ECE 558 Project 02

Problem 1

a) 2D Convolution –

p1_conv2d.m - Main script file to implement 2d convolution on the input image with provided kernels

```
% Project 2 Question 1a and 1b
%% Convolution. Spatial filtering in images clc; clear all; close all;
img = im2double(imread('lena.png'));
% img = rgb2gray(img);
img1 = im2double(imread('wolves.png'));
img1 = rgb2gray(img1); %considering a grayscale conversion for wolves.png
%defining all the filters
box_deriv = {1/9*[1,1,1;1,1,1;1,1,1],[1,-1],[1;-1]};
prewitt = {[-1,0,1;-1,0,1;-1,0,1],[-1,-1,-1;0,0,0;1,1,1]};
sobel = {[-1,0,1;-2,0,2;-1,0,1],[1,2,1;0,0,0;-1,-2,-1]};
roberts = {[0,1 ; -1,0],[1,0;0,-1]};
%creating a cell of all kernels kernels = horzcat(box_deriv,prewitt, sobel, roberts);
%setting prompts for selecting kernel and padding type
prompt = 'Set padding type\n1. Zero Padding\n2. Copy Edge\n3. Wrap around\n4. Reflect across
edge\n';
prompt2 = ['Set Kernel type\n1. Box Filter 2. Derivative horizontal'...
    ' 3. Derivative vertical\n4. Prewitt horizontal 5. Prewitt vertical\n'...
    '6. Sobel horizontal 7. Sobel vertical\n8. Roberts Horizontal'...
    ' 9 Roberts Vertical\n'];
%setting up cells of kernel and padding type for saving output with
%suitable filename padType = {'Zero', 'Copy Edge', 'Wrap Around', 'Reflect'};
kernType = {'Box', 'DerivHorizontal', 'DerivVertical', 'PrewittHorizontal',...
    'PrewittVertical','SobelHorizontal','SobelVertical', 'RobertsHorizontal',...
    'RobertsVertical'};
kern = input(prompt2); %take input of kernel from user pad = input(prompt); %take padding
type from user if size(img,3)==3 %if the image is a color image, convolve channels separately
op(:,:,1) = conv2d(img(:,:,1), kernels{kern},pad);
    op(:,:,2) = conv2d(img(:,:,2), kernels{kern},pad);
    op(:,:,3) = conv2d(img(:,:,3), kernels{kern},pad);
else     op = conv2d(img, kernels{kern},pad); %else convolve the image directly
end ops = (op-min(op(:)))./(max(op(:))-min(op(:))); %scale image to visualize negative values
better
%the process is repeated to check wolves.png as a grayscale image.  if size(img1,3)==3
op1(:,:,1) = conv2d(img1(:,:,1), kernels{kern},pad);
    op1(:,:,2) = conv2d(img1(:,:,2), kernels{kern},pad);
    op1(:,:,3) = conv2d(img1(:,:,3), kernels{kern},pad);
else     op1 = conv2d(img1, kernels{kern},pad);
end ops1 = (op1-min(op1(:)))./(max(op1(:))-min(op1(:)));
%create a figure to display the results
figure('units', 'normalized', 'outerposition', [0 0 1 1]);
subplot(2,3,1);
imshow(img);
title('lena.png');
subplot(2,3,2);
imshow(op);
title('o/p (Negative values Clipped)');
subplot(2,3,3)
imshow(ops);
title('o/p Scaled');
```

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subplot(2,3,4);
imshow(img1);
title('wolves.png');
subplot(2,3,5);
imshow(op1);
title('o/p (Negative values Clipped)');
subplot(2,3,6)
imshow(ops1);
title('o/p Scaled');
%save the results to a png file
fileName = horzcat('Part1a',kernType{kern},padType{pad},'.png');
print(gcf, fileName,'-dpng', '-r300');
%% part 2  % unit impulse function   %the unit impulse is defined with a matrix of zeros with
a one in the
%center as shown below
uimp = zeros(1024);
uimp(512, 512) = 1;
ouimp = conv2d(uimp, kernels{6}, pad);
%show the results in the figure figure;
subplot(1,2,1)
imshow(uimp)
subplot(1,2,2)
imshow(ouimp)
```

Padding is done using the *SetPadding.m* function which takes the image, kernel and padding type as inputs.

```
function [img_pad] = SetPadding(img, kern, pad)
%SETPADDING Set padding based on kernel size
%   Set padding to set up an image for convolution based on the kernel size
%   of the chosen kernel. The size of the kernel is used as a reference for
%   the amount of padding required. The padding is performed by considering
%   padding type and then slicing appropriate indices from original image
%   to copy them to the actual image.
[r,c] = size(img); %size of image
[rk, ck] = size(kern); %size of kernel
if rk==1 && ck==2 %special case for horizontal derivative filter
    if pad == 1 %zero padding
        img_pad = zeros(r,c+1); %add a column
        img_pad(:, 1:end-1) = img;
    elseif pad == 2 %copy edge
        img_pad = zeros(r,c+1);
        img_pad(:, 1:end-1) = img;
        img_pad(:, end) = img(:,end);
    elseif pad == 3 %wrap around
        img_pad = zeros(r,c+1);
        img_pad(:, 1:end-1) = img;
        img_pad(:, end) = img(:,1);
    elseif pad == 4 %reflect across edge
        img_pad = zeros(r,c+1);
        img_pad(:, 1:end-1) = img;
        img_pad(:, end) = img(:,end);
    end
elseif rk==2 && ck==1 %special case for horizontal derivative filter
    if pad == 1 %zero padding
        img_pad = zeros(r+1,c);
        img_pad(1:end-1,:) = img;
    elseif pad == 2 %copy edge
        img_pad = zeros(r+1,c);
        img_pad(1:end-1,:) = img;
```

```
        img_pad(end,:) = img(end,:);
    elseif pad == 3 %wrap around
        img_pad = zeros(r+1,c);
        img_pad(1:end-1,:) = img;
        img_pad(end,:) = img(1,:);
    elseif pad == 4 %reflect across edge
        img_pad = zeros(r+1,c);
        img_pad(1:end-1,:) = img;
        img_pad(end,:) = img(end,:);
    end
elseif (mod(rk,2) && mod(ck,2)) %for odd sized kernels. (3x3, 5x5...)
    if pad == 1 %zero padding
        img_pad = zeros(r+ceil(rk/2),c+ceil(ck/2)); %add ceil(kernelsize/2) number of rows
and cols
        img_pad((rk+1)/2:end-1, (ck+1)/2:end-1) = img;
    elseif pad == 2 %copy edge
        %set up as zero padding
        img_pad = zeros(r+ceil(rk/2),c+ceil(ck/2));
        img_pad((rk+1)/2:end-1, (ck+1)/2:end-1) = img;
        %copy edges to the newly added edges
        img_pad(floor((rk+1)/2):end-1, 1:floor(ck/2)) = repmat(img(:,1),floor(ck/2));
        img_pad(floor((rk+1)/2):end-1, end-floor(ck/2)+1:end) =
repmat(img(:,end),floor(rk/2));
        img_pad(1:floor(rk/2),floor((ck+1)/2):end-1) = repmat(img(1,:),floor(rk/2));
        img_pad(end-floor(rk/2)+1:end,floor((ck+1)/2):end-1) =
repmat(img(end,:),floor(ck/2));
        %corner cases
        img_pad(1:floor(rk/2), 1:floor(ck/2)) = repmat(img(1,1), floor(rk/2), floor(ck/2));
        img_pad(end-floor(rk/2):end, 1:floor(ck/2)) = repmat(img(end,1), floor(rk/2),
floor(ck/2));
        img_pad(1:floor(rk/2), end-floor(ck/2):end) = repmat(img(1,end), floor(rk/2),
floor(ck/2));
        img_pad(end-floor(rk/2):end, end-floor(ck/2):end) = repmat(img(end,end), floor(rk/2),
floor(ck/2));
    elseif pad == 3 %wrap around
        %set up as zero padding
        img_pad = zeros(r+ceil(rk/2),c+ceil(ck/2));
        img_pad((rk+1)/2:end-1, (ck+1)/2:end-1) = img;
        %wrap edges from other end to the newly added edges
        img_pad(floor((rk+1)/2):end-1, 1:floor(ck/2)) = img(:,end-floor(ck/2)+1:end);
        img_pad(floor((rk+1)/2):end-1, end-floor(ck/2)+1:end) = img(:,1:floor(ck/2));
        img_pad(1:floor(rk/2),floor((ck+1)/2):end-1) = img(end-floor(rk/2)+1:end,:);
        img_pad(end-floor(rk/2)+1:end,floor((ck+1)/2):end-1) = img(1:floor(rk/2),:);
        %corner cases
        img_pad(1:floor(rk/2), 1:floor(ck/2)) = img(end-floor(rk/2)+1:end, end-
floor(ck/2)+1:end);
        img_pad(end-floor(rk/2)+1:end, 1:floor(ck/2)) = img(1:floor(rk/2), end-
floor(ck/2)+1:end);
        img_pad(1:floor(rk/2), end-floor(ck/2)+1:end) = img(end-floor(rk/2)+1:end,
1:floor(ck/2));
        img_pad(end-floor(rk/2)+1:end, end-floor(ck/2)+1:end) = img(1:floor(rk/2),
1:floor(ck/2));
    elseif pad == 4 %reflect across edge
        %set up as zero padding
        img_pad = zeros(r+ceil(rk/2),c+ceil(ck/2));
        img_pad((rk+1)/2:end-1, (ck+1)/2:end-1) = img;
        %reflect across edges
        img_pad(floor((rk+1)/2):end-1, 1:floor(ck/2)) = img(:,floor(ck/2):1);
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        img_pad(floor((rk+1)/2):end-1, end-floor(ck/2)+1:end) = img(:,end:end-floor(ck/2)+1);
        img_pad(1:floor(rk/2),floor((ck+1)/2):end-1) = img(floor(rk/2):1,:);
        img_pad(end-floor(rk/2)+1:end,floor((ck+1)/2):end-1) = img(end:end-floor(rk/2)+1,:);
        %corner cases
        img_pad(1:floor(rk/2), 1:floor(ck/2)) = img(floor(rk/2):1, floor(ck/2):1);
        img_pad(end-floor(rk/2)+1:end, 1:floor(ck/2)) = img(end:end-floor(rk/2)+1,
floor(ck/2):1);
        img_pad(1:floor(rk/2), end-floor(ck/2)+1:end) = img(floor(rk/2):1, end:end-
floor(ck/2)+1);
        img_pad(end-floor(rk/2)+1:end, end-floor(ck/2)+1:end) = img(end:end-floor(rk/2)+1,
end:end-floor(ck/2)+1);
    end
else %for even sized kernels (eg. 2x2, 4x4...)
    if pad == 1 %zero padding
        img_pad = zeros(r+rk/2,c+ck/2);
        img_pad(1:end-(rk/2), 1:end-(ck/2)) = img;
    elseif pad == 2 %copy edge
        %set up as zero padding
        img_pad = zeros(r+rk/2,c+ck/2);
        img_pad(1:end-(rk/2), 1:end-(ck/2)) = img;
        %copy edges to the image.
        img_pad(1:end-(rk/2), end-ck/2+1:end) = repmat(img(:,end), floor(ck/2));
        img_pad(end-rk/2+1:end,1:end-(ck/2)) = repmat(img(end,:), floor(rk/2));
        %corner cases
        img_pad(end-(rk/2)+1:end, end-(ck/2)+1:end) = repmat(img(end,end),
floor(rk/2),floor*ck/2));
    elseif pad == 3 %wrap around
        %set up as zero padding
        img_pad = zeros(r+rk/2,c+ck/2);
        img_pad(1:end-(rk/2), 1:end-(ck/2)) = img;
        %wrap around edges
        img_pad(1:end-1, end-ck/2+1:end) = img(:,1:ck/2);
        img_pad(end-rk/2+1:end,1:end-1) = img(1:rk/2,:);
        %corner case
        img_pad(end-(rk/2)+1:end, end-(ck/2)+1:end) = img(1:(rk/2),1:(ck/2));
    elseif pad == 4 %reflect across edge
        img_pad = zeros(r+rk/2,c+ck/2);
        img_pad(1:end-1, 1:end-1) = img;
        %reflect across edge
        img_pad(1:end-1, end-ck/2+1:end) = img(:,end:end-ck/2+1);
        img_pad(end-rk/2+1:end,1:end-1) = img(end:end-rk/2+1,:);
        %corner case
        img_pad(end-(rk/2)+1:end, end-(ck/2)+1:end) = img(end:end-(rk/2)+1,end:end-(ck/2)+1);
end
end
```

The actual Convolution is done using the *conv2d.m* function which takes the image, kernel and padding type as inputs.

```
function [op_img] = conv2d(img,kern, pad)
%CONV2 perform 2d convolution of an image with given kernel
%   Perform 2d convolution of an image.
    [r,c] = size(img);
    [rk, ck] = size(kern);
    img_pad = SetPadding(img, kern, pad);
    op_img = img;
    if rk==1 && ck==2 %special case, horizontal derivative.
        for i = 2:r+1
```

```
            for j = 2:c+1
                op_img(i-1,j-1) = img_pad(i-1,j-1).*kern(1,1)+ img_pad(i-1,j).*kern(1,2) ;
            end
        end
    elseif rk==2 && ck==1 %special case vertical derivative.
        for i = 2:r+1
            for j = 2:c+1
                op_img(i-1,j-1) = img_pad(i-1,j-1).*kern(1,1)+ img_pad(i,j-1).*kern(2,1) ;
            end
        end
    elseif not(mod(rk,2) && mod(ck,2)) %even sized kernels (eg. 2x2, 4x4...)
        for i = 1:r
            for j = 1:c
                for k = 1:rk
                    for l = 1:ck
                        su(k,l) = img_pad(i+k-1,j+l-1).*kern(k,l);
                    end
                end
                op_img(i,j) = sum(sum(su));
            end
        end
    else %for odd sized kernels (3x3, 5x5...)
        for i = 2:r+1
            for j = 2:c+1
                for k = -floor(rk/2):floor(rk/2)
                    for l = -floor(ck/2):floor(ck/2)
                        su(k+2,l+2) = img_pad(i+k,j+l).*kern(k+2,l+2);
                    end
                end
                op_img(i-1,j-1) = sum(sum(su));
            end
        end
    end
end
```

Output Images.

The output images are saved in the project folder with appropriate names. All images for all the kernels with all the paddings are saved. Below attached are few examples. As we can see there is an improvement over zero padding in the other types of padding. Especially in case of box filter, we can't see the dark edges as we get in zero padding.

The values for output pixels can go to negative ranges, hence, a scaled output is also plotted to visualize the actual convolution operation better.

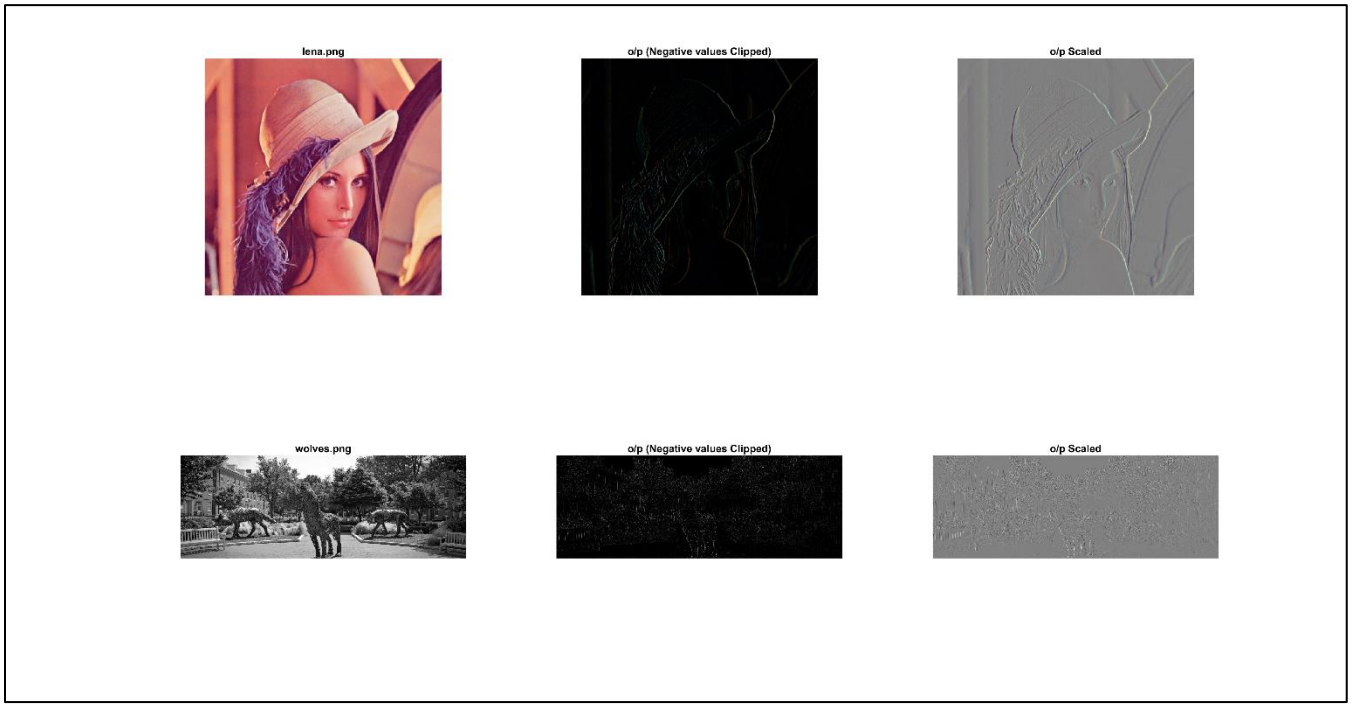
1. Box Filter– Zero Padding

2. Box Filter – Copy Edge

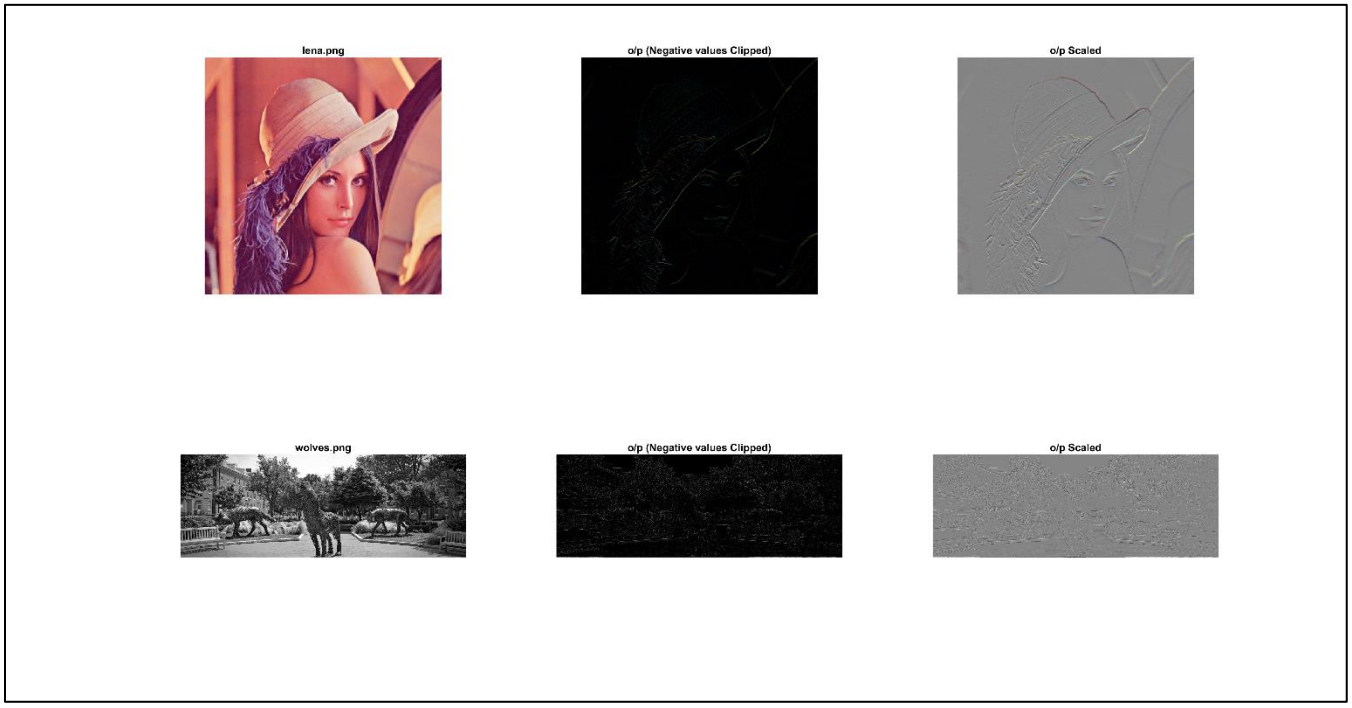
3. Box Filter – Wrap around

4. Box Filter – Reflect across edge

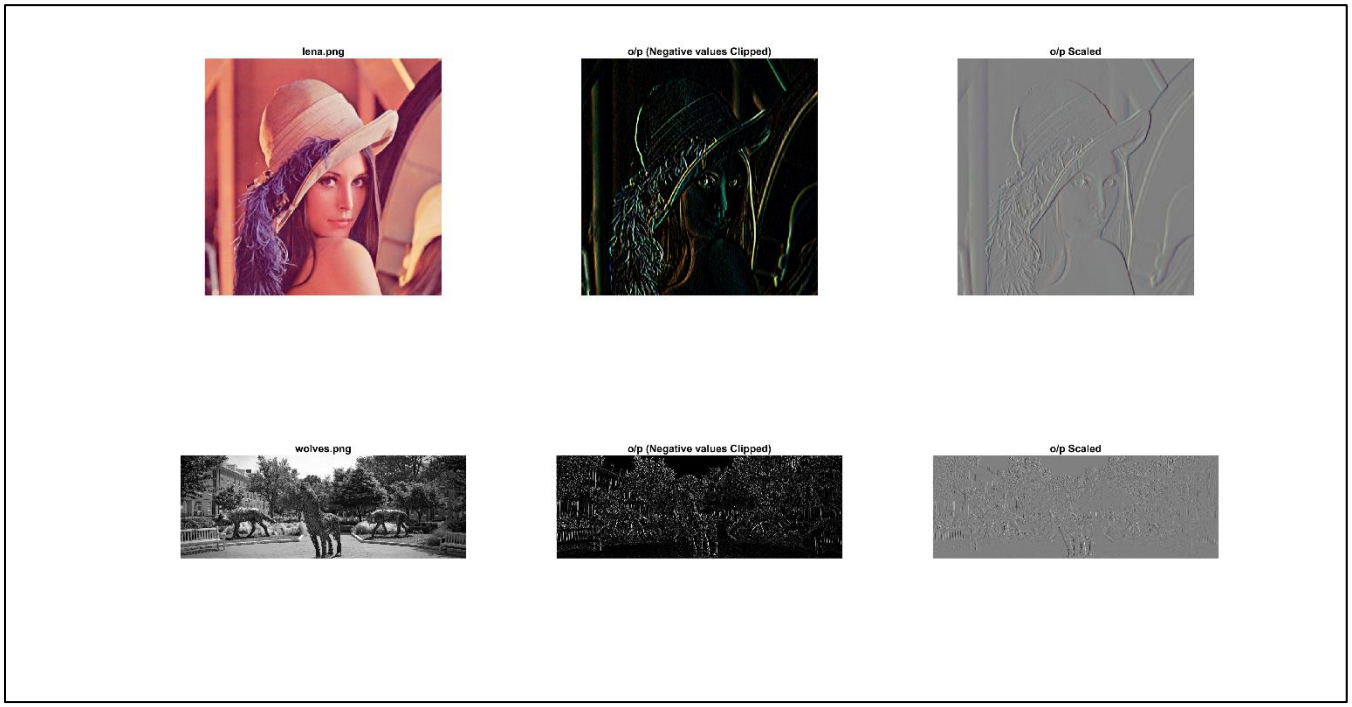
5. Derivative Horizontal – Copy Edge



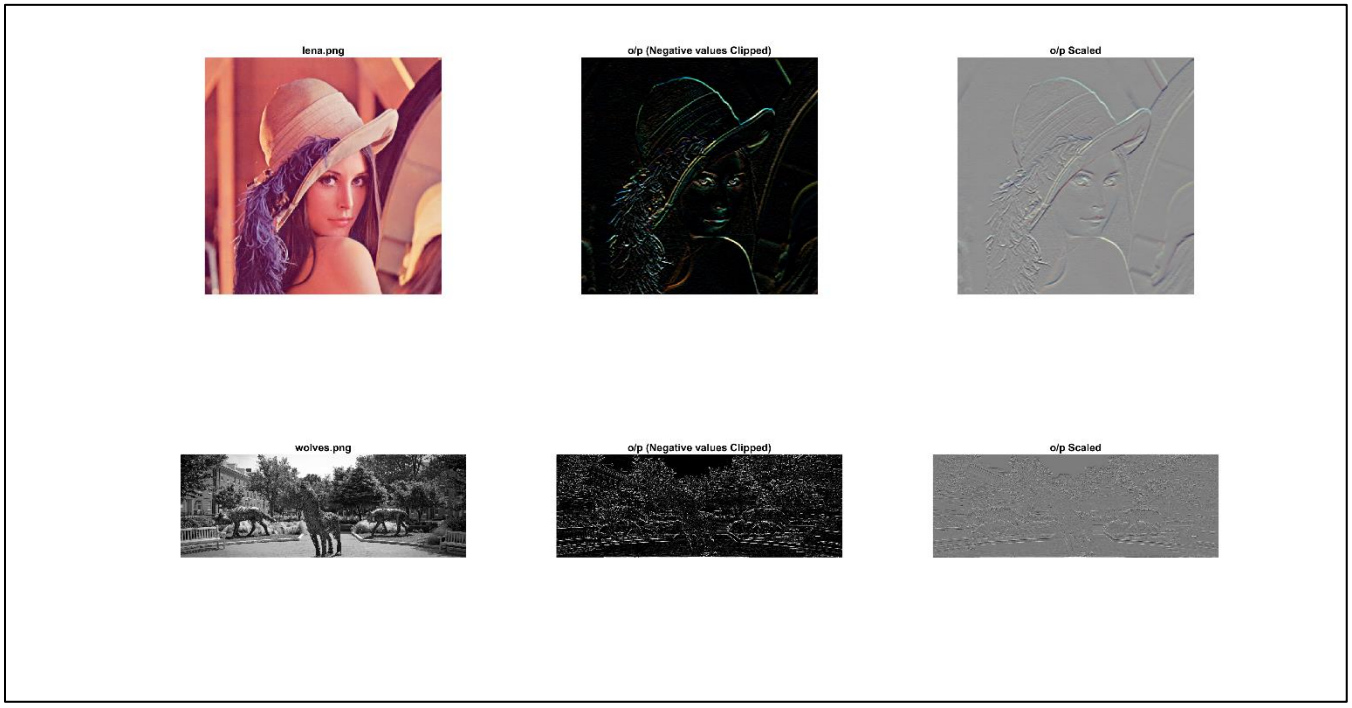
6. Derivative Vertical – Wrap around



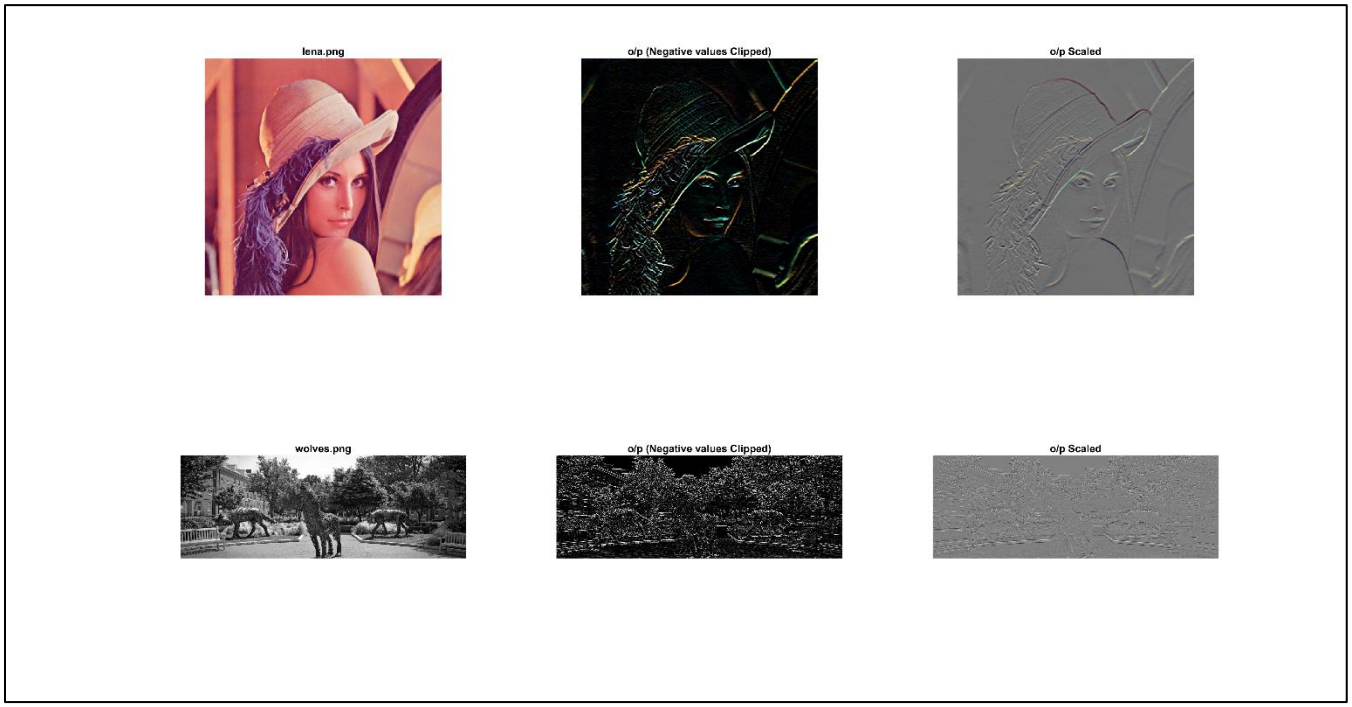
7. Prewitt Horizontal– Zero padding



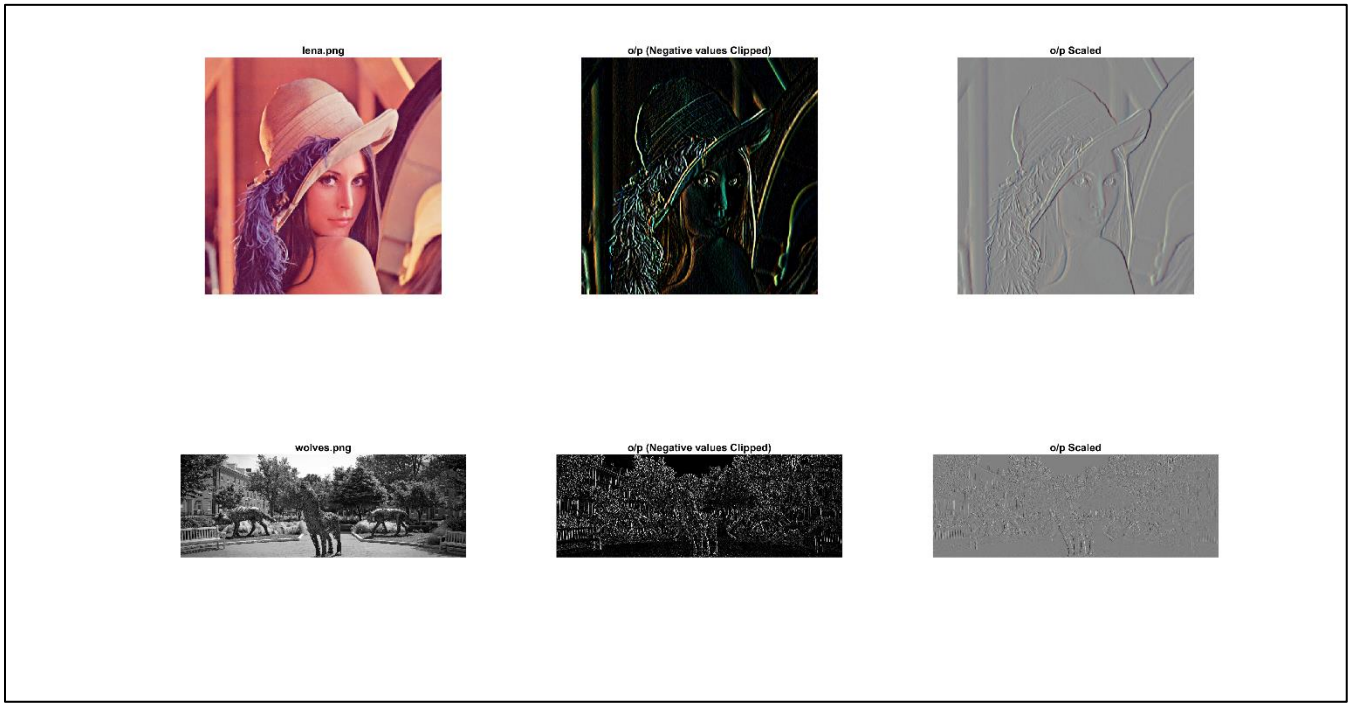
8. Prewitt Vertical – Wrap around



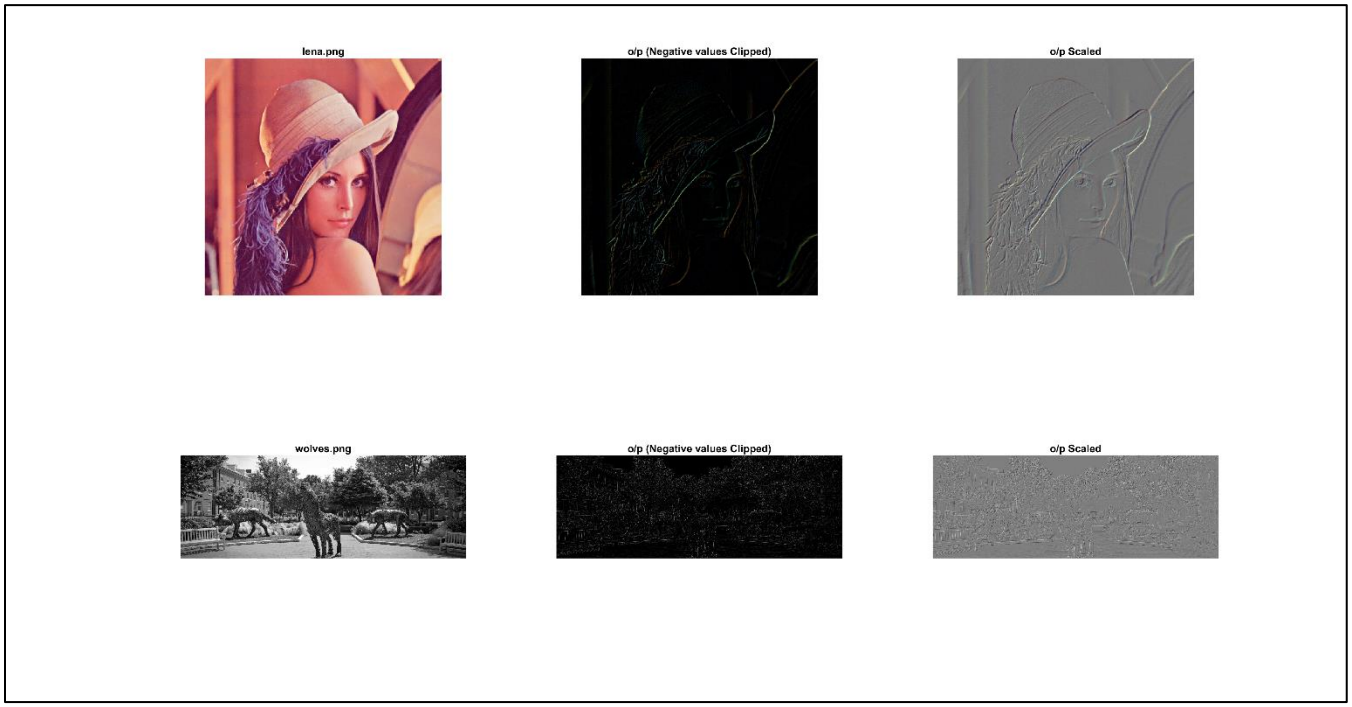
9. Sobel Vertical – Copy Edge



10. Sobel Horizontal – Reflect across edge



11. Roberts Vertical – Copy Edge



12. Roberts Horizontal – Reflect across edge