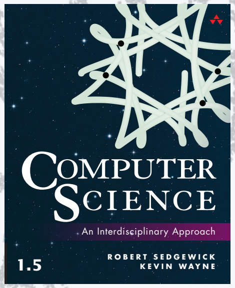
COMPUTER SCIENCE
SEDGEWICK / WAYNE
PART I: PROGRAMMING IN JAVA



http://introcs.cs.princeton.edu

4. Input and Output

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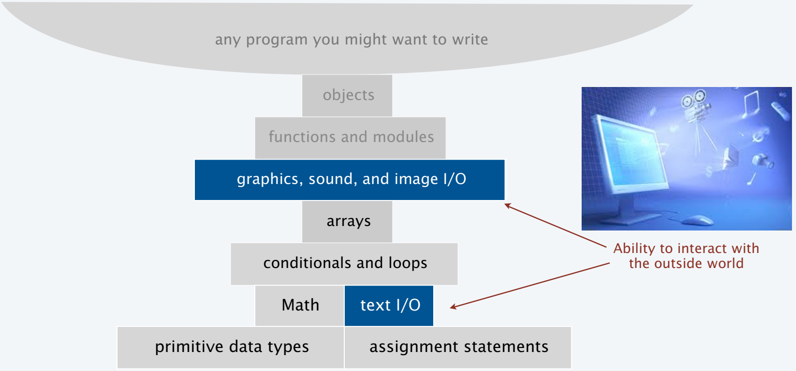
SEDGEWICK / WAYNE
PART I: PROGRAMMING IN JAVA

4. Input and Output

- Standard input and output
- Standard drawing
- Fractal drawings
- Animation

CS.4.A.IO.Standard

Basic building blocks for programming



any program you might want to write

objects

functions and modules

graphics, sound, and image I/O

arrays

conditionals and loops

Math | text I/O

primitive data types | assignment statements

Ability to interact with the outside world

Input and output

Goal: Write Java programs that interact with the outside world via *input* and *output* devices.

Typical INPUT devices

Typical OUTPUT devices

Our approach.

- Define input and output *abstractions*.
- Use operating system (OS) functionality to connect our Java programs to actual devices.

Abstraction

plays an *essential* role in understanding computation.

An *abstraction* is something that exists only as an idea.

Interested in thinking more deeply about this concept?
Consider taking a philosophy course.

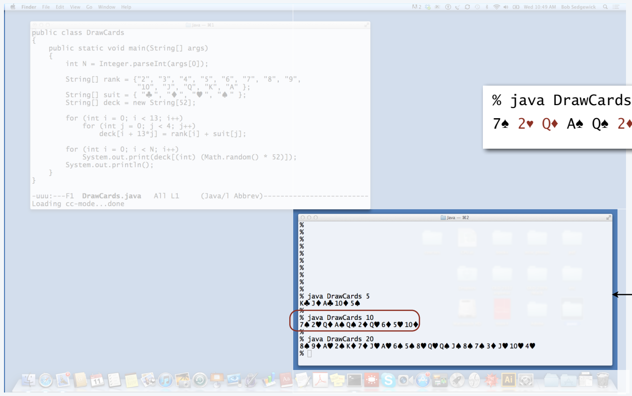
Example: "Printing" is the idea of a program producing text as output.

Good abstractions *simplify* our view of the world, by *unifying* diverse real-world artifacts.

This lecture. Abstractions for delivering input to or receiving output from our programs.

Quick review

Terminal. An abstraction for providing input and output to a program.



```
public class DrawCards
{
    public static void main(String[] args)
    {
        int N = Integer.parseInt(args[0]);

        String[] rank = {"2", "3", "4", "5", "6", "7", "8", "9",
                         "10", "J", "Q", "K", "A" };
        String[] suit = { "♣", "♦", "♥", "♠" };
        String[] deck = new String[52];

        for (int i = 0; i < 13; i++)
            for (int j = 0; j < 4; j++)
                deck[i + 13*j] = rank[i] + suit[j];

        for (int i = 0; i < N; i++)
            System.out.print(deck[(int) (Math.random() * 52)]);
        System.out.println();
    }
}

-uuu:---F1  DrawCards.java   All L1     (Java/l Abbrev)------------------------
Loading cc-mode...done
```

```
%
%
%
%
%
%
%
%
%
%
% java DrawCards 5
K♣ J♦ A♣ 10♦ 5♠
%
% java DrawCards 10
7♠ 2♥ Q♦ A♠ Q♠ 2♦ Q♥ 6♦ 5♥ 10♦
%
% java DrawCards 20
8♠ 9♦ A♥ 2♠ K♦ 7♦ J♥ A♥ 6♠ 5♠ 8♥ Q♥ Q♠ J♠ 8♠ 7♠ 3♦ J♥ 10♥ 4♥
%
```

Input from command line

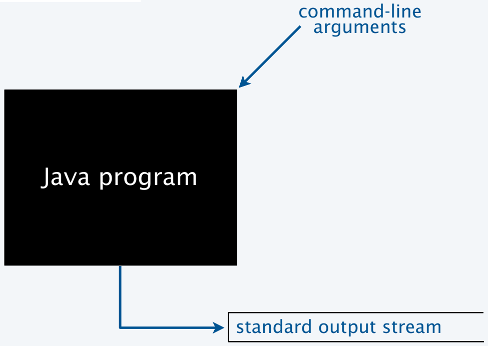
```
% java DrawCards 10
7♠ 2♥ Q♦ A♠ Q♠ 2♦ Q♥ 6♦ 5♥ 10♦
```

Output to standard output stream

Virtual VT-100 terminal

Input-output abstraction (so far)

A mental model of what a Java program does.



command-line arguments

Java program

standard output stream

Review: command-line input

Command-line input. An abstraction for providing arguments (strings) to a program.

Basic properties

- Strings you type after the program name are available as `args[0]`, `args[1]`, ... at *run* time.
- Arguments are available when the program *begins* execution.
- Need to call system conversion methods to convert the strings to other types of data.

```
public class RandomInt
{
   public static void main(String[] args)
   {
      int N = Integer.parseInt(args[0]);
      double r = Math.random();
      int t = (int) (r * N);
      System.out.println(t);
   }
}
```

```
% java RandomInt 6
3

% java RandomInt 10000
3184
```

Review: standard output

Infinity. An abstraction describing something having no limit.

Standard output stream. An abstraction for an infinite output sequence.

Basic properties

- Strings from `System.out.println()` are added to the end of the standard output stream.
- Standard output stream is sent to terminal application by default.

```
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());
   }
}
```

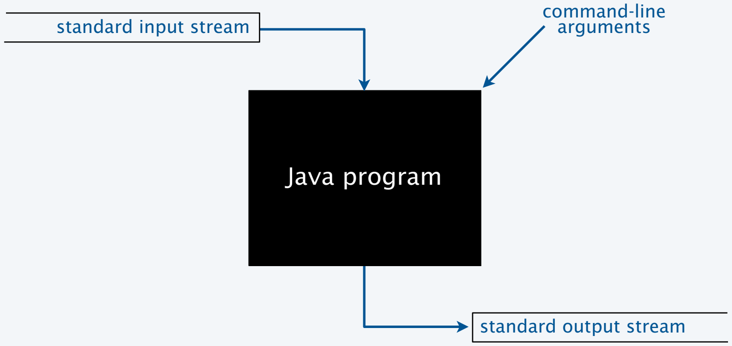
```
% java RandomSeq 4
0.9320744627218469
0.4279508713950715
0.08994615071160994
0.6579792663546435
```

```
% java RandomSeq 1000000
0.09474882292442943
0.2832974030384712
0.1833964252856476
0.2952177517730442
0.8035985765979008
0.7469424300071382
0.5835267075283997
0.3455279612587455
...
```

No limit on amount of output

Improved input-output abstraction

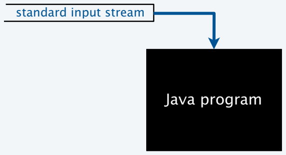
Add an infinite *input* stream.



Standard input

Infinity. An abstraction describing something having no limit.

Standard input stream. An abstraction for an infinite *input* sequence.



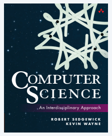
Advantages over command-line input

- Can provide new arguments *while* the program is executing.
- No limit on the amount of data we can input to a program.
- Conversion to primitive types is explicitly handled (stay tuned).

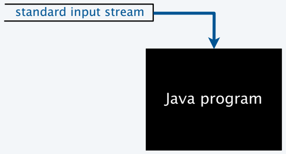
StdIn library

Developed for this course, but broadly useful

- Implement abstractions invented for UNIX in the 1970s.
- Available for download at booksite.
- Included in `introcs` software you downloaded at the beginning of the course.



`public class StdIn`	
`boolean isEmpty()`	*true iff no more values*
`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 readAll()`	*read the rest of the text*



StdOut library

Developed for this course, but broadly useful

- Implement abstractions invented for UNIX in the 1970s.
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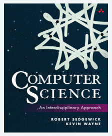
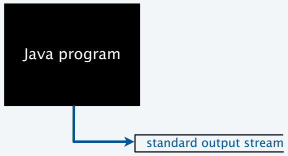


`public class StdOut`	
`void print(String s)`	*put s on the output stream*
`void println()`	*put a newline on the output stream*
`void println(String s)`	*put s, then a newline on the stream*
`void printf(String f, ...)`	*formatted output*


Java program

standard output stream

Q. These are the same as `System.out`. Why not just use `System.out`?

A. We provide a consistent set of simple I/O abstractions in one place.

A. We can make output *independent* of system, language, and locale.

use StdOut from now on

StdIn/StdOut warmup

Interactive input

- Prompt user to type inputs on standard input stream.
- Mix input stream with output stream.

```
public class AddTwo
{
   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 AddTwo
Type the first integer: 1
Type the second integer: 2
Their sum is 3
```

StdIn application: average the numbers on the standard input stream

Average

- Read a stream of numbers.
- Compute their average.

Q. How do I specify the end of the stream?

A. `<Ctrl-d>` (standard for decades).

A. `<Ctrl-z>` (Windows).

```
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);
   }
}
```

Key points

- No limit on the size of the input stream.
- Input and output can be interleaved.

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

Summary: prototypical applications of standard output and standard input

StdOut: Generate a stream of random numbers

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

StdIn: Compute the average of a stream of numbers

```
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);
   }
}
```

Both streams are *infinite* (no limit on their size).

Q. Do I always have to type in my input data and print my output?

A. No! Keep data and results in *files* on your computer, or use *piping* to connect programs.

Redirection: keep data in files on your computer

Redirect standard output to a file

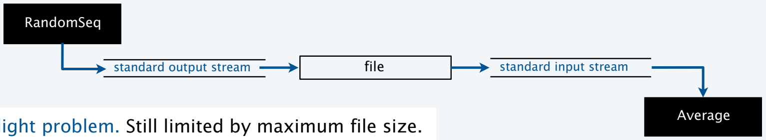
```
% java RandomSeq 1000000 > data.txt

% more data.txt
0.09474882292442943
0.2832974030384712
0.1833964252856476
0.2952177517730442
0.8035985765979008
0.7469424300071382
0.5835267075283997
0.3455279612587455
...
```

"redirect standard output to"

Redirect from a file to standard input

```
% java Average < data.txt
0.4947655567740991
```

"take standard input from"



Slight problem. Still limited by maximum file size.

Piping: entirely avoid saving data

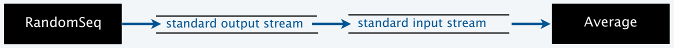
Q. There's no room for a huge file on my computer. Now what?

A. No problem! Use *piping*.

Piping. Connect standard output of one program to standard input of another.

set up a pipe

```
% java RandomSeq 1000000 | java Average
0.4997970473016028

% java RandomSeq 1000000 | java Average
0.5002071875644842
```



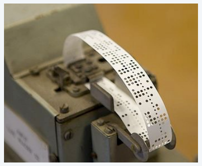
Critical point. No limit *within programs* on the amount of data they can handle.

It is the job of the *system* to collect data on standard output and provide it to standard input.

Streaming algorithms

Early computing

- Amount of available memory was much smaller than amount of data to be processed.
- *But* dramatic increases happened every year.
- Redirection and piping enabled programs to handle much more data than computers could store.



Modern computing

- Amount of available memory *is* much smaller than amount of data to be processed.
- Dramatic increases *still* happen every year.
- *Streaming algorithms* enable our programs to handle much more data than our computers can store.

Lesson. Avoid limits *within your program* whenever possible.

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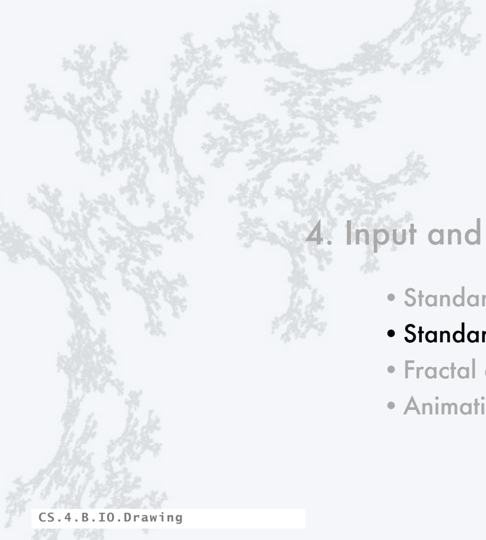
Image sources

http://www.digitalreins.com/wp-content/uploads/2013/05/Binary-code.jpg

http://en.wikipedia.org/wiki/Punched_tape#mediaviewer/File:Harwell-dekatron-witch-10.jpg



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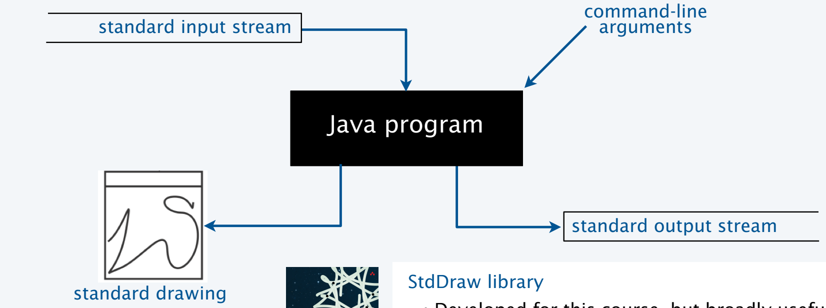
PART I: PROGRAMMING IN JAVA

4. Input and Output

- Standard input and output
- **Standard drawing**
- Fractal drawings
- Animation

Further improvements to our I/O abstraction

Add the ability to create a *drawing*.



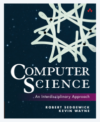
standard input stream

command-line arguments

Java program

standard drawing

standard output stream



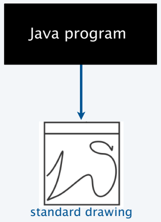
StdDraw library

- Developed for this course, but broadly useful.
- Available for download at booksite.
- Included in `introcs` software.

StdDraw library

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 square(double x, double y, double r)	
void polygon(double x, double y, double r)	
void picture(double x, double y, String filename)	*place* .gif, .jpg *or* .png *file*
void setPenRadius(double r)	
void setPenColor(Color c)	
void setXscale(double x0, double x1)	*reset x range to* $[x_0, x_1)$
void setYscale(double y0, double y1)	*reset y range to* $[y_0, y_1)$
void show(int dt)	*show all; pause* dt *millisecs*

also `filledCircle()`, `filledSquare()`, and `filledPolygon()`

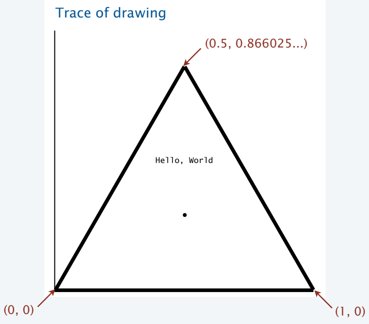


Java program

standard drawing

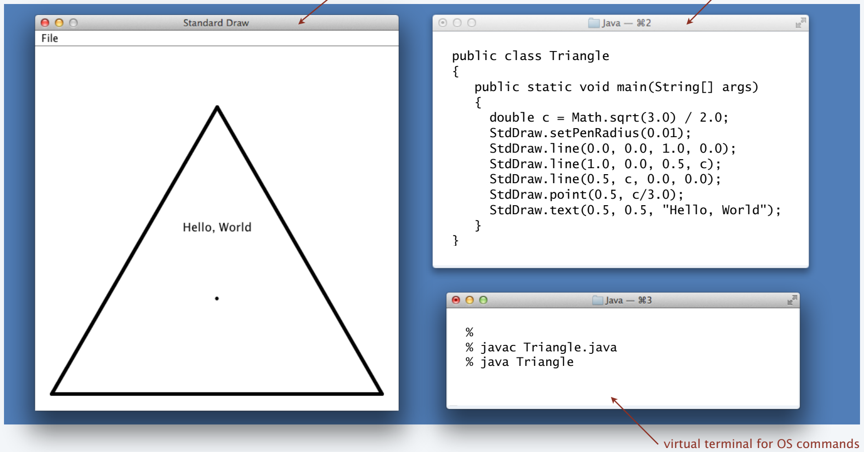
"Hello, World" for StdDraw

```
public class Triangle
{
   public static void main(String[] args)
   {
      double c = Math.sqrt(3.0) / 2.0;
      StdDraw.setPenRadius(0.01);
      StdDraw.line(0.0, 0.0, 1.0, 0.0);
      StdDraw.line(1.0, 0.0, 0.5, c);
      StdDraw.line(0.5, c, 0.0, 0.0);
      StdDraw.point(0.5, c/3.0);
      StdDraw.text(0.5, 0.5, "Hello, World");
   }
}
```



Trace of drawing

“Hello, World” for StdDraw



```
public class Triangle
{
   public static void main(String[] args)
   {
     double c = Math.sqrt(3.0) / 2.0;
     StdDraw.setPenRadius(0.01);
     StdDraw.line(0.0, 0.0, 1.0, 0.0);
     StdDraw.line(1.0, 0.0, 0.5, c);
     StdDraw.line(0.5, c, 0.0, 0.0);
     StdDraw.point(0.5, c/3.0);
     StdDraw.text(0.5, 0.5, "Hello, World");
   }
}
```

```
%
% javac Triangle.java
% java Triangle
```

window for standard drawing

virtual terminal for editor

virtual terminal for OS commands

StdDraw application: data visualization

```
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);
      }
   }
}
```

read coords of bounding box

rescale

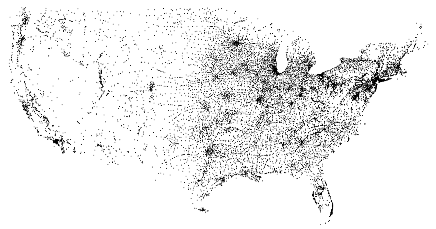
read and plot a point

bounding box coords

```
% 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
```

sequence of point coordinates (13,509 cities)



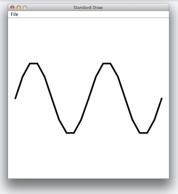
StdDraw application: plotting a function

Goal. Plot $y = \sin(4x) + \sin(20x)$ in the interval $(0, \pi)$.

Method. Take *N* samples, regularly spaced.

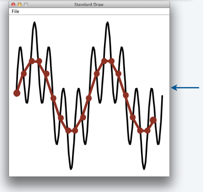
```
public class PlotFunctionEx
{
   public static void main(String[] args)
   {
      int N = Integer.parseInt(args[0]);
      double[] x = new double[N+1];
      double[] y = new double[N+1];
      for (int i = 0; i <= N; i++)
      {
         x[i] = Math.PI * i / N;
         y[i] = Math.sin(4*x[i]) + 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]);
   }
}
```

```
% java PlotFunctionEx 20
```



Lesson 1: Plotting is easy.

```
% java PlotFunctionEx 200
```



Lesson 2: Take a sufficiently large sample—otherwise you might miss something!

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CS.4.B.IO.Drawing

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4. Input and Output

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CS.4.C.IO.Fractals

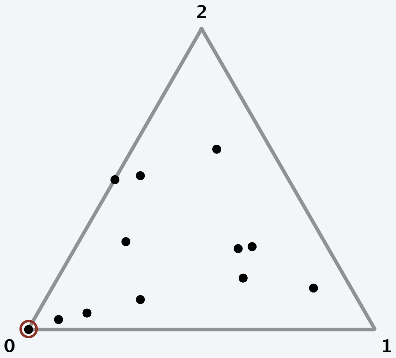
StdDraw application: a random game

Draw an equilateral triangle, number the vertices 0, 1, 2 and make 0 the *current point.*

- Pick a vertex at random.
- Draw a point halfway between that vertex and the current point.
- Repeat.

0	1	2	3	4	5	6	7	8	9	10
2	**1**	**2**	**0**	**1**	**0**	**0**	**0**	**2**	**1**	**1**

vertex	*ID*	*probability*	*new x*	*new y*
(0, 0)	0	1/3	.5*x*	.5*y*
(1, 0)	1	1/3	.5*x* + .5	.5*y*
(.5, √3/2)	2	1/3	.5*x* + .25	.5*y* + .433

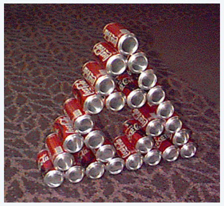


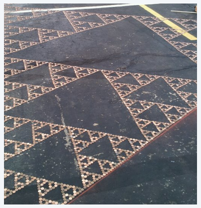
StdDraw application: a random game

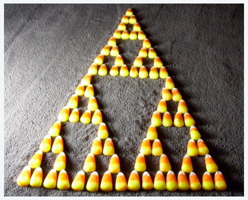
```
public class Chaos
{
   public static void main(String[] args)
   {
      int trials = Integer.parseInt(args[0]);

      double c = Math.sqrt(3.0) / 2.0;
      double[] cx = { 0.000, 1.000, 0.500 };
      double[] cy = { 0.000, 0.000, c };

      StdDraw.setPenRadius(0.01);
      double x = 0.0, y = 0.0;
      for (int t = 0; t < trials; t++)
      {
         int r = (int) (Math.random() * 3);
         x = (x + cx[r]) / 2.0;
         y = (y + cy[r]) / 2.0;
         StdDraw.point(x, y);
      }
   }
}
```

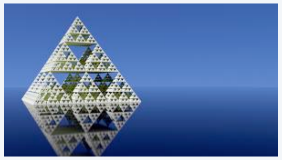
```
% java Chaos 10000
```

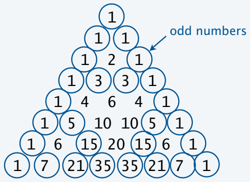
Sierpinski triangles in the wild











Pascal's triangle

Iterated function systems

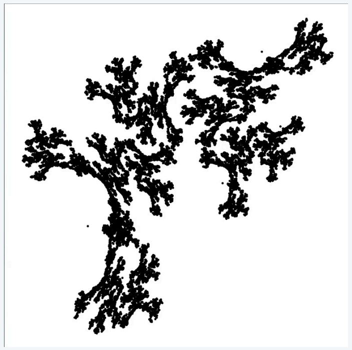
What happens when we change the rules?

probability	*new x*	*new y*
40%	$.31x - .53y + .89$	$-.46x - .29y + 1.10$
15%	$.31x - .08y + .22$	$.15x - .45y + .34$
45%	$.55y + .01$	$.69x - .20y + .38$

`IFS.java` (Program 2.2.3) is a *data-driven* program that takes the coefficients from *standard input.*

```
% more coral.txt
3
   0.40  0.15  0.45
3 3
   0.307692 -0.531469  0.8863493
   0.307692 -0.076923  0.2166292
   0.000000  0.545455  0.0106363
3 3
  -0.461538 -0.293706  1.0962865
   0.153846 -0.447552  0.3383760
   0.692308 -0.195804  0.3808254
```

```
% java IFS 10000 < coral.txt
```



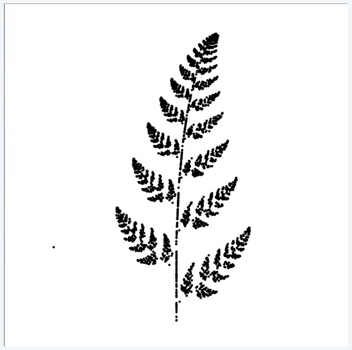
Iterated function systems

Another example of changing the rules

probability	*new x*	*new y*
2%	0.5	$.27y$
15%	$-.14x + .26y + .57$	$.25x + .22y - .04$
13%	$.17x - .21y + .41$	$.22x + .18y + .09$
70%	$.78x + .03y + .11$	$-.03x + .74y + .27$

```
% more barnsley.txt
4
  .02 .15 .13 .70
4 3
  .000  .000  .500
 -.139  .263  .570
  .170 -.215  .408
  .781  .034  .1075
4 3
  .000  .270  .000
  .246  .224 -.036
  .222  .176  .0893
 -.032  .739  .270
```

```
% java IFS 10000 < barnsley.txt
```



Iterated function systems

Simple iterative computations yield patterns that are remarkably similar to those found in the natural world.

Q. What does computation tell us about nature?

Q. What does nature tell us about computation?

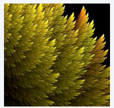
20th century sciences. Formulas.

21st century sciences. Algorithms?

an IFS fern

a real fern

a real plant



an IFS plant

Note. You have seen many practical applications of integrated function systems, in movies and games.

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SEDGEWICK / WAYNE
PART I: PROGRAMMING IN JAVA

Image sources

http://paulbourke.net/fractals/gasket/cokegasket.gif

http://www.buzzfeed.com/atmccann/11-awesome-math-foods#39wokfk

http://sheilakh.deviantart.com/art/The-Legend-of-Sierpinski-308953447

http://commons.wikimedia.org/wiki/File:Lady_Fern_frond_-_normal_appearance.jpg

http://img3.wikia.nocookie.net/__cb20100707172110/jamescameronsavatar/images/e/e1/Avatar_concept_art-3.jpg

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4. Input and Output

- Standard input and output
- Standard drawing
- Fractal drawings
- **Animation**

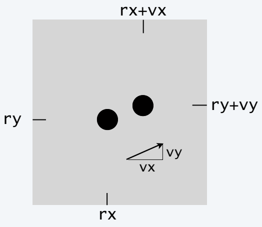
Animation

To create animation with StdDraw.

Repeat the following:

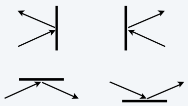
- Clear the screen.
- Move the object.
- Draw the object.
- Display and pause briefly.

When display time is much greater than the screen-clear time, we have the illusion of motion.



Bouncing ball.

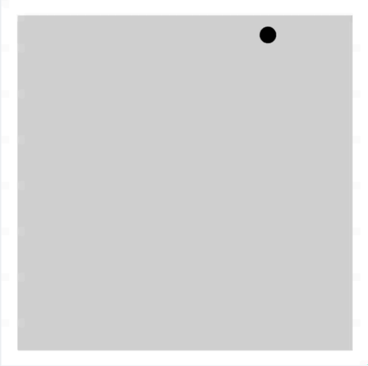
- Ball has position `(rx, ry)` and constant velocity `(vx, vy)`.
- To *move* the ball, update position to `(rx+vx, ry+vy)`.
- If the ball hits a *vertical* wall, set `vx` to `-vx`.
- If the ball hits a *horizontal* wall, set `vy` to `-vy`.



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)
      {
        StdDraw.setPenColor(StdDraw.LIGHT_GRAY);
        StdDraw.filledSquare(0.0, 0.0, 1.0);
        if (Math.abs(rx + vx) + radius > 1.0) vx = -vx;
        if (Math.abs(ry + vy) + radius > 1.0) vy = -vy;
        rx = rx + vx;
        ry = ry + vy;
        StdDraw.setPenColor(StdDraw.BLACK);
        StdDraw.filledCircle(rx, ry, radius);
        StdDraw.show(20);
      }
   }
}
```

```
% java BouncingBall
```



Pop quiz on animation

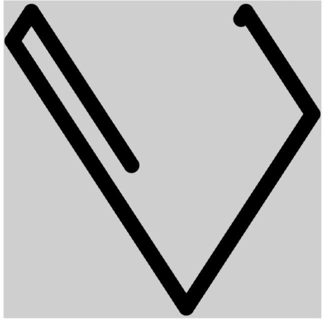
Q. What happens if we move *clear the screen* out of the loop?

```
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)
      {
        StdDraw.setPenColor(StdDraw. LIGHT_GRAY);
        StdDraw.filledSquare(0.0, 0.0, 1.0);
        if (Math.abs(rx + vx) + radius > 1.0) vx = -vx;
        if (Math.abs(ry + vy) + radius > 1.0) vy = -vy;
        rx = rx + vx;
        ry = ry + vy;
        StdDraw.setPenColor(StdDraw.BLACK);
        StdDraw.filledCircle(rx, ry, sz);
        StdDraw.show(20);
      }
   }
```

Pop quiz on animation

Q. What happens if we move *clear the screen* out of the loop?

```
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);
      StdDraw.setPenColor(StdDraw. LIGHT_GRAY);
      StdDraw.filledSquare(0.0, 0.0, 1.0);
      while(true)
      {
         if (Math.abs(rx + vx) + radius > 1.0) vx = -vx;
         if (Math.abs(ry + vy) + radius > 1.0) vy = -vy;
         rx = rx + vx;
         ry = ry + vy;
         StdDraw.setPenColor(StdDraw.BLACK);
         StdDraw.filledCircle(rx, ry, radius);
         StdDraw.show(20);
      }
   }
}
```

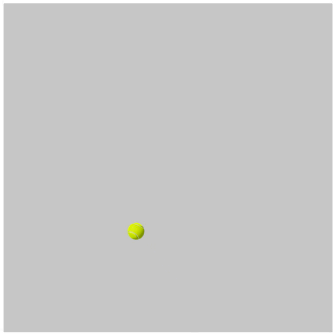


A. We see the ball’s entire path.

Deluxe bouncing ball

```
public class BouncingBallDeluxe
{
   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)
      {
         StdDraw.setPenColor(StdDraw. LIGHT_GRAY);
         StdDraw.filledSquare(0.0, 0.0, 1.0);
         if (Math.abs(rx + vx) + radius > 1.0)
         {  StdAudio.play("pipebang.wav"); vx = -vx;  }
         if (Math.abs(ry + vy) + radius > 1.0)
         {  StdAudio.play("pipebang.wav"); vy = -vy;  }
         rx = rx + vx;
         ry = ry + vy;
         StdDraw.picture(rx, ry, "TennisBall.png");
         StdDraw.show(20);
      }
   }
}
```

```
% java BouncingBallDeluxe
```

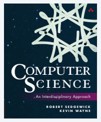


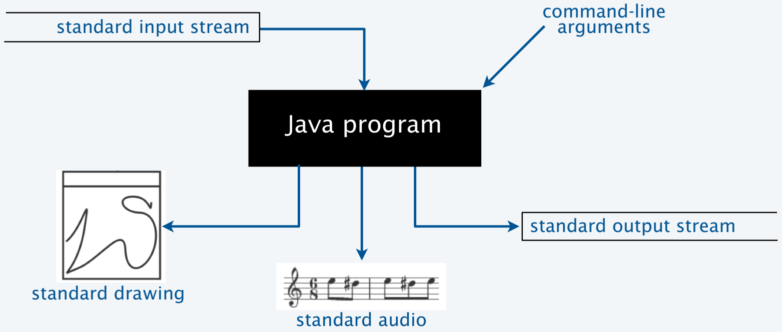
Stay tuned to next lecture for full description of StdAudio.

A set of I/O abstractions for Java

Developed for this course, but broadly useful

- StdIn, StdOut, StdDraw, and StdAudio.
- Available for download at booksite (and included in `introcs` software).





standard input stream

command-line arguments

Java program

standard output stream

standard drawing

standard audio

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CS.4.D.IO.Animation

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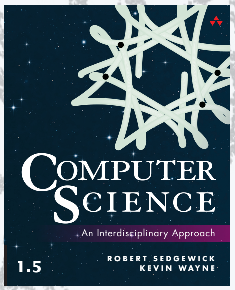

http://introcs.cs.princeton.edu

4. Input and Output