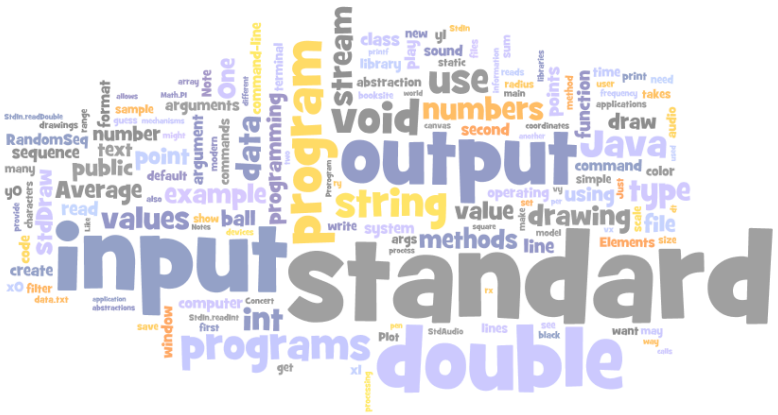
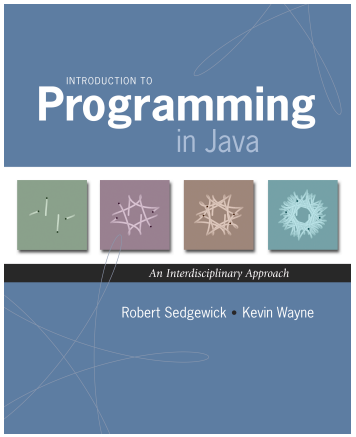


1.5 Input and Output



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.

Input and Output

Input devices.

Keyboard | Mouse | Hard drive | Network | Digital camera | Microphone

Output devices.

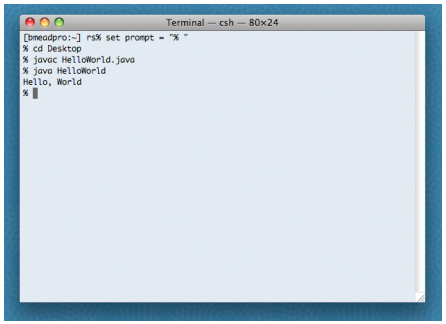
Display | Speakers | Hard drive | Network | Printer | MP3 Player

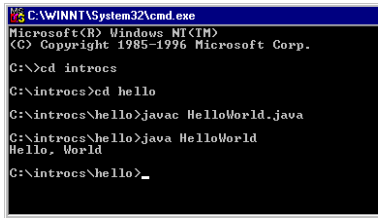
Our approach.

- 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.





Microsoft Windows

Command-Line Input and Standard Output

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

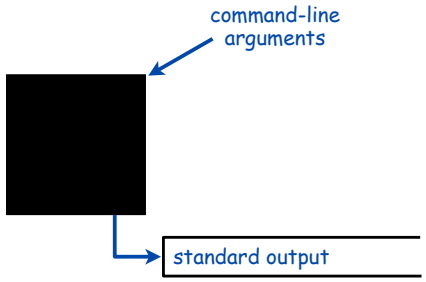
Standard output.

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

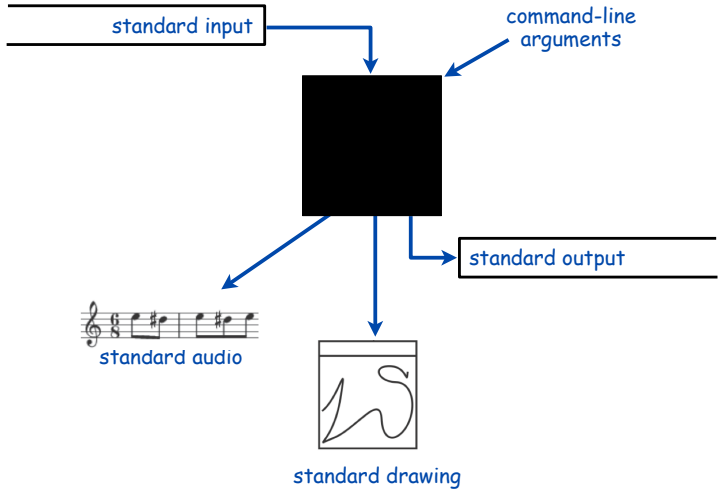
```
public class RandomSeq
{
   public static void main(String[] args)
   {
      int N = Integer.parseInt(args[0]);
      for (int i = 0; i < N; i++)
         System.out.println(Math.random());
   }
}
```

```
% 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 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)

Standard IO Warmup

To use. Download `StdIn.java` and `StdOut.java` from booksite, and put in working directory (or use classpath).

see booksite

```
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
```

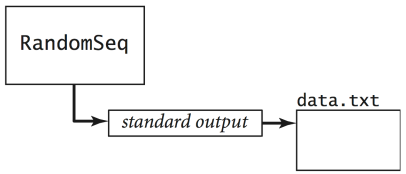
Key point. Program does not limit amount of data.

<Ctrl-d> is OS X/Linux/Unix EOF
<Ctrl-z> is Windows analog
currently no DrJava analog

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).

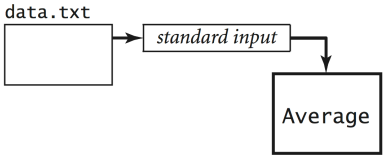



```
% java RandomSeq 1000 > data.txt
```

redirect stdout

Redirecting Standard Input

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



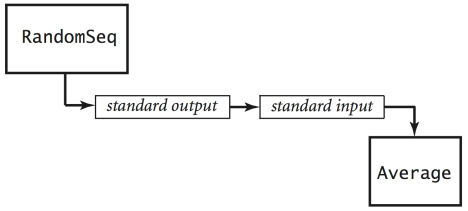

```
% more < data.txt
0.5475375782884312
0.4971087292684019
0.23123808041753813
...
```

redirect stdin

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

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
```

Key point. Program does not limit amount of data.

Standard Drawing

Standard Drawing

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

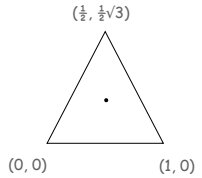
```
public class StdDraw
   void line(double x0, double y0, double x1, double y1)
   void point(double x, double y)
   void text(double x, double y, String s)
   void circle(double x, double y, double r)
   void filledCircle(double x, double y, double r)
   void square(double x, double y, double r)
   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
```

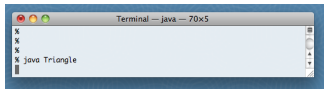
library developed for this course (and also broadly useful)

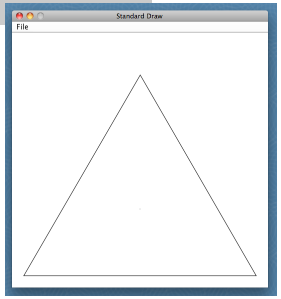
"Hello World" for Standard Draw

To use. Download `StdDraw.java` and put in working directory.

```
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);
   }
}
```







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

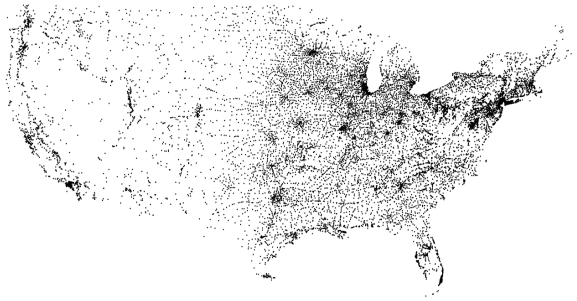
read in points, and plot them

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
```

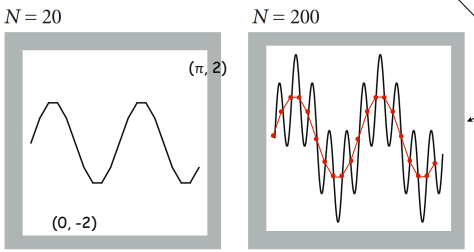
bounding box

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]);
```



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

Lesson 1: Plotting is simple.

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

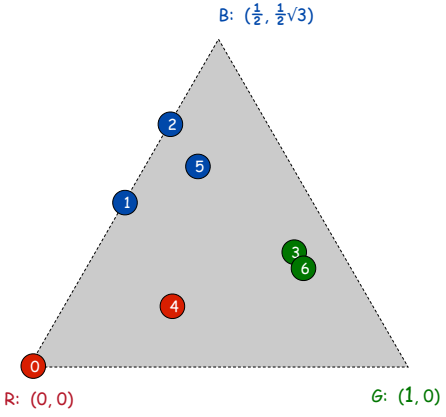
Chaos Game

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);
      }
   }
}
```

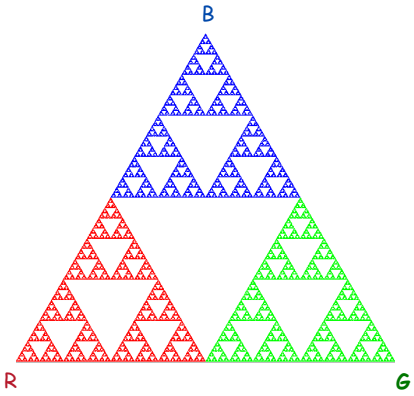
$\frac{1}{2}\sqrt{3}$ (best to avoid hardwired constants like this)

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
```

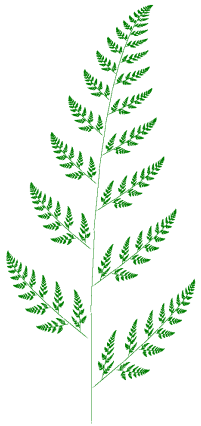


Sierpinski triangle

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?

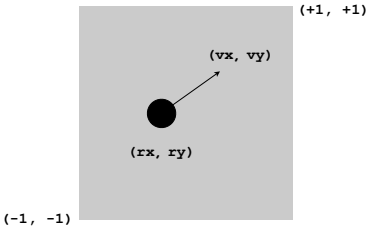
Animation

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.

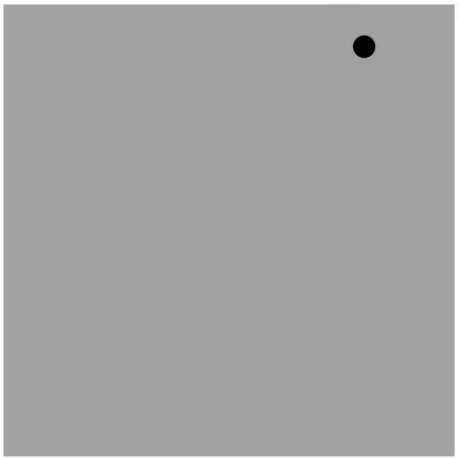


Bouncing Ball

```
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);
         StdDraw.filledSquare(0.0, 0.0. 1.0);                clear background
         StdDraw.setPenColor(StdDraw.BLACK);
         StdDraw.filledCircle(rx, ry, radius);               draw the ball
         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:

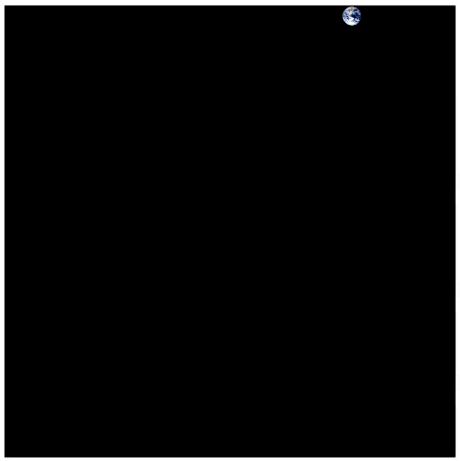
```
StdDraw.picture(rx, ry, "earth.gif");
```

- Add following code upon collision with wall:

```
StdAudio.play("boing.wav");
```


Deluxe Bouncing Ball Demo

```
% java DeluxeBouncingBall
```



Bouncing Ball Challenge

Q. What happens if you call `StdDraw.filledSquare()` before instead of inside 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)
      {
         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.GRAY);
         StdDraw.filledSquare(0.0, 0.0. 1.0);
         StdDraw.setPenColor(StdDraw.BLACK);
         StdDraw.filledCircle(rx, ry, radius);
         StdDraw.show(20);
      }
   }
}
```

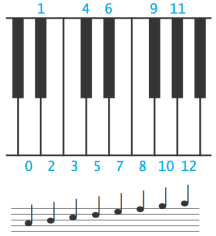
```
public class BouncingBall
{
   public static void main(String[] args)
   {
      double rx = .480, ry = .860;
      double vx = .015, vy = .023;
      double radius = .05;

      StdDraw.setXscale(-1.0, +1.0);
      StdDraw.setYscale(-1.0, +1.0);
      StdDraw.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.GRAY);
         StdDraw.setPenColor(StdDraw.BLACK);
         StdDraw.filledCircle(rx, ry, radius);
         StdDraw.show(20);
      }
   }
}
```


Standard Audio

Crash Course in Sound

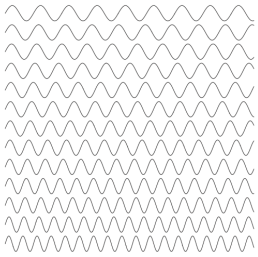
Sound. Perception of the vibration of molecules in our eardrums.

Concert A. Sine wave, scaled to oscillate at 440Hz.
Other notes. 12 notes on chromatic scale, divided logarithmically.



note	i	frequency
A	0	440.00
A♯ or B♭	1	466.16
B	2	493.88
C	3	523.25
C♯ or D♭	4	554.37
D	5	587.33
D♯ or E♭	6	622.25
E	7	659.26
F	8	698.46
F♯ or G♭	9	739.99
G	10	783.99
G♯ or A♭	11	830.61
A	12	880.00

$440 \times 2^{i/12}$



Notes, numbers, and waves

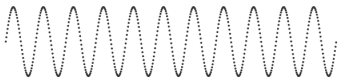
Digital Audio

Sampling. Represent curve by sampling it at regular intervals.

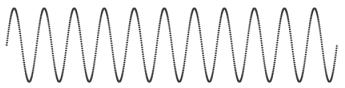
5,512 *samples/second, 137 samples*

11,025 *samples/second, 275 samples*

22,050 *samples/second, 551 samples*



audio CD → 44,100 *samples/second, 1,102 samples*



$$y(i) = \sin\left(\frac{2\pi \cdot i \cdot 440}{44{,}100}\right)$$

Standard Audio

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*
void double[] read(String file)	*read from a .wav file*

Warmup: Musical Tone

Musical tone. Create a music tone of a given frequency and duration.

```
public class Tone
{
   public static void main(String[] args)
   {
      int sps = 44100;
      double hz       = Double.parseDouble(args[0]);
      double duration = Double.parseDouble(args[1]);
      int N = (int) (sps * duration);
      double[] a = new double[N+1];
      for (int i = 0; i <= N; i++)
         a[i] = Math.sin(2 * Math.PI * i * hz / sps);
      StdAudio.play(a);
   }
}
```

$$y(i) = \sin\left(\frac{2\pi \cdot i \cdot hz}{44{,}100}\right)$$

```
% java Tone 440 1.5
[ concert A for 1.5 seconds]
```

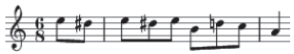
Play That Tune

Goal. Play pitches and durations from standard input on standard audio.

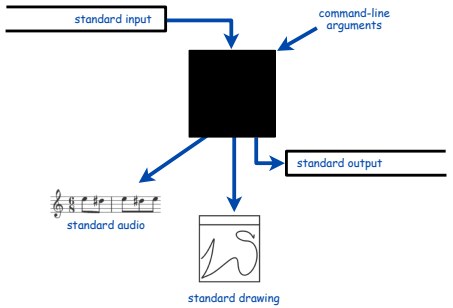
```
public class PlayThatTune
{
   public static void main(String[] args)
   {
      int sps = 44100;
      while (!StdIn.isEmpty())
      {
         int pitch = StdIn.readInt();
         double duration = StdIn.readDouble();
         double hz = 440 * Math.pow(2, pitch / 12.0);
         int N = (int) (sps * duration);
         double[] a = new double[N+1];
         for (int i = 0; i <= N; i++)
            a[i] = Math.sin(2 * Math.PI * i * hz / sps);
         StdAudio.play(a);
      }
   }
}
```

```
% more elise.txt
7 .125
6 .125
7 .125
6 .125
7 .125
2 .125
5 .125
3 .125
0 .25
```

```
% java PlayThatTune < elise.txt
```



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.