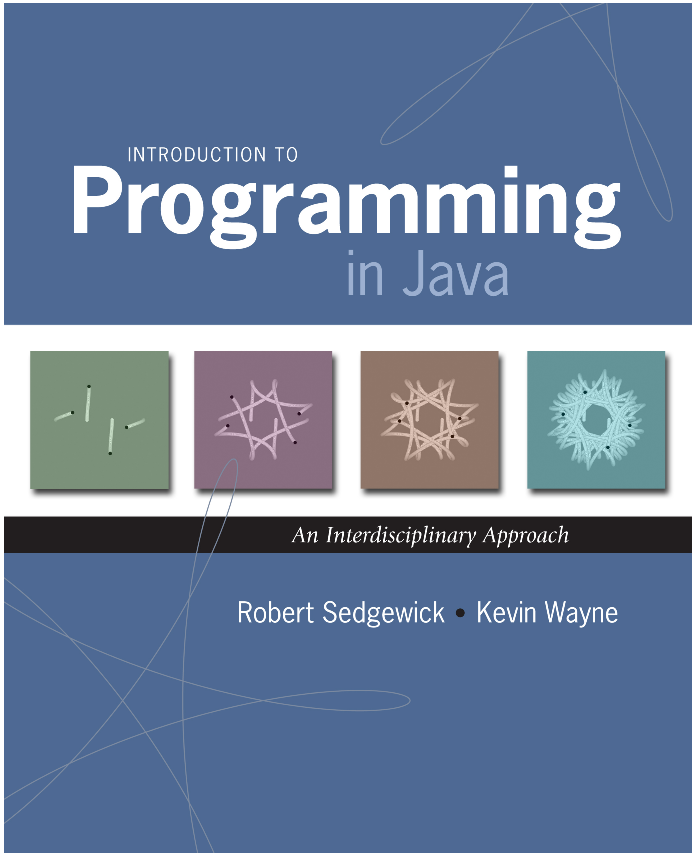
# 2.2 Libraries and Clients

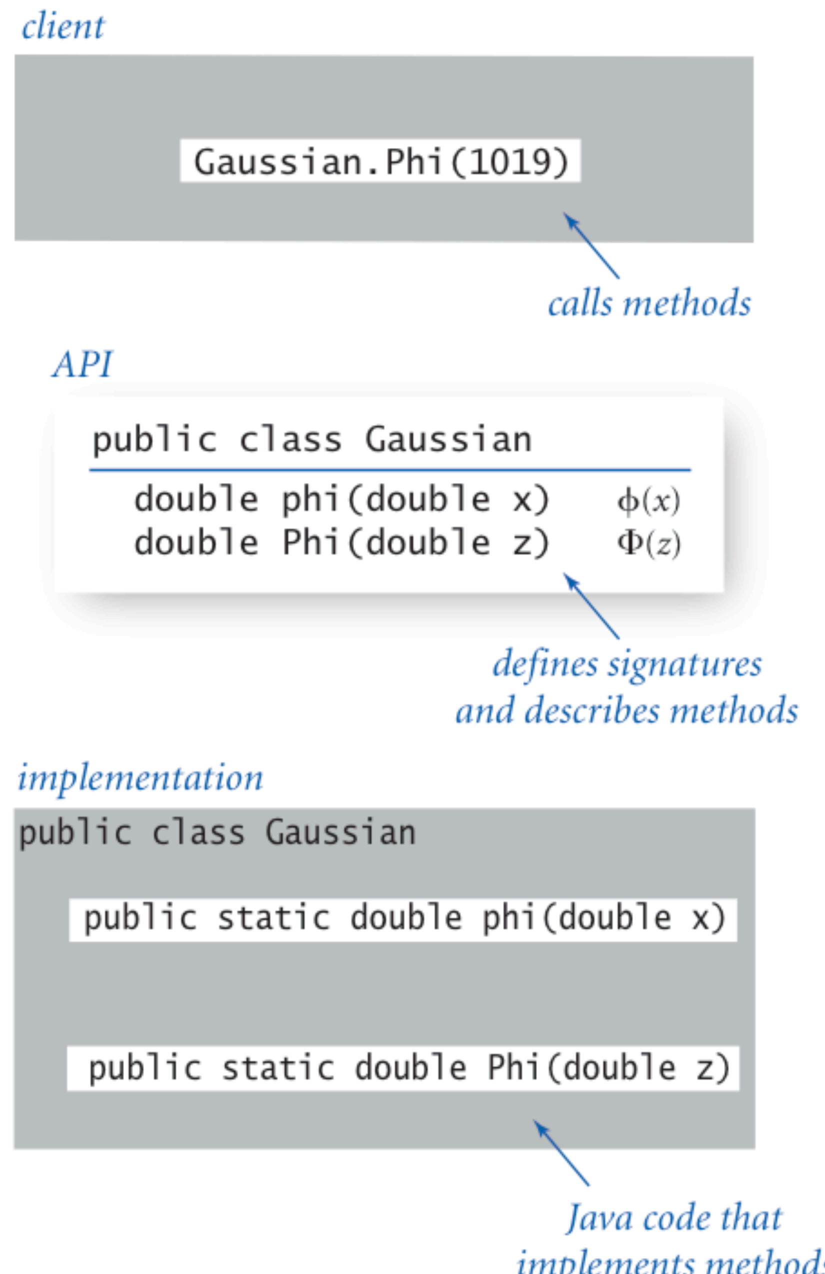


# Libraries

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

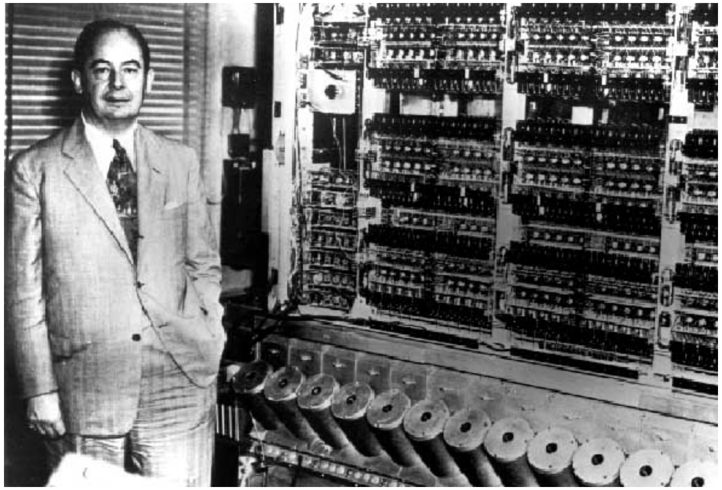
**Client:** Program that calls a library

**API:** Contract between client and implementation



# 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


ALL SPORTS COMMENTARY

# 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.
}
```

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```java
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

Library classes can include testing routines in main()

```
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
```

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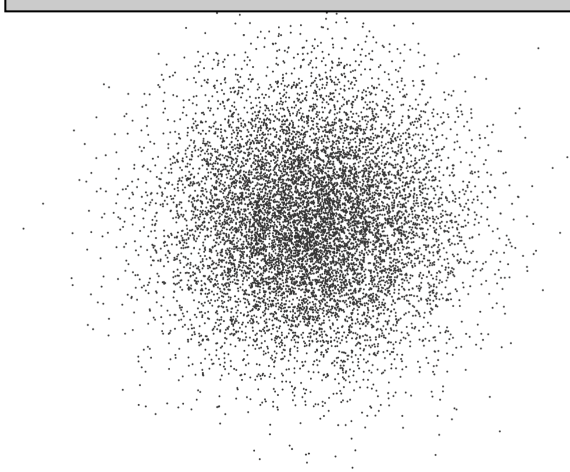
# Using a Library

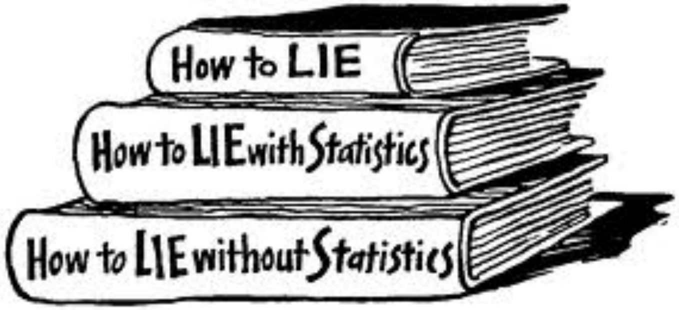
```
public class RandomPoints {
    public static void main(String args[]) {
        int N = Integer.parseInt(args[0]);
        for (int i = 0; i < N; i++) {
            double x = StdRandom.gaussian(0.5, 0.2);
            double y = StdRandom.gaussian(0.5, 0.2);
            StdDraw.point(x, y);
   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

use library name to invoke method

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



# Statistics

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# Example Library: Standard Statistics

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*

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```java
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

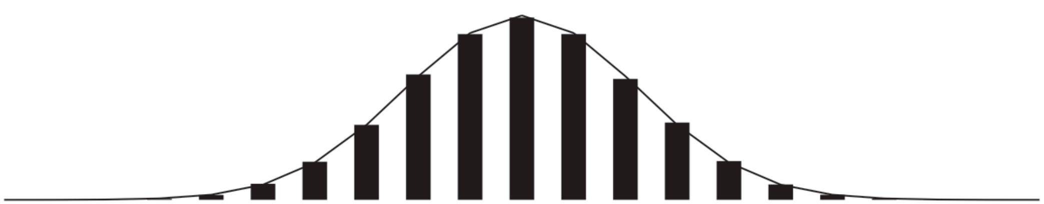
Basic principle:

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

Example: Flip N coins. How many heads?

- 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
```



```
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

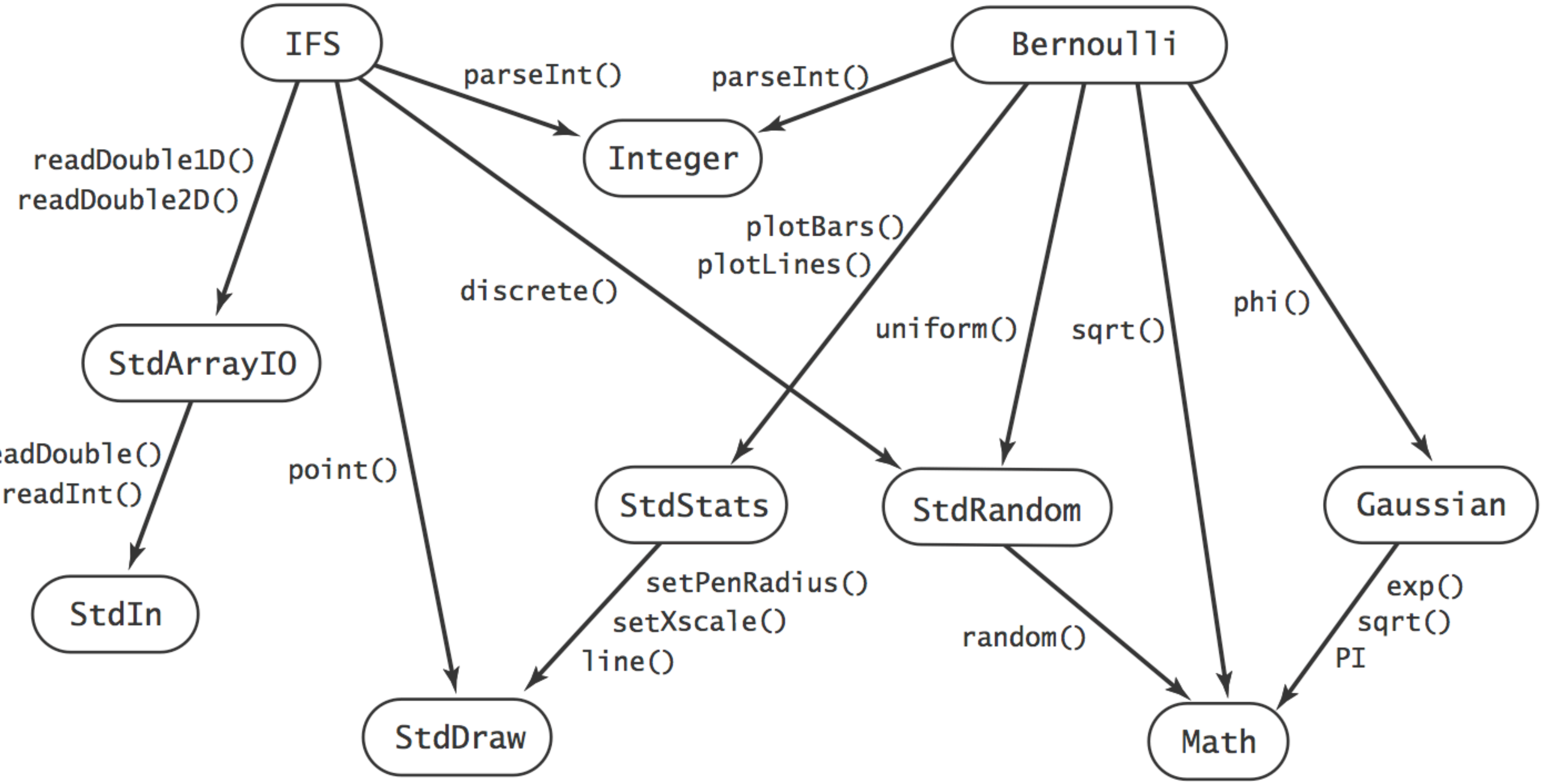
perform T trials of N coin flips each

plot histogram of number of heads

theoretical prediction

# Dependency Graph

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

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# 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.

x = { 0, .1, .1, .1, .1, .1, .5 }


```java
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