

ENGG1003 - Tuesday Week 4

Loose Ends Functions

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Subscript Notation

- ▶ Last chance to learn that we use:

$$x_1, x_2, x_3, \dots, x_n \quad (1)$$

and

$$x_n = x_{n-1} + x_{n-2} \quad (2)$$

notation because it is the simplest method that gets the point across.

Subscript Notation

- ▶ x_n means that x is “some number” and n is an *integer* value
- ▶ n implies *uniqueness* (ie: x_1 and x_2 can differ)
- ▶ n implies an *order* to the x 's
- ▶ A formal mathematical statement of the above would be something like:

$$x_n : x \in \mathbb{R} \text{ and } n \in \mathbb{Z} \quad (3)$$

- ▶ \mathbb{R} is the set of real numbers
- ▶ \mathbb{Z} is the set of all integers

Subscript Notation

- ▶ Without this notation it is *really* hard to write things like:

$$x_n = x_{n-1} + x_{n-2} \quad (4)$$

Subscript Notation

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$$x_n = x_{n-1} + x_{n-2} \quad (4)$$

- ▶ If you instead wrote:
“Calculate a sequence of numbers, a, b, c, d, \dots ”
how would you write the equation?

Considering Dropping?

- ▶ HECS census is Fri 22nd
- ▶ Before you drop:
 - ▶ Talk to me
 - ▶ Are you *legitimately* unprepared or experiencing “imposter syndrome”?
 - ▶ It is surprisingly common
 - ▶ Most of you have to pass eventually
 - ▶ There are some legitimate reasons
- ▶ Ignore unsolicited advice from demonstrators
 - ▶ Seriously, this isn't their job

FOR Loops in C

- ▶ The C FOR loop syntax is:

```
1 for( initial ; condition ; increment ) {  
2     // Loop block  
3 }
```

- ▶ Where:

- ▶ `initial` is a statement executed *once*
- ▶ `condition` is a statement executed and tested *before* every loop iteration
- ▶ `increment` is a statement executed *after* every loop iteration, but *before* the `condition` is tested

FOR Loops in C

```
1 for( x = 0 ; x < 10 ; x++ ) {  
2     printf("%d\n", x);  
3 }
```

- ▶ Run this code
- ▶ Observe that:
 - ▶ 0 is printed
 - ▶ 10 is **not** printed
 - ▶ x increments automatically

FOR Example 1 - Factorials

- ▶ Use FOR to count from 2 to our input number
- ▶ Keep a running product as we go

```
BEGIN
  INPUT x
  result = 1
  FOR k = 2 TO x
    result = result * k
  ENDFOR
END
```

- ▶ Is this algorithm robust? What happens if:
 - ▶ $x = -1$
 - ▶ $x = 1$
 - ▶ $x = 0$ (**NB:** $0! = 1$ because *maths*)

BREAK Statements

- ▶ Sometimes you want to exit flow control early
- ▶ The flow-control mechanism for this is a BREAK statement
- ▶ If executed, execution jumps outside the current `if()`, `while()`, `for()`, etc
- ▶ BREAKs *typically* go inside an IF

FOR Example 2

- ▶ Two equivalent ways to implement the $\cos()$ series from before are:

NB: $|tmp|$ means “absolute value of tmp”.

```
BEGIN
  INPUT x
  sum = 0
  FOR k = 0 to 10
    tmp =  $\frac{(-1)^k x^{2k}}{(2k)!}$ 
    sum = sum + tmp
    IF |tmp| < 1e-6
      BREAK
    ENDIF
  ENDWHILE
END
```

```
BEGIN
  INPUT x
  tmp = 1
  k = 0
  sum = 0
  WHILE (k < 10) AND (|tmp| > 1e-6)
    tmp =  $\frac{(-1)^k x^{2k}}{(2k)!}$ 
    sum = sum + tmp
    k = k + 1
  ENDWHILE
END
```

break Statements

- ▶ The example is mildly pointless
 - ▶ In C, the $|tmp| < 1e - 6$ condition can go in the `for()` statement. In pseudocode it *sort of* can't.
- ▶ It is there to illustrate what `break` does, not explain how to use it
- ▶ As the “experienced engineer” you choose when to use it

FOR Loops in C (Advanced)

- ▶ `for()` syntax allows multiple expressions in the `initial` / `condition` / `increment` sections
- ▶ Separate expressions with commas
- ▶ eg:

```
1 int x, y=10;  
2 for( x = 0 ; x < 10 ; x++, y++ ) {  
3     printf("x: %d y: %d\n", x, y);  
4 }
```

- ▶ This increments both `x` and `y` but only `x` is used in the condition

Loop continue Statements

- ▶ A `continue` causes execution to jump back to the loop start
- ▶ The *condition* is tested before reentry
- ▶ eg, run this in the Che debugger:

```
1 int x;  
2 for(x = 0; x < 10; x++) {  
3     if(x%2 == 0)  
4         continue;  
5     printf("%d is odd\n");  
6 }
```

- ▶ (Not the best example but gets the point across)

break and continue

- ▶ Some programmers claim that `break` and `continue` are “naughty”
- ▶ Well, yes, but actually no
- ▶ They *can* make your code needlessly complicated
- ▶ They might make it simpler
- ▶ It is up to you to judge
- ▶ As engineers you shouldn't follow strict rules
- ▶ Always try to choose the best tool for the job

GOTO

- ▶ There exists a GOTO flow control mechanism
 - ▶ Sometimes also called a *branch*
- ▶ It “jumps” from one line to a different line
 - ▶ An ability some consider to be unnatural
- ▶ It exists for a purpose
- ▶ That purpose does not (typically) exist when writing C code
 - ▶ C *supports* a `goto` statement
 - ▶ It results in “spaghetti code” which is hard to read
 - ▶ Don't use it in ENGG1003
- ▶ You *must* use branch instructions in ELEC1710

switch() - case:

- Sometimes you want to code something like:

```
1 if (x == 0) {  
2     // stuff  
3 } else if (x == 1) {  
4     // stuff  
5 } else if (x == 2) {  
6     // stuff  
7 } ...etc
```

- This is difficult to read and gets unwieldy. Fast.

switch() - case:

- ▶ Instead, C has:

```
1 switch(expression) {  
2     case constant:  
3         break;  
4     case constant:  
5         break;  
6     default:  
7 }
```

- ▶ The *expression* is anything which evaluates to a number
- ▶ The *constants* are either literals or variables declared as `const` (covered later)

switch() - case: Example

```
1 int x=1, y=2;
2
3 switch(x==y) { // Evaluates to 0 or 1
4     case 0:
5         printf("x and y differ\n");
6         break;
7     case 1:
8         printf("x and y are equal\n");
9         break;
10    default:
11        printf("Something went very wrong\n");
12 }
```

- The default: case happens if the expression doesn't match any other option

switch() - case: Example

- If the `break;` is omitted execution continues line by line - run this in Che

```
1 #include<stdio.h>
2 int main() {
3     int x = 2;
4     switch(x) {
5         case 1: printf("x is 1\n");
6         case 2: printf("x is 2\n");
7         case 3: printf("x is 3\n");
8         default: printf("x is not 1, 2, or 3\n");
9     }
10    return 0;
11 }
```

switch() - case: Limits

- ▶ Because the case statements only accept *constants* there are some limitations
- ▶ Example, this doesn't translate well:

```
1 if (x < 0) {  
2     // stuff  
3 } else if (x == 0) {  
4     // stuff  
5 } else if (x > 0) {  
6     // stuff  
7 }
```

- ▶ $(x < 0)$, $(x == 0)$, and $(x > 0)$ are all 0 or 1
- ▶ Can't *easily* translate this into three unique constants

Loose End: Increment Example

```
1 #include <stdio.h>
2 int main() {
3     int x = 0;
4     int y = 0;
5     int z = 0;
6     y = ++x + 10;
7     printf("Pre-increment: %d\n", y);
8     y = z++ + 10;
9     printf("Post-increment: %d\n", y);
10    return 0;
11 }
```

Pre/post-inc/decrements have many applications, more details in coming weeks.

Binary Nomenclature

- ▶ A data type's value range is a result of the underlying binary storage mechanism
- ▶ A single binary digit is called a *bit*
- ▶ There are 8 bits in a *byte*
- ▶ In programming we use the “power of two” definitions of kB, MB, etc:
 - ▶ 1 kilobyte is $2^{10} = 1024$ bytes
 - ▶ 1 Megabyte is $2^{20} = 1048576$ bytes
 - ▶ 1 Gigabyte is $2^{30} = 1073741824$ bytes
 - ▶ (Advanced) These numbers look better in hex: 0x3FF, 0xFFFFF, etc.

Binary Nomenclature

- ▶ Observe that kilobyte, Megabyte, Gigabyte, etc use scientific prefixes
- ▶ These *normally* mean a power of 10:
 - ▶ kilo- = 10^3
 - ▶ Mega- = 10^6
 - ▶ Giga- = 10^9
 - ▶ ...etc (see the inside cover of a physics text)
- ▶ Computer science adopted these terms and re-defined them

Binary Nomenclature

- ▶ This has made some people *illogically angry*
- ▶ Instead, we can use a more modern standard:
 - ▶ 2^{10} bytes = 1 kibiByte (KiB)
 - ▶ 2^{20} bytes = 1 Mebibyte (MiB)
 - ▶ 2^{30} bytes = 1 Gibibyte (GiB)
 - ▶ ...etc
- ▶ Generally speaking, KB (etc) implies:
 - ▶ powers of two to *engineers*
 - ▶ powers of ten to *marketing*
 - ▶ The number is smaller
 - ▶ Hard drive manufacturers, ISPs, etc like this

Unambiguous Integer Data Types

- ▶ Because the standard `int` and `long` data types don't have fixed size unambiguous types exist
- ▶ Under OnlineGDB (ie: Linux with `gcc`) these are defined in `stdint.h` (`#include` it)
- ▶ You will see them used commonly in embedded systems programming (eg: Arduino code)
- ▶ The types are:
 - ▶ `int8_t`
 - ▶ `uint8_t`
 - ▶ `int16_t`
 - ▶ `...etc`

Code Blocks in C

- ▶ Semi-revision:
- ▶ The curly braces `{ }` encompass a *block*
- ▶ You have used these with `if()` and `while()`
- ▶ They define the set of lines executed inside the `if()` or `while()`

Code Blocks in C

- ▶ You can place blocks anywhere you like
- ▶ Nothing wrong with:

```
1 int main() {  
2     int x;  
3     {  
4         printf("%d\n", x);  
5     }  
6     return 0;  
7 }
```

- ▶ This just places the `printf()` ; inside a block
- ▶ It doesn't do anything useful, but...

Variable Scope

- ▶ A variable's "existence" is limited to the block where it is declared
 - ▶ Plus any blocks within that one
- ▶ Example this code won't compile:

```
1 #include <stdio.h>
2 int main() {
3     int x = 2;
4     if(x == 2) {
5         int k;
6         k = 2*x;
7     }
8     printf("%d\n", k);
9     return 0;
10 }
```

Variable Scope

- ▶ Note that `k` was declared inside the `if()`
- ▶ That means that it no longer exists when the `if()` has finished
- ▶ This generates a compiler error
- ▶ It frees up some RAM
- ▶ It also lets the variable's name be reused elsewhere
 - ▶ This can be *really* confusing. Be careful.

Functions

- ▶ A *function* is a block of code which can be *called* multiple times, from multiple places
- ▶ They are used when you want the same block of code to execute in many places throughout your code
- ▶ A function requires:
 - ▶ A name
 - ▶ (optional) A *return value*
 - ▶ (optional) One or more *arguments*

Functions in Mathematics

- ▶ In mathematics you saw functions written as:

$$y = f(x)$$

- ▶ Here, the function is called f , takes an argument of x and returns a value which is given to y
- ▶ C and pure mathematics have these general ideas in common

Functions in Mathematics

- ▶ In mathematics you saw functions written as:

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- ▶ Here, the function is called f , takes an argument of x and returns a value which is given to y
- ▶ C and pure mathematics have these general ideas in common
- ▶ The similarities stop there

Function Examples

- ▶ So far, some of you have used *library functions*
- ▶ These are functions which are pre-existing within the compiler (and its libraries)
- ▶ I have shown you:
 - ▶ `scanf()` ;
 - ▶ `printf()` ;
 - ▶ `rand()` ;

Function Syntax

- ▶ Writing `rand()` ; in you code is *calling* the function
- ▶ The program execution “jumps” into the function’s code, executes it, then jumps back
- ▶ Function call syntax is:
`name([arguments])`
- ▶ Not all functions take arguments
- ▶ The function can “turn into” its *return value*

Function Examples

▶ Example 1:

```
1 x = rand();
```

- ▶ rand is the function name
- ▶ It returns a “random” integer
- ▶ The return value is allocated to x
- ▶ It doesn't take an argument

Function Examples

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▶ Example 2:

```
1 y = sqrtf(x);
```

- ▶ `sqrtf` is the function name
- ▶ `x` is the argument
- ▶ It returns the square root of `x`
- ▶ The return value is allocated to `y`

Functions

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- ▶ Example from documentation
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 - ▶ The return value is an `int`
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Functions

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- ▶ Example from documentation
 - ▶ `int rand(void);`
 - ▶ The return value is an `int`
 - ▶ The argument is type `void`
 - ▶ This just means there aren't any
 - ▶ `float sqrtf(float x);`
 - ▶ The return value is a `float`
 - ▶ The argument is a `float`
 - ▶ Argument is called `x` in documentation but you can pass it any `float`

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 - ▶ In conditions
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- ▶ Function return values, variables, and literals can all be used in the same places:
 - ▶ In arithmetic
 - ▶ In conditions
 - ▶ As arguments to other functions
- ▶ The C standard is *very* specific about what return values are but I will be informal for now
 - ▶ Technically, for example, an expression like $x=y+5.0$; also has a “return value” equal to the value allocated to x

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 - ▶ `if((rand()%6) < 2)`
 - ▶ `while(sin(x) < 0)`

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 - ▶ `if((rand()%6) < 2)`
 - ▶ `while(sin(x) < 0)`
 - ▶ This next one is complicated...
 - ▶ `x = sin((double)rand());`
 - ▶ Generates a random integer, casts to `double`, uses that number as an argument to the `sin()` function

Using Functions

- ▶ (semi-revision)
- ▶ Before you use a function you must:
 - ▶ Read the documentation
 - ▶ `#include` the correct header file
 - ▶ Add the correct library to the compiler options
 - ▶ In C we've done this for the maths library
 - ▶ `stdio` and `stdlib` are always there
 - ▶ Be aware of the data types
 - ▶ Do you need any type casting?
 - ▶ Are you using the correct function?

Maths Functions

- ▶ Since some of you have already used them, lets learn about the maths library...
- ▶ It includes functions for:
 - ▶ Trigonometry
 - ▶ Exponentials (base e) & logarithms (base e, 10, 2)
 - ▶ Exponents (`pow()` ;)
 - ▶ Rounding (`floor()` ; & `ceil()` ;)
 - ▶ Floating point modulus (`fmod()` ;)
 - ▶ Square roots
 - ▶ ...etc

Maths Functions

- ▶ There are typically *different* functions for `float` and `double`
- ▶ This can have a huge speed impact
- ▶ Use the right ones!
- ▶ `float` maths functions typically end in 'f'
 - ▶ `cosf()` ;
 - ▶ `sqrtf()` ;
 - ▶ `atanf()` ;
 - ▶ ...etc
- ▶ `double` maths functions **don't**
 - ▶ `cos()` ;
 - ▶ `log()` ;

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 - ▶ Inverse trig functions are called “arcus functions”
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 - ▶ \tan^{-1} is $\text{atan}()$;
 - ▶ The “4 quadrant” arctan function is $\text{atan2}()$;
 - ▶ $\text{atan}(x)$; returns $[-\pi/2, \pi/2]$
 - ▶ $\text{atan2}(x, y)$; returns $[-\pi, \pi]$ depending on the quadrant of the point x, y
 - ▶ Very useful for polar to Cartesian coordinate transforms (probably beyond 1st semester 1st year)

Example - Quadratic Equation

Write a C program which uses the standard library function `sqrtf()` ; as part of the calculations required to produce solutions to a quadratic equation:

$$ax^2 + bx + c = 0 \quad (5)$$

using

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (6)$$

...do it live in Che

Example - `scanf()` ; 's Return Value

Read the `scanf()` ; documentation and observe that it returns an `int`. What does that `int` represent? Write some test code and experiment with its behaviour.

Demonstrate it live in Che .

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Writing Functions

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 4. Write a *function prototype*
 - ▶ Write it at the top of your code [or in a header file]
 5. Somewhere below `main()` (or in another `.c` file) write the function *definition*
- ▶ For now just keep everything in one file
 - ▶ Unless you study ahead. I won't stop you.

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- ▶ Before a function is *called* the compiler needs to know:
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Function Prototypes

- ▶ Huh? What's a function prototype?
- ▶ Before a function is *called* the compiler needs to know:
 - ▶ Its name
 - ▶ Its argument's data type(s)
 - ▶ Its return data type
- ▶ A function prototype documents these things for the compiler

Function Prototypes

- ▶ The function prototype syntax is:

```
1 [return data type] function_name(arguments);
```

Function Prototypes

- ▶ The function prototype syntax is:

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1 [return data type] function_name(arguments);
```

- ▶ The arguments section is a comma separated list with the following syntax:

```
1 (datatype name, datatype name, ...)
```

- ▶ Examples:

- ▶ `float sqrtf(float x);`
- ▶ `int rand(void);`
- ▶ `double log(double x);`
- ▶ `double atan2(double x, double y);`

Void

- ▶ If either the arguments or return value aren't required declare them as `void`
- ▶ This is an explicit way of saying "this item doesn't exist"

Function Prototypes

- ▶ The function prototype must be *before* the function's first use
- ▶ For “small” projects: above `main()`
- ▶ For “big” projects: in their own *header file*
 - ▶ We'll cover this later
- ▶ Don't leave the prototype's arguments blank
 - ▶ The compiler won't complain but it is a deprecated language feature

Function Definitions

- ▶ The function prototype tells the compiler how the function interacts with other code
- ▶ The function definition is the *actual code* that gets executed when the function is called

```
1 int add(int a, int b); // Prototype
2
3 main() {
4     // do stuff
5 }
6
7 int add(int a, int b) { // Definition
8     return a + b;
9 }
```

Function Prototypes Vs Definitions

- ▶ For the time being:
 - ▶ The prototype goes *above* `main()`
 - ▶ It is 1 line and ends with a semicolon ;
 - ▶ The definition goes *below* `main()`
 - ▶ It is the prototype repeated followed by a `{ }` block

Writing Functions - Example

- ▶ Lets implement the Week 2 `sqrt` algorithm as a function
- ▶ ...Then compare with `sqrtf()` ;
- ▶ Keep it simple: fixed iteration count `n=10`

Writing Functions - Example

- In mathematics, calculate \sqrt{k} by iterating:

$$x_n = \frac{1}{2} \left(x_{n-1} + \frac{k}{x_{n-1}} \right)$$
$$x_0 \neq 0$$

- In a code snippet:

```
1 // Calculate sqrt(k)
2 float k = 26; // Test value, sqrt(26)=5.0990
3 float xn = x/2.0; // x0 = x/2 because why not?
4 int n;
5 for(n = 0; n < 10; n++) {
6     xn = 0.5*(xn + k/xn);
7 }
```

Writing Functions - Example

- ▶ Lets make some design decisions:
 - ▶ Name: `mySqrt()` ;
 - ▶ Argument: `float k`
 - ▶ Return Value: `float`
- ▶ The function prototype is therefore:

```
1 float mySqrt(float k);
```

Writing Functions - Example

- Place the function prototype before `main()`:

```
1 #include <stdio.h>
2
3 float mySqrt(float k);
4
5 int main() {
6     // Do stuff
7 }
```

Writing Functions - Example

- Write the function definition below `main()`

```
1 #include <stdio.h>
2 float mySqrt(float k);
3 int main() {
4     printf("sqrt(26) = %f\n", mySqrt(26.0));
5 }
6
7 float mySqrt(float k) {
8     int n;
9     float xn = k/2.0;
10    for(n = 0; n < 10; n++)
11        xn = 0.5*(xn + k/xn);
12    return xn;
13 }
```

End of Tuesday lecture marker