# Inf1B

## Arrays[1]

Perdita Stevens
adapting earlier versions by Ewan Klein, Volker Seeker, et al.

School of Informatics

[1] Thanks to Sedgewick&Wayne for much of this content

# Arrays

# Many Variables of the Same Type

How do we initialize 10 variables of the same type?

```
double a0, a1, a2, a3, a4, a5, a6, a7, a8, a9;
a0 = 0.0;
a1 = 0.0;
a2 = 0.0;
a3 = 0.0;
a4 = 0.0;
a5 = 0.0;
a6 = 0.0;
a7 = 0.0;
a8 = 0.0;
a9 = 0.0;
...
a4 = 3.0;
a4 = 8.5;
...
double x = a4 + a5;
```

# Many Variables of the Same Type

How do we initialize 10 variables of the same type?

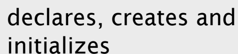
Much more efficient would be something like this:

```
double a = 0.0 X 10;
```

# Many Variables of the Same Type

How do we initialize 10 variables of the same type?

```
// easy alternative
double[] a = new double[10];
...
a[4] = 3.0;
a[8] = 8.0;
...
double x = a[4] + a[8];
```



# Many Variables of the Same Type

How do we initialize 1 million variables of the same type?

```
// just as easy with large arrays
double[] a = new double[1000000];
...
a[123456] = 3.0;
a[987654] = 8.0;
...
double x = a[123456] + a[987654];
```

# Arrays

Arrays: allow us to store and manipulate large quantities of data.
An array is an indexed sequence of values of the same type.

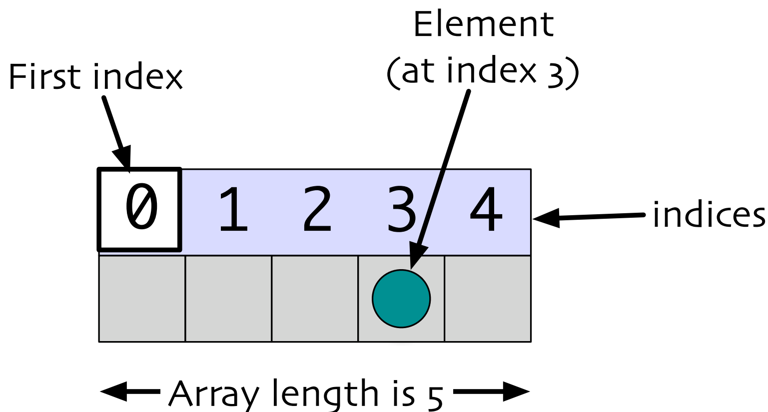
Examples

- 52 playing cards in a deck.
- 17,000 undergraduates in UoE.
- 1 million characters in a book.
- 10 million audio samples in an MP3 file.
- 4 billion nucleotides in a DNA strand.
- 90 billion Google queries per year.
- 50 trillion cells in the human body.

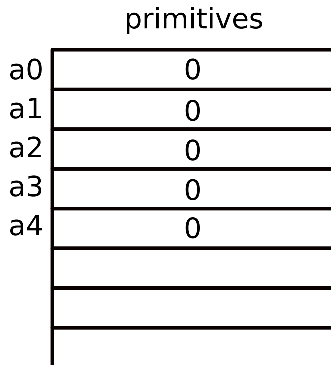
| *index* | *value* |
|---|---|
| 0 | Rebecca |
| 1 | Isla |
| 2 | Brooke |
| 3 | Megan |
| 4 | Niamh |
| 5 | Eilidh |
| 6 | Eva |
| 7 | Abbie |
| 8 | Skye |
| 9 | Aimee |

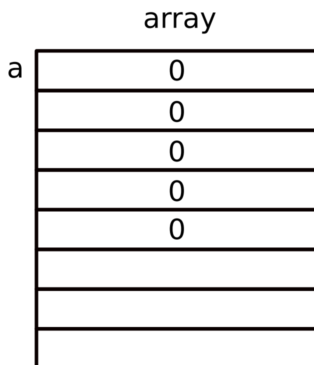
(From 100 most popular Scottish girls' names, 2007)

# Arrays



# What happens in memory?



# Arrays in Java

- In Java, arrays are considered objects
- They are a special kind of object

We will get back to that in later lectures ...

# Arrays in Java

Java has special support for arrays:

- To make an array: declare, create and initialize it.

## Declare an array

```
int[] arrayOfInts;
```

## Create an array of length 10

```
arrayOfInts = new int[10];
```

# Arrays in Java

Java has special support for arrays:

- To make an array: declare, create and initialize it.
- To access element `i` of array named `a`, use `a[i]`.
- Array indices start at `0`.

```
int n = 10;                     // size of array
double[] a;                     // declare the array
a = new double[n];              // create the array
for (int i = 0; i < n; i++) {
   a[i] = 0.0;                  // initialise each elt
}
```

# Arrays in Java

Java has special support for arrays:

- To make an array: declare, create and initialize it.
- To access element `i` of array named `a`, use `a[i]`.
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```
int n = 10;                    // size of array
double[] a;                    // declare the array
a = new double[n];             // create the array
for (int i = 0; i < n; i++) {
   a[i] = 0.0;                 // initialise each elt
}
```

Compact alternative:

- Declare, create and initialize in one statement.

```
int n = 10;                  // size of array
double[] a = new double[n]; // declare, create, init
```

# Default Initialization of Arrays

Each array element is automatically initialized to a default value:

| | |
|---|---|
| int: | 0 |
| double: | 0.0 |
| boolean: | false |
| String: | null |

# Types of Array

All elements of a given array must be of the same type.

## Array Types

```
int[]
double[]
String[]
char[]
...
```

Array of `Strings`:

```
String[] names = new String[5];
names[0] = "Rebecca";
names[1] = "Isla";
names[2] = "Brooke";
names[3] = "Megan";
names[4] = "Niamh";
```

# Alternative Initialization Syntax for Arrays

- Shorthand syntax for initializing arrays.
- Handy if you only have a few data items.

```
String[] names = {"Rebecca", "Isla", "Brooke", "Megan", "Niamh"};
int[] mynums = { 0, 7, 9, 1, 4 };
double[] morenums = { 2.5, -0.1, 33.0 };
```

# The Length of Arrays

Given an array `a`,

- check the length of the array: `a.length`
- first element is `a[0]`
- second element is `a[1]`
- ...
- last element is `a[a.length-1]`
- If an array index is too small or too large, Java throws run-time error: `ArrayIndexOutOfBoundsException`

# Arrays: Another Example

```
public class ArrayEx {
    public static void main(String[] args) {
        String[] names = { "Rebecca", "Isla", "Brooke", "Megan", "Niamh" };
        System.out.println(names.length);
        System.out.println(names[1]);
        System.out.println(names[names.length]);
    }
}
```

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```
public class ArrayEx {
    public static void main(String[] args) {
        String[] names = { "Rebecca", "Isla", "Brooke", "Megan", "Niamh" };
        System.out.println(names.length);
        System.out.println(names[1]);
        System.out.println(names[names.length]);
    }
}
```

## Output

```
5
```

# Arrays: Another Example

```
public class ArrayEx {
    public static void main(String[] args) {
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        System.out.println(names[names.length]);
    }
}
```

## Output

```
5
Isla
```

# Arrays: Another Example

```
public class ArrayEx {
    public static void main(String[] args) {
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        System.out.println(names[1]);
        System.out.println(names[names.length]);
    }
}
```

## Output

```
5
Isla
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsExcept
```

# Arrays: Another Example

```
public class ArrayEx {
    public static void main(String[] args) {
        String[] names = { "Rebecca", "Isla", "Brooke", "Megan", "Niamh" };
        System.out.println(names.length);
        System.out.println(names[1]);
        System.out.println(names[names.length]);
    }
}
```

## Output

```
5
Isla
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsExcept
```

To get at last element, use `names[names.length-1]`.

# Vector Dot Product

Dot Product: Given two vectors x[] and y[] of length n, their dot product is the sum of the products of their corresponding components.

```
double[] x = { 0.3, 0.6, 0.1 };
double[] y = { 0.5, 0.1, 0.4 };
double sum = 0.0;
for (int i = 0; i < x.length; i++) {
    sum = sum + x[i] * y[i];
}
```

## States

| i | x[i] | y[i] | x[i]*y[i] | sum |
|---|---|---|---|---|
| 0 | 0.30 | 0.50 | 0.15 | 0.15 |
| 1 | 0.60 | 0.10 | 0.06 | 0.21 |
| 2 | 0.10 | 0.40 | 0.04 | 0.25 |

# Array-processing Examples

Create an array with random values

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Create an array with random values

```
double[] a = new double[n];
for (int i = 0; i < a.length; i++) {
  a[i] = Math.random();
}
```

# Array-processing Examples

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```
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Print the array values, one per line

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}
```

Print the array values, one per line

```
for (int i = 0; i < a.length; i++) {
  System.out.println(a[i]);
}
```

# Array-processing Examples

Create an array with random values

```
double[] a = new double[n];
for (int i = 0; i < a.length; i++) {
  a[i] = Math.random();
}
```

Print the array values, one per line

```
for (int i = 0; i < a.length; i++) {
  System.out.println(a[i]);
}
```

Find the maximum of the array values

# Array-processing Examples

Create an array with random values

```
double[] a = new double[n];
for (int i = 0; i < a.length; i++) {
  a[i] = Math.random();
}
```

Print the array values, one per line

```
for (int i = 0; i < a.length; i++) {
  System.out.println(a[i]);
}
```

Find the maximum of the array values

```
double max = a[0];
for (int i = 1; i < a.length; i++) {
  if (a[i] > max) max = a[i];
}
```

# Array-processing Examples

Copy one array to another.

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Copy one array to another.

```
double[] a = {0.3, 1.2, 1.7, 0.4, 1.5};
double[] b = new double[a.length];
for (int i = 0; i < a.length; i++) {
  b[i] = a[i];
}
```

# Let's practise that

https://www.theodysseyonline.com/your-brain-is-muscle-exercise-it

# Dot Product

Fill in the blanks for an algorithm to calculate the dot product of 2 vectors, a and b.

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Fill in the blanks for an algorithm to calculate the dot product of 2 vectors, a and b.

```
double[] a = {0.3, 0.6,  0.1};
double[] b = {0.5, 0.1, 0.4};

double sum=0.0;
for (/* BLANK 1 */) {
  /* BLANK 2 */
}
System.out.println(sum);
```

# Dot Product

Fill in the blanks for an algorithm to calculate the dot product of 2 vectors, a and b.

```
double[] a = {0.3, 0.6,  0.1};
double[] b = {0.5, 0.1, 0.4};

double sum=0.0;
for (int i=0; i < b.length; i++) {
  sum = sum + a[i] * b[i];
}
System.out.println(sum);
```

# Average

Fill in the blanks for an algorithm to calculate the average value of an array of doubles.

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```
double[] data = {0.3, 1.2, 1.7, 0.4, 1.5};
/* BLANK 1 */

for (int i = 0; i < data.length; i++) {
  /* BLANK 2 */
}

System.out.println(/* BLANK 3 */);
```

# Average

Fill in the blanks for an algorithm to calculate the average value of an array of doubles.

```
double[] data = {0.3, 1.2, 1.7, 0.4, 1.5};
double sum = 0.0;

for (int i = 0; i < data.length; i++) {
  sum += data[i];
}

System.out.println(sum / data.length);
```

# Setting Array Values at Run Time

Print a random card.

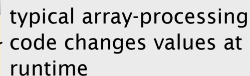
```
String[] rank = { "2", "3", "4", "5", "6", "7", "8",
        "9", "10", "Jack", "Queen", "King", "Ace" };

String[] suit = { "Clubs", "Diamonds", "Hearts", "Spades" };

int i = (int) (Math.random() * 13); // between 0 and 12
int j = (int) (Math.random() * 4);  // between 0 and 3

System.out.println(rank[i] + " of " + suit[j]);
```

**Output**

```
7 of Spades
...
Jack of Diamonds
...
```

# Setting Array Values at Run Time

```
String[] deck = new String[52];
for (int i = 0; i < 13; i++) {
    for (int j = 0; j < 4; j++) {
        deck[4 * i + j] = rank[i] + " of " + suit[j];
    }
}
for (int k = 0; k < deck.length; k++) {
    System.out.println(deck[k]);
}
```




Q: In what order does the program print the deck?

## Output 1

```
2 of Clubs
2 of Diamonds
2 of Hearts
2 of Spades
3 of Clubs
...
```

## Output 2

```
2 of Clubs
3 of Clubs
4 of Clubs
5 of Clubs
6 of Clubs
...
```

# Remark on hard-wired constants

```
String[] suit = { "Clubs", "Diamonds", "Hearts",
    "Spades" };
String[] rank = { "2", "3", "4", "5", "6", "7",
    "8", "9", "10", "Jack", "Queen", "King", "Ace" };

String[] deck = new String[52];
for (int i = 0; i < 13; i++) {
  for (int j = 0; j < 4; j++) {
    deck[4 * i + j] = rank[i] + " of " + suit[j];
  }
}

for (int k = 0; k < 52; k++) {
    System.out.println(deck[k]);
}
```

`suit` and `rank` are intended to stay fixed throughout the program, and 52 should be the product of their lengths. But those facts are not yet enforced...

# Remark on hard-wired constants

```
final String[] SUIT = { "Clubs", "Diamonds", "Hearts",
    "Spades" };
final String[] RANK = { "2", "3", "4", "5", "6", "7",
    "8", "9", "10", "Jack", "Queen", "King", "Ace" };

final int CARDS = SUIT.length * RANK.length;

String[] deck = new String[CARDS];
for (int i = 0; i < 13; i++) {
  for (int j = 0; j < 4; j++) {
    deck[4 * i + j] = RANK[i] + " of " + SUIT[j];
  }
}

for (int k = 0; k < CARDS; k++) {
    System.out.println(deck[k]);
}
```

Use a local constant value instead!

The `final` keyword allows only a single initialisation of that variable. Further attempts to change it are caught by the compiler.

# Remark on hard-wired constants

```
final String[] SUIT = { "Clubs", "Diamonds", "Hearts",
    "Spades" };
final String[] RANK = { "2", "3", "4", "5", "6", "7",
    "8", "9", "10", "Jack", "Queen", "King", "Ace" };

final int SUITS = SUIT.length;
final int RANKS = RANK.length;
final int CARDS = SUITS * RANKS;

String[] deck = new String[CARDS];
for (int i = 0; i < RANKS; i++) {
  for (int j = 0; j < SUITS; j++) {
    deck[SUITS * i + j] = RANK[i] + " of " + SUIT[j];
  }
}

for (int k = 0; k < CARDS; k++) {
    System.out.println(deck[k]);
}
```

Constants also improve readability and get rid of "magic" numbers.

# Remark on hard-wired constants

There are other ways to deal with this situation such as using *global* constants, functions or even `enums`. But more about that later ...

Do not blindly replace every "magic number" by a named constant (e.g. don't replace 0 by ZERO!)

Think about what you are trying to achieve.

1. Make the program easy to comprehend (readability).
2. Make foreseeable changes as easy as possible (maintainability).

# Shuffling

Given an array, rearrange its elements in random order.
Shuffling algorithm:

1. In iteration `i`, pick random card from `deck[i]` through `deck[CARDS-1]`, with each card equally likely.
2. Exchange it with `deck[i]`.

# Shuffling

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Shuffling algorithm:

1. In iteration `i`, pick random card from `deck[i]` through `deck[CARDS-1]`, with each card equally likely.
2. Exchange it with `deck[i]`.

```
for (int i = 0; i < CARDS; i++) {
  int randCard = i + (int) (Math.random() * (
      CARDS - i));
  String temp = deck[randCard];
  deck[randCard] = deck[i];
  deck[i] = temp;
}
```

# Shuffling a Deck of Cards: Putting Everything Together

```
public class Deck {
  public static void main(String[] args) {
    final String[] SUIT = { "Clubs", "Diamonds", "Hearts", "Spades" };
    final String[] RANK = { "2", "3", "4", "5", "6", "7",
        "8", "9", "10", "Jack", "Queen", "King", "Ace" };
    final int SUITS = SUIT.length;
    final int RANKS = RANK.length;
    final int CARDS = SUITS * RANKS;

    String[] deck = new String[CARDS];
    for (int i = 0; i < RANKS; i++) {
      for (int j = 0; j < SUITS; j++) {
        deck[SUITS * i + j] = RANK[i] + " of " + SUIT[j];
      }
    }
    for (int i = 0; i < CARDS; i++) {
      int randCard = i + (int) (Math.random() * (CARDS - i));
      String temp = deck[randCard];
      deck[randCard] = deck[i];
      deck[i] = temp;
    }
    for (int k = 0; k < CARDS; k++) {
        System.out.println(deck[k]);
    }
  }
}
```

# Shuffling a Deck of Cards

**Output**

```
% java Deck
Jack of Clubs
4 of Spades
5 of Clubs
10 of Diamonds
2 of Hearts
Queen of Clubs
8 of Hearts
5 of Hearts
3 of Clubs
7 of Hearts
10 of Hearts
6 of Hearts
Jack of Spades
...
3 of Hearts
```

**Output**

```
% java Deck
4 of Spades
2 of Diamonds
5 of Hearts
7 of Diamonds
3 of Hearts
10 of Hearts
2 of Clubs
King of Diamonds
Queen of Diamonds
10 of Clubs
3 of Spades
7 of Hearts
8 of Clubs
...
3 of Clubs
```

# Two-Dimensional Arrays

Examples of two-dimensional arrays:

- Table of data for each experiment and outcome.
- Table of grades for each student and assignment.
- Table of grayscale values for each pixel in a 2D image.

Mathematical abstraction: matrix
Java abstraction: 2D Array

# Two-Dimensional Arrays in Java

Array access: Use a[i][j] to access element in row i and column j. Zero-based indexing: Row and column indices start at 0.

```
int m = 10;
int n = 3;
double[][] a = new double[m][n];
for (int i = 0; i < m; i++) {
   for (int j = 0; j < n; j++) {
      a[i][j] = 0.0;
   }
}
```

Initialize a 10-by-3 array of doubles



| a[0][0] | a[0][1] | a[0][2] |
| --- | --- | --- |
| a[1][0] | a[1][1] | a[1][2] |
| a[2][0] | a[2][1] | a[2][2] |
| a[3][0] | a[3][1] | a[3][2] |
| a[4][0] | a[4][1] | a[4][2] |
| a[5][0] | a[5][1] | a[5][2] |
| a[6][0] | a[6][1] | a[6][2] |
| a[7][0] | a[7][1] | a[7][2] |
| a[8][0] | a[8][1] | a[8][2] |
| a[9][0] | a[9][1] | a[9][2] |

A 10-by-3 array

# Setting 2D Array Values at Compile Time

Initialize 2D array of doubles by listing values. Each element of the array `p` is itself an array of type `double[]`.

```
double[][] p = {
    { .02, .92, .02, .02, .02 },
    { .02, .02, .32, .32, .32 },
    { .02, .02, .02, .92, .02 },
    { .92, .02, .02, .02, .02 },
    { .47, .02, .47, .02, .02 },
};
```

```
0.02 0.92 0.02 0.02 0.02
0.02 0.02 0.32 0.32 0.32
0.02 0.02 0.02 0.92 0.02
0.92 0.02 0.02 0.02 0.02
0.47 0.02 0.47 0.02 0.02
```

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```
double[][] p = {
    { .02, .92, .02, .02, .02 },
    { .02, .02, .32, .32, .32 },
    { .02, .02, .02, .92, .02 },
    { .92, .02, .02, .02, .02 },
    { .47, .02, .47, .02, .02 },
};
```

p[1][3]

```
0.02 0.92 0.02 0.02 0.02
0.02 0.02 0.32 0.32 0.32
0.02 0.02 0.02 0.92 0.02
0.92 0.02 0.02 0.02 0.02
0.47 0.02 0.47 0.02 0.02
```

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    { .02, .92, .02, .02, .02 },
    { .02, .02, .32, .32, .32 },
    { .02, .02, .02, .92, .02 },
    { .92, .02, .02, .02, .02 },
    { .47, .02, .47, .02, .02 },
};
```

p[1][3]

```
0.02 0.92 0.02 0.02 0.02
0.02 0.02 0.32 0.32 0.32
0.02 0.02 0.02 0.92 0.02
0.92 0.02 0.02 0.02 0.02
0.47 0.02 0.47 0.02 0.02
```

row 1 → (second row highlighted)

# Setting 2D Array Values at Compile Time

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double[][] p = {
    { .02, .92, .02, .02, .02 },
    { .02, .02, .32, .32, .32 },
    { .02, .02, .02, .92, .02 },
    { .92, .02, .02, .02, .02 },
    { .47, .02, .47, .02, .02 },
};
```

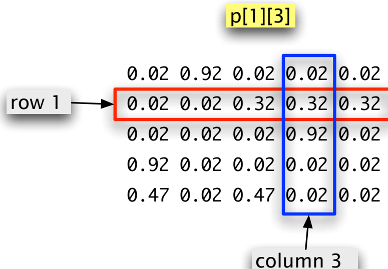

# Setting 2D Array Values at Compile Time

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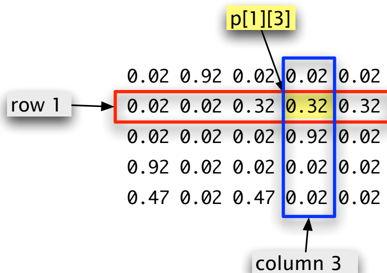
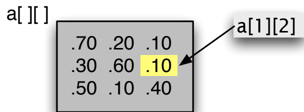
```
double[][] p = {
    { .02, .92, .02, .02, .02 },
    { .02, .02, .32, .32, .32 },
    { .02, .02, .02, .92, .02 },
    { .92, .02, .02, .02, .02 },
    { .47, .02, .47, .02, .02 },
};
```

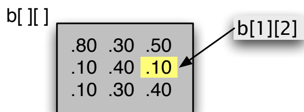


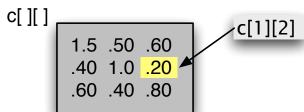
# Matrix Addition

Matrix Addition: given two n-by-n matrices `a` and `b`, define `c` to be the n-by-n matrix where `c[i][j]` is the sum `a[i][j] + b[i][j]`.

```
double[][] c = new double[n][n];
for (int i = 0; i < n; i++) {
   for (int j = 0; j < n; j++) {
      c[i][j] = a[i][j] + b[i][j];
   }
}
```



# Matrix Multiplication

Matrix Multiplication: given two n-by-n matrices `a` and `b`, define `c` to be the n-by-n matrix where `c[i][j]` is the dot product of the `i`$^{th}$ row of `a[][]` and the `j`$^{th}$ column of `b[][]`.

```
double[][] c = new double[n][n];
for (int i = 0; i < n; i++) {
   for (int j = 0; j < n; j++) {
      for (int k = 0; k < n; k++) {
         c[i][j] += a[i][k] * b[k][j];
      }
   }
}
```

# Enhanced for loop, 1

Ordinary for loops are easy to get wrong! Often there's a better way:

```
int[] numbers = {2, 5, 6, 1, 0, 5};
```

## Ordinary for loop

```
for (int i = 0; i < numbers.length; i++) {
    System.out.println(numbers[i]);
}
```

## Enhanced for loop

```
for (int num : numbers)
    System.out.println(num);
}
```

# Enhanced `for` loop, 2

- Also called *for-each* loop, with `:` pronounced "in".
- On each iteration, an element of the iterable gets assigned to the loop variable.
- Loop gets executed once for each element in the iterable.
- Easier and more concise: no need to initialise loop counter, increment, set termination condition...
- ... but less flexible; no access to the loop counter.
- Use them whenever you don't need access to the loop counter.
- Typical use: when you need access to all the elements of an array, but you don't care about their indexes.

General form:

```
for ( variable declaration : iterable ){
...
}
```

NB the variable must have same type as elements in *iterable*.

# Enhanced for loop, 3

## Another Example: Right

```
String[] words = {"hello", "world", "yes", "we", "can"};
for (String w : words) {
    System.out.println(w);
}
```

## Another Example: Wrong

```
String[] words = {"hello", "world", "yes", "we", "can" };
for ( int  w : words) {
    System.out.println(w);
}
```

# Summary

Arrays:

- Method of storing large amounts of data.
- Almost as easy to use as primitive types.
- We can directly access an element given its index.

Local Constants:

- specify constants using the `final` keyword to improve maintainability and readability

Enhanced for loop:

- Good alternative to ordinary for loop where you just want to iterate over an array, and don't care about the indexes.

# Reading

Java Tutorial

pp51-57

i.e. now it's time to read carefully the section on Arrays within Chapter 3, *Language Basics*, that I suggested skimming over before.