COMP1521 26T1

Week 5 Lecture 2

Floating Point, Operating Systems and File Systems

Assignment 1 is due Friday 6pm

Week 4 test: due thursday 9pm (MIPS basics, control, arrays)

Week 6 Flexibility Week Next Week

No lectures, tutorials or labs. Nothing due!

Week 5 lab: due monday midday week 7
Week 5 test: due thursday 9pm week 7 (MIPS strings)
Week 6 test: due thursday 9pm week 7 (bitwise operators C)
There is no lab6

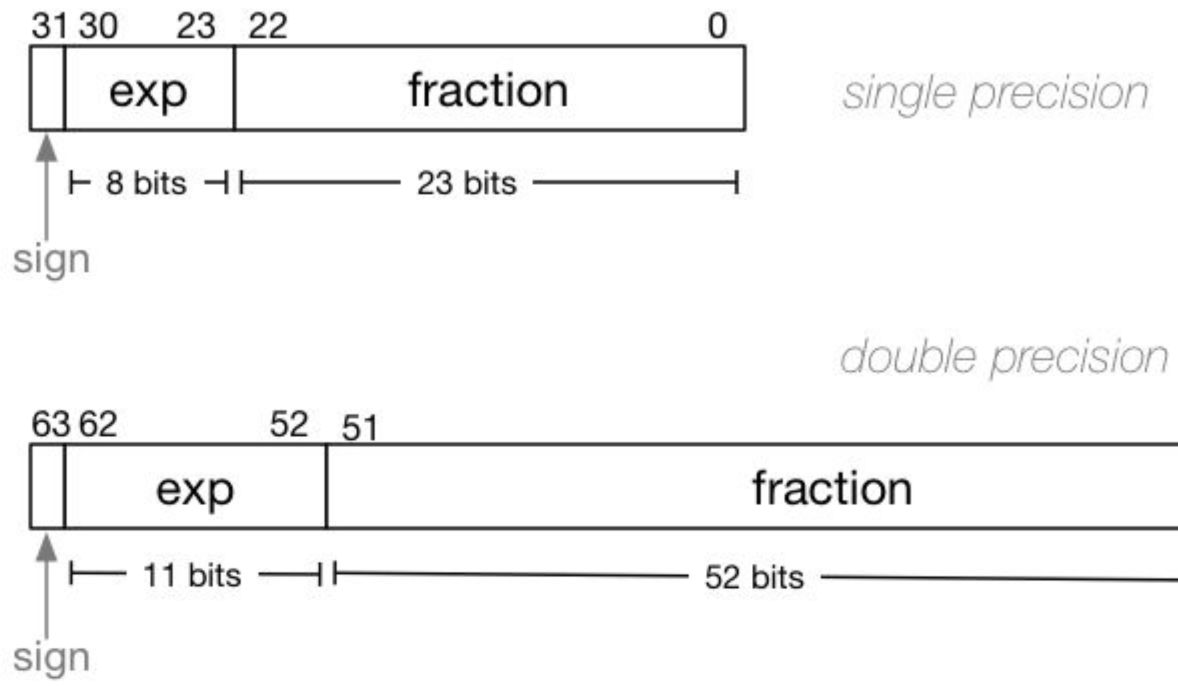
There will still be **help sessions** on.

There will be **bitwise operators revision sessions** on - stay tuned to course forum announcements for details

Today's Lecture

- Floating Point Representation
- Operating Systems
- File Systems
    - System Calls

IEEE 754 Standard



Note:
float in C is represented in this single precision format.
double in C is represented in this double precision format

Note: the fraction part is often called the mantissa

IEEE 754 Example

150.75 = 10010110.11

// normalise fraction, compute exponent

= 1.001011011 × 2^7

// determine sign bit,

// map fraction to 24 bits, (don't store the leading 1)

// map exponent to 8 bits after adding on the bias of 127

= 01000011000101101100000000000000

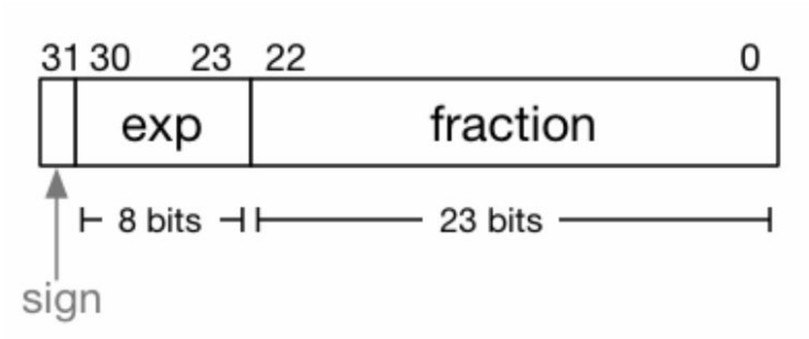
where red is sign bit, green is exponent, blue is fraction

Note: *B*=127, *e*=2^7, so exponent = 127+7 = 134 = **10000110**

Check using explain_float_representation.c or Floating Point Calculator

Floating Point Recap Exercise

Keep in mind 10000000 = 2^7 = 128



Convert -42.5 to IEEE 754 float?

Convert to decimal from IEEE 754 float

00111110100000000000000000000000

IEEE 754 Standard: Special Cases

Value	**Exponent**	**Fraction**	**Example**
0 (+ve or -ve)	all 0’s	all 0’s	
inf (∞ and -∞)	all 1’s	all 0’s	1.0/0
nan	all 1’s	Not all 0’s	0.0/0

IEEE 754 infinity.c

Representation of +- infinity : propagates sensibly through calculations

```
double x = 1.0/0.0;
printf("%lf\n", x);            //prints inf
printf("%lf\n", -x);           //prints -inf
printf("%lf\n", x - 1);        // prints inf
printf("%lf\n", 2 * atan(x)); // prints 3.141593
printf("%d\n", 42 < x);        // prints 1 (true)
printf("%d\n", x == INFINITY);// prints 1 (true)
```

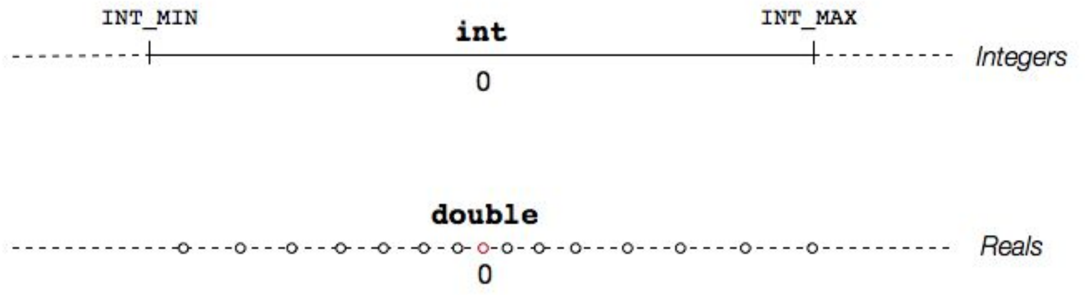
IEEE 754 nan.c

Representation for invalid results NaN (not a number)

- ensures errors propagates sensibly through calculations

```c
double x = 0.0/0.0;
printf("%lf\n", x);         //prints nan
printf("%lf\n", x - 1);    // prints nan
printf("%d\n", x == x);    // prints 0 (false)
printf("%d\n", isnan(x)); // prints 1 (true)
```

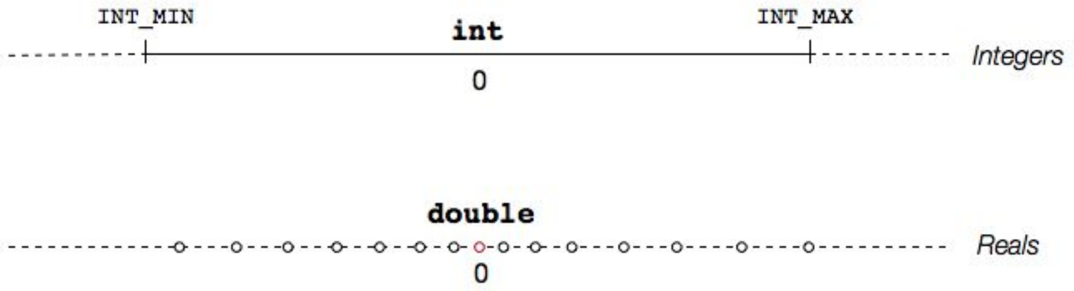
Distribution of Floating Point Numbers



integers ... subset (range) of the mathematical integers

- can represent all integer values in that subset
- each integer is 1 away from the next one and previous one
- all integers are represented accurately

Distribution of Floating Point Numbers



floating point ... subset of the mathematical real numbers

- floating point numbers not evenly distributed
    - numbers closer to 0 have higher precision which is good
    - representations get further apart as values get bigger
    - this works well for most calculations but can cause weird bugs

Distribution of Floating Point Numbers

A 64-bit **double** uses 52 bits for the fraction.

- Between $\mathbf{2^n}$ and $\mathbf{2^{n+1}}$ there are $\mathbf{2^{52}}$ doubles evenly spaced
  - e.g. in the interval 2^{-42} and 2^{-43} there are 2^{52} doubles
  - and in the interval between 0.5 and 1 there are 2^{52} doubles
  - and in the interval between 1 and 2 there are 2^{52} doubles
  - and in the interval between 2 and 4 there are 2^{52} doubles
  - and in the interval between 4 and 8 there are 2^{52} doubles
  - and in the interval between 2^{42} and 2^{43} there are 2^{52} doubles

Distribution of Floating Point Numbers

- This results in doubles
  - near 0.001 - being about 0.0000000000000000002 apart
  - near 1000 - being about 0.0000000000002 apart
  - near 1000000000000000 - being about 0.25 apart
  - **above 2^{53} - doubles are more than 1 apart**

Code Demos

double_disaster.c

explain_float_representation.c

double_catastrophe.c (advanced example)

Operating Systems

Operating Systems

- This course is a great way to see different areas in computing to
    - See what electives you might be interested in!!
    - See what area you might want to work in!!
- **Question** : What is YOUR favourite operating system?
    - Call out or write in the chat
- **Question 2**: What do operating systems do?
    - Hands up or write in the chat

A World without Operating Systems

- Manually Boot Your Computer
  - No OS means no automatic booting into a familiar environment.
- Write your own file system
  - No file names, no directories, your hard drive is just raw data
- Run Programs… If You Can
  - Multi-tasking?? Good luck.
- Security?
  - Your dodgy game can steal your passwords you typed into your online banking… if you could connect to the internet… because…
- Why won’t my mouse, printer, usb port, internet connection work??
  - No OS = No drivers. Every program must **talk directly to the hardware**

A World without Operating Systems

- You would need to learn to do this for every specific computer unless it happened to have the same exact configuration of hardware
    - You would not be too keen to use a different device
    - Or to get an upgrade…

- You would need to write different code for all different configurations of hardware!

Why do we Need an Operating System

- Computers have many different hardware configurations
- The OS sits between users/programs and the hardware
- It provides a consistent **virtual machine** interface

What do Operating Systems give us?

- **Abstraction:** Use the computer without knowing hardware details (voltages, device specifics, etc.)
- **Portability:** Programs can run on many different machines
- **Ease of use:** Writing and running programs is much simpler
- **Resource management:** Coordinates files, memory, devices, and multiple processes safely
- **Reliability:** Complex, error-prone low-level operations are handled by the OS

Result: Users and programs see the *same interface* even when the underlying hardware is different

Operating Systems: Privileged Mode

- Needs hardware to provide a **privileged** mode
  - Code can access all hardware, memory and CPU instructions
  - **OS kernel** runs in this mode
    - The OS kernel is the core of the operating system that manages the hardware and system resources.
- Needs hardware to provide a **non-privileged** mode which
  - code can not access hardware directly
  - code can only access the memory it was allocated
  - **user code** runs in this mode

Operating Systems: System Calls

- System calls allow user level code to request hardware operations
- System calls transfer execution to OS kernel code in **privileged** mode
    - includes arguments specifying details of request being made
    - OS checks operation is valid & permitted
    - OS carries out operation
    - transfers execution back to user code in **non-privileged** mode

System Calls

- Different operating system have different system calls
  - Linux system calls are very different Windows system calls
  - Linux provides 400+ system calls
  - type **`man syscalls`** to find out more information
- Examples of operations that might be provided by system call
  - read or write bytes to a file
  - create a process (run a program) or terminate a process
  - send information over the network

Mipsy System Calls

- **mipsy** provides a virtual machine which can execute MIPS programs
- **mipsy** also provides a tiny operating system
- **mipsy** system calls
- **syscall** instruction
  - small number of very specific system calls
  - designed for students writing small programs with no library functions
  - MIPS programs running on real hardware and real OS also use **syscall**

Experimenting with Linux System Calls

- Linux system calls also have a number
  - e.g system call **1** is **write** bytes to a file
- Linux provides 400+ system calls

```
$ cat /usr/include/x86_64-linux-gnu/asm/unistd_64.h
...
#define __NR_read 0
#define __NR_write 1
#define __NR_open 2
#define __NR_close 3
...
#define __NR_set_mempolicy_home_node 450
```

Reminder: Linux Manual

The linux manual (**`man`**) is divided into sections.

Important sections for this course include:

1. Executable programs eg. ls, cp
2. System calls
   - we will be looking at many of these today and in the coming weeks
3. Library functions, types, constants eg. strcpy, scanf, ssize_t

7. Miscellaneous and headers e.g. limits.h

And other sections that you can find out about by using the command **`man man`**
Advice: **`man`** will be available in the exam. Get used to using it!

File Systems in Linux

3 ways to do System Calls in Linux

syscall:

- Make a system call without writing assembler code
- Not usually used by programmers
- Syscalls vary between operating system code is not portable
- Cryptic to use and read
- Handy if there is a new syscall with no wrapper yet

3 ways to do System Calls in Linux

Libc named syscall wrappers:

- More meaningful names
- Helps with type checking
- More portable than syscall but not portable
  - some work on POSIX compliant systems (like linux and MacOS) but won’t work on Windows for example.

3 ways to do System Calls in Linux

Higher level library functions like **stdio.h**:

- useful most of the time
- calls syscall wrapper for you
- portable
- does other cool stuff to make thing easier
- you have been using these to indirectly do your system calls the whole time!

System Calls to Manipulate Files

Important file related system calls

Id	Name	Function
0	read	read some bytes from a **file descriptor**
1	write	write some bytes to a **file descriptor**
2	open	open a file system object, returning a **file descriptor**
3	close	close a **file descriptor**
4	stat	get file system metadata for a pathname
8	lseek	move **file descriptor** to a specified offset within a file

System call to print a message to stdout

`syscall` : make a system call without writing assembler code

- not usually used by programmers
- use to experiment and learn

```
char bytes[13] = "Hello, Zac!\n";

// argument 1 to syscall is the system call number, 1 is write
// remaining arguments are specific to each system call

// write system call takes 3 arguments:
//   1) file descriptor, 1 == stdout
//   2) memory address of first byte to write
//   3) number of bytes to write

syscall(1, 1, bytes, 12); // prints Hello, Zac! on stdout
```

Source code for hello_syscalls.c

Libc wrapper to print message to stdout

```c
char bytes[13] = "Hello, Zac!\n";

// write takes 3 arguments:
//   1) file descriptor, 1 == stdout
//   2) memory address of first byte to write
//   3) number of bytes to write
write(1, bytes, 12); // prints Hello, Zac! on stdout
```

[Source code for hello_libc.c]

stdio library to print message to stdout

```
char bytes[] = "Hello, Zac!\n";
printf("%s", bytes);
```

`printf` will do the write system call for us!
Let's prove it by running **`strace`**

See more ways to print using `stdio.h` with `hello_stdio.c`

Source code for hello_stdio.c

Live Coding: syscall vs libc wrapper, vs stdio

hello.c printing a string to stdout

read_char.c reading byte from stdin

Unix Files

- On Unix-like systems a **file** is sequence/stream of zero or more bytes
    - file metadata doesn't record that it is e.g. ASCII, MP4, JPG, …
    - file extensions are just hints

Demo: Different File formats on Linux

Files and File Systems

- Files typically live on a mechanical or solid state drive
  - To interact with their data - they need to be read into RAM
  - We need to use **system calls** to do this!
    - A system call to open the file
    - System calls to read or write bytes from/to the file
    - A system call to close the file when we finish
- File Systems provide a mapping from the file name to where the files are stored on the drive.

File Descriptors

- **File descriptors** are small integers
  - Uniquely identify a stream/file that is open within a process
  - Are indexes into a per process OS kernel file descriptor table

- OS stores info for each file descriptor such as:
  - File offset: current position in the file
  - File status: read-only, write-only etc
  - Information to locate the actual bytes related to the file/stream

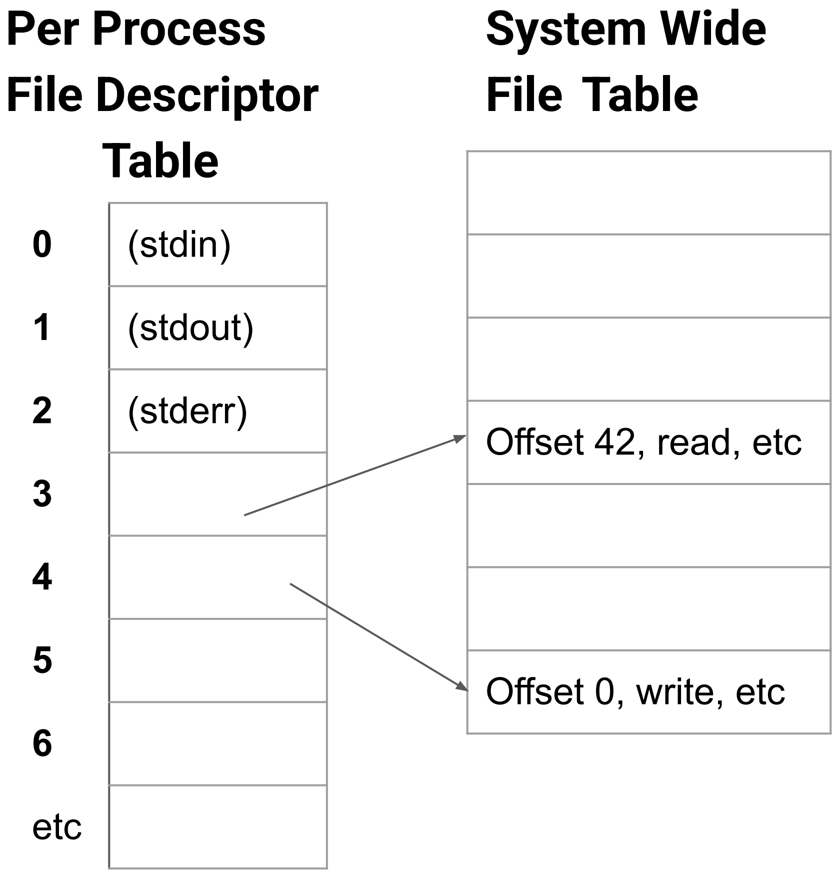
File Descriptors

Every process starts with the 3 standard streams, 0, 1, 2.

When a file is opened, the next available free file descriptor is used.

When a file is closed the file descriptor is released.

When a file is read to or written from, the file offset is updated



What on earth is stderr?

- There are 3 standard streams in linux
  - stdin (0), stdout (1), stderr (2)
- They are treated like they are files in linux
  - They are a sequence of bytes like a file is
- By default
  - stdin : connected to keyboard
  - stdout: connected to terminal
  - stderr: connected to terminal

What on earth is stderr?

- The user can use redirection to send stdout and stderr to different places to separate the output from the error messages
  - ./prog **>** output   #redirects stdout to a file
  - ./prog **2>** error_msgs   #redirects stderr to a file
- Demo: stderr_example.c

Libc Named System Call Wrappers

- Unix-like systems have C library wrapper functions corresponding to most system calls
  - e.g. **open**, **read**, **write**, **close**
  - Typically return **-1** on error and set the error code **errno**
  - Not portable
    - Better to use library functions (eg stdio.h functions) when possible.

errno

- C library has an interesting way of returning error information
    - functions typically return **-1** to indicate error
    - and set **errno** to integer value indicating reason for error
    - you can think of **errno** as a global integer variable

- These integer values are **#define**-d in **errno.h**
    - see man errno for more information
    - **perror()** looks at **errno** and prints message with reason
    - **strerror()** converts **errno** to string describing reason for error

- To see all error codes type **errno -l** on command line

Libc wrapper to open a file

```
int open(char *pathname, int flags);
```

- open file at **`pathname`**, according to **`flags`**
- **`flags`** is a bit-mask defined in **`<fcntl.h>`**

```
int open(char *pathname, int flags, mode_t mode);
```

- Use this version when potentially creating a new file
- **`mode`** is an **octal** number to give the file sensible user access permissions

if successful they return **file descriptor** (small non-negative int)
if unsuccessful they return **`-1`** and set **`errno`** to value indicating reason

Libc wrapper to open a file

Flag	Use
`O_RDONLY`	open for reading
`O_WRONLY`	open for writing
`O_RDWR`	open object for reading and writing
`O_APPEND`	append on each write
`O_CREAT`	create file if doesn't exist
`O_TRUNC`	truncate to size 0

flags can be combined e.g. **`(O_WRONLY|O_CREAT|O_TRUNC)`**

Libc wrapper to close a file

`int close(int fd);`

- release open file descriptor **`fd`**
- if successful, return **`0`**
- if unsuccessful, return **`-1`** and set errno
  - could be unsuccessful if **`fd`** is not an open file descriptor
  - e.g. if **`fd`** has already been closed

number of file descriptors may be limited (maybe to 1024)

- limited number of file open at any time, so use **`close()`**

Libc library wrapper for read system call

```
ssize_t read(int fd, void *buf, size_t count);
```

- read (up to) **`count`** bytes from **`fd`** into **`buf`**
  - **`buf`** should point to array of at least **`count`** bytes
  - read cannot check **`buf`** points to enough space
- if successful, number of bytes actually read is returned
- if no more bytes to read, **`0`** returned
- if error, **-1** is returned and **errno** set
- file descriptor **current position** in file is updated

Libc library wrapper for write system call

```
ssize_t write(int fd, const void *buf, size_t count);
```

- attempt to write **`count`** bytes from **`buf`** into stream identified by **`fd`**
- if successful, number of bytes actually written is returned
- if unsuccessful, **-1** returned and **errno is set**
- file descriptor **current position** in file is updated

Libc syscall Wrappers: Common Types

ssize_t:

- Used for a count of bytes or an error indication.
- A signed integer type that can store range [-1, SSIZE_MAX]

size_t:

- used for a count of bytes
- An unsigned integer type that can store range [0, SIZE_MAX]

off_t:

- used files sizes and offsets. A signed integer type.

Code Demo

open_read.c

open_write_no_truncate.c

open_write_truncate.c

open_write_append.c

open_issue.c

Coming up after Flex week

Working with stdio.h library and files

And much more about file systems and other system calls!

See you in week 7. Have a great Flex Week!

Feedback Please!

Your feedback is valuable!

If you have any feedback from today's lecture, please follow the link below or use the QR Code.

Please remember to keep your feedback constructive, so I can action it and improve your learning experience.

https://forms.office.com/r/hP0wEPPFPX

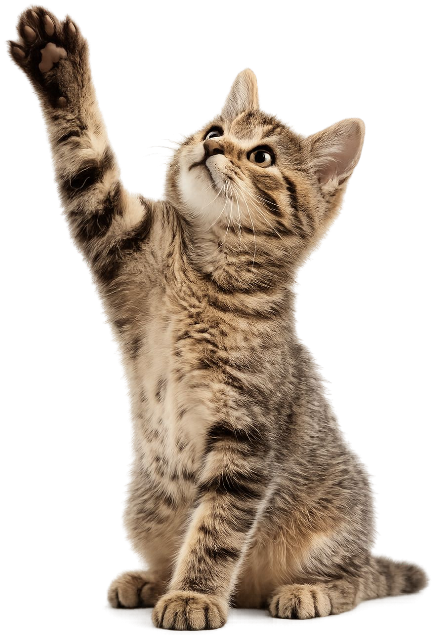
Reach Out

Content Related Questions:

[Forum]

Admin related Questions email:

cs1521@cse.unsw.edu.au



Student Support | I Need Help With...

My Feelings and Mental Health Managing Low Mood, Unusual Feelings & Depression	**Mental Health Connect**	student.unsw.edu.au/**counselling** Telehealth	
	Mind HUB	student.unsw.edu.au/**mind-hub** Online Self-Help Resources	
	In Australia Call Afterhours UNSW Mental Health Support Line	1300 787 026 5pm-9am	
	Outside Australia Afterhours 24-hour Medibank Hotline	+61 (2) 8905 0307	
Uni and Life Pressures Stress, Financial, Visas, Accommodation & More	**Student Support Indigenous Student Support**	student.unsw.edu.au/**advisors**	
Reporting Sexual Assault/Harassment	**Equity Diversity and Inclusion (EDI)**	edi.unsw.edu.au/**sexual-misconduct**	
Educational Adjustments To Manage my Studies and Disability / Health Condition	**Equitable Learning Service (ELS)**	student.unsw.edu.au/**els**	
Academic and Study Skills	**Academic Language Skills**	student.unsw.edu.au/**skills**	
Special Consideration Because Life Impacts our Studies and Exams	**Special Consideration**	student.unsw.edu.au/**special-consideration**	