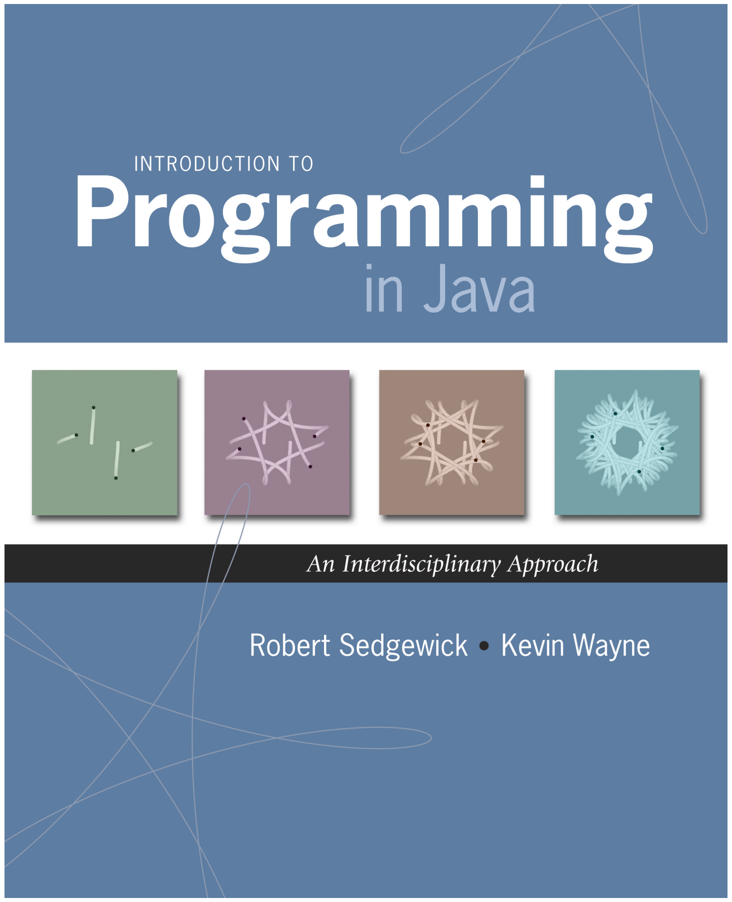
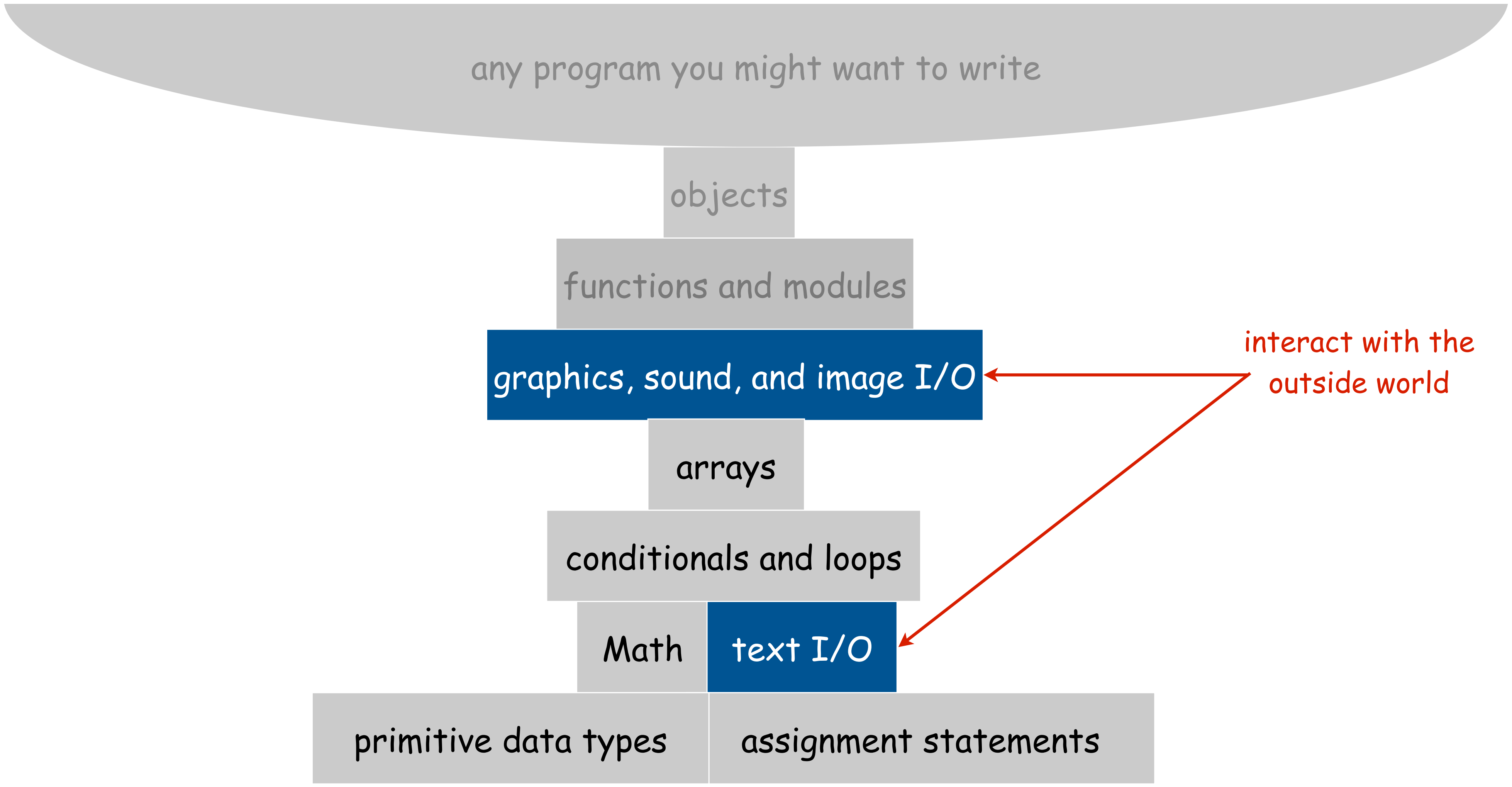
1.5 Input and Output



A Foundation for Programming



Input and Output

Input devices.

Keyboard

Mouse

Hard drive

Network

Digital camera

Microphone

Output devices.

Display

Speakers

Hard drive

Network

Printer

MP3 Player

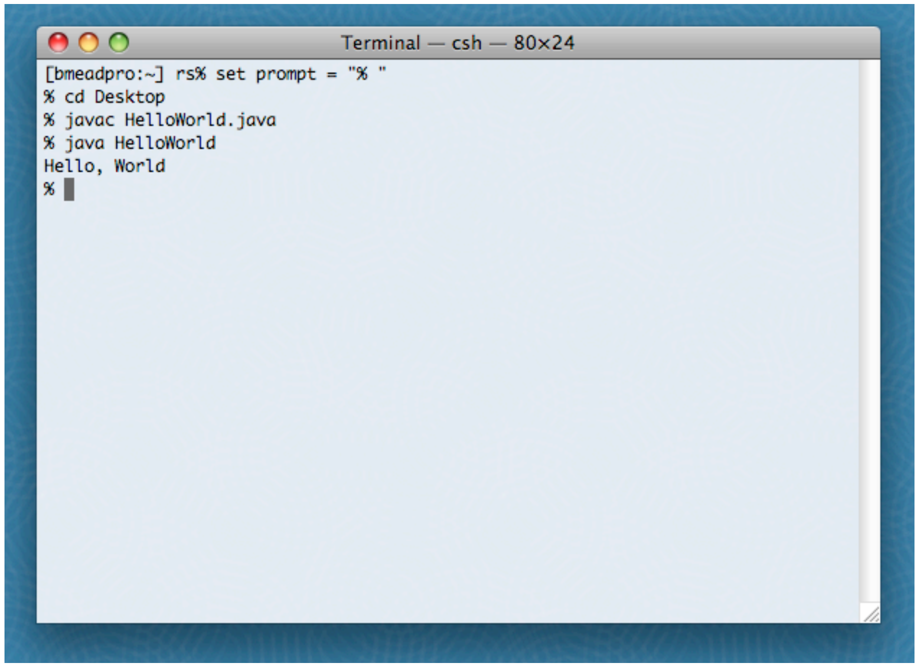
Goal. Java programs that interact with the outside world.

Our approach.

- Define Java libraries of functions for input and output.
- Use operating system (OS) to connect Java programs to: file system, each other, keyboard, mouse, display, speakers.

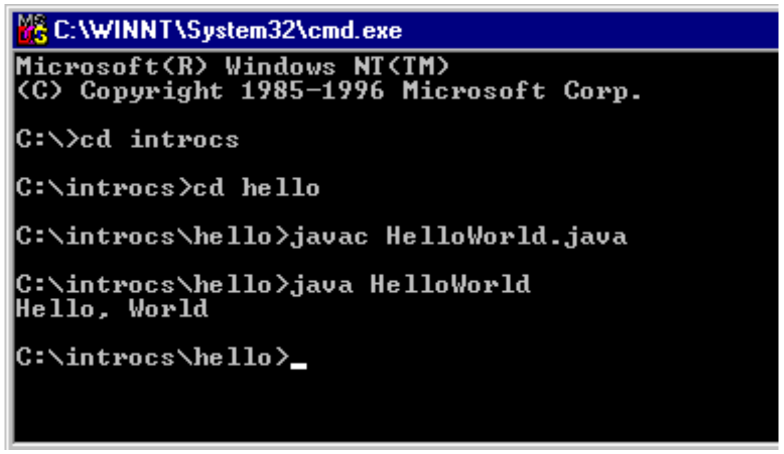
Terminal

Terminal. Application for typing commands to control the operating system.



```
[bmeadpro:~] rs% set prompt = "% "
% cd Desktop
% javac HelloWorld.java
% java HelloWorld
Hello, World
%
```

Mac Terminal



```
Microsoft(R) Windows NT(TM)
(C) Copyright 1985-1996 Microsoft Corp.

C:\>cd introcs

C:\introcs>cd hello

C:\introcs\hello>javac HelloWorld.java

C:\introcs\hello>java HelloWorld
Hello, World

C:\introcs\hello>_
```

Microsoft Windows (of long long ago...)

Command-Line Input and Standard Output

Command-line input. Read an integer `N` as command-line argument.

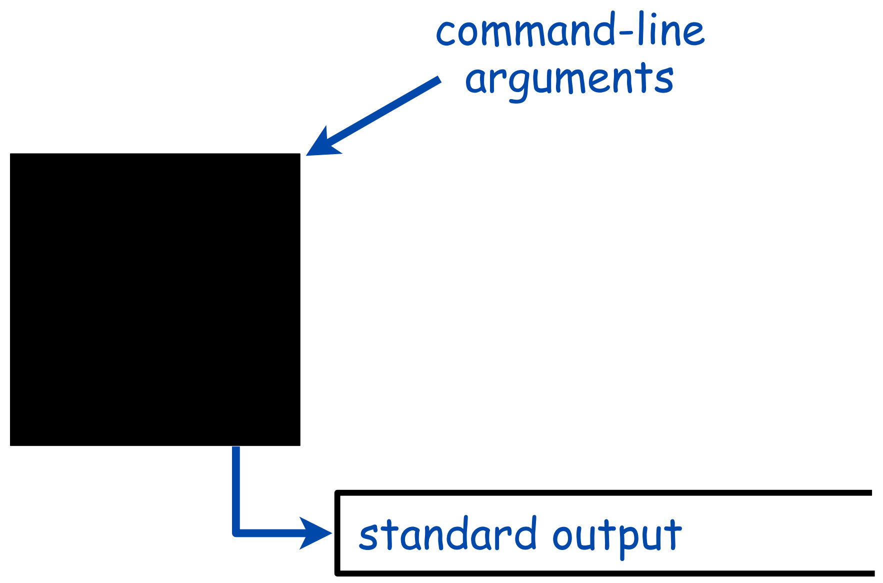
Standard output.

- Flexible OS abstraction for output.
- In Java, output from `System.out.println()` goes to standard output.
- By default, standard output is sent to the terminal.

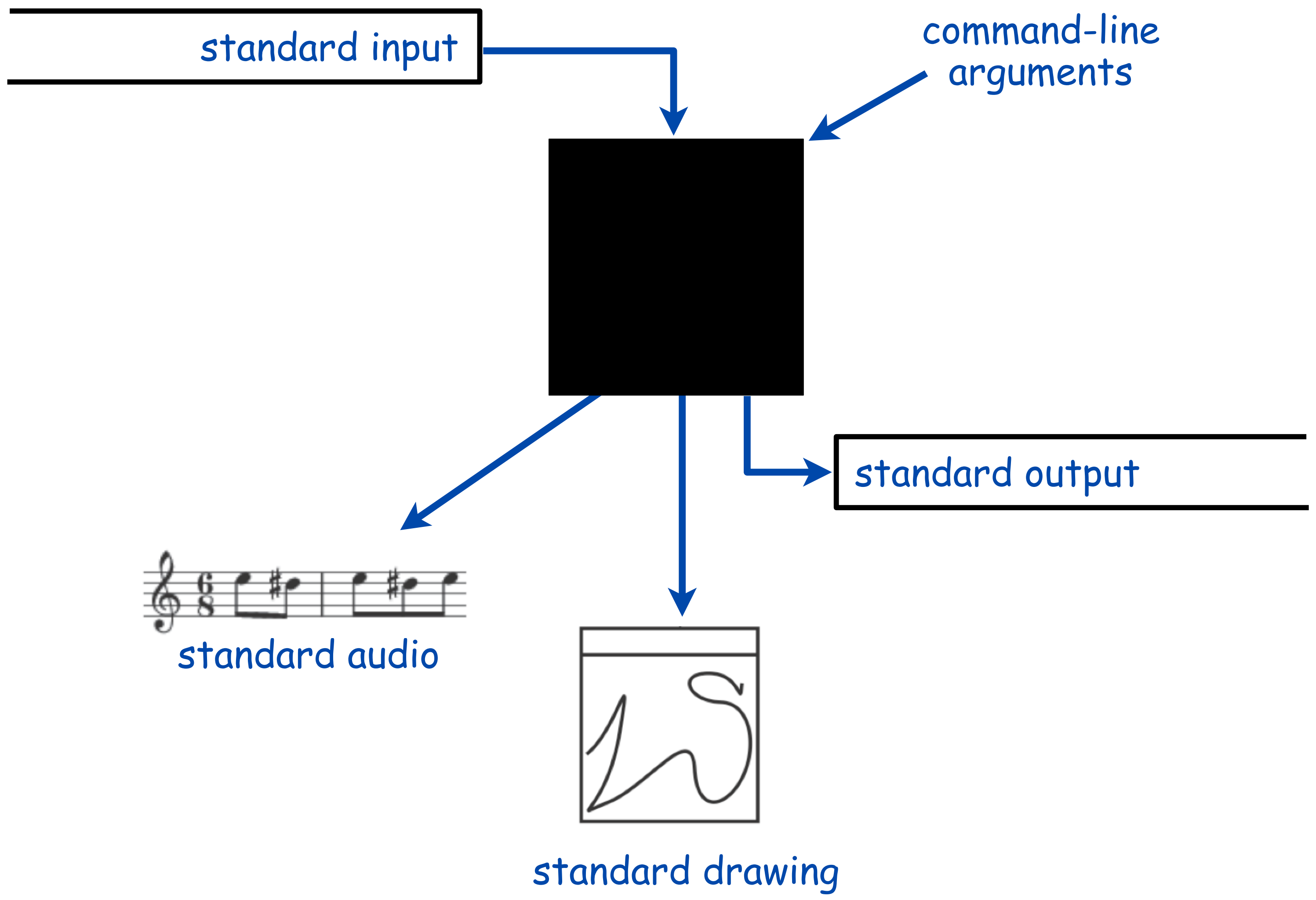
```java
public class RandomSeq
{
   public static void main(String[] args)
   {
      int N = Integer.parseInt(args[0]);
      for (int i = 0; i < N; i++)
         System.out.println(Math.random());
   }
}
```

```
% java RandomSeq 4
0.9320744627218469
0.4279508713950715
0.08994615071160994
0.6579792663546435
```

Old Bird's Eye View



New Bird's Eye View



Standard Input and Output

Command-Line Input vs. Standard Input

Command-line inputs.

- Useful for providing a few user values (arguments) to a program.
- Not practical for a large or unspecified number of user inputs.
- Input entered before program begins execution.

Standard input.

- Flexible OS abstraction for input.
- Useful for providing an unlimited amount of data to a program.
- By default, standard input is received from Terminal window.
- Input entered while program is executing.

Standard IO Warmup

To use. If you installed your programming environment correctly in Assignment 0, then you're all set. Otherwise, download `StdIn.java` and `StdOut.java` from the booksite, and put in working directory (with Add.java).

```
public class Add
{
   public static void main(String[] args)
   {
      StdOut.print("Type the first integer: ");
      int x = StdIn.readInt();
      StdOut.print("Type the second integer: ");
      int y = StdIn.readInt();
      int sum = x + y;
      StdOut.println("Their sum is " + sum);
   }
}
```

```
% java Add
Type the first integer: 1
Type the second integer: 2
Their sum is 3
```

Standard IO Example: Averaging A Stream of Numbers

Average. Read in a stream of numbers, and print their average.

```
public class Average
{
   public static void main(String[] args)
   {
      double sum = 0.0;   // cumulative total
      int n = 0;          // number of values
      while (!StdIn.isEmpty())
      {
         double x = StdIn.readDouble();
         sum = sum + x;
         n++;
      }
      StdOut.println(sum / n);
   }
}
```

```
% java Average
10.0 5.0  6.0
 3.0 7.0 32.0
<Ctrl-d>
10.5
```

`<Ctrl-d>` is OS X/Linux/Unix/DrJava EOF
`<Ctrl-z>` is Windows analog

Key point. Program does not limit amount of data.

Standard Input and Output

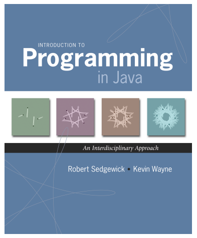
Standard input. `StdIn` library has methods to read text input.

Standard output. `StdOut` library has methods to write text output.

public class StdIn	
`boolean isEmpty()`	`true` if no more values, `false` otherwise
`int readInt()`	read a value of type `int`
`double readDouble()`	read a value of type `double`
`long readLong()`	read a value of type `long`
`boolean readBoolean()`	read a value of type `boolean`
`char readChar()`	read a value of type `char`
`String readString()`	read a value of type `String`
`String readLine()`	read the rest of the line
`String readAll()`	read the rest of the text

public class StdOut	
`void print(String s)`	print `s`
`void println(String s)`	print `s`, followed by a newline
`void println()`	print a new line
`void printf(String f, ...)`	formatted print

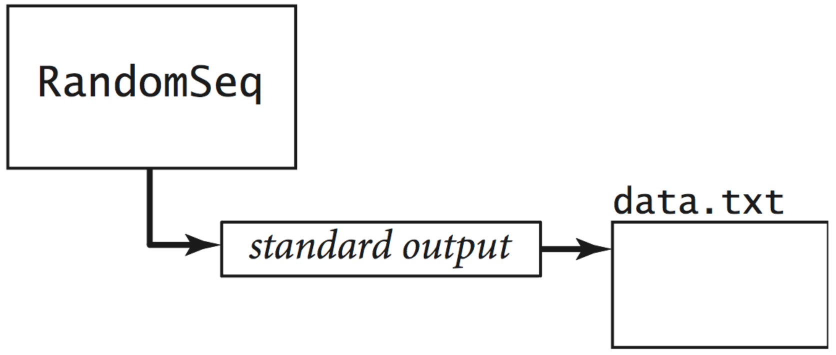
libraries developed
for this course
(and also broadly useful)



Redirection and Piping

Redirecting Standard Output

Redirecting standard output. Use OS directive to send standard output to a file for permanent storage (instead of terminal window).

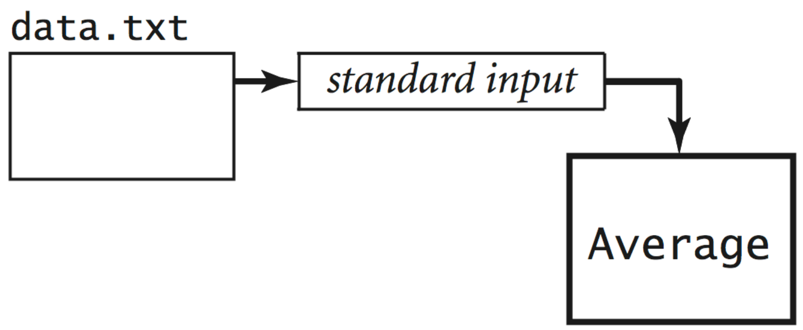


```
% java RandomSeq 1000 > data.txt
```

redirect standard output

Redirecting Standard Input

Redirecting standard input. Use OS directive to read standard input from a file (instead of terminal window).

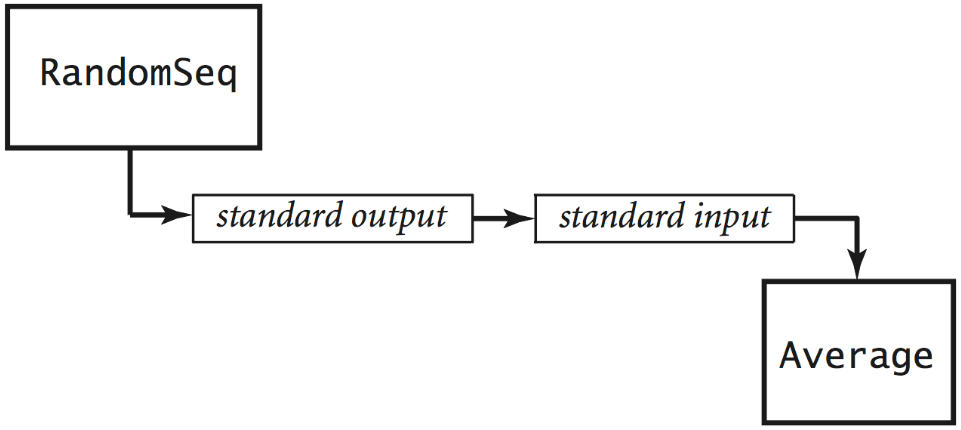


```
% more < data.txt
0.5475375782884312
0.4971087292684019
0.2312380804175381 3
…

% java Average < data.txt
0.4947655567740991
```

redirect standard input

Connecting Programs

Piping. Use OS directive to make the standard output of one program become the standard input of another.



```
% java RandomSeq 1000000 | java Average
0.4997970473016028

% java RandomSeq 1000000 | java Average
0.5002071875644842
```

pipe standard output to standard input

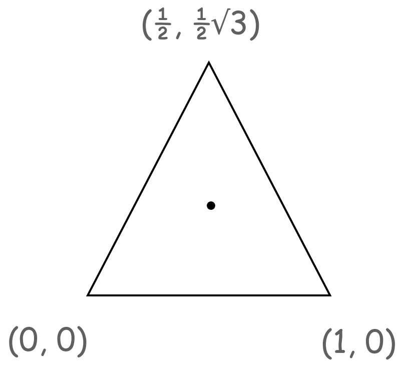
Key point. Program does not limit amount of data.

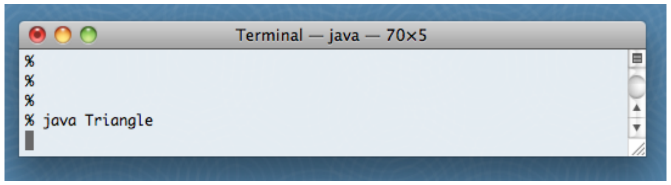
Standard Drawing

"Hello World" for Standard Draw

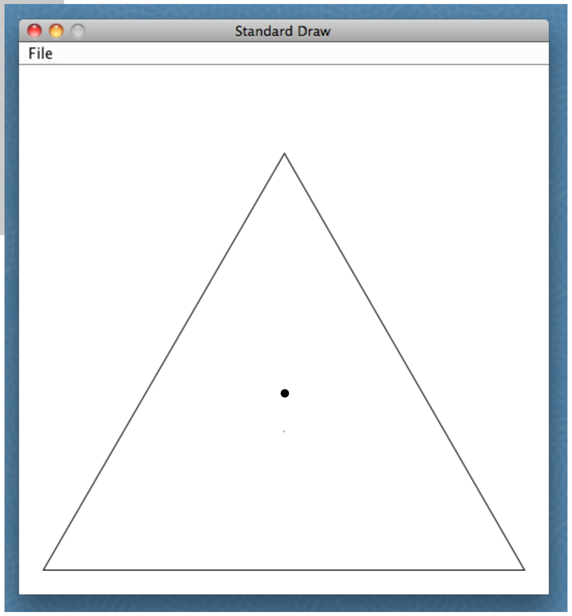
To use. If you installed your programming environment correctly in Assignment 0, you're all set. Otherwise, download `StdDraw.java` and put in working directory (with Triangle.java).

```
public class Triangle
{
   public static void main(String[] args)
   {
      double t = Math.sqrt(3.0) / 2.0;
      StdDraw.line(0.0, 0.0, 1.0, 0.0);
      StdDraw.line(1.0, 0.0, 0.5,   t);
      StdDraw.line(0.5,   t, 0.0, 0.0);
      StdDraw.point(0.5, t/3.0);
   }
}
```





```
%
%
%
% java Triangle
```



Data Visualization

Plot filter. Read in a sequence of (x, y) coordinates from standard input, and plot using standard drawing.

```
public class PlotFilter
{
   public static void main(String[] args)
   {
      double xmin = StdIn.readDouble();
      double ymin = StdIn.readDouble();
      double xmax = StdIn.readDouble();
      double ymax = StdIn.readDouble();
      StdDraw.setXscale(xmin, xmax);
      StdDraw.setYscale(ymin, ymax);

      while (!StdIn.isEmpty())
      {
         double x = StdIn.readDouble();
         double y = StdIn.readDouble();
         StdDraw.point(x, y);
      }
   }
}
```

← rescale coordinate system

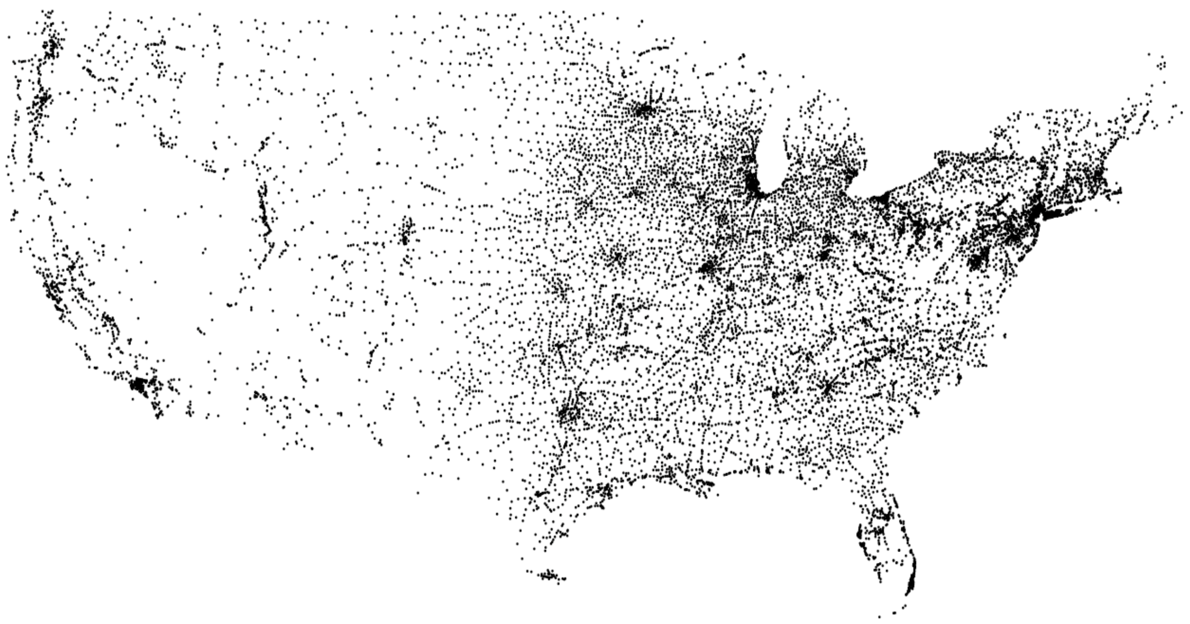
← read in points, and plot them

Data Visualization

```
% more < USA.txt
669905.0 247205.0 1244962.0 490000.0
 1097038.8890  245552.7780
 1103961.1110  247133.3330
 1104677.7780  247205.5560
 ...


% java PlotFilter < USA.txt
```

bounding box

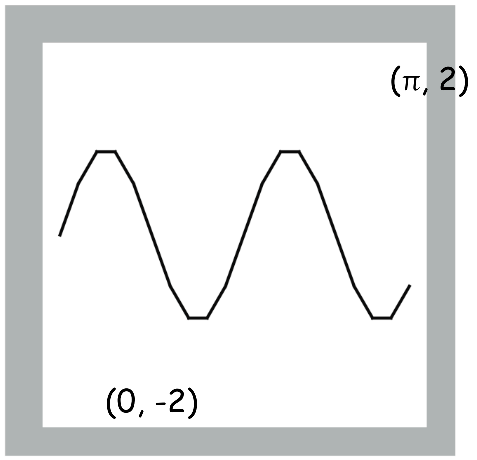
coordinates of
13,509 US cities



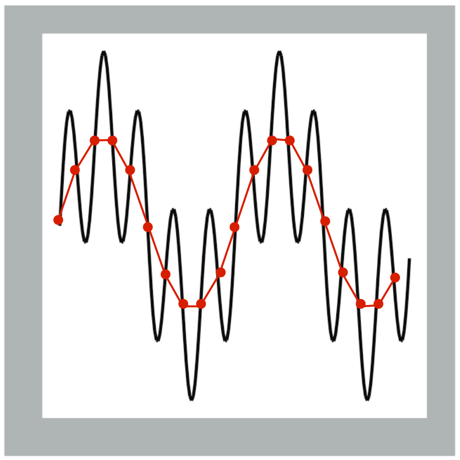
Plotting a Function with `StdDraw`

```
double[] x = new double[N+1];
double[] y = new double[N+1];
for (int i = 0; i <= N; i++)
{
   x[i] = Math.PI * i / N;
   y[i] = Math.sin(4*x[i]) + Math.sin(20*x[i]);
}
StdDraw.setXscale(0, Math.PI);
StdDraw.setYscale(-2.0, +2.0);
for (int i = 0; i < N; i++)
   StdDraw.line(x[i], y[i], x[i+1], y[i+1]);
```

$N = 20$



$N = 200$



Lesson 1: Plotting is simple.

Lesson 2: If you don't plot enough points, you might miss something!

$$y = \sin 4x + \sin 20x, \quad x \in [0, \pi]$$

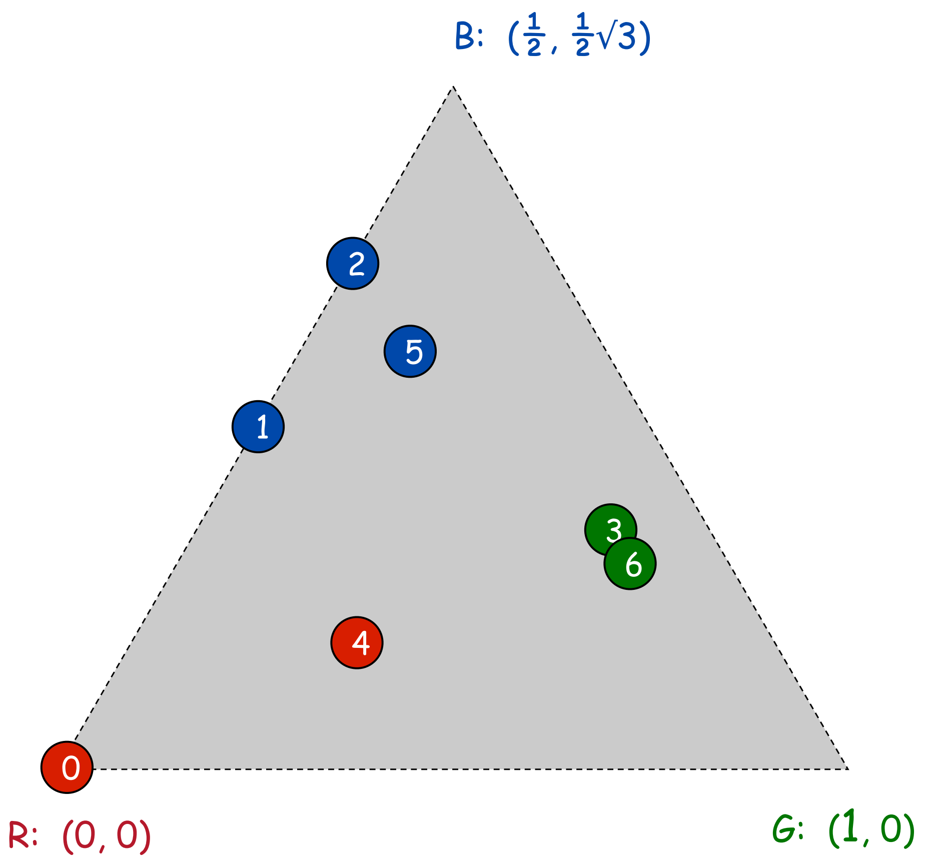
Chaos Game

Chaos game. Play on equilateral triangle, with vertices R, G, B.

- Start at R.
- Repeat the following `N` times:
  - pick a random vertex
  - move halfway between current point and vertex
  - draw a point in color of vertex

Q. What picture emerges?

B B G R B G …



Example: Chaos Game

```
public class Chaos
{
   public static void main(String[] args)
   {
      int T = Integer.parseInt(args[0]);
      double[] cx = { 0.000, 1.000, 0.500 };
      double[] cy = { 0.000, 0.000, 0.866 };


      double x = 0.0, y = 0.0;
      for (int t = 0; t < T; t++)
      {
         int r = (int) (Math.random() * 3);
         x = (x + cx[r]) / 2.0;
         y = (y + cy[r]) / 2.0;
         StdDraw.point(x, y);
      }
   }
}
```

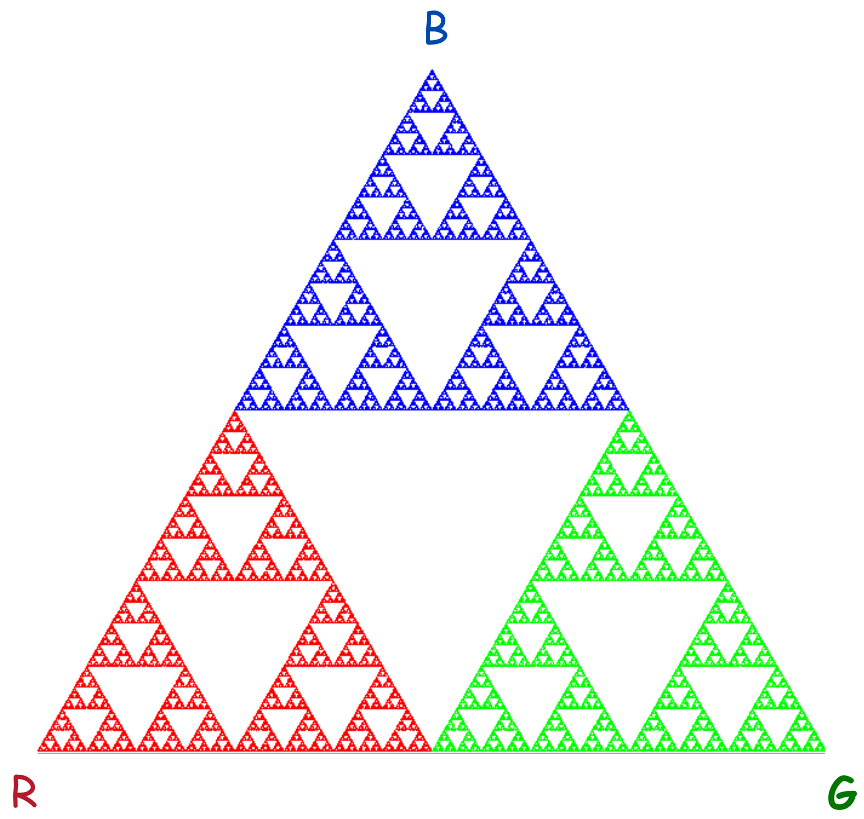
$\frac{1}{2}\sqrt{3}$
(best to avoid hardwired constants like this)

result: 0, 1 , or 2

Chaos Game

Easy modification. Color point according to random vertex chosen using `StdDraw.setPenColor(StdDraw.RED)` to change the pen color.

```
% java Chaos 10000
```

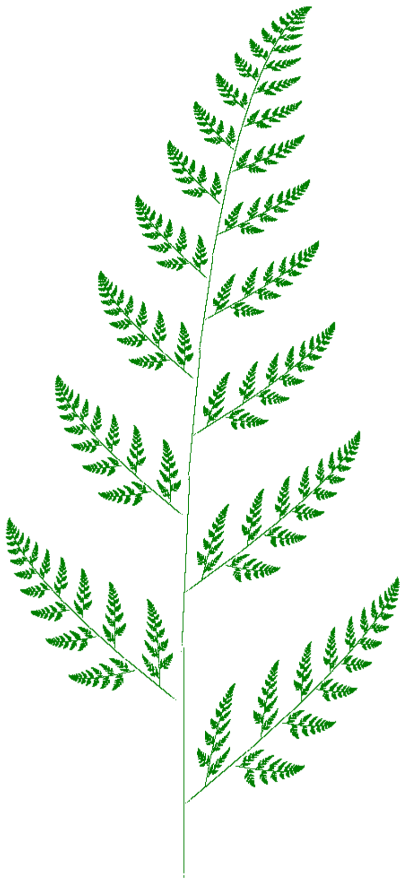


Sierpinski triangle

Barnsley Fern

Barnsley fern. Play chaos game with different rules.

probability	new x	new y
2%	`.50`	`.27y`
15%	`-.14x + .26y + .57`	`.25x + .22y - .04`
13%	`.17x - .21y + .41`	`.22x + .18y + .09`
70%	`.78x + .03y + .11`	`-.03x + .74y + .27`



Q. What does computation tell us about nature?

Q. What does nature tell us about computation?

20th century sciences. Formulas.

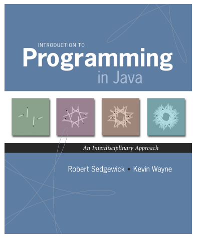
21st century sciences. Algorithms?

Standard Drawing

Standard drawing. `StdDraw` library has methods to produce graphical output.

```
public class StdDraw
    void line(double x0, double y0, double x1, double y1)
    void point(double x, double y)
    void text(double x, double y, String s)
    void circle(double x, double y, double r)
    void filledCircle(double x, double y, double r)
    void square(double x, double y, double r)
    void filledSquare(double x, double y, double r)
    void polygon(double[] x, double[] y)
    void filledPolygon(double[] x, double[] y)
    void setXscale(double x0, double x1)    reset x range
    void setYscale(double y0, double y1)    reset y range
    void setPenRadius(double r)
    void setPenColor(Color c)
    void setFont(Font f)
    void setCanvasSize(int w, int h)
    void clear(Color c)                     clear the canvas; color it c
    void show(int dt)                       show all; pause dt millisecs
    void save(String filename)              save to .jpg or .png file
```

library developed
for this course
(and also broadly useful)


INTRODUCTION TO
Programming
in Java
An Interdisciplinary Approach
Robert Sedgewick · Kevin Wayne

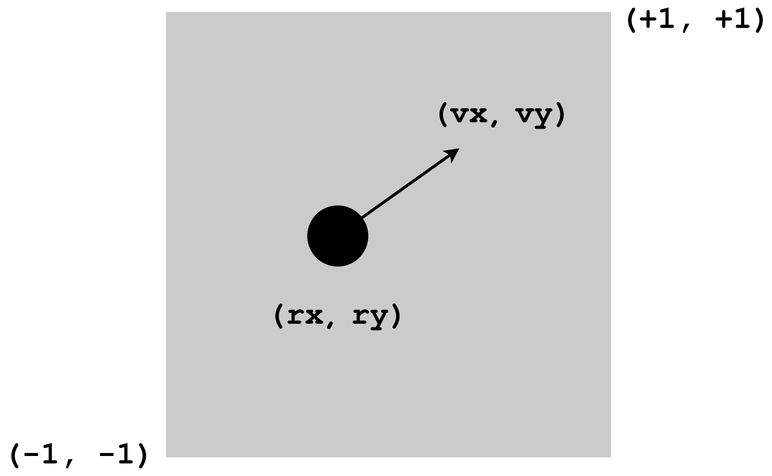
Animation

Animation loop. Repeat the following:

- Clear the screen.
- Move the object.
- Draw the object.
- Display and pause for a short while.

Ex. Bouncing ball.

- Ball has position `(rx, ry)` and constant velocity `(vx, vy)`.
- Detect collision with wall and reverse velocity.

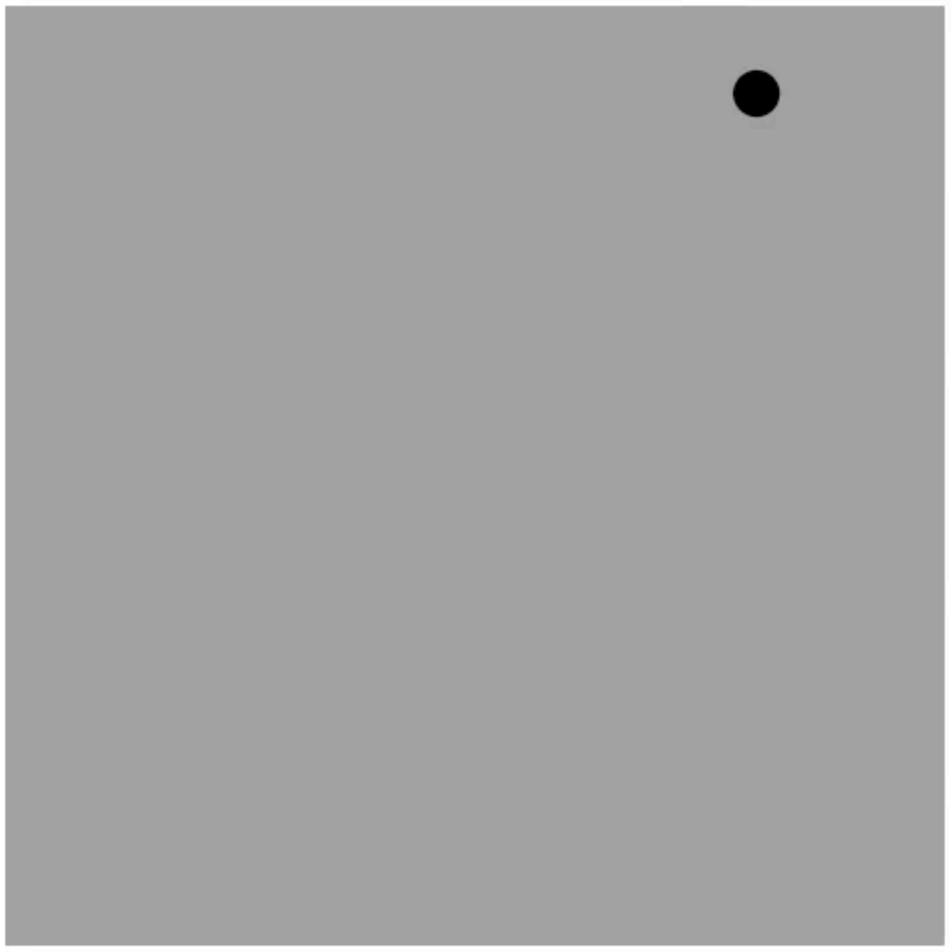


Bouncing Ball

```
public class BouncingBall
{
   public static void main(String[] args)
   {
      double rx = .480, ry = .860;
      double vx = .015, vy = .023;
      double radius = .05;

      StdDraw.setXscale(-1.0, +1.0);
      StdDraw.setYscale(-1.0, +1.0);

      while(true)
      {
         if (Math.abs(rx + vx) + radius > 1.0) vx = -vx;     bounce
         if (Math.abs(ry + vy) + radius > 1.0) vy = -vy;

         rx = rx + vx;                                       update position
         ry = ry + vy;

         StdDraw.setPenColor(StdDraw.GRAY);                  clear background
         StdDraw.filledSquare(0.0, 0.0. 1.0);
         StdDraw.setPenColor(StdDraw.BLACK);                 draw the ball
         StdDraw.filledCircle(rx, ry, radius);
         StdDraw.show(20);  <-- turn on animation mode:
      }                         display and pause for 50ms
   }
}
```

Bouncing Ball Demo

```
% java BouncingBall
```



Special Effects

Images. Put `.gif`, `.png`, or `.jpg` file in the working directory and use `StdDraw.picture()` to draw it.

Sound effects. Put `.wav`, `.mid`, or `.au` file in the working directory and use `StdAudio.play()` to play it.

stay tuned for more on `StdAudio`

Ex. Modify `BouncingBall` to display image and play sound upon collision.

- Replace `StdDraw.filledCircle()` with:

```
StdDraw.picture(rx, ry, "earth.gif");
```

- Add following code upon collision with walls:

```
StdAudio.play("laser.wav");   // vertical walls
StdAudio.play("pop.wav");     // horizontal walls
```

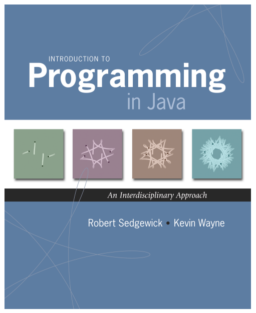
Digital Audio in Java

Standard audio. Library for playing digital audio.

public class StdAudio	
`void play(String file)`	*play the given .wav file*
`void play(double[] a)`	*play the given sound wave*
`void play(double x)`	*play sample for 1/44100 second*
`void save(String file, double[] a)`	*save to a .wav file*
`double[] read(String file)`	*read from a .wav file*

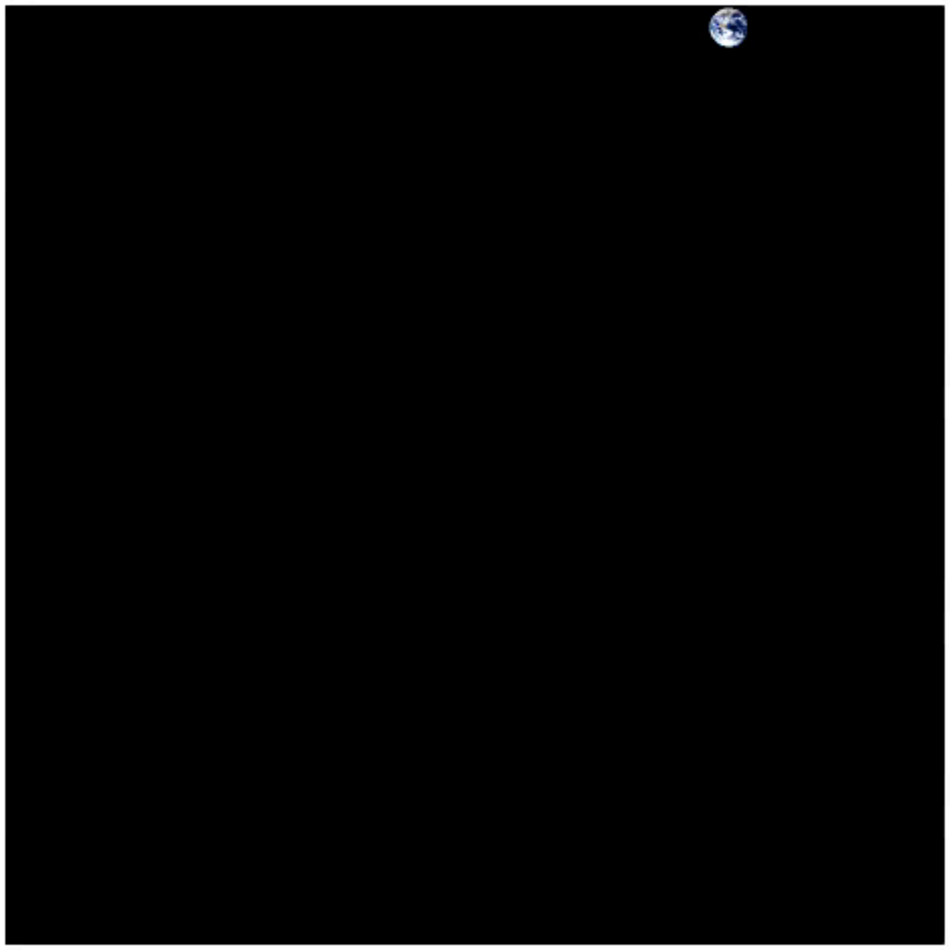
library developed for this course (also broadly useful)

Stay tuned. Example client in next lecture.



Deluxe Bouncing Ball Demo

```
% java DeluxeBouncingBall
```



Deluxe Bouncing Ball Challenge

Q. What happens if you call `StdDraw.filledSquare()` before instead of inside loop?

```java
public class DeluxeBouncingBall
{
   public static void main(String[] args)
   {
      double rx = .480, ry = .860;
      double vx = .015, vy = .023;
      double radius = .05;

      StdDraw.setXscale(-1.0, +1.0);
      StdDraw.setYscale(-1.0, +1.0);

      while(true)
      {
         if (Math.abs(rx + vx) + radius > 1.0)
            { vx = -vx; StdAudio.play("laser.wav"); }
         if (Math.abs(ry + vy) + radius > 1.0)
            { vy = -vy; StdAudio.play("pop.wav"); }

         rx = rx + vx;
         ry = ry + vy;

         StdDraw.filledSquare(0.0, 0.0. 1.0);
         StdDraw.picture(rx, ry, "earth.gif");
         StdDraw.show(20);
      }
   }
}
```

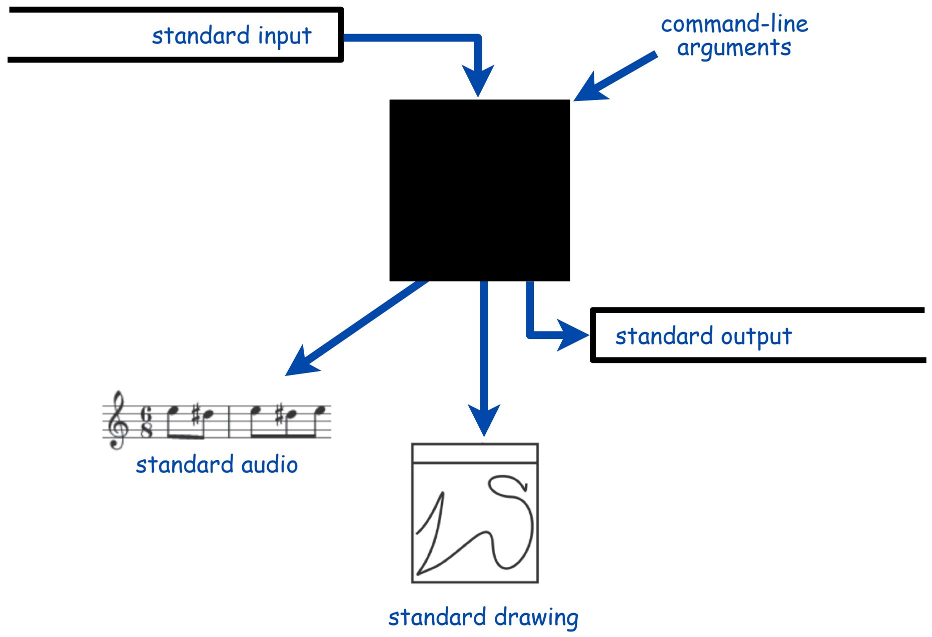
```java
public class DeluxeBouncingBall
{
   public static void main(String[] args)
   {
      double rx = .480, ry = .860;
      double vx = .015, vy = .023;
      double radius = .05;

      StdDraw.setXscale(-1.0, +1.0);
      StdDraw.setYscale(-1.0, +1.0);
      StdDraw.filledSquare(0.0, 0.0. 1.0);

      while(true)
      {
         if (Math.abs(rx + vx) + radius > 1.0)
            { vx = -vx; StdAudio.play("laser.wav"); }
         if (Math.abs(ry + vy) + radius > 1.0)
            { vy = -vy; StdAudio.play("pop.wav"); }

         rx = rx + vx;
         ry = ry + vy;

         StdDraw.picture(rx, ry, "earth.gif");
         StdDraw.show(20);
      }
   }
}
```

Deluxe Bouncing Ball Challenge

Q. What happens if you call `StdDraw.filledSquare()` before instead of inside loop?

```
% java DeluxeBouncingBall
```

Input/Output Summary



Command-line arguments. Parameters to control your program.

Standard input. Data for your program to process.

Standard output. Results of your program, or data for another program.

Standard drawing. Graphical output.

Standard audio. Sound output.

The N-body Assignment

Challenge. Add gravity.

```
% java NBody < planets.txt
```