[A] Pattern pre-processing algorithms

(1) Smoothing and cleaning algorithms

Smoothing is used to straighten the edges and remove noises from an image. Smoothing and noise removal can be done by a filtering mask, where using an algorithm, the output image is determined by matching values of the pixels in the neighborhood of the corresponding input pixel with the selected filter mask. Single pixel noises and one pixel wide noises can be removed using smoothing.

Smoothing using 3x3 linear filter mask

Algorithm:

Input:

- A 2 dimensional array of integer, **'Binary Matrix'** with binary values (0, 1) from **Binary Image**
- A 2 dimensional array of integers, **'Filter Mask'** with 4 filter values

[= , = , =]	[x , = , =]	[x , x , x]	[= , = , x]
[= , **T** , =]	[x , **T** , =]	[= , **T** , =]	[= , **T** , x]
[x , x , x]	[x , = , =]	[= , = , =]	[= , = , x]

Output: A 2 dimensional array of integer, **'Result Matrix'** with pixels matching the smoothing condition of 3x3 filter mask with filter value 4.

```
pixelChange <- false
  for each pixel from lower right corner of Binary Matrix
      target <- pixel in the center of Binary Matrix
       if neighbors of target pixel are aligned with '=' in the Filter Mask
          set target<- match the pixel value denoted by '='
          pixelChange<- true
      end if
 end for
return Result Matrix
```

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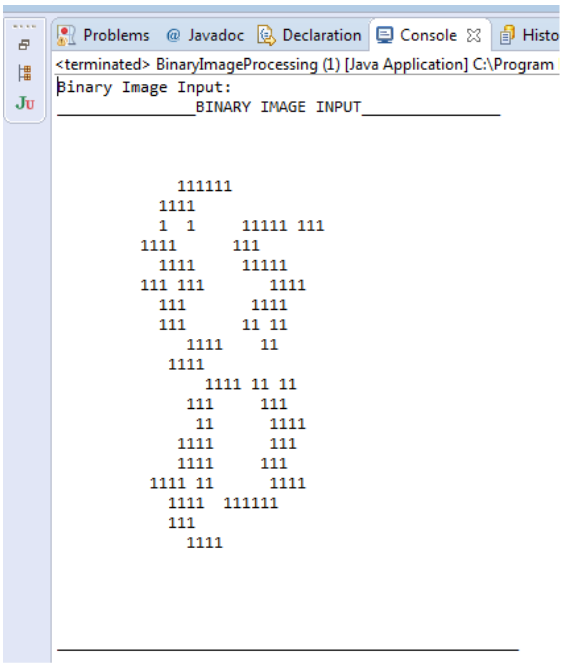
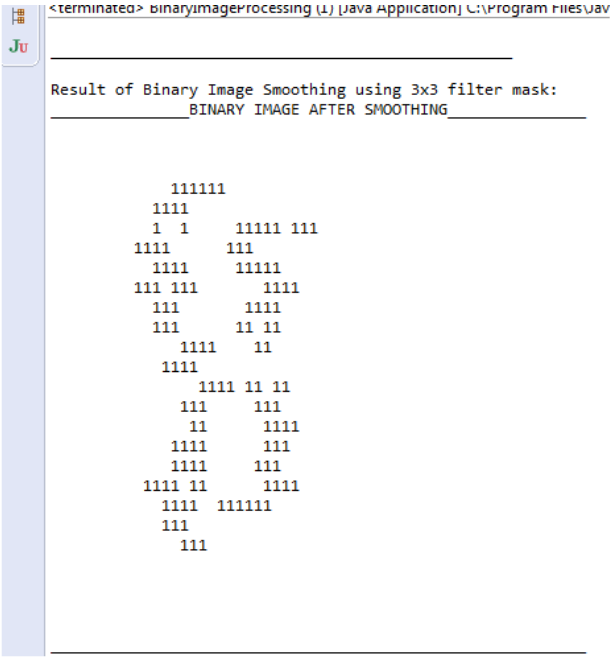
Results:

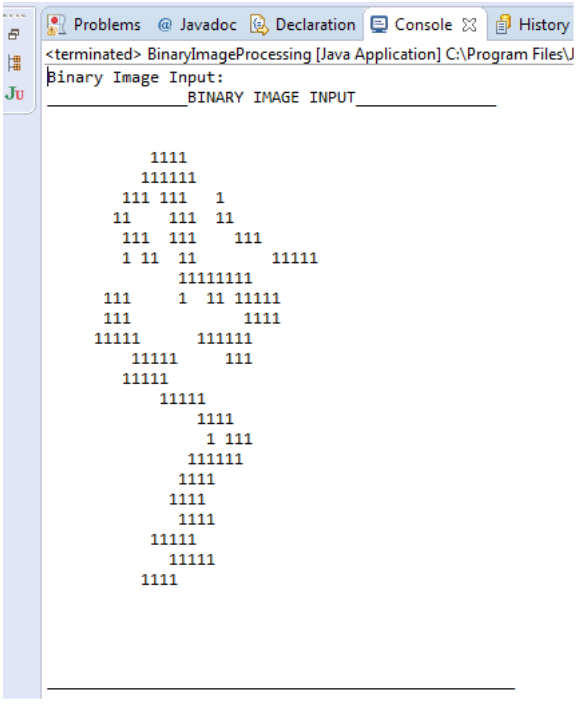
INPUT: Image 8



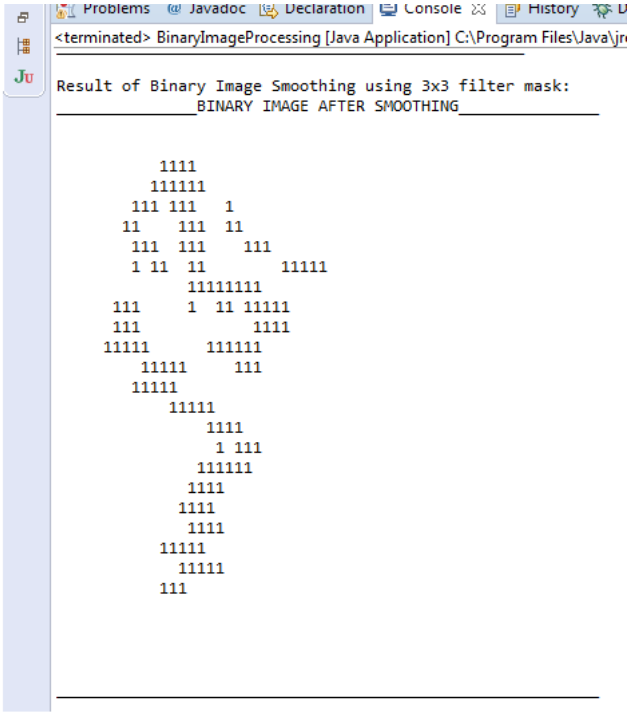
OUTPUT: Image 8 after smoothing using 3x3 Filter



INPUT: Image 9



OUTPUT: Image 9 after smoothing using 3x3 Filter



(2) Filling: 4 Neighbors filling

4 Neighbors Filling algorithm is used to fill the pixels which are blank in the image with the 4 immediate neighbors (East, West, North, and South) of Target Pixel. 4 Neighbors filling uses its immediate neighbors for the filling of pixels.ie, if Target pixels immediate 3 neighbors (East or West or North or South) are filled, then the Target pixel is filled else the Target pixel is not changed.

	N	
W	**T**	**E**
	S	

Algorithm:

Input: A 2 dimensional array of integer, **'Binary Matrix'** with binary values (0, 1) from **smoothing process**

Output: A 2 dimensional array of integer, **'Result Matrix'** with pixels matching **4 neighbors filling** conditions

for each pixel from upper left corner of **Binary Matrix**
Target Pixel <- pixel in the center of **Binary Matrix**
Left Pixel <- left pixel adjacent to the **Target Pixel**
Right Pixel <- right pixel adjacent to the **Target Pixel**
Upper Pixel <- Upper pixel adjacent to the **Target Pixel**
Lower Pixel <- lower pixel adjacent to the **Target Pixel**

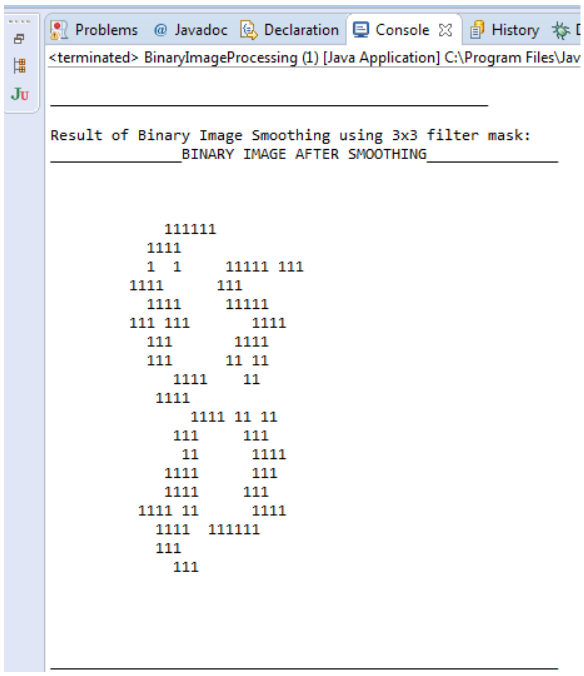
Target Pixel <- Target Pixel || (Upper Pixel & Lower Pixel & (Left Pixel | Right Pixel)) || (Left Pixel & Right Pixel & (Upper Pixel | Lower Pixel)) ;

end for

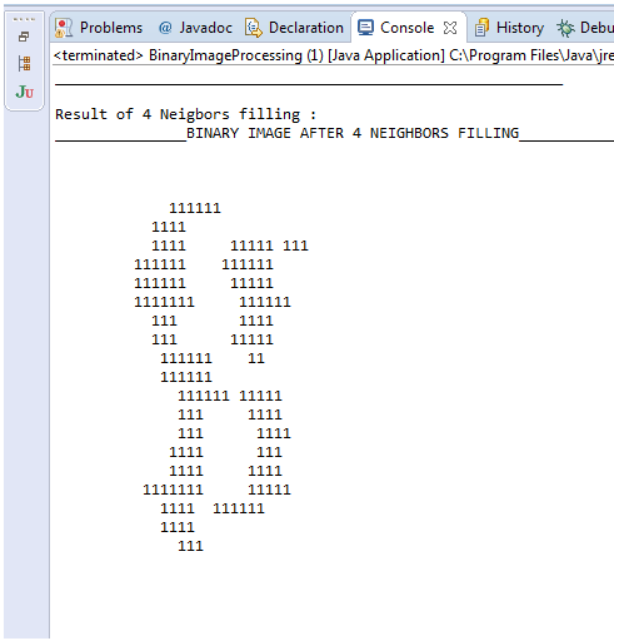
return Result Matrix

Results:

INPUT: Image 8 after smoothing

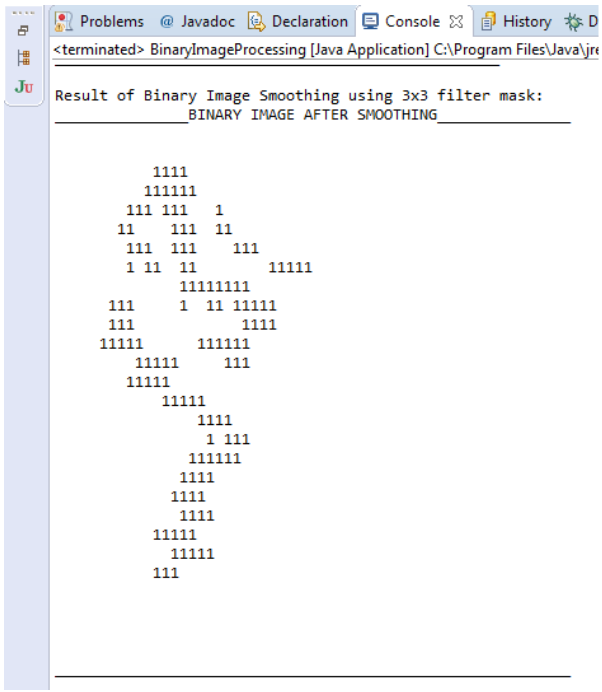


OUTPUT: Image 8 after 4 neighbors filling

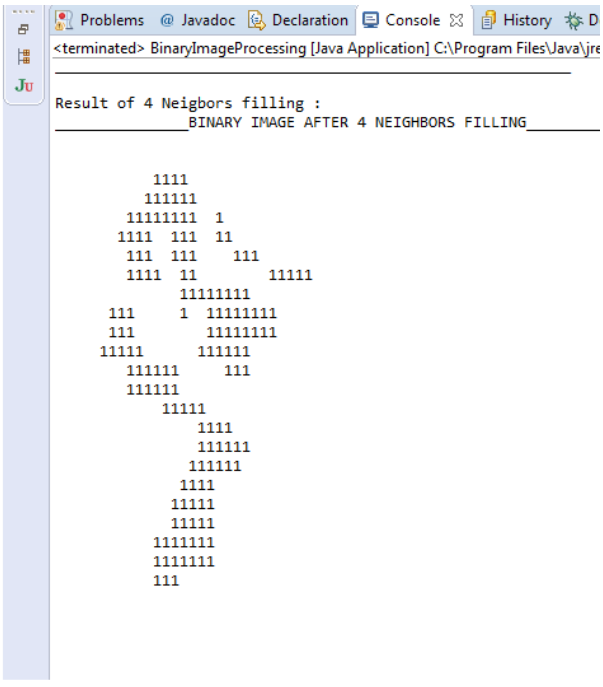


Results:

INPUT: Image 9 after smoothing



OUTPUT: Image 9 after 4 neighbors filling



(2) Filling: 8 neighbors filling

8 Neighbors Filling algorithm is used to fill the pixels which are blank in the image with the 4 immediate neighbors (East, West, North, and South) and 4 diagonal neighbors (Northeast, Northwest, Southeast and Southwest) of Target Pixel. 8 Neighbors filling uses its diagonal neighbors for the filling of pixels.ie, if Target pixels diagonal pixels are filled then the Target pixel is filled else the Target pixel is not changed.

NW	**N**	**NE**
W	**T**	**E**
SW	**S**	**SE**

Algorithm:
Input: A 2 dimensional array of integer, **'Binary Matrix'** with binary values (0, 1) from **4 neighbors filling** process

Output: A 2 dimensional array of integer, **'Result Matrix'** with pixels matching **8 neighbors filling** conditions

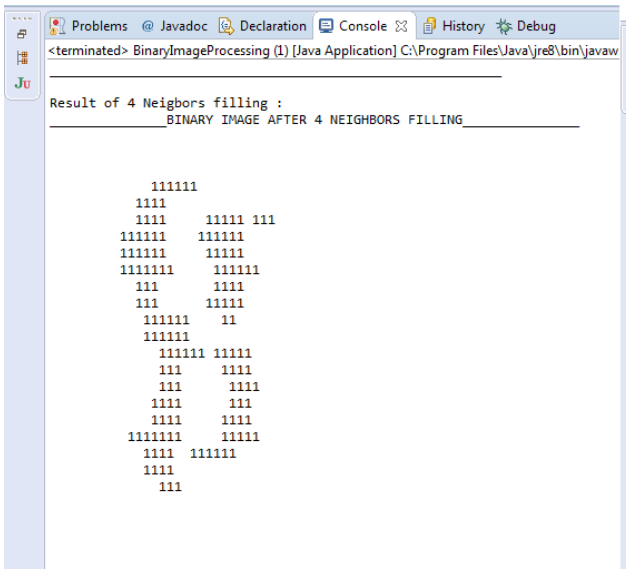
for each pixel from upper left corner of **Binary Matrix**
Target Pixel <- pixel in the center of **Binary Matrix**
Left Pixel <- left pixel adjacent to the **Target Pixel**
Right Pixel <- right pixel adjacent to the **Target Pixel**
Upper Pixel <- Upper pixel adjacent to the **Target Pixel**
Lower Pixel <- lower pixel adjacent to the **Target Pixel**

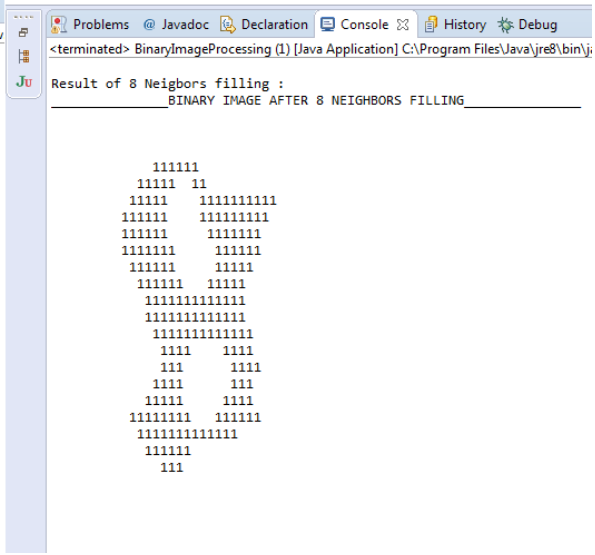
Left Upper Pixel <- left upper pixel adjacent to the **Target Pixel**
Left Lower Pixel <- left lower pixel adjacent to the **Target Pixel**
Right Upper Pixel <- right upper pixel adjacent to the **Target Pixel**
Right Lower Pixel <- right lower adjacent to the **Target Pixel**

Target Pixel <- Target Pixel
|| Left Upper Pixel && Right Lower Pixel
|| Upper Pixel && Lower Pixel
|| Right Upper Pixel && Left Lower Pixel
|| Left Pixel && Right Pixel

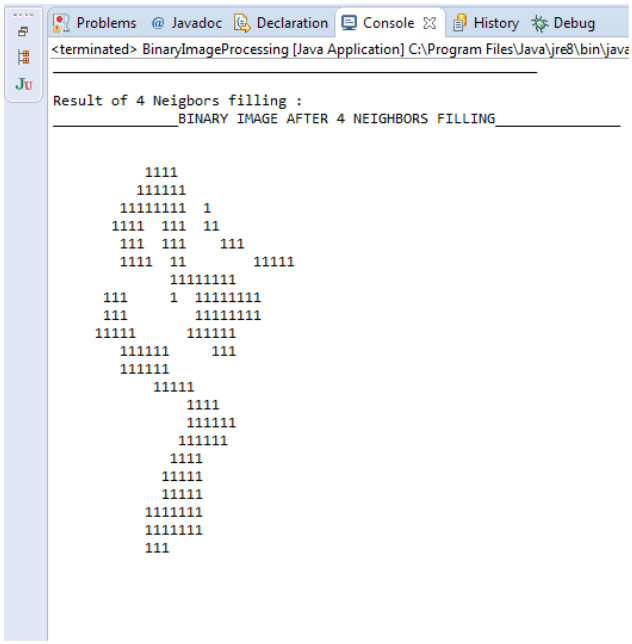
end for
return Result Matrix

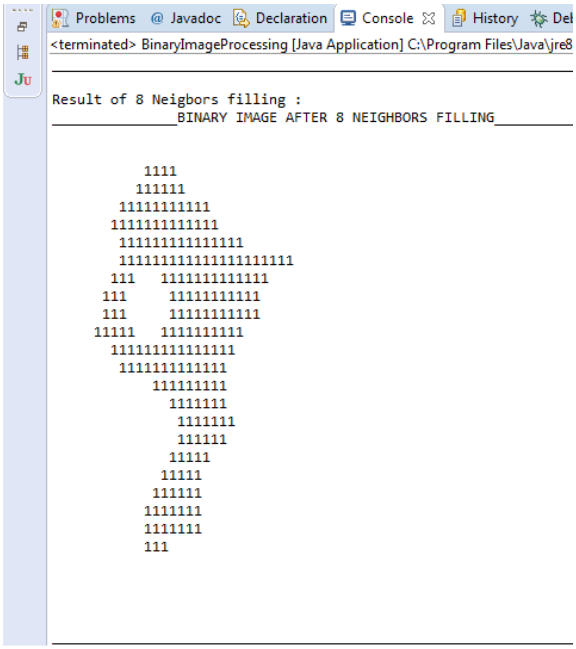
Results:
INPUT: Image 8 after 4 neighbors filling OUTPUT: Image 8 after 8 neighbors filling





Results:
INPUT: Image 9 after 4 neighbors filling OUTPUT: Image 9 after 8 neighbors filling





[A] (ii) Normalization

Size Normalization: The goal of the size normalization is to reduce the shape of the original image to a standard pre-defined size. Image length and width are reduced to a standard pane with a pre-defined length and width.

Using linear normalization method, width and height (W1 and H1) of original character is reduced normalized image size (W2 and H2).Using backward mapping process, From left top corner of Image each pixel is scanned and index of each pixel is multiplied with the normalization ratio(alpha – length, beta- Width) and the pixel index is set.

Algorithm:

Input: A 2 dimensional array of integer, **'Binary Matrix'** with binary values (0, 1) from **8 neighbors filling** process

Output: A 2 dimensional array of integer, **'Normalized Result Matrix'** with **Normalized row size** and **Normalized Column size,** after the Size Normalization

Set:

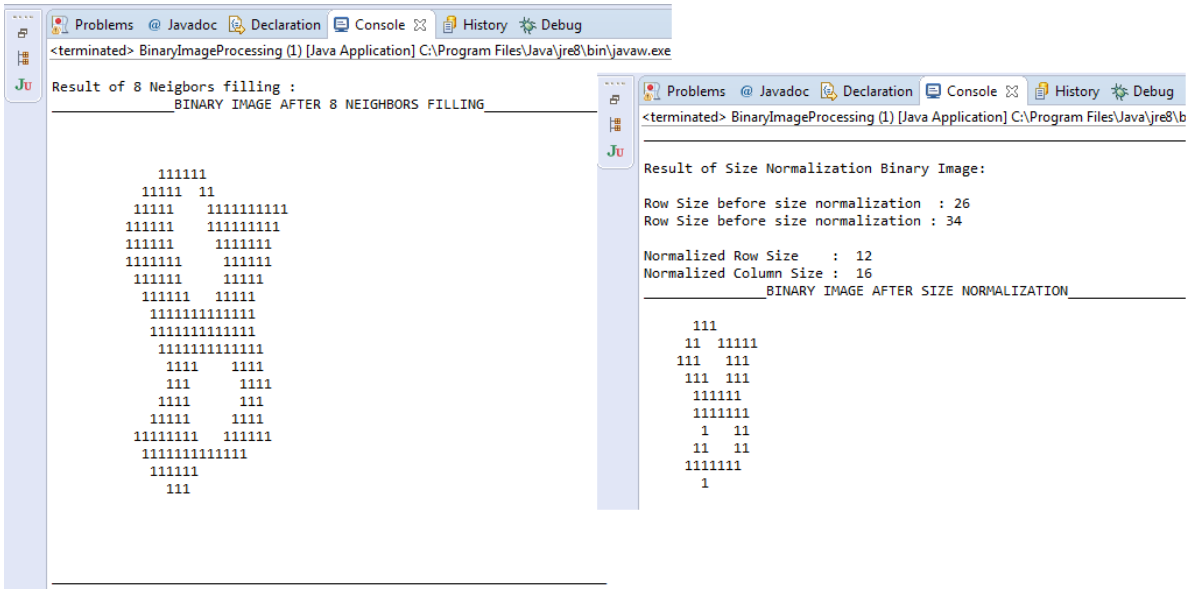
Alpha <- Normalization ratio for length of the Binary Image

Beta <- Normalization ratio for breadth of the Binary Image

```
for each X value from upper corner of Binary Matrix
   for each Y value from upper corner of Binary Matrix
        X' Index <-  X Index / Alpha
        Y' Index <-  Y Index / Beta
        Result Matrix( X' Index, Y' Index) <- Binary Matrix( X Index, Y Index)
   end for
end for
return Result Matrix
```

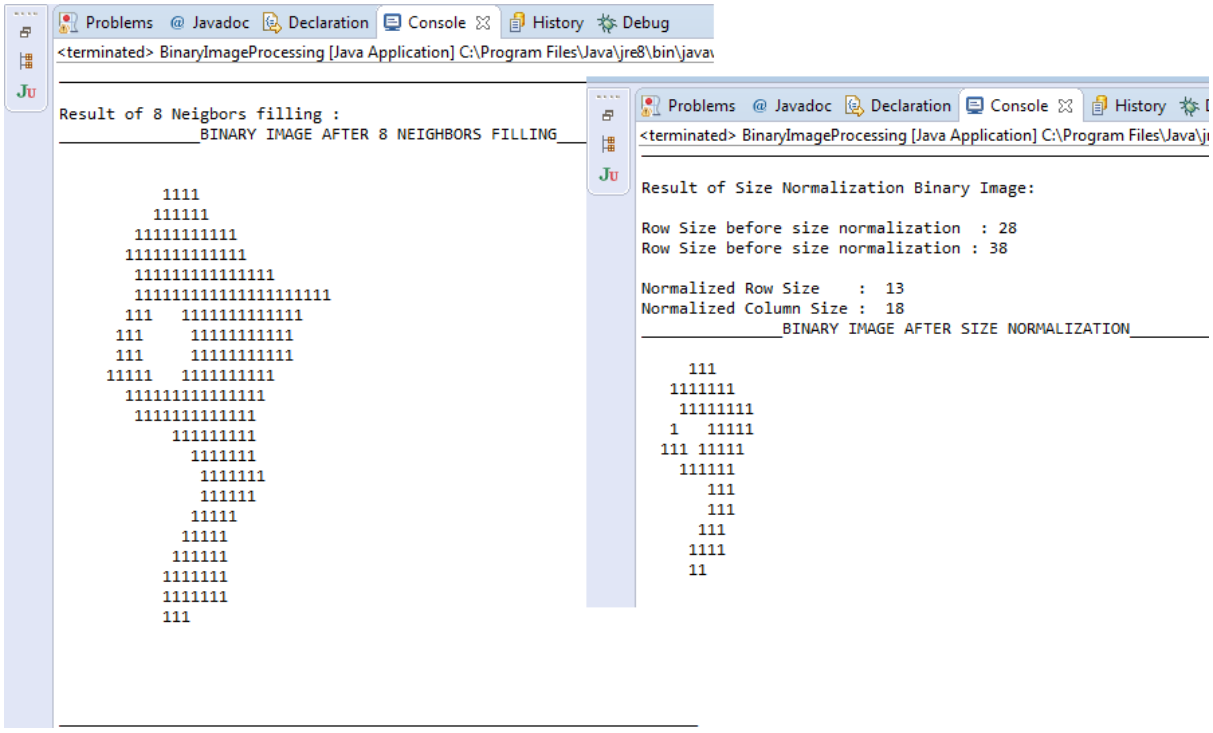
Results:
Size reduced to 50%

INPUT: Image 8 after 8 neighbor filling **OUTPUT: Image 8 after Size Normalization**



Results:
Size reduced to 50%

INPUT: Image 8 after 8 neighbor filling **OUTPUT: Image 8 after Size Normalization**



[A] (III) Center of Gravity

Center of Gravity is the point around which the black pixels (1's in binary image) is equally distributed.

Center of Gravity can be calculated by sum of the pixels in the region each multiplied by its value, divided by the sum of these values.

0	1	0
1	COG	1
0	1	0

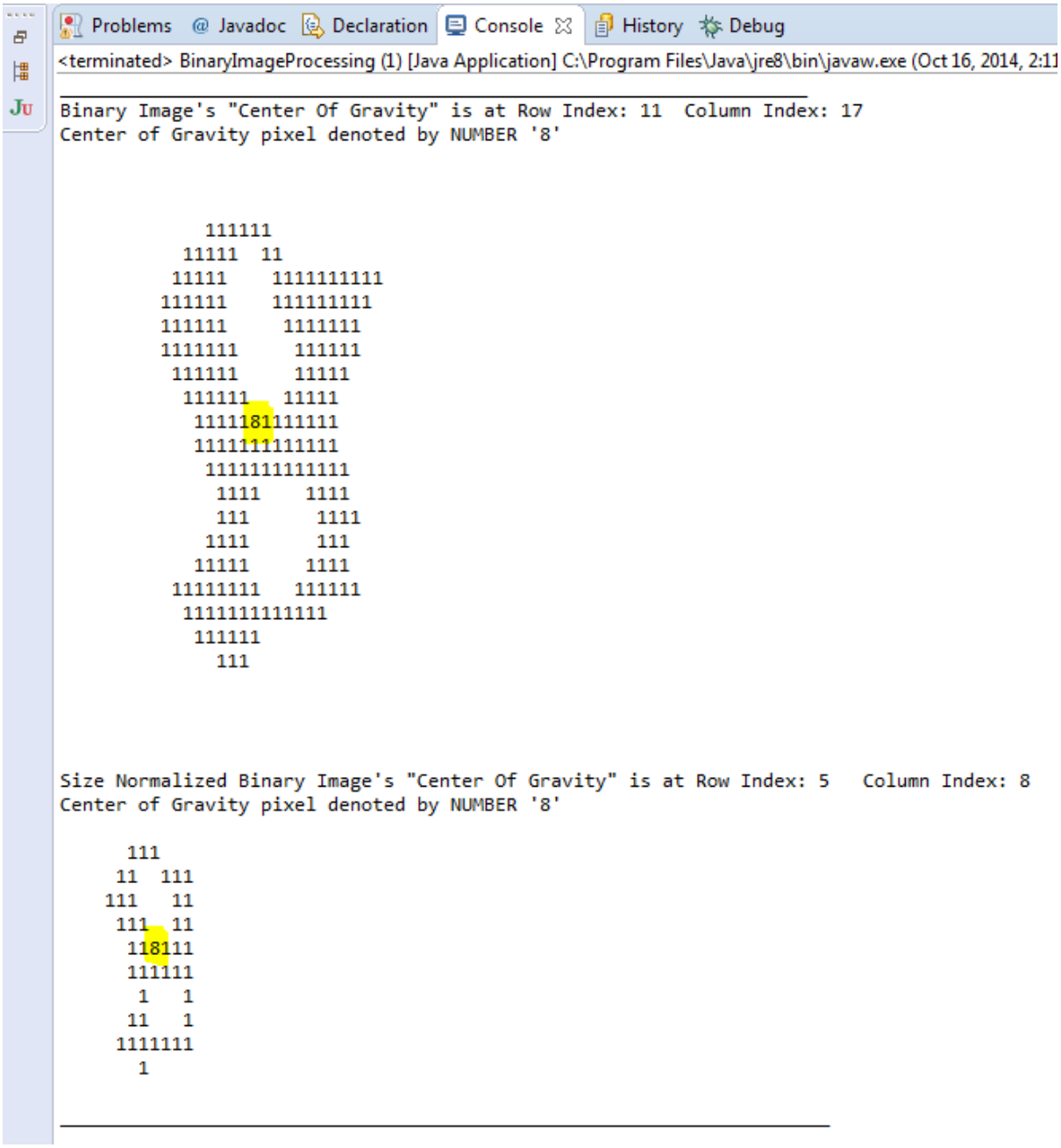
Algorithm:
Input: A 2 dimensional array of integer, **'Binary Matrix'** with binary values (0, 1)

Output: A **Pixel(X Index, Y Index)** which denotes the center of gravity for the Binary Image

Set: **X Index Sum** <- 0
Y Index Sum <- 0
Pixel Count <- 0
for each **X** value from upper corner of **Binary Matrix**
for each **Y** value from upper corner of **Binary Matrix**
if Binary Matrix(X, Y) is a **true**
set: **X Index Sum = X Index Sum + X**
Y Index Sum = Y Index Sum + Y
Increment **Pixel Count**
end if
end for
end for
COG X Index = X Index Sum / Pixel Count
COG Y Index = Y Index Sum / Pixel Count
return **Pixel(COG X Index, COG Y Index)**

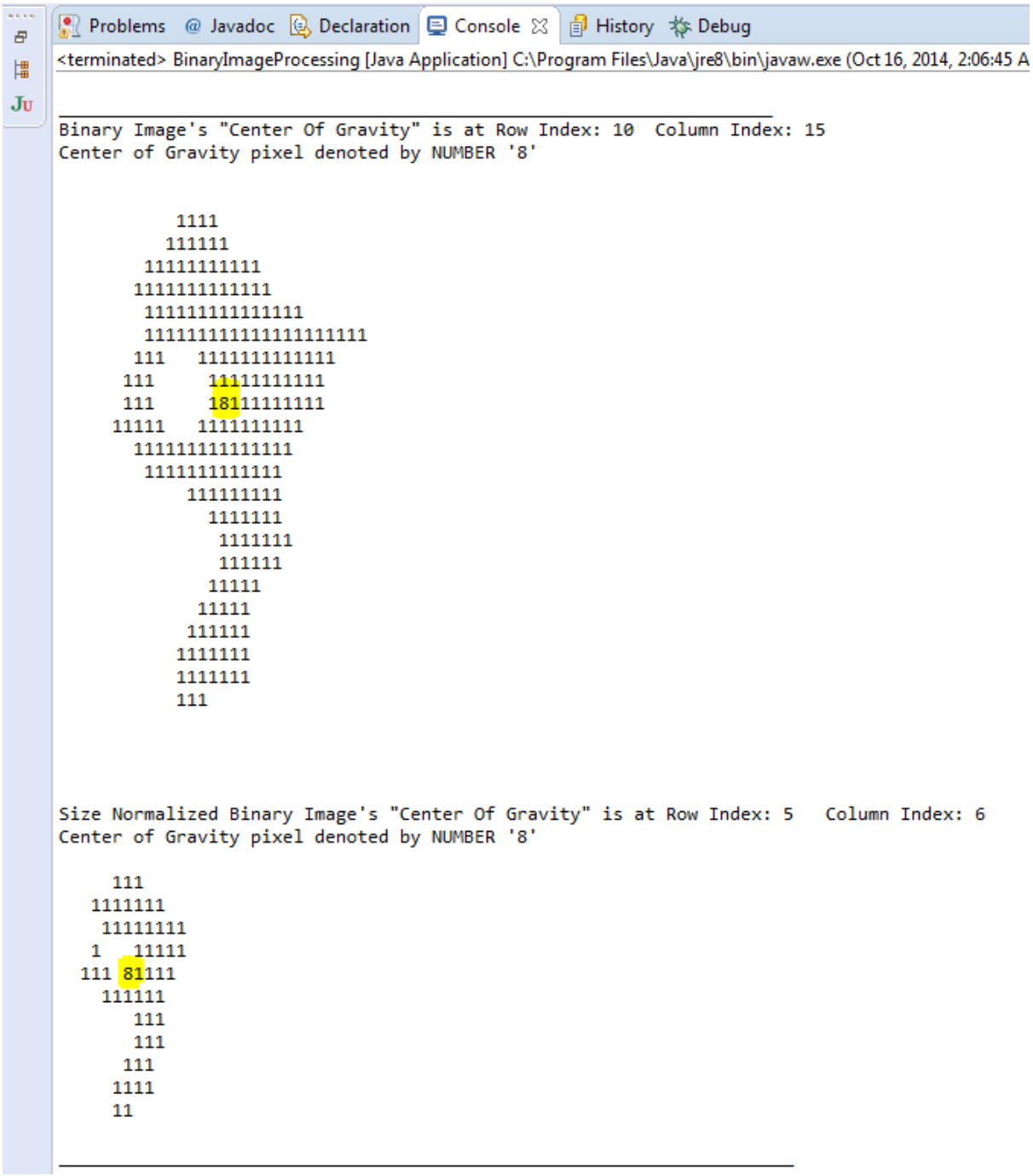
Results:

OUTPUT: Image 8 & Normalized Image 8 with Center of Gravity



Results:

OUTPUT: Image 9 & Normalized Image 9 with Center of Gravity



(B) Skeleton extraction

Skeletonizing is a process for reducing foreground regions (number of 1's) in a binary image to a skeletal remnant that largely preserves the extent and connectivity of the original region (binary image of size 1) while removing most of the original foreground pixels.

Zhang-Suen Skeletonizing

This skeletonizing algorithm repeatedly removes foreground pixels from a region in a binary image until skeletal remnant is present. **Zhang-Suen Skeletonizing** uses two iterations algorithm to remove the foreground pixels. The 1st pass checks for the 8-neighbors of target pixel, which uses southeast boundary and northwest corner point and checks if the pixel can be removed without disturbing the ideal skeleton. The 2nd pass uses the same procedure from northwest boundary points and southeast corner pixel. Iterations are done until there are no changes of pixels are detected in the two passes in the binary image.

Algorithm:

Input: A 2 dimensional array of integer, **'Binary Matrix'** with binary values (0, 1) from Size Normalization

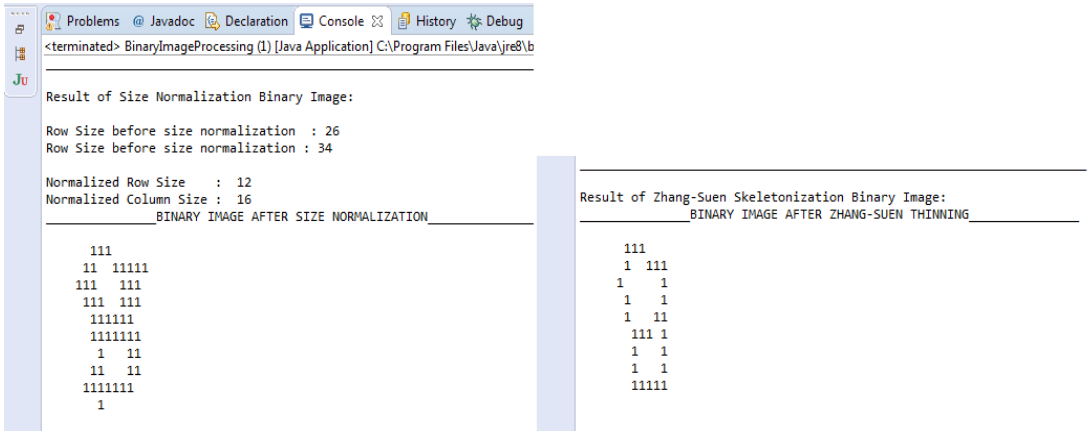
Output: 1 pixel size width skeletonized 2 dimensional array of integer, **'Result Matrix'**

P8	**P1**	**P2**
P7	**P**	**P3**
P6	**P5**	**P4**

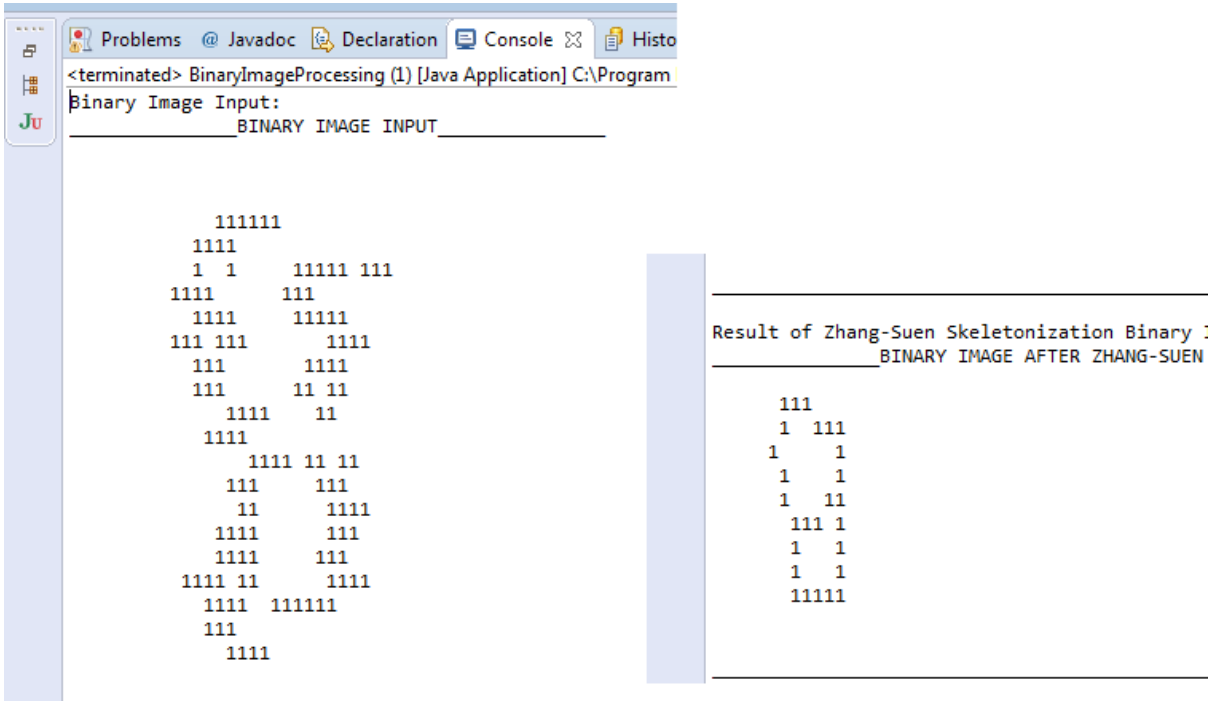
A <- Binary Image {0, 1}
for each **X** value from upper corner of **Binary Matrix A**
    for each **Y** value from upper corner of **Binary Matrix A**
        P<- pixel in the center of **Binary Matrix A**
        P1, P2, P3, P4, P5, P6, P7, P8 be the 8-neighbors of Pixel **P**
        B (P) <- number of non-zero 8-neighbors pf **P**
        A (P) <- number of zero-to-one transitions in the sequence of
            P1->P2->P3->P4->P5->P6->P7->P8->P1
        i**f**
            2<= B (P) <= 6 and A(P) == 1 and P1.P3.P5 == 0 and P3.P5.P7 == 0
            then remove Pixel **P**
        end if
        else if
            2<= B (P) <= 6 and A(P) == 1 and P1.P3.P7 == 0 and P1.P5.P7 == 0
            then remove Pixel **P**
        end if
    end for
end for

Results of Image 8

Output: Image 8 after Zhang-Suen Skeletonizing

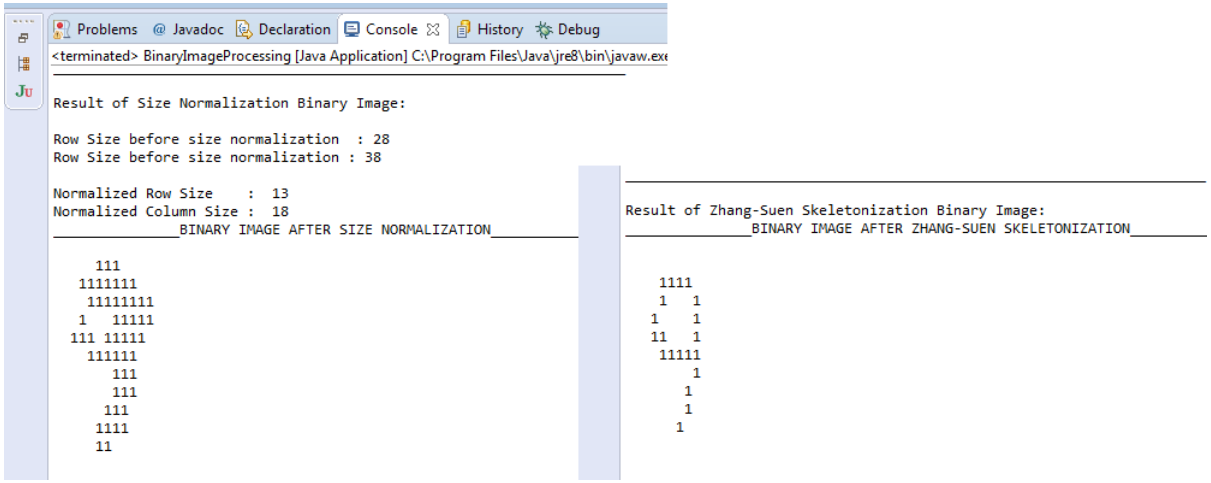


Output: Input Image 8 and Image 8 after Zhang-Suen Skeletonizing



Result of Image 9

Output: Image 9 after Zhang-Suen Skeletonizing



Output: Input Image 9 and Image 9 after Zhang-Suen Skeletonizing