
i=0
while ((i < 1000))
do
    is_prime $i && echo $i
    i=$((i + 1))
done
```

source code for bash_arithmetic.sh