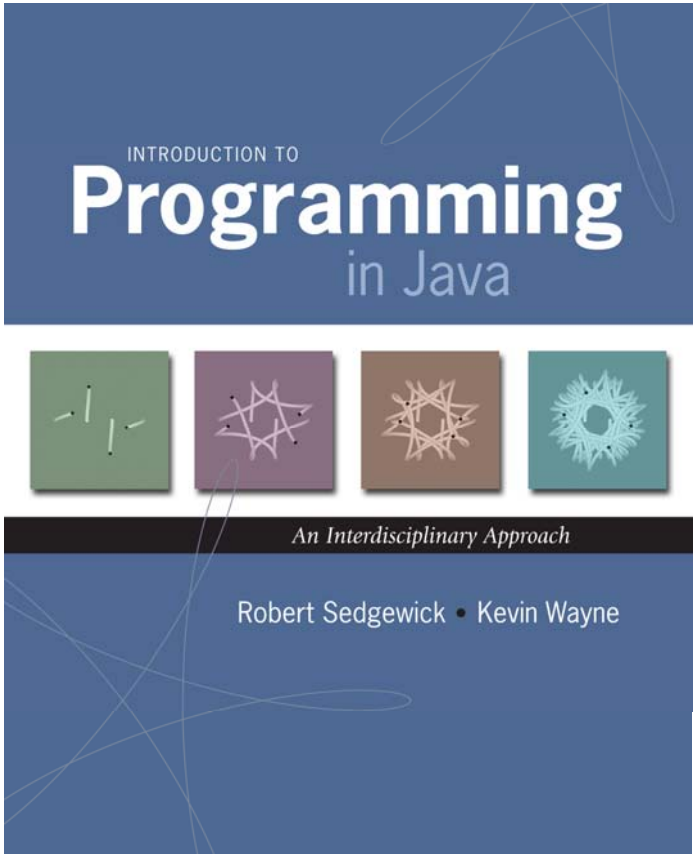
2.2 Libraries and Clients



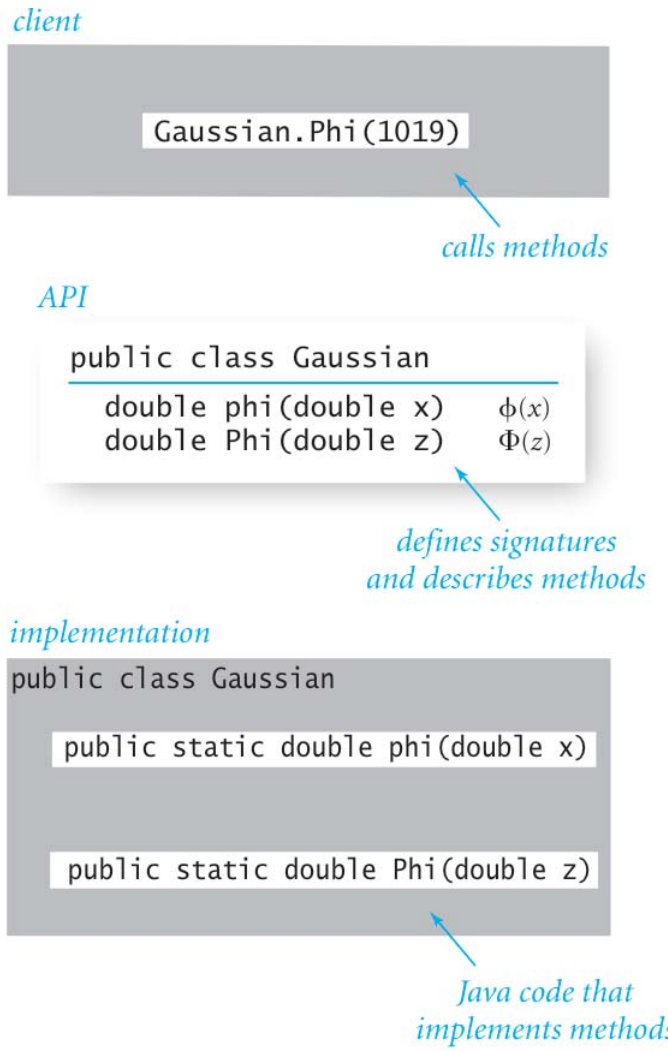
Libraries

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

Client. Program that calls a library.

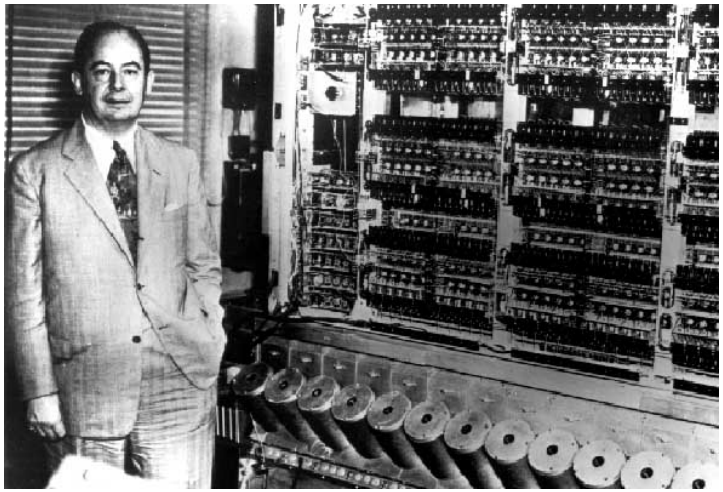
API. Contract between client and implementation.

Implementation. Program that implements the methods in an API.



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)

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()
      // recall Assignment 0

   // 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]);
      double[] t = { .5, .3, .1, .1 };
      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.printf("%2d "  , discrete(t));
         StdOut.println();
      }
   }
}
```

```
% java StdRandom 5
 61 21.76541  true 9.30910  0
 57 43.64327 false 9.42369  3
 31 30.86201  true 9.06366  0
 92 39.59314  true 9.00896  0
 36 28.27256 false 8.66800  1
```

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

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

```
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

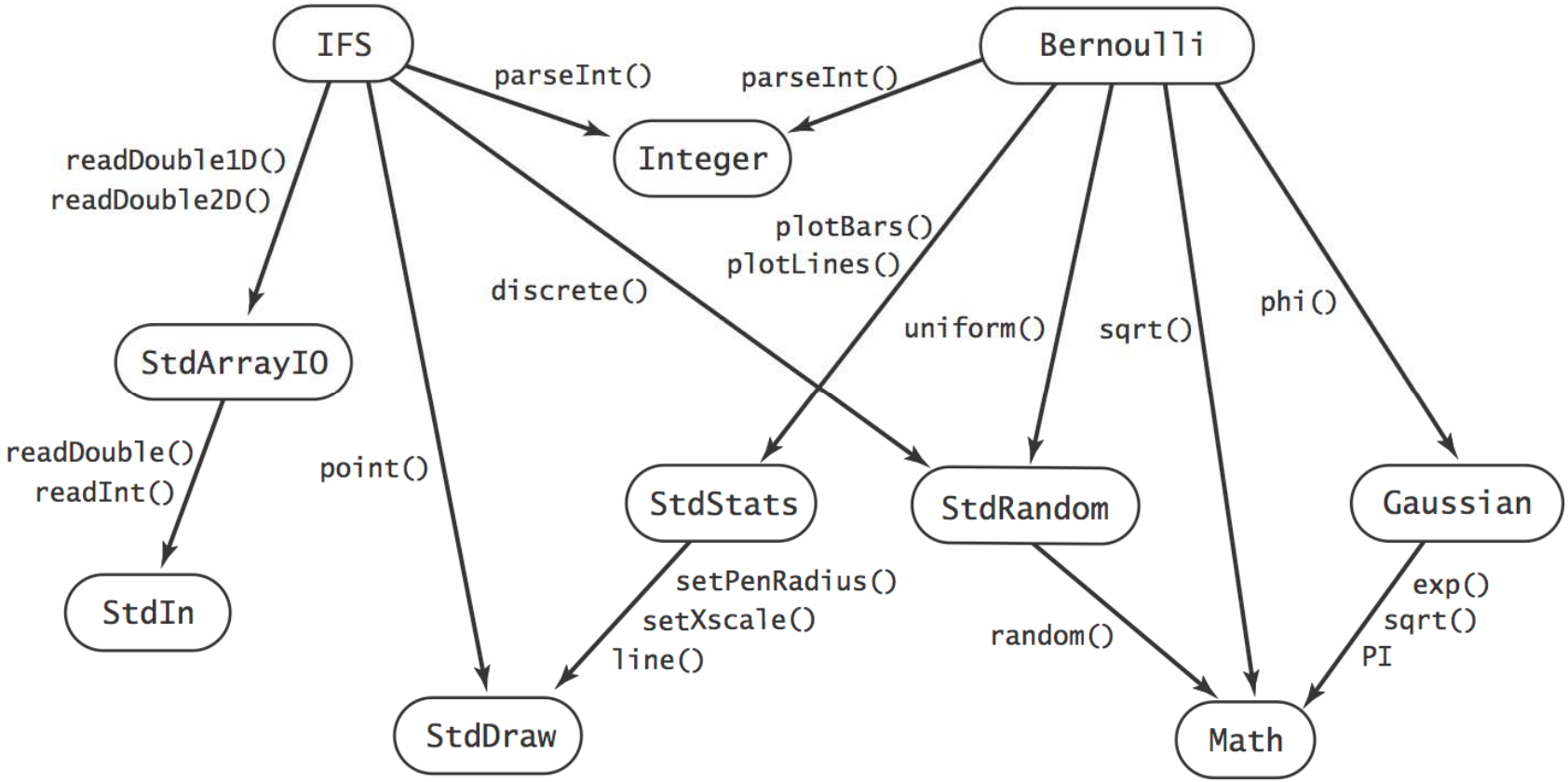
perform T trials of N coin flips each

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