Software documentation for Context-Aware MRF-based Image Inpainting

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SUMMER INTERNSHIP

July-August 2016

COURSE: COMPUTER GRAPHICS

Optimizing the image inpainting code of the method reported in

T. Ružic and A. Pižurica, “Context-aware patch-based image inpainting using Markov random field modeling,” IEEE Transactions on Image Processing, vol. 24, no. 1, pp. 444-456, Jan 2015.

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1. INTODUCTION

Image inpainting is an image processing task of filling in the missing region in an image in a visually plausible way. Numerous applications include image restauration, photo editing, and error concealment in image coding and transmission. Here we document the code of the context-aware patch-based image inpainting method using Markov Random Field (MRF) modelling, developed by Tijana Ružić and Aleksandra Pižurica. The main idea of this method is to employ contextual (textural) descriptors to guide and improve the inpainting process. Two main components are:

- Context-aware selection strategy for candidate patches
- A globally optimal solution to the puzzle problem using an MRF prior model

Context-aware patch selection strategy is not limited to global inpainting. It aims at improving and accelerating the search for candidate patches in patch-based methods in general.

In this particular realization of the method normalized texton histograms computed from Gabor filter responses are used as contextual descriptors. In general any other contextual descriptors can be used.

There are two strategies for dividing an image into regions based on the context:

- Division into fixed-size square non-overlapping blocks
- Division into blocks of adaptive size

In this particular realization of the inpaintig method division into blocks of adaptive size is used.

Interface method for global MRF-based inpainting uses novel optimization approach that makes it suitable in case of a large number of labels.

The original code was written in Matlab by T. Ružić.

This document describes an optimized version of the program. The main program file and every function that is called from it contains an explanation that can be read by using the help function in Matlab. The script version of the main program file is: **content_aware_mrf_inpainting** and its version written as a function is: **content_aware_mrf_inpainting_func**.

2. SCRIPT VERSION

The function version of the main program is described at the end of this document. Here we give the script version that calls all other functions. The structure of the program is given below:

1. **content_aware_mrf_inpainting**
    - 1.1. **textonGenerateContrastNorm**
        - 1.1.1. **createGabor**
    - 1.2. **decomposition_adaptive_blocksize**
        - 1.2.1. **splitVertically**
        - 1.2.2. **splitHorizontally**
        - 1.2.3. **chiTestTexton**
    - 1.3. **textonHistBlock**
    - 1.4. **gist_matches_all_adaptive_blocksize_weighted**
        - 1.4.1. **find_neighbours_adaptive**
    - 1.5. **find_label_pos_per_adaptive_blocksize**
    - 1.6. **comp_data_gist_ver4_adaptive_scaled_weighted**
        - 1.6.1. **compdata.c**
    - 1.7. **label_extraction_gist_weighted**
        - 1.7.1. **find_first**
        - 1.7.2. **label_pruning_art_fast**
        - 1.7.3. **find_neighbours**
        - 1.7.4. **calculate_weighted_dif_fast1**
            - 1.7.4.1. **overlap_region**
            - 1.7.4.2. **calculatediffhelper.c**
        - 1.7.5. **upade_priority_scaled**

1.8. **compute_pot_art**

1.8.1. **find_neighbours**

1.8.2. **comp_matrix_pot_art**

1.8.2.1. **overlap_region**

1.8.2.2. **calculatepotentionalhelper.c**

1.9. **compute_cost_art**

1.9.1. **getpatch**

1.9.2. **ssd3**

1.10. **NCMP**

1.10.1. **find_neighbours**

1.10.2. **normalise_new_inf**

1.11. **output_art_mincut**

1.11.1. **binomialFilter**

1.11.2. **getpatch**

1.11.3. **dpmain**

1.11.3.1. **dp1**

1.11.3.2. **dp2**

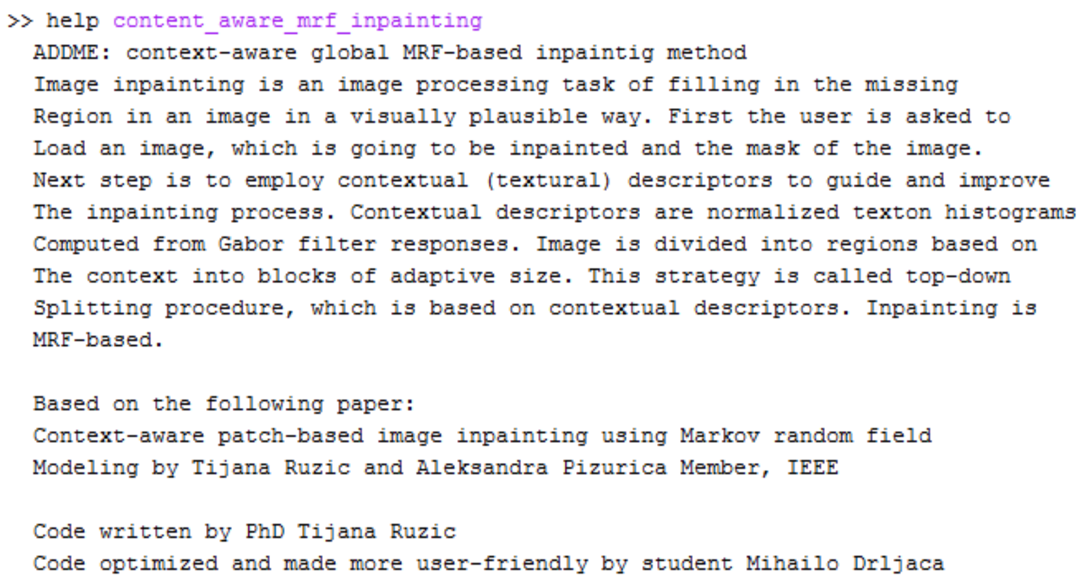
1.11.3.3. **randmin**

1.11.4. **dp**

1.11.5. **rconv2**

1.12. **show_order**

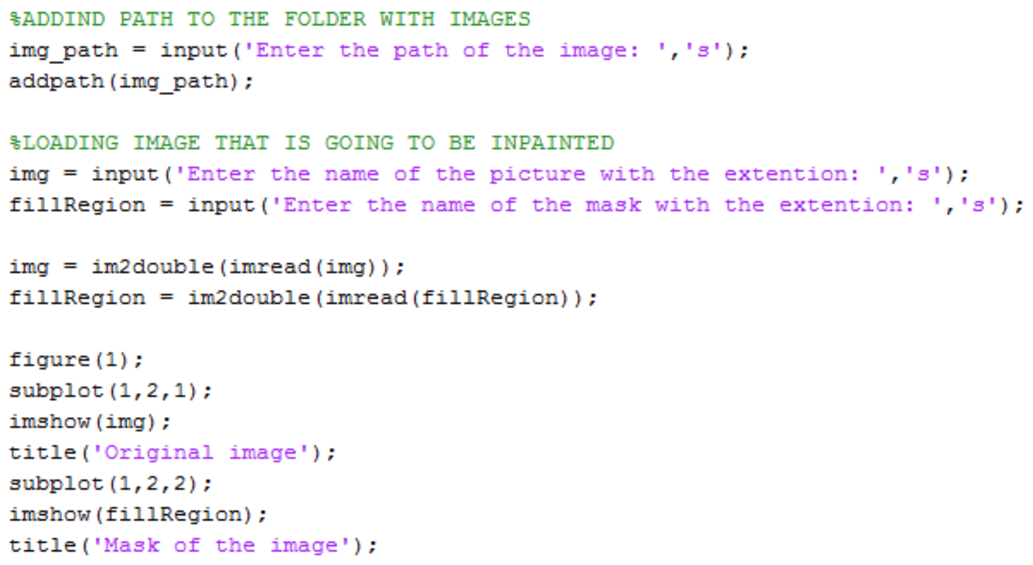
The script file is called **content_aware_mrf_inpainting**. Using the **help** function, one gets the following explanation about this file:



```
>> help content_aware_mrf_inpainting
  ADDME: context-aware global MRF-based inpaintig method
  Image inpainting is an image processing task of filling in the missing
  Region in an image in a visually plausible way. First the user is asked to
  Load an image, which is going to be inpainted and the mask of the image.
  Next step is to employ contextual (textural) descriptors to guide and improve
  The inpainting process. Contextual descriptors are normalized texton histograms
  Computed from Gabor filter responses. Image is divided into regions based on
  The context into blocks of adaptive size. This strategy is called top-down
  Splitting procedure, which is based on contextual descriptors. Inpainting is
  MRF-based.

  Based on the following paper:
  Context-aware patch-based image inpainting using Markov random field
  Modeling by Tijana Ruzic and Aleksandra Pizurica Member, IEEE

  Code written by PhD Tijana Ruzic
  Code optimized and made more user-friendly by student Mihailo Drljaca
```

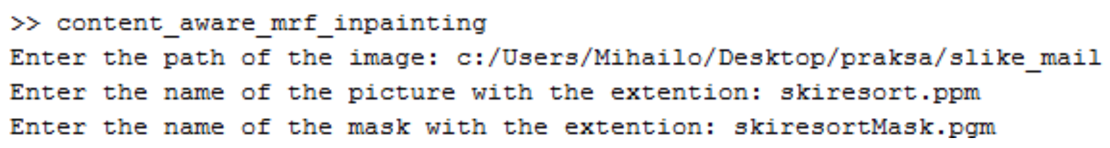
Picture 2.1. Matlab command window

Before creating contextual descriptors, the input image and the mask (indicating the missing region) have to be loaded. The user is prompt to insert a path to the mask and the image. Then the user has to insert the image name and the file extension. Matlab function **input** is being used to prompt the user. Functions **imread** and **im2double** are used to load the image and the mask. After that the mask and the image are displayed. (Picture 2.4)



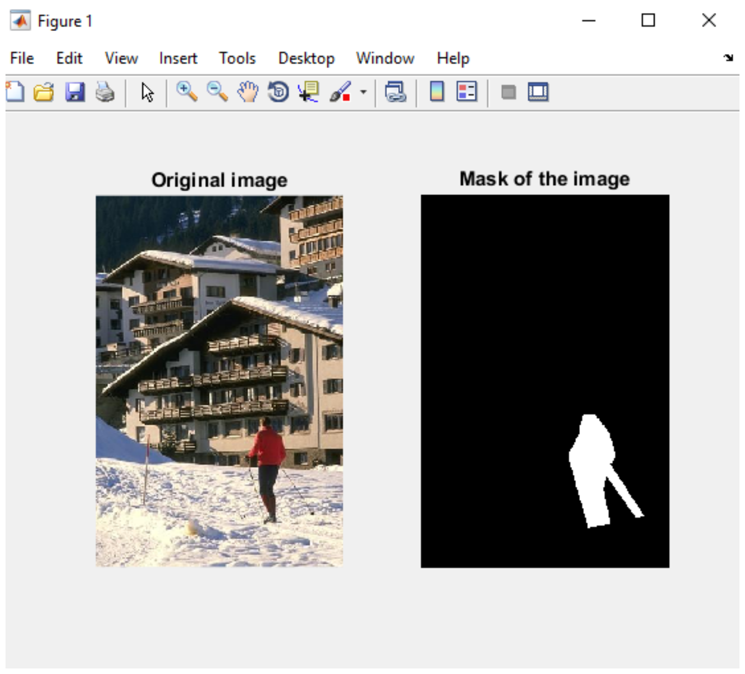
```
%ADDIND PATH TO THE FOLDER WITH IMAGES
img_path = input('Enter the path of the image: ','s');
addpath(img_path);

%LOADING IMAGE THAT IS GOING TO BE INPAINTED
img = input('Enter the name of the picture with the extention: ','s');
fillRegion = input('Enter the name of the mask with the extention: ','s');

img = im2double(imread(img));
fillRegion = im2double(imread(fillRegion));

figure(1);
subplot(1,2,1);
imshow(img);
title('Original image');
subplot(1,2,2);
imshow(fillRegion);
title('Mask of the image');
```

Picture 2.2. Part of the code that is responsible for loading image and mask



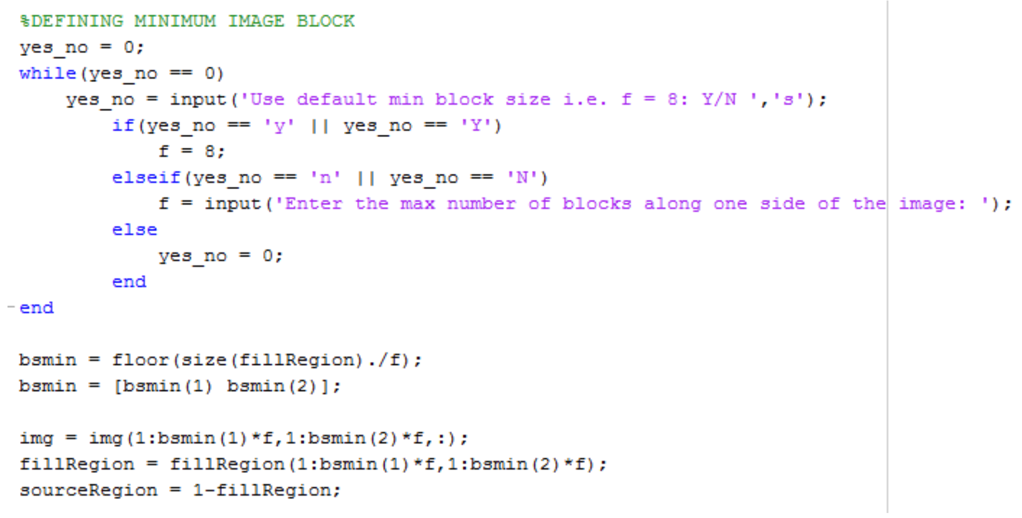
```
>> content_aware_mrf_inpainting
Enter the path of the image: c:/Users/Mihailo/Desktop/praksa/slike_mail
Enter the name of the picture with the extention: skiresort.ppm
Enter the name of the mask with the extention: skiresortMask.pgm
```

Picture 2.3. User interface – Matlab command window



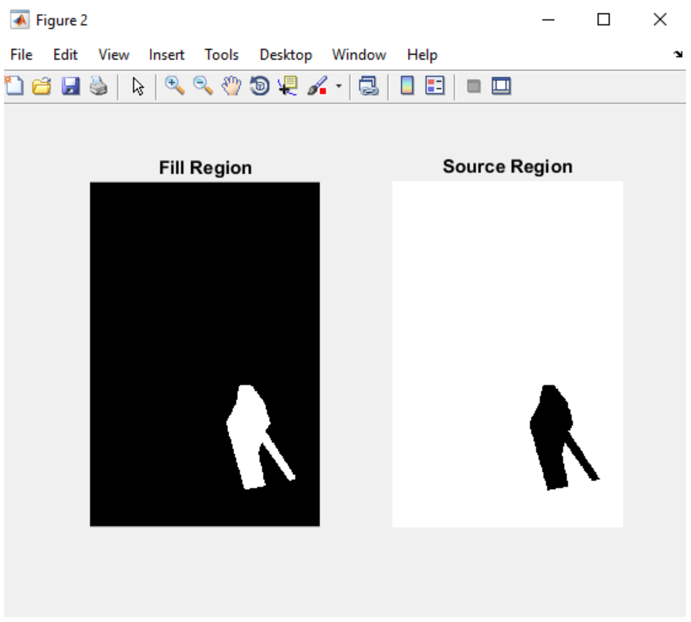
Picture 2.4. Plotted image and mask

The next step is to define the minimum block size of the image. The default parameter is $f = 8$. User is prompt to decide weather to use default value or not. The length and the width are divided by f and stored as *bsmin* parameter. The source and fill regions are plotted. (Picture 2.6)



```
%DEFINING MINIMUM IMAGE BLOCK
yes_no = 0;
while(yes_no == 0)
    yes_no = input('Use default min block size i.e. f = 8: Y/N ','s');
        if(yes_no == 'y' || yes_no == 'Y')
            f = 8;
        elseif(yes_no == 'n' || yes_no == 'N')
            f = input('Enter the max number of blocks along one side of the image: ');
        else
            yes_no = 0;
        end
end

bsmin = floor(size(fillRegion)./f);
bsmin = [bsmin(1) bsmin(2)];

img = img(1:bsmin(1)*f,1:bsmin(2)*f,:);
fillRegion = fillRegion(1:bsmin(1)*f,1:bsmin(2)*f);
sourceRegion = 1-fillRegion;
```

Picture 2.5. Part of the code that is responsible for defining minimum block size

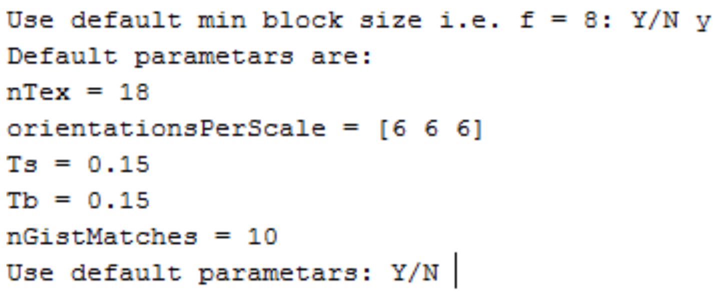


Picture 2.6. Plotted source and fill region

For the context-aware patch inpainting algorithm, the following parameters have to be loaded.

- nTex – number od textons
- orientationsPerScale - number of orientations over 3 scales
- Ts - block similarity threshold used while decomposing image
- Tb - block similarity threshold while context aware patch selection is being performed
- nGistMatches - max number of blocks from where the patches are considerd

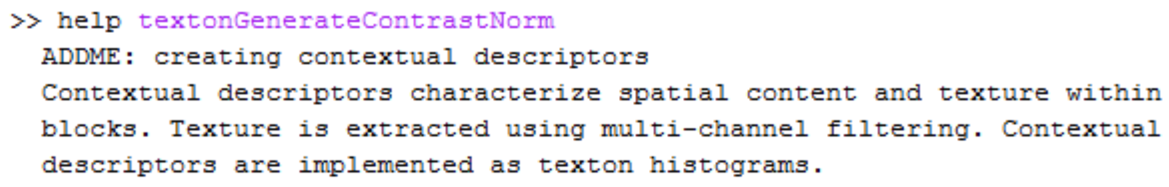
Once again, the user can choose between the default and personalized values.



```
Use default min block size i.e. f = 8: Y/N y
Default parametars are:
nTex = 18
orientationsPerScale = [6 6 6]
Ts = 0.15
Tb = 0.15
nGistMatches = 10
Use default parametars: Y/N
```

Picture 2.7. Parameters displayed in Matlab command widow

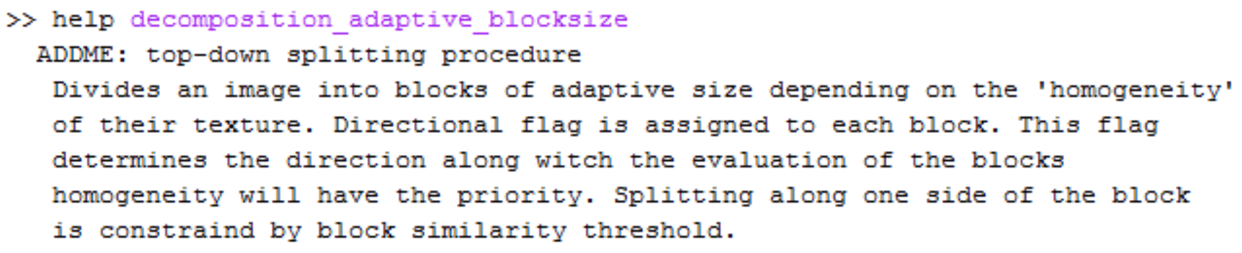
After loading of the parameters, contextual descriptors are being calculated. The function that is responsible for this part of the method is **textonGenerateContrastNorm**. Further explanation about this function is given in the Matlab help selection. (Picture 2.8)



```
>> help textonGenerateContrastNorm
  ADDME: creating contextual descriptors
  Contextual descriptors characterize spatial content and texture within
  blocks. Texture is extracted using multi-channel filtering. Contextual
  descriptors are implemented as texton histograms.
```

Picture 2.8. Matlab command window

The next step is to divide the image into blocks of adaptive size. The function that is responsible for this division is **decomposition_adaptive_blocksize**. (Picture 2.9)



```
>> help decomposition_adaptive_blocksize
  ADDME: top-down splitting procedure
   Divides an image into blocks of adaptive size depending on the 'homogeneity'
   of their texture. Directional flag is assigned to each block. This flag
   determines the direction along witch the evaluation of the blocks
   homogeneity will have the priority. Splitting along one side of the block
   is constraind by block similarity threshold.
```

Picture 2.9. Matlab command window

After the decomposition, the processed image is displayed. (Picture 2.10)

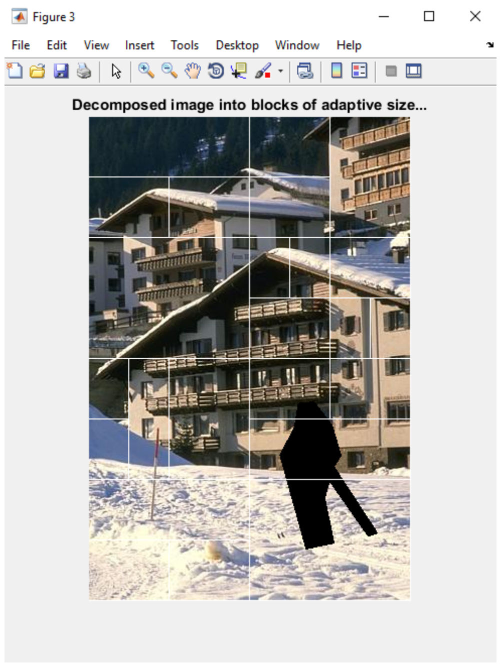
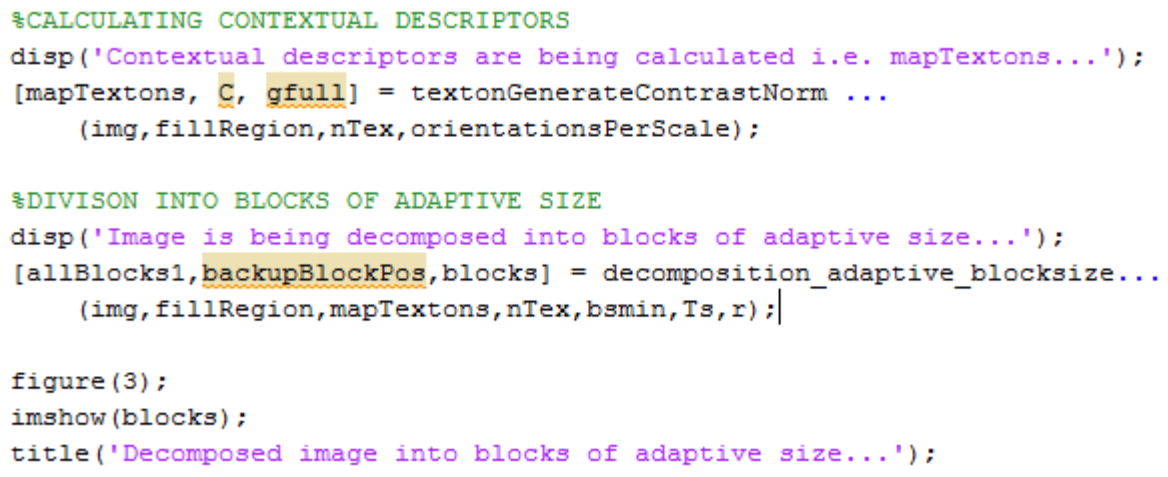


Figure 3
File Edit View Insert Tools Desktop Window Help
Decomposed image into blocks of adaptive size...

Picture 2.10. Decomposed image

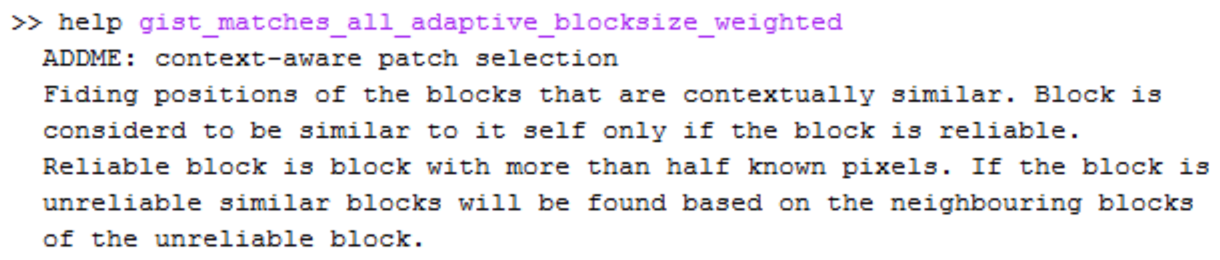
The part of the code that is responsible for the previously described process is shown below.



```
%CALCULATING CONTEXTUAL DESCRIPTORS
disp('Contextual descriptors are being calculated i.e. mapTextons...');
[mapTextons, C, gfull] = textonGenerateContrastNorm ...
    (img,fillRegion,nTex,orientationsPerScale);

%DIVISON INTO BLOCKS OF ADAPTIVE SIZE
disp('Image is being decomposed into blocks of adaptive size...');
[allBlocks1,backupBlockPos,blocks] = decomposition_adaptive_blocksize...
    (img,fillRegion,mapTextons,nTex,bsmin,Ts,r);

figure(3);
imshow(blocks);
title('Decomposed image into blocks of adaptive size...');
```

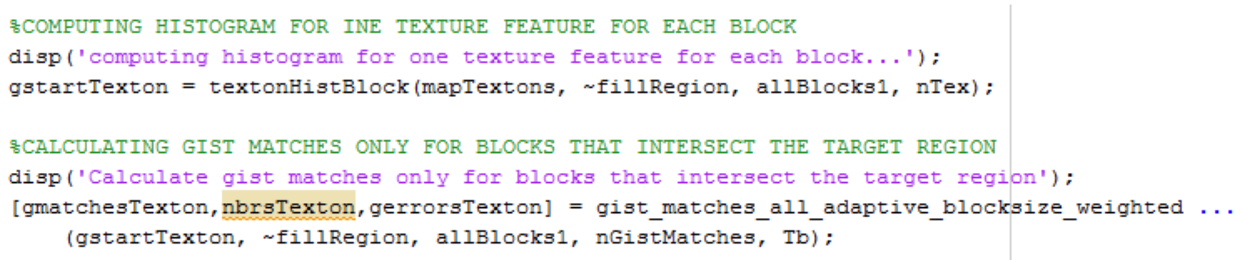
Picture 2.11. *Part of the code responsible for creating contextual descriptors and dividing image into blocks of adaptive size*

Next, the positions of the blocks that are contextually similar to the surrounding of the target patch need to be identified. Functions that are employed in this section are **textonHistBlock** and **gist_matches_all_adaptive_blocksize_weighted**.



```
>> help gist_matches_all_adaptive_blocksize_weighted
  ADDME: context-aware patch selection
  Fiding positions of the blocks that are contextually similar. Block is
  considerd to be similar to it self only if the block is reliable.
  Reliable block is block with more than half known pixels. If the block is
  unreliable similar blocks will be found based on the neighbouring blocks
  of the unreliable block.
```

Picture 2.12. *Matlab command window*



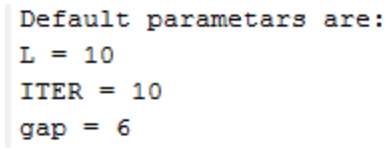
```
%COMPUTING HISTOGRAM FOR INE TEXTURE FEATURE FOR EACH BLOCK
disp('computing histogram for one texture feature for each block...');
gstartTexton = textonHistBlock(mapTextons, ~fillRegion, allBlocks1, nTex);

%CALCULATING GIST MATCHES ONLY FOR BLOCKS THAT INTERSECT THE TARGET REGION
disp('Calculate gist matches only for blocks that intersect the target region');
[gmatchesTexton,nbrsTexton,gerrorsTexton] = gist_matches_all_adaptive_blocksize_weighted ...
    (gstartTexton, ~fillRegion, allBlocks1, nGistMatches, Tb);
```

Picture 2.13. *Part of the code responsible for finding positions of the blocks that are contextually similar*

To enable the MRF-based inpainting, the following parameters have to be loaded.

- L – number of labels kept after pruning
- ITER- number of iterations
- gap - determines the patch size as 2gap+1

Here again the user can choose between the default and personalized values.

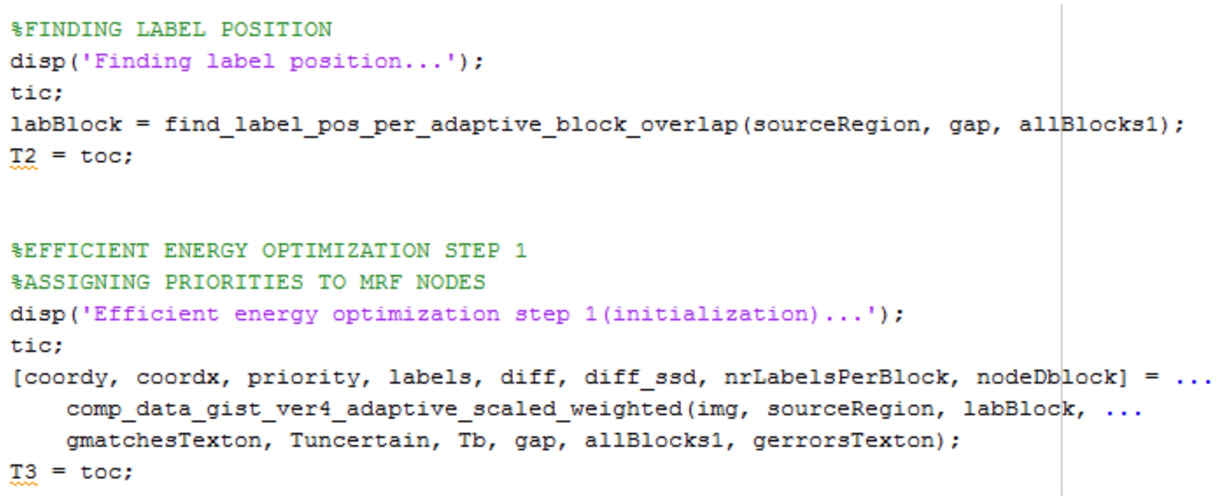


```
Default parametars are:
L = 10
ITER = 10
gap = 6
```

Picture 2.14. Parameters displayed in Matlab command widow

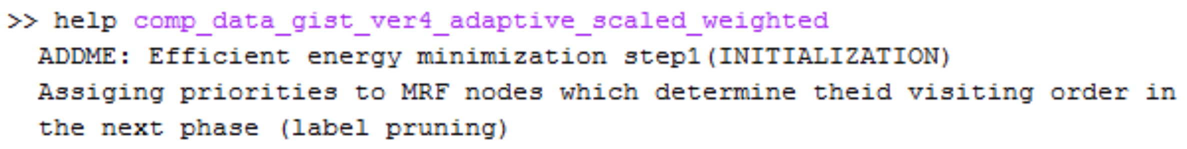
The part of the code that is responsible for patch-based inpainting process emloys a memory efficient optimization method. This method consists of three steps. Initialization, label pruning and inference.

The function responsible for the initialization is **comp_data_gist_ver4_adaptive_scaled_weighted**. Before executing initialization, it is necessary to find the positions all the involved labels, which is done with the function called **find_label_pos_per_adaptive_block_overlap.**



```
%FINDING LABEL POSITION
disp('Finding label position...');
tic;
labBlock = find_label_pos_per_adaptive_block_overlap(sourceRegion, gap, allBlocks1);
T2 = toc;


%EFFICIENT ENERGY OPTIMIZATION STEP 1
%ASSIGNING PRIORITIES TO MRF NODES
disp('Efficient energy optimization step 1(initialization)...');
tic;
[coordy, coordx, priority, labels, diff, diff_ssd, nrLabelsPerBlock, nodeDblock] = ...
    comp_data_gist_ver4_adaptive_scaled_weighted(img, sourceRegion, labBlock, ...
    gmatchesTexton, Tuncertain, Tb, gap, allBlocks1, gerrorsTexton);
T3 = toc;
```

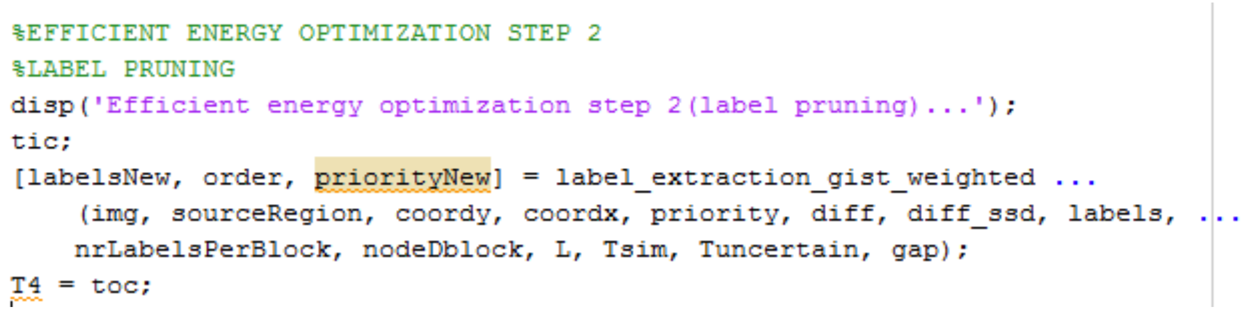
Picture 2.15. Part of the code responsible for initialization of energy efficient optimization



```
>> help comp_data_gist_ver4_adaptive_scaled_weighted
  ADDME: Efficient energy minimization step1(INITIALIZATION)
  Assiging priorities to MRF nodes which determine theid visiting order in
  the next phase (label pruning)
```

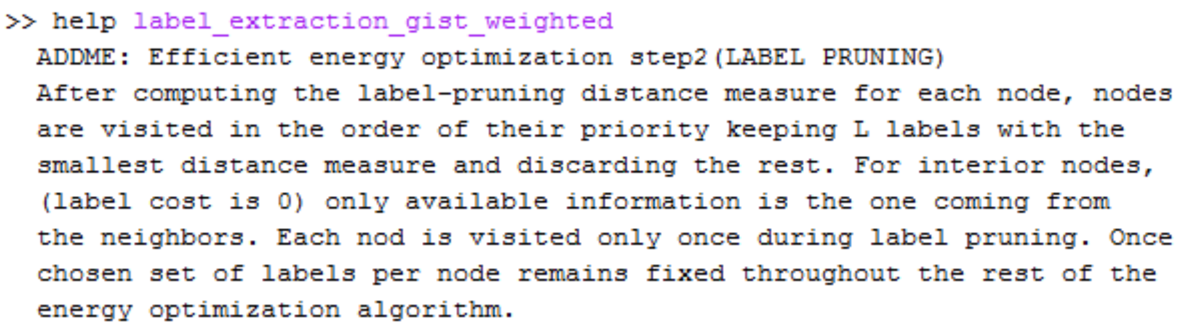
Picture 2.16. Matlab commad prompt window

The second, step label pruning, is realized with **label_extraction_gist_weighted.**



```
%EFFICIENT ENERGY OPTIMIZATION STEP 2
%LABEL PRUNING
disp('Efficient energy optimization step 2(label pruning)...');
tic;
[labelsNew, order, priorityNew] = label_extraction_gist_weighted ...
    (img, sourceRegion, coordy, coordx, priority, diff, diff_ssd, labels, ...
    nrLabelsPerBlock, nodeDblock, L, Tsim, Tuncertain, gap);
T4 = toc;
```

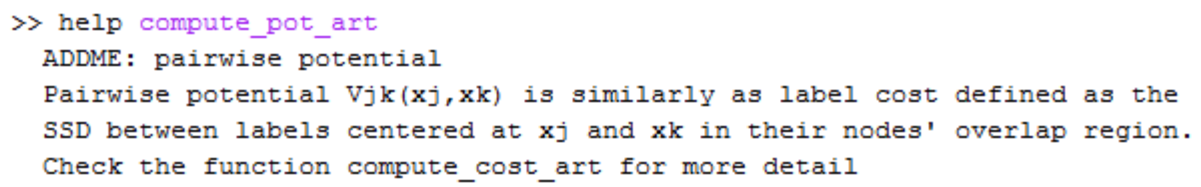
Picture 2.17. Part of the code responsible for label pruning



```
>> help label_extraction_gist_weighted
  ADDME: Efficient energy optimization step2(LABEL PRUNING)
  After computing the label-pruning distance measure for each node, nodes
  are visited in the order of their priority keeping L labels with the
  smallest distance measure and discarding the rest. For interior nodes,
  (label cost is 0) only available information is the one coming from
  the neighbors. Each nod is visited only once during label pruning. Once
  chosen set of labels per node remains fixed throughout the rest of the
  energy optimization algorithm.
```

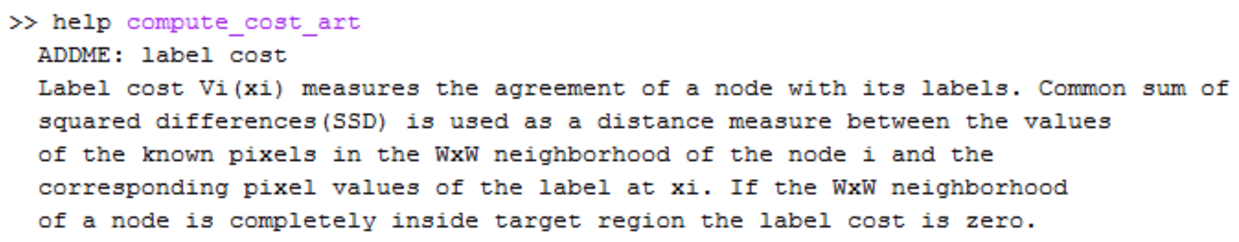
Picture 2.18. Matlab command prompt

The third and last the step in the energy optimization is neighbor consensus message passing. The function is called **NCMP**. Before calling NCMP, label cost and pairwise potential have to be calculated. The function that calculates the label cost is called **compute_cost_art.** Inside **compute_cost_art** there is **ssd3** function that calculates common sum of squared differences. Pairwise potential is calculated with **compute_pot_art** function.



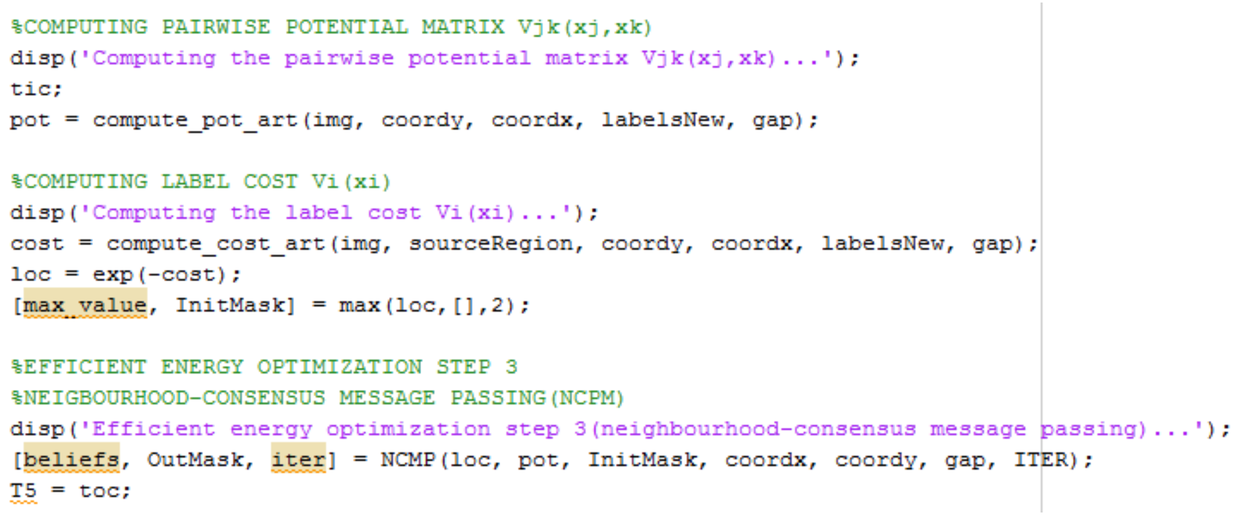
```
>> help compute_pot_art
  ADDME: pairwise potential
  Pairwise potential Vjk(xj,xk) is similarly as label cost defined as the
  SSD between labels centered at xj and xk in their nodes' overlap region.
  Check the function compute_cost_art for more detail
```

Picture 2.19. Matlab commad prompt



```
>> help compute_cost_art
  ADDME: label cost
  Label cost Vi(xi) measures the agreement of a node with its labels. Common sum of
  squared differences(SSD) is used as a distance measure between the values
  of the known pixels in the WxW neighborhood of the node i and the
  corresponding pixel values of the label at xi. If the WxW neighborhood
  of a node is completely inside target region the label cost is zero.
```

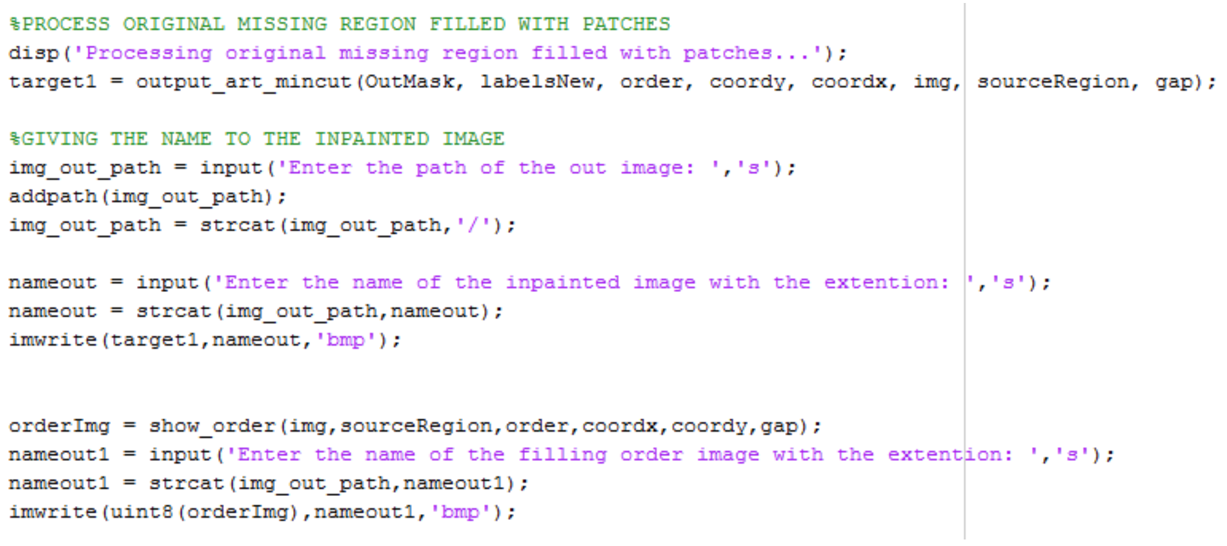
Picture 2.20. Matlab commad prompt



```
%COMPUTING PAIRWISE POTENTIAL MATRIX Vjk(xj,xk)
disp('Computing the pairwise potential matrix Vjk(xj,xk)...');
tic;
pot = compute_pot_art(img, coordy, coordx, labelsNew, gap);

%COMPUTING LABEL COST Vi(xi)
disp('Computing the label cost Vi(xi)...');
cost = compute_cost_art(img, sourceRegion, coordy, coordx, labelsNew, gap);
loc = exp(-cost);
[max_value, InitMask] = max(loc,[],2);

%EFFICIENT ENERGY OPTIMIZATION STEP 3
%NEIGBOURHOOD-CONSENSUS MESSAGE PASSING(NCPM)
disp('Efficient energy optimization step 3(neighbourhood-consensus message passing)...');
[beliefs, OutMask, iter] = NCMP(loc, pot, InitMask, coordx, coordy, gap, ITER);
T5 = toc;
```

Picture 2.21. Part of the code responsible for the final step of the energy optimization

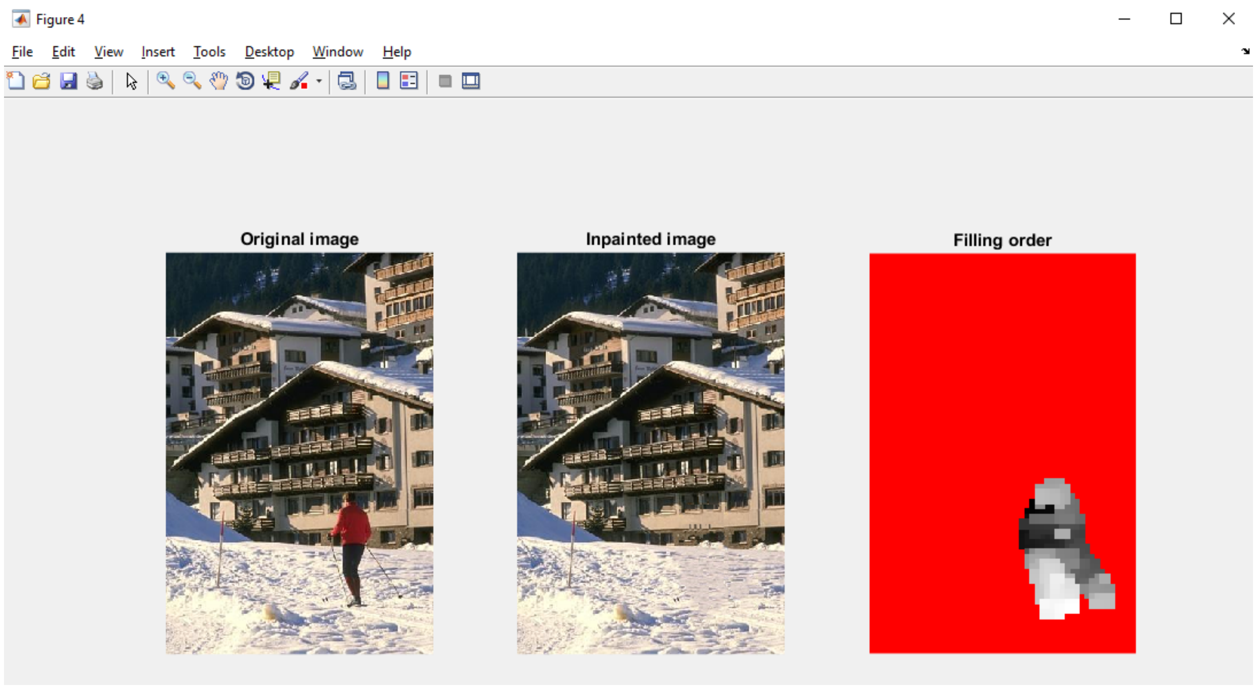
After the missing region is filled in with patches of the original image, the function **output_art_mincut**, the name and the path for storing the inpaited image and the image representing the filling order need to be given.



```
%PROCESS ORIGINAL MISSING REGION FILLED WITH PATCHES
disp('Processing original missing region filled with patches...');
target1 = output_art_mincut(OutMask, labelsNew, order, coordy, coordx, img, sourceRegion, gap);

%GIVING THE NAME TO THE INPAINTED IMAGE
img_out_path = input('Enter the path of the out image: ','s');
addpath(img_out_path);
img_out_path = strcat(img_out_path,'/');

nameout = input('Enter the name of the inpainted image with the extention: ','s');
nameout = strcat(img_out_path,nameout);
imwrite(target1,nameout,'bmp');


orderImg = show_order(img,sourceRegion,order,coordx,coordy,gap);
nameout1 = input('Enter the name of the filling order image with the extention: ','s');
nameout1 = strcat(img_out_path,nameout1);
imwrite(uint8(orderImg),nameout1,'bmp');
```

Picture 2.22. Part of the code responsible for storing the inpainted image

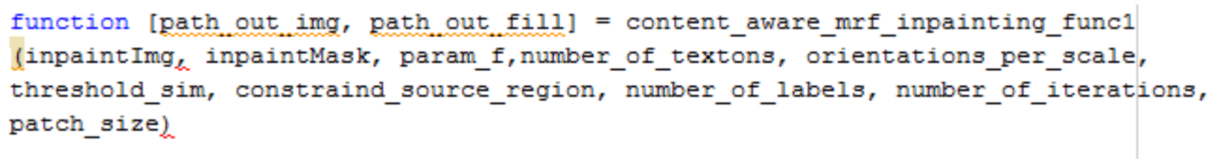
After the inpaintig process is finished, the original image, the inpainted image and the filling-order image are displayed.



Picture 2.23. *Original image, inpainted image and filling order image*

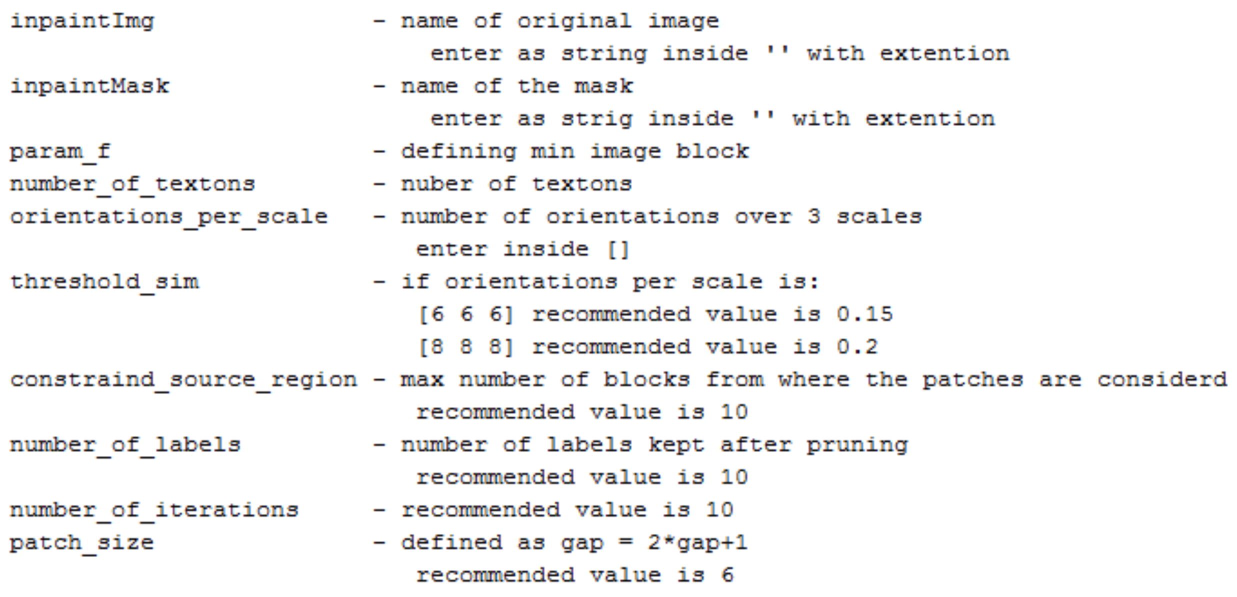
3. FUNCTION VERSION

In the function called **content_aware_mrf_inpainting_func**, all the parametars that were prompted from the user in the script file are now requested as parameters of the function. The function returns the inpainted image and the filling order image.



```
function [path_out_img, path_out_fill] = content_aware_mrf_inpainting_func1
(inpaintImg, inpaintMask, param_f,number_of_textons, orientations_per_scale,
threshold_sim, constraind_source_region, number_of_labels, number_of_iterations,
patch_size)
```

Picture 2.24. *Function **content_aware_mrf_inpainting_func***



```
inpaintImg               - name of original image
                            enter as string inside '' with extention
inpaintMask              - name of the mask
                            enter as strig inside '' with extention
param_f                  - defining min image block
number_of_textons        - nuber of textons
orientations_per_scale   - number of orientations over 3 scales
                           enter inside []
threshold_sim            - if orientations per scale is:
                           [6 6 6] recommended value is 0.15
                           [8 8 8] recommended value is 0.2
constraind_source_region - max number of blocks from where the patches are considerd
                           recommended value is 10
number_of_labels         - number of labels kept after pruning
                           recommended value is 10
number_of_iterations     - recommended value is 10
patch_size               - defined as gap = 2*gap+1
                           recommended value is 6
```

Picture 2.25. *Parametars of the function*

Based on the following paper:

T. Ružic and A. Pižurica, “Context-aware patch-based image inpainting using Markov random field modeling,” IEEE Transactions on Image Processing, vol. 24, no. 1, pp. 444-456, Jan 2015.