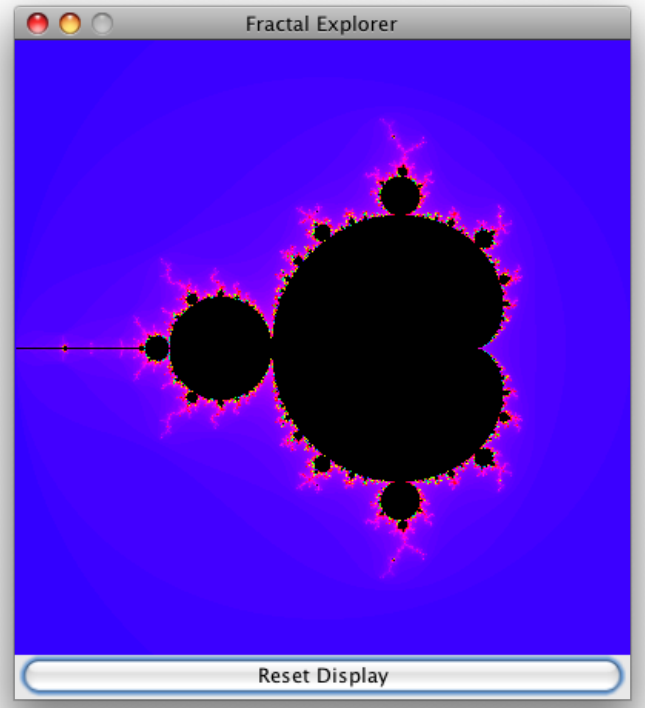
Java Lab 3: Fractal Explorer

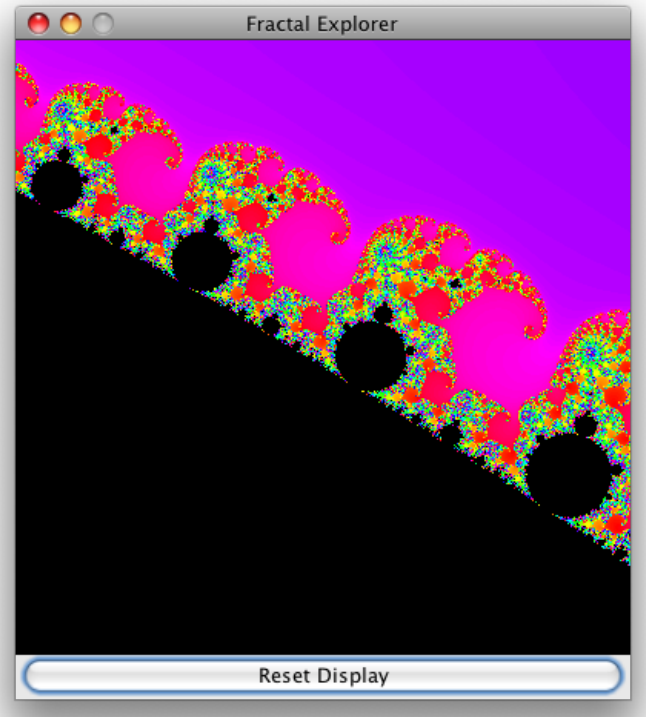
For the next few labs you will put together a fun little Java application that can draw some amazing fractals. If you have never played with fractals before, you will be amazed at how easy it is to create some breathtakingly beautiful images. We will do this all with the Swing Framework, the Java API that allows you to create graphical user interfaces.

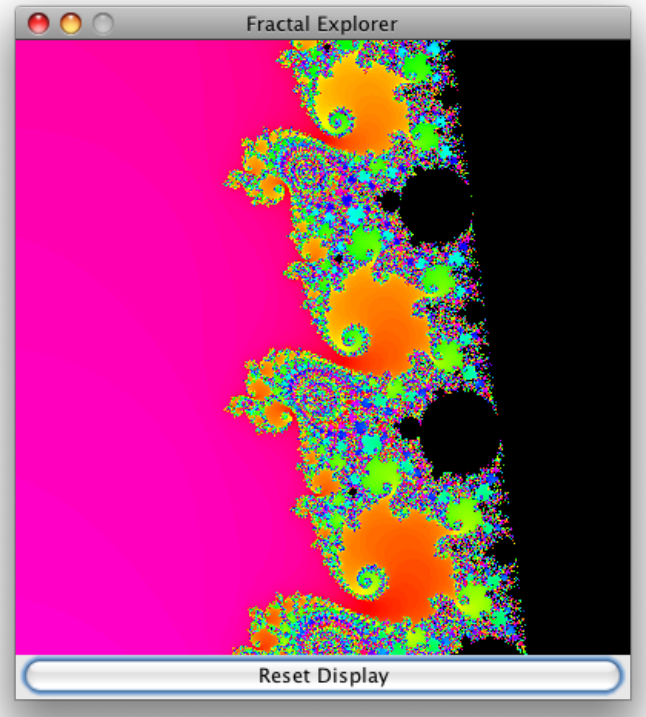
We will be building this application over multiple labs, so our initial version will be pretty simple, but we will build it up over the next few labs to include some neat features, like being able to save the images we generate, and being able to switch between different kinds of fractals. Both the GUI itself and the mechanism for supporting different fractals will depend on class hierarchies.

Here is a simple example of the GUI in its initial state:



And, here are some interesting areas of the fractal: elephants and seahorses!





Creating the User Interface

Before we can draw any fractals, we'll need to create a graphics widget that will allow us to display them. Swing doesn't provide such a component, but it is very easy to create one ourselves. Note that we will be using a wide range of Java AWT and Swing classes in this lab, and there is simply no way we can explain the details of each one. However, there is no need to, because the online Java API docs are very comprehensive and easy to use. Just navigate to the package of a given Java class, select the class itself, and then read the detailed information about how to use the class.

- Create a class `JImageDisplay` that derives from `javax.swing.JComponent`. The class should have one private field, an instance of a `java.awt.image.BufferedImage`. The `BufferedImage` class manages an image whose contents we can actually write to.

- The `JImageDisplay` constructor should take an integer width and height, and initialize its `BufferedImage` member to be a new image of that width and height, and an image-type of `TYPE_INT_RGB`. The type simply specifies how each pixel's colors are represented in the image; this particular value means that the red, green, and blue components are each 8 bits, and they appear in the int in that order.

  Your constructor must do one other thing too: it must call the parent class' `setPreferredSize()` method with the specified width and height. (You will have to pass these values in a `java.awt.Dimension` object you create specifically for this call.) This way, when your component is included in the user interface, it will actually display the entire image.

- Custom Swing components must provide their own drawing code by overriding the `protected paintComponent(Graphics g)` method of `JComponent`. Since our component will simply display the image data itself, our implementation will be very simple! First, the superclass `paintComponent(g)` implementation must always be called, so that any borders or other features are drawn properly. Once you have called the superclass version, you can draw the image into the component using an operation like this:

  ```
  g.drawImage(image, 0, 0, image.getWidth(), image.getHeight(), null);
  ```

  (We are passing `null` for the `ImageObserver`, since we don't need that functionality.)
- You also need to provide two public methods for writing data into the image: a `clearImage()` method that sets all pixels in the image data to black (RGB value 0), and a `drawPixel(int x, int y, int rgbColor)` method that sets a pixel to have a specific color. Both of these methods will need to use one of the `setRGB()` methods on the `BufferedImage` class.
- Of course, don't forget to write clear, complete and concise documentation for your class and methods, explaining what everything does.

Computing the Mandelbrot Fractal

Next you will write the code to compute the very well-known Mandelbrot fractal. In order to support multiple fractals in the future, you are provided with the `FractalGenerator.java` source file, which all of your fractal generators will derive from. You will also notice that some very helpful operations are provided to translate from screen coordinates into the coordinate-system of the fractal being computed.

The kinds of fractals we will be working with are computed in the complex plane, and involve very simple mathematical functions that are iterated repeatedly until some condition is satisfied. For the Mandelbrot fractal, the function is $z_n = z_{n-1}^2 + c$, where all values are complex numbers, $z_0 = 0$, and c is the particular point in the fractal that we are displaying. This computation is iterated until either $|z| > 2$ (in which case the point is not in the Mandelbrot set), or until the number of iterations hits a maximum value, e.g. 2000 (in which case we assume the point is in the set).

The process of plotting the Mandelbrot set is very simple: we simply iterate over each pixel in our image, compute the number of iterations for the corresponding coordinate, and then set the pixel to a color based on the number of iterations we computed. But, we will get to this in a second - for now, you simply need to implement the above computation.

- Create a subclass of `FractalGenerator` called `Mandelbrot`. You will see that there are only two methods that you need to provide in the subclass, `getInitialRange()` and `numIterations()`.
- The `getInitialRange(Rectangle2D.Double)` method simply allows the fractal generator to specify what part of the complex plane is the most "interesting" for a particular fractal. Note that the rectangle object is passed as an argument to the method, and the method must modify the rectangle's fields to reflect the proper initial range for the fractal. (You can see an example of this in the `FractalGenerator.recenterAndZoomRange()` method.) The `Mandelbrot` implementation of this method should set the initial range to (-2 - 1.5i) - (1 + 1.5i). That is, the x and y values will be -2 and -1.5 respectively, and the width and height will both be 3.

- The `numIterations(double, double)` method will implement the iterative function for the Mandelbrot fractal. You can define a constant for the "maximum iterations" like this:

  ```
  public static final int MAX_ITERATIONS = 2000;
  ```

  Then you can refer to this value in your implementation.

  Note that Java has no data type for complex numbers, so you will need to implement the iterative function using separate `double` components for the real and imaginary parts. (I suppose you could implement your own complex number class, but that will probably not be worth it.) You should try to make your implementation fast; for example, don't comppare $|z|$ to 2; compare $|z|^2$ to 2^2 to avoid nasty and

slow square-root computations. And don't use `Math.pow()` to compute small integer powers; multiply them out directly, otherwise your code will be very slow.

Finally, when you are iterating your function, if you hit `MAX_ITERATIONS` then simply return -1 to indicate that the point didn't escape outside of the boundary.

Putting It All Together

Finally we are ready to begin displaying fractals! Now you will create a `FractalExplorer` class that allows you to examine different parts of the fractal by creating and showing a Swing GUI, and handling events caused by various user interactions.

As you can see from the above images of the user interface, the Fractal Explorer is very simple, consisting of a `JFrame` containing a `JImageDisplay` object that displays the fractal, and a single `JButton` for resetting the display to show the entire fractal. You can achieve this simple layout by setting the frame to have a `BorderLayout`, then putting the display in the center of the layout, and the reset button in the "south" part of the layout.

- Your `FractalExplorer` class will need to keep track of several important fields for the program's state:
  - An integer "display size", which is simply the width and height of the display in pixels. (Our fractal display will be square.)
  - A `JImageDisplay` reference, so that we can update our display from various methods, as we compute the fractal.
  - A `FractalGenerator` object. We will use a base-class reference so that we can show other kinds of fractals in the future.
  - A `Rectangle2D.Double` object specifying the range of the complex plane that we are currently displaying.

  Of course, all of these fields will be private...
- The class should have a constructor that takes a display-size as an argument, then stores this value in the corresponding field, and also initializes the range and fractal-generator objects. Note that the constructor shouldn't set up any Swing components; these will be set up in the next method.
- Provide a `createAndShowGUI()` method that initializes the Swing GUI: a `JFrame` containing a `JImageDisplay` object and a button for resetting the display. You should set the frame to use a `java.awt.BorderLayout` for its contents; add the image-display object in the `BorderLayout.CENTER` position, and the button in the `BorderLayout.SOUTH` position.

  You should also give the frame a suitable title for your application, and set the frame's default close operation to "exit" (see the `JFrame.setDefaultCloseOperation()` method).

  Finally, after the UI components are initialized and laid out, include this sequence of operations:

  ```
  frame.pack();
  frame.setVisible(true);
  frame.setResizable(false);
  ```

  This will properly lay out the contents of the frame, cause it to be visible (windows are not initially visible when they are created, so that you can configure them before displaying them), and then disallow resizing of the window.
- You should implement a private helper method to display the fractal, e.g. called `drawFractal()`. This method should loop through every pixel in the display (i.e. *x* will range from 0 to display-size, as will *y*), and do the following:
  - Compute the number of iterations for the corresponding coordinates in the fractal's display area. You can determine the floating-point coordinates for a specific set of pixel coordinates using the `FractalGenerator.getCoord()` helper method; for example, to to get the x-coordinate corresponding to a pixel-X coordinate, you would do this:

    ```
    // x is the pixel-coordinate; xCoord is the coordinate in the fractal's space
    double xCoord = FractalGenerator.getCoord(range.x, range.x + range.width, displaySize, x);
    ```

  - If the number of iterations is -1 (i.e. the point doesn't escape, se the pixel's color to black (rgb value 0). Otherwise, you need to choose a value based on the number of iterations. We can actually use the HSV color space for this: as the hue ranges from 0 to 1, we get a smooth sequence of colors from red through yellow, green, blue, violet, and then back to red! You can use an operation like this:

    ```
    float hue = 0.7f + (float) numIters / 200f;
    int rgbColor = Color.HSBtoRGB(hue, 1f, 1f);
    ```

    Of course, if you come up with some other interesting way to color pixels based on the number of iterations, feel free to use it!
  - Of course, the display needs to be updated with the color for each pixel, so you will use your `drawPixel()` operation from earlier.
  - Finally, when you have finished drawing all pixels, you need to force the `JImageDisplay` to be repainted to match the current contents of its image. Do this by calling `repaint()` on the component. If you forget to do this, your display will never update!
- Create an inner class to handle `java.awt.event.ActionListener` events from the reset button. The handler simply needs to reset the range to the initial range specified by the generator, and then draw the fractal.

Once you have completed this class, update your `createAndShowGUI()` method to register an instance of this handler on the reset button.

- Create another inner class to handle `java.awt.event.MouseListener` events from the display. Really you only need to handle mouse-click events, so you should derive this inner class from the `MouseAdapter` AWT class mentioned in the lecture 3 slides. When this handler receives a mouse-click event, it should map the click pixel-coordinates into the area of the fractal that is being displayed, and then call the generator's `recenterAndZoomRange()` method with the coordinates that were clicked, and a scale of 0.5. This way, just by clicking on a location in the fractal display will zoom in on that location!

  Of course, don't forget to redraw the fractal after you have altered the area of the fractal being displayed.

  After this class is done, update your `createAndShowGUI()` method to register an instance of this handler on the fractal-display component.

- Finally, you need to create a static `main()` method for the fractal explorer so that it can be launched. The main method will be very simple at the moment:
  - Initialize a new `FractalExplorer` instance with a display-size of 800 (or whatever suits you, but not too large).
  - Call `createAndShowGUI()` on the explorer object.
  - Call `drawFractal()` on the explorer to see the initial view!

Once you have completed all these steps, you should be able to cruise around the Mandelbrot fractal looking at the amazing detail. If you zoom in enough you will run into two interesting issues:

- First, you will eventually find that the level of detail eventually runs out; this is because we would need more than 2000 iterations to find out if the point is in the Mandelbrot set or not! Of course, we might be tempted to increase the maximum iterations, but then the black areas of the fractal would *really* slow us down!
- Second, if you zoom in *really* far, you will eventually run into pixellated display output! This is because you are running into the limit of what double-precision floating-point values can represent.

You will probably also notice that it is kind of annoying how the entire display hangs while the fractal is being drawn. This is something we will explore in future labs, as well as taking advantage of multiple processors to draw our fractals much faster. But for now, once you have your Fractal Explorer completed (and well commented), you can submit your work to csman!

[end lab 3]

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