Building Java Programs
Chapter 5

Program Logic and Indefinite Loops

Indefinite Loops

Reading

- Building Java Programs, Ch. 5.1 - 5.5

Learning Outcomes

- While loops
- Fencepost loops
- Sentinel values
- Boolean expressions
- Assertions

A deceptive problem...

- Write a method `printNumbers` that prints each number from 1 to a given maximum, separated by commas.

  For example, the call:

```
printNumbers(5)
```

  should print:

```
1, 2, 3, 4, 5
```

Flawed solutions

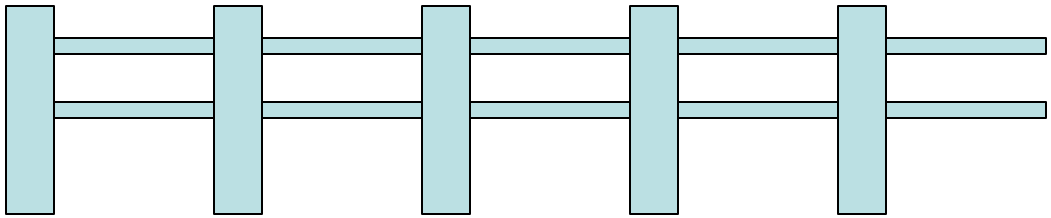
- ```
  public static void printNumbers(int max) {
      for (int i = 1; i <= max; i++) {
          System.out.print(i + ", ");
      }
      System.out.println();  // to end the line of output
  }
  ```
  - Output from `printNumbers(5)`: `1, 2, 3, 4, 5,`

- ```
  public static void printNumbers(int max) {
      for (int i = 1; i <= max; i++) {
          System.out.print(", " + i);
      }
      System.out.println();  // to end the line of output
  }
  ```
  - Output from `printNumbers(5)`: `, 1, 2, 3, 4, 5`

Fence post analogy

- We print n numbers but need only n - 1 commas.
- Similar to building a fence with wires separated by posts:
  - If we use a flawed algorithm that repeatedly places a post + wire, the last post will have an extra dangling wire.

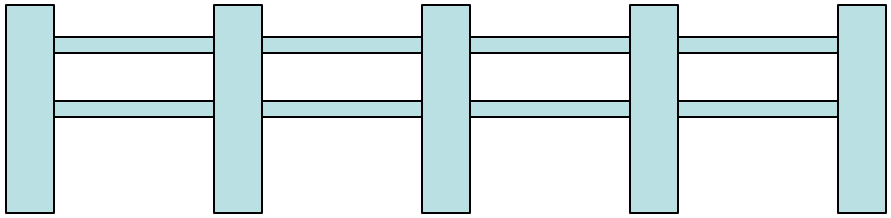
```
for (length of fence) {
    place a post.
    place some wire.
}
```



Fencepost loop

- Add a statement outside the loop to place the initial "post."
  - Also called a fencepost loop or a "loop-and-a-half" solution.

```
place a post.
for (length of fence - 1) {
    place some wire.
    place a post.
}
```



Fencepost method solution

```
public static void printNumbers(int max) {
    System.out.print(1);
    for (int i = 2; i <= max; i++) {
        System.out.print(", " + i);
    }
    System.out.println();      // to end the line
}
```

- Alternate solution: Either first or last "post" can be taken out:

```
public static void printNumbers(int max) {
    for (int i = 1; i <= max - 1; i++) {
        System.out.print(i + ", ");
    }
    System.out.println(max);  // to end the line
}
```

`while` loops

Categories of loops

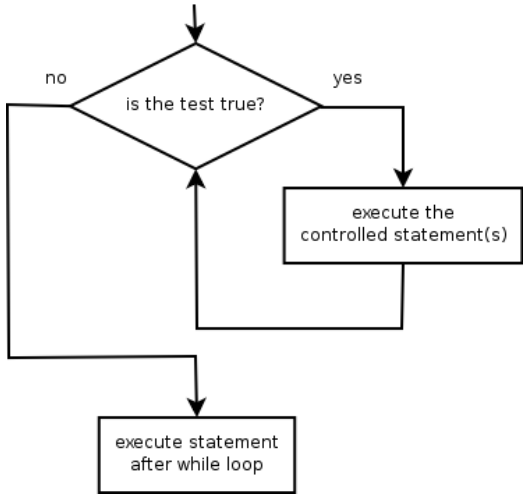
- **definite loop**: Executes a known number of times.
  - The `for` loops we have seen are definite loops.
    - Print "hello" 10 times.
    - Find all the prime numbers up to an integer n.
    - Print each odd number between 5 and 127.

- **indefinite loop**: One where the number of times its body repeats is not known in advance.
    - Prompt the user until they type a non-negative number.
    - Print random numbers until a prime number is printed.
    - Repeat until the user has types "q" to quit.

The `while` loop

- **`while` loop**: Repeatedly executes its body as long as a logical test is true.

```
while (test) {
    statement(s);
}
```



- Example:

```
int num = 1;                          // initialization
while (num <= 200) {                  // test
    System.out.print(num + " ");
    num = num * 2;                    // update
}
// output:  1 2 4 8 16 32 64 128
```

Example `while` loop

```
// finds the first factor of 91, other than 1
int n = 91;
int factor = 2;
while (n % factor != 0) {
    factor++;
}
System.out.println("First factor is " + factor);
// output:  First factor is 7
```

- `while` is better than `for` because we don't know how many times we will need to increment to find the factor.

Sentinel values

- **sentinel**: A value that signals the end of user input.
  - **sentinel loop**: Repeats until a sentinel value is seen.

- Example: Write a program that prompts the user for numbers until the user types 0, then outputs their sum.
  - (In this case, 0 is the sentinel value.)

```
Enter a number (0 to quit): 10
Enter a number (0 to quit): 20
Enter a number (0 to quit): 30
Enter a number (0 to quit): 0
The sum is 60
```

Flawed sentinel solution

- What's wrong with this solution?

```
Scanner console = new Scanner(System.in);
int sum = 0;
int number = 1;   // "dummy value", anything but 0

while (number != 0) {
    System.out.print("Enter a number (0 to quit): ");
    number = console.nextInt();
    sum = sum + number;
}

System.out.println("The total is " + sum);
```

Changing the sentinel value

- Modify your program to use a sentinel value of -1.
  - Example log of execution:

```
Enter a number (-1 to quit): 15
Enter a number (-1 to quit): 25
Enter a number (-1 to quit): 10
Enter a number (-1 to quit): 30
Enter a number (-1 to quit): -1
The total is 80
```

Changing the sentinel value

- To see the problem, change the sentinel's value to -1:

```
Scanner console = new Scanner(System.in);
int sum = 0;
int number = 1;  // "dummy value", anything but -1

while (number != -1) {
    System.out.print("Enter a number (-1 to quit): ");
    number = console.nextInt();
    sum = sum + number;
}

System.out.println("The total is " + sum);
```

- Now the solution produces the wrong output. Why?

```
The total was 79
```

The problem with our code

- Our code uses a pattern like this:

```
sum = 0.
while (input is not the sentinel) {
    prompt for input; read input.
    add input to the sum.
}
```

- On the last pass, the sentinel -1 is added to the sum:

```
    prompt for input; read input (-1).
    add input (-1) to the sum.
```

- This is a fencepost problem.
  - Must read N numbers, but only sum the first N-1 of them.

A fencepost solution

```
sum = 0.
prompt for input; read input.                  // place a "post"

while (input is not the sentinel) {
    add input to the sum.                      // place a "wire"
    prompt for input; read input.              // place a "post"
}
```

- Sentinel loops often utilize a fencepost "loop-and-a-half" style solution by pulling some code out of the loop.

Correct sentinel code

```
Scanner console = new Scanner(System.in);
int sum = 0;

// pull one prompt/read ("post") out of the loop
System.out.print("Enter a number (-1 to quit): ");
int number = console.nextInt();

while (number != -1) {
    sum = sum + number;      // moved to top of loop
    System.out.print("Enter a number (-1 to quit): ");
    number = console.nextInt();
}

System.out.println("The total is " + sum);
```

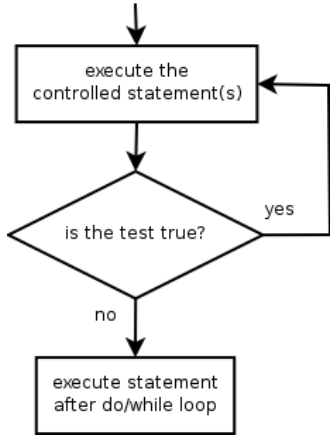
Sentinel as a constant

```
public static final int SENTINEL = -1;
...
Scanner console = new Scanner(System.in);
int sum = 0;

// pull one prompt/read ("post") out of the loop
System.out.print("Enter a number (" + SENTINEL +
                 " to quit): ");
int number = console.nextInt();

while (number != SENTINEL) {
    sum = sum + number;      // moved to top of loop
    System.out.print("Enter a number (" + SENTINEL +
                     " to quit): ");
    number = console.nextInt();
}

System.out.println("The total is " + sum);
```

The `do/while` loop

- **`do/while` loop**: Performs its test at the end of each repetition.
  - Guarantees that the loop's `{}` body will run at least once.

```
do {
    statement(s);
} while (test);
```




```
// Example: prompt until correct password is typed
String phrase;
do {
    System.out.print("Type your password: ");
    phrase = console.next();
} while (!phrase.equals("abracadabra"));
```

Type `boolean`

Methods that are tests

- Some methods return logical values.
  - A call to such a method is used as a **test** in a loop or `if`.

```
Scanner console = new Scanner(System.in);
System.out.print("Type your first name: ");
String name = console.next();

if (name.startsWith("Dr.")) {
    System.out.println("Will you marry me?");
} else if (name.endsWith("Esq.")) {
    System.out.println("And I am Ted 'Theodore' Logan!");
}
```

Type `boolean`

- **`boolean`**: A logical type whose values are `true` and `false`.
  - A logical **test** is actually a `boolean` expression.
  - It is legal to:
    - create a `boolean` variable
    - pass a `boolean` value as a parameter
    - return a `boolean` value from methods
    - call a method that returns a `boolean` and use it as a test

```
boolean minor    = (age < 21);
boolean isProf   = name.contains("Prof");
boolean lovesCSE = true;

// allow only CSE-loving students over 21
if (minor || isProf || !lovesCSE) {
    System.out.println("Can't enter the
club!");
}
```

Using `boolean`

- Why is type `boolean` useful?
  - Can capture a complex logical test result and use it later
  - Can write a method that does a complex test and returns it
  - Makes code more readable
  - Can pass around the result of a logical test (as param/return)

```
boolean goodAge    = age >= 12 && age < 29;
boolean goodHeight = height >= 78 && height < 84;
boolean rich       = salary >= 100000.0;
if ((goodAge && goodHeight) || rich) {
    System.out.println("Okay, let's go out!");
} else {
    System.out.println("It's not you, it's me...");
}
```

Returning `boolean`

```
public static boolean isPrime(int n) {
    int factors = 0;
    for (int i = 1; i <= n; i++) {
        if (n % i == 0) {
            factors++;
        }
    }
    if (factors == 2) {
        return true;
    } else {
        return false;
    }
}
```

- Calls to methods returning `boolean` can be used as tests:

```
if (isPrime(57)) {
    ...
}
```

Boolean question

- Improve our "rhyme" / "alliterate" program to use boolean methods to test for rhyming and alliteration.

```
Type two words: Bare blare
They rhyme!
They alliterate!
```

Boolean answer

```
    if (rhyme(word1, word2)) {
        System.out.println("They rhyme!");
    }
    if (alliterate(word1, word2)) {
        System.out.println("They alliterate!");
    }
    ...

// Returns true if s1 and s2 end with the same two letters.
public static boolean rhyme(String s1, String s2) {
    if (s2.length() >= 2 && s1.endsWith(s2.substring(s2.length() - 2))) {
        return true;
    } else {
        return false;
    }
}

// Returns true if s1 and s2 start with the same letter.
public static boolean alliterate(String s1, String s2) {
    if (s1.startsWith(s2.substring(0, 1))) {
        return true;
    } else {
        return false;
    }
}
```

"Boolean Zen", part 1

- Students new to `boolean` often test if a result is `true`:

```
if (isPrime(57) == true) {     // bad
    ...
}
```

- But this is unnecessary and redundant. Preferred:

```
if (isPrime(57)) {             // good
    ...
}
```

- A similar pattern can be used for a `false` test:

```
if (isPrime(57) == false) {    // bad
if (!isPrime(57)) {            // good
```

"Boolean Zen", part 2

- Methods that return `boolean` often have an `if/else` that returns `true` or `false`:

```
public static boolean bothOdd(int n1, int n2) {
    if (n1 % 2 != 0 && n2 % 2 != 0) {
        return true;
    } else {
        return false;
    }
}
```

  - But the code above is unnecessarily verbose.

Solution w/ `boolean` var

- We could store the result of the logical test.

```
public static boolean bothOdd(int n1, int n2) {
    boolean test = (n1 % 2 != 0 && n2 % 2 != 0);
    if (test) {    // test == true
        return true;
    } else {       // test == false
        return false;
    }
}
```

  - Notice: Whatever `test` is, we want to return that.
    - If `test` is `true` , we want to return `true`.
    - If `test` is `false`, we want to return `false`.

Solution w/ "Boolean Zen"

- Observation: The `if/else` is unnecessary.
  - The variable `test` stores a `boolean` value;

    its value is exactly what you want to return. So return that!

```
public static boolean bothOdd(int n1, int n2) {
    boolean test = (n1 % 2 != 0 && n2 % 2 != 0);
    return test;
}
```

- An even shorter version:
  - We don't even need the variable `test`.

    We can just perform the test and return its result in one step.

```
public static boolean bothOdd(int n1, int n2) {
    return (n1 % 2 != 0 && n2 % 2 != 0);
}
```

"Boolean Zen" template

- Replace

```
public static boolean name(parameters) {
    if (test) {
        return true;
    } else {
        return false;
    }
}
```

- with

```
public static boolean name(parameters) {
    return test;
}
```

Improved `isPrime` method

- The following version utilizes Boolean Zen:

```
public static boolean isPrime(int n) {
    int factors = 0;
    for (int i = 1; i <= n; i++) {
        if (n % i == 0) {
            factors++;
        }
    }
    return factors == 2;  // if n has 2 factors, true
}
```

- Modify our Rhyme program to use Boolean Zen.

Boolean Zen answer

```
public static void main(String[] args) {
    Scanner console = new Scanner(System.in);
    System.out.print("Type two words: ");
    String word1 = console.next().toLowerCase();
    String word2 = console.next().toLowerCase();

    if (rhyme(word1, word2)) {
        System.out.println("They rhyme!");
    }
    if (alliterate(word1, word2)) {
        System.out.println("They alliterate!");
    }
}

// Returns true if s1 and s2 end with the same two letters.
public static boolean rhyme(String s1, String s2) {
    return s2.length() >= 2 && s1.endsWith(s2.substring(s2.length() - 2));
}

// Returns true if s1 and s2 start with the same letter.
public static boolean alliterate(String s1, String s2) {
    return s1.startsWith(s2.substring(0, 1));
}
```

"Short-circuit" evaluation

- Java stops evaluating a test if it knows the answer.
  - `&&` stops early if any part of the test is `false`
  - `||` stops early if any part of the test is `true`

- The following test will crash if s2's length is less than 2:

```
// Returns true if s1 and s2 end with the same two letters.
public static boolean rhyme(String s1, String s2) {
    return s1.endsWith(s2.substring(s2.length() - 2)) &&
           s1.length() >= 2 && s2.length() >= 2;
}
```

- The following test will not crash; it stops if length < 2:

```
// Returns true if s1 and s2 end with the same two letters.
public static boolean rhyme(String s1, String s2) {
    return s1.length() >= 2 && s2.length() >= 2 &&
           s1.endsWith(s2.substring(s2.length() - 2));
}
```

De Morgan's Law

- **De Morgan's Law**: Rules used to negate boolean tests.
  - Useful when you want the opposite of an existing test.

Original Expression	Negated Expression	Alternative
`a && b`	`!a || !b`	`!(a && b)`
`a || b`	`!a && !b`	`!(a || b)`

  - Example:

Original Code	Negated Code

`if (x == 7 && y > 3) {`
`  ...`
`}`
	`if (x != 7 || y <= 3) {`
	`  ...`
	`}`

When to return?

- Methods with loops and return values can be tricky.
  - When and where should the method return its result?

- Write a method `seven` that accepts a `Random` parameter and uses it to draw up to ten lotto numbers from 1-30.
  - If any of the numbers is a lucky 7, the method should stop and return `true`. If none of the ten are 7 it should return `false`.
  - The method should print each number as it is drawn.

```
19 22
```

```
15 29 18 29 11 3 30 17
```
(first call)
```
29 5 29 4 7
```
(second call)

Flawed solution

```
// Draws 10 lotto numbers; returns true if one is 7.
public static boolean seven(Random rand) {
    for (int i = 1; i <= 10; i++) {
        int num = rand.nextInt(30) + 1;
        System.out.print(num + " ");
        if (num == 7) {
            return true;
        } else {
            return false;
        }
    }
}
```

- The method always returns immediately after the first roll.
- This is wrong if that roll isn't a 7; we need to keep rolling.

Returning at the right time

```
// Draws 10 lotto numbers; returns true if one is 7.
public static boolean seven(Random rand) {
    for (int i = 1; i <= 10; i++) {
        int num = rand.nextInt(30) + 1;
        System.out.print(num + " ");
        if (num == 7) {    // found lucky 7; can exit now
            return true;
        }
    }
    return false;   // if we get here, there was no 7
}
```

- Returns `true` immediately if 7 is found.
- If 7 isn't found, the loop continues drawing lotto numbers.
- If all ten aren't 7, the loop ends and we return `false`.

`while` loop question

- Write a method `digitSum` that accepts an integer parameter and returns the sum of its digits.
  - Assume that the number is non-negative.
  - Example: `digitSum(29107)` returns 2+9+1+0+7 or `19`
  - Hint: Use the `%` operator to extract a digit from a number.

`while` loop answer

```
public static int digitSum(int n) {
    n = Math.abs(n);              // handle negatives
    int sum = 0;
    while (n > 0) {
        sum = sum + (n % 10);     // add last digit
        n = n / 10;               // remove last digit
    }
    return sum;
}
```

Boolean return questions

- `hasAnOddDigit` : returns `true` if any digit of an integer is odd.
  - `hasAnOddDigit(4822116)` returns `true`
  - `hasAnOddDigit(2448)` returns `false`

- `allDigitsOdd` : returns `true` if every digit of an integer is odd.
  - `allDigitsOdd(135319)` returns `true`
  - `allDigitsOdd(9174529)` returns `false`

- `isAllVowels` : returns `true` if every char in a `String` is a vowel.
  - `isAllVowels("eIeIo")` returns `true`
  - `isAllVowels("oink")` returns `false`

    - These problems are available in our Practice-It! system under **5.x**.

Boolean return answers

```
public static boolean hasAnOddDigit(int n) {
    while (n != 0) {
        if (n % 2 != 0) {    // check whether last digit is odd
            return true;
        }
        n = n / 10;
    }
    return false;
}
public static boolean allDigitsOdd(int n) {
    while (n != 0) {
        if (n % 2 == 0) {    // check whether last digit is even
            return false;
        }
        n = n / 10;
    }
    return true;
}
public static boolean isAllVowels(String s) {
    for (int i = 0; i < s.length(); i++) {
        String letter = s.substring(i, i + 1);
        if (!isVowel(letter)) {
            return false;
        }
    }
    return true;
}
```

Logical Assertions

Logical assertions

- **assertion**: A statement that is either true or false.

  Examples:
  - Java was created in 1995.
  - The sky is purple.
  - 23 is a prime number.
  - 10 is greater than 20.
  - x divided by 2 equals 7. (depends on the value of x)

- An assertion might be false ("The sky is purple" above), but it is still an assertion because it is a true/false statement.

Reasoning about assertions

- Suppose you have the following code:

```
if (x > 3) {
    // Point A
    x--;
} else {
    // Point B
    x++;
    // Point C
}
// Point D
```

- What do you know about `x`'s value at the three points?
  - Is `x > 3`? Always? Sometimes? Never?

Assertions in code

- We can make assertions about our code and ask whether they are true at various points in the code.
  - Valid answers are ALWAYS, NEVER, or SOMETIMES.

```
  System.out.print("Type a nonnegative number:
");
  double number = console.nextDouble();
  // Point A: is number < 0.0 here?    (SOMETIMES)

  while (number < 0.0) {
      // Point B: is number < 0.0 here?
      System.out.print("Negative; try again: ");
                                        (ALWAYS)
      number = console.nextDouble();
      // Point C: is number < 0.0 here?
  }
                                        (SOMETIMES)

  // Point D: is number < 0.0 here?

                                        (NEVER)
```

Reasoning about assertions

- Right after a variable is initialized, its value is known:

```
int x = 3;
// is x > 0?  ALWAYS
```

- In general you know nothing about parameters' values:

```
public static void mystery(int a, int b) {
// is a == 10?  SOMETIMES
```

- But inside an `if`, `while`, etc., you may know something:

```
public static void mystery(int a, int b) {
    if (a < 0) {
        // is a == 10?  NEVER
        ...
    }
}
```

Assertions and loops

- At the start of a loop's body, the loop's test must be `true`:

```
while (y < 10) {
    // is y < 10?  ALWAYS
    ...
}
```

- After a loop, the loop's test must be `false`:

```
while (y < 10) {
    ...
}
// is y < 10?  NEVER
```

- Inside a loop's body, the loop's test may become `false`:

```
while (y < 10) {
    y++;
    // is y < 10?  SOMETIMES
}
```

"Sometimes"

- Things that cause a variable's value to be unknown (often leads to "sometimes" answers):
  - reading from a `Scanner`
  - reading a number from a `Random` object
  - a parameter's initial value to a method

- If you can reach a part of the program both with the answer being "yes" and the answer being "no", then the correct answer is "sometimes".
  - If you're unsure, "Sometimes" is a good guess.

Assertion example 1

```
public static void mystery(int x, int y) {
    int z = 0;

    // Point A

    while (x >= y) {
        // Point B
        x = x - y;
        z++;

        if (x != y) {
            // Point C
            z = z * 2;
        }

        // Point D

    }

    // Point E
    System.out.println(z);
}
```

Which of the following assertions are true at which point(s) in the code? Choose ALWAYS, NEVER, or SOMETIMES.

	x < y	x == y	z == 0
Point A	SOMETIMES	SOMETIMES	ALWAYS
Point B	NEVER	SOMETIMES	SOMETIMES
Point C	SOMETIMES	NEVER	NEVER
Point D	SOMETIMES	SOMETIMES	NEVER
Point E	ALWAYS	NEVER	SOMETIMES

Assertion example 2

```
public static int mystery(Scanner console) {
    int prev = 0;
    int count = 0;
    int next = console.nextInt();

    // Point A

    while (next != 0) {
        // Point B

        if (next == prev) {
            // Point C

            count++;
        }

        prev = next;
        next = console.nextInt();

        // Point D

    }

    // Point E

    return count;
}
```

Which of the following assertions are true at which point(s) in the code? Choose ALWAYS, NEVER, or SOMETIMES.

	next == 0	prev == 0	next == prev
Point A	SOMETIMES	ALWAYS	SOMETIMES
Point B	NEVER	SOMETIMES	SOMETIMES
Point C	NEVER	NEVER	ALWAYS
Point D	SOMETIMES	NEVER	SOMETIMES
Point E	ALWAYS	SOMETIMES	SOMETIMES

Assertion example 3

```
// Assumes y >= 0, and returns x^y
public static int pow(int x, int y) {
    int prod = 1;

    // Point A
    while (y > 0) {
        // Point B
        if (y % 2 == 0) {
            // Point C
            x = x * x;
            y = y / 2;
            // Point D
        } else {
            // Point E
            prod = prod * x;
            y--;
            // Point F
        }
    }
    // Point G
    return prod;
}
```

Which of the following assertions are true at which point(s) in the code? Choose ALWAYS, NEVER, or SOMETIMES.

	`y > 0`	`y % 2 == 0`
Point A	SOMETIMES	SOMETIMES
Point B	ALWAYS	SOMETIMES
Point C	ALWAYS	ALWAYS
Point D	ALWAYS	SOMETIMES
Point E	ALWAYS	NEVER
Point F	SOMETIMES	ALWAYS
Point G	NEVER	ALWAYS