ENGG1003 - Monday Week 5

Static Variables
Commenting
Arrays
Maybe Strings

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Static Variable Example

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- Function prototype: `int counter(void);`
- Function definition:

```
1 int counter() {
2   static int count = 0;
3   return count++;
4 }
```

Static Variable Example

- The variable `count` is declared `static`
- The initialisation, `count = 0`, happens *once*
- The value of `count` is retained between function calls

```
1 int counter() {
2   static int count = 0;
3   return ++count;
4 }
```

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  - For multiple reasons we try to avoid variables with global scope
    - Good discussion here

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- The function can be called from *anywhere* in your code
- A "counter" variable that did the same job would have to be "global" to be visible anywhere
  - For multiple reasons we try to avoid variables with global scope
    - Good discussion here
  - There are *very good* reasons to use them in embedded systems, but not on a desktop PC or server

Static Variable Example

Wrapping the function in some test code:

```
1  #include <stdio.h>
2
3  int counter(void);
4
5  int main() {
6    for(int k = 0; k < 10; k++)
7      printf("counter(): %d\n", counter() );
8    return 0;
9  }
10
11 int counter(void) {
12   static int count = 0;
13   return count++;
14 }
```

Test Code?

- "Test code" is a term I made up
- It means the minimum amount of code required to verify a function's behaviour
- Always test your functions *in isolation*!

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- It means the minimum amount of code required to verify a function's behaviour
- Always test your functions *in isolation*!
- If you write "too much" code before testing it will make debugging **much** harder

Test Code

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Test Code

- How much is "too much"?
- Personally?
- After 20 years of experience?
  - 1-5 lines
- Never underestimate:
  - How hard programming is
  - How easy it is to make mistakes
  - How *brutally catastrophic* bugs can be

Bug Case Study

Paraphrased from Wikipedia:

"The Therac-25 was a computer-controlled radiation therapy machine ... It was involved in at least six accidents ... in which patients were given massive overdoses of radiation. Because of concurrent programming errors, it sometimes gave its patients radiation doses that were hundreds of times greater than normal, resulting in death or serious injury."

Back to Functions...

- When should functions be used?

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- When should functions be used?
- Well, what do they achieve?
  - *Much* easier to solve problems when they're broken down into sub-tasks
  - Reduce code line count and complexity (if they are called multiple times)
  - Allows code re-use between projects
  - *Much* easier to perform project management between multiple programmers
  - Bugs in a function are easier to fix than a bug in code which has been copy+pasted multiple times
  - ...the list goes on

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  - Break a big problem into multiple sub-problems
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    - Do what you feel is most "readable"
    - Your opinion here will change with experience, I will try to provide guidance

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- This one sparks joy:

```
1 main() {
2   int x;
3   // do stuff
4   if(x < 0) {
5     // do other stuff
6     x++;
7   }
8 }
```

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- This one does not spark joy:

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1 main() {
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1 main() { int x; // do stuff
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1 main() { int x; // do stuff
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```

- We indent to make code easier to read
- Every block gets indented by one tab
  - Or 2-4 spaces
- Try to keep one statement per line

Indenting

- Lots of indentation styles exist
- Indentation is the correct word
  - I say indenting because I'm slack
- Great list on Wikipedia
- In industry, different companies / teams / projects can use different indentation styles
  - None of them are "better" than the others
  - The "best" is "whatever you're used to"
  - I vaguely follow "K&R" style

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- Pick a style you like and *be consistent*

Functions and Comments

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- But what is "good" commenting?
- Lets look at some examples:
  - From the Linux kernel source
  - From an embedded systems library
- Just a little different from each other, eh?
- Commenting is very application specific
- Commenting is very audience specific

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- On one hand: only comment what *you* need
- On the other: we need to assess your comments eventually...
- And the assessment needs to minimise demonstrator judgement...
- Maybe I create different strict rules for different assignments? Similar to ENGG1500 report rules.

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- What do you do if you need a million of them?

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- Use an *array*!
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- What do you do if you need a million of them?
- Declare a million variables?
- Cry?
- Use an *array*!
  - Maybe still cry...at first.
- An *array* is a collection of variables of the same data type

Arrays

- Remember the mathematics notation:

$$x_0, x_1, x_2, x_3, \ldots$$

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- We used it for a single variable, x, changing with time
  - The "old" values of x were discarded
- An array allows us to store *all* the values of x_n in memory
- The variable name, x, and the "index", n, are both needed to access a particular value

Arrays

- In C, an array declaration **needs** three things:
  - The data type
  - A name
  - The number of *elements*
- (Optional) Arrays can be initialised
- The syntax for an array of length N is:

```
data_type name[N];
```

- Examples:
  - `int list[20];`
  - `char name[200], c; //array and var`
  - `double data[100000];`

Arrays

- The length may be a variable
  - Careful: "a" variable, lengths don't change
- The variable's value must be known at the time of declaration
- This is fine:

```
1 int x;
2 scanf("%d", &x);
3 int array[x];
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  - If `x` is large enough your program will access memory the operating system has not allowed it to
  - This will cause segmentation faults (Linux/macOS) or illegal operations (Windows)

Using Arrays

- A C array of size N is *indexed* from 0 to $N-1$
  - Programmers get *illogically angry* when arguing about 0-indexing Vs 1-indexing
- To access an *element* use the syntax:

```
1 arrayName[index]
```

  where `index` **must be an integer**
- Each array index has a *different* physical memory address
- Each array index accesses a unique variable

Array Initialisation

- General rule: all variables need to be initialised before use
- For arrays, there are two solutions:
  1. Initialise at declaration with the syntax:

```
1 int x[10] = {1,2,3,4,5,6,7,8,9,0};
```

     When doing this the size is optional:

```
1 int x[] = {1,2,3}; // int x[3]
```

  2. Manually initialise in a loop

Array Initialisation

- When the array is "large" do this instead:

```
1 int x[N];
2 int counter;
3 for(counter = 0; counter < N; counter++) {
4   x[counter] = 0;
5 }
```

Array Usage

- Array elements can be used anywhere that variables, literals, and function return values can be used
- This includes:
  - In arithmetic expressions
  - As function arguments
  - As lvalues (left side of =)
- Examples:
  - `x = y[12] + 28.0;`
  - `x[0] = 1.0;`
  - `printf("%f\n", x[2]);`
  - `y = sin(x[i]);`

Array Usage

- Arrays are very frequently used in loops
- Example: add up all numbers in an array:

```
1 float x[1000];
2 // x[] gets filled with numbers somehow
3 float sum = 0;
4 float i; // Array index
5 for(i = 0; i < 1000; i++)
6   sum = sum + x[i];
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```

- The Week 5 lab gets you to use an array in statistical analysis

When to use Arrays

- An array must be used when a loop is used to process data
  - There is no other way to "index" individual variables
- Arrays are required to process *strings*
  - Written ASCII text, seen later
- An array *should* be used when it is a convenient way to group together multiple variables with a similar "theme"
  - This is for readability and maintainability

Array Problems

- The size of an array is not intrinsically known
- You must manually make sure that the array index never exceeds the array's boundary!
- The following program is **guaranteed** to crash:

```
1 #include <stdio.h>
2
3 int main() {
4   int x[10];
5   int idx;
6   for(idx = 0; idx < 100000000000L; idx++)
7     printf("%d\n", x[idx]);
8 }
```

Variables in Memory

- Visualising how data fits in computer memory is crucial
- Foundation principles:
  - Everything is stored in binary
  - Memory locations have *addresses*
  - Memory is *byte-addressed*
  - C data types can be multiple bytes long
  - Variables get unique memory addresses

Variables in Memory

- Each variable gets a unique "chunk" of memory
- Details are complicated, just imagine they get packed next to each other for now
- An array is packed into a *contiguous block*
  - They are all in single blob, no gaps
  - `x[0]` gets the lowest memory address
  - `x[1]` the one above that, etc
- Lets draw some boxes...

Variables in Memory

- How are these variables "packed" into memory?

```
1 char a; // 1 byte
2 int i; // 4 bytes
3 int x[2]; // 2 integers, each 4 bytes
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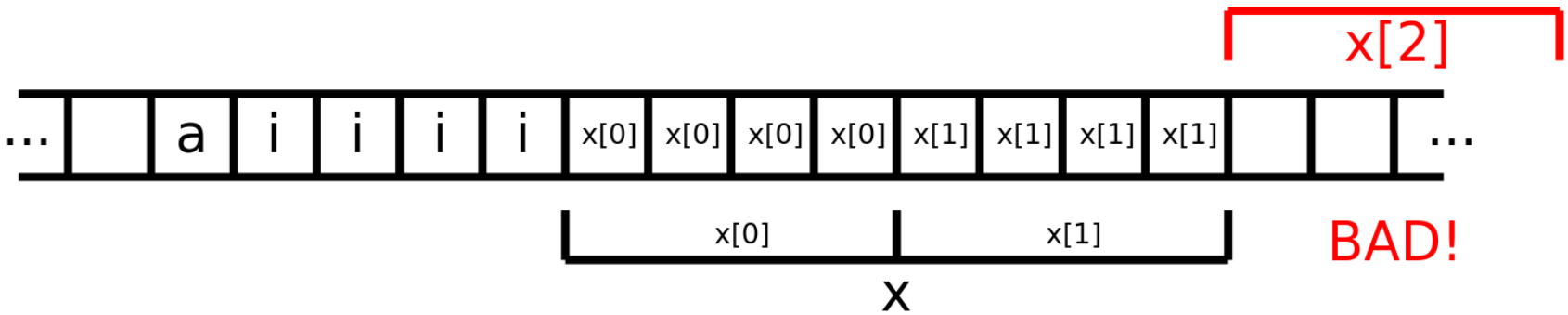
Variables in Memory

- How are these variables "packed" into memory?

```
1 char a; // 1 byte
2 int i; // 4 bytes
3 int x[2]; // 2 integers, each 4 bytes
```

- What would memory `x[2]` access?
- Each box below is one byte:



Variables in Memory

- In that example, `x[2]` accesses memory outside that allocated to `x[]`
- The compiler won't stop you accessing "bad" memory addresses!
- You will either be given "junk" data or cause a crash
- Drawing memory diagrams will help you understand pointers later

Variables in Memory

- Lets study this with a real example
- The `&` symbol is an *operator* which turns a variable name into a memory address
- We can use this to explore how the compiler allocates memory to variables

```
1 char a;
2 int i;
3 int x[2];
4 printf("Address of a:   \t%lu\n", &a);
5 printf("Address of i:   \t%lu\n", &i);
6 printf("Address of x[0]:\t%lu\n", &x[0]);
7 printf("Address of x[1]:\t%lu\n", &x[1]);
```

Variables in Memory

- The output on a 64-bit Linux system is:

```
Address of a:     140722511065979
Address of i:     140722511065980
Address of x[0]:  140722511065984
Address of x[1]:  140722511065988
```