Inf1B

Arrays[1]

Volker Seeker
adapting earlier version by Perdita Stevens and Ewan Klein

School of Informatics

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[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];
```

declares, creates and initializes

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.

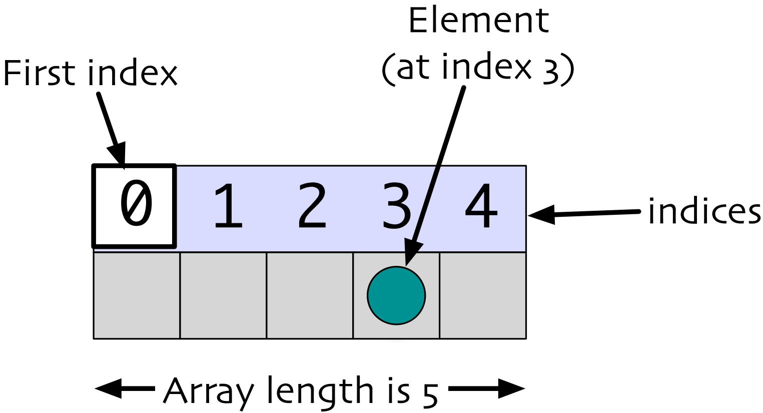
Examples

- 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.

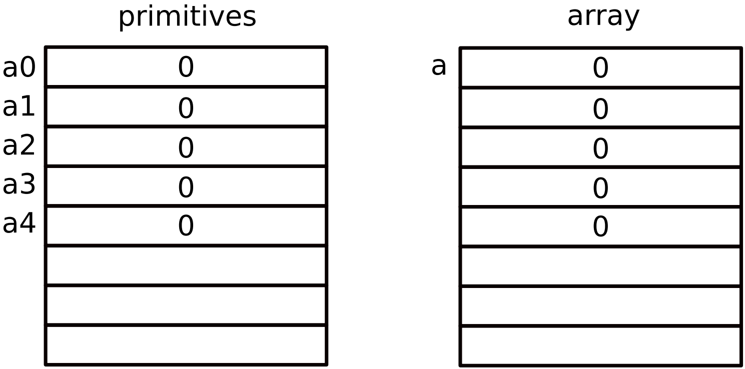
index	*value*
0	Rebecca
1	Isla
2	Brooke
3	Megan
4	Niamh
5	Eilidh
6	Eva
7	Abbie
8	Skye
9	Aimee

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

Arrays


Element
(at index 3)
First index
0
1
2
3
4
indices
Array length is 5

What happens in memory?



	primitives
a0	0
a1	0
a2	0
a3	0
a4	0

	array
a	0
	0
	0
	0
	0

Arrays in Java

Your first Object!

- 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].
- 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
}
```

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 `String`s:

```
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

```java
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]);
    }
}
```

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
```

Arrays: Another Example

```java
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
```

Arrays: Another Example

```java
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
```

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();
}
```

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```

Print the array values, one per line

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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]);
}
```

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.

Array-processing Examples

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 practice that

TOP HAT

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]);
}
```

typical array-processing code changes values at runtime

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

```java
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]);
}
```

Avoid hard-wired constants to increase readability and maintainability.

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

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

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

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].

```
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

```java
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.

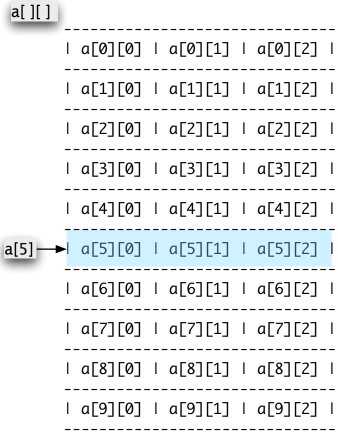
Mathematical abstraction: matrix
Java abstraction: 2D Array

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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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 },
};
```

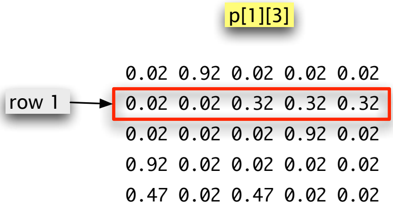
p[1][3]

```
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
```

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 },
};
```

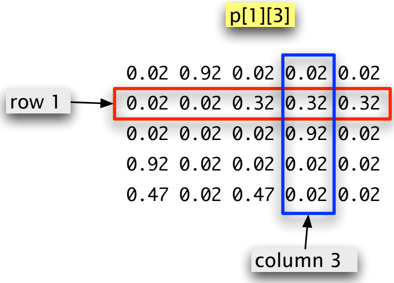


```
0.02 0.92 0.02 0.02 0.02
0.02 0.02 0.32 0.32 0.32
0.02 0.02 0.02 0.92 0.02
0.92 0.02 0.02 0.02 0.02
0.47 0.02 0.47 0.02 0.02
```

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[]`.

```java
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
```

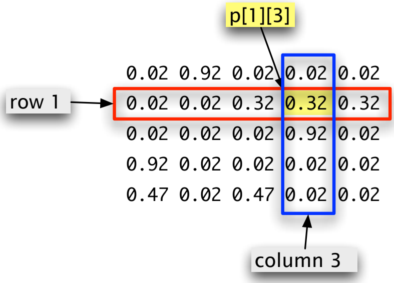
row 1

column 3

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 },
};
```

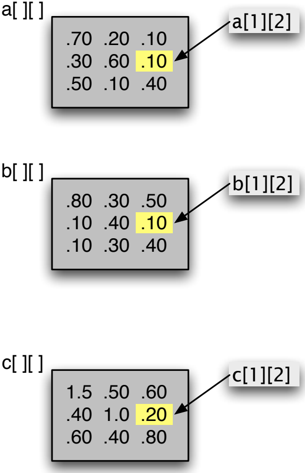


```
0.02 0.92 0.02 0.02 0.02
0.02 0.02 0.32 0.32 0.32
0.02 0.02 0.02 0.92 0.02
0.92 0.02 0.02 0.02 0.02
0.47 0.02 0.47 0.02 0.02
```

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];
   }
}
```



a[ ][ ]

.70	.20	.10
.30	.60	.10
.50	.10	.40

b[ ][ ]

.80	.30	.50
.10	.40	.10
.10	.30	.40

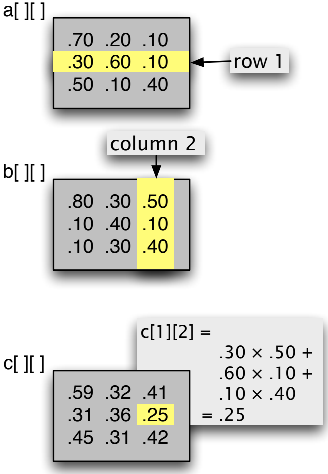
c[ ][ ]

1.5	.50	.60
.40	1.0	.20
.60	.40	.80

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 ith row of a[][] and the jth 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];
      }
   }
}
```



a[ ][ ]

.70	.20	.10
.30	.60	.10
.50	.10	.40

row 1

column 2

b[ ][ ]

.80	.30	.50
.10	.40	.10
.10	.30	.40

c[ ][ ]

.59	.32	.41
.31	.36	.25
.45	.31	.42

c[1][2] =
.30 × .50 +
.60 × .10 +
.10 × .40
= .25

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.