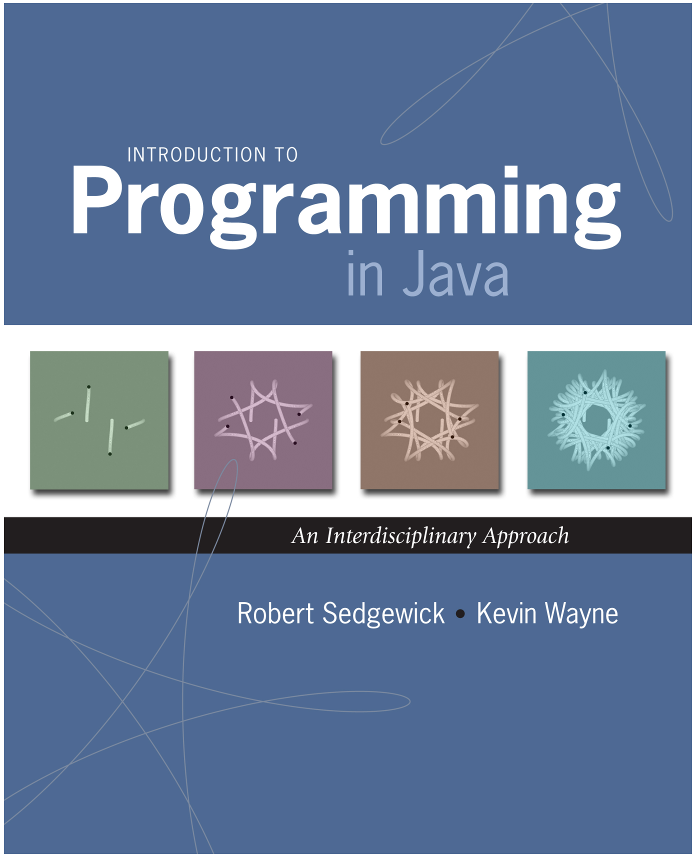
# 2.2 Libraries and Clients



INTRODUCTION TO

**Programming**

in Java

*An Interdisciplinary Approach*

Robert Sedgewick • Kevin Wayne

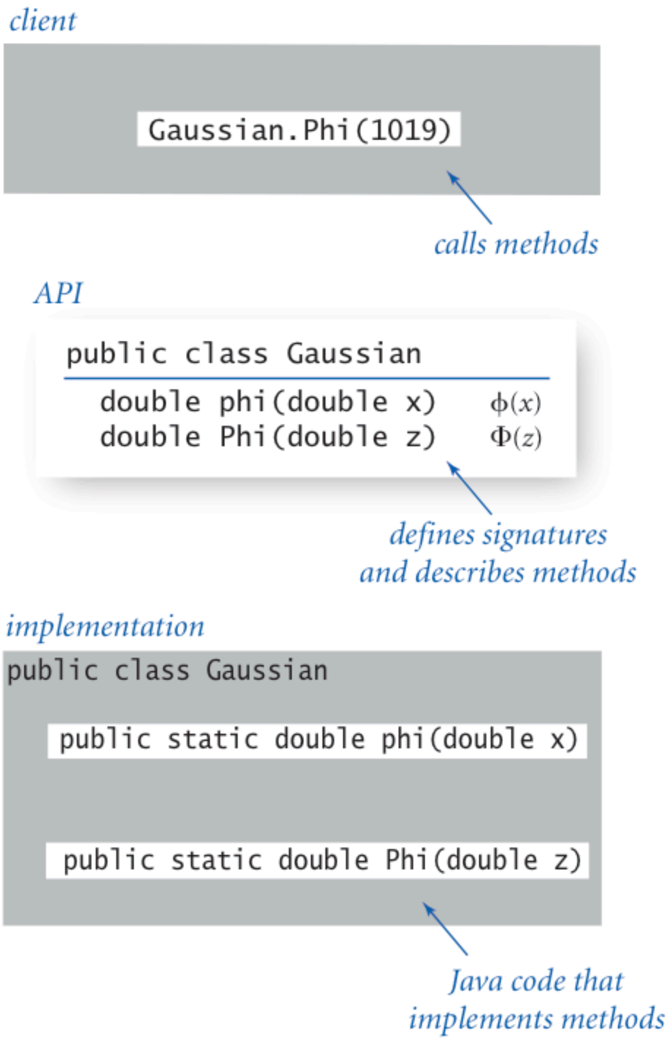
# Libraries

Library. A module whose methods are primarily intended for use by many other programs.

Client. Program that calls a library.

API. Contract between client and implementation.

Implementation. Program that implements the methods in an API.



*client*

```
Gaussian.Phi(1019)
```

*calls methods*

*API*

```
public class Gaussian
   double phi(double x)     ϕ(x)
   double Phi(double z)     Φ(z)
```

*defines signatures and describes methods*

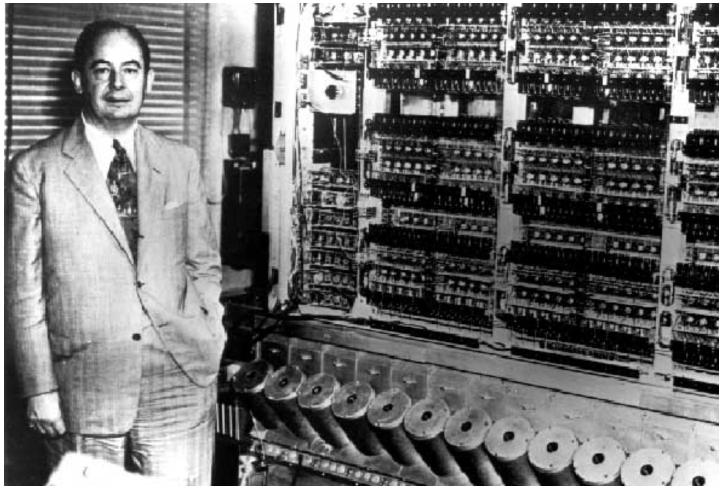
*implementation*

```
public class Gaussian

   public static double phi(double x)


   public static double Phi(double z)
```

*Java code that implements methods*

# Random Numbers

> " *The generation of random numbers is far too important to leave to chance. Anyone who considers arithmetical methods of producing random digits is, of course, in a state of sin.* "



*Jon von Neumann (left), ENIAC (right)*

# Random Numbers

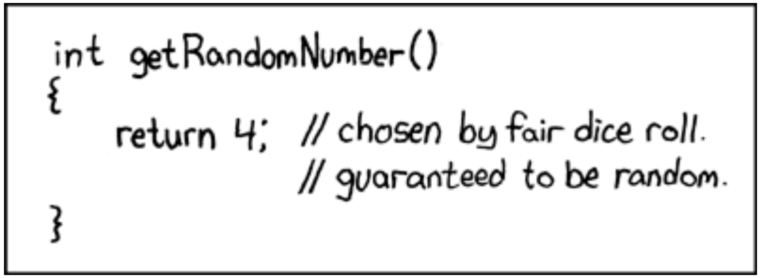
A WEIGHTED RANDOM NUMBER GENERATOR JUST PRODUCED A NEW BATCH OF NUMBERS.
LET'S USE THEM TO BUILD NARRATIVES!

ALL SPORTS COMMENTARY

# Standard Random

Standard random. Our library to generate pseudo-random numbers.

| public class StdRandom | | |
|---|---|---|
| int | uniform(int N) | *integer between* 0 *and* N-1 |
| double | uniform(double lo, double hi) | *real between* lo *and* hi |
| boolean | bernoulli(double p) | true *with probability* p |
| double | gaussian() | *normal, mean* 0*, standard deviation* 1 |
| double | gaussian(double m, double s) | *normal, mean* m*, standard deviation* s |
| int | discrete(double[] a) | i *with probability* a[i] |
| void | shuffle(double[] a) | *randomly shuffle the array* a[] |



```
int getRandomNumber()
{
    return 4;  // chosen by fair dice roll.
               // guaranteed to be random.
}
```

# Standard Random

```
public class StdRandom {

   // between a and b
   public static double uniform(double a, double b) {
      return a + Math.random() * (b-a);
   }

   // between 0 and N-1
   public static int uniform(int N) {
      return (int) (Math.random() * N);
   }

   // true with probability p
   public static boolean bernoulli(double p) {
      return Math.random() < p;
   }

   // gaussian with mean = 0, stddev = 1
   public static double gaussian()
      /* see Exercise 1.2.27 */

   // gaussian with given mean and stddev
   public static double gaussian(double mean, double stddev) {
      return mean + (stddev * gaussian());
   }

   ...
}
```

# Unit Testing

Unit test. Include `main()` to test each library.

```
public class StdRandom {
   ...

   public static void main(String[] args) {
      int N = Integer.parseInt(args[0]);
      for (int i = 0; i < N; i++) {
         StdOut.printf("  %2d " , uniform(100));
         StdOut.printf("%8.5f  ", uniform(10.0, 99.0));
         StdOut.printf("%5b  "  , bernoulli(.5));
         StdOut.printf("%7.5f  ", gaussian(9.0, .2));
         StdOut.println();
      }
   }
}
```

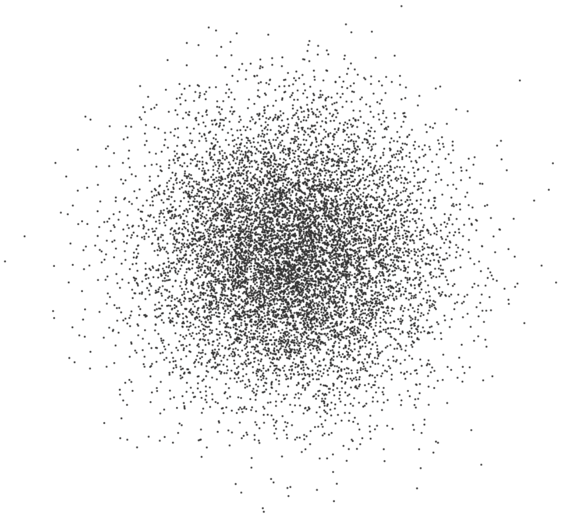
```
% java StdRandom 5
 61 21.76541  true 9.30910
 57 43.64327 false 9.42369
 31 30.86201  true 9.06366
 92 39.59314  true 9.00896
 36 28.27256 false 8.66800
```

# Using a Library

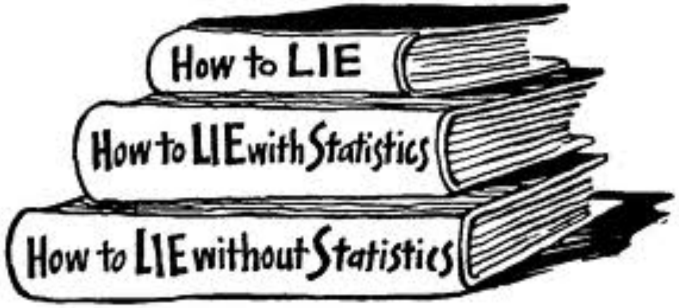
```
public class RandomPoints {
   public static void main(String args[]) {
      int N = Integer.parseInt(args[0]);
      for (int i = 0; i < N; i++) {
         double x = StdRandom.gaussian(0.5, 0.2);
         double y = StdRandom.gaussian(0.5, 0.2);
         StdDraw.point(x, y);
      }
   }
}
```

use library name
to invoke method

```
% javac RandomPoints.java
% java RandomPoints 10000
```

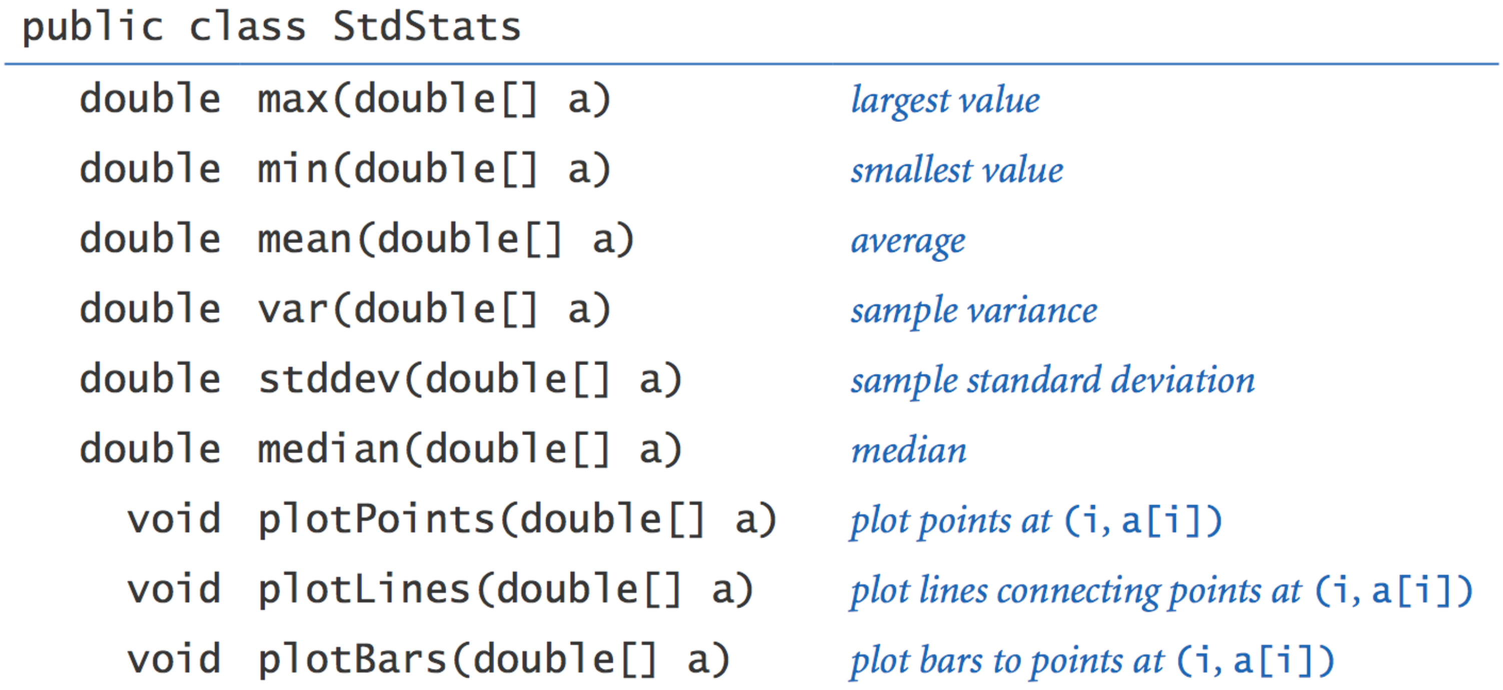


# Statistics


How to LIE
How to LIE with Statistics
How to LIE without Statistics

# Standard Statistics

Ex. Library to compute statistics on an array of real numbers.



| public class StdStats | | |
|---|---|---|
| double | max(double[] a) | *largest value* |
| double | min(double[] a) | *smallest value* |
| double | mean(double[] a) | *average* |
| double | var(double[] a) | *sample variance* |
| double | stddev(double[] a) | *sample standard deviation* |
| double | median(double[] a) | *median* |
| void | plotPoints(double[] a) | *plot points at* (i, a[i]) |
| void | plotLines(double[] a) | *plot lines connecting points at* (i, a[i]) |
| void | plotBars(double[] a) | *plot bars to points at* (i, a[i]) |

$$\mu = \frac{a_0 + a_1 + \cdots + a_{n-1}}{n}, \quad \sigma^2 = \frac{(a_0-\mu)^2 + (a_1-\mu)^2 + \cdots + (a_{n-1}-\mu)^2}{n-1}$$

*mean* *sample variance*

# Standard Statistics

Ex. Library to compute statistics on an array of real numbers.

```
public class StdStats {

   public static double max(double[] a)  {
      double max = Double.NEGATIVE_INFINITY;
      for (int i = 0; i < a.length; i++)
         if (a[i] > max) max = a[i];
      return max;
   }

   public static double mean(double[] a)  {
      double sum = 0.0;
      for (int i = 0; i < a.length; i++)
         sum = sum + a[i];
      return sum / a.length;
   }

   public static double stddev(double[] a)
     // see text

}
```

# Modular Programming

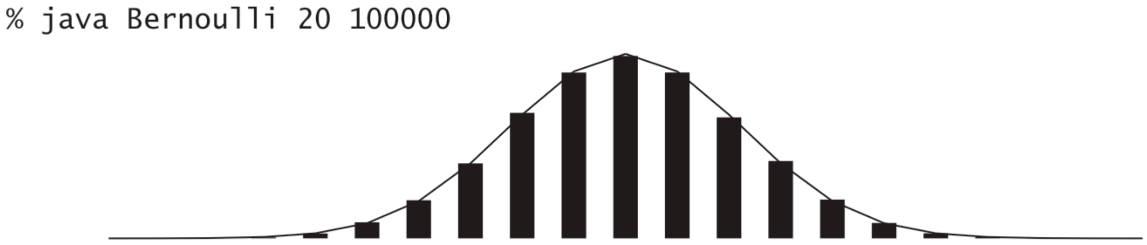
# Modular Programming

Modular programming.

- Divide program into self-contained pieces.
- Test each piece individually.
- Combine pieces to make program.

Ex. Flip N coins. How many heads?

- Read arguments from user.
- Flip one fair coin.
- Flip N fair coins and count number of heads.
- Repeat simulation, counting number of times each outcome occurs.
- Plot histogram of empirical results.
- Compare with theoretical predictions.



```
% java Bernoulli 20 100000
```

# Bernoulli Trials

```java
public class Bernoulli {
   public static int binomial(int N) {
      int heads = 0;
      for (int j = 0; j < N; j++)
         if (StdRandom.bernoulli(0.5)) heads++;
      return heads;
   }

   public static void main(String[] args) {
      int N = Integer.parseInt(args[0]);
      int T = Integer.parseInt(args[1]);

      int[] freq = new int[N+1];
      for (int i = 0; i < T; i++)
         freq[binomial(N)]++;

      double[] normalized = new double[N+1];
      for (int i = 0; i <= N; i++)
         normalized[i] = (double) freq[i] / T;
      StdStats.plotBars(normalized);

      double mean = N / 2.0, stddev = Math.sqrt(N) / 2.0;
      double[] phi  = new double[N+1];
      for (int i = 0; i <= N; i++)
         phi[i] = Gaussian.phi(i, mean, stddev);
      StdStats.plotLines(phi);
   }
}
```

flip N fair coins;
return # heads

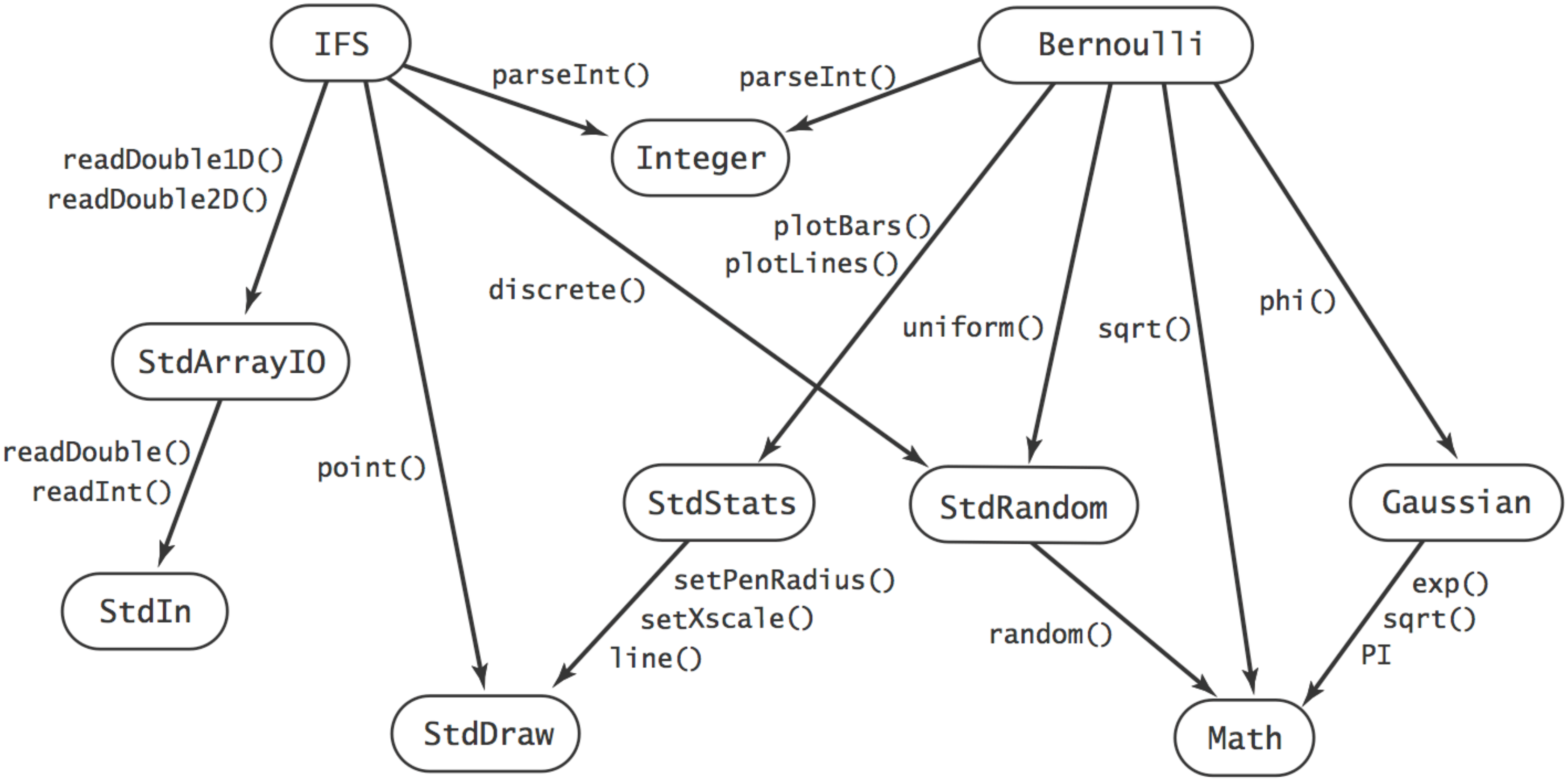
perform T trials
of N coin flips each

plot histogram
of number of heads

theoretical prediction

# Dependency Graph

Modular programming. Build relatively complicated program by combining several small, independent, modules.



# Libraries

Why use libraries?

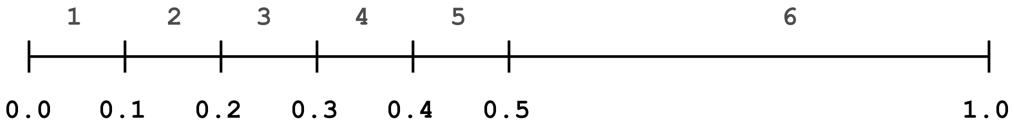
- Makes code easier to understand.
- Makes code easier to debug.
- Makes code easier to maintain and improve.
- Makes code easier to reuse.

# Extra Slides

# Discrete Distribution

Discrete distribution. Given an array of weights (that sum to 1), choose an index at random with probability equal to its weight.

```
p = { 0, .1, .1, .1, .1, .1, .5 }
```



```
public static int discrete(double[] p) {
   // check that weights are nonnegative and sum to 1
   double r = Math.random();
   double sum = 0.0;
   for (int i = 0; i < p.length; i++) {
      sum = sum + p[i];
      if (sum >= r) return i;
   }
   return -1;
}
```

something went wrong