

# 3.1 Data Types

any program you might want to write

objects

create your own  
data types

functions and modules

graphics, sound, and image I/O

arrays

conditionals and loops

Math

text I/O

primitive data types

assignment statements

# Abstract Data Types

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

**Abstract data type.** Data type whose representation is hidden from the user.

**Primitive types.**

- values directly map to machine representations
- operations 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.

**Object-oriented programming.**

- Create your own data types (sets of values and ops on them)
- Use them in your programs (manipulate objects that hold values).

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

**Abstract data type (ADT).** Object representation is hidden.

**Impact.** We can use ADTs without knowing implementation details.

- this lecture: how to write client programs for several useful ADTs
- next lecture: how to implement your own ADTs

# Constructors and Methods

To use a data type, you need to know how to:

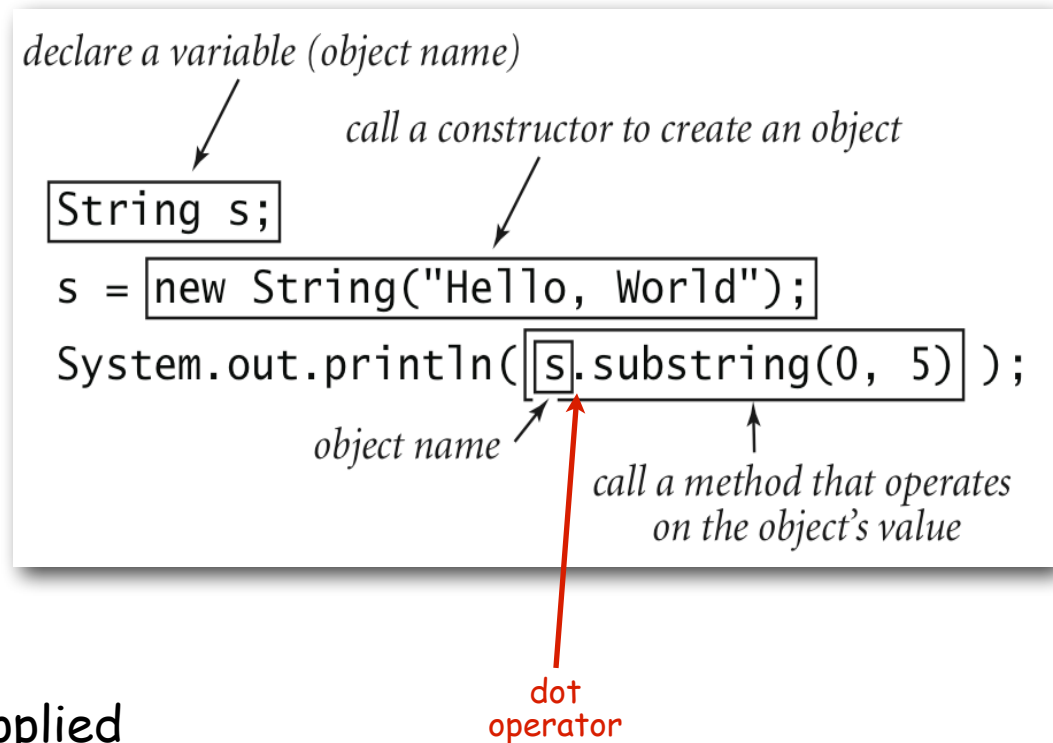
- Construct new objects.
- Apply operations to a given object.

To construct a new object:

- Use keyword `new` to invoke a "constructor."
- Use name of data type to specify which type of object.

To apply an operation:

- Use name of object to specify which object
- Use the **dot operator** to indicate an operation is to be applied
- Use a **method name** to specify which operation



# Image Processing

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# 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) specifies **set of operations**.

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

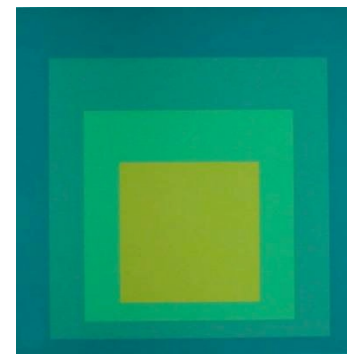
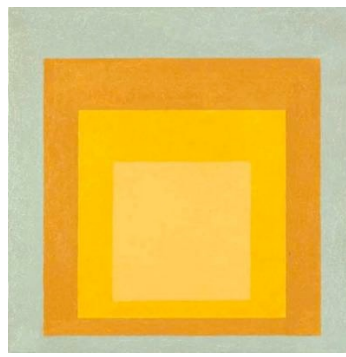
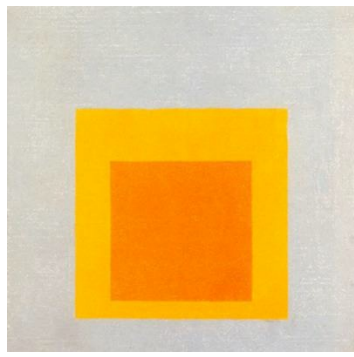
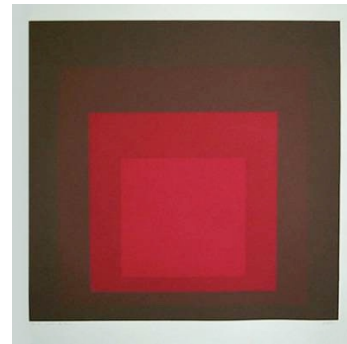
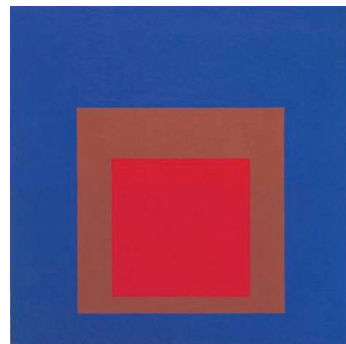
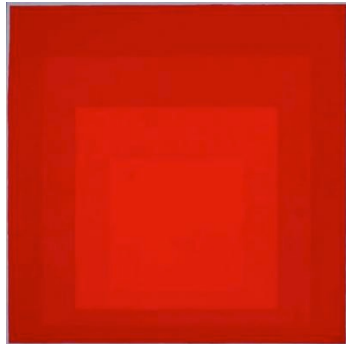
---

```
    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
    boolean equals(Color c) is this color's value the same as c's?
```

<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
```

blue  
↓

gray  
↓



# Example Client Program for Color ADT

```
import java.awt.Color;
```

to access Color library

```
public class AlbersSquares
```

```
{
```

```
    public static void main(String[] args)
```

```
    {
```

```
        int r1 = Integer.parseInt(args[0]); first color
```

```
        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]); second color
```

```
        int g2 = Integer.parseInt(args[4]);
```

```
        int b2 = Integer.parseInt(args[5]);
```

```
        Color c2 = new Color(r2, g2, b2);
```

```
        StdDraw.setPenColor(c1); first square
```

```
        StdDraw.filledSquare(.25, .5, .2);
```

```
        StdDraw.setPenColor(c2);
```

```
        StdDraw.filledSquare(.25, .5, .1);
```

```
        StdDraw.setPenColor(c2); second square
```

```
        StdDraw.filledSquare(.75, .5, .2);
```

```
        StdDraw.setPenColor(c1);
```

```
        StdDraw.filledSquare(.75, .5, .1);
```

```
    }
```

```
}
```

# 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  $> 128$ .



```
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

<i>red</i>	<i>green</i>	<i>blue</i>		
9	90	166	<i>this color</i>	
74	74	74	<i>grayscale version</i>	
0	0	0	<i>black</i>	

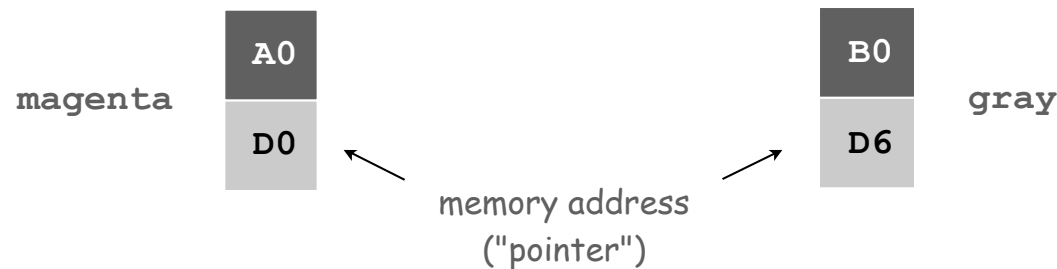
$$0.299 * 9 + 0.587 * 90 + 0.114 * 166 = 74.445$$

**Bottom line.** We are writing programs that manipulate **color**.

# OOP Context for Color

Possible memory representation (in TOY).

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.

# 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)
```

```
    Picture(int w, int h)
```

```
    int width()
```

```
    int height()
```

```
    Color get(int x, int y)
```

```
    void set(int x, int y, Color c)
```

```
    void show()
```

```
    void save(String filename)
```

*create a picture from a file*

*create a blank w-by-h picture*

*return the width of the picture*

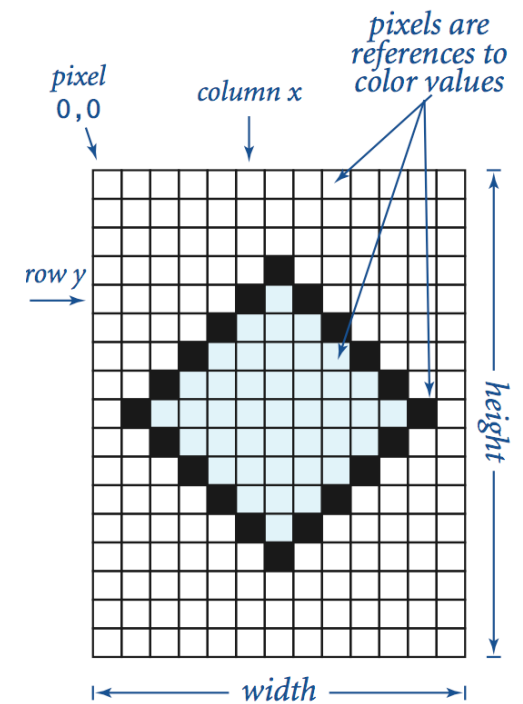
*return the height of the picture*

*return the color of pixel (x, y)*

*set the color of pixel (x, y) to c*

*display the image in a window*

*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 x = 0; x < pic.width(); x++)
            for (int y = 0; y < pic.height(); y++)
            {
                Color color = pic.get(x, y);
                Color gray = Luminance.toGray(color);
                pic.set(x, y, gray);
            }

        pic.show();
    }
}
```

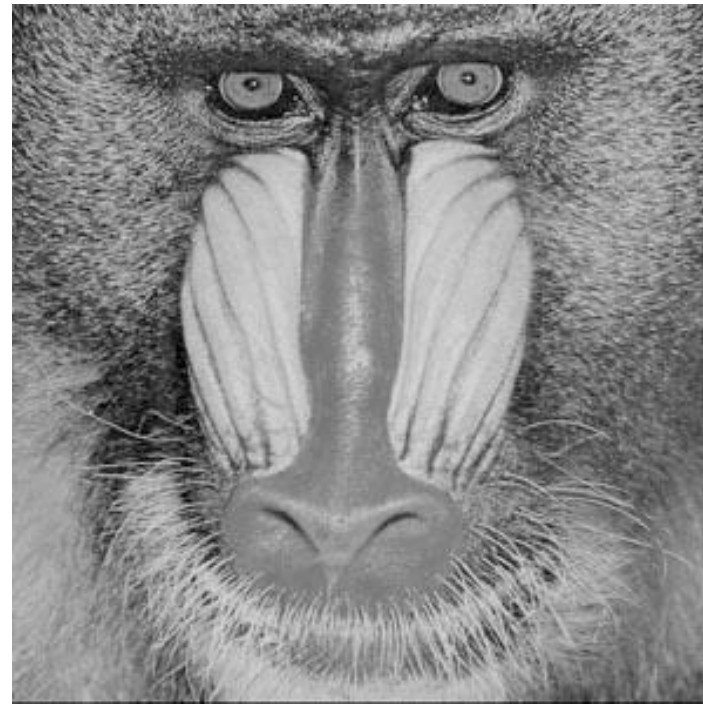
← set each  
pixel to  
gray

# Image Processing: Grayscale Filter

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



`mandrill.jpg`



`% java Grayscale mandrill.jpg`

# Image Processing Challenge 1

What does the following code do? (Easy question!)

```
Picture pic = new Picture(args[0]);  
for (int x = 0; x < pic.width(); x++)  
    for (int y = 0; y < pic.height(); y++)  
        pic.set(x, y, pic.get(x, y));  
pic.show();
```

## Image Processing Challenge 2

What does the following code do? (Hard question.)

```
Picture pic = new Picture(args[0]);  
for (int x = 0; x < pic.width(); x++)  
    for (int y = 0; y < pic.height(); y++)  
        pic.set(x, pic.height() - y - 1, pic.get(x, y));  
pic.show();
```

## Image Processing Challenge 3

What does the following code do? (Hard question.)

```
Picture source = new Picture(args[0]);
int width  = source.width();
int height = source.height();
Picture target = new Picture(width, height);
for (int x = 0; x < width; x++)
    for (int y = 0; y < height; y++)
        target.set(x, height - y - 1, source.get(x, y));
target.show();
```

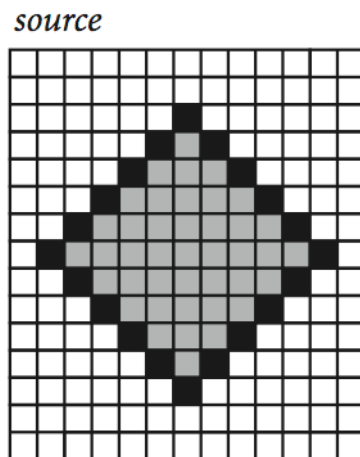
# Image Processing: Scaling Filter

**Goal.** Shrink or enlarge an image to desired size.

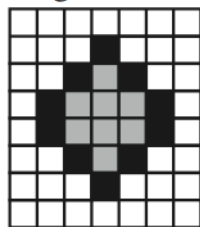
**Downscaling.** To shrink in half, delete half the rows and columns.

**Upscaling.** To enlarge to double, replace each pixel by 4 copies.

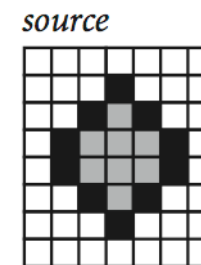
*downscaling*



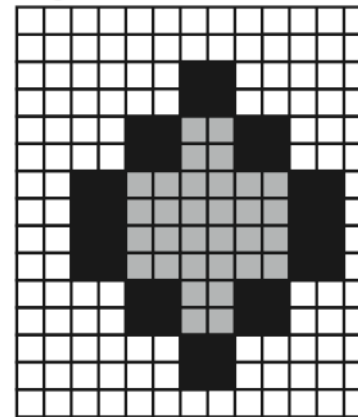
*target*



*upsampling*



*target*

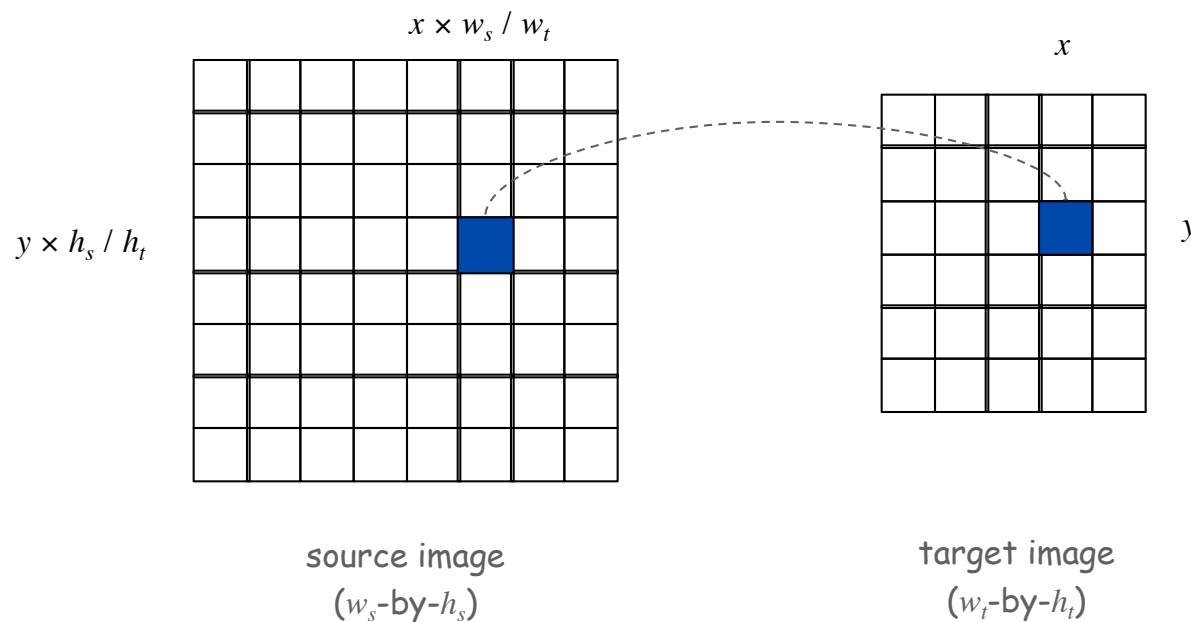


# Image Processing: Scaling Filter

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



# Image Processing: Scaling Filter

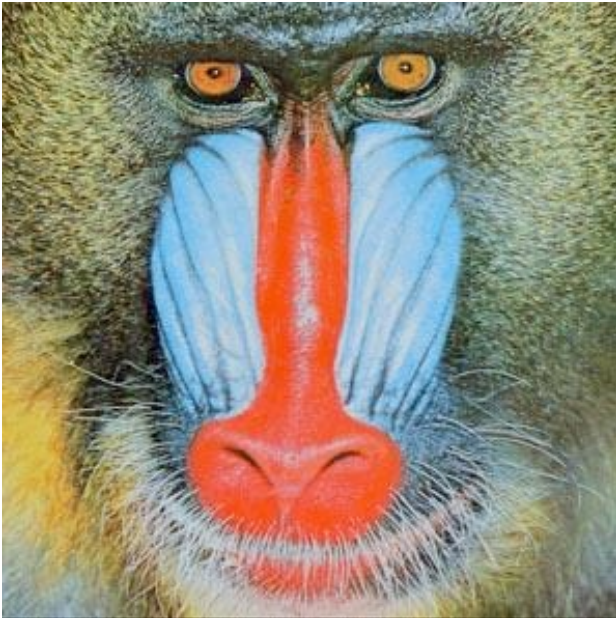
```
import java.awt.Color;

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 tx = 0; tx < w; tx++)
            for (int ty = 0; ty < h; ty++)
            {
                int sx = tx * source.width() / w;
                int sy = ty * source.height() / h;
                Color color = source.get(sx, sy);
                target.set(tx, ty, color);
            }
        source.show();
        target.show();
    }
}
```

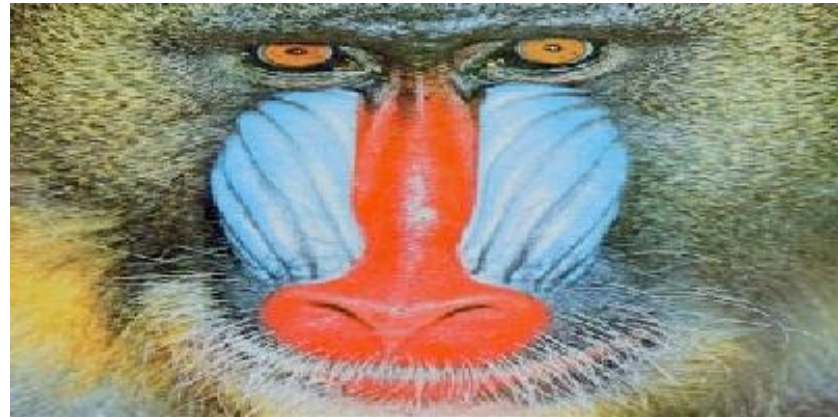


## Image Processing: Scaling Filter

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



`mandrill.jpg`

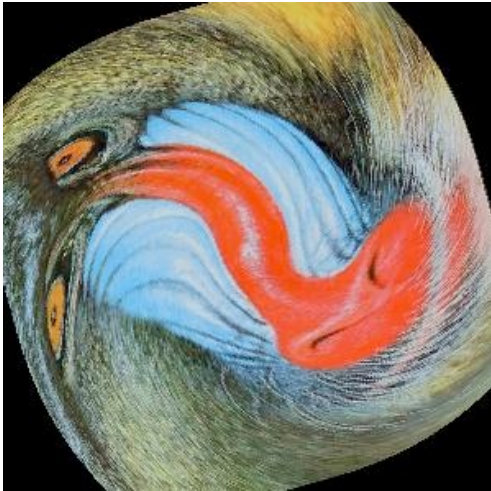


```
% java Scale mandrill.jpg 400 200
```

# More Image Processing Effects



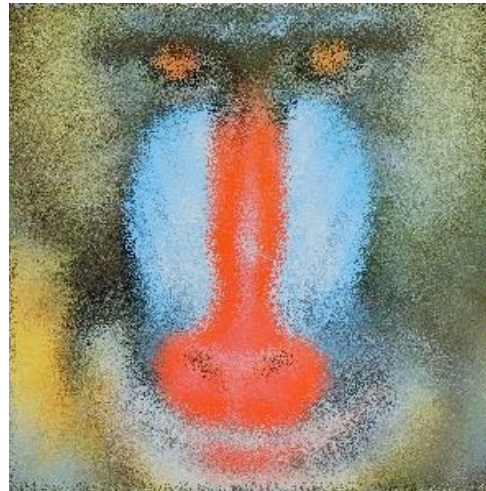
RGB color separation



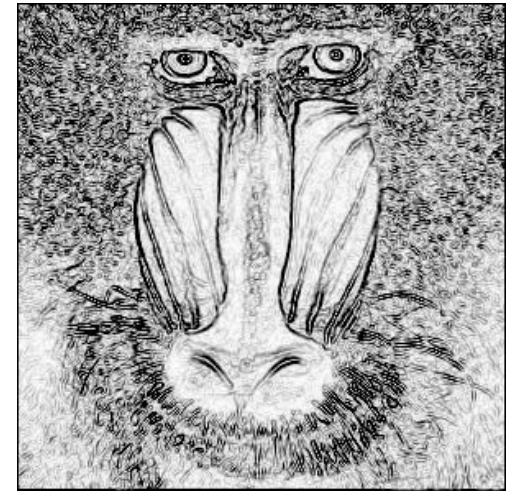
swirl filter



wave filter



glass filter



Sobel edge detection

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

# Typical String Processing Code

<i>is the string a palindrome?</i>	<pre>public static boolean isPalindrome(String s) {     int N = s.length();     for (int i = 0; i &lt; N/2; i++)         if (s.charAt(i) != s.charAt(N-1-i))             return false;     return true; }</pre>
<i>extract file name and extension from a command-line argument</i>	<pre>String s = args[0]; int dot = s.indexOf("."); String base = s.substring(0, dot); String extension = s.substring(dot + 1, s.length());</pre>
<i>print all lines in standard input that contain a string specified on the command line</i>	<pre>String query = args[0]; while (!StdIn.isEmpty()) {     String s = StdIn.readLine();     if (s.contains(query)) StdOut.println(s); }</pre>
<i>print all the hyperlinks (to educational institutions) in the text file on standard input</i>	<pre>while (!StdIn.isEmpty()) {     String s = StdIn.readString();     if (s.startsWith("http://") &amp;&amp; s.endsWith(".edu"))         StdOut.println(s); }</pre>

# Gene Finding

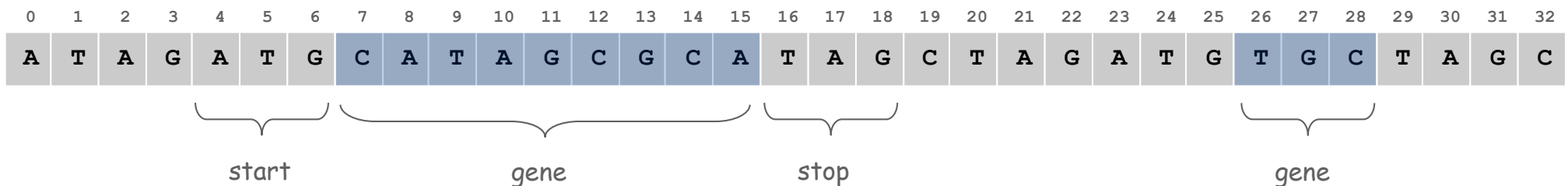
**Pre-genomics era.** Sequence a human genome.

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

i	codon		beg	gene	remaining portion of input string
	start	stop			
0			-1		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
1		TAG	-1		A <b>TAG</b> ATGCATAGCGCATAGCTAGATGTGCTAGC
4	ATG		4		ATAG <b>ATG</b> CATAGCGCATAGCTAGATGTGCTAGC
9		TAG	4	multiple of 3	ATAG <b>ATG</b> C <b>ATAG</b> CGCATAGCTAGATGTGCTAGC
16		TAG	4	CATAGCGCA	ATAG <b>ATG</b> <b>CATAGCGCA</b> <b>TAG</b> CTAGATGTGCTAGC
20		TAG	-1		ATAGATGCATAGCGCATAGC <b>TAG</b> ATGTGCTAGC
23	ATG		23		ATAGATGCATAGCGCATAGCTAG <b>ATG</b> TGCTAGC
29		TAG	23	TGC	ATAGATGCATAGCGCATAGCTAG <b>ATG</b> <b>TGC</b> <b>TAG</b> C

# Gene Finding: Implementation

```
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 && beg+3 < i)
            {
                String gene = genome.substring(beg+3, i);
                if (gene.length() % 3 == 0)
                {
                    StdOut.println(gene);
                    beg = -1;
                }
            }
        }
    }
}
```

Fixes bug in Prog. 3.1.8

Q1: What's the bug?

Q2: What input makes Prog 3.1.8 crash?

```
% more genomeTiny.txt
ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
```

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



# OOP Context for Strings

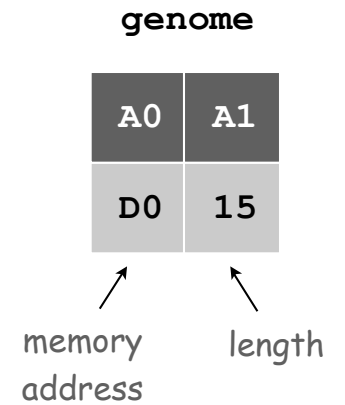
Possible memory representation of a string (using TOY addresses).

- `genome = "aacaagttacaagc";`

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

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

s		t	
B0	B1	B2	B3
D1	4	D9	4



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

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

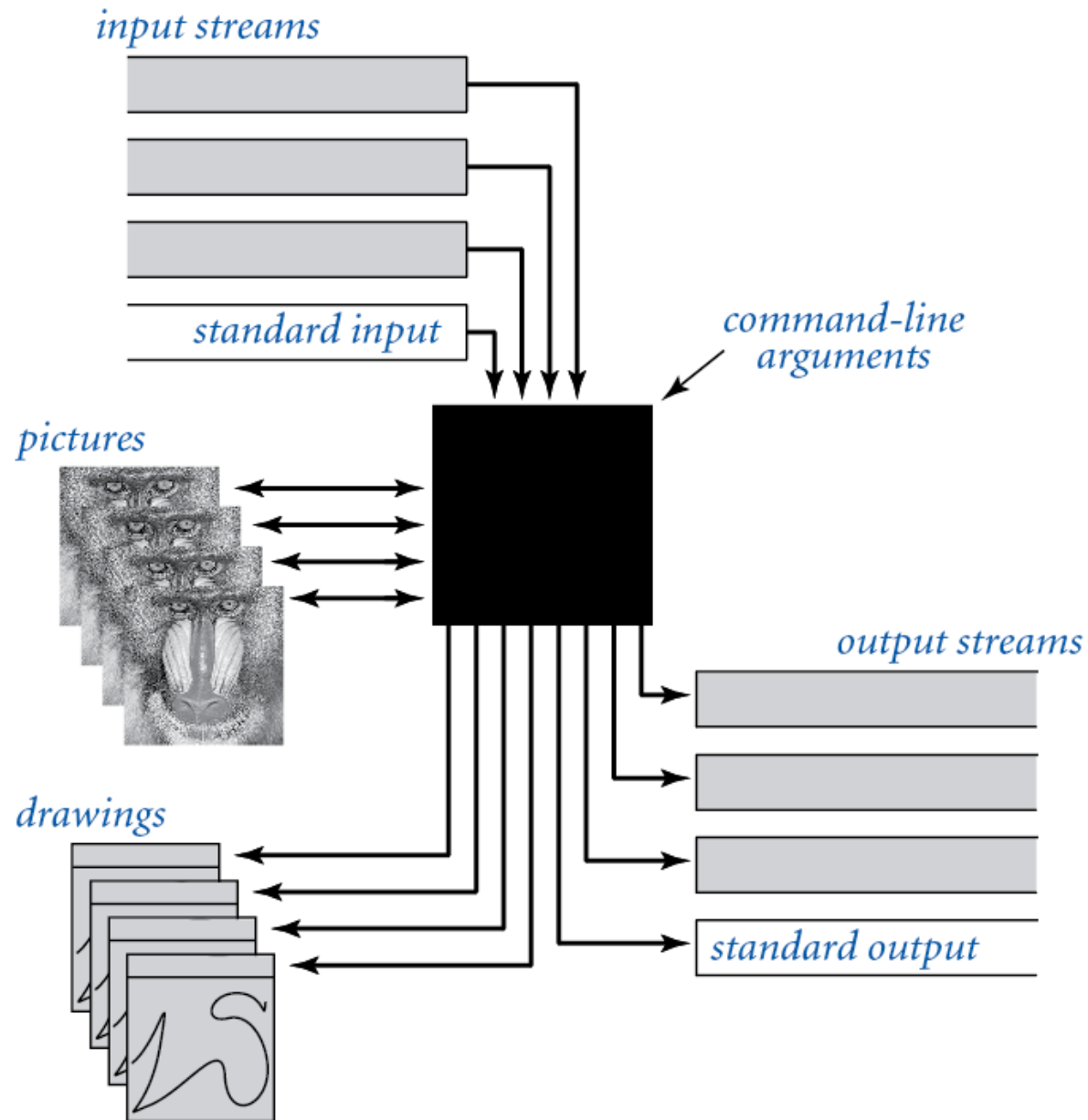
*compares pointers*

*compares character sequences*

# Input and Output

---

# Bird's Eye View (Re-Revisited)



# Non-Standard Input

**Standard input.** Read from terminal window.  or use OS to redirect from one file

**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.

Step 1. Find web source.

Google Inc - NASDAQ:GOOG - Stock Quote & News - TheStreet

www.thestreet.com/quote/goog.html

Mobile | MainStreet | StockPickr | Jim Cramer | Doug Kass | Real Money | The Deal

## The Street

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### Google Inc (GOOG)

NASDAQ: TECHNOLOGY

**\$1,209.93**  
**↑17.83 | 1.50%**  
Today's Range: 1,193.06 - 1,211.00  
GOOG Avg. Daily Volume:  
2,143,700  
03/18/14 - 3:36 PM ET  
[TRADE NOW](#)

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Quote Ratings Earnings Company Profile Options Chain Advanced Chart

Last Update: 3:36 PM ET 03/18/14

Volume: 1,385,094

GOOG YTD Performance: **↑6.37%**

Open: 1,194.67

Previous Close: 1,192.10

52 Week Range: 761.26 - 1,228.88

Outstanding Shares: 336,050,831

Market Cap: 328,247,354,726

1-DAY CHART: GOOGLE (GOOG)

1-Day | 5-Day | 1-Month | 3-Month | 6-Month | 1-Year

--- : Prior Day's Close  
See Advanced Charting for GOOG

[Find out if \(GOOG\) is in Cramer's Portfolio](#)

DOW	16,328.52	+81.30	0.50%
S&P 500	1,871.14	+12.31	0.66%
NASDAQ	4,328.88	+48.93	1.14%

GOOG Chatter

<http://www.thestreet.com/quote/goog.html>

← NYSE symbol

# Screen Scraping

**Goal.** Find current stock price of Google.

**Step 2.** Find string representation (HTML code) of web source.

```
. . .  
<div id="topTradeInfo">  
  
<div id="tradeInfo">  
  <span id="price-tabs">$1,209.93</span>  
  <span class="valueGreen-tabs">  
    
and next </span>,  
after topTradeInfo

# Screen Scraping

**Goal.** Find current stock price of Google.

**Step 3.** Write code to extract stock price from HTML code.

```
public class StockQuote
{
    public static void main(String[] args)
    {
        String name = "http://www.thestreet.com/quote/";
        In in = new In(name + args[0] + ".html");
        String input = in.readAll();
        int start    = input.indexOf("topTradeInfo", 0);
        int from     = input.indexOf("price-tabs", start);
        int to       = input.indexOf("</span>", from);
        String price = input.substring(from + 12, to);
        StdOut.println(price);
    }
}
```

price is string  
between "price-tabs">  
and next </span>,  
after topTradeInfo

```
% java StockQuote goog
$1,209.93
```

- `s.indexOf(t, i)`: index of first occurrence of `t` in `s`, starting at offset `i`.
- Read raw html from <http://www.thestreet.com/quote/goog.html>
- Find string delimited by "**price-tabs**>" and "**</span>**", after **topTradeInfo**.

# 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.



*The New Yorker, September 6, 1999*



# 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.**

Today, you saw how to write programs that manipulate colors, pictures, strings, and I/O streams.

**Next time.**

You will learn to define **your own** abstractions **and** to write programs that manipulate them.