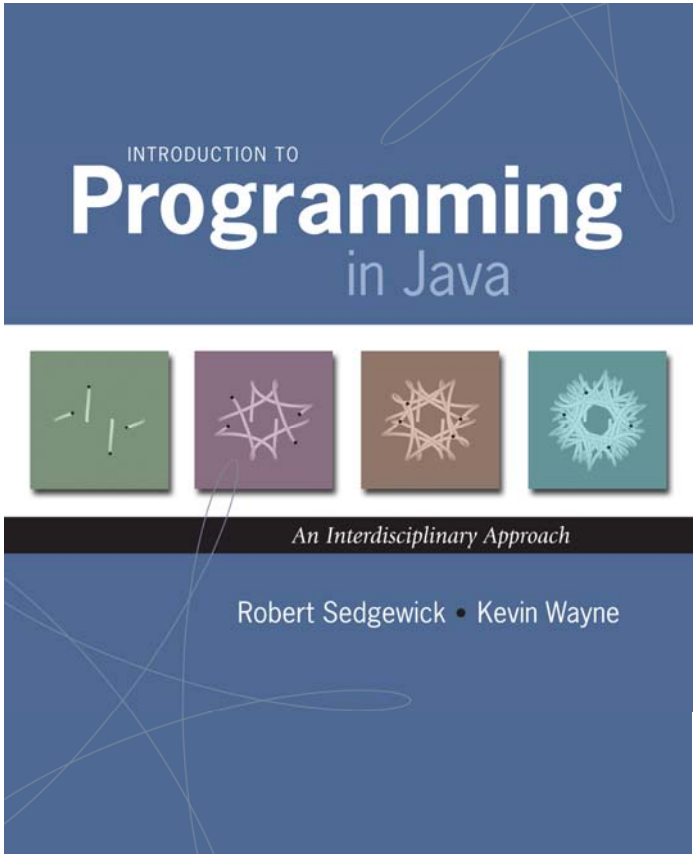
3.1 Using Data Types



Data Types

Data type. Set of values and operations on those values.

Primitive types. Ops directly translate to machine instructions.

Data Type	Set of Values	Operations
`boolean`	`true`, `false`	not, and, or, xor
`int`	-2^{31} to $2^{31} - 1$	add, subtract, multiply
`double`	any of 2^{64} possible reals	add, subtract, multiply

We want to write programs that process other types of data.

- Colors, pictures, strings, input streams, …
- Complex numbers, vectors, matrices, polynomials, …
- Points, polygons, charged particles, celestial bodies, …

Objects

Object. Holds a data type value; variable name refers to object.

Impact. Enables us to create our own data types; define operations on them; and integrate into our programs.

Data Type	Set of Values	Operations
`Color`	24 bits	get red component, brighten
`Picture`	2D array of colors	get/set color of pixel (i, j)
`String`	sequence of characters	length, substring, compare

Constructors and Methods

To construct a new object: Use keyword `new` and name of data type.

To apply an operation: Use name of object, the dot operator, and the name of the method.

declare a variable (object name)

call a constructor to create an object

```
String s;
s = new String("Hello, World");
System.out.println( s.substring(0, 5) );
```

object name

call a method that operates on the object's value

Image Processing

Color Data Type

Color. A sensation in the eye from electromagnetic radiation.

Set of values. [RGB representation] 256^3 possible values, which quantify the amount of red, green, and blue, each on a scale of 0 to 255.

R	G	B	Color
255	0	0	
0	255	0	
0	0	255	
255	255	255	
0	0	0	
255	0	255	
105	105	105	

Color Data Type

Color. A sensation in the eye from electromagnetic radiation.

Set of values. [RGB representation] 256^3 possible values, which quantify the amount of red, green, and blue, each on a scale of 0 to 255.

API. Application Programming Interface.

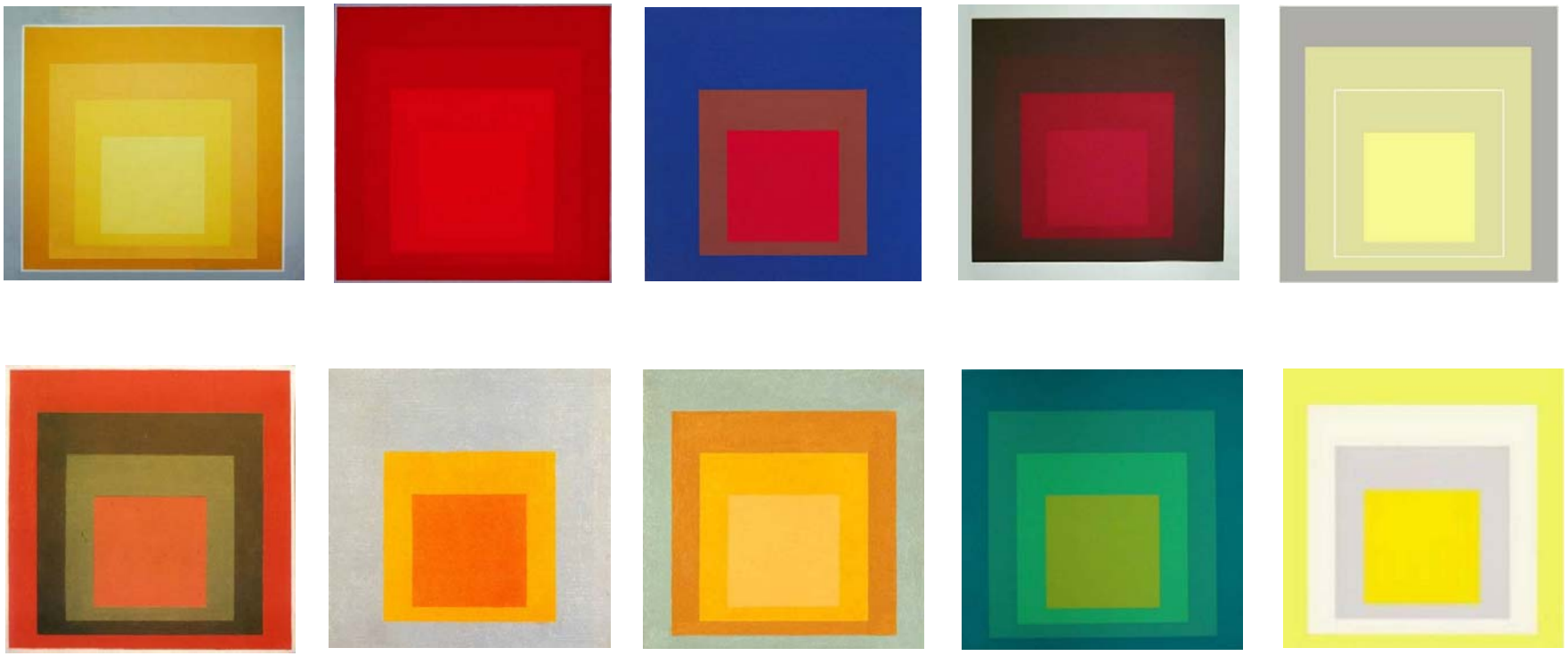
```
public class java.awt.Color
```

	Color(int r, int g, int b)	
int	getRed()	*red intensity*
int	getGreen()	*green intensity*
int	getBlue()	*blue intensity*
Color	brighter()	*brighter version of this color*
Color	darker()	*darker version of this color*
String	toString()	*string representation of this color*

http://java.sun.com/j2se/1.5.0/docs/api/java/awt/Color.html

Albers Squares

Josef Albers. Revolutionized the way people think about color.



Homage to the Square by Josef Albers (1949-1975)

Albers Squares

Josef Albers. Revolutionized the way people think about color.

```
% java AlbersSquares 9 90 166 100 100 100
```

Using Colors in Java

```
import java.awt.Color;

public class AlbersSquares {
   public static void main(String[] args) {
      int r1 = Integer.parseInt(args[0]);
      int g1 = Integer.parseInt(args[1]);
      int b1 = Integer.parseInt(args[2]);
      Color c1 = new Color(r1, g1, b1);

      int r2 = Integer.parseInt(args[3]);
      int g2 = Integer.parseInt(args[4]);
      int b2 = Integer.parseInt(args[5]);
      Color c2 = new Color(r2, g2, b2);

      StdDraw.setPenColor(c1);
      StdDraw.filledSquare(.25, .5, .2);
      StdDraw.setPenColor(c2);
      StdDraw.filledSquare(.25, .5, .1);

      StdDraw.setPenColor(c2);
      StdDraw.filledSquare(.75, .5, .2);
      StdDraw.setPenColor(c1);
      StdDraw.filledSquare(.75, .5, .1);
   }
}
```

to access **Color** library

first color

second color

first square

second square

Monochrome Luminance

Monochrome luminance. Effective brightness of a color.

NTSC formula. $Y = 0.299r + 0.587g + 0.114b$.

```
import java.awt.Color;

public class Luminance {

   public static double lum(Color c) {
      int r = c.getRed();
      int g = c.getGreen();
      int b = c.getBlue();
      return .299*r + .587*g + .114*b;
   }

}
```

Color Compatibility

Q. Which font colors will be most readable with which background colors on computer monitors and cell phone screens?

A. Rule of thumb: difference in luminance should be ≥ 128.

256	208	105	47	28	14

```
public static boolean compatible(Color a, Color b) {
   return Math.abs(lum(a) - lum(b)) >= 128.0;
}
```

Grayscale

Grayscale. When all three R, G, and B values are the same, resulting color is on grayscale from 0 (black) to 255 (white).

Convert to grayscale. Use luminance to determine value.

```
public static Color toGray(Color c) {
   int y = (int) Math.round(lum(c));
   Color gray = new Color(y, y, y);
   return gray;
}
```

round **double** to nearest **int**

red	green	blue	
9	90	166	*this color*
74	74	74	*grayscale version*
0	0	0	*black*

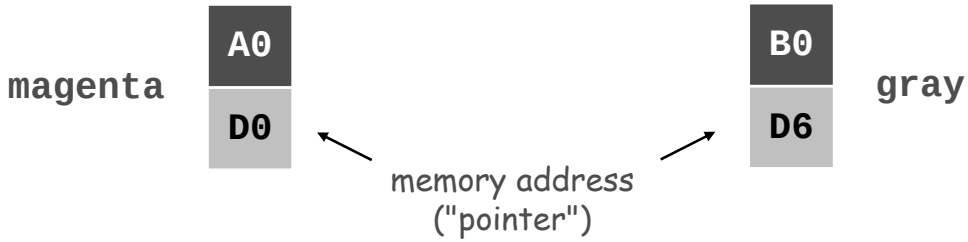
$0.299 * 9 + 0.587 * 90 + 0.114 * 166 = 74.445$

Bottom line. We are writing programs that manipulate color.

OOP Context for Color

Possible memory representation.

D0	D1	D2	D3	D4	D5	D6	D7	D8
255	0	255	0	0	0	105	105	105



Object reference is analogous to variable name.

- We can manipulate the value that it holds.
- We can pass it to (or return it from) a method.

References

René Magritte. "This is not a pipe."

Java. This is not a color.

```
Color sienna = new Color(160, 82,  45);
Color c = sienna.darker();
```

OOP. Natural vehicle for studying abstract models of the real world.

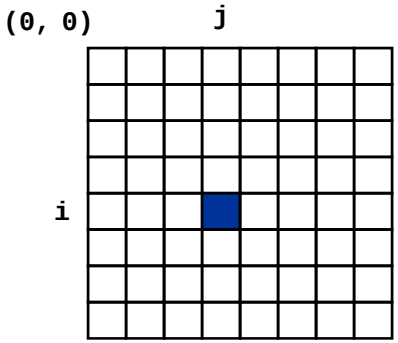
This is Not a Pipe

Dan Piraro, `http://www.uexpress.com`

Neither is this.

```
% java RandomSeq 10000 | java Average
```

Picture Data Type



Raster graphics. Basis for image processing.

Set of values. 2D array of `Color` objects (pixels).

API.

```
public class Picture
```

	`Picture(String filename)`	*create a picture from a file*
	`Picture(int w, int h)`	*create a blank* w*-by-*h *picture*
`int`	`width()`	*return the width of the picture*
`int`	`height()`	*return the height of the picture*
`Color`	`get(int i, int j)`	*return the color of pixel (i, j)*
`void`	`set(int i, int j, Color c)`	*set the color of pixel (i, j) to* c
`void`	`show()`	*display the image in a window*
`void`	`save(String filename)`	*save the image to a file*

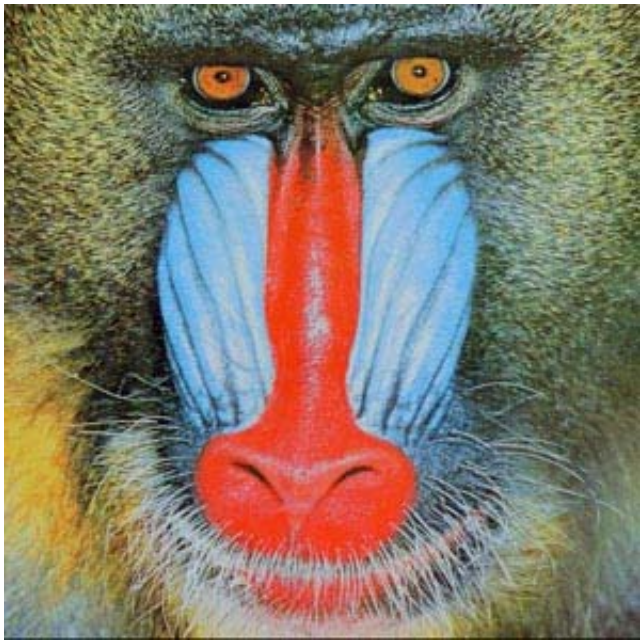
Image Processing: Grayscale Filter

Goal. Convert color image to grayscale according to luminance formula.

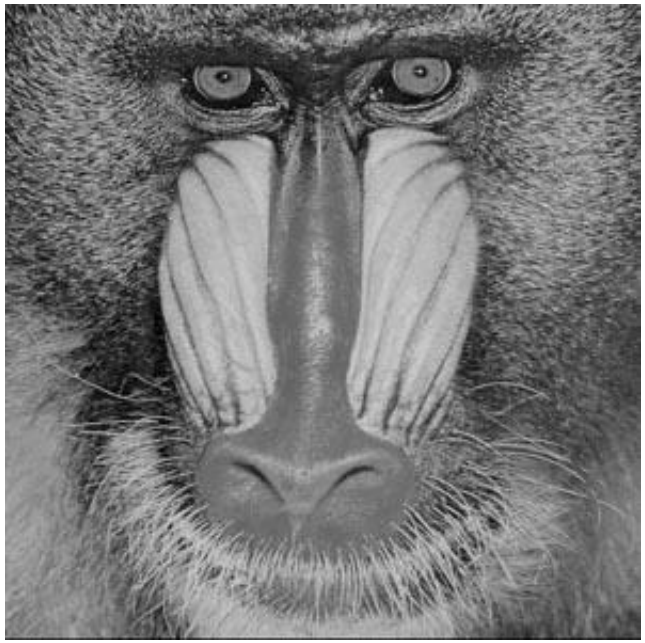
```
import java.awt.Color;

public class Grayscale {
   public static void main(String[] args) {
      Picture pic = new Picture(args[0]);
      for (int i = 0; i < pic.width(); i++) {
         for (int j = 0; j < pic.height(); j++) {
            Color color = pic.get(i, j);
            Color gray  = Luminance.toGray(color);
            pic.set(i, j, gray);
         }
      }
      pic.show();
   }
}
```

Image Processing: Grayscale Filter

Goal. Convert color image to grayscale according to luminance formula.



mandrill.jpg

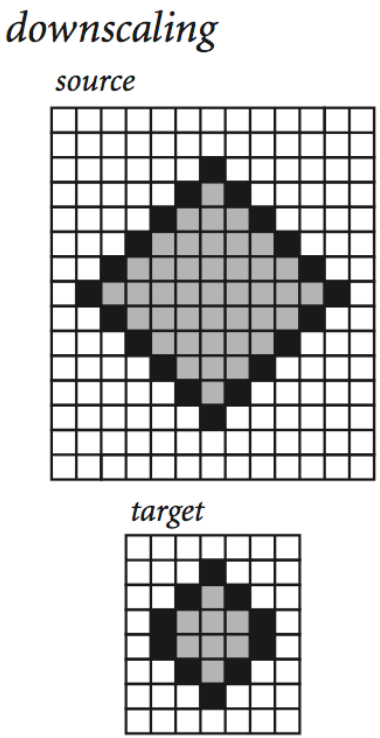


% java Grayscale mandrill.jpg

Image Processing: Scaling Filter

Goal. Shrink or enlarge an image to desired size.

Downscaling. To shrink, delete half the rows and columns.
Upscaling. To enlarge, replace each pixel by 4 copies.



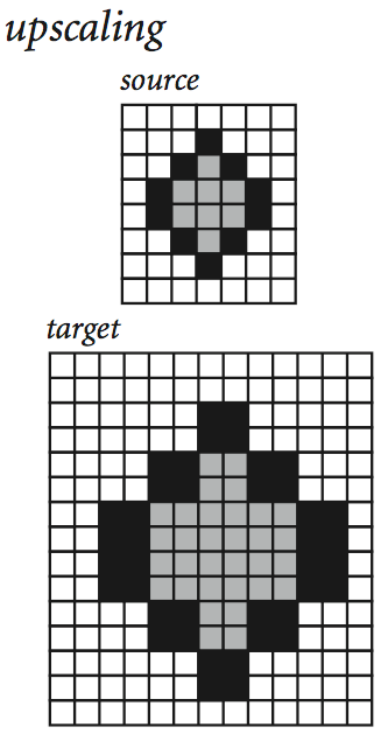


Image Processing: Scaling Filter

Goal. Shrink or enlarge an image to desired size.

Uniform strategy. To convert from w_s-by-h_s to w_t-by-h_t:

- Scale row index by w_s / w_t.
- Scale column index by h_s / h_t.
- Set color of pixel (i, j) in target image to color of pixel $(i \times w_s / w_t,\ j \times h_s / h_t)$ in source image.

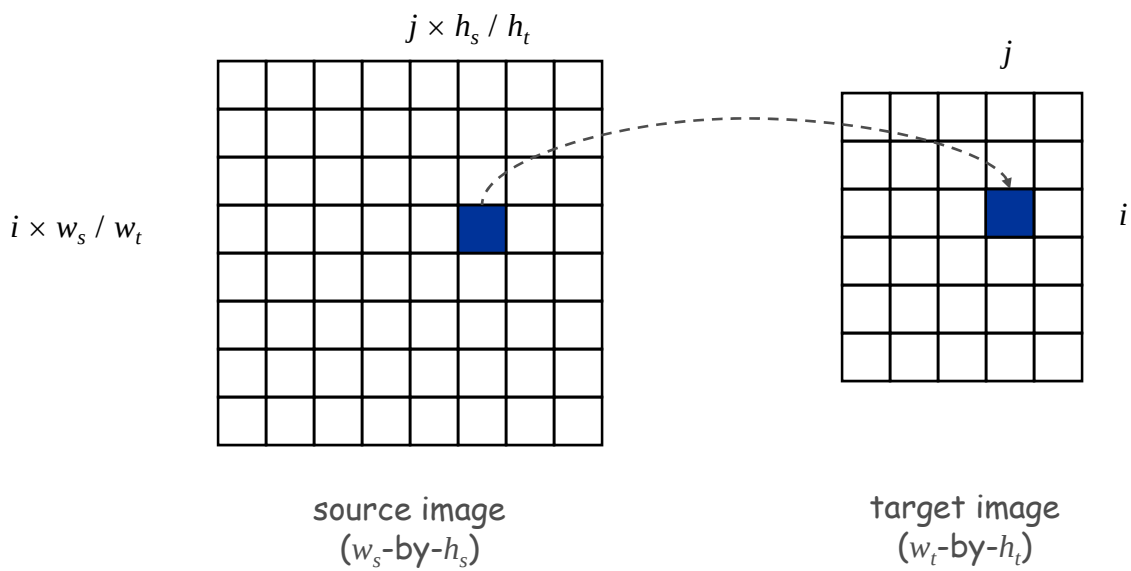
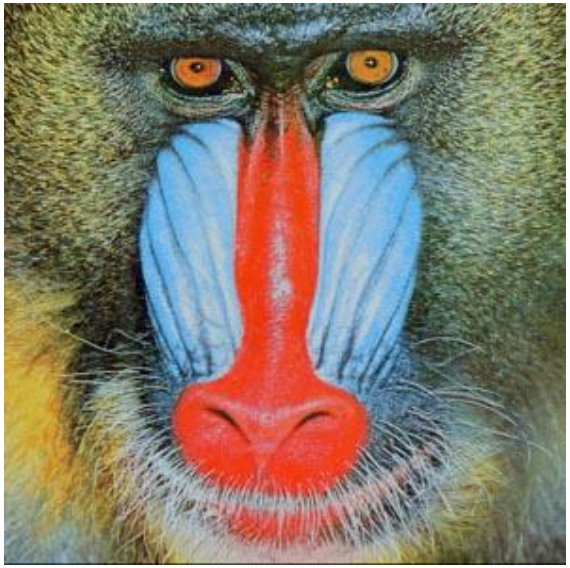


Image Processing: Scaling Filter

```
import java.awt.Color;

public class Scale {
   public static void main(String args[]) {
      String filename = args[0];
      int w = Integer.parseInt(args[1]);
      int h = Integer.parseInt(args[2]);
      Picture source = new Picture(filename);
      Picture target = new Picture(w, h);
      for (int ti = 0; ti < w; ti++) {
         for (int tj = 0; tj < h; tj++) {
            int si = ti * source.width()  / w;
            int sj = tj * source.height() / h;
            Color color = source.get(si, sj);
            target.set(ti, tj, color);
         }
      }
      source.show();
      target.show();
   }
}
```

Image Processing: Scaling Filter

Scaling filter. Creates two `Picture` objects and two windows.

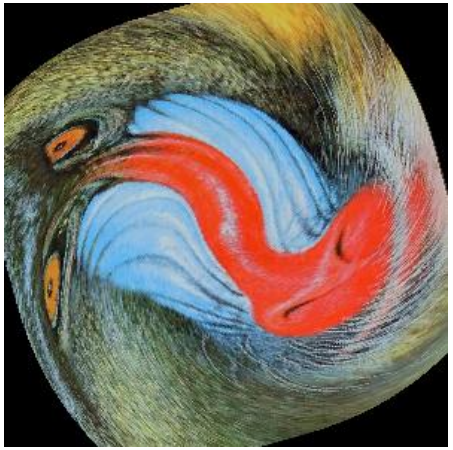


mandrill.jpg

% java Scale 400 200 mandrill.jpg

More Image Processing Effects

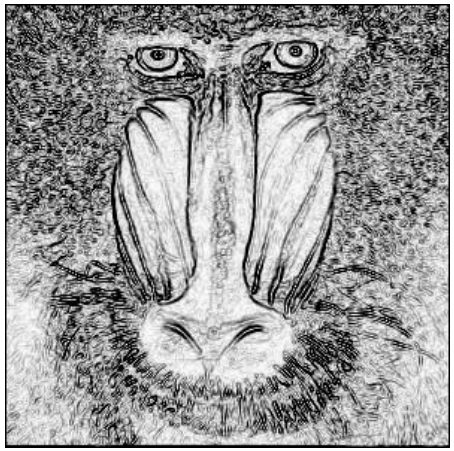
RGB color separation



swirl filter

wave filter

glass filter



Sobel edge detection

Text Processing

String Data Type

String data type. Basis for text processing.
Set of values. Sequence of Unicode characters.

API.

public class String (Java string data type)

	String(String s)	*create a string with the same value as* s
int	length()	*string length*
char	charAt(int i)	*i th character*
String	substring(int i, int j)	*i th through (j-1)st characters*
boolean	contains(String sub)	*does string contain* sub *as a substring?*
boolean	startsWith(String pre)	*does string start with* pre*?*
boolean	endsWith(String post)	*does string end with* post*?*
int	indexOf(String p)	*index of first occurrence of* p
int	indexOf(String p, int i)	*index of first occurrence of* p *after* i
String	concat(String t)	*this string with* t *appended*
int	compareTo(String t)	*string comparison*
String	replaceAll(String a, String b)	*result of changing* a*s to* b*s*
String[]	split(String delim)	*strings between occurrences of* delim
boolean	equals(String t)	*is this string's value the same as* t*'s?*
	…	

http://java.sun.com/j2se/1.5.0/docs/api/java/lang/String.html

Typical String Processing Code

is the string a palindrome?	`public static boolean isPalindrome(String s)`
	`{`
	`  int N = s.length();`
	`  for (int i = 0; i < N/2; i++)`
	`  if (s.charAt(i) != s.charAt(N-1-i))`
	`  return false;`
	`  return true;`
	`}`

extract file name and extension from a command-line argument	`String s = args[0];`
	`int dot = s.indexOf(".");`
	`String base  = s.substring(0, dot);`
	`String extension = s.substring(dot + 1, s.length());`

print all lines in standard input that contain a string specified on the command line	`String query = args[0];`
	`while (!StdIn.isEmpty())`
	`{`
	`  String s = StdIn.readLine();`
	`  if (s.contains(query)) StdOut.println(s);`
	`}`

print all the hyperlinks (to educational institutions) in the text file on standard input	`while (!StdIn.isEmpty())`
	`{`
	`  String s = StdIn.readString();`
	`  if (s.startsWith("http://") && s.endsWith(".edu"))`
	`  StdOut.println(s);`
	`}`

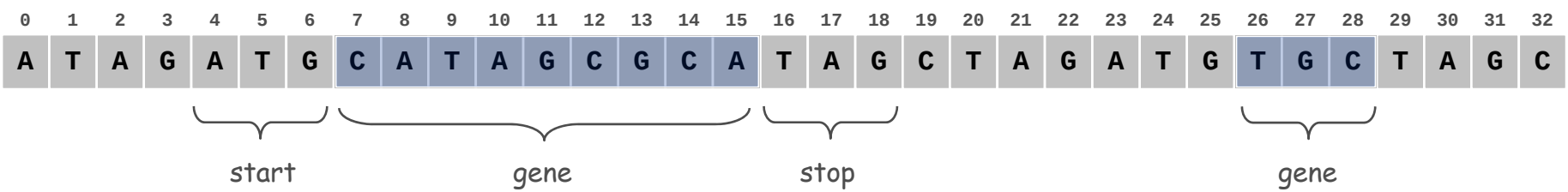
Gene Finding

Pre-genomics era. Sequence a human genome.
Post-genomics era. Analyze the data and understand structure.

Genomics. Represent genome as a string over { A, C, T, G } alphabet.

Gene. A substring of genome that represents a functional unit.

- Preceded by ATG. [start codon]
- Multiple of 3 nucleotides. [codons other than start/stop]
- Succeeded by TAG, TAA, or TGA. [stop codons]



Gene Finding: Algorithm

Algorithm. Scan left-to-right through genome.

- If start codon, then set `beg` to index `i`.
- If stop codon and substring is a multiple of 3
  - output gene
  - reset `beg` to -1

	i	codon	beg	*output*	*remaining portion of input string*
	0		-1		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
	1	TAG	-1		TAGATGCATAGCGCATAGCTAGATGTGCTAGC
	4	ATG	4		ATGCATAGCGCATAGCTAGATGTGCTAGC
start	9	TAG	4	multiple of 3	TAGCGCATAGCTAGATGTGCTAGC
	16	TAG	4	CATAGCGCA	TAGCTAGATGTGCTAGC
stop	20	TAG	-1		TAGATGTGCTAGC
	23	ATG	23		ATGTGCTAGC
	29	TAG	23	TGC	TAGC

Gene Finding: Implementation

```java
public class GeneFind {
   public static void main(String[] args) {
      String start  = args[0];
      String stop   = args[1];
      String genome = StdIn.readAll();

      int beg = -1;
      for (int i = 0; i < genome.length() - 2; i++) {
         String codon = genome.substring(i, i+3);
         if (codon.equals(start)) beg = i;
         if (codon.equals(stop) && beg != -1) {
            String gene = genome.substring(beg+3, i);
            if (gene.length() % 3 == 0) {
               StdOut.println(gene);
               beg = -1;
            }
         }
      }
   }
}
```

```
% more genomeTiny.txt
ATAGATGCATAGCGCATAGCTAGATGTGCTAGC

% java GeneFind ATG TAG < genomeTiny.txt
CATAGCGCA
TGC
```

OOP Context for Strings

Possible memory representation of a string.

- `genome = "aacaagtttacaagc";`

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	DA	DB	DC	DD	DE
a	a	c	a	a	g	t	t	t	a	c	a	a	g	c

genome

A0	A1
D0	15

memory address

length

OOP Context for Strings

Possible memory representation of a string.

- `genome = "aacaagtttacaagc";`

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	DA	DB	DC	DD	DE
a	a	c	a	a	g	t	t	t	a	c	a	a	g	c

genome

A0	A1
D0	15

memory address

length

s

B0	B1
D1	4

t

B2	B3
D9	4

- `s = genome.substring(1, 5);`
- `t = genome.substring(9, 13);`

s and t are different strings that share the same value **"acaa"**

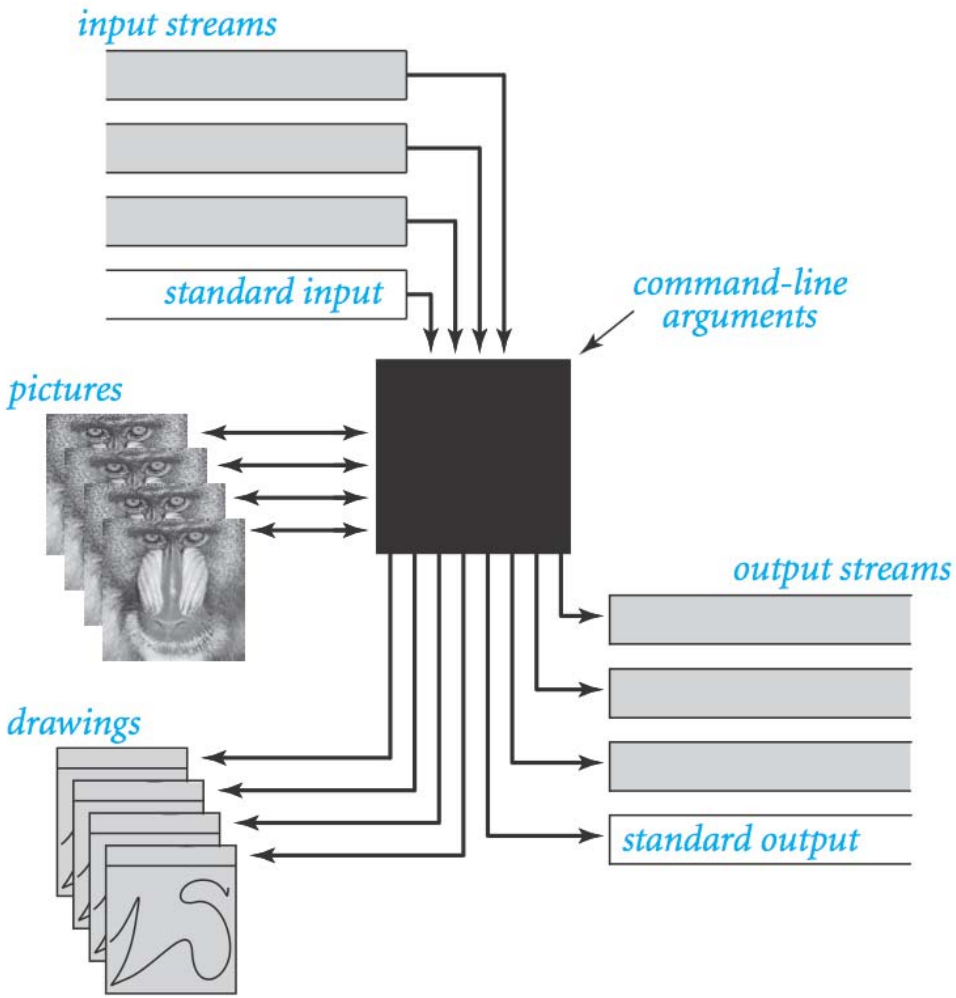
- `(s == t)` is **false**, but `(s.equals(t))` is **true**.

compares pointers

compares character sequences

In and Out

Bird's Eye View (Revisited)



Non-Standard Input

or use OS to redirect from one file

Standard input. Read from terminal window.

Goal. Read from several different input streams.

`In` data type. Read text from stdin, a file, a web site, or network.

Ex: Are two text files identical?

```
public class Diff {
   public static void main(String[] args) {
      In in0 = new In(args[0]);
      In in1 = new In(args[1]);
      String s = in0.readAll();
      String t = in1.readAll();
      StdOut.println(s.equals(t));
   }
}
```

Screen Scraping

Goal. Find current stock price of Google.

```
…
<tr>
<td class="yfnc_tablehead1" width="48%">
Last Trade:
</td>
<td class="yfnc_tabledata1">
<big>
<b>459.52</b>
</big>
</td>
</tr>
<tr>
<td class="yfnc_tablehead1" width="48%">
Trade Time:
</td>
<td class="yfnc_tabledata1">
11:45AM ET
</td>
</tr>
…
```

http://finance.yahoo.com/q?s=goog

NYSE symbol

Screen Scraping

Goal. Find current stock price of Google.

- `s.indexOf(t, i)`: index of first occurrence of pattern `t` in string `s`, starting at offset `i`.
- Read raw html from `http://finance.yahoo.com/q?s=goog`.
- Find first string delimited by `<b>` and `</b>` after `Last Trade`.

```
public class StockQuote {
   public static void main(String[] args) {
      String name = "http://finance.yahoo.com/q?s=";
      In in = new In(name + args[0]);
      String input = in.readAll();
      int start    = input.indexOf("Last Trade:", 0);
      int from     = input.indexOf("<b>",  start);
      int to       = input.indexOf("</b>", from);
      String price = input.substring(from + 3, to);
      StdOut.println(price);
   }
}
```

```
% java StockQuote goog
459.52
```

Day Trader

Add bells and whistles.

- Plot price in real-time.
- Notify user if price dips below a certain price.
- Embed logic to determine when to buy and sell.
- Automatically send buy and sell orders to trading firm.

Warning. Use at your own financial risk.

OOP Summary

Object. Holds a data type value; variable name refers to object.

In Java, programs manipulate references to objects.

- Exception: primitive types, e.g., `boolean`, `int`, `double`.
- Reference types: `String`, `Picture`, `Color`, arrays, everything else.
- OOP purist: language should not have separate primitive types.

Bottom line. We wrote programs that manipulate colors, pictures, and strings.

Next time. We'll write programs that manipulate our own abstractions.

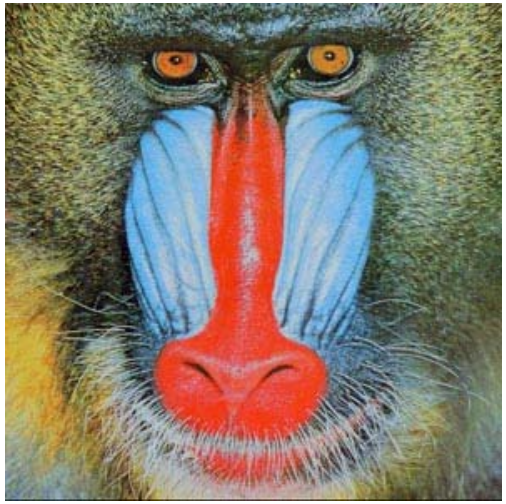
Extra Slides

Color Separation

```
import java.awt.Color;
public class ColorSeparation {
    public static void main(String args[]) {
        Picture pic = new Picture(args[0]);
        int width  = pic.width();
        int height = pic.height();

        Picture R = new Picture(width, height);
        Picture G = new Picture(width, height);
        Picture B = new Picture(width, height);

        for (int i = 0; i < width; i++) {
            for (int j = 0; j < height; j++) {
                Color c = pic.get(i, j);
                int r = c.getRed();
                int g = c.getGreen();
                int b = c.getBlue();
                R.set(i, j, new Color(r, 0, 0));
                G.set(i, j, new Color(0, g, 0));
                B.set(i, j, new Color(0, 0, b));
            }
        }
        R.show();
        G.show();
        B.show();
    }
}
```

Color Separation

ColorSeparation.java. Creates three `Picture` objects and windows.



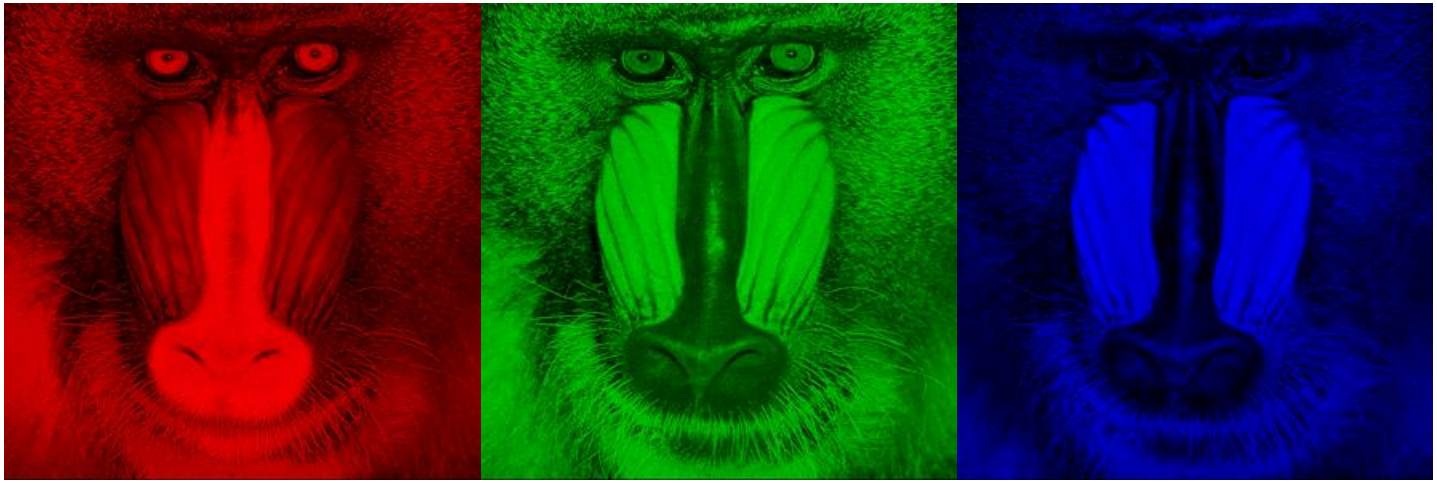
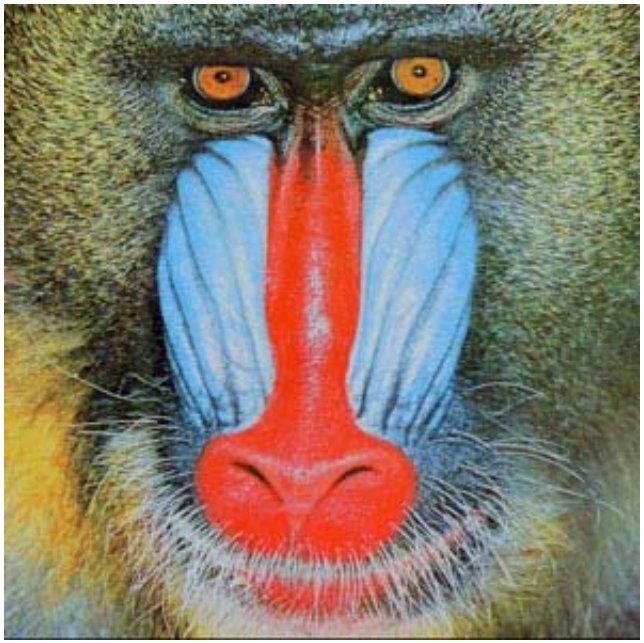


Image Processing: Swirl Filter

Swirl.java. Creates two `Picture` objects and windows.



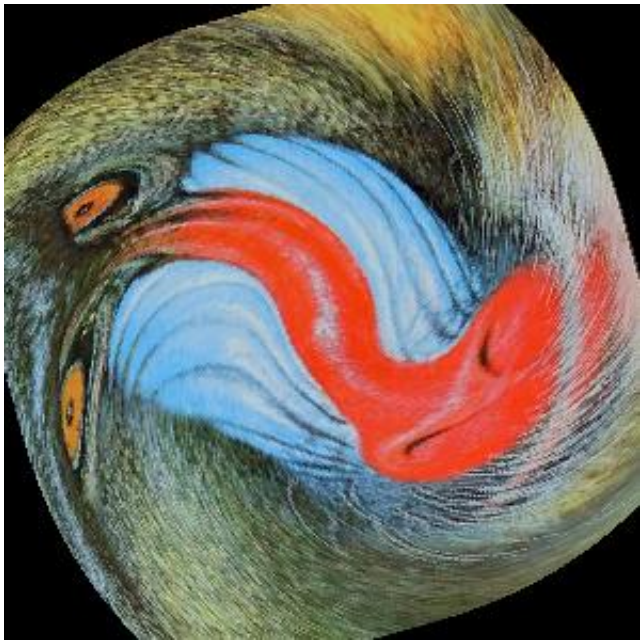


Image Processing: Swirl Filter

Goal. Create swirl special effect by setting color of output pixel (i, j) to color of some other input pixel (ii, jj).

```
double i0 = 0.5 * width;
double j0 = 0.5 * height;

for (int i = 0; i < width; i++) {
   for (int j = 0; j < height; j++) {
      double di = i - i0;
      double dj = j - j0;
      double r = Math.sqrt(di*di +dj*dj);
      double a = Math.PI / 256 * r;
      int ii = (int)(-di*Math.cos(a) + dj*Math.sin(a) + i0);
      int jj = (int)( di*Math.sin(a) + dj*Math.cos(a) + j0);
      if (ii >= 0 && ii < width && jj >= 0 && jj < height)
         pic2.set(i, j, pic1.get(ii, jj));
   }
}
```

Memory Management

Value types.

- Allocate memory when variable is declared.
- Can reclaim memory when *variable* goes out of scope.

Reference types.

- Allocate memory when object is created with `new`.
- Can reclaim memory when *last reference* goes out of scope.
- Significantly more challenging if several references to same object.

Garbage collector. System automatically reclaims memory; programmer relieved of tedious and error-prone activity.