UNIVERSITY OF WATERLOO
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ECE 150 *Fundamentals of Programming*

# While loops

ECE150

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# Outline

- In this lesson, we will:
  - See how to implement while loops in C++
  - Implement while loops that
    - Play a guessing game with the user
    - Find all prime factors of a given integer
    - Implement the Collatz conjecture
  - Learn how to convert a description of an algorithm to one that you can program
    - We will use the greatest-common divisor algorithm
  - Observe that all for loops can be written as while loops

# Repetition statements

- A for loop is a special case of a repetition statement:
  - The loop body is executed a fixed number of times based on
    - The initial value of a loop variable,
    - A condition involving the loop variable, and
    - An update to that loop variable executed after the loop body is run

```
for ( int k{0}; k < n; ++k ) {
    // Loop body
    std::cout << k << ", ";
}
```

- Very often, at compile time, you can determine how often this loop will be executed

# Repetition statements

- In some cases, however, we don't know how often a loop body will be executed
  - An alternative approach is a *while loop*
  - A while loop only has a condition and a loop body
    - The loop body is run as long as the condition is TRUE

```
while ( Boolean-valued condition ) {
    // The loop body or block of statements
    // - to be executed as long as the
    //   condition is 'true'
}

// Continue executing here as soon as the
// condition evaluates to 'false'
```

# Infinite loops

- A common loop is the *infinite loop*:

```
while ( true ) {
    // The loop body or block of statements
    // - will be repeatedly executed forever
    //   or until we get out of the loop otherwise
}
```

  - You can get out of an infinite loop with a break statement or a return statement.

# Accessing a value from the user

- Like with the `for` loop, a while loop can use a break statement:

```
// Must be declared outside the loop
int n{};

while ( true ) {
    // Ensure the user enters a positive integer
    std::cout << "Enter a positive integer: ";
    std::cin  >> n;

    if ( n > 0 ) {
        break;
    }
}
```

# Accessing a value from the user

- Here is an alternate strategy:

```
int n{ 0 };   // 0 will cause the condition to fail

while ( n <= 0 ) {
    std::cout << "Enter a positive integer: ";
    std::cin  >> n;
}
```

# A guessing game

- Suppose we want to play a guessing game:
  - Player A enters a number to be guessed
  - Player B continues to try to guess that number until that Player B guesses correctly

- Put another way:
  - Inside an infinite loop:
    - Query Player B for a guess
    - If that guess is correct, we will break out of this loop

# A guessing game

- A while loop is used when it is unknown how often a loop may run

```
#include <iostream>

// Function declarations
int main();

// Function definitions
int main() {
    int secret_number{};
    std::cout << "Player A: enter a secret number: ";
    std::cin >> secret_number;
```

# A guessing game

```
    while ( true ) {
        int guessed_number{};
        std::cout << "Player B: enter a guess: ";
        std::cin  >> guessed_number;

        if ( guessed_number == secret_number ) {
            std::cout << "You guessed the secret number"
                      << std::endl;
            break;
        } else {
            std::cout "Incorrect guess" << std::endl;
        }
    }

    return 0;
}
```

# The game of high-low

- Let's refine this guessing game so that
  - Player A enters a number between 1 and 100 to be guessed
  - Player B continues to try to guess that number
    - If the guess is correct, the game is over
    - If the guess is greater than the number,
      we tell the player that the guess is too high
    - Otherwise, we tell the player that the guess is too low

- Put another way:
  - In an infinite loop:
    - Query Player B for a guess
    - If that guess is correct, we will break out of this loop
    - Otherwise, we will tell the player if the guess was too high or too low

# The game of high-low

- Implementing this game

```
#include <iostream>

// Function declarations
int main();

// Function definitions
int main() {
    int secret_number{};
    std::cout << "Player A: enter a secret number from 1 to 100: ";
    std::cin >> secret_number;

    while ( (secret_number < 1) || (secret_number > 100) ) {
        std::cout << "Enter a secret number from 1 to 100: ";
        std::cin >> secret_number;
    }
```

# The game of high-low

- An alternative condition

```
#include <iostream>

// Function declarations
int main();

// Function definitions
int main() {
    int secret_number{};
    std::cout << "Player A: enter a secret number from 1 to 100: ";
    std::cin >> secret_number;

    while ( !( (secret_number >= 1) && (secret_number <= 100) ) ) {
        std::cout << "Enter a secret number from 1 to 100: ";
        std::cin >> secret_number;
    }
```

# The game of high-low

```
    while ( true ) {
        int guessed_number{};
        std::cout << "Player B: enter a guess from 1 to 100: ";
        std::cin >> guessed_number;

        if ( guessed_number == secret_number ) {
            std::cout << "You guessed the secret number"
                      << std::endl;
            break;
        } else if ( guessed_number < secret_number ) {
            std::cout "Too low, guess again..." << std::endl;
        } else {
            std::cout "Too high, guess again..." << std::endl;
        }
    }

    return 0;
}
```

# Finding prime factors of an integer

- Suppose we want to print all prime factors of an integer:
  - For example:
    - $123 = 3 \times 41$
    - $124 = 2 \times 2 \times 31$
    - $125 = 5 \times 5 \times 5$

- Now, 2666 is divisible by 2, so the prime factors are:
  - 2 and the prime factors of $2666 \div 2 = 1333$
  - This looks like an interesting strategy…

# Finding prime factors of an integer

- Does this approach work?
  - Given *n*, start with *k* = 2, 3, 4, 5, 6, 7, …
    if *n* is divisible by *k*, assign *n* the value of *n*/*k* and go to the next

```
for ( int k{ 2 }; k < n; ++k ) {
    if ( n%k == 0 ) {
        std::cout << k << ", ";
        n /= k;
    }
}
```

  - What is the output for *n* = 14, 28, 56?

# Finding prime factors of an integer

```
int main() {
    int n{};
    std::cout << "Enter a positive integer to be factored: ";
    std::cin >> n;

    int possible_factor{2};

    while ( n > 1 ) {
        while ( n%possible_factor == 0 ) {
            std::cout << possible_factor << ", ";
            n /= possible_factor;
        }

        // Ideally, we should go to the next highest prime,
        // but this works, too.
        ++possible_factor;
    }

    return 0;
}
```

# Collatz conjecture

- The Collatz conjuecture says that if you start with any positive integer *n* and
  - If *n* is even, divide it by two
  - If *n* is odd, multiply it by three and add one

- If ever *n* = 1, then the sequence carries on forever:

  1, 4, 2, 1, 4, 2, 1, 4, 2, 1, …

- The Collatz conjecture says that regardless of your initial *n*,

  this sequence always gets to 1

# Collatz conjecture

- We can try this with any number of initial values

  1

  2, 1

  3, 10, 5, 16, 8, 4, 2, 1

  4, 2, 1

  5, 16, 8, 4, 2, 1

  6, 3, 10, 5, 16, 8, 4, 2, 1

  7, 22, 11, 34, 17, 52, 26, 13, 40, 20, 10, 5, 16, 8, 4, 2, 1

  8, 4, 2, 1

  9, 28, 14, 7, 22, 11, 34, 17, 52, 26, 13, 40, 20, 10, 5, 16, 8, 4, 2, 1

  10, 5, 16, 8, 4, 2, 1

  11, 34, 17, 52, 26, 13, 40, 20, 10, 5, 16, 8, 4, 2, 1

  12, 6, 3, 10, 5, 16, 8, 4, 2, 1

# Collatz conjecture

- Here are some longer examples
  - For example,

112 iterations

27, 82, 41, 124, 62, 31, 94, 47, 142, 71, 214, 107, 322, 161, 484, 242, 121, 364, 182, 91, 274, 137, 412, 206, 103, 310, 155, 466, 233, 700, 350, 175, 526, 263, 790, 395, 1186, 593, 1780, 890, 445, 1336, 668, 334, 167, 502, 251, 754, 377, 1132, 566, 283, 850, 425, 1276, 638, 319, 958, 479, 1438, 719, 2158, 1079, 3238, 1619, 4858, 2429, 7288, 3644, 1822, 911, 2734, 1367, 4102, 2051, 6154, 3077, 9232, 4616, 2308, 1154, 577, 1732, 866, 433, 1300, 650, 325, 976, 488, 244, 122, 61, 184, 92, 46, 23, 70, 35, 106, 53, 160, 80, 40, 20, 10, 5, 16, 8, 4, 2, 1

125 iterations

171, 514, 257, 772, 386, 193, 580, 290, 145, 436, 218, 109, 328, 164, 82, 41, 124, 62, 31, 94, 47, 142, 71, 214, 107, 322, 161, 484, 242, 121, 364, 182, 91, 274, 137, 412, 206, 103, 310, 155, 466, 233, 700, 350, 175, 526, 263, 790, 395, 1186, 593, 1780, 890, 445, 1336, 668, 334, 167, 502, 251, 754, 377, 1132, 566, 283, 850, 425, 1276, 638, 319, 958, 479, 1438, 719, 2158, 1079, 3238, 1619, 4858, 2429, 7288, 3644, 1822, 911, 2734, 1367, 4102, 2051, 6154, 3077, 9232, 4616, 2308, 1154, 577, 1732, 866, 433, 1300, 650, 325, 976, 488, 244, 122, 61, 184, 92, 46, 23, 70, 35, 106, 53, 160, 80, 40, 20, 10, 5, 16, 8, 4, 2, 1

# Collatz conjecture

- We can implement this:

```
int main() {
    int n{};
    std::cout << "Enter a positive integer: ";
    std::cin >> n;

    while ( n != 1 ) {
        std::cout << n << ", ";

        if ( n%2 == 0 ) {
            n /= 2;
        } else {
            n = 3*n + 1;
        }
    }

    std::cout << 1 << std::endl;

    return 0;
}
```

# How to design a while loop

- Suppose you are attempting to implement an algorithm where you repeated apply a number of steps
  - How do you make the transition from manual to programmatic?

- Recommendation:
  - Do the algorithm on paper—in full
  - Examine the steps you took, and determine:
    - What steps were repeated?
    - What condition caused you to stop repeating the steps?
    - What local variables could you use?

# The greatest-common divisor

- From secondary school, you saw that the algorithm for calculating the greatest common denominator (gcd)
  - You are asked to find the gcd of 8008 and 8085
  - You first note that 8085 > 8008
  - Next, you find that 8085 ÷ 8008 equals 1 with a remainder of 77
  - Next, you find that 8008 ÷ 77 equals 104 with a remainder of 0
  - From this, you are told that the gcd is 77

# The greatest-common divisor

- Let's try again:
  - You are asked to find the gcd of 1583890 and 85800
  - You first note that 1583890 > 85800
  - Next, you find that 1583890 ÷ 85800 has a remainder of 39490
  - Next, you find that 85800 ÷ 39490 has a remainder of 6820
  - Next, you find that 39490 ÷ 6820 has a remainder of 5390
  - Next, you find that 6820 ÷ 5390 has a remainder of 1430
  - Next, you find that 5390 ÷ 1430 has a remainder of 1100
  - Next, you find that 1430 ÷ 1100 has a remainder of 330
  - Next, you find that 1100 ÷ 330 has a remainder of 110
  - Next, you find that 330 ÷ 110 has a remainder of 0
  - From this, you are told that the gcd is 110

# The greatest-common divisor

| m | n | m%n |
|---|---|---|
| 1583890 | 85800 | 39490 |
| 85800 | 39490 | 6820 |
| 39490 | 6820 | 5390 |
| 6820 | 5390 | 1430 |
| 5390 | 1430 | 1100 |
| 1430 | 1100 | 330 |
| 1100 | 330 | 110 |
| 330 | 110 | 0 |

```
while ( m%n != 0 ) {
    int rem{m%n};
    m = n;
    n = rem;
}

std::cout << "The gcd is " << n << std::endl;
```

# The greatest-common divisor

- Thus, here is our program:

```
int main() {
    int m{};
    int n{};

    std::cout << "Enter the first integer: ";
    std::cin >> m;

    if ( m < 0 ) {
        m = -m;
    }

    std::cout << "Enter a second integer: ";
    std::cin >> n;

    if ( n < 0 ) {
        n = -n;
    }
```

# The greatest-common divisor

```
    // Make sure m >= n
    if ( m < n ) {
        int tmp{m};
        m = n;
        n = tmp;
    }

    // Perform our gcd algorithm
    while ( m%n != 0 ) {
        int rem{m%n};
        m = n;
        n = rem;
    }

    std::cout << "The gcd is " << n << std::endl;

    return 0;
}
```

# The greatest-common divisor

```
    // Make sure m >= n
    if ( m < n ) {
        int tmp{m};
        m = n;
        n = tmp;
    }

    // Perform a slightly different gcd algorithm
    int rem{m%n};                  // We now have m, n, m%n

    while ( rem != 0 ) {
        m = n;
        n = rem;
        rem = m%n;
    }

    std::cout << "The gcd is " << n << std::endl;

    return 0;
}
```

# The greatest-common divisor

- Testing:
  - Testing two prime numbers: the gcd should be 1

```
Enter the first integer: 157
Enter a second integer: 521
The gcd is 1
```

  - Testing a multiple of a number: gcd should be smaller

```
Enter the first integer: 53241
Enter a second integer: 48609033
The gcd is 53241
```

  - Testing two relatively prime composites: gcd should be 1

```
Enter the first integer: 43010
Enter a second integer: 150423
The gcd is 1
```

  - Testing two highly composite numbers: gcd should be 2310

```
Enter the first integer: 48510
Enter a second integer: 254100
The gcd is 2310
```

# The greatest-common divisor

- Testing with negative numbers:

```
Enter the first integer: -157
Enter a second integer: 521
The gcd is 1

Enter the first integer: 157
Enter a second integer: -521
The gcd is 1

Enter the first integer: -157
Enter a second integer: -521
The gcd is 1
```

# The greatest-common divisor

- Testing with zero: the gcd should be the other number

```
Enter the first integer: 0
Enter a second integer: 521
Floating point exception (core dumped)
```

  - Issue, just like dividing by zero causes a program to terminate so does calculating `m%0`

# The greatest-common divisor

- Thus, after we enter the numbers, we should check before we run the algorithm:

```
// Make sure m >= n
if ( m < n ) {
    int tmp{m};
    m = n;
    n = tmp;
}

if ( n == 0 ) {
    std::cout << "The gcd is " << m << std::endl;
    return 0;
}

// Perform our gcd algorithm
//    ...
```

# Every for loop can be written as a while loop

- The following two are essentially identical:

```
int sum{0};

for ( int k{0}; k < n; ++k ) {
    sum += k;
}
```

```
int sum{0};
int k{0};

while ( k < n ) {
    sum += k;
    ++k;
}
```

# Infinite loop?

- Question:
  - What do you do if you accidentally execute a program that has an infinite loop?

- Solution:
  - In all IDEs,
    there is a *stop* button that is active when a program is executing

  - At the console, press Ctrl-C

# Summary

- Following this lesson, you now
  - Understand how to implement while loops in C++
  - Seen how to implement various algorithms requiring looping statements:
    - Playing guessing games
    - Finding all prime factors
    - The Collatz conjecture
    - The factorial function
  - Understand how to convert a description of an algorithm to one that you can program
    - The example we used was the greatest-common divisor
  - Understand that all for loops can be written as while loops
  - Know how to terminate a program in an infinite loop

# References

[1] Wikipedia
https://en.wikipedia.org/wiki/While_loop

[2] cplusplus.com
http://www.cplusplus.com/doc/tutorial/control/

[3] tutorialspoint
https://www.tutorialspoint.com/cplusplus/cpp_while_loop.htm

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# Colophon

These slides were prepared using the Georgia typeface. Mathematical equations use Times New Roman, and source code is presented using `Consolas`.

The photographs of lilacs in bloom appearing on the title slide and accenting the top of each other slide were taken at the Royal Botanical Gardens on May 27, 2018 by Douglas Wilhelm Harder. Please see

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for more information.

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