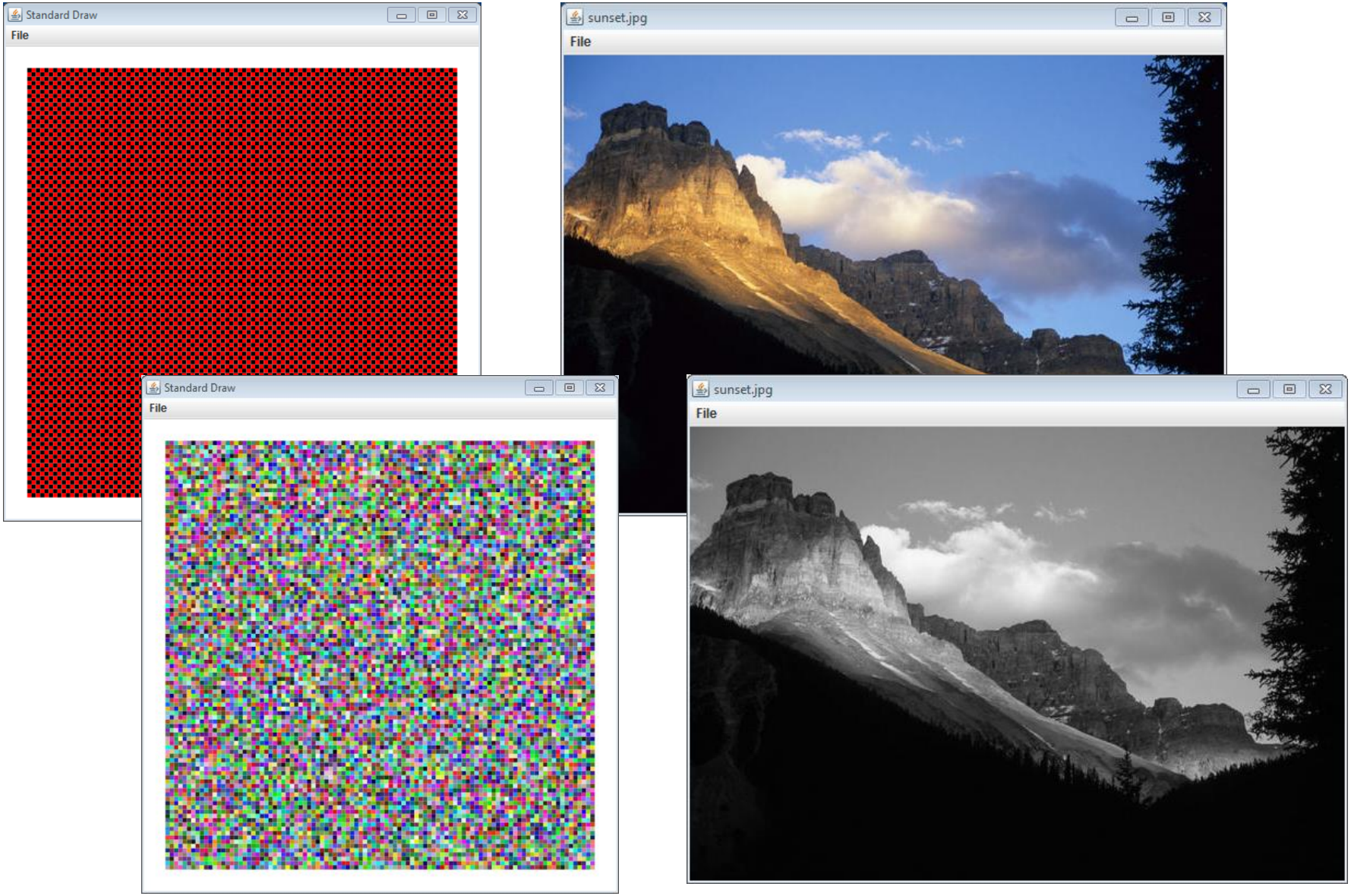
Using data types



Overview

- Using data types
  - What they are
  - Constructors and methods
  - Application Programming Interface (API)
  - Image processing
  - Text processing
- A slight diversion:
  - Incrementing and decrementing variables
- Methods
  - Parameter and return type puzzler

Data types

- Data type
  - "Set of values and operations on those values"
    - Set of values = what an object knows
      - Persistent state of an object
    - Operations on those values = what an object can do
      - Methods you can call on the object
- Contrast with primitive types:
  - Values map directly to machine representation
  - Operations directly map to machine instructions

Primitive type	Set of values	Operations
`boolean`	true, false	not, and, or, xor
`int`	-2^{31} to $2^{31}-1$	add, subtract, multiply, divide
`double`	any of 2^{64} possible reals	add, subtract, multiple, divide

Why custom data types?

- Data type
  - "Set of values and operations on those values"
  - Programs need to process other types of data:
    - e.g. colors, pictures, strings, complex numbers, vectors, matrices, polynomials, points, polygons, charged particles, celestial bodies, …
- Big software projects
  - Non-trivial to manage dozens of programmers
  - Requires careful organization and structure
  - Divide project into small independent modules with clean and simple interfaces

Objects

- Objects
  - Holds a data type value
  - Variable name refers to object
- Object Oriented Programming (OOP)
  - Create your own data types
  - Use them in your programs

Data type	Set of values	Example 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 (to invoke constructor)
  - Use name of data type (to specify which object type)
- To apply an operation:
  - Use name of object (to specify which object)
  - Use dot operator (to invoke a method)
  - Use name of the method (to specify operation)

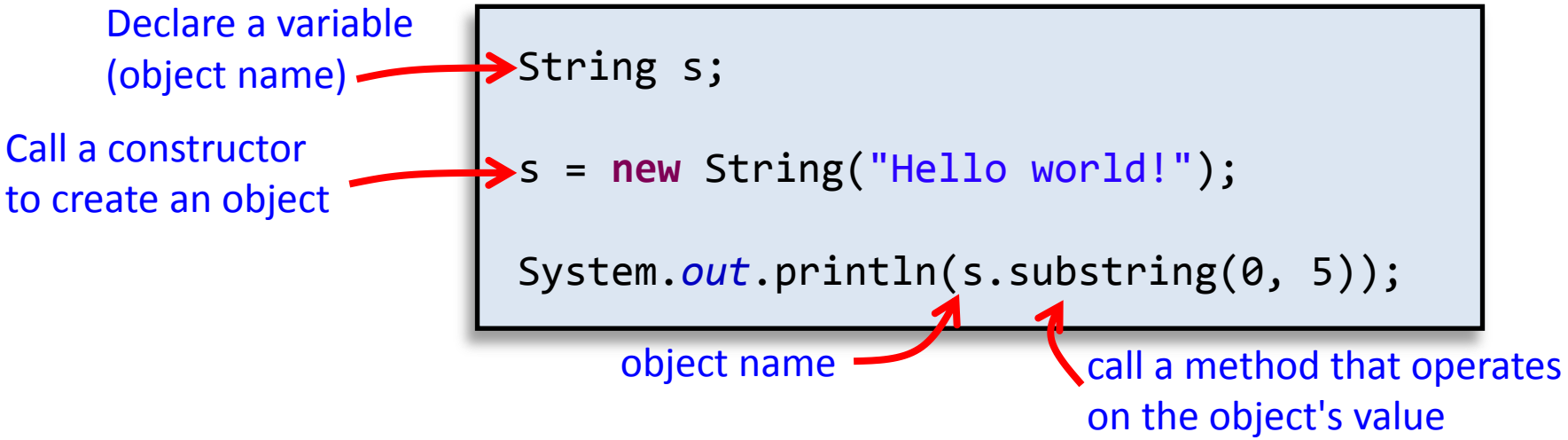


Image processing

- Color data type
  - Color = sensation in eye from electromagnetic radiation
  - Set of values:
    - RGB representation, 2563 possible values
    - Quantify amount of red, green, and blue, scale 0-255

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	

Image processing

- Color data type
  - Application Programming Interface (API)
    - Public specification for what a data type does
    - All a program needs to know to use data type
    - Consists of: signature, return type, and comment for all public methods

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://docs.oracle.com/javase/7/docs/api/java/awt/Color.html

Using Color data type

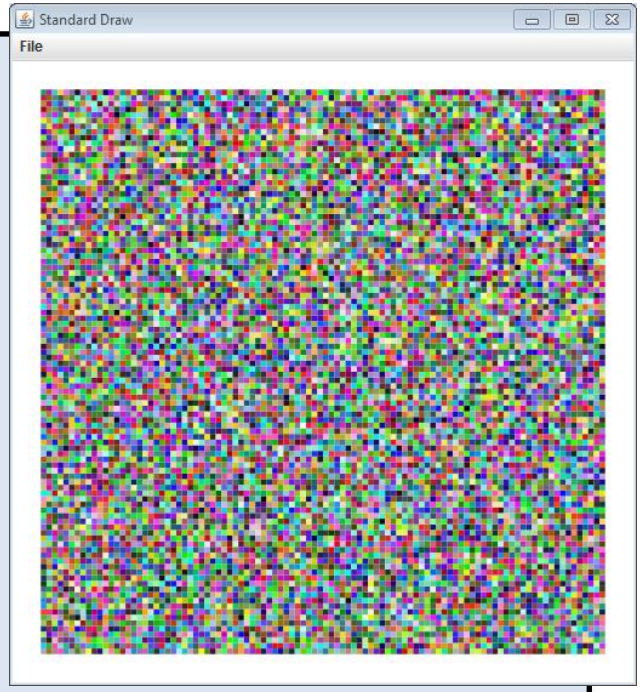
- Goal: Draw randomly colored checkerboard
  - User specifies grid size on command line
- Approach:
  - Modify our red and black checkerboard program

```
int N = Integer.parseInt(args[0]);
StdDraw.setXscale(0, N);
StdDraw.setYscale(0, N);

for (int i = 0; i < N; i++)
{
   for (int j = 0; j < N; j++)
   {
      if ((i + j) % 2 != 0) StdDraw.setPenColor(StdDraw.BLACK);
      else                  StdDraw.setPenColor(StdDraw.RED);
      StdDraw.filledSquare(i + .5, j + .5, .5);
   }
}
```

Using Color data type

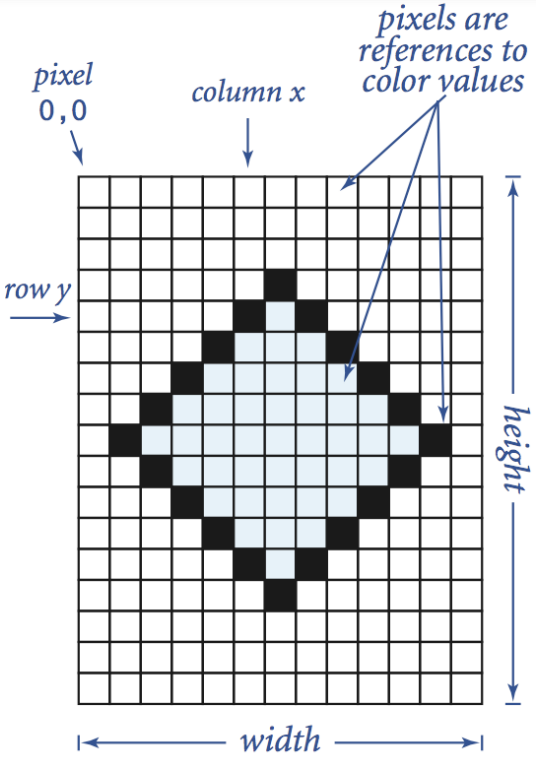
- Goal: Draw randomly colored checkerboard
  - User specifies grid size on command line

```
int N = Integer.parseInt(args[0]);
StdDraw.setXscale(0, N);
StdDraw.setYscale(0, N);

for (int i = 0; i < N; i++)
{
   for (int j = 0; j < N; j++)
   {
      int r = (int) (Math.random() * 256);
      int g = (int) (Math.random() * 256);
      int b = (int) (Math.random() * 256);

      Color c = new Color(r, g, b);
      StdDraw.setPenColor(c);

      StdDraw.filledSquare(i + .5, j + .5, .5);
   }
}
```



API for object representing an image

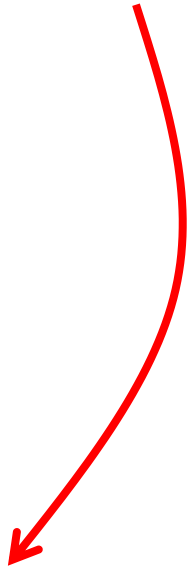
```
public class Picture
-----------------------------------------------------------------------
       Picture(String filename)   // create a picture from a file
       Picture(int w, int h)      // create a blank w-by-h picture
   int width()                    // return the width of the picture
   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
```



Using Color data type

- Goal: Convert a color photo to greyscale
  - Greyscale = RGB with the same values

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	



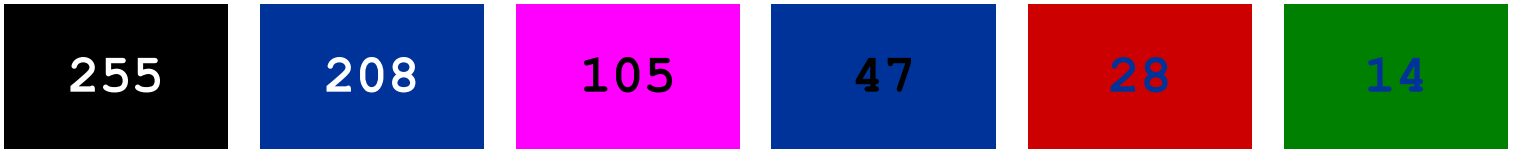
Using Color data type

- Goal: Convert a color photo to greyscale
  - How do we perceive the brightness of a color?
    - NTSC formula: `Y = 0.299r + 0.587g + 0.114b`

```
import java.awt.Color;

public class Luminance
{
    // return the monochrome luminance of given color
    public static double lum(Color color)
    {
        int r = color.getRed();
        int g = color.getGreen();
        int b = color.getBlue();

        return .299*r + .587*g + .114*b;
    }
}
```

Color compatibility

- Practical use of luminance:
  - Which font colors will be most readable with which background colors?
  - Good rule: difference in luminance >= 128




```
// are the two colors compatible?
public static boolean compatible(Color a, Color b)
{
   return Math.abs(lum(a) - lum(b)) >= 128.0;
}
```

Grayscale

- How to convert to grayscale?
  - Use luminance to determine R, G and B values

```
// return a gray version of this Color
public static Color toGray(Color color)
{
   int y = (int) (Math.round(lum(color)));   // round to nearest int
   Color gray = new Color(y, y, y);
   return gray;
}
```

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

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

Grayscale filter program

- Goal: Convert a color photo to greyscale
- Our solution:
  - Use the data types: `Picture, Color`
  - Use static methods in the library: `Luminance`

```
Picture pic = new Picture(args[0]);
int width  = pic.width();
int height = pic.height();

// convert to grayscale
for (int x = 0; x < width; x++)
{
   for (int y = 0; y < height; y++)
   {
      Color color = pic.get(x, y);
      Color gray = Luminance.toGray(color);
      pic.set(x, y, gray);
   }
}
pic.show();
```

Text processing

- String data type
  - Basis for text processing
  - Set of values = sequence of Unicode characters

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://docs.oracle.com/javase/7/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 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());
```

Typical string processing code

Print all lines from standard input that contain a string specified on the command line.

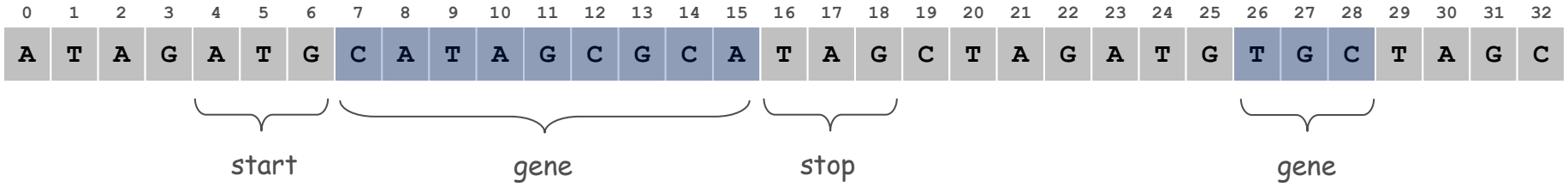
```
String query = args[0];
while (!StdIn.isEmpty())
{
   String s = StdIn.readLine();
   if (s.contains(query))
      System.out.println(s);
}
```

Print all hyperlinks (to educational institutions) contained in the text received on standard input.

```
while (!StdIn.isEmpty())
{
   String s = StdIn.readString();
   if (s.startsWith("http://") && s.endsWith("edu"))
      System.out.println(s);
}
```

Gene finding

- Genomics
  - Represent genome as string over alphabet: A C T G
- Gene
  - Genome substring representing 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]
  - Goal: Find all genes



Gene finding: algorithm

- Algorithm:
  - Scan left-to-right through genome
  - If start codon, set `beg` to index `i`
  - If stop codon and substring 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		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
4	ATG		4		ATAGATGCATAGCGCATAGCTAGATGTGCTAGC
9		TAG	4		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)
            {
               System.out.println(gene);
               beg = -1;
            }
         }
      }
   }
}
```

```
% more genomeTiny.txt
ATAGATGCATAGCGCATAGCTAGATGTGCTAGC

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

Increment and decrement

```
x = x + 1;

x += 1;

x++;

++x;
```

Each line increments x by one.

```
x = x - 1;

x -= 1;

x--;

--x;
```

Each line decrements x by one.

numOfHits++

The ++ means add 1 to whatever's there (in other words, increment by 1).

numOfHits++ is the same (in this case) as saying numOfHits = numOfHits + 1, except slightly more efficient.

Incrementing 1 trillion times

```
public class IncrementSpeed
{
   public static void main(String[] ar
   {
      long num   = Long.parseLong(args[0]);
      long val   = 0;
      long start = System.currentTimeMillis();
      for (long i = 0; i < num; i++)
         val = val + 1;
      long elapsed = System.currentTimeMillis() - start;
      System.out.printf("Time = %.3f", (elapsed / 1000.0));
   }
}
```

```
% java IncrementSpeed 1000000000000
Time = 592.153
```

```
public class IncrementSpeed2
{
   public static void main(String[] ar
   {
      long num   = Long.parseLong(args[0]);
      long val   = 0;
      long start = System.currentTimeMillis();
      for (long i = 0; i < num; i++)
         val++;
      long elapsed = System.currentTimeMillis() - start;
      System.out.printf("Time = %.3f", (elapsed / 1000.0));
   }
}
```

```
% java IncrementSpeed2 1000000000000
Time = 594.194
```

Pre and post increment/decrement

```
++x;
--x;
```

prefix
increment/decrement
evaluates to value after the change

```
x++;
x--;
```

postfix
increment/decrement
evaluates to value before the change

- If used on a line by itself, no difference
  - Use whichever one you fancy
  - Otherwise, you better know what you are doing!

```
int x = 0;
int z = ++x;
System.out.println("x=" + x +
                   ", z=" + z);
```

```
x=1, z=1
```

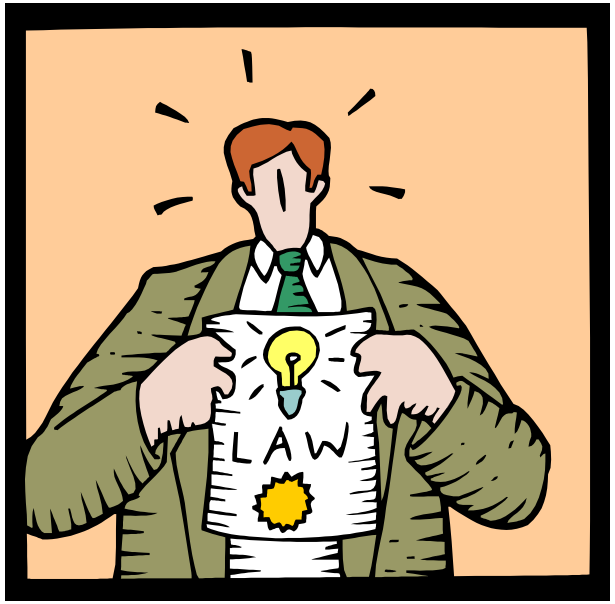
```
int x = 0;
int z = x++;
System.out.println("x=" + x +
                   ", z=" + z);
```

```
x=1, z=0
```

Calling methods puzzler

```
int calcArea(int height, int width)
{
   return height * width;
}
```

Given the method above, which of the methods calls on the right are legal?

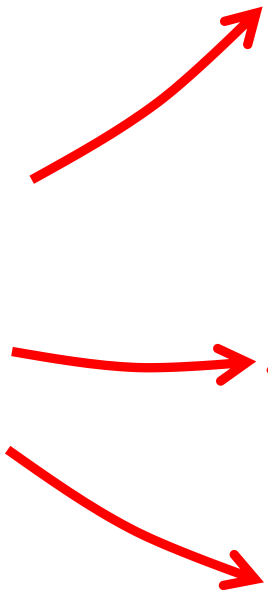



```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) int d = calcArea(57);

4) calcArea(2, 3);

5) long t = 42;
   int f = calcArea(t, 17);

6) int g = calcArea();

7) calcArea();

8) byte h = calcArea(4, 20)

9) int j = calcArea(2, 3, 5);

10) int k = calcArea(2.0, 2.0);
```

```
int calcArea(int height, int width)
{
   return height * width;
}
```

```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) int d = calcArea(57);

4) calcArea(2, 3);

5) long t = 42;
   int f = calcArea(t, 17);

6) int g = calcArea();

7) calcArea();

8) byte h = calcArea(4, 20)

9) int j = calcArea(2, 3, 5);

10) int k = calcArea(2.0, 2.0);
```

Wrong number of arguments to method. We must pass exactly two parameters!



```
int calcArea(int height, int width)
{
   return height * width;
}
```

Parameter type problem.
A long won't fit into an int parameters without spilling.

Return type problem.
Method returns an int which won't fit into a byte without spilling.

Parameter type problem.
The double's won't demote to lowly int parameters.

```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) int d = calcArea(57);

4) calcArea(2, 3);

5) long t = 42;
   int f = calcArea(t, 17);

6) int g = calcArea();

7) calcArea();

8) byte h = calcArea(4, 20)

9) int j = calcArea(2, 3, 5);

10) int k = calcArea(2.0, 2.0);
```

```
int calcArea(int height, int width)
{
   return height * width;
}
```

```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) int d = calcArea(57);

4) calcArea(2, 3);

5) long t = 42;
   int f = calcArea(t, 17);

6) int g = calcArea();

7) calcArea();

8) byte h = calcArea(4, 20)

9) int j = calcArea(2, 3, 5);

10) int k = calcArea(2.0, 2.0);
```

Lovely. Just how we'd expect somebody to do it!

First parameter is a `short` but it can fit in an `int` parameter since it is a bigger data type.

Sort of weird but it will compile. We get an `int` result back, but we just ignore it.

```
double calcArea(double height,
                double width)
{
   return height * width;
}
```

Which are legal if instead the method took two `double`'s and returned a `double`?

```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) double d = calcArea(7.0, 2);

4) double e = calcArea(7, 2.0);

5) double f = calcArea(7.2, 2.0);

6) int g = calcArea(7.2, 2.0);

7) float  h = 1.99f;
   double i = calcArea(h, h);

8) double j = calcArea("7.0",
                       "12.0");

9) String k = "" + calcArea(1, 2);

10) double m = calcArea(-1.0, -9.0);
```

```
double calcArea(double height,
                double width)
{
   return height * width;
}
```

```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) double d = calcArea(7.0, 2);

4) double e = calcArea(7, 2.0);

5) double f = calcArea(7.2, 2.0);

6) int g = calcArea(7.2, 2.0);

7) float  h = 1.99f;
   double i = calcArea(h, h);

8) double j = calcArea("7.0",
                       "12.0");

9) String k = "" + calcArea(1, 2);

10) double m = calcArea(-1.0, -9.0);
```

Parameters 7 and 12 promote to double, but return value can't demote to an int.

Parameters are fine, but return value can't demote to an int.

```
double calcArea(double height,
                double width)
{
   return height * width;
}
```

```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) double d = calcArea(7.0, 2);

4) double e = calcArea(7, 2.0);

5) double f = calcArea(7.2, 2.0);

6) int g = calcArea(7.2, 2.0);

7) float  h = 1.99f;
   double i = calcArea(h, h);

8) double j = calcArea("7.0",
                       "12.0");

9) String k = "" + calcArea(1, 2);

10) double m = calcArea(-1.0, -9.0);
```

Parameters are of type `String` and won't convert to `double` without a call to `Double.parseDouble()`

```
double calcArea(double height,
                double width)
{
   return height * width;
}
```

Types such as `short`, `int`, and `float` will all type promote to `double` if needed.

The `double` return result can be appended to a `String` using + (but we must have the blank string "" first).

```
1) int a = calcArea(7, 12);

2) short c = 7;
   calcArea(c, 15);

3) double d = calcArea(7.0, 2);

4) double e = calcArea(7, 2.0);

5) double f = calcArea(7.2, 2.0);

6) int g = calcArea(7.2, 2.0);

7) float  h = 1.99f;
   double i = calcArea(h, h);

8) double j = calcArea("7.0",
                       "12.0");

9) String k = "" + calcArea(1, 2);

10) double m = calcArea(-1.0, -9.0);
```

Summary

- Data type
  - "Set of values and operations on those values"
  - Declaring/creating variables of a custom data type
    - Use the `new` operator
  - Allows us to build bigger, more complex software
- Using data types
  - Knowing the API, we can create useful programs:
    - e.g. converting images to grayscale, fining genes
- Incrementing/decrementing variables
  - More than one way to do it
    - Be careful if you rely on prefix/postfix semantics!