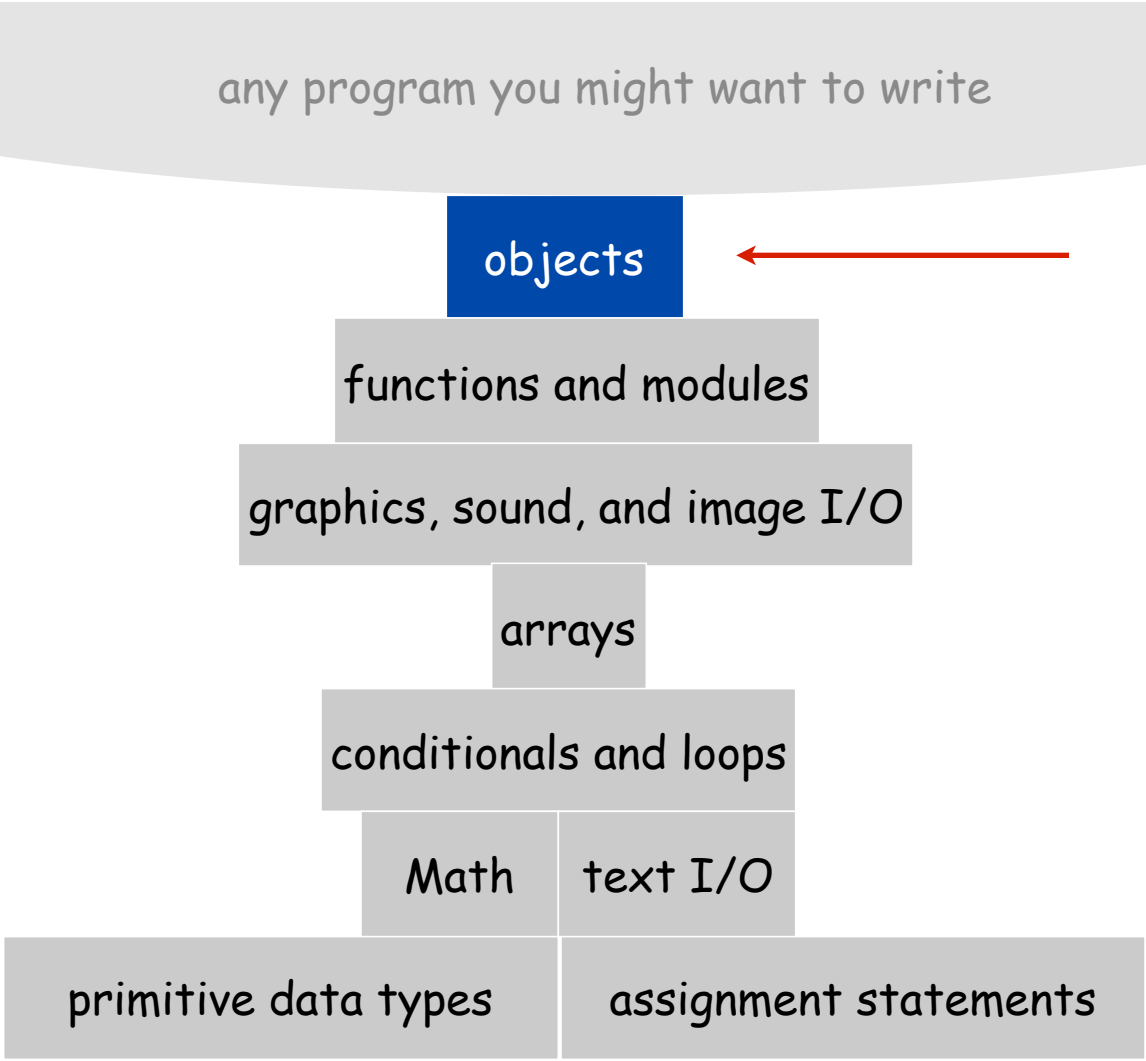
3.1 Data Types



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

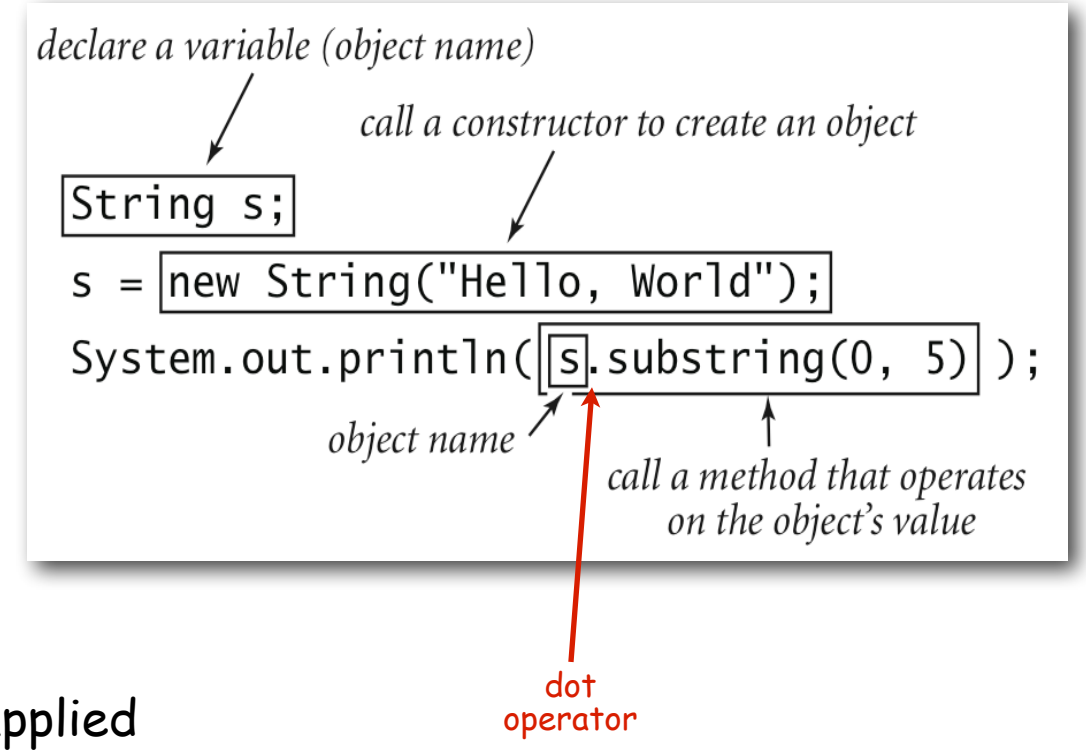
Constructors and Methods

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

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

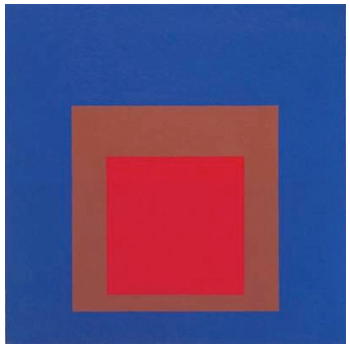
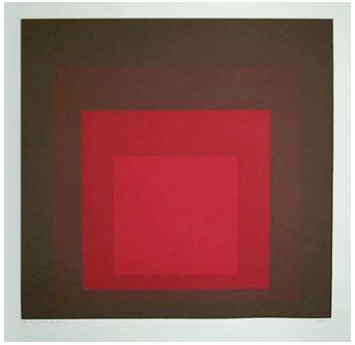
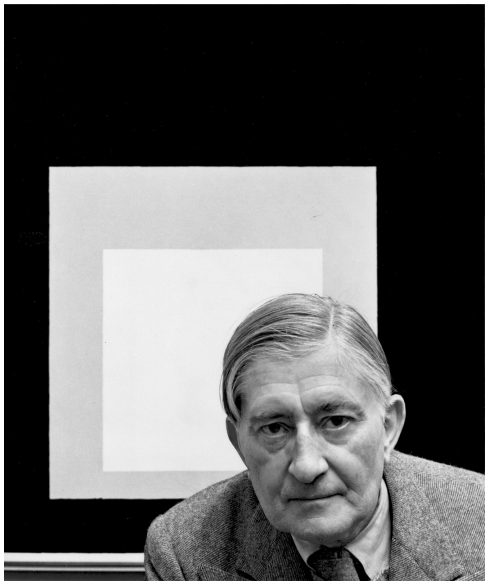
	Color(int r, int g, int b)	
int	getRed()	*red intensity*
int	getGreen()	*green intensity*
int	getBlue()	*blue intensity*
Color	brighter()	*brighter version of this color*
Color	darker()	*darker version of this color*
String	toString()	*string representation of this color*
boolean	equals(Color c)	*is this color's value the same as c's?*

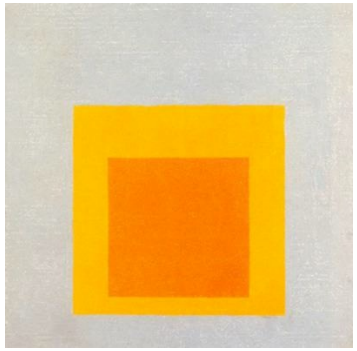
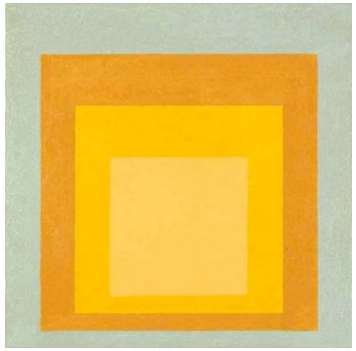
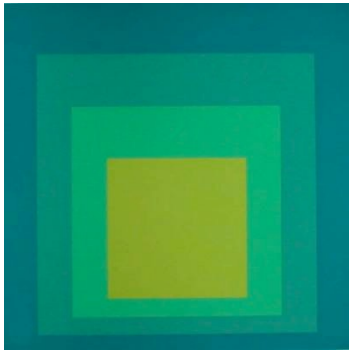
http://java.sun.com/j2se/1.5.0/docs/api/java/awt/Color.html

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.

blue gray

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

Example Client Program for Color ADT

```
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.

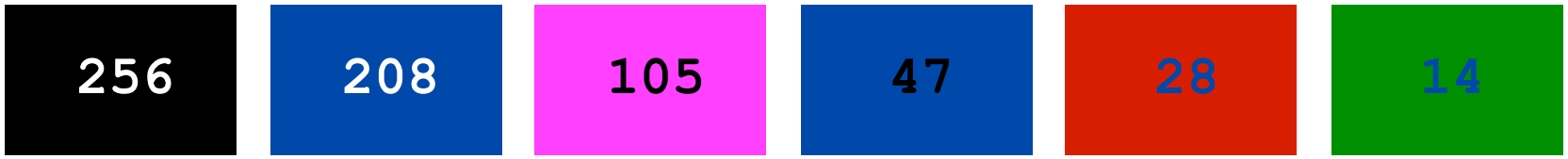
NTSC formula. $Y = 0.299r + 0.587g + 0.114b.$

```
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.




```
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*

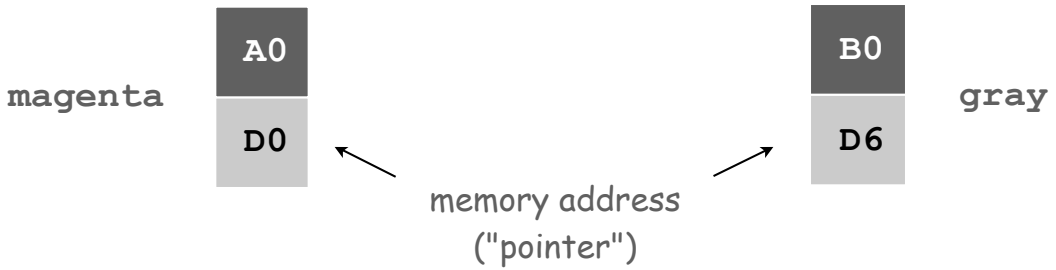
$$0.299 * 9 + 0.587 * 90 + 0.114 * 166 = 74.445$$

Bottom line. We are writing programs that manipulate color.

OOP Context for Color

Possible memory representation (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.

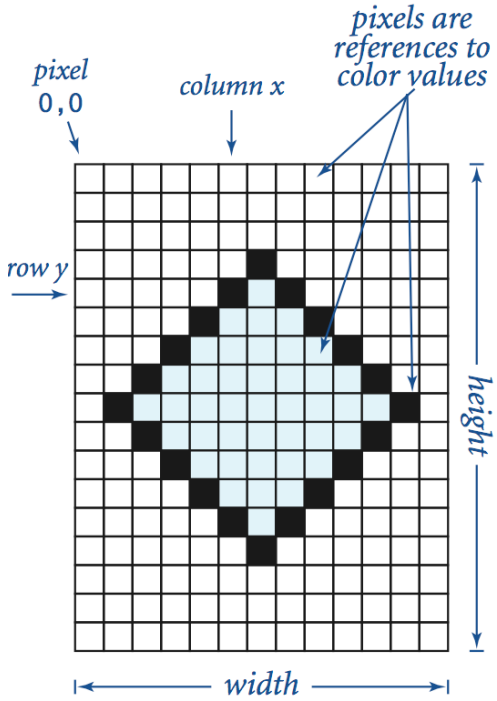
```
Color sienna = new Color(160, 82,  45);
Color c = sienna.darker();
```

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)`	*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 x, int y)`	*return the color of pixel (x, y)*
`void set(int x, int y, Color c)`	*set the color of pixel (x, y) 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.

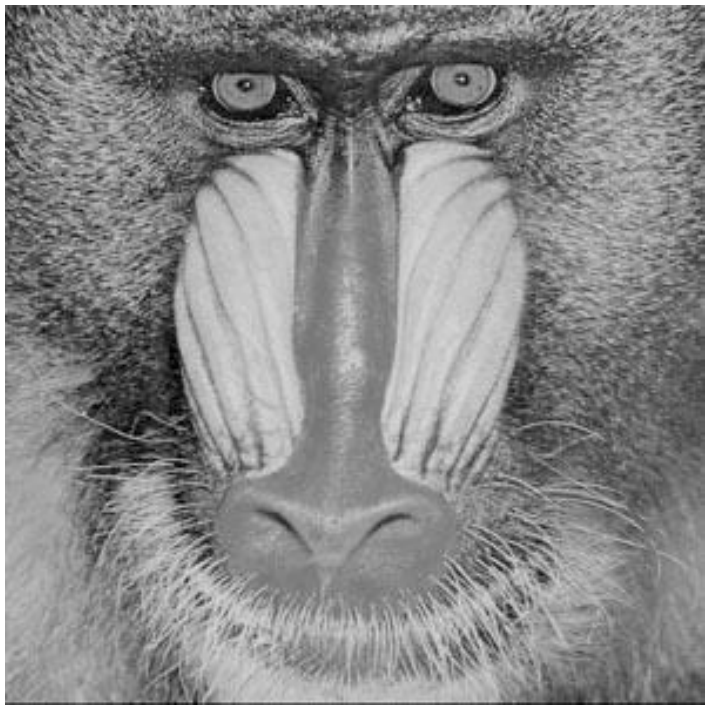
```
import java.awt.Color;

public class Grayscale
{
   public static void main(String[] args)
   {
      Picture pic = new Picture(args[0]);
      for (int 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.)

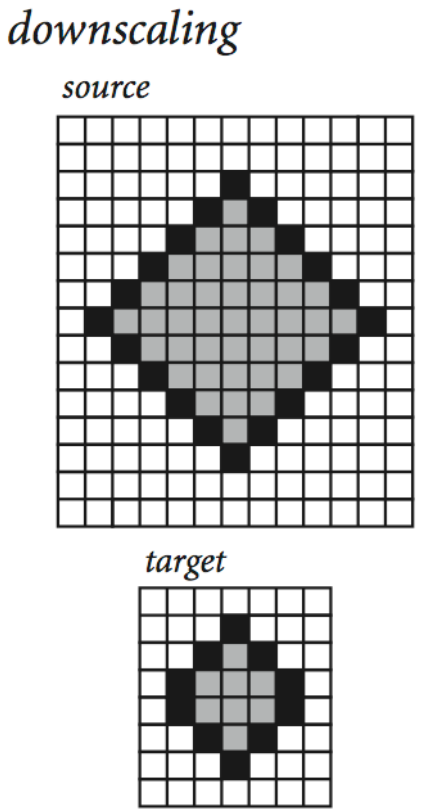
```
Picture source = new Picture(args[0]);
int width  = source.width();
int height = source.height();
Picture target = new Picture(width, height);
for (int x = 0; x < width; x++)
   for (int y = 0; y < height; y++)
      target.set(x, height - y - 1, source.get(x, y));
target.show();
```

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.



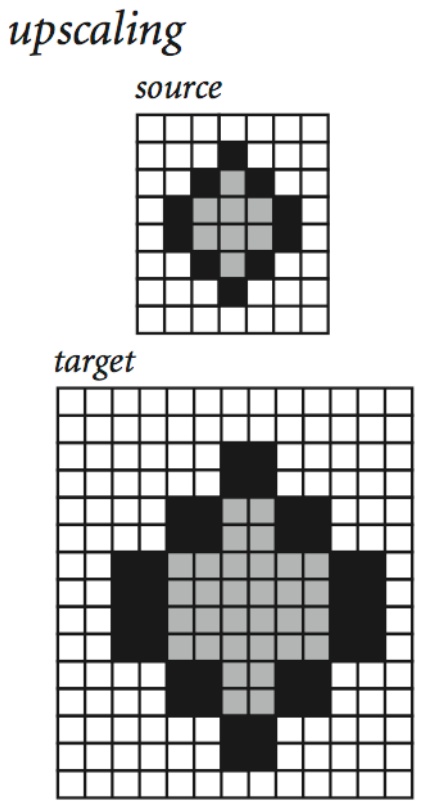


Image Processing: Scaling Filter

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.

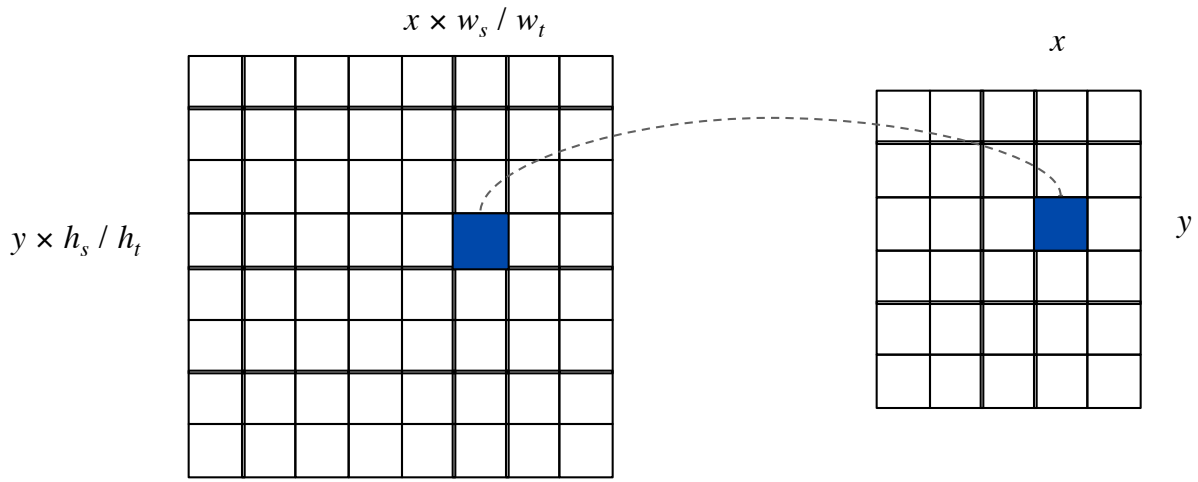
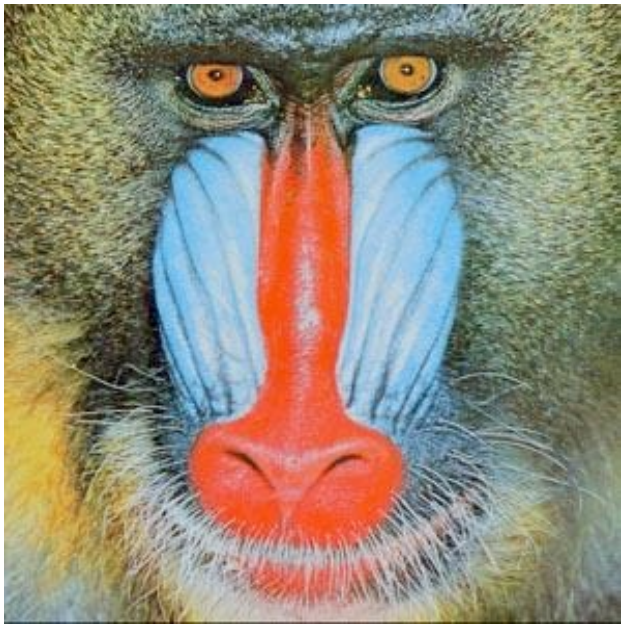


Image Processing: Scaling Filter

```
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.

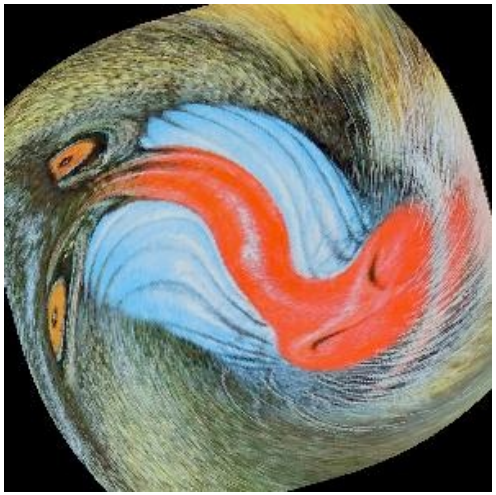


mandrill.jpg

% java Scale mandrill.jpg 400 200

More Image Processing Effects

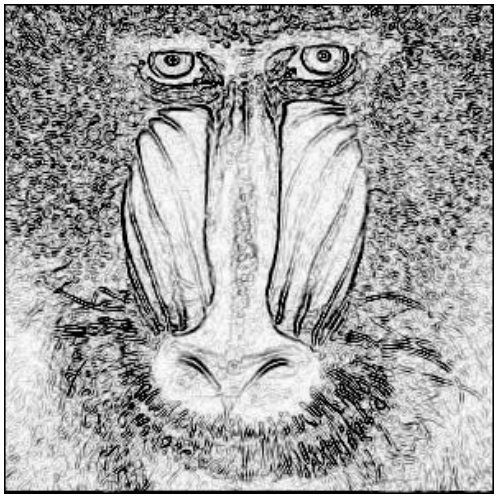
RGB color separation



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)	*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/javase/6/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

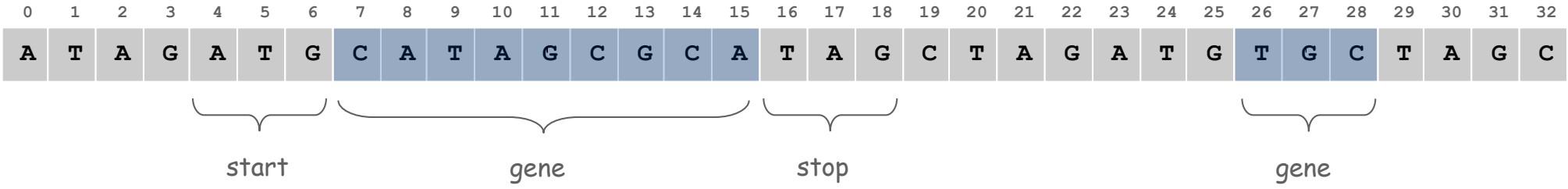
Pre-genomics era. Sequence a human genome.

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

i	codon start	codon stop	beg	gene	remaining portion of input string
0			-1		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
1		TAG	-1		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
4	ATG		4		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
9		TAG	4	multiple of 3	ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
16		TAG	4	CATAGCGCA	ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
20		TAG	-1		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
23	ATG		23		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
29		TAG	23	TGC	ATAGATGCATAGCGCATAGCTAGATGTGCTAGC

Gene Finding: Implementation

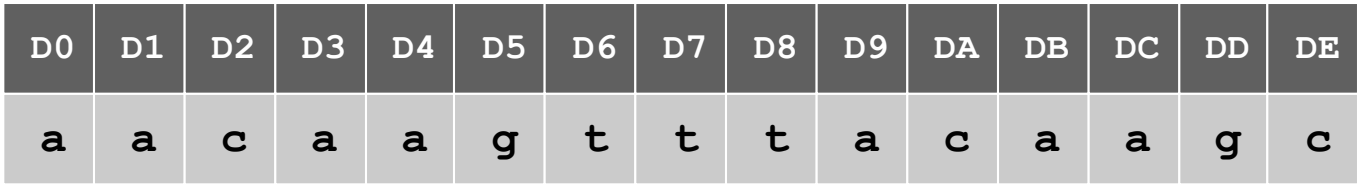
```
public class GeneFind
{
   public static void main(String[] args)
   {
      String start  = args[0];
      String stop   = args[1];
      String genome = StdIn.readAll();

      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;
            }
         }
      }
   }
}
```

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

s

B0	B1
D1	4

t

B2	B3
D9	4

s and t are different strings that have the same value: `"acaa"`

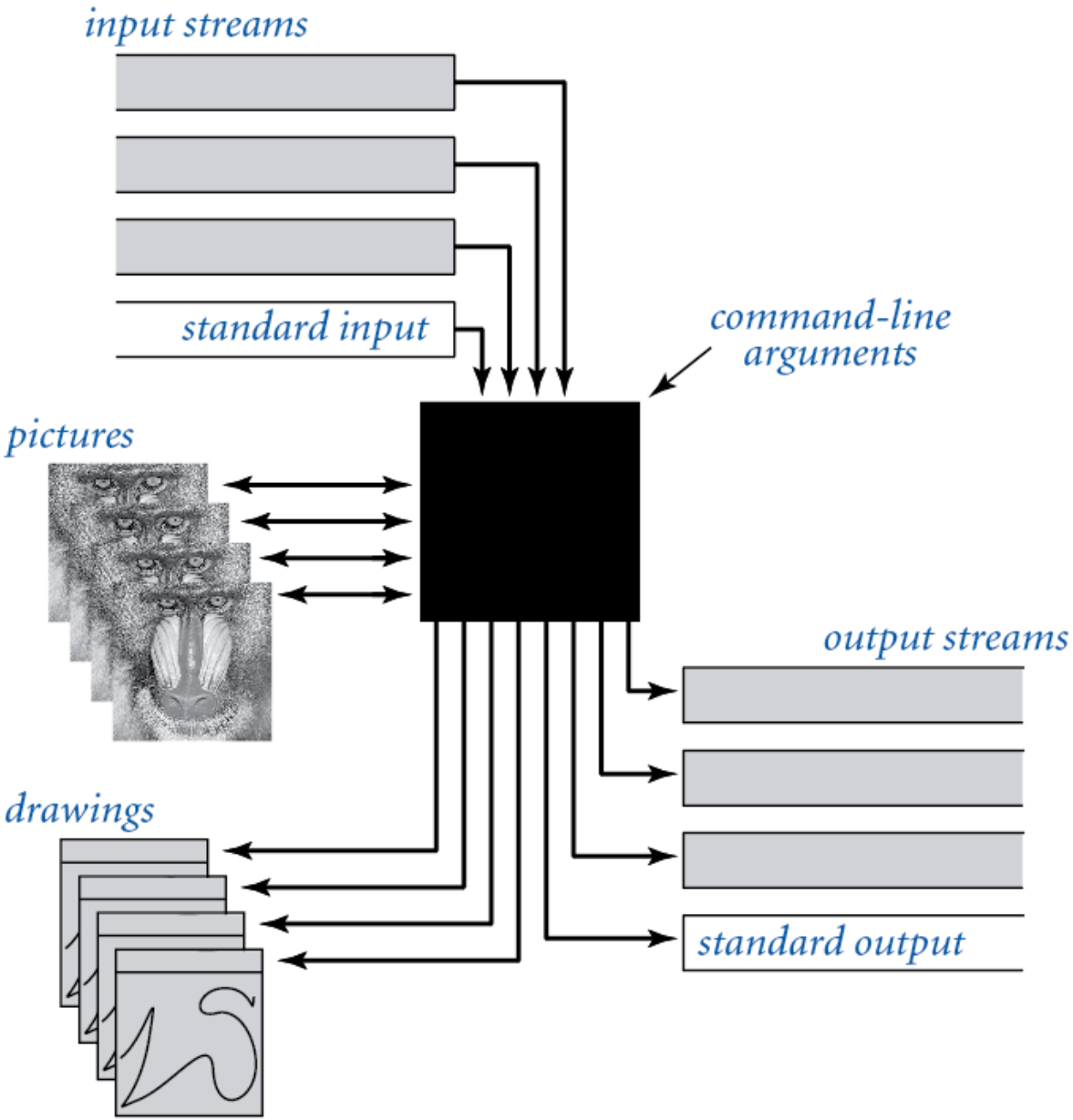
- `(s == t)` is `false`, but `(s.equals(t))` is `true`!

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.

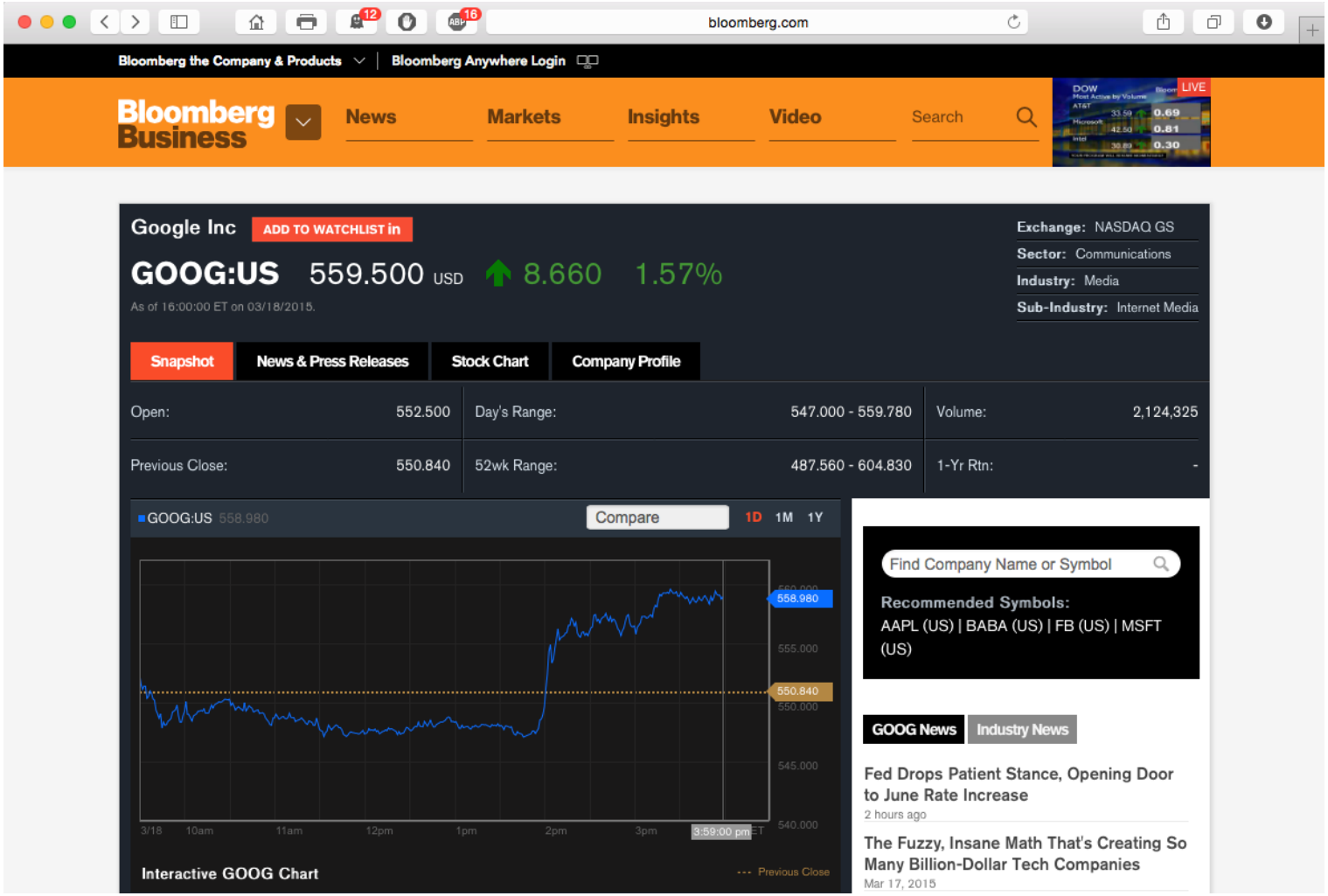
Ex: Are two text files identical?

```
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.



`http://www.bloomberg.com/quote/GOOG:US`

NYSE symbol

Screen Scraping

Goal. Find current stock price of Google.

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

```
. . .

<h3 class=""><span itemprop="tickersymbol">GOOG</span>:US </h3>

    <span class=" price">
      <meta itemprop="price" content="559.500" />
      559.500
          <span itemprop="priceCurrency"> USD</span>
    </span>


. . .
```

price is string between **content=** and next />, after **tickersymbol**

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.bloomberg.com/quote/";
        In in = new In(name + args[0] + ":US");
        String input = in.readAll();
        int start = input.indexOf("tickersymbol", 0);
        int from  = input.indexOf("content=", start);
        int to    = input.indexOf("/>", from);

        String price = input.substring(from + 9, to - 2); //small fiddles
        StdOut.println(price);
    }
}
```

price is string between `content=` and next `/>`, after `tickersymbol`

```
% java-introcs StockQuote GOOG
559.500
```

- `s.indexOf(t, i)`: index of first occurrence of `t` in `s`, starting at offset `i`.
- Read raw html from `http://www.bloomberg.com/quote/GOOG:US`
- Find string delimited (with small fiddles) by `content=` and `/>`, after `tickersymbol`.

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 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.