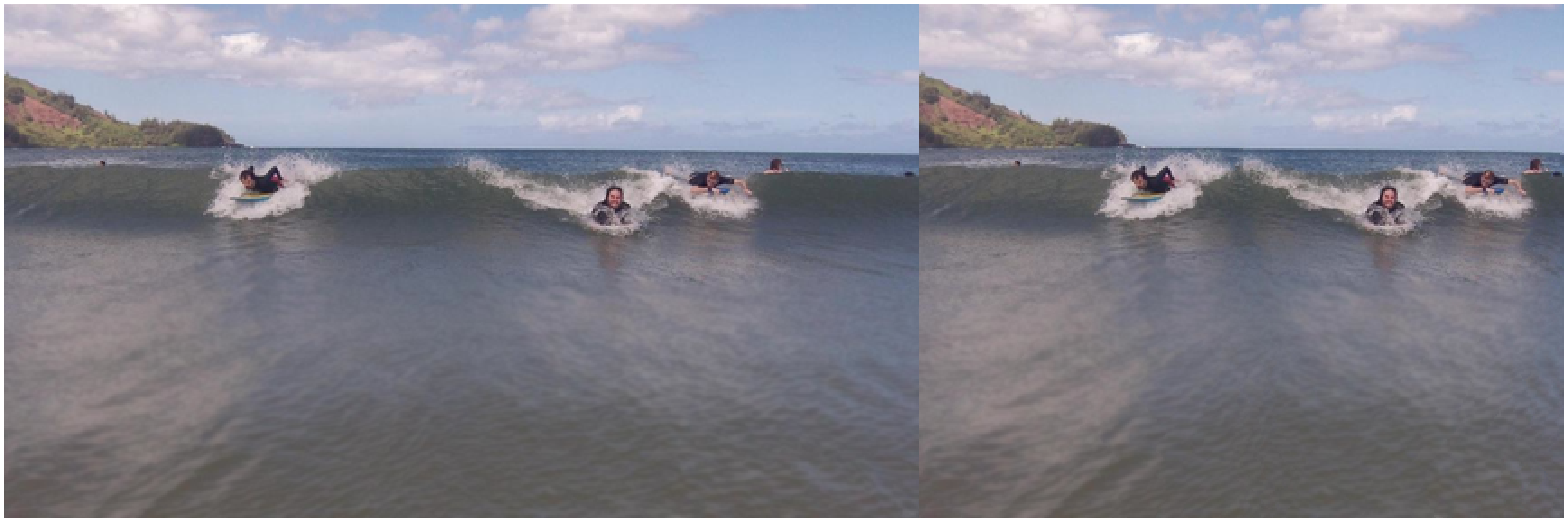
Seam Carving Assignment

Web Clip

Seam-carving is a content-aware image resizing technique where the image is reduced in size by one pixel of height (or width) at a time. A *vertical seam* in an image is a path of pixels connected from the top to the bottom with one pixel in each row; a *horizontal seam* is a path of pixels connected from the left to the right with one pixel in each column. Below left is the original 505-by-287 pixel image; below right is the result after removing 150 vertical seams, resulting in a 30% narrower image. Unlike standard content-agnostic resizing techniques (such as cropping and scaling), seam carving preserves the most interest features (aspect ratio, set of objects present, etc.) of the image.

Although the underlying algorithm is simple and elegant, it was not discovered until 2007. Now, it is now a core feature in Adobe Photoshop and other computer graphics applications.



In this assignment, you will create a data type that resizes a *W*-by-*H* image using the seam-carving technique. Finding and removing a seam involves three parts and a tiny bit of notation:

Notation. In image processing, pixel (*x*, *y*) refers to the pixel in column *x* and row *y*, with pixel (0, 0) at the upper-left corner and pixel (*W* − 1, *H* − 1) at the lower-right corner. This is consistent with the Picture data type in `algs4.jar`.

a 3-by-4 image

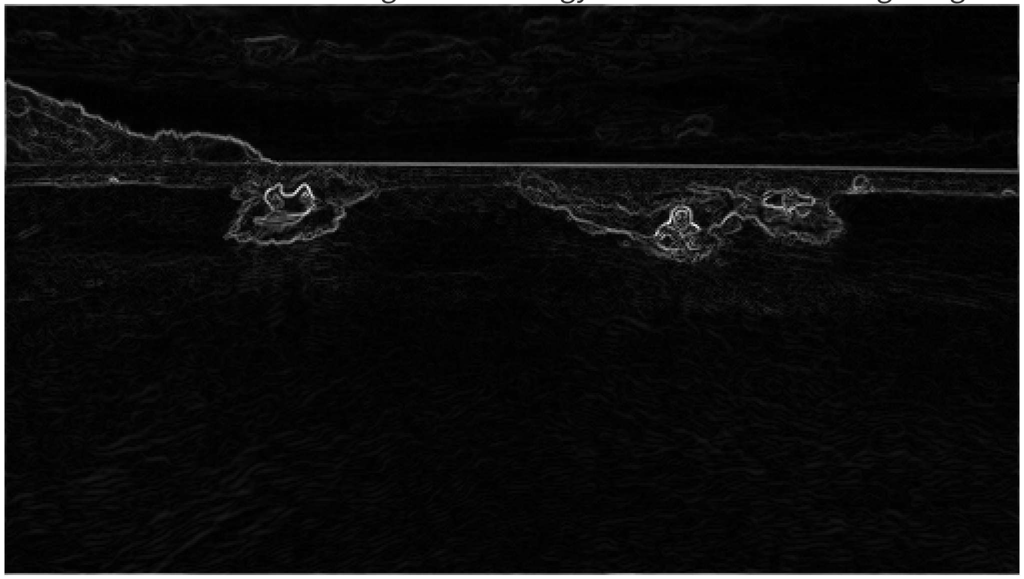
(0, 0)	(1, 0)	(2, 0)
(0, 1)	(1, 1)	(2, 1)

(0, 2)	(1, 2)	(2, 2)
(0, 3)	(1, 3)	(2, 3)

Warning: this is the opposite of the standard mathematical notation used in linear algebra, where (*i*, *j*) refers to row *i* and column *j* and (0, 0) is at the lower-left corner.

We also assume that the color of each pixel is represented in RGB space, using three integers between 0 and 255. This is consistent with the java.awt.Color data type.

Energy calculation. The first step is to calculate the *energy* of a pixel, which is a measure of its importance—the higher the energy, the less likely that the pixel will be included as part of a seam (as you will see in the next step). In this assignment, you will use the *dual-gradient energy function*, which is described below. Here is the dual-gradient energy function of the surfing image above:

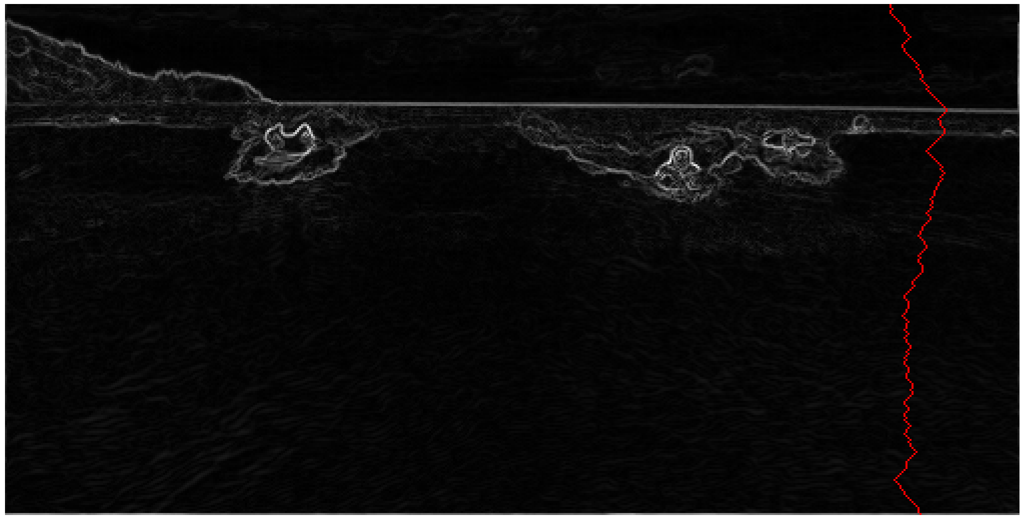


The energy is high (white) for pixels in the image where there is a rapid color gradient (such as the boundary between the sea and sky and the boundary between the surfing Josh Hug on the left and the ocean behind him). The seam-carving technique avoids removing such high-energy pixels.

Seam identification. The next step is to find a vertical seam of minimum total energy. (Finding a horizontal seam is analogous.) This is similar to the classic shortest path problem in an edge-weighted digraph, but there are three important differences:

- The weights are on the vertices instead of the edges.
- The goal is to find the shortest path from *any* of the *W* pixels in the top row to *any* of the *W* pixels in the bottom row.
- The digraph is acyclic, where there is a downward edge from pixel (*x*, *y*) to pixels (*x* − 1, *y* + 1), (*x*, *y* + 1), and (*x* + 1, *y* + 1), assuming that the coordinates are in the prescribed ranges.

Seams cannot wrap around the image (e.g., a vertical seam cannot cross from the leftmost column of the image to the rightmost column).



Seam removal. The final step is remove from the image all of the pixels along the vertical or horizontal seam.

The SeamCarver API. Your task is to implement the following mutable data type:

```
public class SeamCarver {

 // create a seam carver object based on the given picture
 public SeamCarver(Picture picture)

 // current picture
 public Picture picture()

 // width of current picture
 public int width()

 // height of current picture
 public int height()

 // energy of pixel at column x and row y
 public double energy(int x, int y)

 // sequence of indices for horizontal seam
 public int[] findHorizontalSeam()

 // sequence of indices for vertical seam
 public int[] findVerticalSeam()
```

```
   // remove horizontal seam from current picture
   public void removeHorizontalSeam(int[] seam)

   // remove vertical seam from current picture
   public void removeVerticalSeam(int[] seam)

   //  unit testing (required)
   public static void main(String[] args)

}
```

Corner cases. Your code must throw an exception when a constructor or method is called with an invalid argument, as documented below:

Throw an `IllegalArgumentException` if `energy()` is called with either an *x*-coordinate or *y*-coordinate outside its prescribed range.

Throw an `IllegalArgumentException` if the constructor, `removeVerticalSeam()`, or `removeHorizontalSeam()` is called with a null argument.

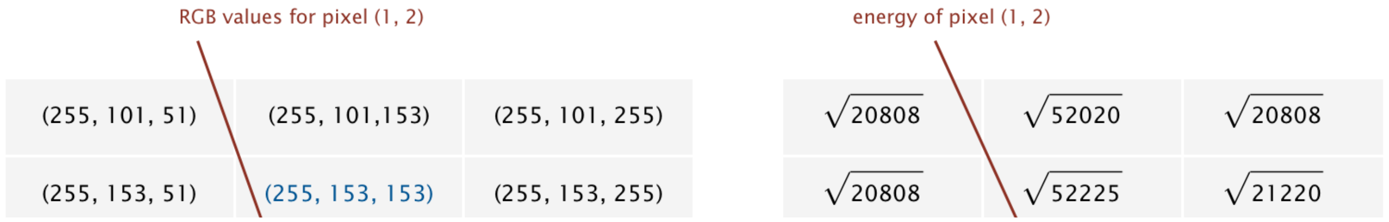
Throw an `IllegalArgumentException` if either `removeVerticalSeam()` or `removeHorizontalSeam()` is called with an array of the wrong length or if the array is not a valid seam (either an entry is outside the height/width bounds or two adjacent entries differ by more than 1).

Throw an `IllegalArgumentException` if either `removeVerticalSeam()` or `removeHorizontalSeam()` is called when the width or height of the current picture is 1, respectively.

Constructor. The data type may not mutate the `Picture` argument to the constructor.

Computing the energy of a pixel. You will use the *dual-gradient energy function*: The energy of pixel (x, y) is $\sqrt{\Delta_x^2(x, y) + \Delta_y^2(x, y)}$, where the square of the *x*-gradient $\Delta_x^2(x, y) = R_x(x, y)^2 + G_x(x, y)^2 + B_x(x, y)^2$, and where the central differences $R_x(x, y)$, $G_x(x, y)$, and $B_x(x, y)$ are the differences in the red, green, and blue components between pixel $(x + 1, y)$ and pixel $(x - 1, y)$, respectively. The square of the *y*-gradient $\Delta_y^2(x, y)$ is defined in an analogous manner. To handle pixels on the borders of the image, calculate energy by defining the leftmost and rightmost columns as adjacent and the topmost and bottommost rows as adjacent. For example, to compute the energy of a pixel $(0, y)$ in the leftmost column, use its right neighbor $(1, y)$ and its "left" neighbor $(W - 1, y)$.

As an example, consider the following 3-by-4 image (supplied as [3x4.png]):


RGB values for pixel (1, 2)
energy of pixel (1, 2)

(255, 101, 51)	(255, 101,153)	(255, 101, 255)
(255, 153, 51)	(255, 153, 153)	(255, 153, 255)

$\sqrt{20808}$	$\sqrt{52020}$	$\sqrt{20808}$
$\sqrt{20808}$	$\sqrt{52225}$	$\sqrt{21220}$

(255, 203, 51)	(255, 204, 153)	(255, 205, 255)
(255, 255, 51)	(255, 255, 153)	(255, 255, 255)

a 3-by-4 image (RGB values)

$\sqrt{20809}$	$\sqrt{52024}$	$\sqrt{20809}$
$\sqrt{20808}$	$\sqrt{52225}$	$\sqrt{21220}$

dual-gradient energies

The energy of the *non-border pixel* (1, 2) is calculated from pixels (0, 2) and (2, 2) for the *x*-gradient

$R_x(1, 2) = 255 - 255 = 0,$

$G_x(1, 2) = 205 - 203 = 2,$

$B_x(1, 2) = 255 - 51 = 204,$

yielding $\Delta_x^2(1, 2) = 2^2 + 204^2 = 41620;$

and pixels (1, 1) and (1, 3) for the *y*-gradient

$R_y(1, 2) = 255 - 255 = 0,$

$G_y(1, 2) = 255 - 153 = 102,$

$B_y(1, 2) = 153 - 153 = 0,$

yielding $\Delta_y^2(1, 2) = 102^2 = 10404.$

Thus, the energy of pixel (1, 2) is $\sqrt{41620 + 10404} = \sqrt{52024}$. Similarly, the energy of pixel (1, 1) is $\sqrt{204^2 + 103^2} = \sqrt{52225}$.

The energy of the *border pixel* (1, 0) is calculated by using pixels (0, 0) and (2, 0) for the *x*-gradient

$R_x(1, 0) = 255 - 255 = 0,$

$G_x(1, 0) = 101 - 101 = 0,$

$B_x(1, 0) = 255 - 51 = 204,$

yielding $\Delta_x^2(1, 0) = 204^2 = 41616;$

and pixels (1, 3) and (1, 1) for the *y*-gradient

$R_y(1, 0) = 255 - 255 = 0,$

$G_y(1, 0) = 255 - 153 = 102,$

$B_y(1, 0) = 153 - 153 = 0,$

yielding $\Delta_y^2(1, 0) = 102^2 = 10404.$

Thus, the energy of pixel (1, 0) is $\sqrt{41616 + 10404} = \sqrt{52020}$.

Finding a vertical seam. The `findVerticalSeam()` method returns an array of length *H* such that entry *y* is the column number of the pixel to be removed from row *y* of the image. For example, the dual-gradient energies of a 6-by-5 image (supplied as 6x5.png) are shown in the table below.

energy of seam = 159.43 + 107.89 + 133.07 + 174.01 + 70.06 = 644.47

240.18	225.59	302.27	**159.43**	181.81	192.99
124.18	237.35	151.02	234.09	**107.89**	159.67
111.10	138.69	228.10	**133.07**	211.51	143.75
130.67	153.88	**174.01**	284.01	194.50	213.53
179.82	175.49	**70.06**	270.80	201.53	191.20

the minimum energy vertical seam in a 6-by-5 image

The minimum energy vertical seam is highlighted in blue. In this case, the method `findVerticalSeam()` returns the array { 3, 4, 3, 2, 2 } because the pixels in the minimum energy vertical seam are (3, 0), (4, 1), (3, 2), (2, 3), and (2, 4).

Finding a horizontal seam. The behavior of `findHorizontalSeam()` is analogous to that of `findVerticalSeam()` except that it returns an array of length *W* such that entry *x* is the row number of the pixel to be removed from column *x* of the image. For the 6-by-5 image, the method `findHorizontalSeam()` returns the array { 2, 2, 1, 2, 1, 2 } because the pixels in the minimum energy horizontal seam are (0, 2), (1, 2), (2, 1), (3, 2), (4, 1), and (5, 2).

energy of seam = 111.10 + 138.69 + 151.02 + 133.07 + 107.89 + 143.75 = 785.53

240.18	225.59	302.27	159.43	181.81	192.99
124.18	237.35	**151.02**	234.09	**107.89**	159.67
111.10	**138.69**	228.10	**133.07**	211.51	**143.75**
130.67	153.88	174.01	284.01	194.50	213.53
179.82	175.49	70.06	270.80	201.53	191.20

the minimum energy horizontal seam in a 6-by-5 image

Unit testing. Your `main()` method must call each public constructor and method directly and help verify that they work as prescribed (e.g., by printing results to standard output).

Performance requirements. Make it fast.

Analysis of running time. Estimate empirically the running times (in seconds) to reduce a *W*-by-*H* image by one column and one row. Express your answer as a function of both *W*, and *H*. Use tilde notation to simplify your answer.

Submission. Submit `SeamCarver.java`. You may not call any library functions other than those in `java.lang`, `java.util`, `java.awt.Color`, and `algs4.jar`. Finally, submit a readme.txt file and answer the questions.

Grading.

file	*points*
finding seams	14
removing seams	10
other	10
`readme.txt`	6
	40

Reminder: You can lose up to 4 points for poor style and up to 4 points for inadequate unit testing.

This assignment was developed by Josh Hug, Maia Ginsburg, and Kevin Wayne.