

Confusing Your Tutor

Introduction to C Obfuscation

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“Don’t do this, don’t make your tutor cry.”
— Dr. Andrew Taylor, COMP1511 18s1

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- In short, making code harder to read.
- A slightly separate concern: code golf.
- Writing code using as few characters as possible.

Why Obfuscate?

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 - In an exam, your marker gives up on reading your code.
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- For C in particular, most techniques are defeated by the compiler...

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int fib(int n) {  
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Then we'll compile them with optimisation enabled (-O) and inspect the assembly code (-S):

```
clang -S -O -o fibonacci.s fibonacci.c
```

```
clang -S -O -o fibonacci-obf.s fibonacci-obf.c
```


Why Not?

```

        .text
        .file    "fibonacci.c"
        .globl   fib
        .p2align 4, 0x90
        .type    fib,@function

fib:
        .cfi_startproc
# %bb.0:
        movl     $1, %eax
        cmpl     $2, %edi
        jl       .LBB0_3
# %bb.1:
        addl     $-1, %edi
        movl     $1, %ecx
        xorl     %edx, %edx
        .p2align 4, 0x90
.LBB0_2:
        movl     %edx, %eax
        addl     %ecx, %eax
        movl     %ecx, %edx
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- The compiler is a lot smarter than we are.
- So this can't actually stop people from figuring out what the *compiled* program is doing.
- There are other ways to do that, which this workshop is too narrow to contain.

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I'm not an expert in C so I can't show you everything, but I should be able to at least show you some things.

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- We will cover a few examples relating to MATH11[34]1, MATH1081, COMP1521, but you don't need to have taken these courses.
- If you want to follow along, you should have an editor / IDE and a C compiler at the ready.

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Between each of these we'll take a quick 5 minute break.

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// Simple to read

#define FACTOR 42
int eliminate_divisible(int * numbers,
                        int size)
{
    int count = 0;

    for (int i = 0; i < size; i++) {
        if (numbers[i] % FACTOR == 0) {
            numbers[i] = 0;

            // Record how many numbers we
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```
// Is it still obvious what this is doing?

int e(int * n, int s)
{
    int c = 0;

    for (int i = 0; i < s; i++) {
        if (n[i] % 42 == 0) {
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Obfuscation Quiz 1: MATH1081

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What does this function return if called as `e(47, 19)`?

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int e(int a, int b)
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Answer: 1. This is actually the *Euclidean Algorithm* for calculating the GCD of two numbers. 47 and 19 are both prime, so their GCD is definitely 1. For a non-mathematician especially the Euclidean Algorithm would be hard to identify just by pseudocode, so removing the name makes it difficult to read.

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```
// Those look like functions,
// but are they really?

#define D(a,b,c) a[b] % c == 0
#define F(v,l) int v = 0; v < l; v++

int e(int * n, int s)
{
    int c = 0;

    for (F(i, s)) {
        if (D(n, i, 42)) {
            n[i] = 0;
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    }

    return c;
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#define ERR(s) fprintf(stderr, s); exit(1);

FILE * open_check(const char * name)
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    if (f == NULL)
        ERR("Failed to open file\n");

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How many semicolons are on the end of the line inside the `if` statement? Does this matter?

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What does this program print?

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#include <stdio.h>

#define A 3
#define B 5
#define C A + B

int main(void)
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    printf("%d\n", C * A);
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Answer: 18. The macros are expanded literally to be $3 + 5 * 3$, where BIDMAS takes over.

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Answer: 18. The macros are expanded literally to be $3 + 5 * 3$, where BIDMAS takes over. This is in contrast to what would happen if A, B and C were variables.

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- Doesn't work well for simple functions, sometimes people write simple functions like that anyway.
- Macros can be defeated trivially with `gcc -E`.
- Macros also must be on their own line (more relevant for golfing which we will discuss later).

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```
// A function using if statements  
  
char toggle_case(char c)  
{  
    if (c >= 'a' && c <= 'z') {  
        return c + ('A' - 'a');  
    } else {  
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    return (c >= 'a' && c <= 'z')
        ? c + ('A' - 'a')
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int factors(int n)
{
    int c = 0;

    for (int i = 1; i <= n; i++) {
        // What's happening here?
        c += (n % i) ? 0 : 1;
    }

    return c;
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        // What's happening here?
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    }

    return c;
}
```

```
void fizzbuzz(int n)
{
    // Ace your interviews with this one
    // weird trick!
    printf((n % 3 && n % 5)
        ? "%d%s\n"
        : "%s%s\n",
        (n % 3 && n % 5)
        ? n
        : ((n % 3) ? "" : "Fizz"),
        (n % 5)
        ? ""
        : "Buzz");
}
```

As the example on the right shows, nesting ternary operators can lead to some very nasty code.

Obfuscation Quiz 3: Positives and Negatives

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What does this code print?

```
#include <stdio.h>

int main(void)
{
    int a = 0, b = 0, c = 0;
    printf("%d\n", (a=1)?(a--?(--a(++b)+c++):(c+++a)):(--a(--b)-(--c)));
}
```

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}
```

1 1

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}
```

1 1

2 0

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3 -1

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4 Compilation error

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4 Compilation error

Answer: 0.

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2 0

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4 Compilation error

Answer: 0. `a = 1` sets `a` to 1 and evaluates as 1 (true).

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Answer: 0. `a = 1` sets `a` to 1 and evaluates as 1 (true). `a--` sets `a` to 0 but evaluates as 1 (true).

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```

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3 -1

4 Compilation error

Answer: 0. `a = 1` sets `a` to 1 and evaluates as 1 (true). `a--` sets `a` to 0 but evaluates as 1 (true). Then `--a+(++b)+c++` evaluates to `--0+(++0)+0++` or `(-1)+(1)+(0)` (but setting `c` to 1 after evaluating).

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Answer: 0. `a = 1` sets `a` to 1 and evaluates as 1 (true). `a--` sets `a` to 0 but evaluates as 1 (true). Then `--a+(++b)+c++` evaluates to `--0+(++0)+0++` or `(-1)+(1)+(0)` (but setting `c` to 1 after evaluating). Side note: Is `c+++a` equivalent to `(c++)+a` or `c+(++a)`?

Conditionals in Arithmetic

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In C, zero is treated as false, and non-zero values are treated as true. You've probably seen this being used already to check for the end of strings, or the return value of `malloc()`.

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In C, zero is treated as false, and non-zero values are treated as true. You've probably seen this being used already to check for the end of strings, or the return value of `malloc()`.

```
// String Length
int length(char * str)
{
    int l = 0;

    for (int i = 0; s[i]; i++) {
        l++;
    }

    return l;
}
```

Conditionals in Arithmetic

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```
// String length

int length(char * str)
{
    int l = 0;

    for (int i = 0; s[i]; i++) {
        l++;
    }

    return l;
}
```

```
// New linked list node

node_t * new_node(int val)
{
    node_t * new = malloc(sizeof(node_t));

    if (!new) {
        fprintf(stderr, "PANIC! PANIC!\n");
        return NULL;
    }

    new->next = NULL;
    new->val = val;

    return new;
}
```

Conditionals in Arithmetic

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This trick lets us write even shorter / weirder versions of our ternary operator statements in some cases.

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```
int factors(int n)
{
    int c = 0;

    for (int i = 1; i <= n; i++) {
        c += !(n % i);
    }

    return c;
}
```

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{
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    for (int i = 1; i <= n; i++) {
        c += !(n % i);
    }

    return c;
}
```

```
double median(double * x, int n)
{
    return (x[n / 2]
        + (!(n % 2) * x[n / 2 - 1]))
        / (!(n % 2) + 1);
}
```


Conditionals in Arithmetic

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Be warned, unlike `if` statements or the ternary operator, conditionals in arithmetic do not stop the other case from being *evaluated*, they can only stop it from being used.

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```
// Stack overflow!  
  
unsigned int factorial(unsigned int n) {  
    return n * (factorial(n - 1) - 1) + 1;  
}
```

Obfuscation Quiz 4: That Sequence

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What does this code print?

```
int main(void)
{
    int n = 5;

    do {
        printf("%d\n", n);
    } while ((n = (1 - (n % 2)) * (n / 2) + (n % 2) * (3 * n + 1)) - 1);

    printf("%d\n", n);
}
```

Obfuscation Quiz 4: That Sequence

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1 5, 5, 5, 5 ... (Infinite loop)

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- ❶ 5, 5, 5, 5 ... (Infinite loop)
- ❷ 5, 16, 8, 4, 2, 1

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Answer: 5, 16, 8, 4, 2, 1.

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Answer: 5, 16, 8, 4, 2, 1. This is the *Hailstone Sequence* from the somewhat well-known *Collatz Conjecture*.

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① 5, 5, 5, 5 ... (Infinite loop)

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Answer: 5, 16, 8, 4, 2, 1. This is the *Hailstone Sequence* from the somewhat well-known *Collatz Conjecture*. The number will eventually return to 1, stopping the loop since $(n = \dots) - 1$ will evaluate to $(1) - 1$.

goto — The Most Evil Keyword

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C programmers are told to never use `goto`, because when misused it makes the program very difficult to follow. Fortunately, this is very interesting to us!

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C programmers are told to never use `goto`, because when misused it makes the program very difficult to follow. Fortunately, this is very interesting to us! `goto` is also a clean and well accepted way to do error handling in long functions if you have some complex error handling.

```
big_struct_t * initialise()
{
    big_struct_t * new = malloc(sizeof(big_struct_t));
    if (new == NULL)
        goto error;

    // More initialisation which might fail...

    return new;
}

error:
    fprintf(stderr, "Could not create big_struct_t\n");

    // More complex error handling...

    return NULL;
}
```

goto — The Most Evil Keyword

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With enough labels, you can make your code go in whatever order you want:

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```
// Easy(ish) to follow

int palindrome_factor(char * str)
{
    int len = strlen(str);
    char * tmp = malloc(len + 1);

    for (int i = len, j = 0;
         i >= 0;
         i--, j++) {
        tmp[i] = str[j];
    }

    int count = 0;

    for (int i = 0; i < len; i++) {
        if (tmp[i] == str[i])
            count++;
    }

    return count;
}
```

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With enough labels, you can make your code go in whatever order you want:

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         i >= 0;
         i--, j++) {
        tmp[i] = str[j];
    }

    int count = 0;

    for (int i = 0; i < len; i++) {
        if (tmp[i] == str[i])
            count++;
    }

    return count;
}
```

// Hard to follow

```
int palindrome_factor(char * str)
{
    int len; char * tmp; int count;
    int i; int j;
    goto d;

a:
    i = 0; count = 0; goto e;
b:
    tmp[i--] = str[j++];
    if (i >= 0) goto b; goto a;
c:
    i = len - 1, j = 0; goto b;
d:
    len = strlen(str); tmp = malloc(len + 1);
    goto c;
e:
    if (tmp[i] == str[i]) count++; i++;
    if (i < len) goto e; return count;
}
```

The Almighty `for`

The Almighty for

- What is a loop generally?

The Almighty for

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 - 1 Initialise some variables.

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- `for` loops are surprisingly general.

The Almighty for

The Almighty `for`

`while` loops are quite general too, but because `for` loops are usually used for one specific type of loop, it's more jarring to see them used for something else.

The Almighty for

while loops are quite general too, but because for loops are usually used for one specific type of loop, it's more jarring to see them used for something else. How jarring is this code?

```
int sum_list(node_t * list)
{
    int sum = 0;

    // Shouldn't this normally be a while loop?
    for (node_t * curr = list; curr != NULL; curr = curr->next) {
        sum += curr->val;
    }

    return sum;
}
```

The Almighty for

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if (condition()) {  
    action();  
}
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if (condition()) {  
    action();  
}
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```
for (int i = condition(); i; i = 0) {  
    action();  
}
```

// Alternatively:

```
for (;condition();) {  
    action();  
    break;  
}
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```
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}
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    break;  
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```
while (condition()) {  
    action();  
}
```

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for (;condition();) {  
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The Almighty for

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With a bit of trickery and the comma “operator”, nested `for` loops or successive `for` loops can be turned into a single `for` loop:

The Almighty for

With a bit of trickery and the comma “operator”, nested for loops or successive for loops can be turned into a single for loop:

```
for (int i = 0; i < n; i++) {  
    for (int j = 0; j < m; j++) {  
        action(i, j);  
    }  
}
```

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for (int i = 0; i < n; i++) {  
    for (int j = 0; j < m; j++) {  
        action(i, j);  
    }  
}
```

```
for (int i = 0, j = 0;  
     i < n;  
     j = (j + 1) % m, i += (j == 0)) {  
    action(i, j);  
}
```

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With a bit of trickery and the comma “operator”, nested for loops or successive for loops can be turned into a single for loop:

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for (int i = 0; i < n; i++) {  
    for (int j = 0; j < m; j++) {  
        action(i, j);  
    }  
}
```

```
for (int i = 0; i < n; i++) {  
    action(i);  
}
```

```
for (int j = 0; i < m; j++) {  
    other_action(j);  
}
```

```
for (int i = 0, j = 0;  
     i < n;  
     j = (j + 1) % m, i += (j == 0)) {  
    action(i, j);  
}
```

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for (int i = 0; i < n; i++) {  
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        action(i, j);  
    }  
}
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for (int i = 0, j = 0;  
     i < n;  
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    action(i, j);  
}
```

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for (int i = 0; i < n; i++) {  
    action(i);  
}
```

```
for (int j = 0; i < m; j++) {  
    other_action(j);  
}
```

*// This does use an if statement,
// but it's still harder to read*

```
for (int i = 0, j = 0, k = 0;  
     k <= 2;  
     i += (k == 0), j += (k == 1),  
     k += (i == n || j == m)) {  
    if (k == 0)  
        action(i);  
    else  
        action(j);  
}
```

The Almighty for

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An even smaller version exists for certain kinds of nested loops, particularly “square” ones, which are useful for dealing with graphics.

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The Almighty for

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```
for (int i = 0; i < n; i++) {  
    for (int j = 0; j < n; j++) {  
        action(i, j);  
    }  
}
```

*// Take note that the *outer* loop uses /
// and the *inner* loop uses %*

```
for (int i = 0; i < n * n; i++) {  
    action(i / n, i % n);  
}
```

The Almighty `for`

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The “incrementation” part of the `for` loop is essentially just a compulsory line at the end of the `for` loop body. Thanks to the comma “operator”, you can turn smaller `for` loops into “empty” ones:

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```
for (int i = 0; i < n; i++) {  
    action(i);  
}
```

```
// We don't actually use the comma operator  
// but you might need to
```

```
for (int i = 0; i < n; action(i++));
```

Obfuscation Quiz 5: Genetic Algorithm?

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What sort of pattern does this code print?

```
for (int i = 0, j = 0, k = 0; i < 200; j = (++i) / 10 % 10, k = i % 10) {  
    if (k == j) {  
        printf("\\");  
    } else if (k == 9 - j) {  
        printf("/");  
    } else if ((k >= j && k <= 9 - j) || (k <= j && k >= 9 - j)) {  
        printf("~");  
    } else {  
        printf(" ");  
    }  
  
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1 Spiral

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    } else if ((k >= j && k <= 9 - j) || (k <= j && k >= 9 - j)) {  
        printf("~");  
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    if (k == 9)  
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Obfuscation Quiz 5: Genetic Algorithm?

What sort of pattern does this code print?

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Answer: Helix (specifically, a DNA-style helix).

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- Why?
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Variable Economy

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```
// Swap two variables without using a third  
// Avoids using the XOR trick, but watch out for overflow!  
a = a + b  
b = a - b  
a = a - b
```

Variable Economy

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- Strategy one: Giant global array.
- Rather than variables, simply have a global array with a pre-calculated size and with a good data type (like `int` — for alignment purposes).
- Use offsets into that array in place of variable names.
- Good for programs using multiple arrays.

Variable Economy

Variable Economy

```
int sum_matching(int * a1, int * a2, int n)
{
    int sum = 0;

    for (int i = 0; i < n; i++) {
        sum += a1[i] + a2[i];
    }

    return sum;
}

int main(int argc, char ** argv)
{
    int n = atoi(argv[1]);
    int * a1 = malloc(sizeof(int) * n);
    int * a2 = malloc(sizeof(int) * n);

    for (int i = 0; i < n; i++)
        a1[i] = atoi(argv[i + 2]);
    for (int i = 0; i < n; i++)
        a2[i] = atoi(argv[i + 2 + n]);

    printf("%d\n", sum_matching(a1, a2, n));
    return 0;
}
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    }

    return sum;
}

int main(int argc, char ** argv)
{
    int n = atoi(argv[1]);
    int * a1 = malloc(sizeof(int) * n);
    int * a2 = malloc(sizeof(int) * n);

    for (int i = 0; i < n; i++)
        a1[i] = atoi(argv[i + 2]);
    for (int i = 0; i < n; i++)
        a2[i] = atoi(argv[i + 2 + n]);

    printf("%d\n", sum_matching(a1, a2, n));
    return 0;
}
```

```
int data[2003];

void sum_matching(void)
{
    for (*data = 0; *data < data[1];
        (*data)++) {
        data[2] += data[3 + *data]
                + data[1003 + *data];
    }
}

int main(int argc, char ** argv)
{
    data[1] = atoi(argv[1]);

    for (; *data < data[1]; (*data)++)
        data[3 + *data]
        = atoi(argv[*data + 2]);
    for (*data = 0; *data < data[1];
        (*data)++)
        data[1003 + *data]
        = atoi(argv[*data + 2 + data[1]]);

    sum_matching();
    printf("%d\n", data[2]);
    return 0;
}
```

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- To reduce the number of variables we use, we can reuse them.
- Prime candidates:
 - `argc` and `argv`
 - `for` loop counters.
 - Temporary variables.
- It really helps to have all your variables be global.

Array Switches

Sometimes, you may be able to replace long `if-else` chains with just one array and some clever indexing.

Array Switches

Sometimes, you may be able to replace long if-else chains with just one array and some clever indexing.

```
void fizzbuzz(int n)
{
    if (n % 15 == 0) {
        printf("FizzBuzz\n");
    } else if (n % 5 == 0) {
        printf("Buzz\n");
    } else if (n % 3 == 0) {
        printf("Fizz\n");
    } else {
        printf("%d\n", n);
    }

    return 0;
}
```

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        printf("Fizz\n");
    } else {
        printf("%d\n", n);
    }

    return 0;
}
```

```
char * fmt[4] = { "%d\n",
                  "Fizz\n",
                  "Buzz\n",
                  "FizzBuzz\n" };

void fizzbuzz(int n)
{
    printf(fmt[(n % 3 == 0)
              + 2 * (n % 5 == 0)], n);
    return 0;
}
```

Confusing Arithmetic

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It's time to put your maths skills and your COMP1521 bitwise magic skills to good use!

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```
int count_bits(unsigned int n)
{
    int count = 0;

    for (int i = 0; i < 32; i++) {
        if (n & (1 << i))
            count++;
    }

    return count;
}
```

Confusing Arithmetic

It's time to put your maths skills and your COMP1521 bitwise magic skills to good use! Rewrite simple expressions as more complicated ones which are mathematically equivalent.

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```

```
int count_bits(unsigned int n)
{
    int count = 0;

    // A famous trick
    // Think about why it works
    while (n > 0) {
        n &= n - 1;
        count++;
    }

    return count;
}
```

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Bitfields are often harder to read than just a regular array of bools, despite accomplishing the same thing.

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int flag1 = 0, flag2 = 0, flag3 = 0;

flag2 = 1;

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}
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int flag1 = 0, flag2 = 0, flag3 = 0;

flag2 = 1;

if ((flag1 || flag2) && flag3) {
    do_something();
}
```

```
int field = 0;

field |= 1 << 1;

if ((field & 3) && (field & 4)) {
    do_something();
}
```

Weird Literals

Weird Literals

String literals are essentially just a statically defined char array, and so you can use them to define such an array easily.

Quiz 6: Tribute to Grothendieck

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char* p = "\2\3\5\7\v\r\x11\x13\x17\x1d\x1f%)+/5;=CGIOSYa";  
  
int main(void)  
{  
    int n = 57;  
  
    while (1) {  
        int f = 0;  
        for (int i = 24; i >= 0 && !f; i--) {  
            if (n % p[i] == 0) {  
                printf("%d ", p[i]);  
                n /= p[i]; f = 1;  
            }  
        }  
        if (!f) break;  
    }  
  
    printf("\n");  
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        for (int i = 24; i >= 0 && !f; i--) {  
            if (n % p[i] == 0) {  
                printf("%d ", p[i]);  
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            }  
        }  
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Answer: 19 3. This is a really small prime factorisation algorithm.

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1 57 19 3 1 1 ... (Infinite loop)

2 Divide by zero error

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4 57 1

Answer: 19 3. This is a really small prime factorisation algorithm. The primes are embedded in the 'string' p as individual characters. Thus it only works for sufficiently small numbers. 🔍 ↻

Weird Literals

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This is Python code which was used to generate the primes array from the previous slide.

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```
#!/usr/bin/env python3

import re

c_bytes = [2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47,
           53, 59, 61, 67, 71, 73, 79, 83, 89, 97]

# Convert the bytes into a C string
c_string = ''
for byte in c_bytes:
    if byte < 8:
        # Lower bytes are particularly common, so use their single octal digit form
        c_string += f'\\{byte}'
    elif byte in range(7, 14):
        # These bytes have a specific single character representation
        c_string += ['\\a', '\\b', '\\t', '\\n', '\\v', '\\f', '\\r'][byte - 7]
    elif byte in range(32, 127):
        # Handle " and \ specially, but just use the literal character otherwise
        if byte == 34:
            c_string += '\\\"'
        elif byte == 92:
            c_string += '\\\\'
        else:
            c_string += chr(byte)
```

Weird Literals

This is Python code which was used to generate the primes array from the previous slide.

```
else:
    # For other characters, use the \xHH representation
    c_string += f'\\x{byte:02x}'

# Deal with a weird quirk in C which Nick will explain, and add double quotes
c_string = ''' + re.sub(r'(\x[0-9a-f][0-9a-f])([0-9A-Fa-f])', r'\1""\2', c_string) + '''

# Print the resulting C string
print(c_string)
```

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This is especially good for dealing with graphics. We can revisit our DNA printer example from the quiz slide earlier.

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```
for (int i = 0, j = 0, k = 0; i < 200; j = (++i) / 10 % 10, k = i % 10) {  
    printf("%c", " \\/~"[  
        (k == j)  
        + 2 * (k == 9 - j)  
        + 3 * ((k > j && k < 9 - j) || (k < j && k > 9 - j))  
    ]);  
  
    if (k == 9)  
        printf("\n");  
}
```

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This is important if you want to shape your code in a particular way.

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Not only does this make it less likely you'll need a two-letter variable name, it also avoids extra declarations.

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    int a = 0;
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    for (int i = 0; i < n - 1; i++) {
        int tmp = a + b;
        a = b;
        b = tmp;
    }

    return b;
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int main(void) {
    for (int i = 1; i < 20; i++) {
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```
a, b, i, j, n, tmp;

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```

Most C compilers will complain heavily when you try this, but it saves 4 characters from every `int` you need to declare, and at least 4 characters from every program (due to `main`).

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- For effective golfing, you really need large structural changes to your code.
- For example, replacing all the variable names is not as effective as finding a way to remove two whole loops.

Terminal Graphics

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- These allow terminals to do things such as display colour and graphics with just text.
- We can use these to do very cheap and quick graphics with just `printf`. No graphics library or `libncurses` required!

Terminal Graphics

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- `\e[n;mH` — Moves the cursor to row n , column n .

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Fonts on a Budget

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Introducing *Workshop Mono*, our very own 7x7 pixel bitmap font.



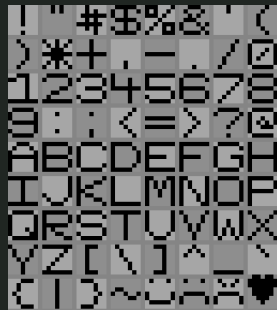
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- It only supports upper case letters. Characters are drawn in ASCII order and are actually 8x8 pixels with 1 pixel of padding on the bottom and right. We also have some extra fun characters.
- 8x8 gives us an advantage, we can directly embed the font into our C program. Each character will take up 8 bytes, or about 1-4 characters in the source code.



Fonts on a Budget

Fonts on a Budget

This is our strategy for embedding the fonts in C:

- Go through each 8x8 character, and for each of those characters read one 8 pixel column at a time.
- Convert that column into an 8-bit number; 1 = filled in pixel, 0 = blank pixel.
- Append this 8-bit number to a C string as one character / byte.

Not all characters can be represented by ASCII cleanly, so we'll need to use special conversion to represent them in the C string.

Fonts on a Budget

Fonts on a Budget

```
#!/usr/bin/env python3
import PIL.Image, re

font_bytes = []

# Open the image
with PIL.Image.open('workshop-mono.png') as image:
    # Scan each character, going along each row left to right
    for row in range(0, image.height, 8):
        for col in range(0, image.width, 8):
            # Append each vertical line as a new byte
            for line in range(8):
                bits = 0
                # Going "backwards" is a neat compression trick which Nick will explain
                for pixel in range(7, -1, -1):
                    # Black = 1, white = 0
                    # [:3] ignores any alpha channel if it exists
                    if image.getpixel((col + line, row + pixel))[:3] == (0, 0, 0):
                        bits = (bits << 1) | 1
                    else:
                        bits = (bits << 1)

            # Write this byte to the list of bytes
            font_bytes.append(bits)
```

This is our script for converting bitmap font images to C strings.

Fonts on a Budget

Fonts on a Budget

```
# Convert the font bytes into a C string
c_string = ''
for byte in font_bytes:
    if byte < 8:
        # Lower bytes are particularly common, so use their single octal digit form
        c_string += f'\\{byte}'
    elif byte in range(7, 14):
        # These bytes have a specific single character representation
        c_string += ['\\a', '\\b', '\\t', '\\n', '\\f', '\\r'][byte - 7]
    elif byte in range(32, 127):
        # Handle " and \ specially, but just use the literal character otherwise
        if byte == 34:
            c_string += '\\\"'
        elif byte == 92:
            c_string += '\\\\'
        else:
            c_string += chr(byte)
    else:
        # For other characters, use the \xHH representation
        c_string += f'\\x{byte:02x}'
```

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Fonts on a Budget

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```
# Deal with a weird quirk in C which Nick will explain, and add double quotes
c_string = '"' + re.sub(r'(\x[0-9a-f][0-9a-f])([0-9A-Fa-f])', r'\1"\2', c_string) + '"'

# Print the resulting C string
print(c_string)
```

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Fonts on a Budget

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Using this script we'll notice a problem:

```
$ ./bitmap-fonts.py | wc -c  
1073
```

We have way too many characters. There are a number of ways we can deal with this:

- Each character has at least one column of spacing which will appear as ‘\0’, so we can skip this column entirely when encoding.

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- There are many other columns which are entirely blank which will also appear as `'\0'`. We could replace `'\0'` with another single character that doesn't appear in the C string (e.g. `'w'`), halving the size of each of these zeroes when embedded in the C string.

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- We could use a smaller font size such as 5x5. But it would be harder to decode, since individual characters wouldn't fit neatly into bytes.
- We could use some form of run-length encoding. But it could make the C string actually larger depending on the way it's used, and would make decoding more complicated.

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Now we can embed this font into our C code and start to use it.

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6 Worked Examples

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