

Part2

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1. Overview and Division of Work

In this problem, we deal with the deblurring problem. Main method using in this problem are SVD decomposition and truncated reconstruction.

Note: our group upload two codes corresponding to this question. Both of them will return good results. The difference are only in input format, you can choose any of them which you think is more convenient.(report follows the input of part2Ma.m)

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- (1). Transform data and plot original, blurry and reconstructed image.(2.2)
- (2). Judge the type of the picture and get the size of it.(2.3)
- (3). Get the blurry image(2.5)
- (4). Construct SVD decomposition and compute pseudoinverse of A_l, A_r and truncated reconstruction. (2.6)
- (5). Packaging all method as a function.(2.9)
- (6). Debug the program.

Haoyu Ma(120020168):

- (1). Construct input. (2.1)
- (2). Construct three different blurry kernel A_l, A_r.(2.4)
- (3). Compute PNSR and cpu-time.(2.8)
- (4). Measure the performance of different truncation number and blurry kernel and analyze the performance.(3)
- (5). Conclude and write report.
- (6). Debug the program.

2. Main Process

2.1 Input parameters.

In this step, let the user input truncation number and picture name and which blurry kernel and svd method he want to use.

```
%input picture name,(256_256_buildings.png,640_640_lion.png,512_512_town_02.png)
X_name=input('please input the picture name ','s');
n=get_size_of_X(X_name);
%input truncation number
l_trunc=input('please input left truncation number ');
r_trunc=input('please input right truncation number ');

%input the blurry matrix you want
%blurry="original"(method1) or "shift"(method2) or "geometric"(method3);
blurry=input('please input which blurry matrix you want to use ','s');

%input the svd method you want
%svdme="builtin"(matlab built in svd) or "mySVD1"(phase A) or "mySVD2"(phase B);
svdme=input('please input which svd method you want to use ','s');
```

2.2 Data Transformation

In this problem, the first step was transform the given figure into data. Here, we use “imread()” function to transform the figure “X_name” into matrix “X” as our original picture. Then use “double()” function to convert the type of X into double type.

2.3 Judge the type of the picture and get the size of it.

In this step, we judge whether the picture is colorful or not and get the size of it.

```
function judge=colorful(X_name)
    X=imread(X_name);
    num_of_dim=ndims(X);
    if num_of_dim==2
        judge=false;
    else
        judge=true;
    end
end

function value=get_size_of_X(X_name)
    X=imread(X_name);
    n=size(X);
    value=n(1);
end
```

2.4 Blurring Kernel Construction

In this part, we build A_l and A_r as blurring kernels using following different method. Method 1:

Using T_k in previous exercise ($A_l = A_r = T_k$) :

Observing that the power of $T_k = 2 \times$ the number of diagonals + 1, so if we want more diagonals, we can just input a larger k .

Then let $T_{kl} = T_{kr} = T_k$.

```
function [Tkl Tkrl]=originalTk(n,k1,kr)
    a=linspace(1/4.1,1/4.1,n-1);
    d=linspace(2.1/4.1,2.1/4.1,n);
    T=zeros(n);
    for i = 1:(n-1)
        T(i,i)=d(i);
        T(i+1,i)=a(i);
        T(i,i+1)=a(i);
    end
    T(n,n)=d(n);
    Tkl=T;
    Tkrl=T;
```

Method 2:

Construct different asymmetric A_l and A_r by create different diagonals.

Here, we construct different T_{kl} and T_{kr} by construct three different diagonals.

For T_{kl} , it was larger n_2 on left subdiagonal and smaller n_3 on right subdiagonal.

For T_{kr} , it was larger n_2 on right subdiagonal and smaller n_3 on left subdiagonal.

```
function [Tkl Tkrl]=shiftTk(n,k1,kr,n1,n2,n3)
    a=linspace(n2,n2,n-1);
    a1=linspace(n3,n3,n-1);
    d=linspace(n1,n1,n);
    Tl=zeros(n);
    Tr=zeros(n);
    for i = 1:(n-1)
        Tl(i,i)=d(i);
        Tr(i,i)=d(i);
        Tl(i+1,i)=a(i);
        Tr(i+1,i)=a1(i);
        Tl(i,i+1)=a(i);
        Tr(i,i+1)=a1(i);
        Tl(i+1,i+1)=a1(i);
    end
    Tkrl=Tl;
    Tkl=Tr;
    for i=1:(k1-1)
        Tkl=Tkl*Tl;
    end
    for i=1:(kr-1)
        Tkrl=Tkr*Tr;
    end
```

Method 3:

In this method, observing that in method 1, the power of $T_k = 2 \times$ the number of diagonals + 1, so I use geometric sequence to build the blurry kernel. When I build geometric sequence, I assume the common ratio $q = 2$, you can also change it easily. Using the condition “ $a_1+a_2+...+a_2n=1$ ” I got the two simultaneous equations and got the

following method.

```
function [Tkl Tkrl]=geometricTk(n,q)
    %Geometric sequence
    an=(1-1/q)/(2*(1-(1/q)^n)-(1-1/q));
    T=zeros(n);
    for i = 0:(n-1)
        for j=1:(n-i)
            T(j,j+i)=an/q^i;
            T(j+i,j)=an/q^i;
        end
    end
    Tkl=T;
    Tkrl=T;
end
```

2.5 Get the blurry image

In this step, we compute the blurry image by using the blurry kernel we built in 2.3.

```
% get the blurry picture
B=[];
if colorful(X_name)
    for i=1:3
        B(:,:,i)=A_l*X(:,:,i)*A_r;
    end
else
    B=A_l*X*A_r;
end
% show the blurry image
subplot(1,3,2);imshow(B),title('blurry picture')
```

2.6 Compute the pseudoinverse of A_l, Ar and recover the blurry image

In this step, we use MATLAB built-in function “svd” to compute pseudoinverse of A_l, Ar. Then using the truncated SVDs with some truncation number.

```
% get SVD decomposition of A_l, A_r from built-in svd
if svdme=='builtin'
    [U_l,sigma_l,V_l]=svd(A_l);
    [U_r,sigma_r,V_r]=svd(A_r);
    fprintf("When we use the svd result in built-in function svd")
elseif svdme=='mySVD1'
    [U_l,sigma_l,V_l]=mySVD1(A_l);
    [U_r,sigma_r,V_r]=mySVD1(A_r);
    fprintf("When we use the svd result in phaseA")
else
    [U_l,sigma_l,V_l]=mySVD2(A_l);
    [U_r,sigma_r,V_r]=mySVD2(A_r);
    fprintf("When we use the svd result in phaseB")
end

% recover the original image
X_trunc=[];
if colorful(X_name)
    for i=1:3
        X_trunc(:,:,i)=A_l_pseudoinverse*B(:,:,i)*A_r_pseudoinverse;
    end
else
    X_trunc=A_l_pseudoinverse*B*A_r_pseudoinverse;
end

% determine the value of truncation number
l_trunc=trunc;
r_trunc=trunc;
%compute the pseudoinverse of A_l, A_r
A_l_pseudoinverse=zeros(n);
A_r_pseudoinverse=zeros(n);
for i=1:l_trunc
    A_l_pseudoinverse=A_l_pseudoinverse+V_l(:,i)*U_l(:,i)'/sigma_l(i,i);
end
for i=1:r_trunc
    A_r_pseudoinverse=A_r_pseudoinverse+V_r(:,i)*U_r(:,i)'/sigma_r(i,i);
end
```

2.7 Get the singular value

In this step, I plot A_l and A_r's singular value in sigma_l.mat and sigma_r.mat to prevent fussy output. You can check singular value in sigma_l.mat and sigma_r.mat easily.

```
% save the singular values of A_l,A_r
save sigma_l
save sigma_r
```

2.8 Measure the quality of reconstruction and cpu-time

In this step, we compute PSNR to measure the quality of reconstruction and use MATLAB built-in tic and toc to measure our code's cpu-time.

```
tic
toc
time=toc;
% compute PSNR and cputime
XF=X_trunc-X;
if colorful(X_name)
    num1=trace(XF(:,:,1).*XF(:,:,1));
    num2=trace(XF(:,:,2).*XF(:,:,2));
    num3=trace(XF(:,:,3).*XF(:,:,3));
    num=num1+num2+num3;
else
    num=trace(XF);
end
PSNR=10*log10(n^2/num);
```

2.9 Packaging all method as a function

In this step, we package all method used before to be a function to help us analyze different truncation number.

```
function [time,PSNR]=deblur_and_recover_picture(X_name,Tkl,Tkr,l_trunc,r_trunc,svdme)
```

2. Main results, Observations and Discussions

3.1 256_256_buildings.png:

3.1.1 Using method 1 (i.e.original Tk)

When I use truncation number = 210, Tk as blurry kernel and kl = kr = 6, the result id the following:

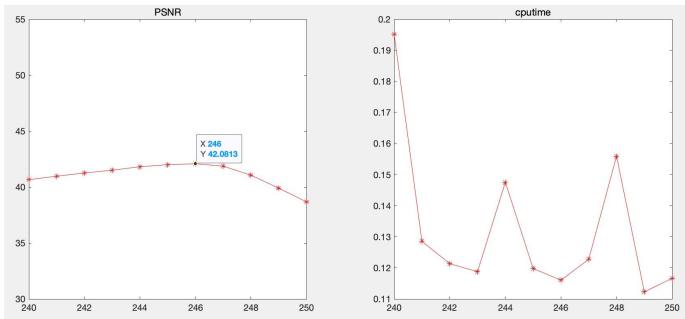


PSNR = 34.116726, cpu-time = 0.131111s.

When kl = kr = 1,2,3,4,5... we also have the same PSNR and similar cpu-time.

For kl = kr = 5, we can get the largest PSNR when truncation number = 246. The cpu-time has little difference. You can also try

other k's and truncation numbers. (You can check this code in evaluating.m)



But when $kl = kr \geq 9$, the picture was too blurry to be reconstructed.

When $kl = kr = 9$, look at the following picture, figure 3 has some strange colorful points.



Discussion:

1. In this method, the larger the k is, the more blurry of the second picture, and the harder to recover it.
2. When k is small and truncation number is fixed at a enough large value (e.g. 210), the PSNR are same.
3. When the difference between l_trunc and r_trunc is too large, we can't get a good reconstruction.

$l_trunc = 210, r_trunc=20$:



$l_trunc = 20, r_trunc=210$:



3.1.2 Using method 2 (i.e. shift Tk)

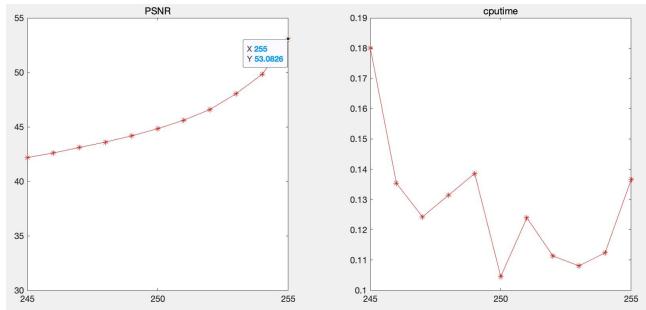
When I use shifted blurry kernel I built in method 2 and let left and right truncation number = 210, n1 = 0.6, n2 = 0.3, n3 = 0.1, $kl = kr = 5$, I got the following result. You can input different parameters to build different blurry kernel.

And note that $n1+n2=n3=1$, $n2 \geq n3$.



PSNR = 33.091477, cpu-time=0.172891s.

Using $n1 = 0.6$, $n2 = 0.3$, $n3 = 0.1$, $kl = kr = 5$, I got the largest PSNR at truncation number = 255, which is 53.0826.



Discussion:

1. The larger the $n1$ you input, it means the blurry matrix is closer to identity matrix, so the blurry degree is smaller.
2. The larger the $n2$ and $n3$ you input, it means the blurry matrix is more dispersive, so the blurry degree is larger.
3. If you input $n3 = 0$, then Tkl only has diagonal and left subdiagonals.
4. If you input $n2 = n3$, then it was similar to method 1, which only change the parameter in the diagonals.
5. In this method, the blurry picture move to right and downside slightly.

And the larger kl is, the more distance it moves down. When $kl = 1$ and $kr = 8$:



The larger kr is, the more distance it moves to right. When $kl = 8$ and $kr = 1$:



And it is also true if we take $n2 = n3$: if $kl > kr$, then the picture will move down, if $kl < kr$, then the picture will move to right.

You can also try other $n1, n2, n3, kl, kr$ and the result is corresponding to the discussion.

6. Remember in method 1, we cannot get good reconstruction when truncation number = 210 and $k \geq 9$, but using this method 2, I find that we can recover the picture successfully when $k=9$, and until $k \leq 15$, this method will always give a good reconstruction.



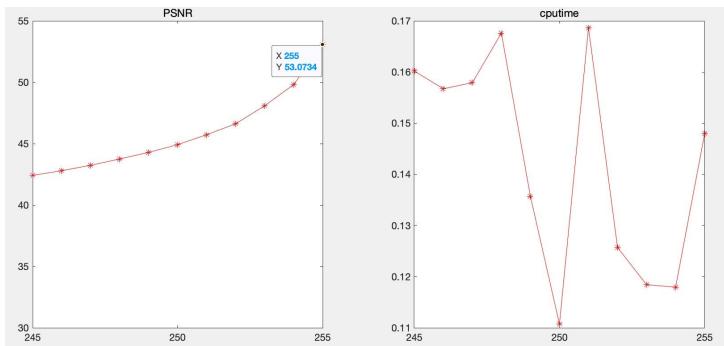
3.1.3 Using method 3 (i.e. geometric Tk)

When I use geometric sequence blurry kernel I built in method 3 and truncation number = 210, q = 2, I got the following result.



PSNR = 34.347611, cpu-time = 0.198642s.

Using this method, I get the biggest PSNR when truncation number = 255, which is 53.0734.



Discussion:

1. The reason that I use this geometric sequence is that I observe that in method 1, when I multiple T to Tk, the number of diagonals is plus 2, it's similar to geometric sequences.
2. All these three method of building blurry matrix have good performance and the PSNR and cpu-time of different method didn't have very large difference.
3. Using MATLAB built-in svd() function, we can deblur the picture rapidly.

3.1.4 Using methods in problem 1

Using methods built in problem1, we can also get the result successfully, but the speed is much slower.(Using method1 as an example)

Phase A: When l_trunc = r_trunc = 210, kl = kr = 5, PSNR = 34.116726, cpu-time = 631.753492s.



Phase B: When l_trunc = r_trunc = 210, kl = kr = 5, PSNR = 34.116726, cpu-time = 750.135112s.



Using two svd methods in problem1, we can also recover the blurry picture successfully. But it was much slower.

And due to it's speed, we will not test this method in following examples.

3.2 640_640_lion.png

For this picture, I will show my result precisely because the theory is similar.

3.2.1 Using method 1 (i.e.original Tk)

When k = 15 and truncation number =500:



PSNR = 27.993494, cpu-time = 0.739998s.

You can measure performance of different k and truncation number easily.

3.2.2 Using method 2 (i.e.shift Tk)

When I use method 2 and let left and right truncation number = 500, n1 = 0.6, n2 = 0.3, n3 = 0.1, kl = kr = 15, I got the following result. You can input different parameters to build different blurry kernel.



PSNR = 27.780650, cpu-time = 0.774896s.

3.2.3 Using method 3 (i.e.geometric Tk)

When I use geometric sequence blurry kernel I built in method 3 and truncation number = 210, q = 2, I got the following result.



PSNR = 28.040590, cpu-time = 0.633339s.

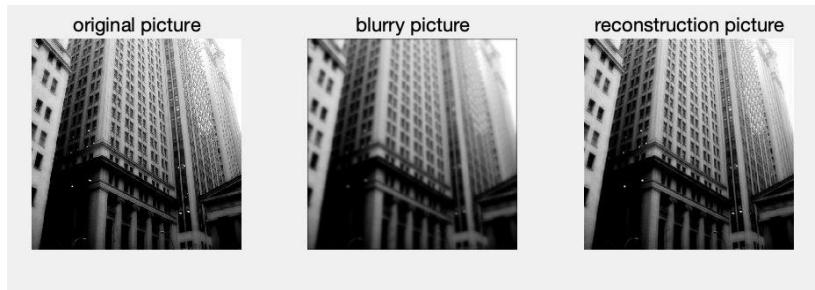
3.3 512_512_town_02.png

For this picture, I will show my result precisely because the theory is similar.

It is a picture without color, but our algorithm can also work.

3.2.1 Using method 1 (i.e.original Tk)

When $kl = kr = 6$ and truncation number = 450:

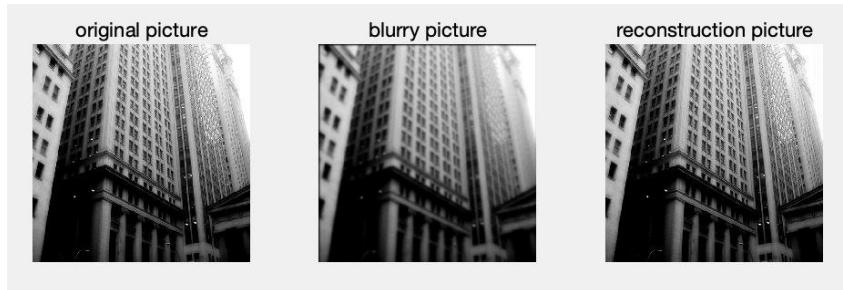


PSNR = 64.759155, cpu-time = 0.312406s.

You can measure performance of different k and truncation number easily.

3.3.2 Using method 2 (i.e.shift Tk)

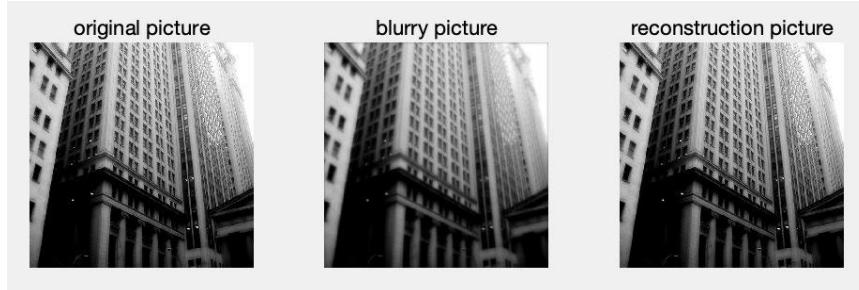
When I use method 2 and let left and right truncation number = 450, $n1 = 0.6$, $n2 = 0.3$, $n3 = 0.1$, $kl = kr = 12$, I got the following result. You can input different parameters to build different blurry kernel.



PSNR = 61.708360, cpu-time = 0.317298s.

3.3.3 Using method 3 (i.e.geometric Tk)

When I use geometric sequence blurry kernel I built in method 3 and truncation number = 450, $q = 2$, I got the following result.



PSNR = 62.162049, cpu-time = 0.311370s.