- Previous Lecture:
  - Image processing
    - Add frame, mirror
- Today's Lecture:
  - More image processing
    - color→grayscale
    - "Noise" filtering
    - Edge finding

- Announcements:
  - Discussion this week in the classrooms as listed on Student Center
  - Project 4 due Mon Oct 26th
  - Pick up your prelim paper during consulting hours

Grayness: a value in [0..255]

0 = black
255 = white

These are *integer* values
Type: `uint8`

```
150  149  152  153  152  155
151  150  153  154  153  156
153  151  155  156  155  158
154  153  156  157  156  159
156  154  158  159  158  161
157  156  159  160  159  162
```

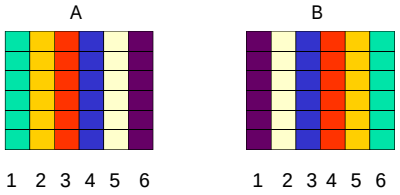

Example: Mirror Image

`LawSchool.jpg`

`LawSchoolMirror.jpg`

1. Read **LawSchool.jpg** from memory and convert it into an array.
2. Manipulate the Array.
3. Convert the array to a jpg file and write it to memory.

Vectorized code simplifies things…
Work with a whole column at a time



Column c in B
is column nc-c+1 in A

Consider a single matrix (just one layer)

```
[nr,nc,np] = size(A);
for c= 1:nc
    B(1:nr,c ) = A(1:nr,nc-c+1 );


end
```


Vectorized code to create a mirror image

```
A = imread('LawSchool.jpg')
[nr,nc,np] = size(A);
for c= 1:nc
    B(:,c,1) = A(:,nc-c+1,1)
    B(:,c,2) = A(:,nc-c+1,2)
    B(:,c,3) = A(:,nc-c+1,3)
end
imwrite(B,'LawSchoolMirror.jpg')
```

Even more compact vectorized code to create a mirror image…

```
for c= 1:nc
    B(:,c,1) = A(:,nc-c+1,1)
    B(:,c,2) = A(:,nc-c+1,2)
    B(:,c,3) = A(:,nc-c+1,3)
end
```

```
B = A(:,nc:-1:1,:)
```

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Vectorized code to create a mirror image

```
A = imread('LawSchool.jpg')
[nr,nc,np] = size(A);
for c= 1:nc
    B(:,c,1) = A(:,nc+1-c,1)
    B(:,c,2) = A(:,nc+1-c,2)
    B(:,c,3) = A(:,nc+1-c,3)
end
imwrite(B,'LawS
```

Can improve efficiency by initializing B to be a 3-d array of the appropriate size

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Example: color → black and white

Can "average" the three color values to get one gray value.

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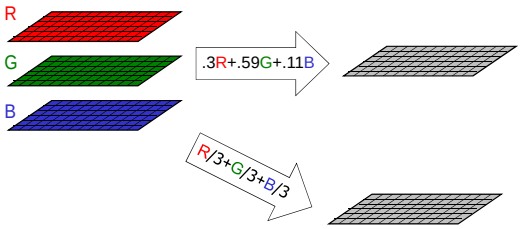
Averaging the RGB values to get a gray value



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Averaging the RGB values to get a gray value


```
for  i= 1:m
   for j= 1:n
      M(i,j)= .3*R(i,j) + .59*G(i,j) + .11*B(i,j)
   end
end
```

scalar operation

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Averaging the RGB values to get a gray value


```
M= .3*R + .59*G + .11*B
```

vectorized operation

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Here are 2 ways to calculate the average. Are gray value matrices g and h the same given image data A?

```
for r= 1:nr
  for c= 1:nc
    g(r,c)= A(r,c,1)/3 + A(r,c,2)/3 + ...
            A(r,c,3)/3;
    h(r,c)= ...
       ( A(r,c,1)+A(r,c,2)+A(r,c,3) )/3;
  end
end
```

A: yes B: no

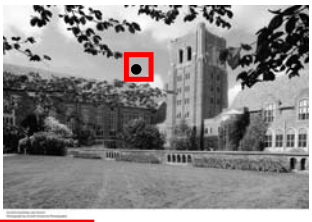
showToGrayscale.m

Matlab has a built-in function to convert from color to grayscale, resulting in a 2-d array:

B = rgb2gray(A)

Clean up "noise" — median filtering

Dirt in the image!



Note how the "dirty pixels" look out of place

150	149	152	153	152	155
151	150	153	154	153	156
153	2	3	156	155	158
154	2	1	157	156	159
156	154	158	159	158	161
157	156	159	160	159	162

What to do with the dirty pixels?

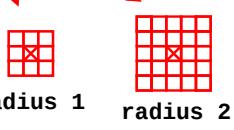
Assign "typical" neighborhood gray values to "dirty pixels"

150	149	152	153	152	155
151	150	153	154	153	156
153	?	?	156	155	158
154	?	?	157	156	159
156	154	158	159	158	161
157	156	159	160	159	162

What are "typical neighborhood gray values"?

Median

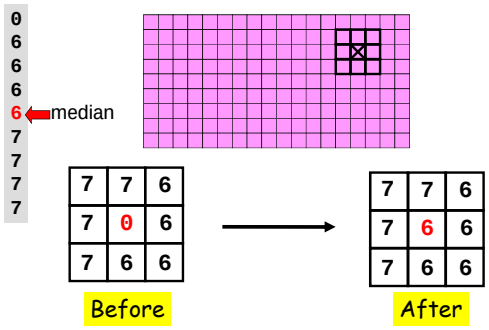
Mean



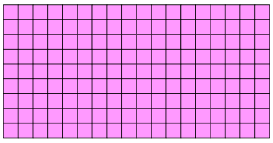
Median Filtering

- Visit each pixel
- Replace its gray value by the median of the gray values in the "neighborhood"

Using a radius 1 "neighborhood"



Visit every pixel; compute its new value.




```
for i=1:m
   for j=1:n
        Compute new gray value for pixel (i,j).
   end
end
```


What we need…

- (1) A function that computes the median value in a 2-dimensional array C:

```
m = medVal(C)
```

- (2) A function that builds the filtered image by using median values of radius r neighborhoods:

```
B = medFilter(A,r)
```


Computing the median

x : | 21 | 89 | 36 | 28 | 19 | 88 | 43 |

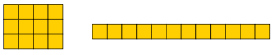
```
x = sort(x)
```

x : | 19 | 21 | 28 | 36 | 43 | 88 | 89 |

```
n = length(x);  % n = 7
m = ceil(n/2);  % m = 4
med = x(m);     % med = 36
```

If n is even, then use : `med = x(m)/2 + x(m+1)/2`

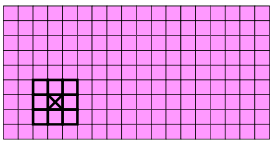
Median of a 2D array



```
function  med = medVal(C)
[nr,nc] = size(C);
x = zeros(1,nr*nc);
for r=1:nr
   x((r-1)*nc+1:r*nc) = C(r,:);
end
%Compute median of x and assign to med
% …
```

See `medVal.m`

When window is inside…



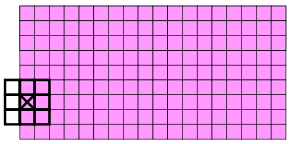
m = 9

n = 18

New gray value for pixel (7,4) =

```
medVal( A(6:8,3:5) )
```


When window is partly outside…



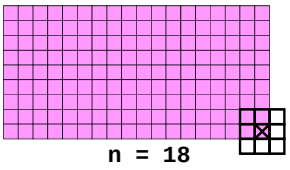
m = 9

n = 18

New gray value for pixel (7,1) =

```
medVal( A(6:8,1:2) )
```


When window is partly outside…



m = 9

n = 18

New gray value for pixel (9,18) =

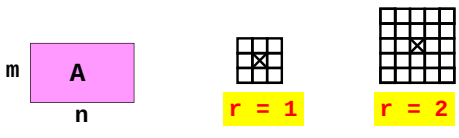
```
medVal( A(8:9,17:18) )
```



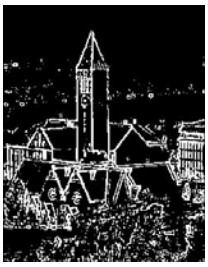
```
function B = medFilter(A,r)
% B from A via median filtering
% with radius r neighborhoods.

[m,n] = size(A);
B = uint8(zeros(m,n));
for i=1:m
   for j=1:n
      C = pixel (i,j) neighborhood
      B(i,j) = medVal(C);
   end
end
```


The Pixel (i,j) Neighborhood

```
iMin = max(1,i-r)
iMax = min(m,i+r)
jMin = max(1,j-r)
jMax = min(n,j+r)
C = A(iMin:iMax,jMin:jMax)
```



Finding Edges



What is an edge?

Near an edge, grayness values change abruptly

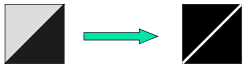
```
200  200  200  200  200  200
200  200  200  200  200  100
200  200  200  200  100  100
200  200  200  100  100  100
200  200  100  100  100  100
200  100  100  100  100  100
```

General plan for showing the edges in in image

- Identify the "edge pixels"
- Highlight the edge pixels
  - make edge pixels white; make everything else black

```
200  200  200  200  200  200
200  BLACK 200  200  200  100
200  200  200  200  100  100
200  200  200  100  100  100
200  200  100  100  100  100
200  100  100  100  BLACK  100
```

WHITE



The Rate-of-Change-Array

Suppose **A** is an image array with integer values between 0 and 255.

Let **B(i,j)** be the maximum difference between and its eight neighbors.

So **B(i,j)** is the maximum value in

```
A(max(1,i-1):min(m,i+1),...
  max(1,j-1):min(n,j+1))   - A(i,j)
```

Neighborhood of A(i,j)

Rate-of-change example

90	81	65
62	60	59
56	57	58

Rate-of-change at middle pixel is 30

Be careful! In "uint8 arithmetic"
57 - 60 is 0


```
function Edges(jpgIn,jpgOut,tau)
% jpgOut is the "edge diagram" of image jpgIn.
% At each pixel, if   rate-of-change > tau
% then the pixel is considered to be on an edge.

A = rgb2gray(imread(jpgIn));   Built-in function to
[m,n] = size(A);               convert to grayscale.
B = uint8(zeros(m,n));         Returns 2-d array.
for i = 1:m
    for j = 1:n

        B(i,j) =  ?????

    end
end
```


Recipe for rate-of-change B(i,j)

```
% The 3-by-3 subarray that includes A(i,j)
% and its 8 neighbors (for an interior pixel)
Neighbors = A(i-1:i+1,j-1:j+1);

% Subtract A(i,j) from each entry
Diff= abs( double(Neighbors) - double(A(i,j)) );
% Compute largest value in each column
colMax = max(Diff);
% Compute the max of the column max's
B(i,j) = max(colMax);
```

```
function Edges(jpgIn,jpgOut,tau)
% jpgOut is the "edge diagram" of image jpgIn.
% At each pixel, if   rate-of-change > tau
% then the pixel is considered to be on an edge.

A = rgb2gray(imread(jpgIn));
[m,n] = size(A);
B = uint8(zeros(m,n));
for i = 1:m
  for j = 1:n
    Neighbors = A(max(1,i-1):min(i+1,m), ...
                  max(1,j-1):min(j+1,n));
    B(i,j)=max(max(abs(double(Neighbors)- ...
                       double(A(i,j)))));



  end
end
```

"Edge pixels" are now identified; display them with maximum brightness (255)

A

1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	90	90
1	1	1	90	90	90
1	1	90	90	90	90
1	1	90	90	90	90

threshold

```
if B(i,j) > tau
    B(i,j) = 255;
end
```

B(i,j)

0	0	0	0	0	0
0	0	0	89	89	89
0	0	89	89	0	0
0	89	89	0	0	0
0	89	0	0	0	0
0	89	0	0	0	0

0	0	0	0	0	0
0	0	0	255	255	255
0	0	255	255	0	0
0	255	255	0	0	0
0	255	0	0	0	0
0	255	0	0	0	0

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```
function Edges(jpgIn,jpgOut,tau)
% jpgOut is the "edge diagram" of image jpgIn.
% At each pixel, if   rate-of-change > tau
% then the pixel is considered to be on an edge.
A = rgb2gray(imread(jpgIn));
[m,n] = size(A);
B = uint8(zeros(m,n));
for i = 1:m
  for j = 1:n
    Neighbors = A(max(1,i-1):min(i+1,m), ...
                  max(1,j-1):min(j+1,n));
    B(i,j)=max(max(abs(double(Neighbors)- ...
                       double(A(i,j)))));
    if B(i,j) > tau
      B(i,j) = 255;
    end
  end
end
imwrite(B,jpgOut,'jpg')
```

Edge finding: Effect of edge threshold, τ

τ ⟶

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