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, charges, particles, ...

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.

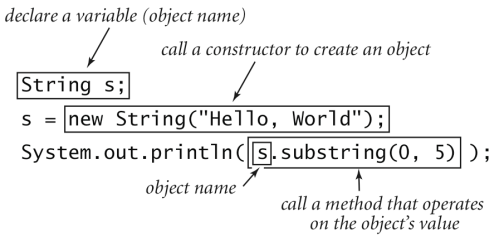


Image Processing

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. [Applications Program Interface]

public class java.awt.Color (partial list of methods)

	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*

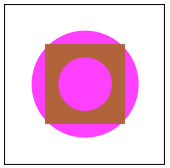
Reference: http://java.sun.com/j2se/1.5.0/docs/api/java/awt/Color.html

Using Colors in Java

One use of objects. Store aggregate data in one variable.

to access Color library

```
import java.awt.Color;

public class ColorTest {
   public static void main(String[] args) {
      Color magenta = new Color(255,  0, 255);
      Color sienna  = new Color(160, 82,  45);
      StdDraw.setPenColor(magenta);
      StdDraw.filledCircle(.5, .5, .667);
      StdDraw.setPenColor(sienna);
      StdDraw.filledSquare(.5, .5, .25);
      StdDraw.setPenColor(magenta);
      StdDraw.filledCircle(.5, .5, .333);
   }
}
```



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.

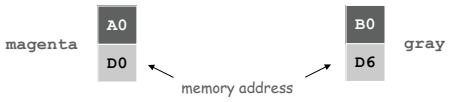
```
public static Color toGray(Color c) {
   int l = (int) Math.round(lum(c));
   Color gray = new Color(l, l, l);
   return gray;
}
```

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

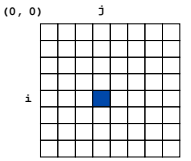
René Magritte. "This is not a pipe."

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.

Picture Data Type



Raster graphics. Basis for image processing.

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

API.

`public class Picture` (our data type for image processing)

	`Picture(String s)`	*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 s)`	*save the image to a file*

Image Processing: Grayscale Filter

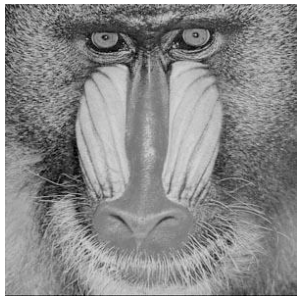
Goal. Convert color image to grayscale according to luminance formula.

```
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 halve the size, delete half the rows and columns.
Upscaling. To double the size, replace each pixel by 4 copies.

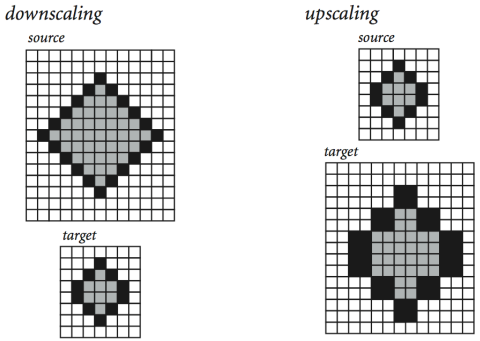


Image Processing: Scaling Filter

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.

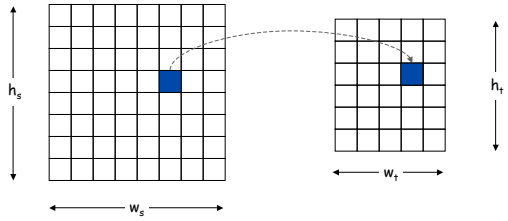
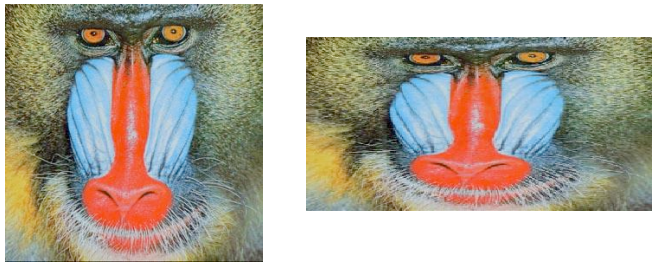


Image Processing: Scaling Filter

```
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: Scale Filter

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



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

OOP Context for Picture

Immutability. Can't change a `Color` object's value once created.
Mutability. Can change a `Picture` object's value.

```
Color color = pic.get(0, 0);
pic.set(0, 3, color);
```

String Processing

String Data Type

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

API. [partial list]

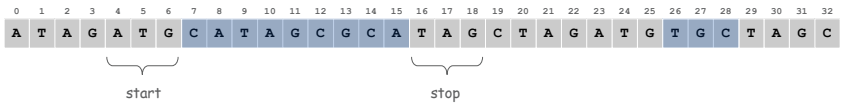
public class String (Java string data type)	
`int length()`	*string length*
`char charAt(int i)`	*i th character*
`String substring(int i, int j)`	*i th through (j-1) st characters*
`boolean startsWith(String pre)`	*does string start with* `pre`*?*
`boolean endsWith(String post)`	*does string end with* `post`*?*
`int indexOf(String s)`	*index of first occurrence of* `s`
`int indexOf(String s, int i)`	*index of first occurrence of* `s` *after* `i`
`String concat(String s)`	*this string with* `s` *appended*
`String toUpperCase()`	*uppercase version of this string*
`String toLowerCase()`	*lowercase version of this string*
`String replace(char a, char b)`	*result of changing* `a` *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?*

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`, `TAG`, 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
9	TAG	4		TAGCGCATAGCTAGATGTGCTAGC
16	TAG	4	CATAGCGCA	TAGCTAGATGTGCTAGC
20	TAG	-1		TAGATGTGCTAGC
23	ATG	23		ATGTGCTAGC
29	TAG	23	TGC	TAGC

Gene Finding: Implementation

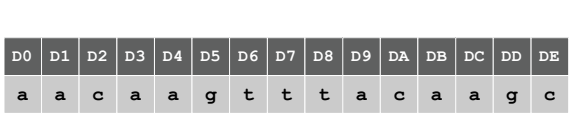
```
public class GeneFind {
   public static void main(String[] args) {
      String start  = args[0];
      String stop   = args[1];
      String genome = StdIn.readAll();

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

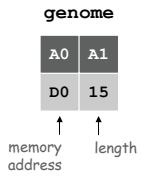
```
% more genomeTiny.txt
ATAGATGCATAGCGCATAGCTAGATGTGCTAGC

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


OOP Context for Strings

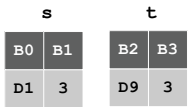
Possible memory representation of a string.

- `String genome = "aacaagtttacaagc";`





- `s = genome.substring(1, 4);`
- `t = genome.substring(9, 12);`

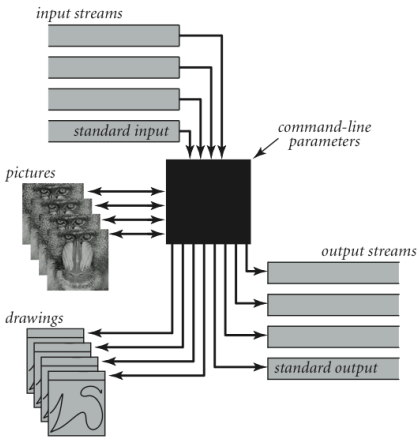


Consequences.

- Use `s.equals(t)` to compare character sequences.
- Use `s == t` to compare object identity.

In and Out

Bird's Eye View (Revisited)



A bird's-eye view of a Java program (revisited again)

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();
      System.out.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>475.11</b></big>
</td></tr>
<tr>
<td class="yfnc_tablehead1" width="48%">
Trade Time:
</td>
<td class="yfnc_tabledata1">
11:13AM ET
...
```

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

Screen Scraping

Goal. Find current stock price of Google.

- `s.indexOf(t, i)`: index of 1st occurrence of pattern `t` in string `s`, starting at offset `i`.
- Read raw html from `http://finance.yahoo.com/q?s=goog` (NYSE symbol)
- Find 1st string delimited by `<b>` and `</b>` appearing 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);
      System.out.println(price);
   }
}
```

```
% java StockQuote goog
475,11
```

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.