Computer Vision

Project 7 – Image Mosaicing

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Main Program

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% STITCHIMAGES – Master Image Stitching Function
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% path – the path the images to stitch together
% fileExt – the extension of the images

%OUTPUT:
% outImages – A cell array of all the output images for each octave


function outImages = stitchImages( path, fileExt)

    % Global Properties
    ipNumber = 50; % the number of interestPoints desired after NMAS
    ipPerTransform = 6; % num of interest points needed per affine transform
    corrThreshold = .1; % value of the cross correlation threshold
    n = 4; % the number of octaves to use

    % Read images into a cell array
    fname = dir( strcat( path, fileExt ) );
    numberImages = length(fname);
    imagesArray = cell( numberImages, 1 );
    %dah = 'at the top'
    %numberImages
    for index = 1:numberImages

        im = imread( strcat( path, fname(index).name ) );
        imagesArray{ index } = im;

    end


    % Scale each image to n different octaves scaled images
    % are stored into a cell array where each row is the
    % set of all images at the same scale and each column
    % is the same image at n different scales

    % 2D cell array to store all images at each scale
    scaledImagesArray = cell(4, numberImages);

    % Loop over images generating sa scaling pyramind, see [xx]
    for index = 1:numberImages

        image = imagesArray{ index };
        pyramid = multiscale( image, n );
        scaledImagesArray(:, index) = pyramid;

    end

    % END generating scaled images

    % Generate the descriptors for each image, storing the set
    % of descriptors

    % Current ocatave or scale being used, must loop through 0 to 3
    % octaves.

    outImages = cell(n, 1);

    for octave = 0:n-1
        % this is a matrix containing the concat of all
        % descriptors for a given octave
        allDescriptors = [];
        allInterestPoints = [];
        %dah = 'Before loop'
        %numberImages
        % Loop over each image at a given octave getting that images
        % descriptors.  Then store the descriptors in a "matrix accumulator"
        % called allDescriptors.
        for index = 1:numberImages
            %dah = 'in loop'
            image = scaledImagesArray{ octave + 1, index };
            %dah = 'image size'
            %size( image )
            %imshow( image );
            [strengthMat, hessians] = harrisDetector( image, 6, 0.04, 1);
            interestPoints = NMAS( ipNumber, strengthMat, octave );
            allInterestPoints = [ allInterestPoints; interestPoints ];
            descriptors = MOPS( image, interestPoints, octave, hessians );
            allDescriptors = [ allDescriptors; descriptors ];

        end

        mapping = interestPointMatching( allDescriptors,
                                         ipNumber,
                                         ipPerTransform,
                                         corrThreshold );
        imList = scaledImagesArray( octave + 1, : );
        outIm = stitching(imList, mapping, allInterestPoints);
        imshow(outIm);
        outImages{octave + 1, 1} = outIm;
    end
end
```

Harris Corner Detection

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% HARRISDETECTOR – Uses the Harris method to detect corners in an image
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% image - the image
% n – the window size
% k – the classic empirically determined constant from the paper (0.04-0.06)
% type – the method to calculate R
%        type 1: harris
%        type 2: harmonic
%        type 3: shi-tomasi

%OUTPUT:
% R – matrix the same size as the image. Contains the R value for each pixel
% M – matrix same size as image. Contains the hessian for every pixel
function [R, M]=harrisDetector(image, n, k, type)
    [r, c, v] = size(image);
    if (v > 1)
        image = rgb2gray(image);
    end
    image = im2double(image);

    padNum = uint16(floor(n/2));
    padRow = zeros(padNum,c);
    padCol = zeros(r+(2*padNum),padNum);
    padImg = [padRow;image;padRow];
    padImg = [padCol,padImg,padCol];

    gauss = fspecial('gaussian', n, n/6);
    R = zeros(r,c);
    [ix, iy] = imgradientxy(padImg);
    M = cell([r,c]);
    for x = 1:r
        startX = x;
        endX = startX+(n-1);
        for y = 1:c
            startY = y;
            endY = startY+(n-1);

            w = conv2(single(padImg(startX:endX, startY:endY)), gauss);
            tempMat = zeros(2,2);

            for i = 1:(n-1)
                for j = 1:(n-1)
                    curX = startX+i;
                    curY = startY+j;
                    curIx = ix(curX, curY);
                    curIy = iy(curX, curY);

                    iMat = [curIx * curIx, curIx * curIy;
                            curIx * curIy, curIy * curIy];
                    tempMat = tempMat + (w(i,j) * iMat);
                end
            end

            M{x,y} = tempMat;
            if (type == 1)
                R(x,y) = det(tempMat) - k*(trace(tempMat))^2;
            elseif (type == 2)
                R(x,y) = det(tempMat)/(trace(tempMat));
            elseif (type == 3)
                [~, val] = eig(tempMat);
                val = diag(val);
                R(x,y) = min(val);
            else
                %error
            end
        end
    end
end
```

Multiscale Corner Detection

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% MULTISCALE — Scales down the image n times, returning the pyramid
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% im - the image
% n — the number of times to scale down the image
%OUTPUT:
% pyramid — a cell array containing all the scaled images

function pyramid = multiscale(im, n)
    image = rgb2gray(im);
    pyramid = cell(n,1);

    gn = 6;
    gauss = fspecial('gaussian', gn, gn/6);

    pyramid{1} = image;
    for i = 1:(n-1)
        scale = 1 / 2^i;
        newIm = imresize(image, scale);
        newIm = imfilter(newIm, gauss);
        pyramid{i+1} = uint8(newIm);
    end
end
```

Adaptive Non-maximal Suppression

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% NMAS — Non-Maximal Area Suppression of the interest points
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% N —
% R — an [n x 3] matrix of the potential interest points. Cols 1&2 the coords
%     col3 is the R value
% threshold — we will keep interest points with R values above this threshold
% octave — the scaling factor for the patches. The size of a patch is defined
%          as 40 / 2^octave
%OUTPUT:
% interestPoints — an [n x 2] matrix. Each row is an interest point
%                  the first column are the x coordinates
%                  the second column are the y coordinates

function interestPoints = NMAS( N, R, octave )

    patchSize = uint8( 40 / 2^octave );
    % Remove interest points that are within patch size of the image edge
    halfPatch = ceil( (1/2)*patchSize );

    topStartRow = 1;
    topEndRow = halfPatch + 1;
    bottomStartRow = size( R, 1 ) - halfPatch - 1;
    bottomEndRow = size( R, 1 );

    frontStartCol = 1;
    frontEndCol = halfPatch + 1;
    backStartCol =size( R, 2 ) - halfPatch - 1;
    backEndCol = size( R, 2 );

    R(topStartRow:topEndRow, : ) = -10000;
    R(bottomStartRow:bottomEndRow, : ) = -10000;

    R(:, frontStartCol:frontEndCol) = -10000;
    R(:, backStartCol:backEndCol) = -10000;

    sortedValues = sort( R(:) );
    maxValues = sortedValues( end-150:end );
    maxIndex = ismember( R, maxValues );
    index = find( maxIndex );
    [x y] = ind2sub( size(R), index );
    idx = sub2ind( [size(R, 1) size(R, 2) ], y, x );
    v = R( idx );

    newRow = y;
    newCol = x;
    newVal = v;

    [ sortedVal, sortedIndecies ] = sort( newVal, 'descend' );
    sortedRow = newRow( sortedIndecies );
    sortedCol = newCol( sortedIndecies );
    pointsMatrix = [ sortedCol, sortedRow  ];
    distVector = pdist( pointsMatrix );
    distMatrix = squareform( distVector );

    pointRadii = zeros( size( newRow, 1 ), 1 );
    pointRadii( 1, 1 ) = size( R, 1 );

    for i = 2: size( newRow, 1 )
        rowVecDist = distMatrix( i, : );
        strength = sortedVal( i );
        upperIndex = find( sortedVal > strength, 1, 'last' );
        potentialVec = rowVecDist( 1:upperIndex );
        radius = min( potentialVec );
        pointRadii( i, 1 ) = radius;

    end

    [ sortedRadii, sortedRadiiIndicies ] = sort( pointRadii, 'descend' );
    finalRow = sortedRow( sortedRadiiIndicies );
    finalCol = sortedCol( sortedRadiiIndicies );
    finalVal = sortedVal( sortedRadiiIndicies );

    interestPoints = [ finalRow( 1:N, 1 ), finalCol( 1:N, 1 )];

end
```

MOPS Descriptors

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% MOPS - creates descriptors for all interest points in an image
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% image - the image the interest points come from
% interestPoints - an n x 2 matrix, each row contains the x and y of
%                  an interest point
% octave - an integer representing the octave to analyze
% hessians - a [r c 2 2] matrix holding a hessian for every pixel in
%            the image
%OUTPUT:
% descriptors- an [n 8 8] matrix where n is the number of interest points
%              basically a matrix holding a descriptor for each interest
%              point
function [ descriptors ] = MOPS( image, interestPoints, octave, hessians )
    d = size(interestPoints);
    numInterestPoints = d(1);
    descriptors = [];
    patchSize = uint8( 40 / 2^octave );

    for idx = 1:numInterestPoints
        currentPoint = interestPoints(idx,:);
        x = currentPoint(1);
        y = currentPoint(2);

        % Realign the image so that the dominant eigenvector of the hessian
        % is along the horizontal
        [evec, evals] = eig(hessians{x,y});

        % The dominant eigenvector is the first eigenvector returned by eig
        dominantEigVec = evec(:,1);

        % rotate the image so that the dominant eigenvector is horizontal.
        angle = double(-radtodeg(atan(dominantEigVec(2)/dominantEigVec(1))));
        rotImage = imrotate(image, angle);

        % for each interest point
        % 1) extract a patch around it (the size of the patch is patchSize x
        %     patchSize)
        % 2) resize the patch to 8x8
        % 3) normalize the patch

        % create a patch of patchSize x patchSize of pixels around
        % interest point
        halfPatch = ceil( (1/2)*patchSize );

        startRow = y - halfPatch;
        endRow = y + halfPatch;

        startCol = x - halfPatch;
        endCol = x + halfPatch;
        % if the patchsize is even, the interest point can not be
        % at the center of the patch. It will be the top left point
        % of the lower right quadrant
        if(mod(patchSize,2) == 0)
            endRow = endRow - 1;
            endCol = endCol - 1;
        end

        % Skip patch if its dimensions exceed matrix dimensions
        if( startRow >= 1 && endRow <= size( image, 1 ) &&
            startCol >= 1 && endCol <= size( image, 2 ) )
            % 1) extract out the patch from the rotated image
            patch = rotImage(startRow:endRow, startCol:endCol);
            % 2) resize the patch to be 8 x 8
            %    if the image is larger than 8 x 8, it will be sized down
            %    if the image is smaller than 8 x 8, it will be interpolated
            %       using bicubic interpolation
            patch = im2double(imresize(patch, [8 8]));

            % 3) normalize
            avg = mean2(patch);
            stdDev = std2(patch);
            patch = patch - avg;
            if stdDev ~= 0
                patch = patch ./ stdDev;
            else
                patch(1,1) = 1;
            end
            % save in descriptors
            descriptors = [ descriptors; patch ];
        else
            error( 'Holy Hart Picks Batman, we have not eliminated all the
                    bad corners!' );
        end
    end
end
```

Matching Correspondences

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% INTERESTPOINTMATCHING – Match Interest Points from descriptors
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% descriptors – all of the descriptors for all images [n x 8 x 8]
%               n is the number of descriptors. Each descriptor is
%               an 8 x 8 patch.
% numPerIm – the number of descriptors there are per image
% ipToFindPerIm - the number of interest points to find per image
% corrThresh – the minimum value that a cross correlation would be
%              considered valid
%OUTPUT:
% mappedIndexes – is a [m x 4] matrix. M is the number of pairs
%                 col 1 is the index of the first image
%                 col 2 is the index of the second image
%                 col 3 is the index descriptor for the first image
%                 col 4 is the index descriptor for the second image


function mappedIndexes=interestPointMatching(descriptors, numPerIm,
ipToFindPerIm, corrThresh)
    %get the size of the descriptors and the size of each patch
    [sizex, sizePatch] = size(descriptors);

    %calculates the number of descriptors exist
    numDesc = sizex/sizePatch;
    %calculates the number of images we are looking at
    numIms = numDesc/numPerIm;
    %zeros out a square matrix that we will store the correlations in
    corrMat = zeros(numDesc);

    %for each descriptor
    for i=1:numDesc
        index = (sizePatch*(i-1))+1; %calculate the starting index
        curDescriptor = descriptors(index:(index+sizePatch-1),1:sizePatch);
        %get the correlation
        xcorrMatResult = normxcorr2(curDescriptor, descriptors);
        %get the image index that we are working on
        curImDesc = floor(i / numPerIm) + 1;

        %store results
        for j=1:numDesc
            %if the descriptors are for the same image ignore them
            if (curImDesc ~= floor(j/numPerIm)+1)
                %set the vert correlation found
                corrMat(i,j) = xcorrMatResult(((j-1)*sizePatch)+1,1);
                corrMat(j,i) = corrMat(i,j); %set the horizontal
            else
                %ignore the descriptors from the same image
                corrMat(i,j) = -1;
            end
        end
    end


    %Find all image mappings
    %First and second index of image.
    %Third and forth index of interest point
    mappedIndexes = [];

    %for each image set
    for fromIm = 1:numIms
        %calc the start of the im range in columns
        colIdx = numPerIm * (fromIm-1) + 1;
        %grab all the columns of that image and zero out anything
        %less than the threshold
        curCol = corrMat(:,colIdx:(colIdx+numPerIm-1)) .*
                  (corrMat(:,colIdx:(colIdx+numPerIm-1)) >= corrThresh);


        %from the fromImage onward
        for toIm = (fromIm+1):numIms
            %calc the start of the im range in the row
            rowIdx = numPerIm * (toIm-1) + 1;
            curRow = curCol(rowIdx:(rowIdx+numPerIm-1),:);
            %get columns indexs of fromIm with maxes in columns
            [colMaxes, colIndexes] = max(curRow, [],2);
            mat = zeros(numPerIm, numPerIm); %create storage
            indexes = sub2ind([numPerIm, numPerIm],
                              (1:numPerIm)', colIndexes);
            %set the rows to their maxes with zeros elsewhere
            mat(indexes) = colMaxes;

            [rowMax, rowIndexes] = max(mat, [], 1); %get the max of the rows
            %sort the maxes and get their indices
            [selectedMaxes,rowOrigIndexes] = sort(rowMax, 'descend');

            numFound = find(selectedMaxes); %count the maxes

            %if the maxes are more than the amount we are looking for
            if (size(numFound,2) >= ipToFindPerIm)
                insertVal(1:ipToFindPerIm,1) = fromIm; %store from im index
                insertVal(1:ipToFindPerIm,2) = toIm;%store to im index
                insertVal(1:ipToFindPerIm,3) =
                              rowOrigIndexes(1:ipToFindPerIm);
                insertVal(1:ipToFindPerIm,4) =
                              rowIndexes(rowOrigIndexes(1:ipToFindPerIm));
                mappedIndexes = [mappedIndexes;insertVal];
            end
        end
    end
end
```

Affine Tranformations

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% BUILDTRANSFORMMAT – build a transformation from one image to another
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% corrVec – nx4 mat of the form [(x1,y1),(x2,y2)] points.  x1,y1 refer to a
%           point in im1 and x2,y2 refer to a point in im2
%OUTPUT:
% transform – the transform to transform im2 into im1's space
function transform=buildTransformMat(corrVec)
%im1 and x2,y2 refer to a point in im2

    [n,~] = size(corrVec);
    mat = [];
    vec = corrVec(:,3:4);
    newVec = size(2*n,1);
    for i=1:n
       x1 = corrVec(i,1);
       y1 = corrVec(i,2);
       index = (2*i)-1;
       mat(index,:) = [x1,y1,0,0,1,0];
       mat(index+1,:) = [0,0,x1,y1,0,1];

       index = 2*(i-1);
       newVec(index+1) = vec(i,1);
       newVec(index+2) = vec(i,2);
    end

    newVec = newVec';
    aVec = mat\newVec;

    transformVec = aVec(1:size(aVec,1)-2,:);
    transform = reshape(transformVec, size(transformVec,1)/2,
                        size(transformVec,1)/2,1);
    translationVec = [-1*aVec(size(aVec,1)-1);aVec(size(aVec,1),:)];
    transform = [transform, translationVec(:)];
    transform = [transform; zeros(1,size(transform,2)-1),1];
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% APPLYTRANFORMATION – apply a transformation to an image
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% im – the image to transform
% affineTransform – the transformation to apply to the image
%OUTPUT:
% out – the transformed image
function out = applyTransformation(im, affineTransform)
    out = imwarp(im, affine2d(affineTransform));
end
```

Image Mapping

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% IMAGEMAPPING – Find a mapping from each image to all its shared points
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% mappedIndex – an [n 4] matrix of all image pairs
%OUTPUT:
% mapping – A cell array where the index is the from index and a vector of
%           all the images it maps to
% maxIdx – the index of the image that has the most correspondences
function [mapping, maxIdx]=imageMapping(mappedIndex)
    %get the column of the images that are the from images
    imCol = mappedIndex(:,1);
    maxImNum = max(imCol, [],1);%get the max number for the mapping
    mapping = cell(maxImNum);%create the cell array

    maxLen = 0;
    maxIdx = -1;
    %for each image
    for i=1:length(mapping)
        row = imCol == i; %get the rows for that image
        %get the unique values in the row
        mapping{i} = unique(mappedIndex(row,2)');
        if (size(mappedIndex,2) > maxLen) %get maxes
            maxIdx = i;
            maxLen = size(mappedIndex,2);
        end
    end
end
```

Stitching

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% STITCHING – Given a mapping, and interest points, stitch images together
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%ARGS:
% imList – the list of images to stitch
% mapping – the mapping of images that have corresponding interest points
% interestPoints – the interest points
%OUTPUT:
% outIm – the output image
function outIm = stitching(imList, mapping, interestPoints)
    %get a list of images the current image is mapped to
    [imMapping, baseImIdx] = imageMapping(mapping);

    warpedIms = cell(length(imMapping));
    visitedList = [];%zeros(1,length(imMapping));
    corners = cell(length(imMapping));
    %calculates data for stitching
    [corners, visitedList, warpedIms] = prepStitch(imList, imMapping,
                                               baseImIdx, mapping,
                                               interestPoints,
                                               visitedList,corners,
                                               eye(3),warpedIms);

    %get data for where our corners will be placed (this is used for
    %   translation
    cornersMat = zeros(4,4*size(visitedList,2));
    for i=1:size(visitedList,2)
       index = (4*(i-1))+1;
       corners{i}
       cornersMat(1:3,index:index+3) = corners{i};
    end

    %get the max and min of the corners so we can define our bounding box
    maxXY = max(cornersMat, [], 2);
    minXY = min(cornersMat, [], 2);

    %get first image to place in the list
    im = imList{visitedList(1)};
    [sizex,sizey] = size(im);

    %get upper and lower bounds based on corners
    lowerBoundY = abs(minXY(1));
    upperBoundY = lowerBoundY + maxXY(1);

    lowerBoundX = abs(minXY(2));
    upperBoundX = lowerBoundX + maxXY(2);

    %set base images offset
    offsetToBaseImX = 1+lowerBoundX;
    offsetToBaseImY = 1+lowerBoundY;

    %build out image
    outIm = zeros(ceil(upperBoundX), ceil(upperBoundY));
    outIm(offsetToBaseImX:offsetToBaseImX+sizex-
1,offsetToBaseImY:offsetToBaseImY+sizey-1) = im;

    %loop through all the
    for imNum = 2:size(visitedList,2)
       %get the index of the image we are displaying next
       imIdx = visitedList(imNum);
       curIm = warpedIms{imIdx}; %get the image
       [sizex,sizey] = size(curIm); %get the size

       %calculate where the minimum point is and tranlate it to that point
       curMinXY = corners{imIdx};
       imMinX = offsetToBaseImX+curMinXY(2);
       imMinY = offsetToBaseImY+curMinXY(1);

       %create a new image
       newIm = zeros(ceil(upperBoundX), ceil(upperBoundY));
       newIm(imMinX:(imMinX+sizex-1),imMinY:(imMinY+sizey-1)) = curIm;

       %blend with other images
       outIm = imfuse(outIm, newIm, 'blend');
    end
end
```

Prep Stitch

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% PREPSTITCH – Recursively goes through all mappings, performing the
%              warp on the image, finding the tranformation for the corners
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% ARGS
%imlist – cell array of images with the current one being indexed by
curImIndex
%cellList – cell array with each index of an image containing the indexes
%       of the images it references
%curImIndex - index of image we are using
%interestPoints - cell array of interest points
%visitedList - a list containing the items we have visited thus far.
%   Should be [] initially
%corners - a cell array with each image index containing column vectors of
%   corners
%curTransformMat - the transformation used to get into the image space of
%   of the prior image (initially identity [1,0,0;0,1,0;0,0,1])
% warpedIms – a cell array that contains the warped images

% OUTPUT
% corners – same as input corners
% visitedList – same as input visitedList
% warpedIms – same as input warpedIms
function [corners, visitedList, warpedIms] = prepStitch(imList, cellList,
curImIndex, mapping, interestPoints, visitedList, corners, curTransformMat,
warpedIms)
    vecConnectIms = [];
    if (curImIndex <= length(cellList))
        vecConnectIms = cellList{curImIndex};
    end
    visitedList = [visitedList,curImIndex];
    im = imList{curImIndex};

    %build corners
    [sizex,sizey] = size(im);
    cornerTL = curTransformMat * [1,1,1]';         %top left corner
    cornerTR = curTransformMat * [1,sizey,1]';
    cornerBL = curTransformMat * [sizex,1,1]';
    cornerBR = curTransformMat * [sizex,sizey,1]';
    corners{curImIndex} = [cornerTL,cornerTR,cornerBL,cornerBR];

    curTransformMat(1:2,3) = [0;0];
    imWarp = imwarp(im, affine2d(curTransformMat));
    warpedIms{curImIndex} = imWarp;
    for i=1:size(vecConnectIms)
        if (~any(vecConnectIms(i) == visitedList))

             indexFrom = mapping(:,1) == curImIndex;
             mappingFrom = mapping(indexFrom,:);
             indexTo = mappingFrom(:,2) == vecConnectIms(i);
             mappingValuesIpValues = mappingFrom(indexTo,3:4);
```

```
                fromIp = interestPoints(mappingValuesIpValues(:,1),:);
                toIp = interestPoints(mappingValuesIpValues(:,2),:);

                transform = buildTransformMat([fromIp,toIp]);
                transform = curTransformMat * transform;
                [corners, visitedList, warpedIms] = prepStitch(imList, cellList,
                                                    vecConnectIms(i),
                                                    mapping,
                                                    interestPoints,
                                                    visitedList, corners,
                                                    transform, warpedIms);
            end
        end
    end
```

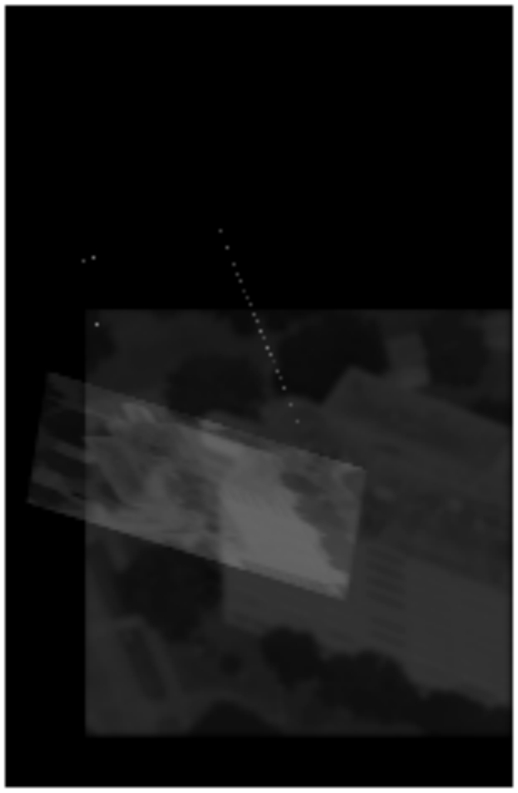
Results

Given the time constraints we were unable to get this fully working. We still have many small bugs in our program, particularly when dealing with handling scaled images as the scale gets small and the original image sizes vary. Of particular difficulty is getting meaningful correspondences from the interest points. We believe this may be caused by not analyzing enough interest points in Non-Maximal Area Suppression, but without more time we can not fully explore the issue.

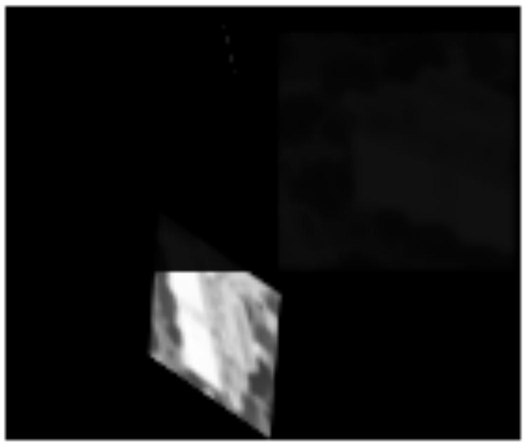
Below are some examples of output we were able to generate for the test_t dataset.

Octave 1:

Octave 2:



Octave 3:



Octave 4:

Notes on Implementation

We read several papers on image stitching that influenced our implementation. One major influence was on adaptive non-maximal area suppression, we based our implementation of the paper Multi-Image Matching Using Multi-Scale Oriented Patches by Brown, Szeliski, and Winder. Beyond the explicit step of using either SSD or cross-correlation we could not find many details on how to implement the interest point matching, so we essentially had to figure out an algorithm on our own. We used cross-correlation as our metric for matching. We used 50 interest points per image, selected using adaptive non-maximal area suppression. For each interest point we extracted a MOP. We then applied cross correlation of all MOPs of a given image to all other images MOPs. In each instance that we found 6 or more MOPs matches above a correlation threshold of 0.5 we recorded a match between the images.

We had numerous problems throughout our implementation, however, interestingly when we hand picked matching points the stitching function worked well. We found it difficult to debug the corner detection, ANAMS, and MOPs generation due to the lack of obvious ways to test correctness of results at these stages. As a result the numerous attempts to 'tweak' the code resulted in more bugs. It went down hill from there.

Work Distribution

As with the previous projects, we generally work together as a group throughout the project. All members read through the primary literature to understand the concepts and algorithms necessary for this project. Chris Kives was the primary author for the Harris Detector, Interest Point Matching, Image Mapping, and Stitching. Jonathan Redmann was the primary author for Non-maximal Area Suppression and the Stitch Images main program. Aaron Maus was the main author for MOPS. On almost all of the functions, we pair programmed as necessary to work through issues, understand concepts, and debug the program.