Stego my Ego: In which our hero hides information in waffles...

Final Programming Project
Due: 09 May 2007 - 17.00 (5PM)

Steganography

Let's start off with a definition. The Wikipedia entry for *steganography* provides the following:

> Steganography is the art and science of writing hidden messages in such a way that no one apart from the intended recipient knows of the existence of the message; this is in contrast to cryptography, where the existence of the message itself is not disguised, but the content is obscured. . . .
>
> Generally, a steganographic message will appear to be something else: a picture, an article, a shopping list, or some other message. This apparent message is the covertext. For instance, a message may be hidden by using invisible ink between the visible lines of innocuous documents.
>
> The advantage of steganography over cryptography alone is that messages do not attract attention to themselves, to messengers, or to recipients. An unhidden coded message, no matter how unbreakable it is, will arouse suspicion and may in itself be incriminating, as in countries where encryption is illegal.

In our final laboratory project this semester you will implement a very basic steganographic system. The program you complete will implement two pairs of data transformations.

First it will provide the ability to hide a secret image within the pixels of a cover image and to reveal such secret images. You have already seen an example illustrating how this can be accomplished. Remember how we hid a picture of the Pentagon inside a picture of Griffin Hall? In that case we used the low 3 bits of each pixel to encode the image of the Pentagon while the high order 5 bits were used to encode the image of Griffin Hall. The variation in the brightness of a pixel that results when only its low 3 bits are changed is so small that we could use those bits to record the brightness values of the Pentagon image without perceptibly changing the image of Griffin. On the other hand, when we extracted the low 3 bits and expanded the range of those bits, a clear picture of the Pentagon emerged, even though only 8 distinct shades of gray could be encoded for each pixel.

While we replaced the lowest 3 bits of each pixel of our cover image with values from the secret Pentagon image, we want you to use even fewer bits for your secret images. In particular, you should replace just the lowest bit in each pixel brightness value in the cover image with the high bit of a brightness value from the secret image. That means you will only preserve two color levels for each brightness value of the secret image. If you try to hide a grayscale image, it will be reduced to a black and white image. If you try to hide a color image, only 8 shades of color will be preserved in the hidden version since you will only have two levels of red, two levels of green and two levels of blue.

Once you have completed the code to hide one image within another, you will implement another pair of transformations that will make it possible to efficiently hide text within an image. First, you will write code to convert a String of text into a black and white image. Each pixel of the image produced will correspond to one bit from the ASCII representation of the `String` being encoded. If the bit is a 1, then the pixel will be bright. If the bit is a 0, then the pixel will be black. The first bit of the first character of the text will determine the color of the pixel in the upper left corner of the image. The second bit of this character will be determine the color of the next pixel in the first column. The remaining bits of the first character and of succeeding characters will be placed in pixels moving down the leftmost column of the image until the end of

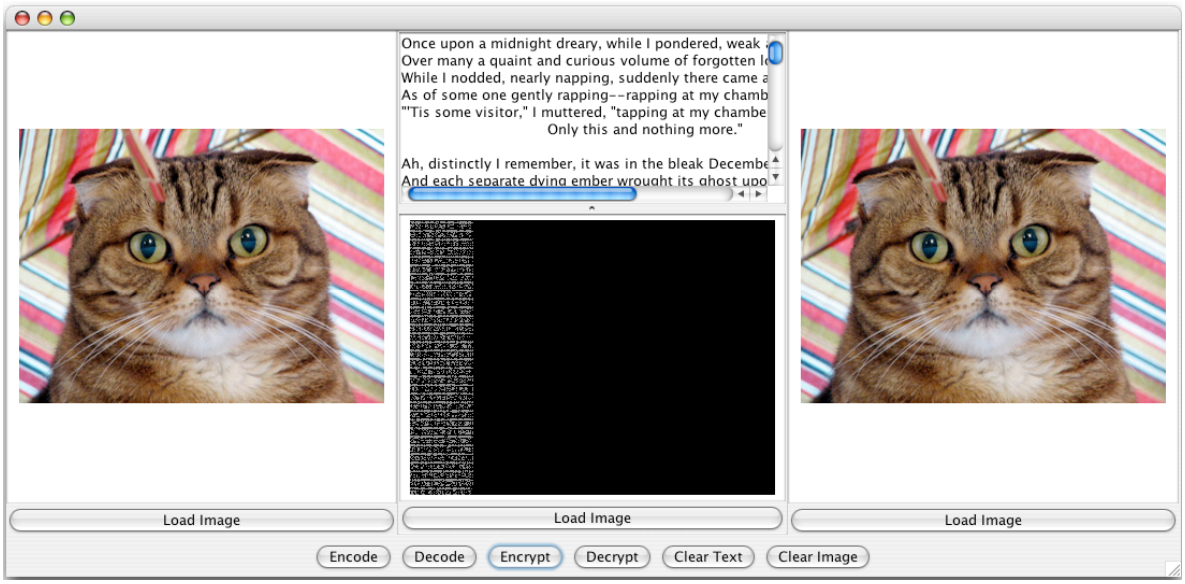
the column is reached. Then you will continue the process starting with the top bit in the second column and so forth. A sample of an image produced in this way is shown to the right.

The pattern of 1s and 0s used to encode a piece of text can be pretty random. That's why the encoded image looks like the matrix (take the red pill and stay in wonderland). As a result, encoding text in this sort of image would not make sense in most contexts. However, if you have a program that can hide black and white images under cover images steganographically, converting text into random looking images is quite handy. You can then hide the image itself under a cover image providing a way to hide quite a bit of text in a small image (the entire Gettysburg Address is encoded in the image shown on the right).

Accordingly, as the second component of this assignment, we want you to incorporate in your program the ability to convert text into images as described above and vice versa. Your program's interface will be designed so that you can combine the text to image conversion with the ability to hide secret images under cover images. This will make it possible to encode text within a cover image.

User Interface

An example of the user interface is given below. It is similar to the dual image viewer you've seen in previous labs. This time, however, the window is divided into three sections displaying three images. The left image is the *cover* image, the middle image is the *secret* image and the right image is the *encrypted* image. We will use these names throughout the exposition so familiarize yourself with them now.



We will provide a simplified version of the `ImageViewer` class to help you construct this interface. This version of `ImageViewer` includes only a Load Image button and a `JLabel` used to display an image. Each of the three sections of your program's window will hold an `ImageViewer`.

The left panel holds a cover image. The rightmost panel holds an image formed by combining a cover image with a secret image. The middle panel is further subdivided into two regions. The bottom holds an `ImageViewer` designed to display a secret image. The top of the center panel holds a `JTextArea` placed within a `JScrollPane`. The image displayed in this panel can be obtained in three ways. It can be loaded from a file using the Load Image button. It can be extracted from the image on the right using the decrypt button. Finally, it can be formed from text entered in the `JTextArea` located above the image by pressing the Encode button.

The nicest way to divide the center panel into two regions is to use a `JSplitPane`. We discuss `JSplitPanes` below. The left and right `ImageViewers` along with the `JSplitPane` are placed in a `JPanel` using a `GridLayout` with 1 row and 3 columns. This `JPanel` is placed in the center of a `contentPane` using a `BorderLayout`. The six buttons are placed in a `JPanel` which is added to the south of the `contentPane`. The `JSplitPane` is similar to a `GridLayout` with 2 rows and 1 column except you can move the center divider. Since we want a `JSplitPane` that splits its two components vertically, you should create it using:

```
JSplitPane split = new JSplitPane(JSplitPane.VERTICAL_SPLIT)
```

You can set the top component with the `setTopComponent` method and the bottom component with the `setBottomComponent` method. Additionally, use `setDividerLocation(0.5)` to set the divider half way between the top and bottom components. This will not work if you do it before all of the window components are placed in the `contentPane` since Java cannot determine the actual size of the `JSplitPane` until it and all your other components have been have been placed in the `contentPane`. Accordingly, place the invocation of `setDividerLocation` at the very end of your `StegoDisplay` constructor.

Overview and Functionality

Encrypting
The Encrypt button encrypts the secret image inside the cover image. The result is an encrypted image. We encrypt the secret image into the cover image by first clearing the low bit of every pixel of the cover image. This has the side-effect of making every pixel value even. For example, 253 becomes 252 but 68 remains the same since its lowest bit is already 0. Next we re-scale the secret image down to 0 / 1 brightness values. Finally, we add the brightness values for the scaled version of the secret image to the bit-cleared cover image. That is, for each pixel in the encrypted image, we add the pixel at that point in the cover image to the pixel at that point in the secret image – *hiding* the secret image in the cover image. The result of this addition is the displayed on the right as the encrypted image. Since we only alter the lowest bits, it's essentially indistinguishable from the original cover image.

Decrypting
The Decrypt button takes the image in the rightmost `ImageViewer` and extracts the low order bit from each pixel to obtain an image where each pixel has value either 0 or 1. To do this, we make a copy of the encrypted image, clear the low order bit for each brightness value, and subtract this copy from the original encrypted image. Finally, we scale the pixel values of the image by multiplying each value by 128 because looking at black images isn't that much fun. This should yield a two-tone version of the secret image.

Encoding
The Encode button takes the text from the `JTextArea` and produces a secret image. The encoded image should have the same width and height as the cover image. Therefore, there must be a cover image present for encoding to work. Trying to encode text when no cover image is present should have no effect.

The details of how to encode text as images are outlined later, but in general it means computing an array of ASCII values for each character in the text field and converting those ASCII values to binary. This results in a large array of bits. Every 8 bit block encodes some ASCII value between 0 and 255 which in turn encodes some character. We could encode the array of bits as an image with two pixel values: 0 and 1. However, both 0 and 1 appear black on the screen so we will instead use a brightness value of 128 to encode each 1 and a brightness value of 0 to encode each 0.

Decoding
The Decode button assumes that the secret image displayed in the center panel was constructed by encoding text and consequently, attempts to extract this text. Extraction can be done by first dividing each brightness value by 128 to obtain the original 0/1 values used to encode the text in ASCII. Then each block of 8 bits can be converted to the corresponding ASCII character and these characters are joined together to form a `String`. Since the encoded text may not have been long enough to provide values for all of the values of the

image, many of the 8 bit blocks will have only zero bits. We ignore such blocks when decoding the image back into text.

Implementation
Begin this lab by implementing the user interface. Call your top-level class `StegoDisplay`. Make sure it extends `GUIManager`. You can leave your `buttonClicked` method empty for now except for the Clear Text and Clear Image button code. Clearing text from the text field means setting the `JTextArea` to the empty string. Clearing the encoded image is similar – just set the image to be a small all-white `SImage`. Recall that `SImage` has several constructors, one of which takes a width, a height, and a brightness level and returns an `SImage` of appropriate brightness and dimensionality. We always create an image with width 100 and height 100. Test your Clear Text and Clear Image button code to make sure it works. We'll fill in the code for the other buttons later.

Encrypting Images
Encrypting messages has three steps. First we take a cover image and clear the low order bit of each pixel. That is, we make it zero. This is equivalent to requantizing the cover image so that it uses only 128 distinct levels of brightness. Then we reduce the range of brightness values used in the secret image from 0-255 to 0-1. This can be done by dividing all pixel values by 128. Finally, add the rescaled secret image to the requanitized source image.

Bit Clearing
Recall that integer division in Java always produces another integer. As a result, consider what happens if we first divide a number by 10 and then immediately multiply the result by 10. The final result will always be the same as the original value with the rightmost digit replaced by a 0. For example, 354 divided by 10 is 35 and 35 times 10 is 350.

Division by 2 in binary behaves the same way as division by 10 does in decimal. If we divide a binary number by 2 and then multiply by two, the result will be the same as simply replacing the last digit of the initial value with 0. For example, the number 27 represented using 8 bits in binary is 00011011. We will always write the bits from *most significant to least significant*. Dividing 27 by 2 yields 13 which is 00001101 when encoded as an 8 bit binary number. Notice that 00001101 is exactly 00011011 shifted to the right one bit (with the final bit chopped off and a 0 bit append to the front). Similarly, multiplying by 2 shifts the binary number to the left by one bit and fills in the low order bit with a 0. For example, if we shift 00001101 to the left by one bit we get 00011010 which is 26. In other words, we can clear the low order bit of a pixel by first dividing by 2 and then multiplying by 2.

Implmentation
Create a class called `BitClearer` that extends `ImageFilter`. You can approach the implementation of this class in two ways. The easiest way is to take advantage of the `Scaler` class we provided in an earlier lab. Recall that `Scaler` takes an image and first multiplies each brightness value by a given factor and then divides each value by another factor. You can create one `Scaler` to divide all of the brightness values in an image by 2 and another to multiply all the values by 2 and then use these two `Scaler`s to do all the work. If you take this approach, you should override the `filter` method of the `ImageFilter` class in your definition of `BitClearer`. Alternately, if you are more comfortable writing loops to process all of the pixels yourself, you can define `BitClearer` by mimicking the code found in our `Scaler` class. The only big differences will be that a) `Scaler` multiplies first and then divides while you will want to perform the operations in the opposite order and b) the values to multiply and divide by are passed as parameters to `Scaler` while your class can simply use 2. If you take this second approach, you will override the `pixelFilter` method. Note that regardless of which approach you choose, `BitClearer` does not need a constructor since implementing `filter` only requires an `SImage`.

Scaling Images
The easiest way to rescale the secret image so that all of its brightness values are either 0 or 1 is to divide all of the original brightness values by 128.

Implementation
You should find that the `Scaler` class provides just the tool you need to rescale the secret image.

Adding Images
For our purposes, adding two images together is as simple as adding two pixel values together. Given two images of the same dimensions, we wish to create a new image where each pixel in the new image is exactly the sum of the pixels in the original images.

Implementation
Create a class called `Adder` that extends `ImageFilter`. The constructor for `Adder` takes a single parameter of type `SImage` called `left`. Override the `layerFilter` method so that given another `SImage right` and an RGB layer, you extract the appropriate RGB layers from `left` and `right`, add the pixels together and return a new two-dimensional array of pixels.

Use the `Adder, Scaler` and `BitClearer` classes to implement the correct functionality of the Encrypt button. That is, clear the low bits of the cover image and add it to the scaled secret image to form the encrypted image.

Decrypting Images

Decrypting images also has three steps although you've already completed one of them – bit clearing – and the functionality of the others – differencing and range expansion/rescaling – is already provided. Recall that decrypting the encrypted image means creating a copy of the image, clearing the low order bits from each brightness value in the copy, differencing the copy from the original, and finally rescaling the brightness values from 0s and 1s to 0s and 128s.

Implementation
Since you already implemented `BitClearer` and since `Differencer` and `Scaler` are provided in the starter project, implement the Decrypt button functionality by creating a `Differencer` with the encrypted image as the original. Then clear the bits of the encrypted image using the `BitClearer`. Notice you don't actually need to make a copy of the encrypted image since `BitClearer` constructs a new `SImage`. Now use the `filter` method of `Differencer` to extract the secret image. Make sure you scale the secret image up by a factor of 128 before displaying it. You can now test your Encrypt and Decrypt functionality by loading an image file which came in the starter project. First load `test-encrypt.png` into the `ImageViewer` of the secret image. Next load the same image into the `ImageViewer` of the cover image. `test-encrypt.png` is comprised of pixels with value 0 and pixels with value 128. It serves as a simulacrum for an image produced by encoding text in an image. We need an image with the same dimensions as our source so that you can actually perform the encryption. Encrypt the secret image, clear the secret image, and then decrypt the encrypted image. You should see the secret image reappear. It's worth noting that this secret image almost surely corresponds to a beautiful sonnet. Alright, it probably doesn't.

Encoding Strings as Images

Encoding strings as images is a two step process. First we convert a string of text into an array of bits. Then we form an image by treating each bit as a pixel.

Converting Strings to Arrays of Bits
Early in the semester we talked about how ASCII provides a way to encode characters as 8-bit binary strings. For example "A" has ASCII code 65 so it corresponds to the 8-bit binary string 01000001. You can determine the numeric value of the ASCII code for any character in a `String` very conveniently in Java. You can extract a character from a `String` by providing the position of the desired character as a parameter to the `String charAt` method. This method returns the character at that position as a value of type `char`, which Java views as a slightly special form of integer value. For example, we can grab the ASCII value of "A" using the following lines of Java

```
String s = "ABC";
```

```
int val = s.charAt(0);  // val is 65
```

This, however, is only the first step if you want to set the brightness values of an image's pixels based on the individual bits used to encode some text in ASCII. We now need a way to convert `val` to its binary representation.

Converting an integer into its binary representation is based on the same observations about binary arithmetic that we used to clear the low order bit of a brightness value. We can first check if the low order bit of an ASCII code is 1 by checking if the number is odd. Then, we can shift the number to the right by one bit by dividing it by 2. Repeating this procedure 8 times while recording whether the low order bit was a 0 or a 1 yields the 8 digit binary representation of an ASCII value.

Implementation
Rather than converting text directly into an image, we will first convert a `String` into an array of integers in which each integer in the array holds the value of a single bit of the ASCII representation of the `String`. For example, if a `String text` has length 10, then each character in `text` requires 8 bits in its binary representation. Therefore the array of bits for `text` will have length 80.

The key to converting `String`s to arrays of bits is carving up the steps correctly.

Create a class called `StringConverter`. The class should have two private methods and two public methods. The two public methods:

- `public int[] convertFromString(String text)`
- `public String convertToString(int[] bits)`

will be used to convert a `String` into an array holding the individual bits of its ASCII representation and vice versa. These methods will be implemented using the two private methods

- `private int[] convertFromInt(int x)`
- `private int convertToInt(int[] bits)`

which will perform similar conversion operations for single characters rather than for complete `String`s.

We'll concentrate on `convertFromInt` and `convertFromString` methods for now. `convertFromInt` takes the integer value of an ASCII code and returns an array of 8 bits where the first bit represents the **most significant bit**. This means that as you convert your integer into its binary format, you'll need to fill in the array from back to front. *Going from front to back is super bad!*

`convertFromString` begins by allocating an array of integers of appropriate size to hold the 8-bit binary representation of `text`. It iterates over the characters of `text`, using `charAt` to extract the ASCII value of each character in the `String`. It then calls `convertFromInt` and copies the result into the final array of integers. Note that when converting the character appearing at index 3 of `text`, we will copy the 8 bits representing that character into the final array starting at position 8*3=24. For example, `convert("AX")` should return a 16 bit array of integers with contents [0 1 0 0 0 0 0 1 0 1 0 1 1 0 0 0] since the ASCII code for A is 01000001 and the ASCII code for X is 01011000.

Converting Arrays of Bits to Images
Earlier in class we talked about how two dimensional arrays are really just arrays of arrays. It's also possible to think of two-dimensional arrays as a single array where each column array is just concatenated end-to-end with its neighbor. In this way, we can copy the bits of our bit array into the consecutive columns of an image.

Implementation
For the process of converting between a 1-dimensional array of bits and a two dimensional image composed of pixel values, you should define two private methods within your `StegoDisplay` class:

- `SImage convertToImage(int[] bits, int width, int height)`
- `int[] convertFromImage(SImage image)`

We'll address the first one now and leave the second until later. `convertToImage` takes an array of integers (each of which represents a single bit) together with two integers specifying the dimensions of an image and returns a greyscale `SImage` of the desired dimensions such that the brightness of the pixel at location `(x,y)` is equal to 128 times the value at position `height*x + y` in the bit array. We can accomplish this by iterating through the image and array of bits simultaneously. For example, given the array [0 1 0 0 0 0 0 1 0 1 0 0 0 0 1 1], an integer width 4, and an integer height 4, we'd return an `SImage` with pixel values

0	0	0	0
128	0	128	0
0	0	0	128
0	128	0	128

If your array of bits runs out, make the remaining pixel values 0. For example, given the array [0 1 0 0 0 0 0 1 0 1 0 0 0 0 1 1], an integer width 4, and an integer height 5, you should return an `SImage` with pixel values

0	0	0	128
128	0	0	*0*
0	128	0	*0*
0	0	0	*0*
0	128	128	*0*

(where the added zeroes are shown in italics). If the image pixels run out first, then stop encoding the array of bits – decoding the image just means the original text will be truncated.

You can now implement the Encode button. Begin by converting the text in the `JTextArea` to its binary representation using the `convertFromString` method of `StringConverter`. Next use the `convertToImage` method of `StegoDisplay` to generate an `SImage`.

Decoding Images into Strings

It's now time to reverse the process of encoding. While the details may not yet be clear, the main idea is to take a two-dimensional array of pixels and make it linear by copying it, one column at a time, into an appropriately sized array of integers. Once we have the array of integers, we can read consecutive blocks of 8 bits to decode the ASCII values into characters and recover the original text.

Converting Images to Arrays of Bits
Given an image with dimensions `width` and `height`, we should create an array of length `width*height` to store our bits. Then we can simultaneously iterate through the image (column by column) and the bit array filling in 1s for pixel values greater than or equal to 128 and 0s for smaller pixel values.

Implementation
We begin by writing the `convertFromImage` method of the `StegoDisplay` class. This method takes an `SImage` and returns an array of integers representing bits. These bits correspond to the binary ASCII values of the original text. Since your bit array is sized according to the dimensions of the image, you should have one bit for every pixel in the image. We assume that the encoded image is grayscale so extract its pixel array using the default `getPixelArray()` method without any parameters.

Converting Arrays of Bits into Strings

Converting arrays of bits into strings is, like many dances, done in two-steps. We begin by iterating over the bit array in 8-bit blocks, extracting each block, and converting that 8-bit array of bits into its corresponding decimal ASCII value. Next we convert this ASCII value into a `String` and append it to our string buffer.

Converting an array of bits into an integer is quite natural given that we've already discussed how to do the converse. Notice that shifting an array of bits to the left by one bit is the same as multiplying its decimal value by 2. For example, if 110 is our 3-bit binary number with decimal value 6 then 1100 is a 4-bit binary number with decimal value 12. If the bit we acquire on the right is a 1 instead of a 0, we multiply by 2 and then add 1. That is, we always double the total and add the new bit. We can use this idea to convert our array of bits into its decimal value. We begin by keeping an integer value `total` that corresponds to the current value of our 8-bit binary number. Then we shift our bit array to the left, and acquire the next bit in our bit array. Likewise, we double `total` and add the newly acquired bit. For example, say our bit array is [0 0 0 0 0 1 0 1] and we want to convert it to its decimal value. We initialize `total` to 0. Starting with the bit at position 0, we double `total` and add 0 since the bit at position 0 is 0. This means `total` has value 0. The steps for positions 1, 2, 3, and 4 will be similar since all of the array elements at these positions are 0. Once we get to position 5, however, the array value found is 1. Therefore, we will again double `total` but this time we will add one leaving the value 1 in `total`. Next we move to the bit at position 6. We double `total` and add 0. This means `total` has value 2. Finally we move to the bit at position 7. We double `total` and add 1. This means `total` has value 5 which is exactly the decimal value of 101.

Once we have the decimal value of our bit array, we need to convert it into its corresponding ASCII character, create a `String` from the character, and append that `String` to our current buffer. In Java, one converts an integer ASCII value into its corresponding character value by casting the integer as a `char`. Then, we can concatenate this `char` onto a `String` much as we can concatenate two `String`s together. For example

```
String text = "HAH";
int x = 65;   // ASCII FOR A
char c = (char) x;
text = text + c; // text equals "HAHA"
```

Implementation

Start by writing the private `convertToInt` method in `StringConverter`. This method takes an array of integers (representing bits) and returns an `int` representing its decimal value. Use the doubling plus adding procedure outlined above to accomplish this implementation.

Next, implement the `convertToString` method of `StringConverter`. This method takes an array of bits and returns a `String` representing the ASCII characters of the consecutive 8-bit blocks of binary numbers in the bit array. You'll probably want to do this with two `for` loops. If there are `length` bits in the array, the outer `for` loop will perform `length/8` iterations. The inner `for` loop will always perform 8 iterations. Most likely your inner `for` loops will copy the 8-bit block into an array of 8 integers and then use `convertToInt` along with the Java code above to recover the ASCII String. You'll append this `String` to your overall buffer and return the buffer after the iteration is finished. There is one caveat. If the converted integer value is 0, then the original 8-bit block had 8 consecutive 0s. This corresponds to the NULL character in ASCII and not surprisingly, to where we stopped encoding our text in the image. We do not want to include the NULL characters it in our decoded text so don't convert them to ASCII or add their values to the final `String`.

You can now implement the Decode button. Begin by grabbing the secret image and converting it to an array of `int`s using the `convertFromImage` method of your `StegoDisplay` class. Next, convert this array of bits to a `String` using the `convertToString` method from `StringConverter`. Now set the `JTextArea` to the recovered `String`. Test your decode method by using the `test-decode.png` image file located in the startup package.