3.1 Data Types

any program you might want to write

objects

functions and modules

graphics, sound, and image I/O

arrays

conditionals and loops

Math
text I/O

primitive data types

assignment statements

create your own
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.

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Set of Values</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean</td>
<td>true, false</td>
<td>not, and, or, xor</td>
</tr>
<tr>
<td>int</td>
<td>$-2^{31}$ to $2^{31} - 1$</td>
<td>add, subtract, multiply</td>
</tr>
<tr>
<td>double</td>
<td>any of $2^{64}$ possible reals</td>
<td>add, subtract, multiply</td>
</tr>
</tbody>
</table>

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).

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

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Set of Values</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>24 bits</td>
<td>get red component, brighten</td>
</tr>
<tr>
<td>Picture</td>
<td>2D array of colors</td>
<td>get/set color of pixel (i, j)</td>
</tr>
<tr>
<td>String</td>
<td>sequence of characters</td>
<td>length, substring, compare</td>
</tr>
</tbody>
</table>
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

```java
declare a variable (object name)
String s;
call a constructor to create an object
s = new String("Hello, World");
call a method that operates on the object’s value
System.out.println(s.substring(0, 5));
```
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.

<table>
<thead>
<tr>
<th>R</th>
<th>G</th>
<th>B</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>255</td>
<td>0</td>
<td>0</td>
<td>Red</td>
</tr>
<tr>
<td>0</td>
<td>255</td>
<td>0</td>
<td>Green</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>255</td>
<td>Blue</td>
</tr>
<tr>
<td>255</td>
<td>255</td>
<td>255</td>
<td>White</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Black</td>
</tr>
<tr>
<td>255</td>
<td>0</td>
<td>255</td>
<td>Pink</td>
</tr>
<tr>
<td>105</td>
<td>105</td>
<td>105</td>
<td>Gray</td>
</tr>
</tbody>
</table>
Color Data Type

**Color.** A sensation in the eye from electromagnetic radiation.

**Set of values.** [RGB representation] 256³ 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.**

```java
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
Example Client Program for Color ADT

```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);
    }
}
```
Monochrome Luminance

**Monochrome luminance.** Effective brightness of a color.

**NTSC formula.** \( Y = 0.299r + 0.587g + 0.114b. \)

```java
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 $\geq 128$. 

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

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

<table>
<thead>
<tr>
<th>red</th>
<th>green</th>
<th>blue</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>90</td>
<td>166</td>
<td>this color</td>
</tr>
<tr>
<td>74</td>
<td>74</td>
<td>74</td>
<td>grayscale version</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>black</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>D0</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>D6</th>
<th>D7</th>
<th>D8</th>
</tr>
</thead>
<tbody>
<tr>
<td>255</td>
<td>0</td>
<td>255</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>105</td>
<td>105</td>
<td>105</td>
</tr>
</tbody>
</table>

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.

```java
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.

```java
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
}
```
**Goal.** Convert color image to grayscale according to luminance formula.

```java
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();
    }
}
```
**Goal.** Convert color image to grayscale according to luminance formula.
Image Processing Challenge 1

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

```java
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();
```
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();
```
What does the following code do?

```java
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.
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.
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();
    }
}
Scaling filter. Creates two Picture objects and two windows.

% 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:

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

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 \texttt{ATG}. [start codon]
- Multiple of 3 nucleotides. [codons other than start/stop]
- Succeeded by \texttt{TAG}, \texttt{TAA}, or \texttt{TGA}. [stop codons]
**Gene Finding: Algorithm**

**Algorithm.** Scan left-to-right through genome.

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

<table>
<thead>
<tr>
<th>$i$</th>
<th>codon</th>
<th>$\text{beg}$</th>
<th>gene</th>
<th>remaining portion of input string</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>-1</td>
<td>ATAGATGCATAGCGCATAGCTAGATGTCATAGC</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>TAG</td>
<td>-1</td>
<td>ATAGATGCATAGCGCATAGCTAGATGTCATAGC</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>ATG</td>
<td>4</td>
<td>ATAGCATAGCGCATAGCTAGATGTCATAGC</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>TAG</td>
<td>4</td>
<td>ATAGCATAGCGCATAGCTAGATGTCATAGC</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>TAG</td>
<td>4</td>
<td>CATAGCGCA</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>TAG</td>
<td>-1</td>
<td>ATAGATGCATAGCGCATAGCTAGATGTCATAGC</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>ATG</td>
<td>23</td>
<td>ATAGATGCATAGCGCATAGCTAGATGTCATAGC</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>TAG</td>
<td>23</td>
<td>TGC</td>
<td></td>
</tr>
</tbody>
</table>
public class GeneFind
{
    public static void main(String[] args)
    {
        String start = args[0];
        String stop = args[1];
        String genome = StdIn.readString();

        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
ATAGATGCA\\TAGCGCA\\TAGCTAGCTAGCTAGC

% java GeneFind ATG TAG < genomeTiny.txt
CATAGCGCA
TGC

Fixes bug in Prog. 3.1.8
Q1: What's the bug?
Q2: What input makes Prog 3.1.8 crash?
Possible memory representation of a string (using TOY addresses).

- genome = "aacaagtttacaagc";

<table>
<thead>
<tr>
<th>D0</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>D6</th>
<th>D7</th>
<th>D8</th>
<th>D9</th>
<th>DA</th>
<th>DB</th>
<th>DC</th>
<th>DD</th>
<th>DE</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>a</td>
<td>c</td>
<td>a</td>
<td>a</td>
<td>g</td>
<td>t</td>
<td>t</td>
<td>t</td>
<td>a</td>
<td>c</td>
<td>a</td>
<td>a</td>
<td>g</td>
<td>c</td>
</tr>
</tbody>
</table>

- 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.
In and Out
Bird's Eye View (Re-Revisited)
Non-Standard Input

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?

```java
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));
    }
}
```
Goal. Find current stock price of Google.

Step 1. Find web source.

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">$810.63</span>
    <span class="valueRed-tabs" alt="Down"></span>
  </div>
  <span class="chg"></span>
...```

(price is string between "price-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.

```java
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);
    }
}
```

```
% java StockQuote goog
$810.63
```

- `s.indexOf(t, i): index of first occurrence of t in s, starting at offset i.`
- Find string delimited by "price-tabs" and </span>.
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.
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.