Inf1-OP

Arrays[1]

Volker Seeker, adapting earlier version by Perdita Stevens and Ewan Klein

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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?

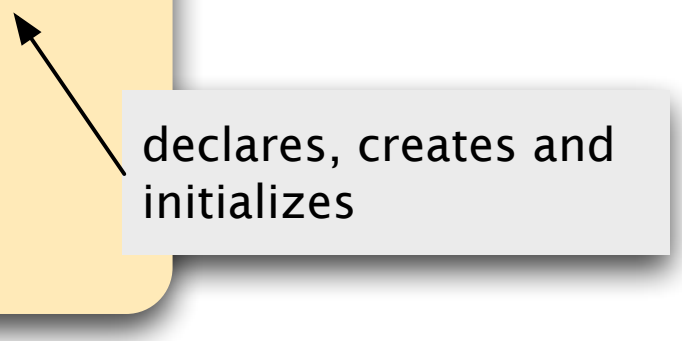
Much more efficient would be something like this:

```
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];
```



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.

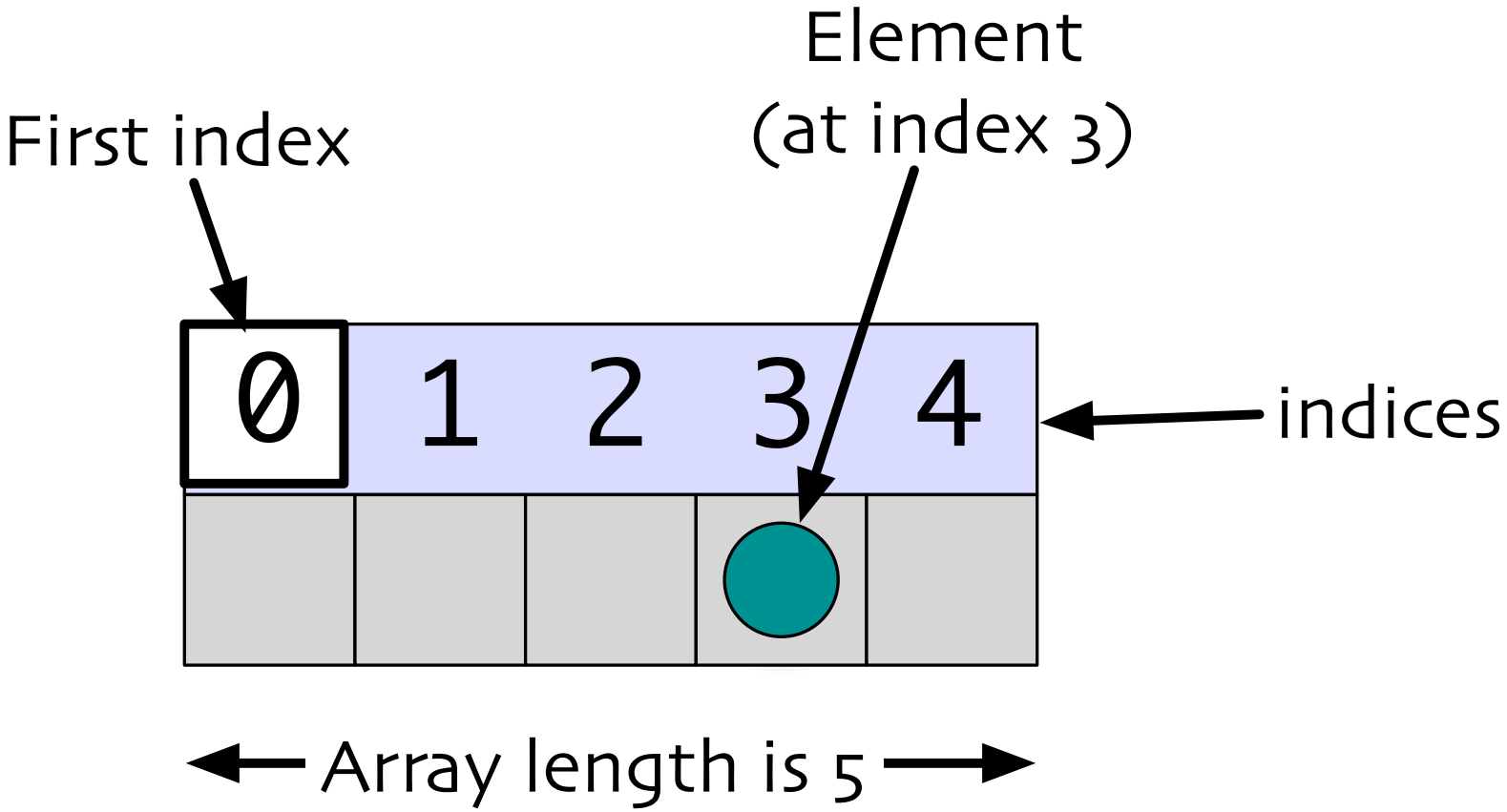
Examples

- 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.

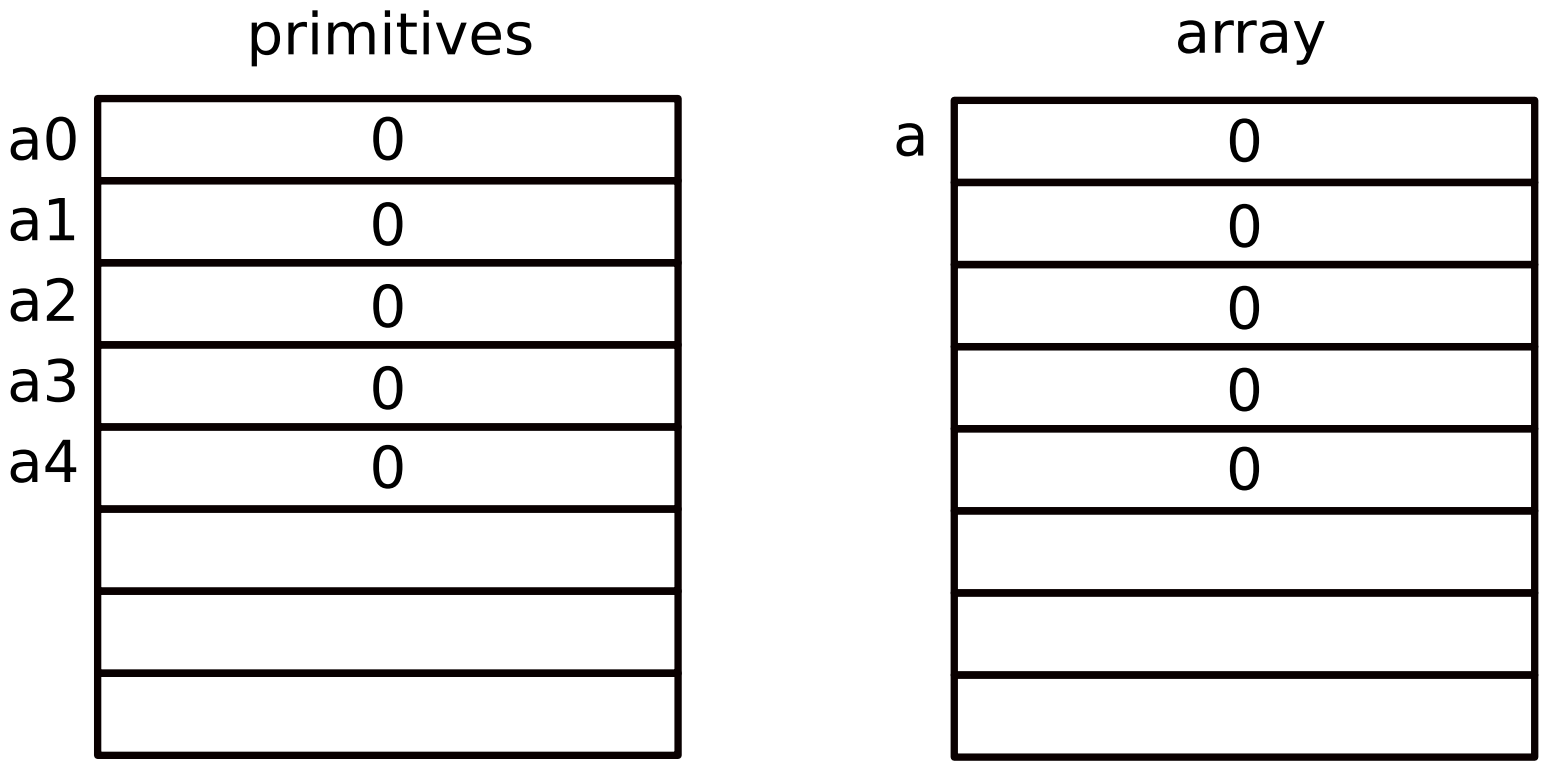
index	*value*
0	Rebecca
1	Isla
2	Brooke
3	Megan
4	Niamh
5	Eilidh
6	Eva
7	Abbie
8	Skye
9	Aimee

(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?



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

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- To make an array: declare, create and initialize it.
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- Array indices start at `0`.

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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]);
    }
}
```

Arrays: Another Example

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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

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    public static void main(String[] args) {
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        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, 1

Create an array with random values

Array-processing Examples, 1

Create an array with random values

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

Array-processing Examples, 1

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```

Print the array values, one per line

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

Print the array values, one per line

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

Array-processing Examples, 1

Create an array with random values

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

Print the array values, one per line

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

Find the maximum of the array values

Array-processing Examples, 1

Create an array with random values

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

Print the array values, one per line

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

Find the maximum of the array values

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

Array-processing Examples, 2

Compute the average of the values in an array (length `n`) of doubles.

Array-processing Examples, 2

Compute the average of the values in an array (length `n`) of doubles.

```
double sum = 0.0;
for (int i = 0; i < n; i++) {
   sum += a[i];
}
double average = sum / n;
```

Array-processing Examples, 3

Copy one array (called `a`, of doubles, length `n`) to another.

Array-processing Examples, 3

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

Array-processing Examples, 4

Reverse the elements within an array (called `a`, of doubles, length `n`).

Array-processing Examples, 4

Reverse the elements within an array (called `a`, of doubles, length `n`).

Using a copy

```
double[] b = new double[n]
for (int i = 0; i < n; i++) {
    b[i] = a[n-1-i];
}
```

Array-processing Examples, 4

Reverse the elements within an array (called a, of doubles, length n).

Using a copy

```
double[] b = new double[n]
for (int i = 0; i < n; i++) {
    b[i] = a[n-1-i];
}
```

In Place

```
for (int i = 0; i < n/2; i++) {
   double temp = a[i];
   a[i] = a[n-1-i];
   a[n-1-i] = temp;
}
```

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
```

Shuffling

Given an array, rearrange its elements in random order.

Shuffling algorithm:

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

Shuffling a Deck of Cards: Putting Everything Together

```
public class Deck {
    public static void main(String[] args) {
        String[] suit = { "Clubs", "Diamonds", "Hearts", "Spades" };
        String[] rank = { "2", "3", "4", "5", "6", "7", "8", "9", "10", "Jack",
                "Queen", "King", "Ace" };

        int SUITS = suit.length;
        int RANKS = rank.length;
        int N = SUITS * RANKS;
        String[] deck = new String[N];

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

        for (int i = 0; i < N; i++)
            System.out.println(deck[i]);
    }
}
```

avoid "hardwired" constants

build the deck

shuffle

print shuffled deck

Remark on Coding Conventions

A set of guidelines agreed upon for each language such as ...

- file organisation
- indentation
- comments
- naming conventions
- etc.

Most of them are not enforced by the compiler but should be followed to maintain readability and maintainability of code.

See for example Google's Java Style Guide:

https://google.github.io/styleguide/javaguide.html

Remark on Coding Conventions

Therefore, SUITS and RANKS etc are in capitals. As per coding convention for values which are not intended to be changed, i.e. constant values.

Constant values can actually be enforced by the compiler by using the final keyword:

```
final int SUITS = suit.length;
```

The **final** keyword used in this way allows only a single initialisation of the corresponding variable.

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.

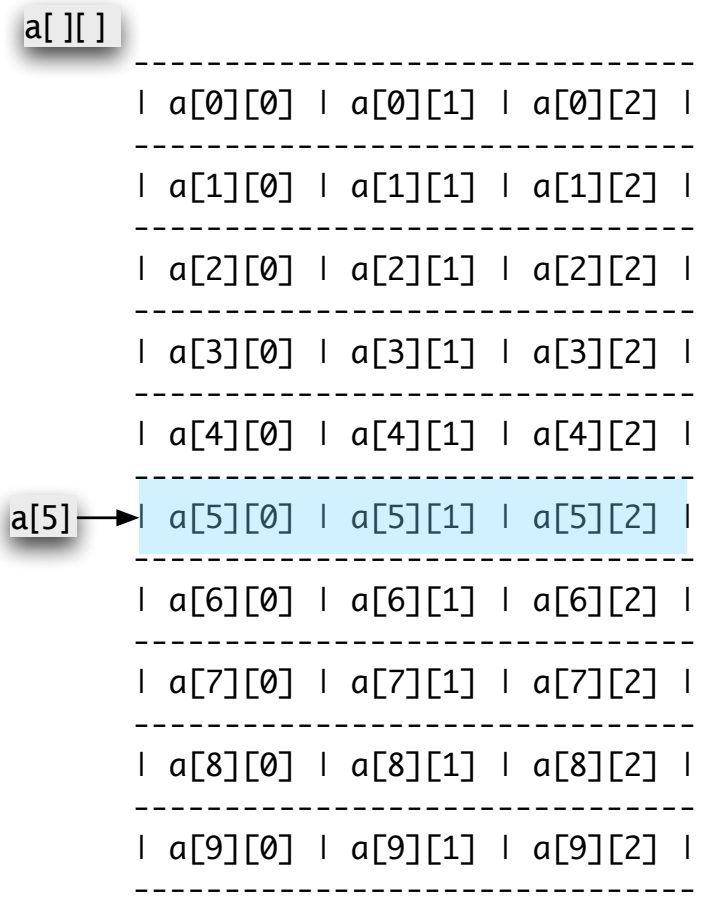
Mathematical abstraction: matrix
Java abstraction: 2D Array

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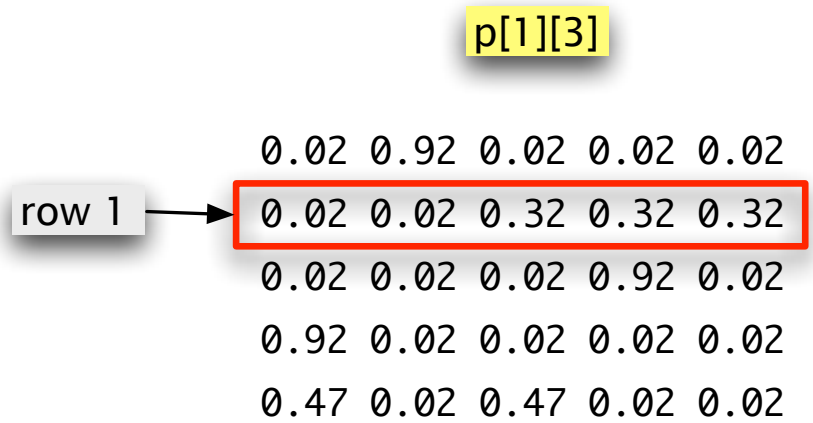
    { .02, .92, .02, .02, .02 },
    { .02, .02, .32, .32, .32 },
    { .02, .02, .02, .92, .02 },
    { .92, .02, .02, .02, .02 },
    { .47, .02, .47, .02, .02 },
};
```



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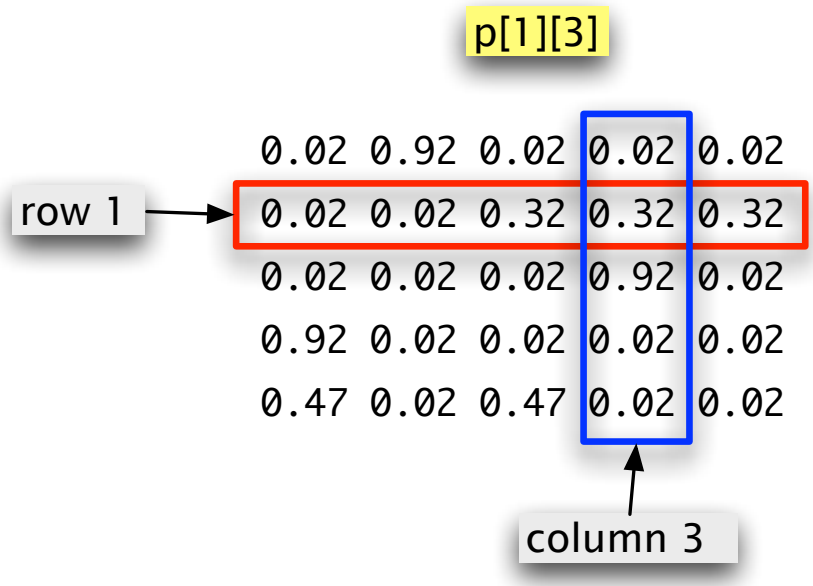
    { .02, .02, .02, .92, .02 },
    { .92, .02, .02, .02, .02 },
    { .47, .02, .47, .02, .02 },
};
```



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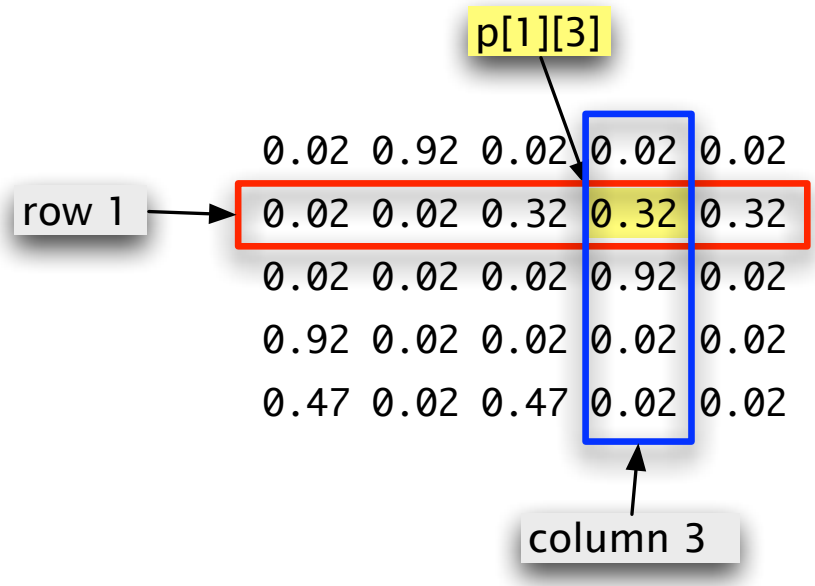
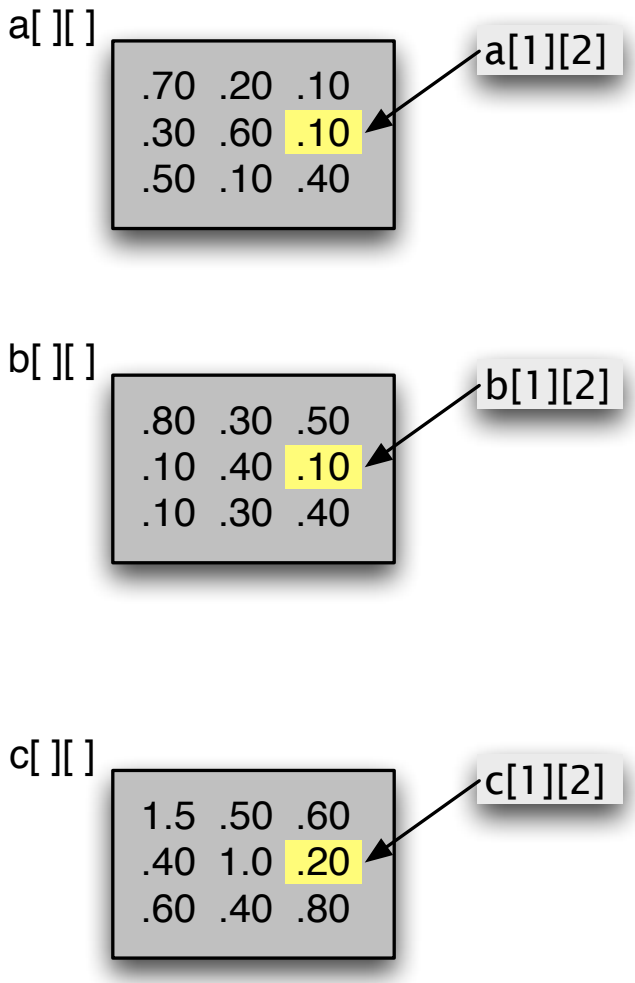
};
```



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]`.

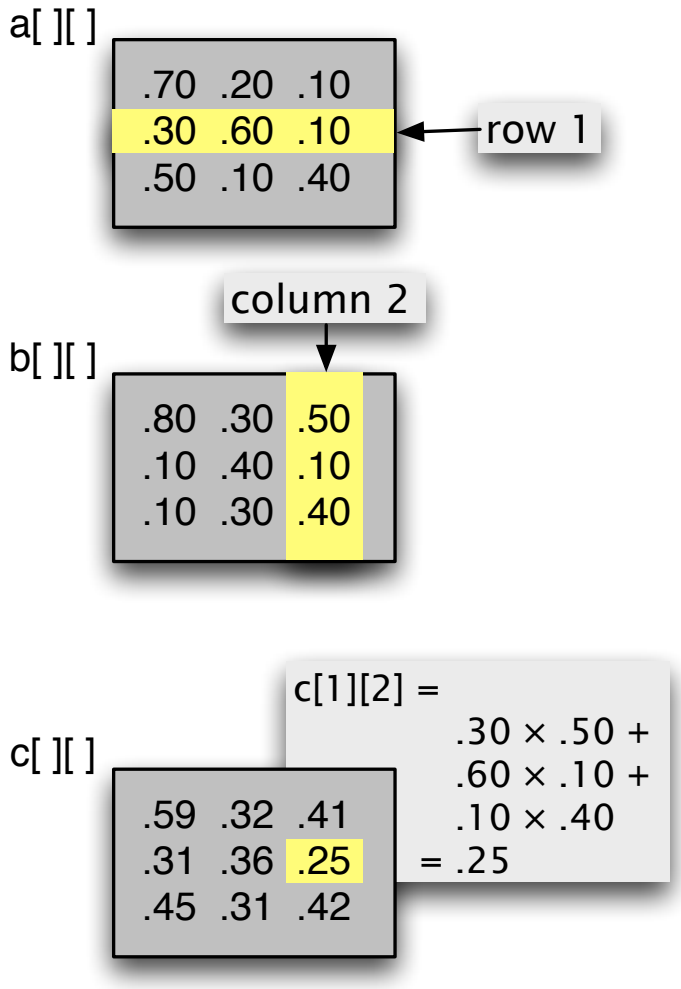
```
double[][] c = new double[n][n];
for (int i = 0; i < n; i++) {
   for (int j = 0; j < n; j++) {
      c[i][j] = a[i][j] + b[i][j];
   }
}
```



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.

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.