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

Contents

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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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- You lose maintainability, portability, debug-ability. You risk introducing errors.
- For C in particular, most techniques are defeated by the compiler...

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  int a = 0;
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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
```

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```
        .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
        movl    %eax, %ecx
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        jne     .LBB0_2
.LBB0_3:
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        .p2align        4, 0x90
        .type   fib,@function
fib:
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.LBB0_2:
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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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- Show you some worked, finished examples.

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- Get you to try out these tools and techniques.
- Show you some worked, finished examples.

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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- All the content is designed to be accessible to fresh COMP1511 graduates.
- 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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  return count;
}
```

```c
// 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) {
      n[i] = 0;
      c++;
    }
  }

  return c;
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```

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

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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.

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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 psuedocode, so removing the name makes it difficult to read.

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```c
// 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;
      c++;
    }
  }

  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)
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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.

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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).

Contents

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```
// A function using if statements

char toggle_case(char c)
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    return 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?
    c += (n % i) ? 0 : 1;
  }

  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)));
}
```

Obfuscation Quiz 3: Positives and Negatives

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```

1. 1

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}
```

1. 1
2. 0

Obfuscation Quiz 3: Positives and Negatives

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)));
}
```

1. 1
2. 0
3. -1

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}
```

1. 1
2. 0
3. -1
4. Compilation error

Answer: `0`.

Obfuscation Quiz 3: Positives and Negatives

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

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int main(void)
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}
```

1. 1
2. 0
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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).

Obfuscation Quiz 3: Positives and Negatives

What does this code print?

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

1. 1
2. 0
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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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int main(void)
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}
```

1. 1
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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()`.

```c
// String length

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

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

  return l;
}
```

Conditionals in Arithmetic

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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// 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;
}
```

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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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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;
}
```

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

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

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

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

1. 5, 5, 5, 5 ... (Infinite loop)
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int main(void)
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  do {
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Obfuscation Quiz 4: That Sequence

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int main(void)
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  do {
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  } while ((n = (1 - (n % 2)) * (n / 2) + (n % 2) * (3 * n + 1)) - 1);

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

1. 5, 5, 5, 5 ... (Infinite loop)
2. 5, 16, 8, 4, 2, 1
3. Random infinite sequence
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Answer: 5, 16, 8, 4, 2, 1.

Obfuscation Quiz 4: That Sequence

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  do {
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  printf("%d\n", n);
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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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What does this code print?

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

1. 5, 5, 5, 5 ... (Infinite loop)
2. 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*. The number will eventually return to 1, stopping the loop since `(n = ...) - 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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`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;
}
```

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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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  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;
}
```

```c
// 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`

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- What is a loop generally?

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  1. Initialise some variables.

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- `for` loops are surprisingly general.

The Almighty `for`

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`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;
}
```

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```
if (condition()) {
  action();
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```
if (condition()) {
  action();
}
```

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

// Alternatively:

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

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while (condition()) {
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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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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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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);
  }
}
```

```
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++) {
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  }
}
```

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

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

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

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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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```
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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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:

```
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(" ");
  }

  if (k == 9)
    printf("\n");
}
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2. Box

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    printf(" ");
  }

  if (k == 9)
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}
```

1. Spiral
2. Box
3. Grid
4. Helix

Obfuscation Quiz 5: Genetic Algorithm?

What sort of pattern does this code print?

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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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  if (k == 9)
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2. Box
3. Grid
4. Helix

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

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Answer: Helix (specifically, a DNA-style helix). The pattern isn't particularly difficult to follow since it's essentially a filled-in cross. The difficulty comes from the structure of the `for` loops being lost.

Contents

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A name helps give meaning — even if the name is just `a` — it signifies that this section of memory has some distinct purpose.
We want to use as little variables as possible.

```
// 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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- 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

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```c
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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{
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  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;
}
```

```c
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

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```
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);
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        return 0;
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```

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        }

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

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

  return count;
}
```

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

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if ((flag1 || flag2) && flag3) {
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int flag1 = 0, flag2 = 0, flag3 = 0;

flag2 = 1;

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}
```

```
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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Answer: 19 3. This is a really small prime factorisation algorithm.

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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.

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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");
}
```

Contents

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- These same techniques can be applied to languages where size *does* matter.
- JavaScript is usually minified in production websites — since it's interpreted and sent over the web every byte of source code counts.

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Additionally, there are a number of places where you specifically can't *add* whitespace, like in the middle of an identifier.
This is important if you want to shape your code in a particular way.

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Also as discussed before, you should try to reuse variables as much as possible.

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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C has an odd quirk where if a variable type is left out, it should be assumed to be an integer. The following programs are equivalent:

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```c
int fib(int n) {
  int a = 0;
  int b = 1;

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

  return b;
}

int main(void) {
  for (int i = 1; i < 20; i++) {
    printf("F_%d = %d\n", i, fib(i));
  }
}
```

What can we Remove?

C has an odd quirk where if a variable type is left out, it should be assumed to be an integer. The following programs are equivalent:

```c
int fib(int n) {
  int a = 0;
  int b = 1;

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

  return b;
}

int main(void) {
  for (int i = 1; i < 20; i++) {
    printf("F_%d = %d\n", i, fib(i));
  }
}
```

```c
a, b, i, j, n, tmp;

fib(n) {
  a = 0;
  b = 1;

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

main(void) {
  for (j = 1; j < 20; j++) {
    printf("F_%d = %d\n", j, fib(j));
  }
}
```

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 varialbe 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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- `https://misc.flogisoft.com/bash/tip_colors_and_formatting`

Fonts on a Budget

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More importantly for us, they don't take up much space.

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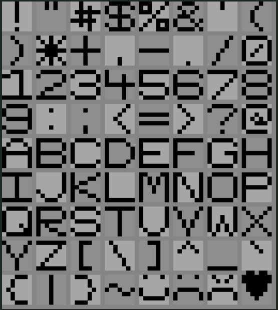
Introducing *Workshop Mono*, our very own 7x7 pixel bitmap font.



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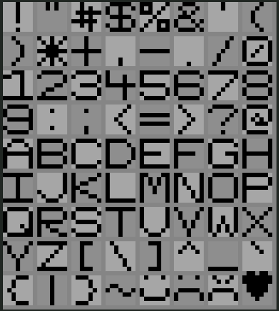

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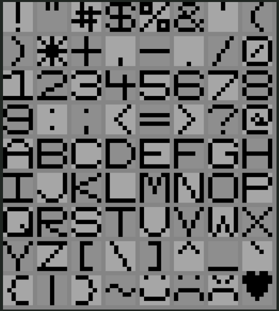
- It only supports upper case letters. Characters are drawn in ASCII order and are actually 8x8 pixels with 1 pixel of padding on the bottom and right. We also have some extra fun characters.
- 8x8 gives us an advantage, we can directly embed the font into our C program. Each character will take up 8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

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

Fonts on a Budget

Fonts on a Budget

```
# 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)
```

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

Fonts on a Budget

Fonts on a Budget

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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```
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807
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$ ./bitmap-fonts.py | wc -c
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```

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

Contents

Worked Examples

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