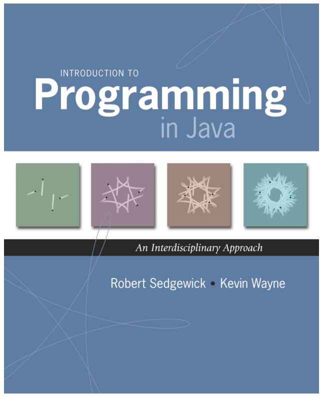
1.4 Arrays



Arrays

This lecture. Store and manipulate huge quantities of data.

Array. Indexed sequence of values of the same type.

Examples.

- 52 playing cards in a deck.
- 5 thousand undergrads at Princeton.
- 1 million characters in a book.
- 10 million audio samples in an MP3 file.
- 4 billion nucleotides in a DNA strand.
- 73 billion Google queries per year.
- 50 trillion cells in the human body.
- 6.02 × 10^{23} particles in a mole.

index	value
0	wayne
1	doug
2	rs
3	maia
4	mona
5	cbienia
6	wkj
7	mkc

Many Variables of the Same Type

Goal. 10 variables of the same type.

```
// tedious and error-prone
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;
a9 = 0.0;
a9 = 0.0;

double x = a4 + a8;
```

Arrays in Java

Java has special language 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;
double[] a;                  // declare the array
a = new double[N];           // create the array
for (int i = 0; i < N; i++)  // initialize the array
   a[i] = 0.0;               // all to 0.0
```

Arrays in Java

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```
int N = 10;
double[] a;                   // declare the array
a = new double[N];            // create the array
for (int i = 0; i < N; i++)   // initialize the array
   a[i] = 0.0;                // all to 0.0
```

Compact alternative.

- Declare, create, and initialize in one statement.
- Default initialization: all numbers automatically set to zero.

```
int N = 10;
double[] a = new double[N];  // declare, create, init
```

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 < N; i++) {
   sum += x[i]*y[i];
}
```

i	x[i]	y[i]	x[i]*y[i]	sum
				0
0	.30	.50	.15	.15
1	.60	.10	.06	.21
2	.10	.40	.04	.25
				.25

Array Processing Code

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 = Double.NEGATIVE_INFINITY;`
	`for (int i = 0; i < N; i++)`
	`   if (a[i] > max) max = a[i];`

compute the average of the array values	`double sum = 0.0;`
	`for (int i = 0; i < N; i++)`
	`   sum += a[i];`
	`double average = sum / N;`

copy to another array	`double[] b = new double[N];`
	`for (int i = 0; i < N; i++)`
	`   b[i] = a[i];`

reverse the elements within an arrayy	`for (int i = 0; i < N/2; i++)`
	`{`
	`   double temp = b[i];`
	`   b[i] = b[N-1-i];`
	`   b[N-i-1] = temp;`
	`}`

Shuffling a Deck

Setting Array Values at Compile Time

Ex. 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]);
```

Setting Array Values at Run Time

Ex. Create a deck of playing cards and print them out.

```
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 i = 0; i < 52; i++)
   System.out.println(deck[i]);
```

Q. What does it output?

Shuffling

Goal. Given an array, rearrange its elements in random order.

Shuffling algorithm.

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

```
int N = deck.length;
for (int i = 0; i < N; i++) {
   int r = i + (int) (Math.random() * (N-i));
   String t = deck[r];                   swap       between i and N-1
   deck[r] = deck[i];                    idiom
   deck[i] = t;
}
```

Shuffling a Deck of Cards

```
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;                      avoid "hardwired" constants

      String[] deck = new String[N];                               build the deck
      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++) {                                shuffle
         int r = i + (int) (Math.random() * (N-i));
         String t = deck[r];
         deck[r] = deck[i];
         deck[i] = t;
      }

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

Shuffling a Deck of Cards

```
% java Deck
5 of Clubs
Jack of Hearts
9 of Spades
10 of Spades
9 of Clubs
7 of Spades
6 of Diamonds
7 of Hearts
7 of Clubs
4 of Spades
Queen of Diamonds
10 of Hearts
5 of Diamonds
Jack of Clubs
Ace of Hearts
...
5 of Spades
```

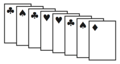
```
% java Deck
10 of Diamonds
King of Spades
2 of Spades
3 of Clubs
4 of Spades
Queen of Clubs
2 of Hearts
7 of Diamonds
6 of Spades
Queen of Spades
3 of Spades
Jack of Diamonds
6 of Diamonds
8 of Spades
9 of Diamonds
...
10 of Spades
```

Coupon Collector

Coupon Collector Problem

Coupon collector problem. Given N different card types, how many do you have to collect before you have (at least) one of each type?

assuming each possibility is equally likely for each card that you collect



Simulation algorithm. Repeatedly choose an integer i between 0 and N-1. Stop when we have at least one card of every type.

Q. How to check if we've seen a card of type i?

A. Maintain a boolean array so that found[i] is true if we've already collected a card of type i.

Coupon Collector: Java Implementation

```
public class CouponCollector {
   public static void main(String[] args) {
      int N = Integer.parseInt(args[0]);
      int cardcnt = 0;    // number of cards collected
      int valcnt = 0;     // number of distinct cards

      // do simulation
      boolean[] found = new boolean[N];
      while (valcnt < N) {
         int val = (int) (Math.random() * N);
         cardcnt++;
         if (!found[val]) {
            valcnt++;
            found[val] = true;
         }
      }

      // all N distinct cards found
      System.out.println(cardcnt);
   }
}
```

type of next card (between 0 and N-1)

Coupon Collector: Debugging

Debugging. Add code to print contents of all variables.

val	found						valcnt	cardcnt
	0	1	2	3	4	5		
	F	F	F	F	F	F	0	0
2	F	F	T	F	F	F	1	1
0	T	F	T	F	F	F	2	2
4	T	F	T	F	T	F	3	3
0	T	F	T	F	T	F	3	4
1	T	T	T	F	T	F	4	5
2	T	T	T	F	T	F	4	6
5	T	T	T	F	T	T	5	7
0	T	T	T	F	T	T	5	8
1	T	T	T	F	T	T	5	9
3	T	T	T	T	T	T	6	10

Challenge. Debugging with arrays requires tracing many variables.

Coupon Collector: Mathematical Context

Coupon collector problem. Given N different possible cards, how many do you have to collect before you have (at least) one of each type?

Fact. About N (1 + 1/2 + 1/3 + … + 1/N).

see ORF 245 or COS 341

Ex. N = 30 baseball teams. Expect to wait ≈ 120 years before all teams win a World Series.

under idealized assumptions

Coupon Collector: Scientific Context

Q. Given a sequence from nature, does it have same characteristics as a random sequence?

A. No easy answer - many tests have been developed.

Coupon collector test. Compare number of elements that need to be examined before all values are found against the corresponding answer for a random sequence.

TOUR OF ACCOUNTING
OVER HERE WE HAVE OUR RANDOM NUMBER GENERATOR.
NINE NINE NINE NINE NINE NINE
10/25/01 © 2001 United Feature Syndicate, Inc.
ARE YOU SURE THAT'S RANDOM?
THAT'S THE PROBLEM WITH RANDOMNESS: YOU CAN NEVER BE SURE.

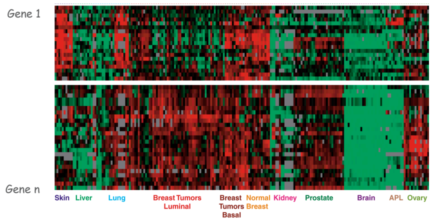
Multidimensional Arrays

Two Dimensional Arrays

Two dimensional arrays.

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

Mathematical abstraction. Matrix.
Java abstraction. 2D array.



Reference: Botstein & Brown group

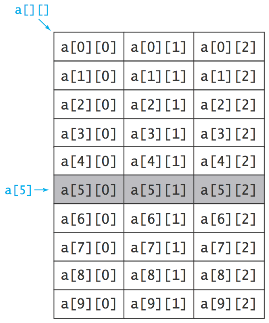
🟥 gene expressed
🟩 gene not expressed

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;
   }
}
```



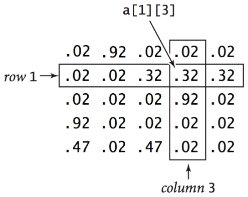
a[0][0]	a[0][1]	a[0][2]
a[1][0]	a[1][1]	a[1][2]
a[2][0]	a[2][1]	a[2][2]
a[3][0]	a[3][1]	a[3][2]
a[4][0]	a[4][1]	a[4][2]
a[5][0]	a[5][1]	a[5][2]
a[6][0]	a[6][1]	a[6][2]
a[7][0]	a[7][1]	a[7][2]
a[8][0]	a[8][1]	a[8][2]
a[9][0]	a[9][1]	a[9][2]

A 10-by-3 array

Setting 2D Array Values at Compile Time

Initialize 2D array by listing values.

```
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 },
};
```

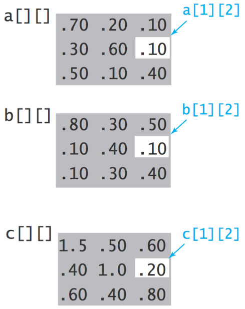


.02	.92	.02	.02	.02
.02	.02	.32	.32	.32
.02	.02	.02	.92	.02
.92	.02	.02	.02	.02
.47	.02	.47	.02	.02

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];
```



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

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

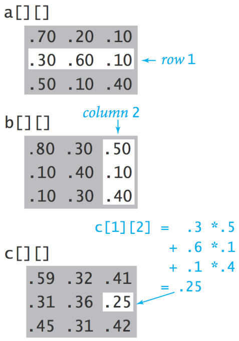
1.5	.50	.60
.40	1.0	.20
.60	.40	.80

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 row of b.

all values initialized to 0

```
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   ← row 1
.50 .10 .40
```

b[][] column 2

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

c[][]

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

c[1][2] = .3 *.5
        + .6 *.1
        + .1 *.4
        = .25

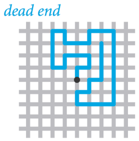
Self-Avoiding Walk

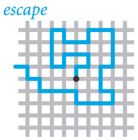
Self-Avoiding Walk

Model.

- N-by-N lattice.
- Start in the middle.
- Randomly move to a neighboring intersection, avoiding all previous intersections.

Applications. Polymers, statistical mechanics, etc.





Q. What fraction of time will you escape in an 5-by-5 lattice?
Q. In an N-by-N lattice?
Q. In an N-by-N-by-N lattice?

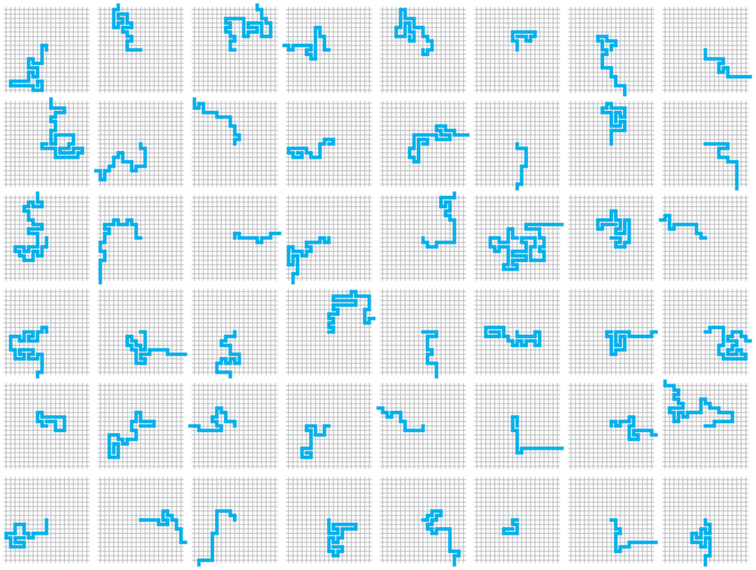
Self-Avoiding Walk: Implementation

```
public class SelfAvoidingWalk {
   public static void main(String[] args) {
      int N = Integer.parseInt(args[0]);     // lattice size
      int T = Integer.parseInt(args[1]);     // number of trials
      int deadEnds = 0;                      // trials resulting in dead end

      for (int t = 0; t < T; t++) {
         boolean[][] a = new boolean[N][N];  // intersections visited
         int x = N/2, y = N/2;               // current position

         while (x > 0 && x < N-1 && y > 0 && y < N-1)  {
            if (a[x-1][y] && a[x+1][y] && a[x][y-1] && a[x][y+1]) {
               deadEnds++;
               break;
            }
            a[x][y] = true;                  // mark as visited
            double r = Math.random();
            if      (r < 0.25) { if (!a[x+1][y]) x++; }
            else if (r < 0.50) { if (!a[x-1][y]) x--; }
            else if (r < 0.75) { if (!a[x][y+1]) y++; }
            else if (r < 1.00) { if (!a[x][y-1]) y--; }
         }
      }
      System.out.println(100*deadEnds/T + "% dead ends");
   }
}
```

dead end

take a random unvisited step

Self-Avoiding Walks



Summary

Arrays.

- Organized way to store huge quantities of data.
- Almost as easy to use as primitive types.
- Can directly access an element given its index.

Ahead. Reading in large quantities of data from a file into an array.