CPS 188

Computer Programming Fundamentals

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Topic 3.1: Bitwise operators, functions

Toronto Metropolitan University

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Today

- User-defined functions
- Bitwise operators
- Bit masking

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Function

A **named block of statements** that performs some operation that is intended to be performed more than once.

In other words, a piece of code we can reuse without having to duplicate the statements.

Functions make a program more **readable**, **simplify** coding, and allow for code **reuse** between programmers.

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Functions

We've *used* many:

In **stdio.h**:
- `printf()`
- `scanf()`

In **`math.h`**:
- `sqrt()`, `pow()`
- `sin()`, `cos()`, `tan()`

- Each of these implements behavior provided to us by C.
- We are not responsible for writing code to compute square root. Someone else did that for us.

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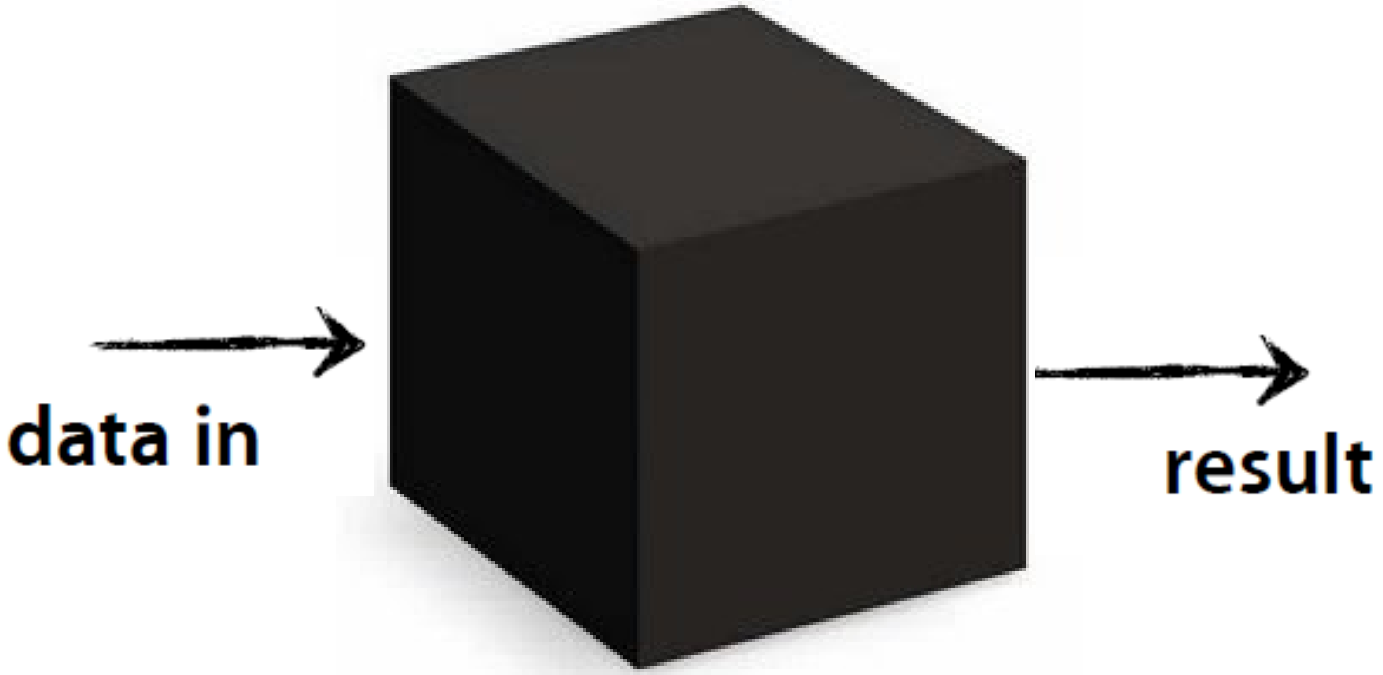
Functions as Black Boxes



- We know what goes in, we know what comes out (ideally)
- We don’t care what goes on inside (for now)

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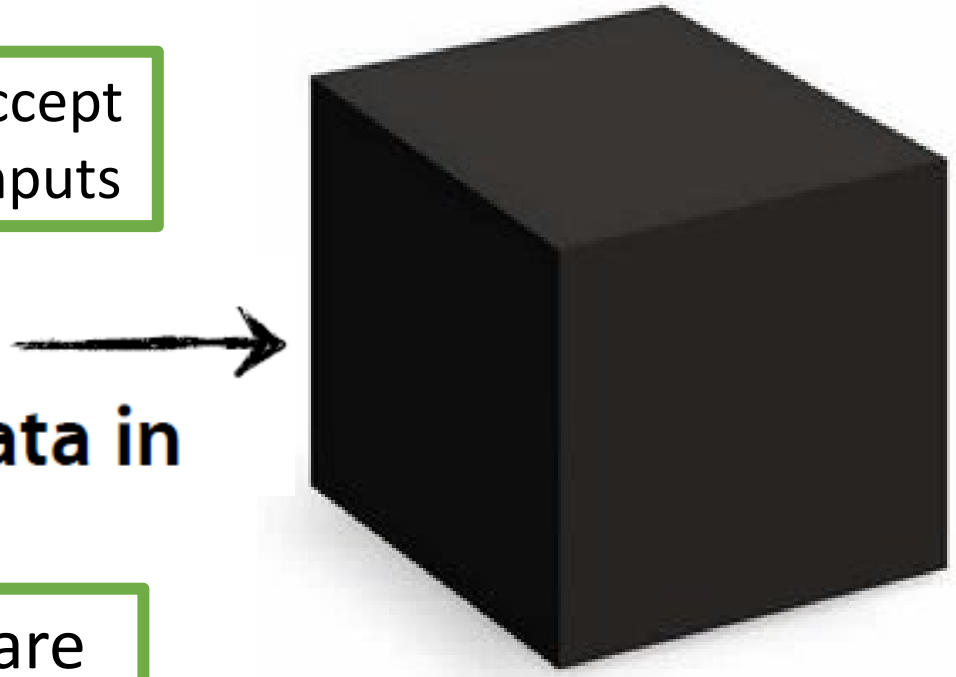
Functions as Black Boxes

A function can accept any number of inputs



A function can return *at most* one result

These inputs are called ***arguments***

Any of the data types we've seen thus far can be returned

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Functions

Input arguments & return values

`sqrt(15.8)`

`sqrt()` takes <u>one</u> input argument of type **`double`**

`sqrt()` returns one value of type **`double`**

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Functions

Multiple input arguments:


```
x = scanf("%d", &num)
```

`scanf()` takes <u>two</u> input arguments here: placeholder string, variable address.

`scanf()` returns one value of type `int`

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Functions

Can we have multiple results?

NO.

A function returns a **single** result *(technically)*.

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Functions

No arguments? No return values?

YES.

- A function need not accept input arguments
- A function need not return anything

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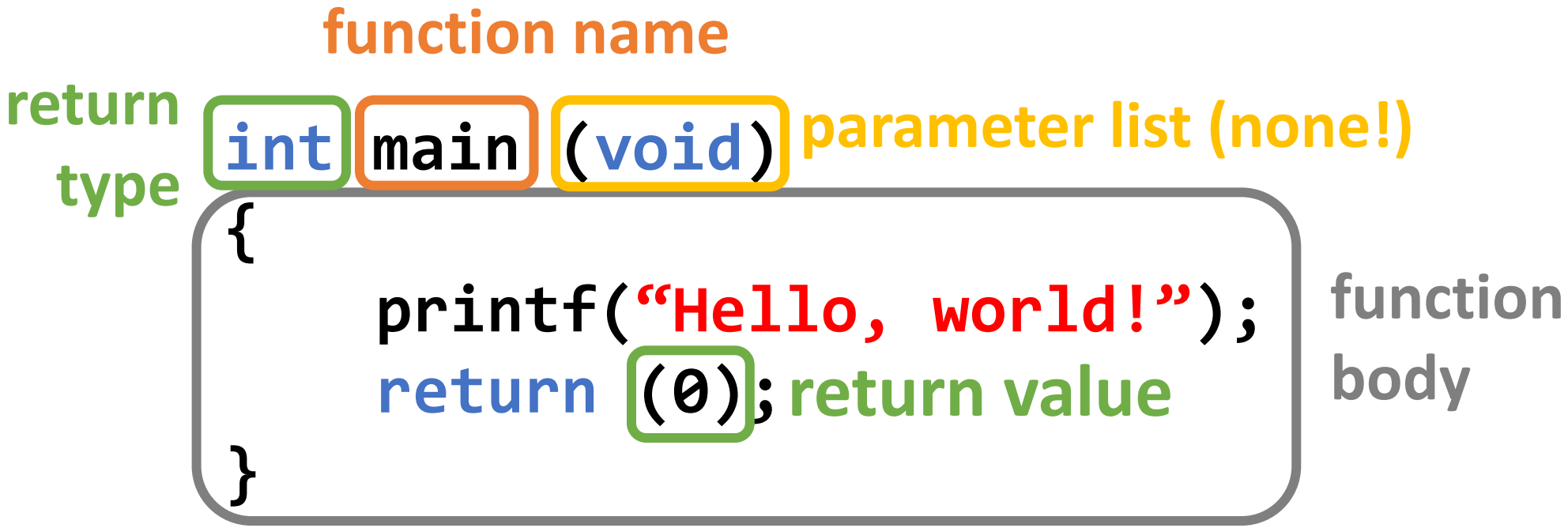
Function Syntax

Remember the `main()` function?



Return value must match return type!

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Function Syntax

In the general sense:

int, char, double, etc.

Function parameters

```
function_type function_name (input: type(s) name(s))
{
    /* Functi
       variab
       C statements  */

    return (result);     /* if needed */
}
```

Be consistent and descriptive

double x, int y, char c, etc.

result type must match function type!

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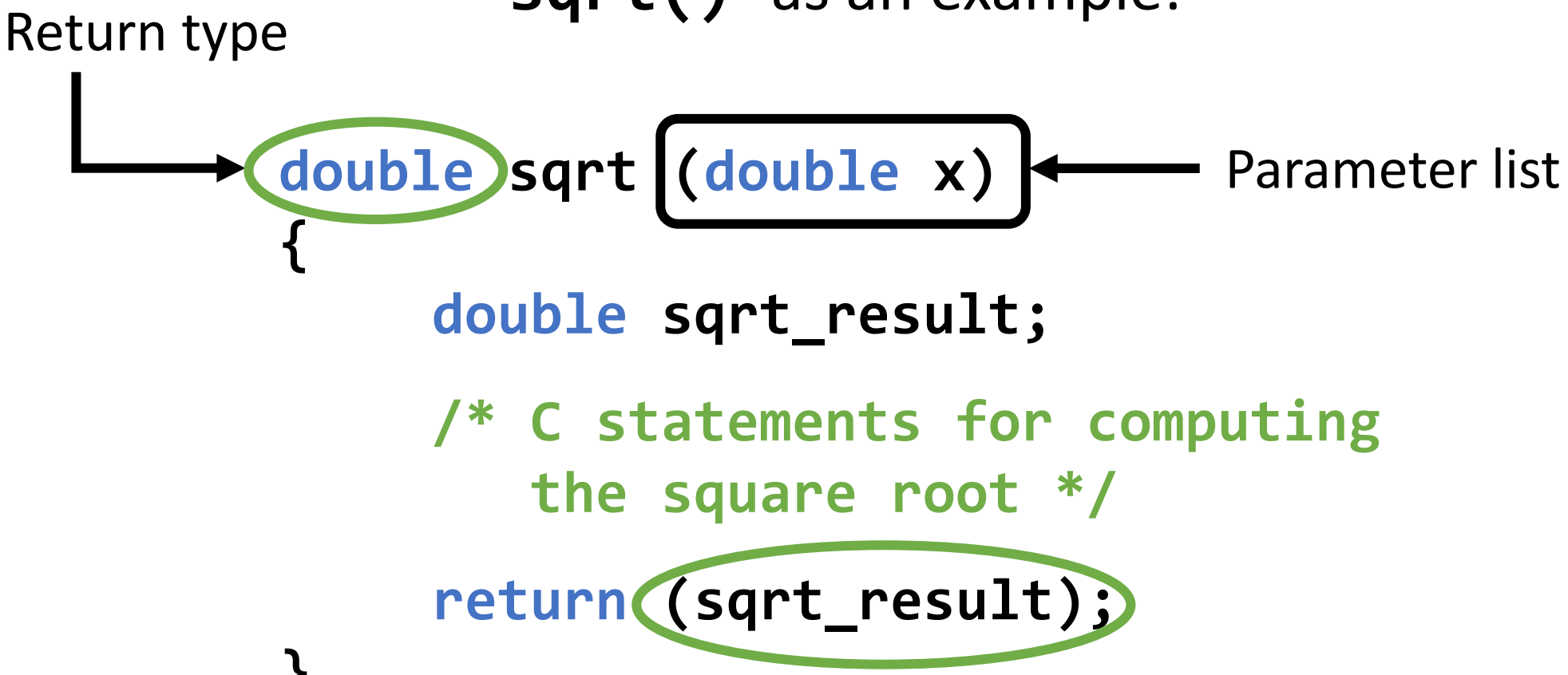
Function Syntax

`sqrt()` as an example:




```
double sqrt (double x)
{
    double sqrt_result;

    /* C statements for computing
       the square root */

    return (sqrt_result);
}
```

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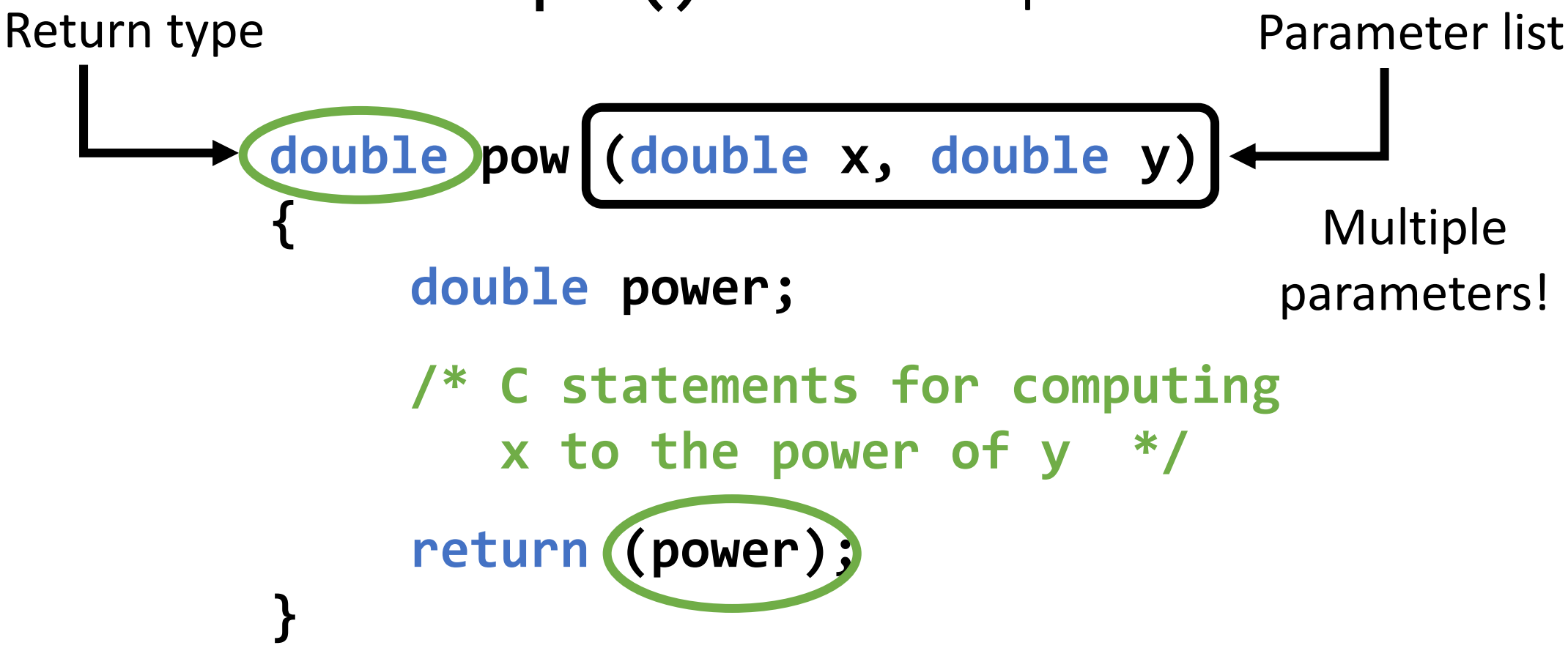
Function Syntax

`pow()` as an example:



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Calling a Function

```
#include <stdio.h>
#include <math.h>

int main (void)
{
      double y, x = 37.9;
      y = sqrt(x);
      printf("%lf", y);
}
```

How many function calls?

What are the arguments?

What are the return values?

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User-Defined Functions

`sqrt()`, **`pow()`**, **`printf()`**, **`scanf()`** are all defined for us.

We gain access to them by including their respective header files.

What if we have our own task for which there is no existing function?

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```c
#include <stdio.h>

int increment (int i)
{
    return i + 1;
}

int main (void)
{
    int x, k = 4;
    x = increment(k);
    printf("k+1 = %d\n", x);
    return 0;
}
```

User-defined function

Return value gets copied into **x**

Argument gets ***copied*** into parameter **i**.
k and **i** are **different** variables!

Calling user-defined function

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```c
#include <stdio.h>

int add_three (int a, int b, int c)
{
     int d = a + b + c;
     return d;
}

int main (void)
{
     printf("sum: %d\n", add_three(1, 2, 3));
     return 0;
}
```

User-defined function

Calling user-defined function

Arguments can be literals!

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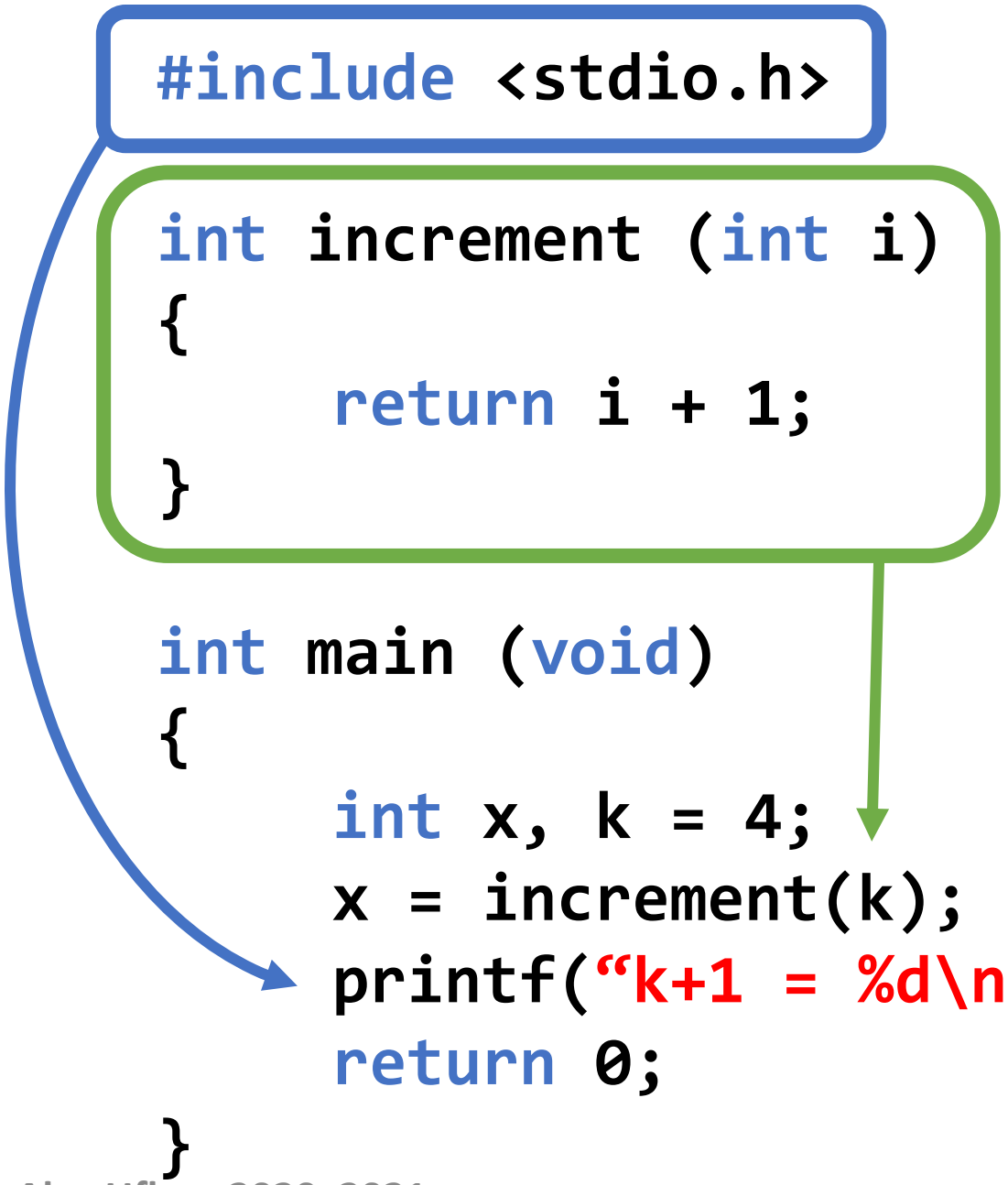

Functions must be declared before the code that makes the function call.

Otherwise we will get a compile error

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```c
#include <stdio.h>

int increment (int i);

int main (void)
{
     int x, k = 4;
     x = increment(k);
     printf("k+1 = %d\n", x);
     return 0;
}

int increment (int i)
{
     return i + 1;
}
```

Solution!

Function *prototype:*
Tells the compiler that this function exists below the call, so don't panic.

Prototype must match function definition.

Problem?

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`void` Functions

```
#include <stdio.h>

void stars (void)  /* No return value, no parameters */
{
     printf("**********\n");
}

int main (void)
{
     stars();
     return 0;
}
```

Nothing to return, **`stars()`** does not need a **`return`** statement.

Since there are no parameters, we pass no arguments.

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Something Useful?

- Function to say Hello?
- Function to compute hypotenuse?
- Function to find area of a circle?
- Function to find roots of a quadratic?

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hello()

```
#include <stdio.h>

void hello (void)
{
    printf("Hello, world!\n");
}

int main (void)
{
    hello();
    return 0;
}
```

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hypotenuse()

```c
#include <stdio.h>
#include <math.h>

double hypotenuse (double a, double b)
{
   return sqrt(a*a + b*b);
}

int main (void)
{
   double s1=3, s2=4;
   printf("hyp=%.2lf", hypotenuse(s1, s2));
   return 0;
}
```

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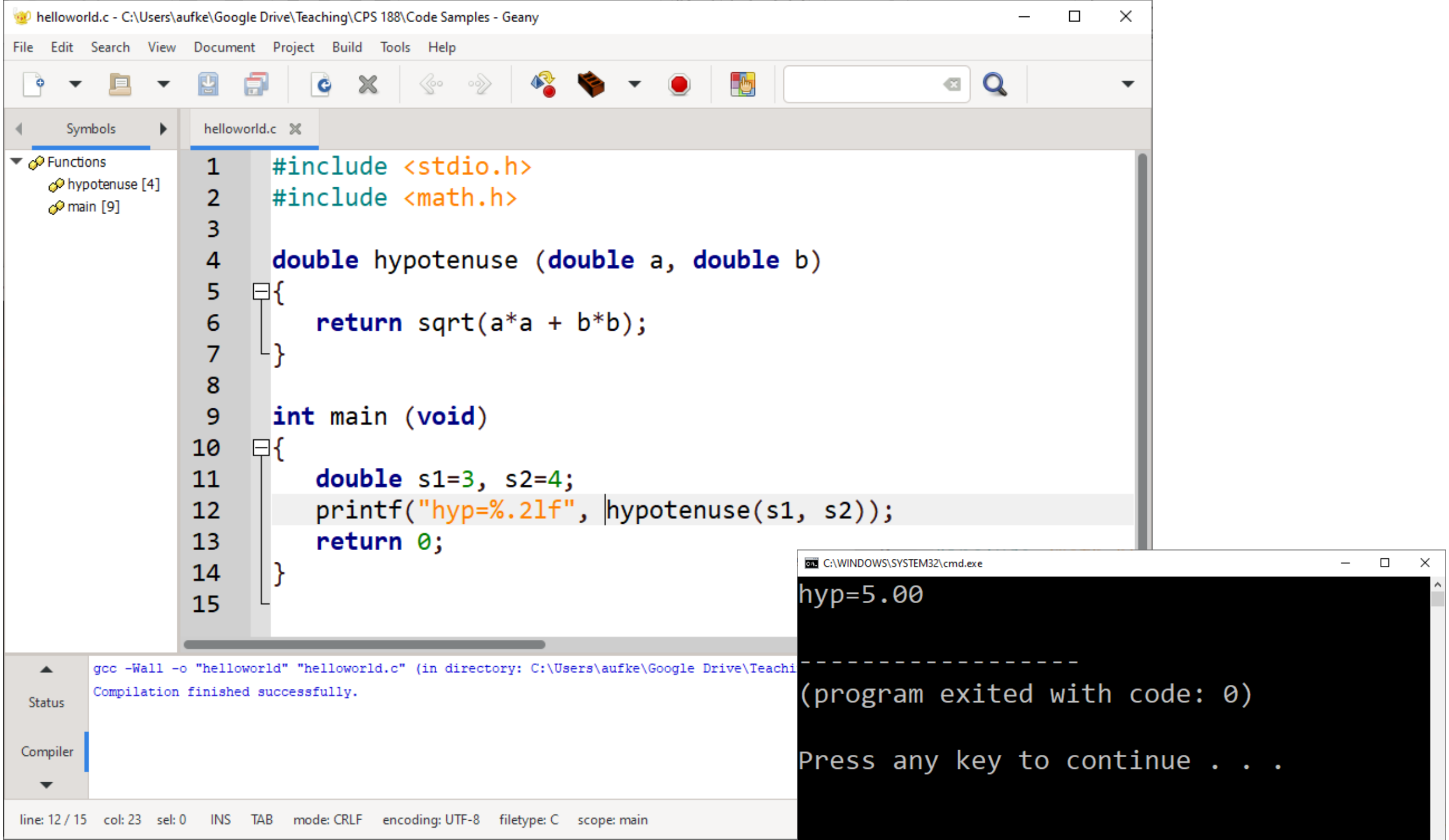
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Symbols
helloworld.c
Functions
hypotenuse [4]
main [9]
1 #include <stdio.h>
2 #include <math.h>
3
4 double hypotenuse (double a, double b)
5 {
6 return sqrt(a*a + b*b);
7 }
8
9 int main (void)
10 {
11 double s1=3, s2=4;
12 printf("hyp=%.2lf", hypotenuse(s1, s2));
13 return 0;
14 }
15
gcc -Wall -o "helloworld" "helloworld.c" (in directory: C:\Users\aufke\Google Drive\Teachi
Compilation finished successfully.
Status
Compiler
line: 12 / 15 col: 23 sel: 0 INS TAB mode: CRLF encoding: UTF-8 filetype: C scope: main
C:\WINDOWS\SYSTEM32\cmd.exe
hyp=5.00
(program exited with code: 0)
Press any key to continue . . .

circ_area()

```
#include <stdio.h>
#define PI 3.141592

double circ_area (double r)
{
    return PI*r*r;
}

int main (void)
{
    double r=5.0;
    printf("area=%.2lf", circ_area(r));
    return 0;
}
```

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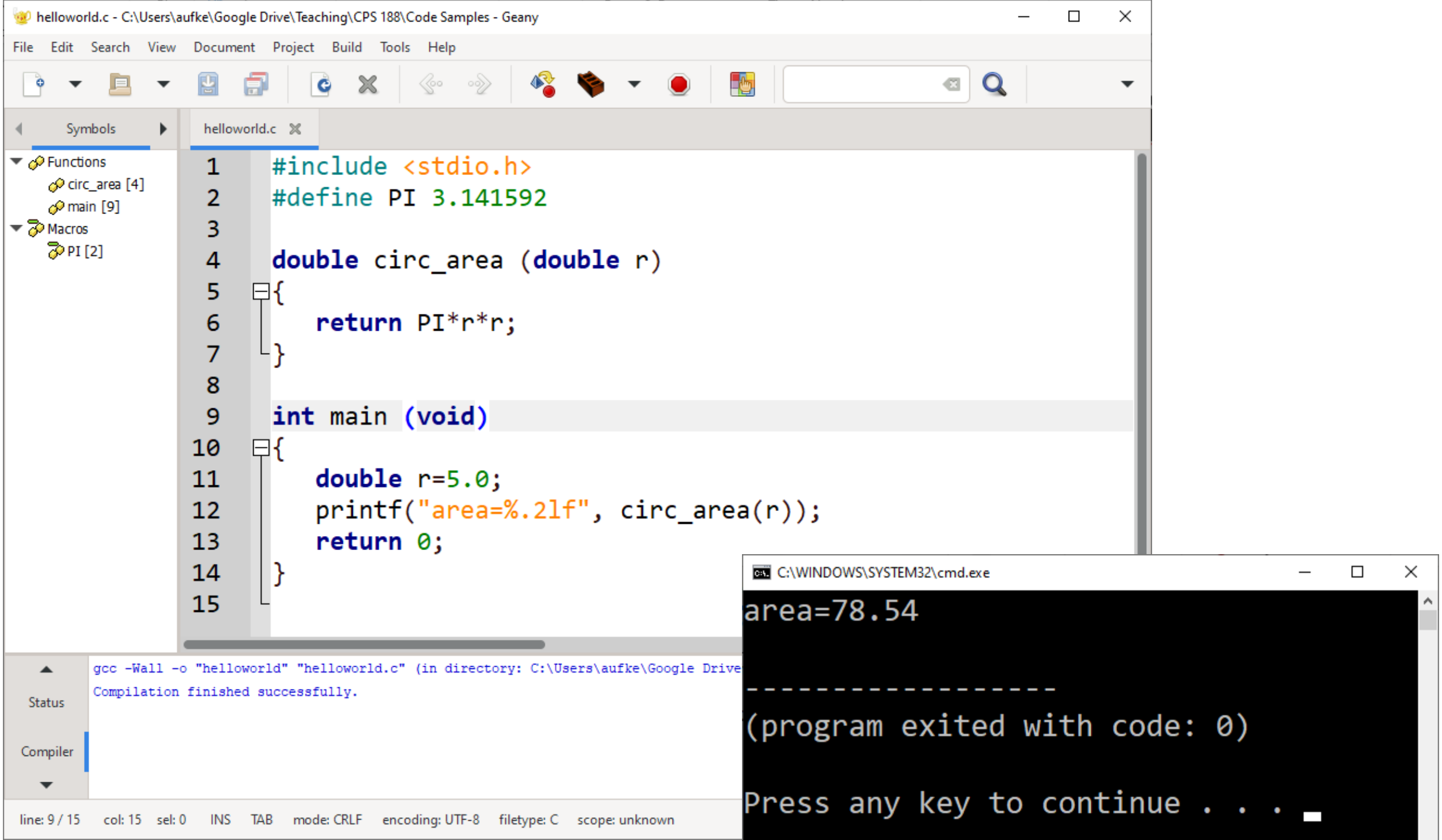
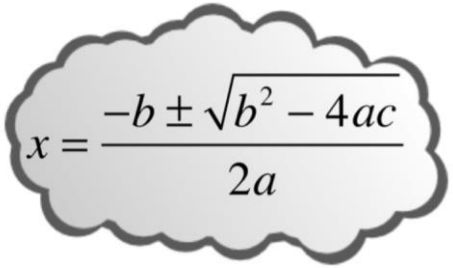

helloworld.c - C:\Users\aufke\Google Drive\Teaching\CPS 188\Code Samples - Geany
File Edit Search View Document Project Build Tools Help
Symbols
helloworld.c
Functions
circ_area [4]
main [9]
Macros
PI [2]
1 #include <stdio.h>
2 #define PI 3.141592
3
4 double circ_area (double r)
5 {
6 return PI*r*r;
7 }
8
9 int main (void)
10 {
11 double r=5.0;
12 printf("area=%.2lf", circ_area(r));
13 return 0;
14 }
15
gcc -Wall -o "helloworld" "helloworld.c" (in directory: C:\Users\aufke\Google Drive
Compilation finished successfully.
Status
Compiler
line: 9 / 15 col: 15 sel: 0 INS TAB mode: CRLF encoding: UTF-8 filetype: C scope: unknown
C:\WINDOWS\SYSTEM32\cmd.exe
area=78.54
(program exited with code: 0)
Press any key to continue . . .

quad()

```c
#include <stdio.h>
#include <math.h>

double quad (double a, double b, double c)
{
    double disc = sqrt(b*b – 4*a*c);
    double root1 = (-b + tmp)/(2*a);
    double root2 = (-b - tmp)/(2*a);
    return root1; // What about root2?
}

int main (void)
{
    double c1=1, c2=2, c3=3;
    double r1 = quad(c1, c2, c3);
    printf(“root1 = %.2lf”, r1);
    return 0;
}
```



“Can we have multiple results?”

NO.

We’re stuck!

- One option? Two separate functions, one for each root.
- Another option? Pointers, which we haven’t learned yet.

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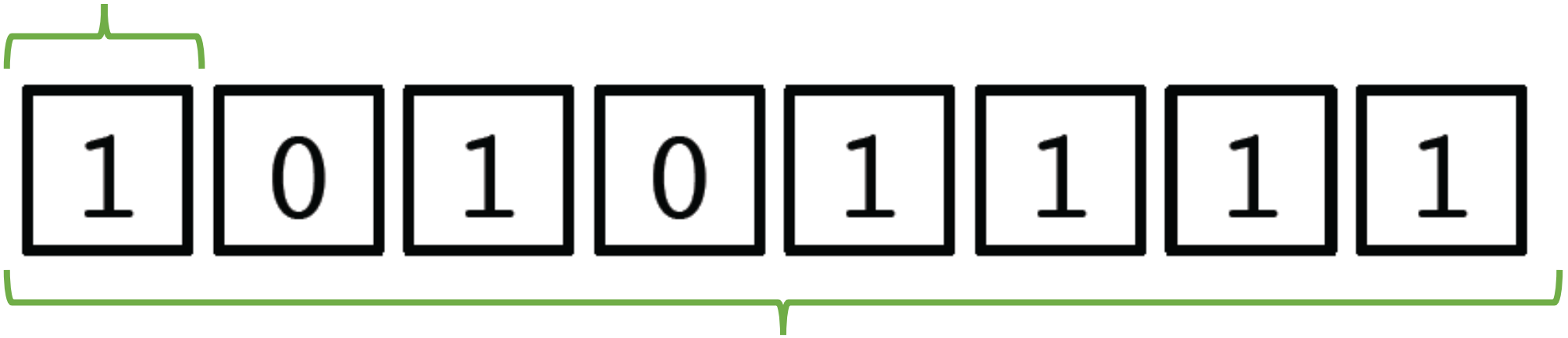
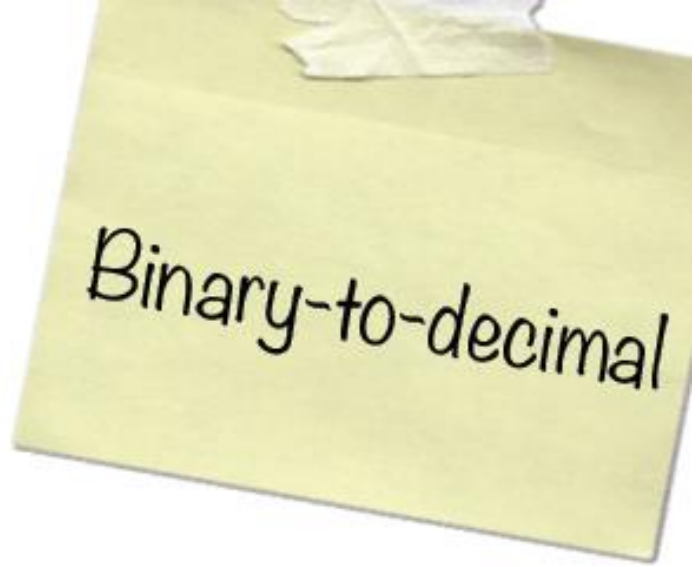
Bitwise Operations

Recall: Binary Numbers

Bit (0 or 1)



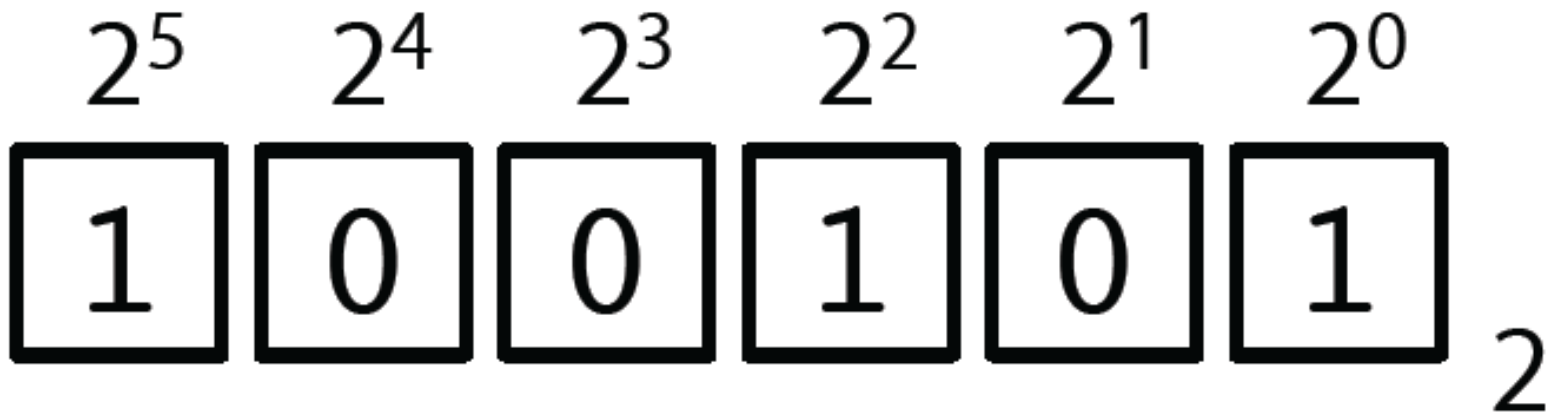
Byte (group of 8 bits)



Binary: Base **2** number system

2^5	2^4	2^3	2^2	2^1	2^0	
1	0	0	1	0	1	2

Indicates base



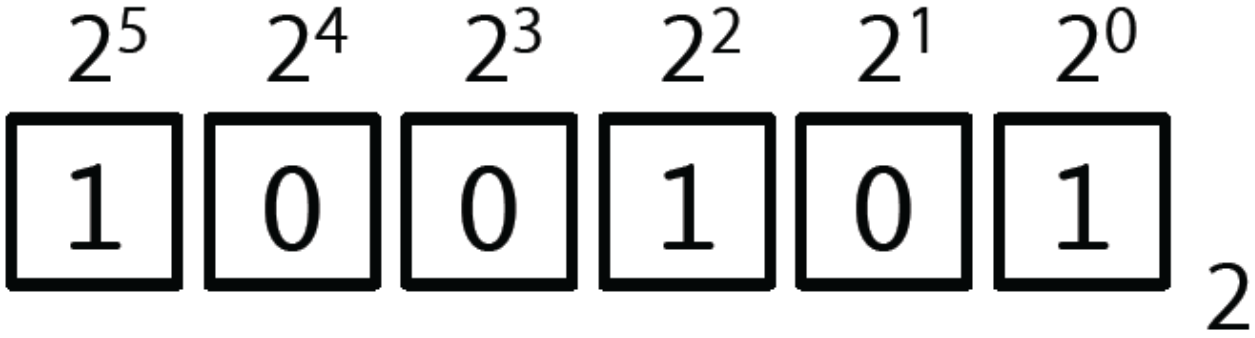
$1 \times 2^0 = 1$
$0 \times 2^1 = 0$
$1 \times 2^2 = 4$
$0 \times 2^3 = 0$
$0 \times 2^4 = 0$
$1 \times 2^5 = 32$

37

Integers

- In practice, integers can be 8, 16, 32, or 64 bits.
- We most commonly deal with 32 bit integers
- This is the size of a standard **`int`** in C

Recall:



Only 6 bits here
How to convert to 32?

Add leading zeroes: 00000000000000000000000000100101

In base 10, 578 is the same number as 000000578. Same applies in binary.

Bitwise Operators

- Arithmetic operators operate on individual numeric values
- These values are represented as a sequence of binary bits
- Bitwise operators operate on individual, corresponding bits

```
&     Bitwise AND
|     Bitwise OR
^     Bitwise XOR (exclusive OR)
~     Bitwise complement
>>    Bit shift right
<<    Bit shift left
```

Bitwise Operators: Truth Tables

&

X	Y	X & Y
0	0	0
0	1	0
1	0	0
1	1	1

|

X	Y	X | Y
0	0	0
0	1	1
1	0	1
1	1	1

Bitwise Arithmetic

- No carry the one, no remainder, no nothing.
- Just a simple operation between corresponding bits.

```
  00101101
& 10110111
----------
  00100101
```

```
  00101101
| 10110111
----------
  10111111
```

Bitwise Operators: Truth Tables

X	Y	X ^ Y
0	0	0
0	1	1
1	0	1
1	1	0

X	~X
0	1
1	0

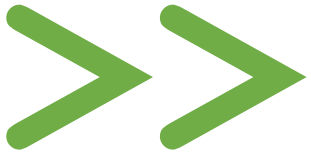
Bitwise Arithmetic

- No carry the one, no remainder, no nothing.
- Just a simple operation between corresponding bits.

```
  00101101
^ 10110111
----------
  10011010
```

```
~ 10110111
----------
  01001000
```

Bitwise Operators: Bit Shifting



X	Y	X >> Y
01010	1	00101
01010	2	00010
01010	3	00001
01010	4	00000

Maintain highest order bit. Negative numbers stay negative!

X	Y	X << Y
00001010	1	00010100
00001010	2	00101000
00001010	3	01010000
00001010	4	10100000

Introduce trailing zeroes

Bit Masking

- Bit masking can be used to access individual bits.
- This is incredibly common at the hardware register level.
- Registers (on the CPU) are *very* fast, and *very* few in number.
- In embedded systems, even main memory can be extremely limited.
- It becomes important to use memory as efficiently as we can.
- We don't think twice about using an **`int`** to represent the number 57.
- However, 57 can be represented in ¼ the size using a **`char`**.
- 32 bits VS 8 bits

Example: Get n^{th} bit

Here, the rightmost bit is considered 0^{th} bit

Quincy 2005 - [main.c]

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```c
#include<stdio.h>

int nthBit(int num, int n)
{
    return (num >> n) & 1;
}

int main(void)
{
    int x = 27;   // 00011011

    printf("bit 0 = %d\n", nthBit(x, 0));
    printf("bit 1 = %d\n", nthBit(x, 1));
    printf("bit 2 = %d\n", nthBit(x, 2));
    printf("bit 3 = %d\n", nthBit(x, 3));
    printf("bit 4 = %d\n", nthBit(x, 4));

    return 0;
}
```

Quincy 2005

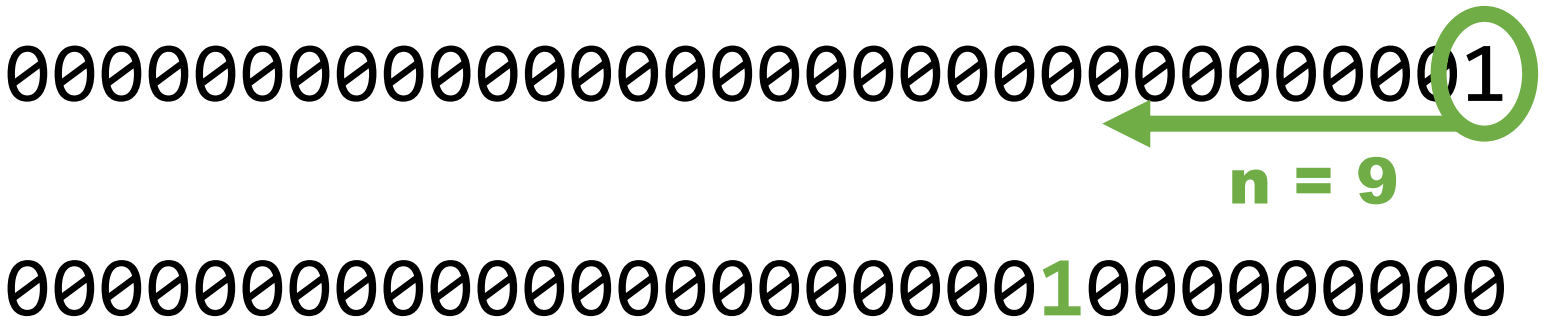
```
bit 0 = 1
bit 1 = 1
bit 2 = 0
bit 3 = 1
bit 4 = 1

Press Enter to return to Quincy...
```

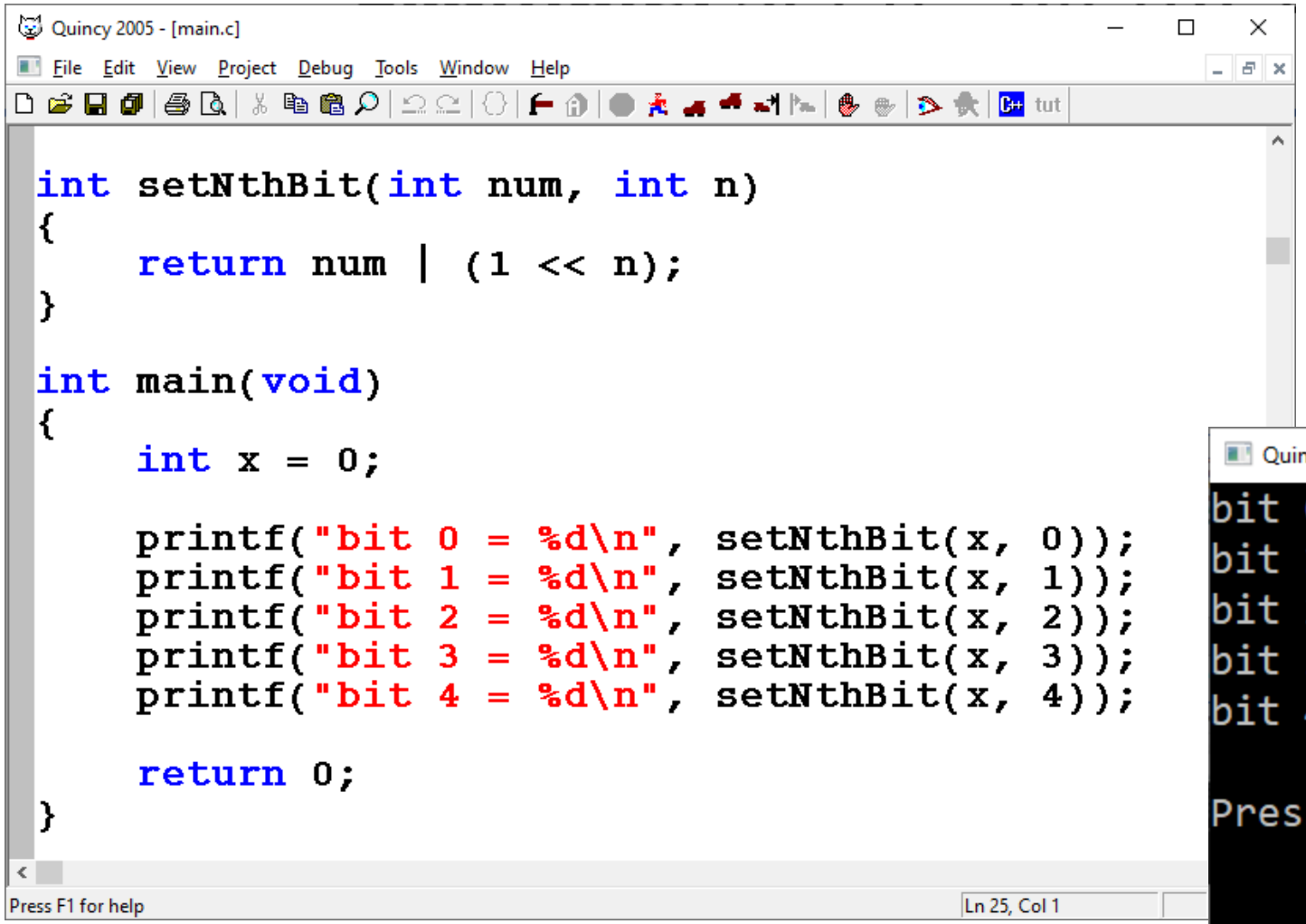
Example: Set n^{th} bit (to 1)

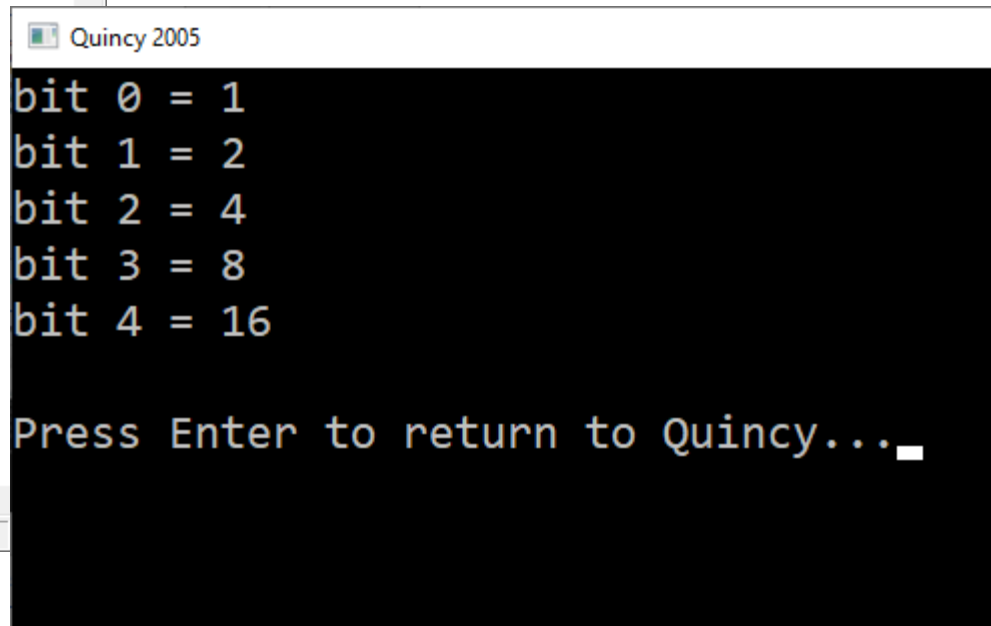
```
x = x | (1 << n);
```

- Start with 1, shift to the left n positions.
- OR with x. n^{th} bit becomes 1, all others stay the same



Example: Set n^{th} bit (to 1)





Example: Toggle n^{th} bit (invert)

If 1, change to 0. If 0, change to 1:

- Simple change, use XOR instead of OR.

Quincy 2005 - [main.c]

File Edit View Project Debug Tools Window Help

```
int toggleNthBit(int num, int n)
{
    return num ^ (1 << n);
}

int main(void)
{
    int x = 27; //  00011011

    printf("bit 0 = %d\n", toggleNthBit(x, 0));
    printf("bit 1 = %d\n", toggleNthBit(x, 1));
    printf("bit 2 = %d\n", toggleNthBit(x, 2));
    printf("bit 3 = %d\n", toggleNthBit(x, 3));
    printf("bit 4 = %d\n", toggleNthBit(x, 4));

    return 0;
}
```

Quincy 2005

```
bit 0 = 26
bit 1 = 25
bit 2 = 31
bit 3 = 19
bit 4 = 11

Press Enter to return to Quincy...
```

Example: Clear n^{th} bit (set to 0)

```
x = x & (~(1 << n));
```

- Start with 1, shift to the left n positions.
- Invert and AND with x. n^{th} bit becomes zero

```
00000000000000000000000000000001
00000000000000000000000010000000
11111111111111111111111101111111
```

Example: Clear n^{th} bit

- Start with 1, shift to the left n positions.
- Invert and AND with x. n^{th} bit becomes zero

Quincy 2005 - [main.c]

File Edit View Project Debug Tools Window Help

```
int clearNthBit(int num, int n)
{
    return num & ~(1 << n);
}

int main(void)
{
    int x = 27; //  00011011

    printf("bit 0 = %d\n", clearNthBit(x, 0));
    printf("bit 1 = %d\n", clearNthBit(x, 1));
    printf("bit 2 = %d\n", clearNthBit(x, 2));
    printf("bit 3 = %d\n", clearNthBit(x, 3));
    printf("bit 4 = %d\n", clearNthBit(x, 4));

    return 0;
}
```

Quincy 2005

```
bit 0 = 26
bit 1 = 25
bit 2 = 27
bit 3 = 19
bit 4 = 11

Press Enter to return to Quincy...
```

Questions?

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