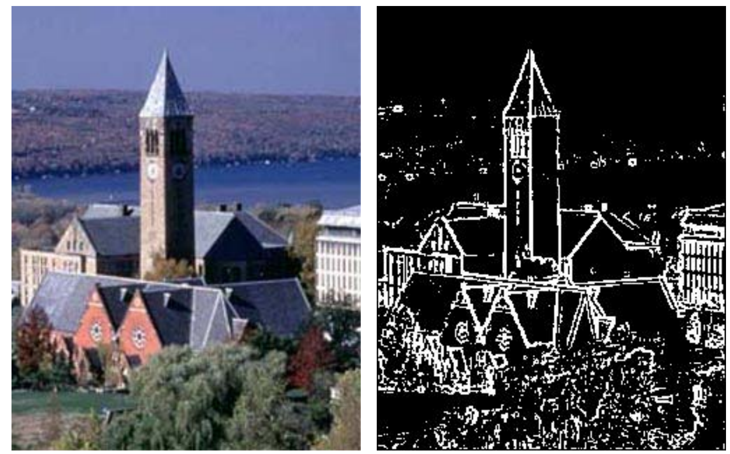
- Previous Lecture:
  - Image processing
    - Add frame, mirror
- Today's Lecture:
  - More image processing
    - color→grayscale
    - "Noise" filtering
    - Edge finding

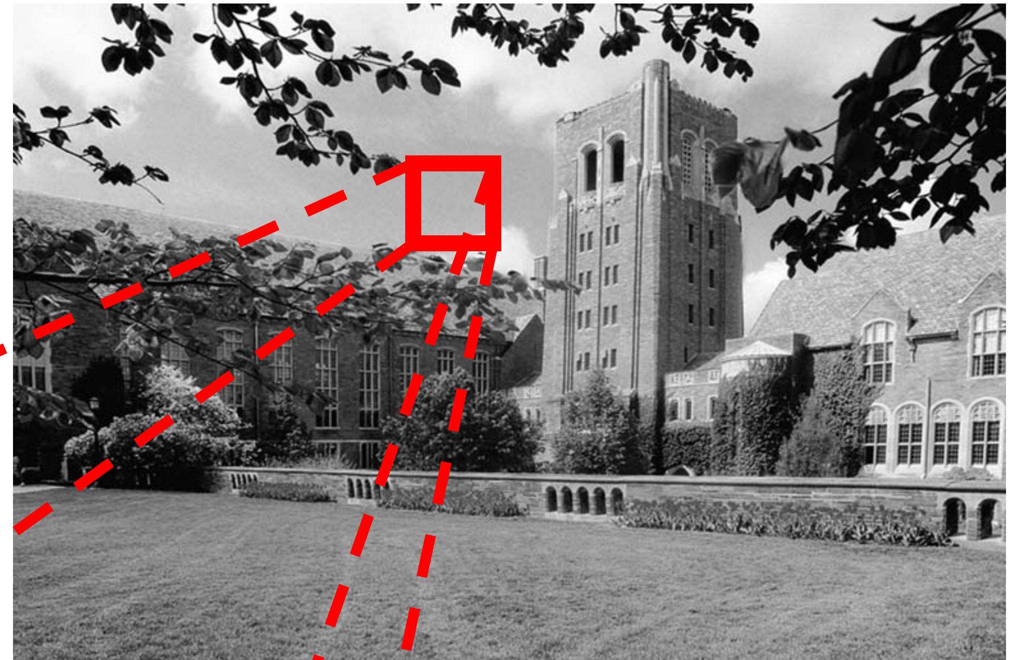


- Announcements:
  - Project 4 due next Thursday
  - Be sure to review—re-do—prelim 1 now so that you have a firm foundation

Grayness: a value in [0..255]

0 = black
255 = white

These are *integer* values
Type: **uint8**

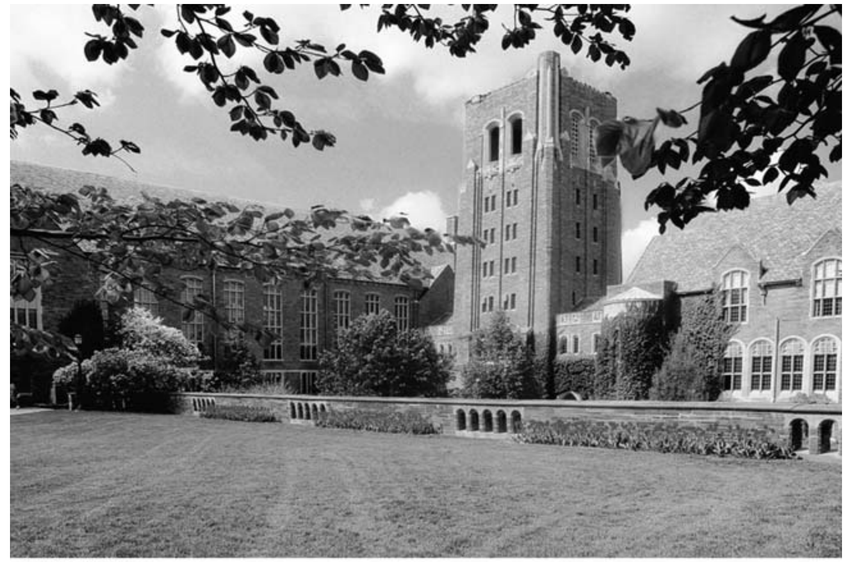


Cornell University Law School
Photograph by Cornell University Photography

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: color → black and white

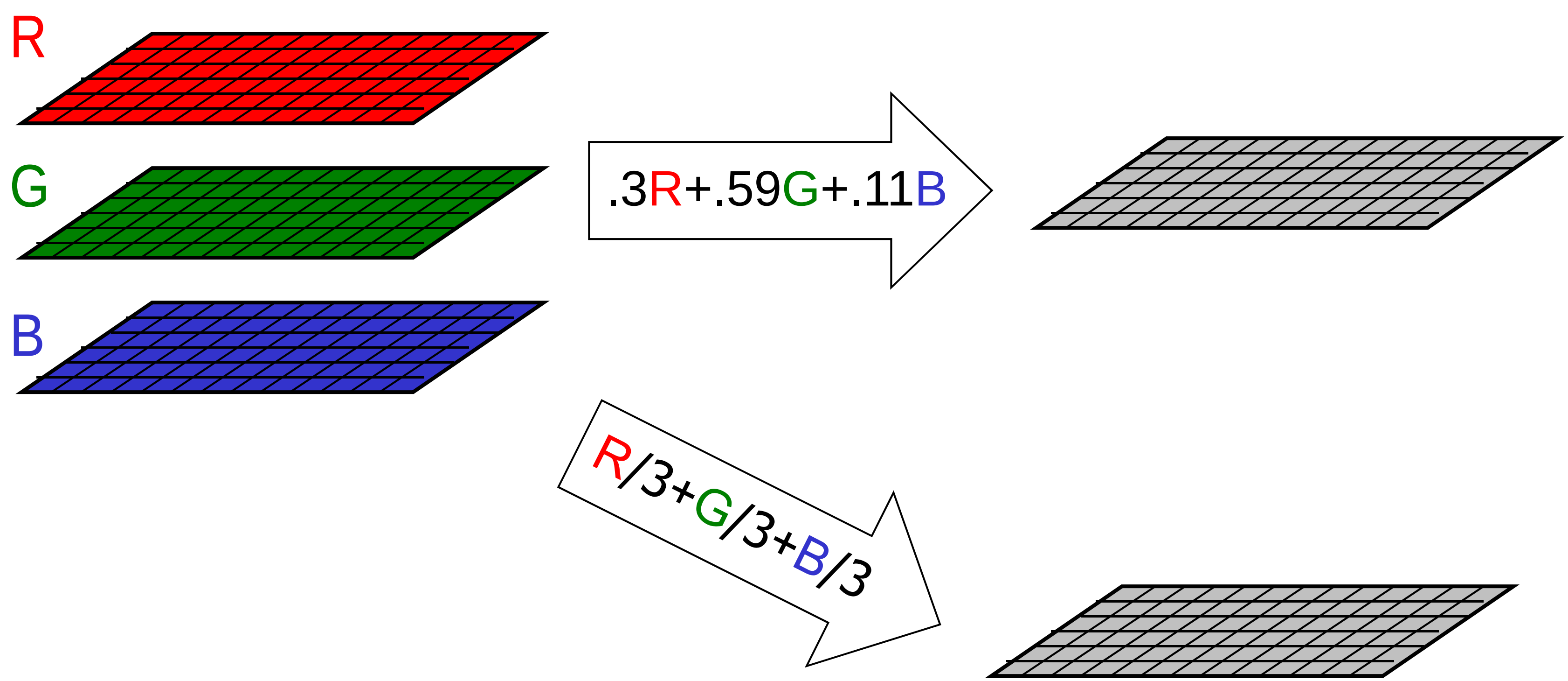
Cornell University Law School
Photograph by Cornell University Photography



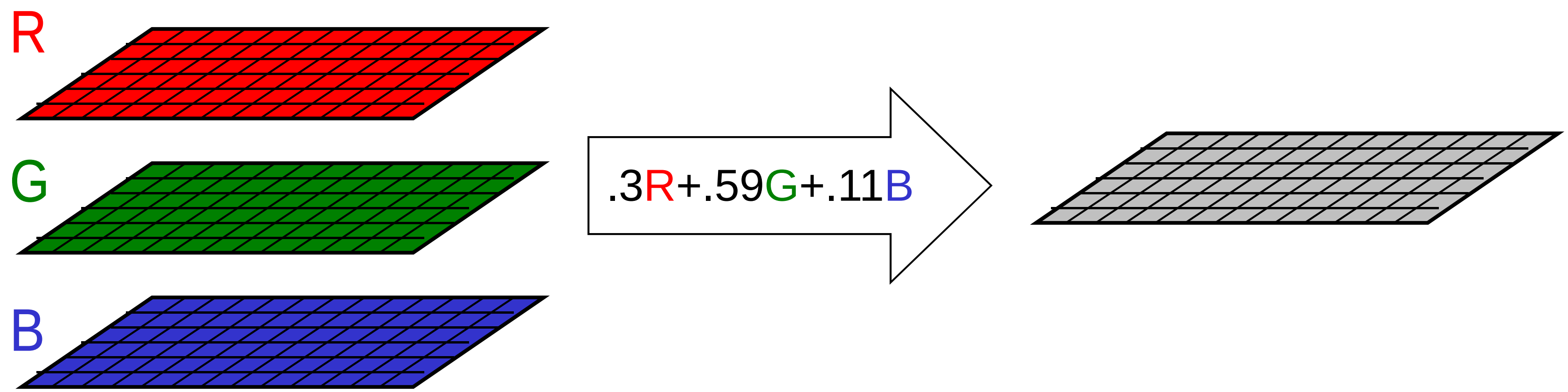
Cornell University Law School
Photograph by Cornell University Photography

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

Averaging the RGB values to get a gray value



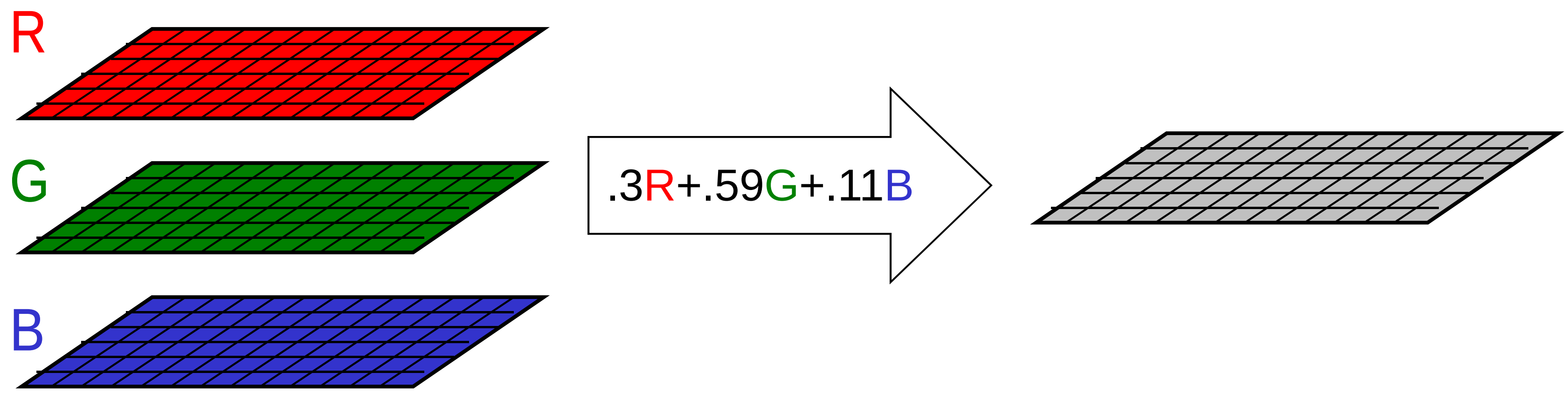
Averaging the RGB values to get a gray value




```
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

Averaging the RGB values to get a gray value



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

vectorized operation

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

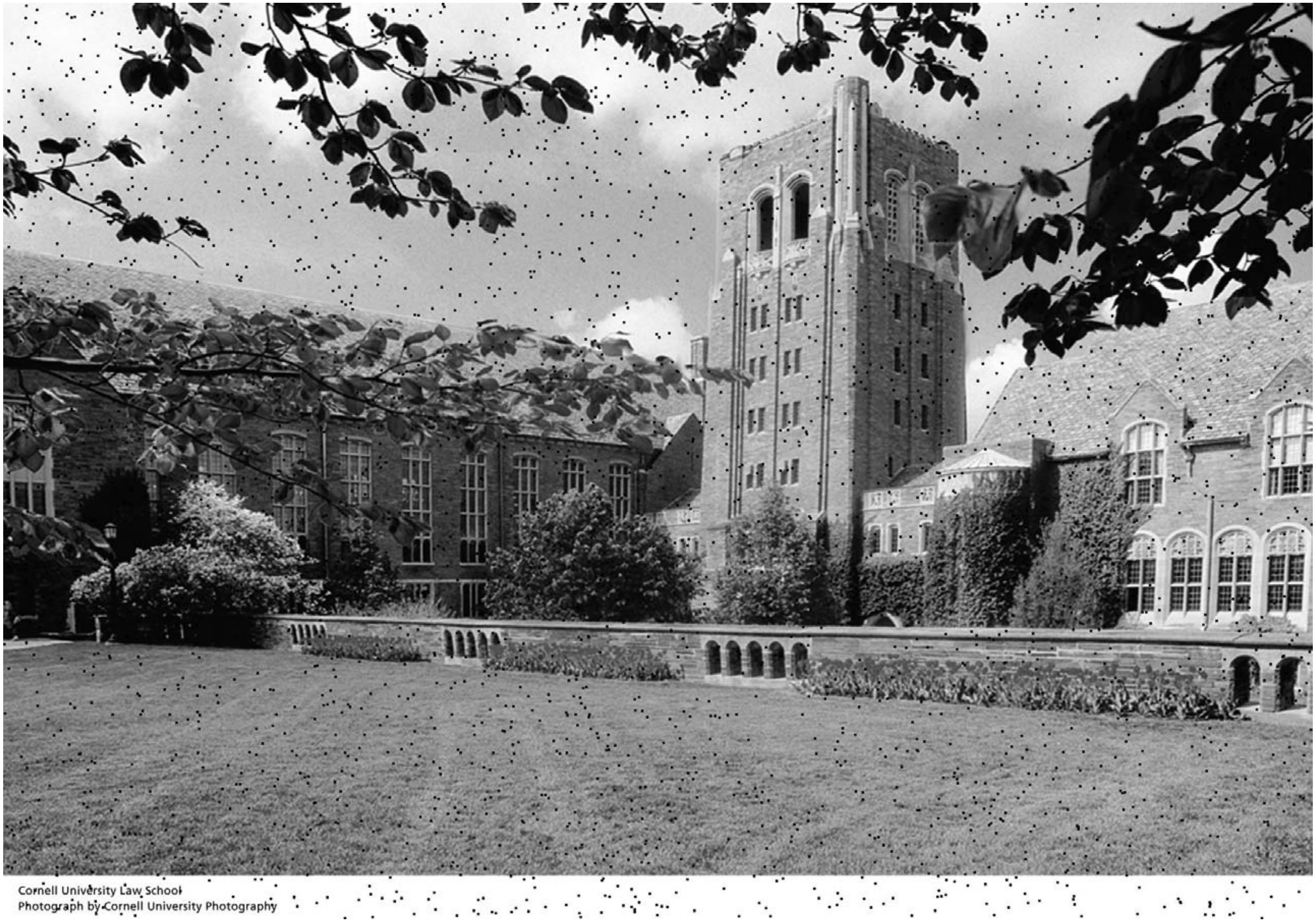
B: no

showToGrayscale.m

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

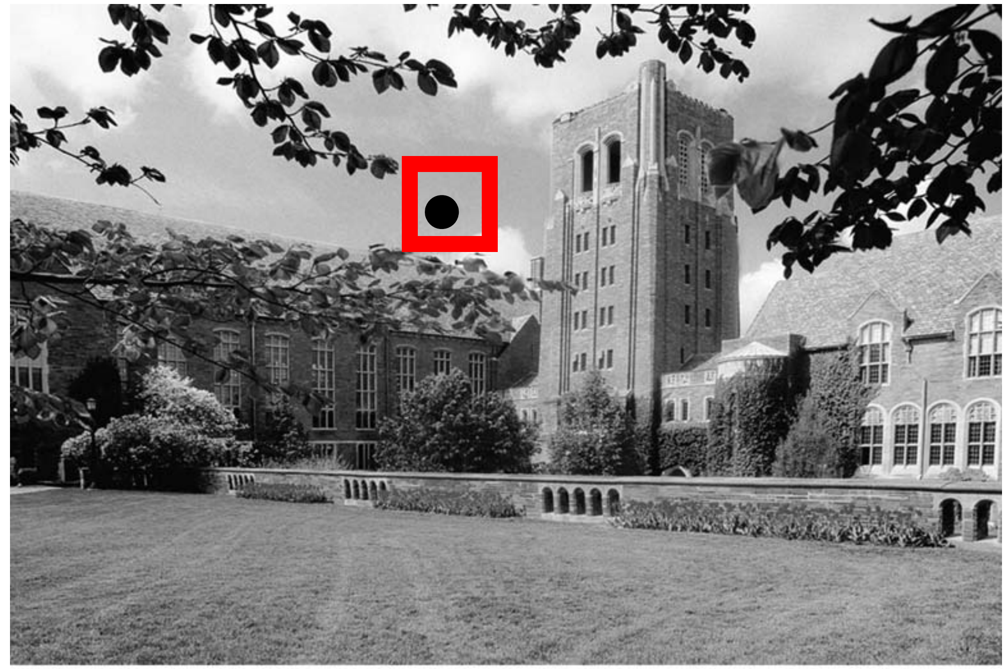
B = rgb2gray(A)

Clean up “noise” — median filtering



Dirt in the image!

Note how the "dirty pixels" look out of place

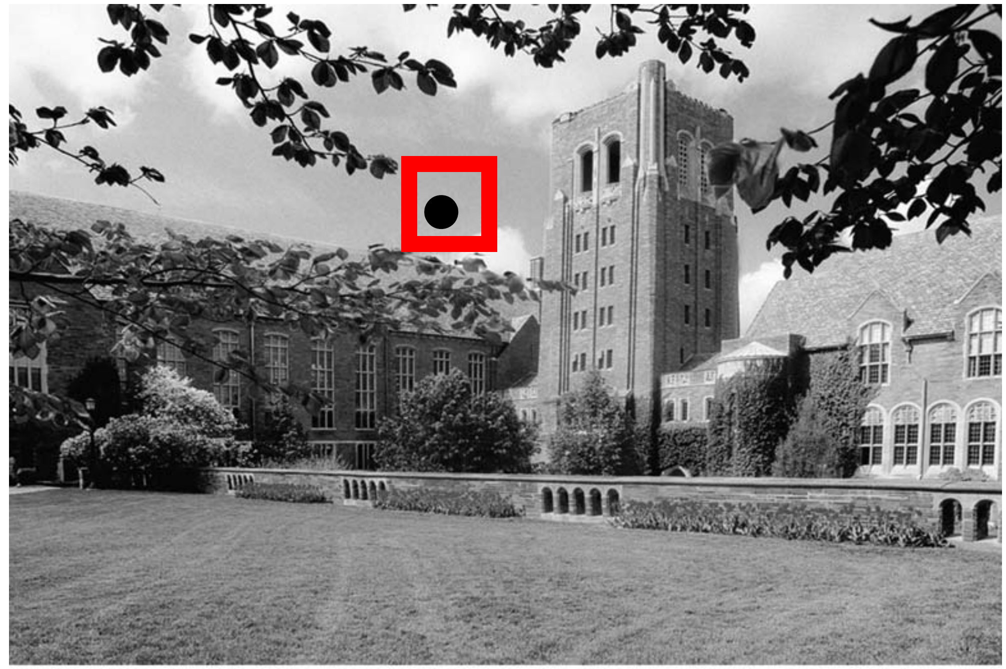


Cornell University Law School
Photograph by Cornell University Photography

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?

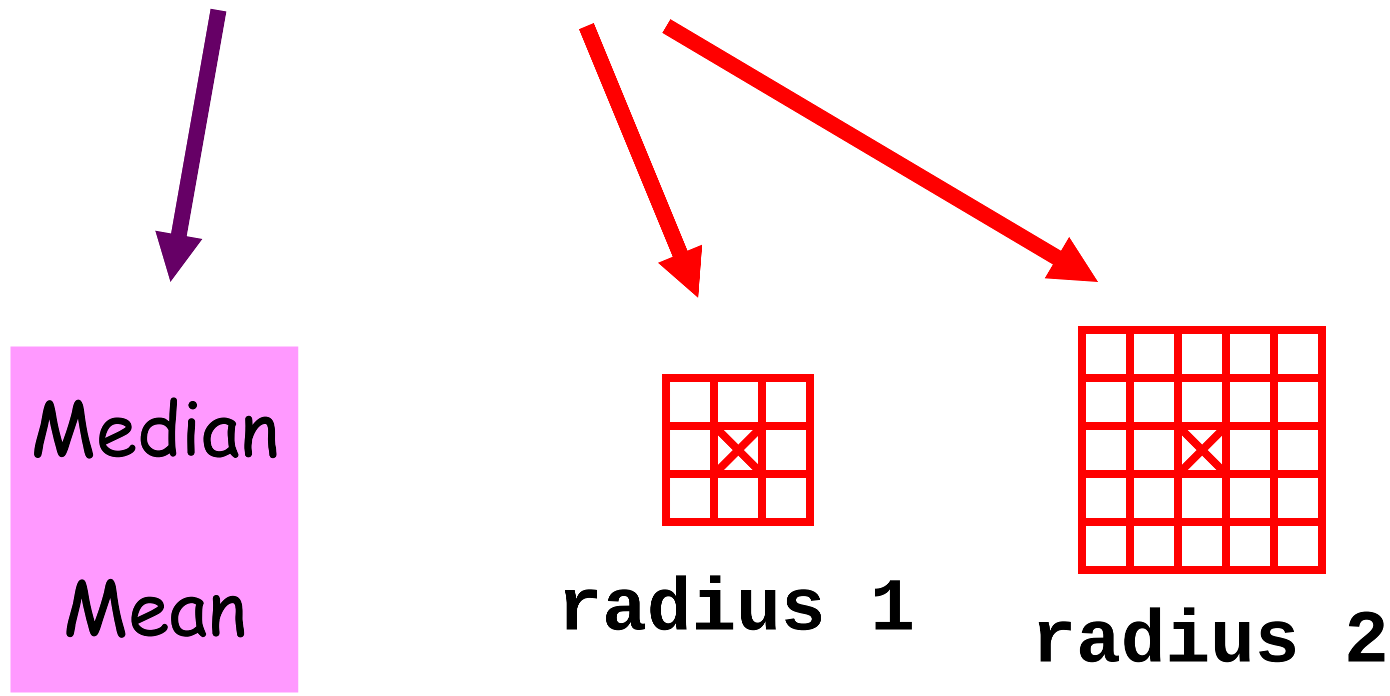
Assign "typical" neighborhood gray values to "dirty pixels"



Cornell University Law School
Photograph by Cornell University Photography

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"?

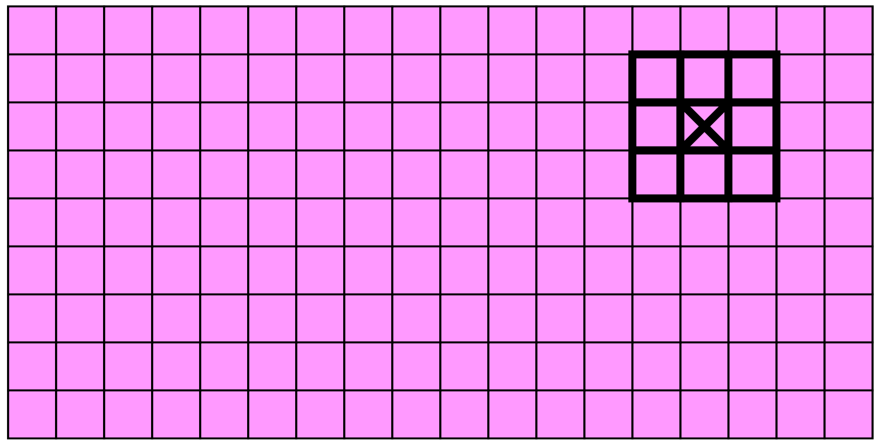


Median Filtering

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

Using a radius 1 "neighborhood"

0
6
6
6
6 median
7
7
7
7



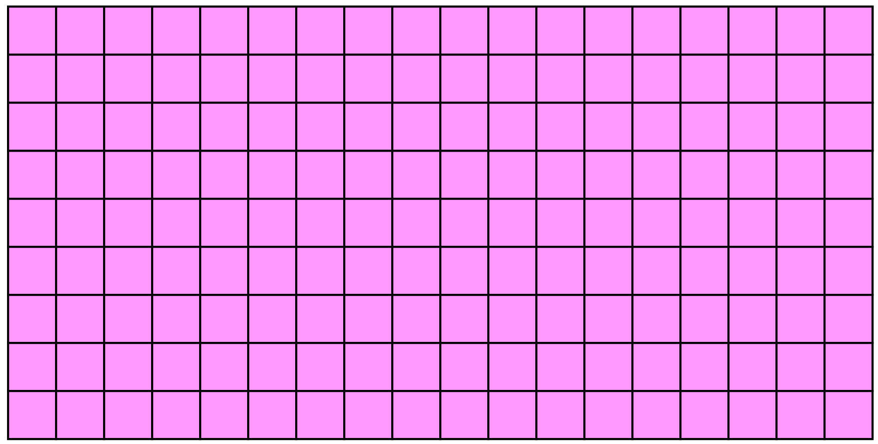
7	7	6
7	0	6
7	6	6

Before

7	7	6
7	6	6
7	6	6

After

Visit every pixel; compute its new value.



m = 9

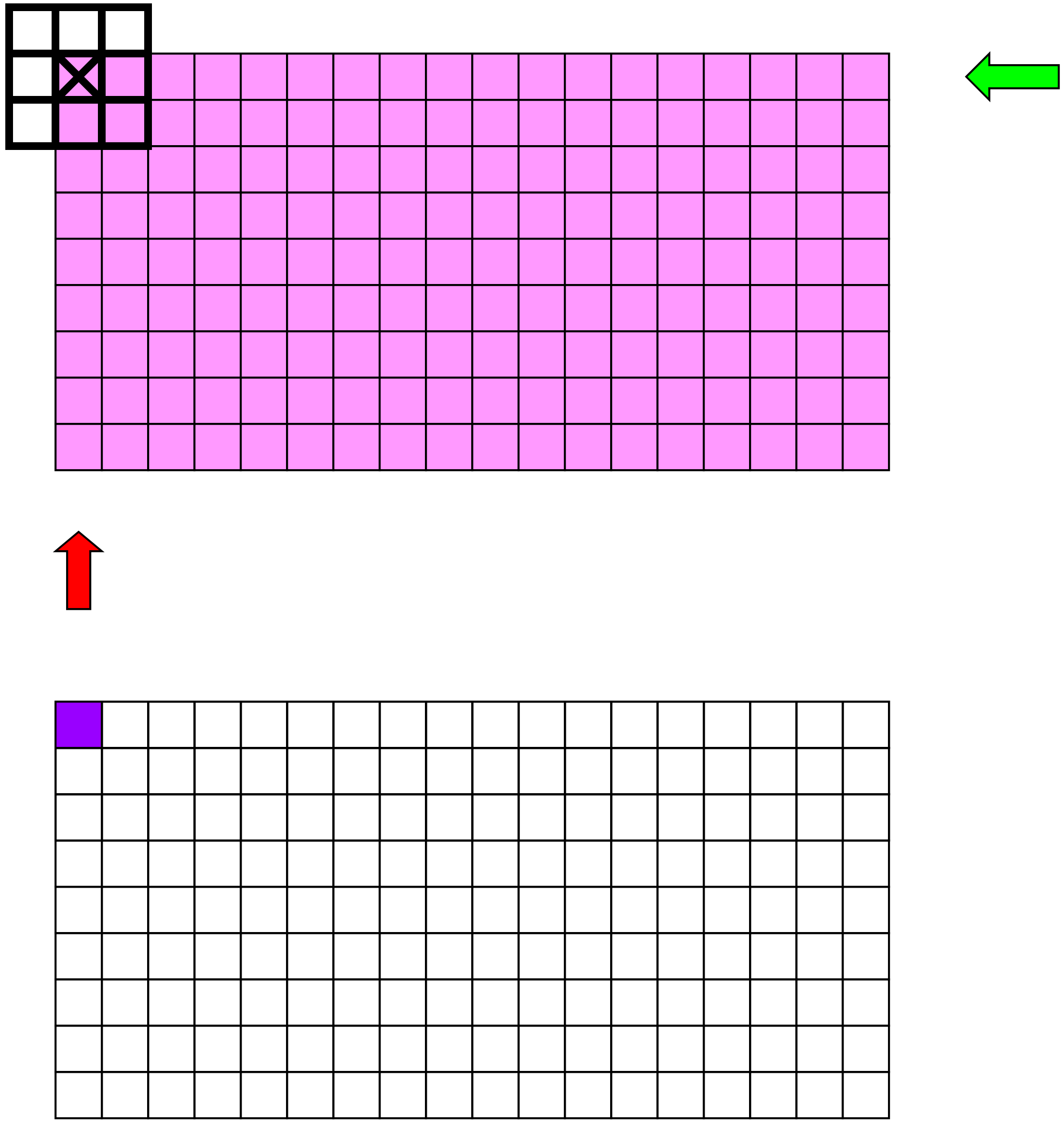
n = 18

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

Original:

i = 1

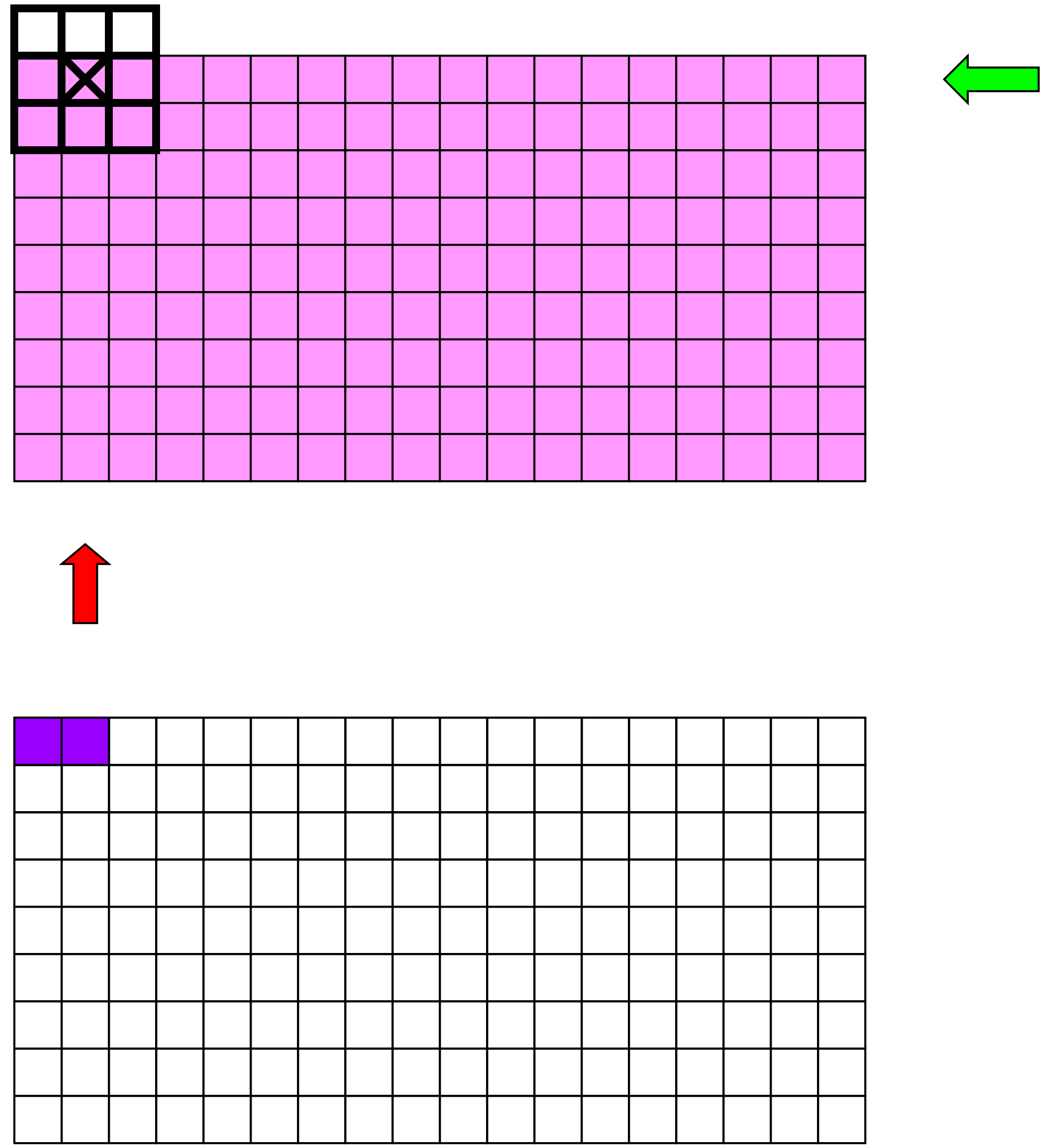
j = 1



Filtered:

Replace ☒ with the median of the values under the window.

Original:



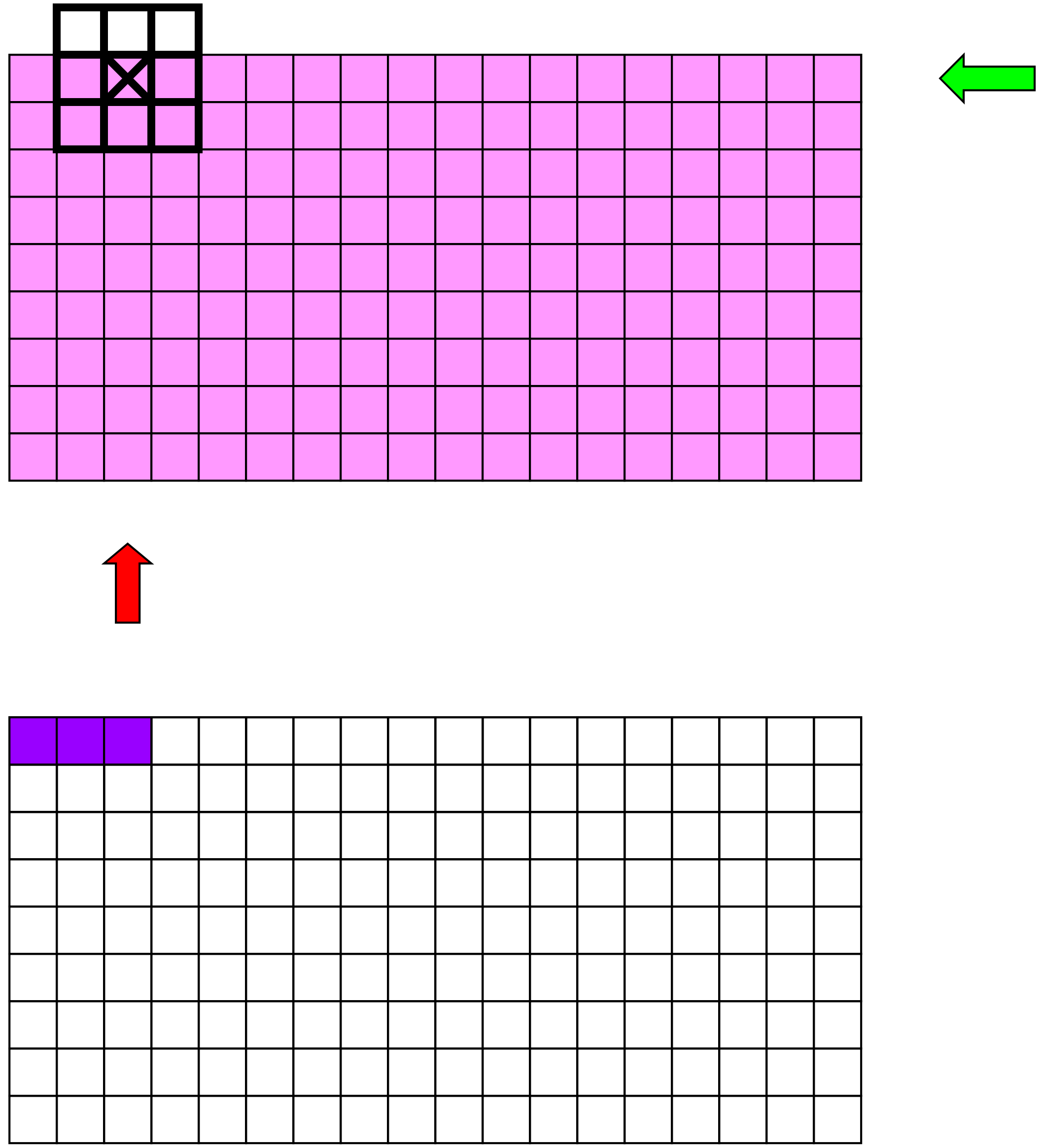
`i = 1`

`j = 2`

Filtered:

Replace $\boxtimes$ with the median of the values under the window.

Original:



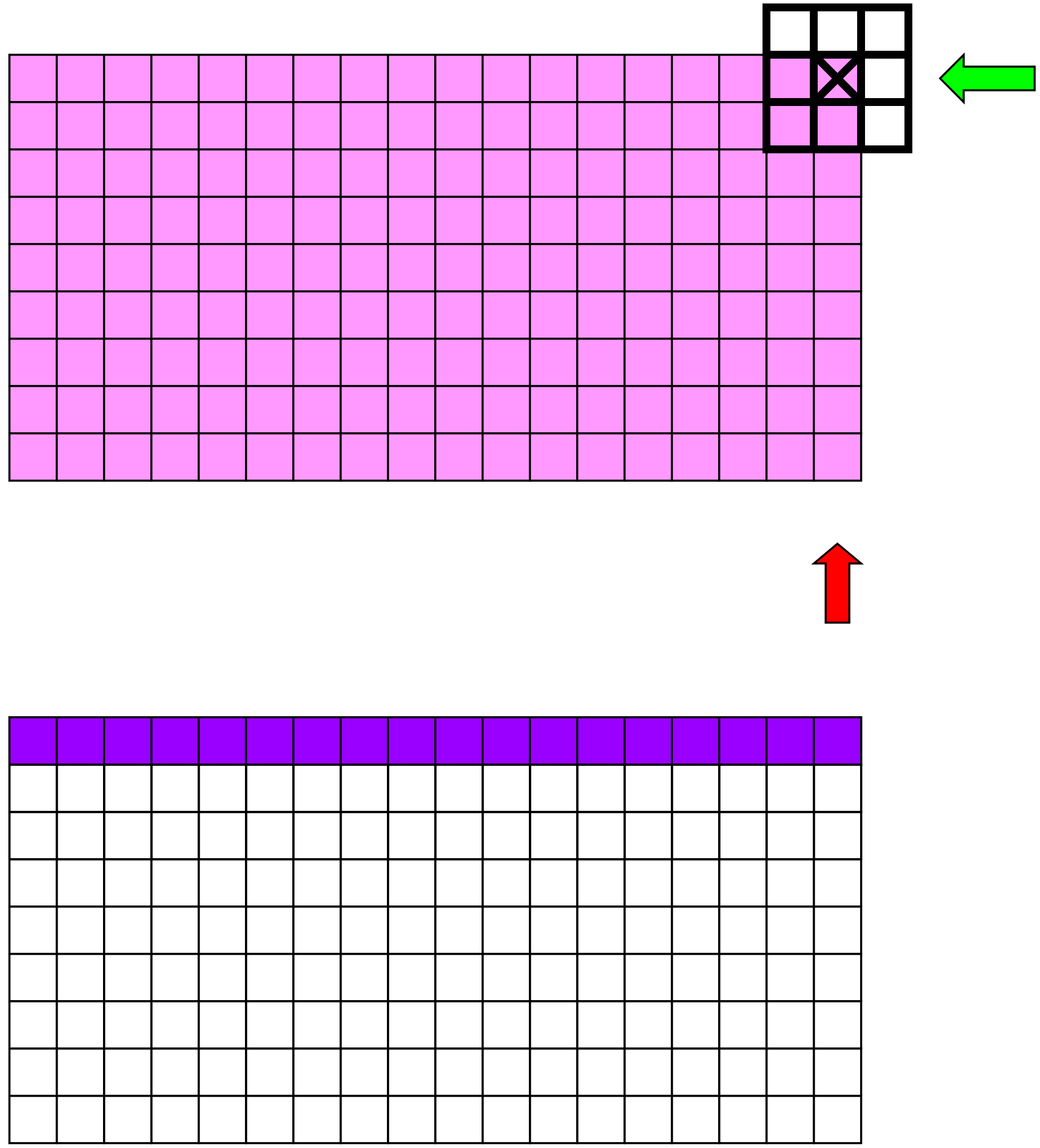
i = 1

j = 3

Filtered:

Replace $\boxtimes$ with the median of the values under the window.

Original:



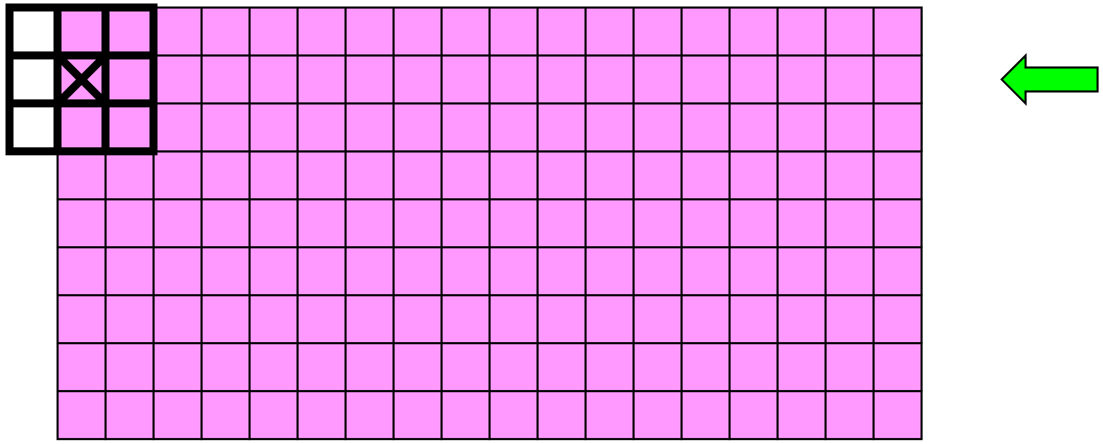
```
i = 1
```

```
j = n
```

Filtered:

Replace $\boxtimes$ with the median of the values under the window.

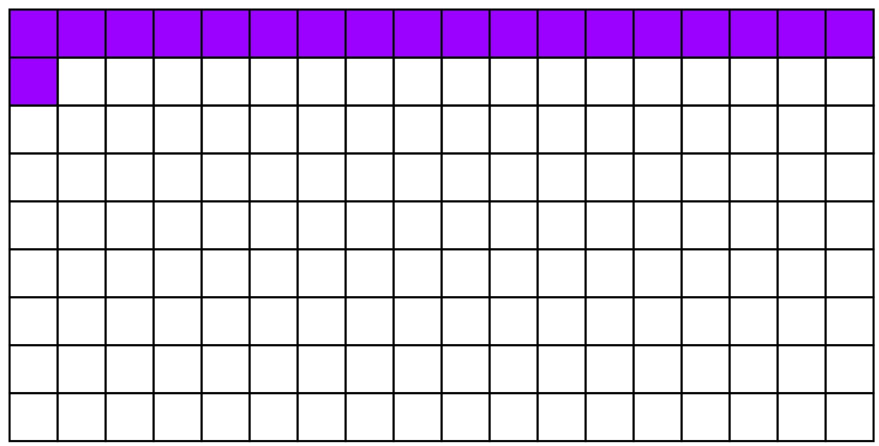
Original:



i = 2

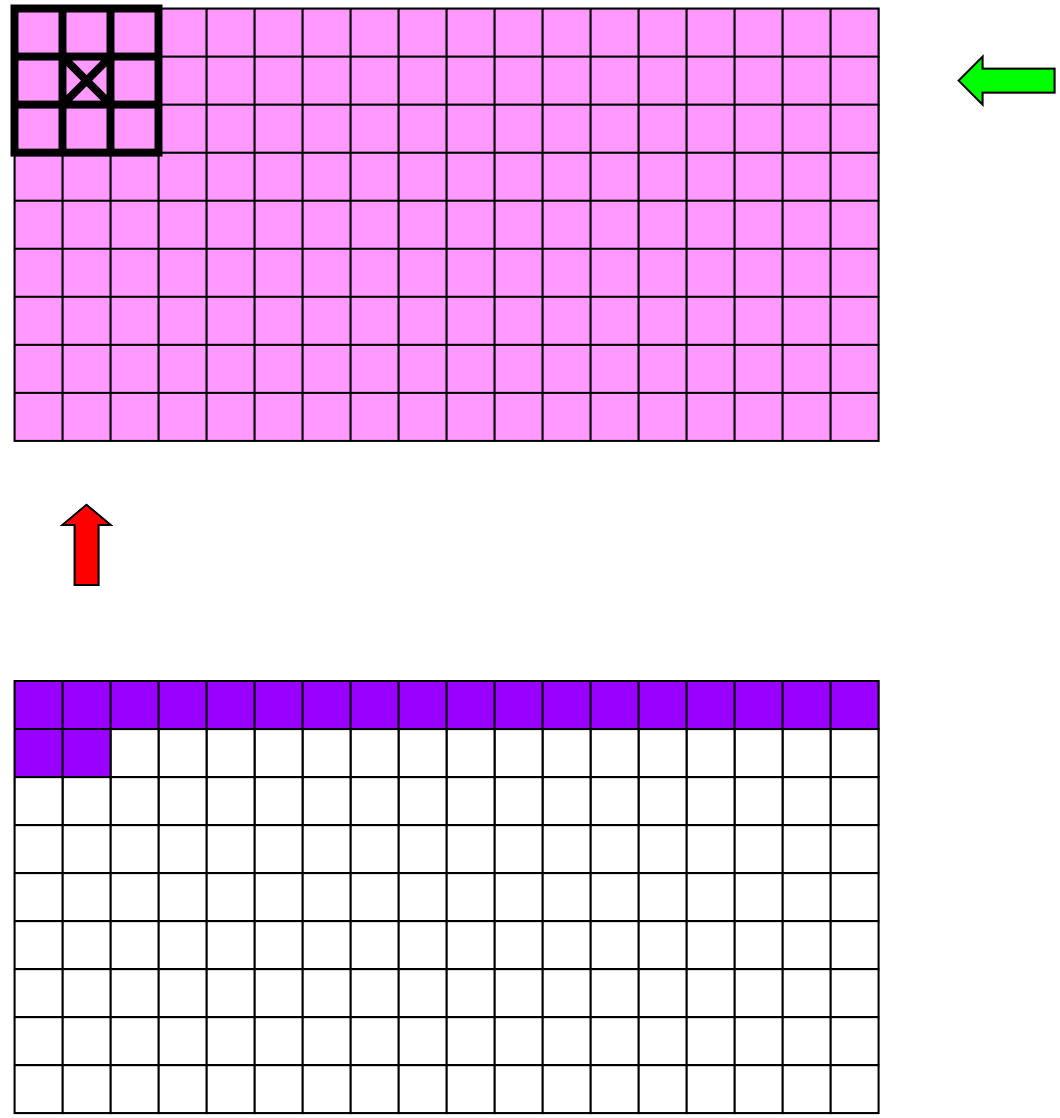
j = 1

Filtered:



Replace $\boxtimes$ with the median of the values under the window.

Original:



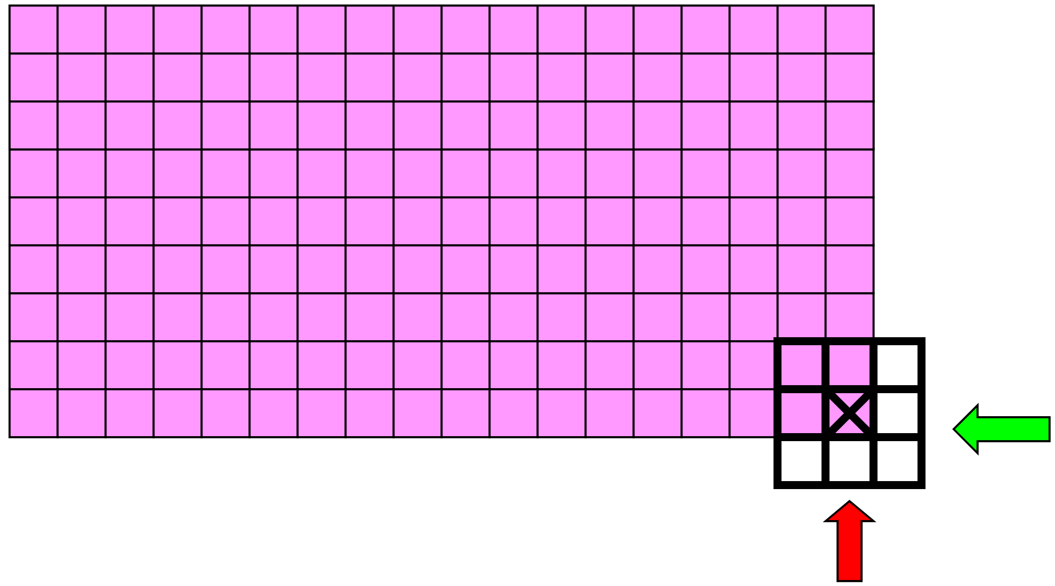
i = 2

j = 2

Filtered:

Replace $\boxtimes$ with the median of the values under the window.

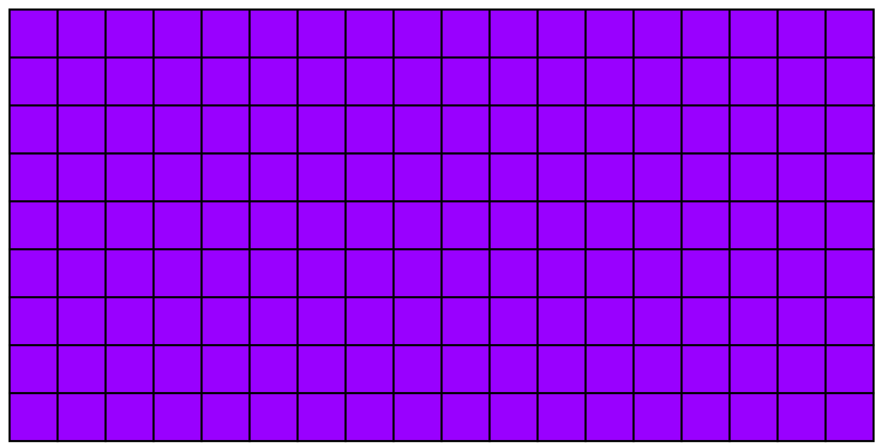
Original:



i = m

j = n

Filtered:



Replace ☒ with the median of the values under the window.

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)
```

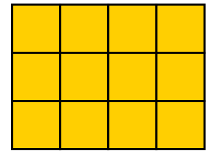
x :

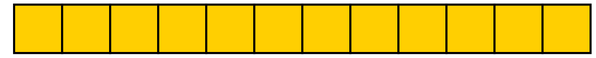
19	21	28	36	43	88	89

```
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

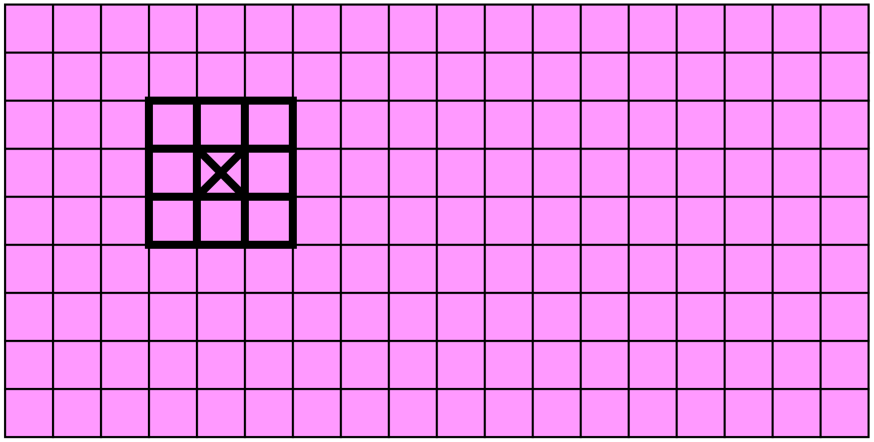




```
function  med = medVal(C)
[nr,nc] = size(C);
x = zeros(1,nr*nc);
for r=1:nr
    x((r-1)*nc+1:r*nc) = C(r,:);
end
%Compute median of x and assign to med
% ...
```

See **medVal.m**

Back to filtering…

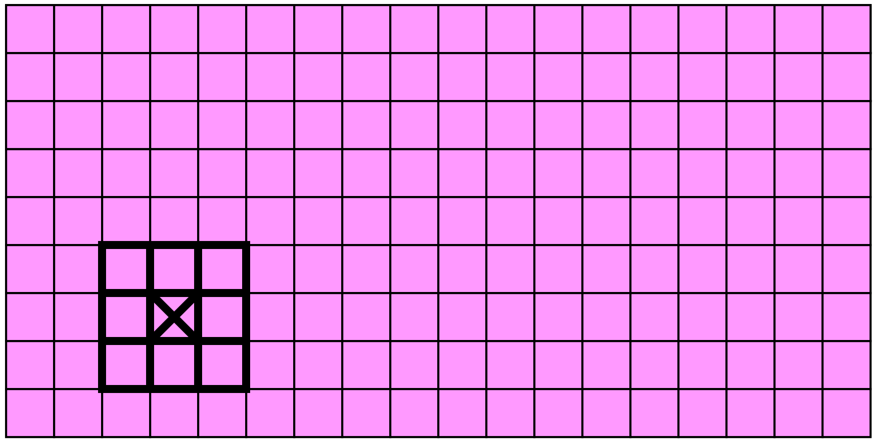


m = 9

n = 18

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

When window is inside…



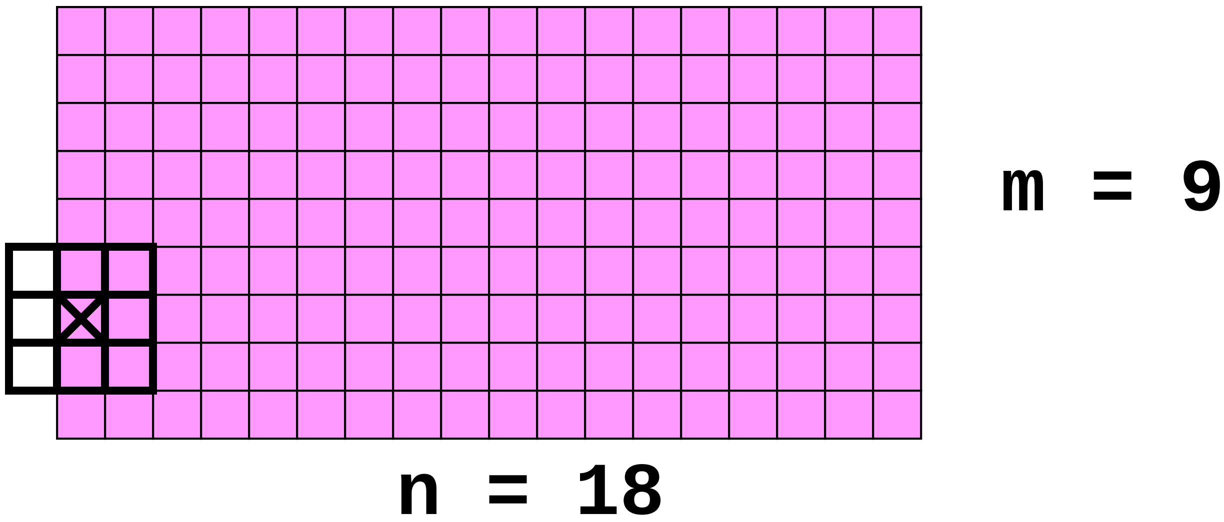
m = 9

n = 18

New gray value for pixel (7,4) =

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

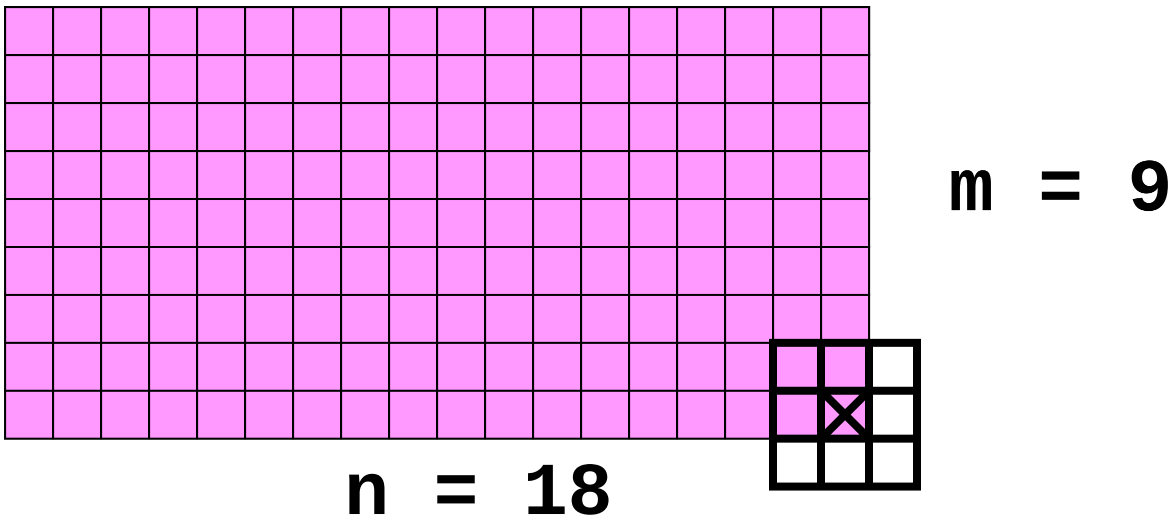
When window is partly outside…



New gray value for pixel (7,1) =

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

When window is partly outside…



New gray value for pixel (9,18) =

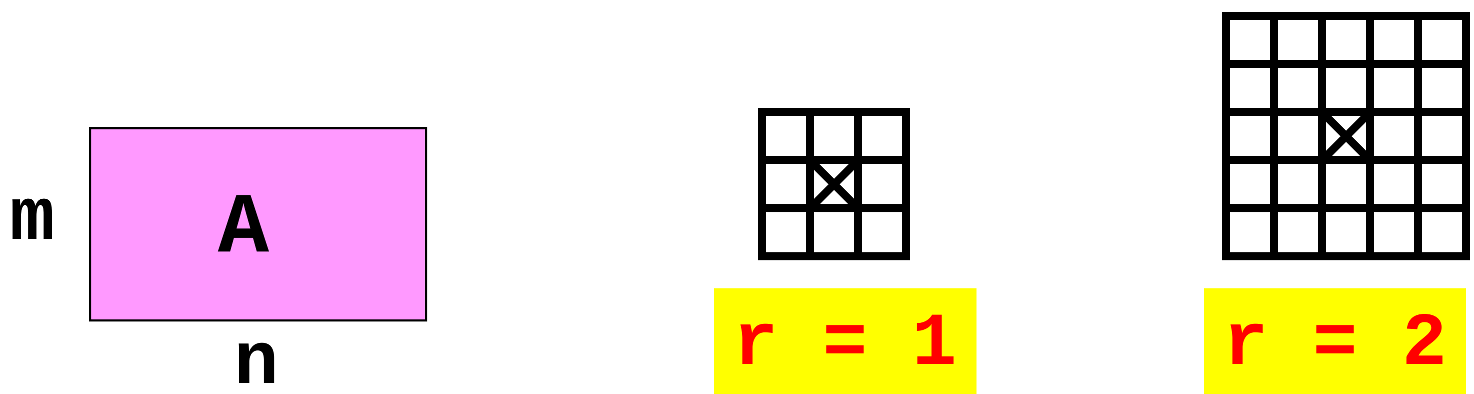
`medVal( A(8:9,17:18) )`

```
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
```

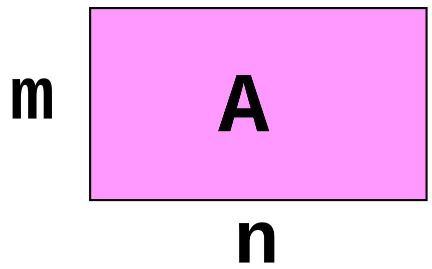
The Pixel (i,j) Neighborhood

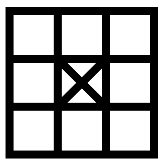
```
iMin =          i-r
iMax =          i+r
jMin =          j-r
jMax =          j+r
C = A(iMin:iMax,jMin:jMax)
```



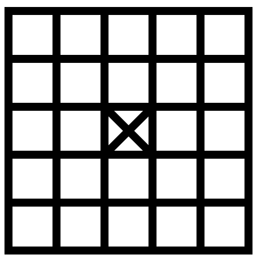
The Pixel (i,j) Neighborhood

```
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)
```

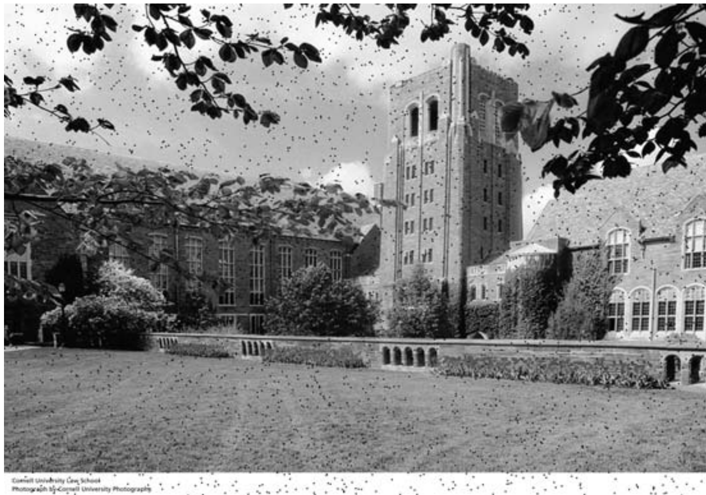




r = 1



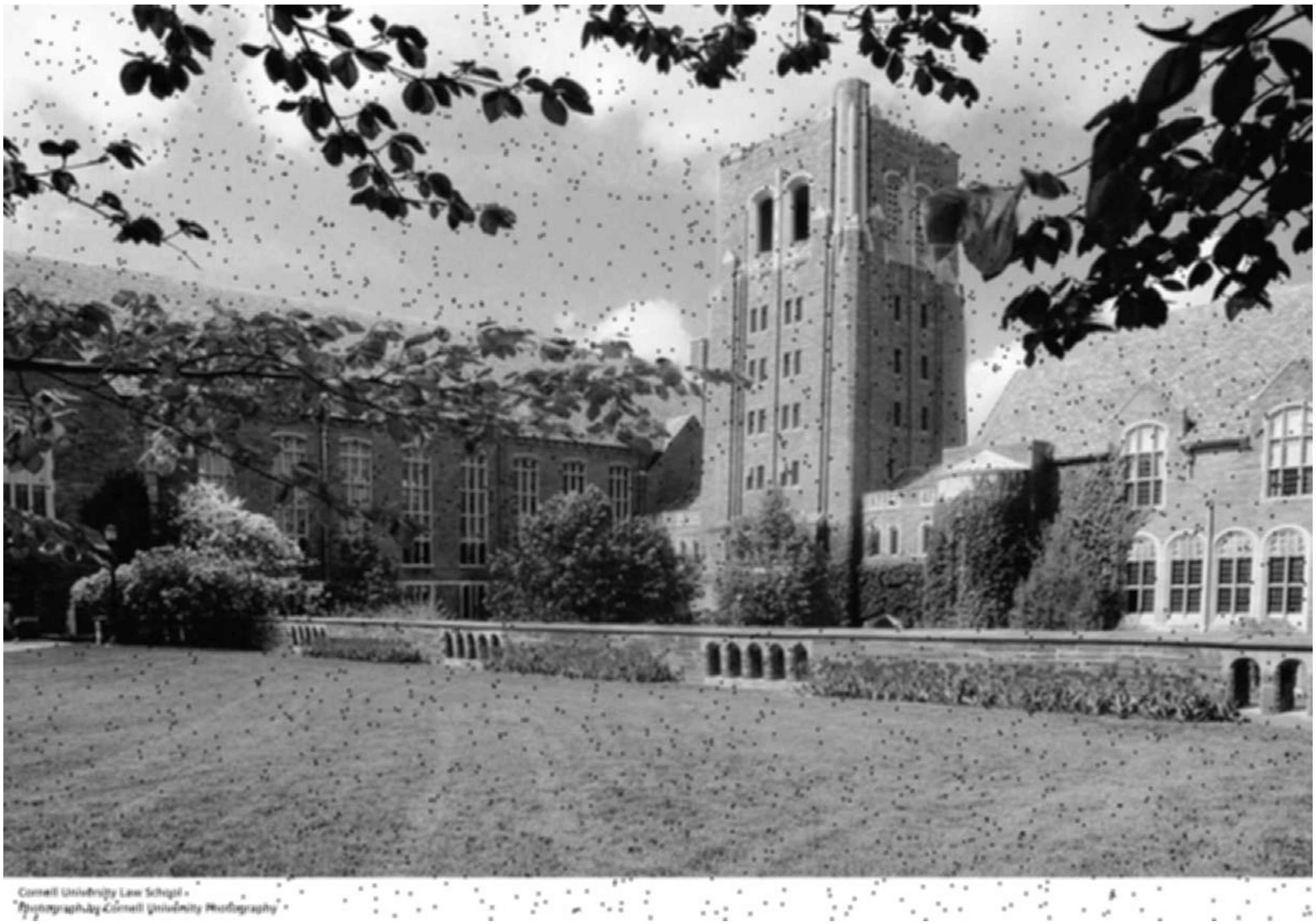
r = 2



A

B = medianFilter(A,3)

Mean Filter with radius 3



Mean Filter with radius 10

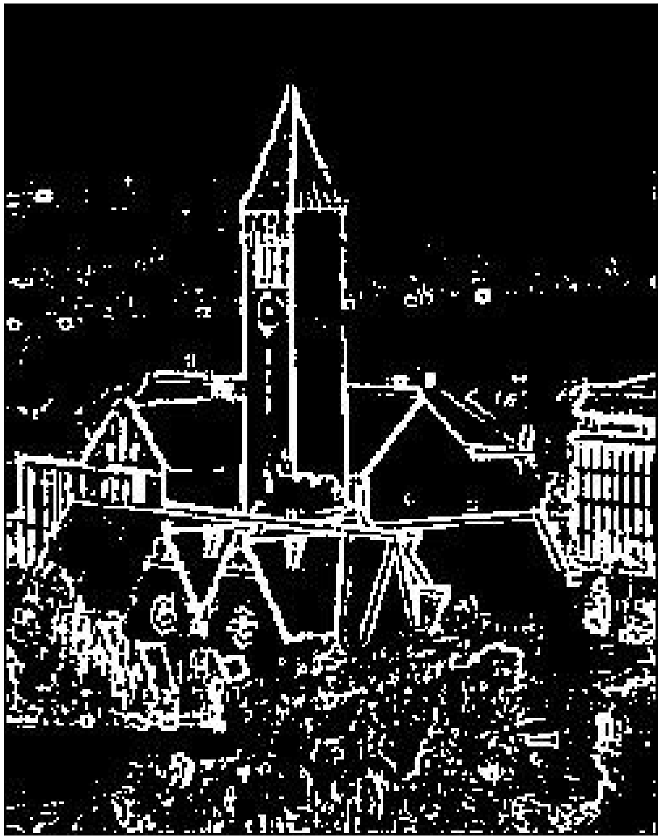
Mean filter fails because the mean does not capture representative values.

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

85	86
87	88

mean-filtered values

Finding Edges



What is an edge?

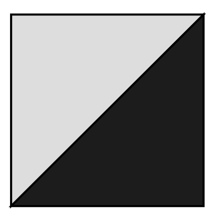
Near an edge, grayness values change abruptly

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	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

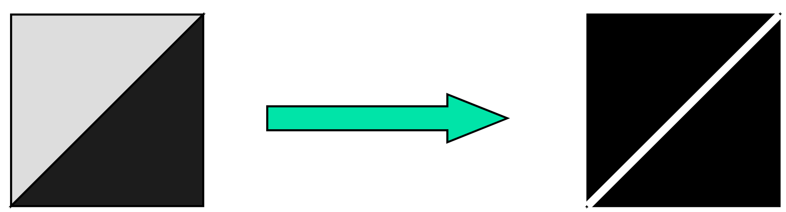
- Identify the “edge pixels”
- Highlight the edge pixels
  - make edge pixels white; make everything else black

200	200	200	200	200	200
200	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

BLACK

WHITE

BLACK



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));
[m,n] = size(A);
B = uint8(zeros(m,n));
for i = 1:m
    for j = 1:n

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

    end
end
```

Built-in function to convert to grayscale. Returns 2-d array.

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

```
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
```

"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

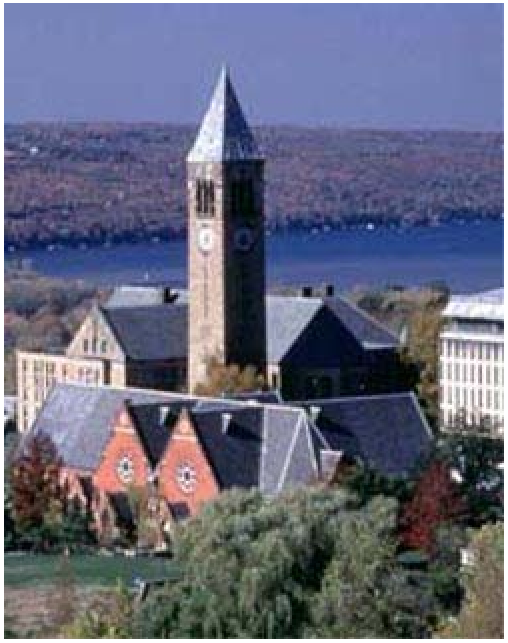
```
if B(i,j) > tau
    B(i,j) = 255;
end
```

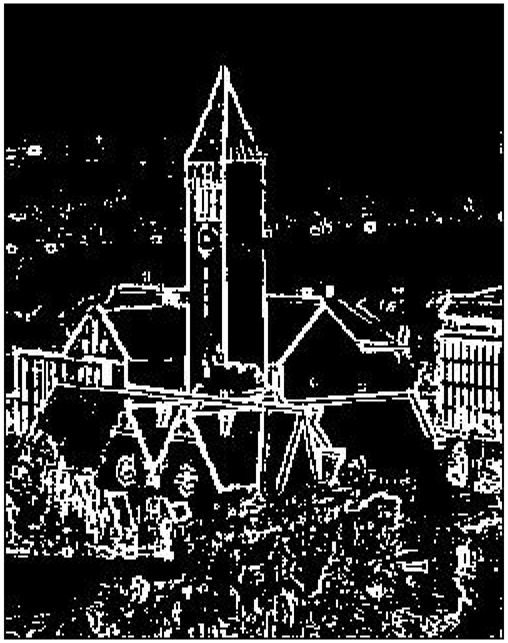
B(i,j)

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

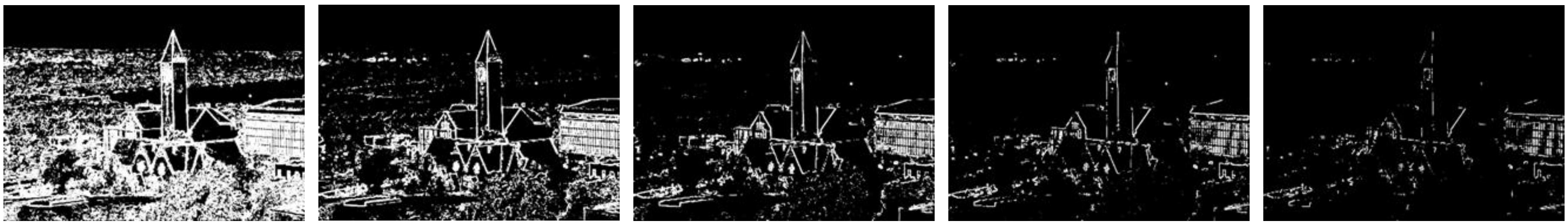
```
function Edges(jpgIn,jpgOut,tau)
% jpgOut is the “edge diagram” of image jpgIn.
% At each pixel, if   rate-of-change > tau
% then the pixel is considered to be on an edge.
A = rgb2gray(imread(jpgIn));
[m,n] = size(A);
B = uint8(zeros(m,n));
for i = 1:m
  for j = 1:n
    Neighbors = A(max(1,i-1):min(i+1,m),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



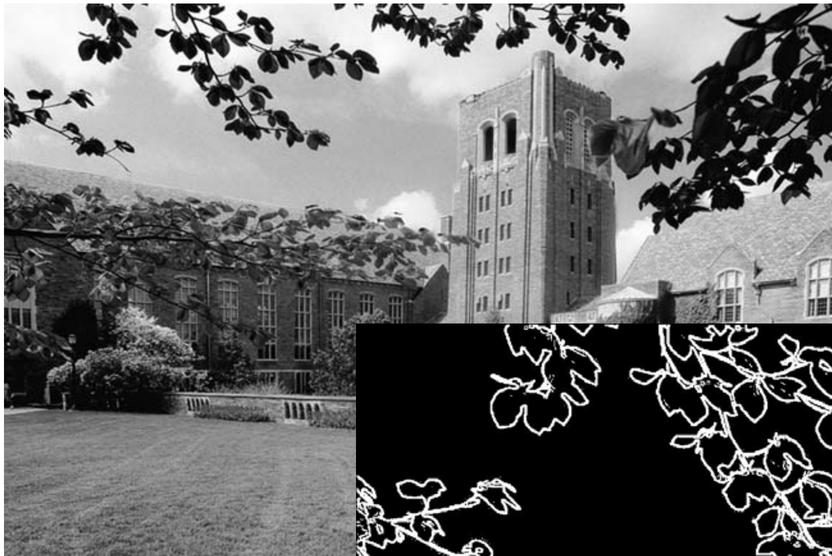


tau = 30

Edge finding: Effect of edge threshold, τ



τ



Cornell University Law School
Photograph by Cornell University Photography

tau = 20