EECE/CS 253 Image Processing

Lecture Notes: Digital Images and Matlab

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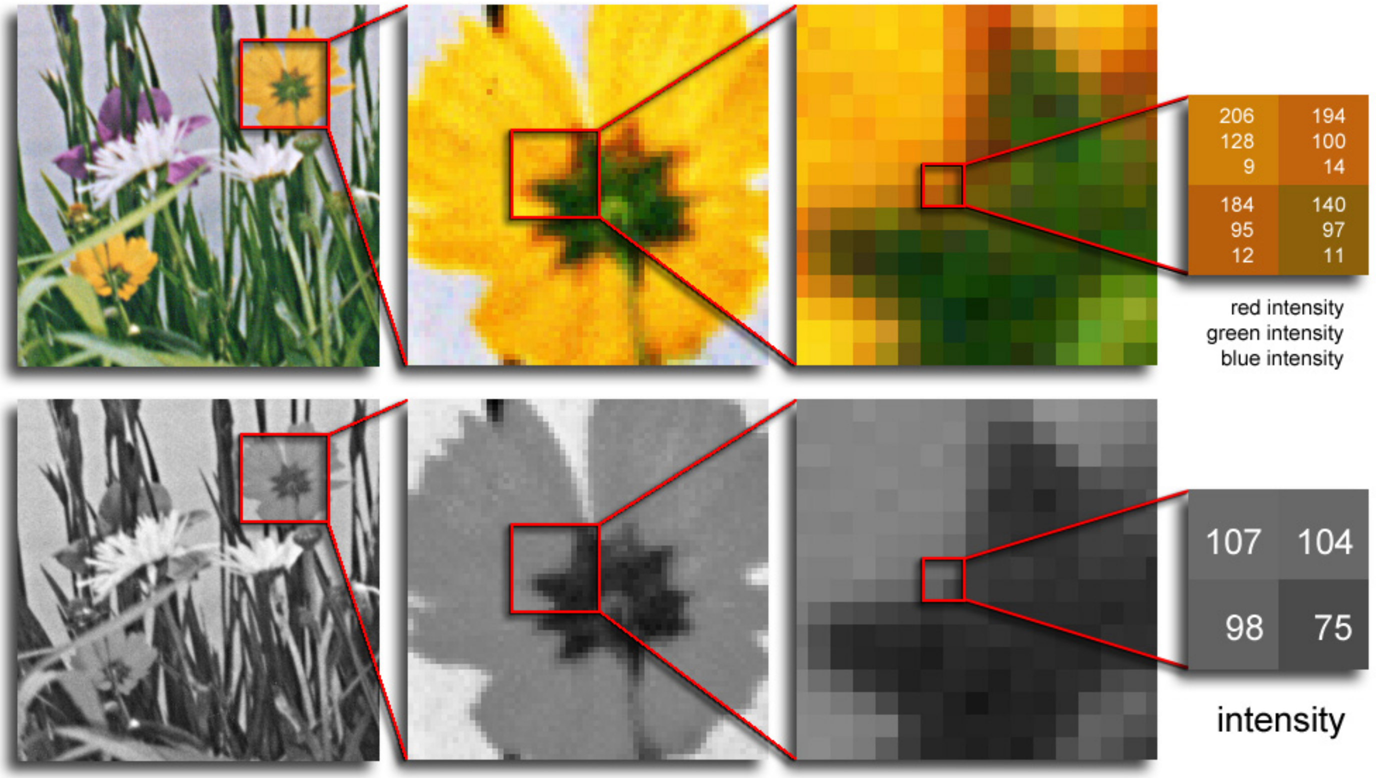
Digital Image

Color images have 3 values per pixel; monochrome images have 1 value per pixel.

a grid of squares, each of which contains a single color

each square is called a pixel (for *picture element*)



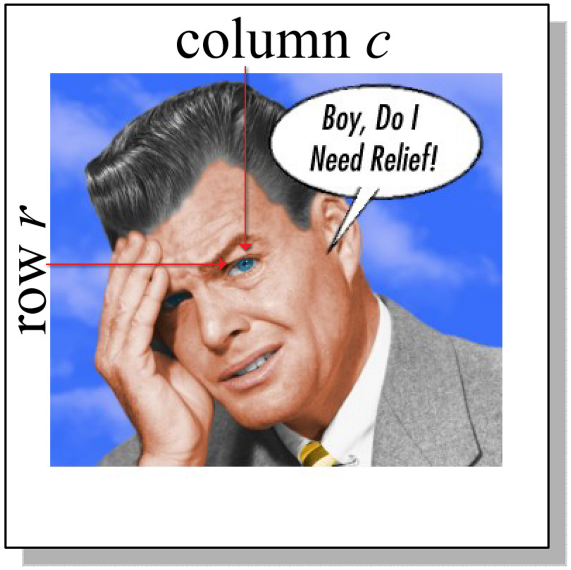
Pixels

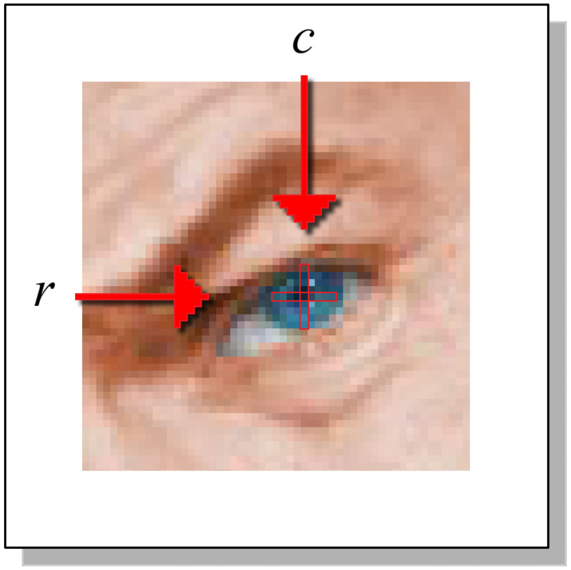
- A digital image, *I*, is a mapping from a 2D grid of uniformly spaced discrete points, $\{p = (r,c)\}$, into a set of positive integer values, $\{I(\,p)\}$, or a set of vector values, *e.g.*, $\{[R\ G\ B]^{\mathsf{T}}(p)\}$.
- At each column location in each row of *I* there is a value.
- The pair (*p, I*(*p*)) is called a "pixel" (for *picture element*).

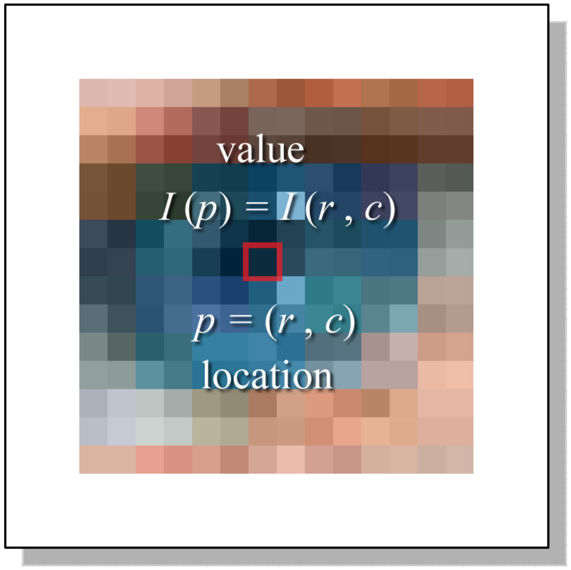
Pixels

- $p = (r,c)$ is the pixel location indexed by row, *r,* and column, *c*.
- $I(\,p) = I(r,c)$ is the value of the pixel at location *p*.
- If $I(\,p)$ is a single number then *I* is monochrome.
- If $I(\,p)$ is a vector (ordered list of numbers) then *I* has multiple bands (*e.g.*, a color image).

Pixels







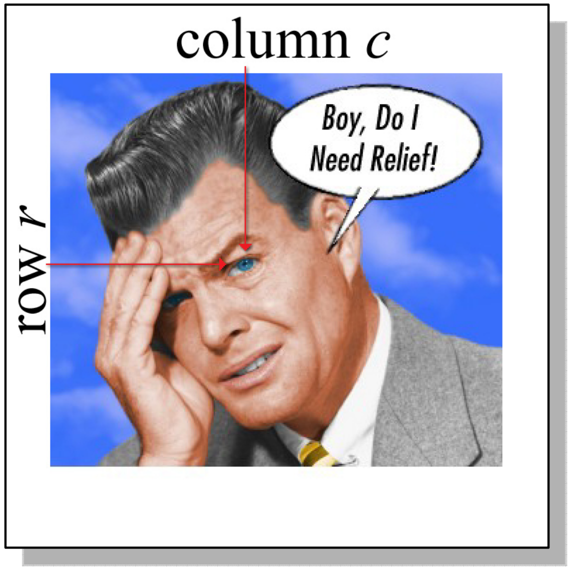
Pixel Location: $p = (r, c)$

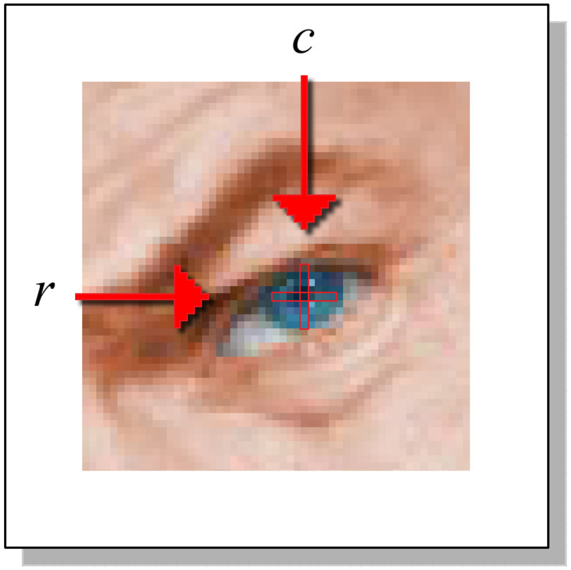
Pixel Value: $I(p) = I(r, c)$

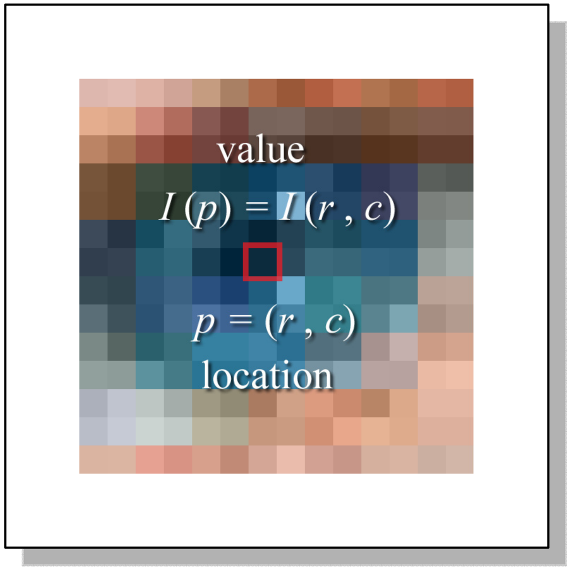
Pixel : $[p, I(p)]$

Pixels

Pixel : [p, $I(p)$]



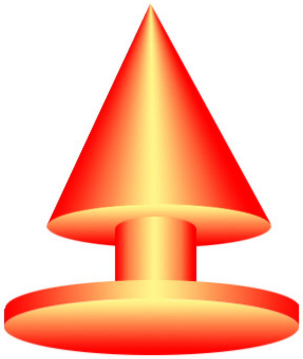




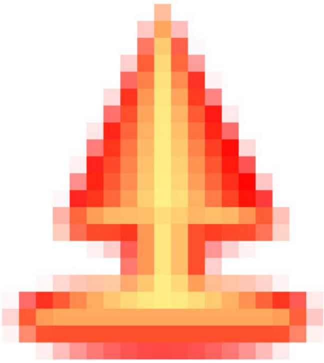
$$\begin{aligned} p &= (r,c) \\ &= (\text{row \#},\ \text{col \#}) \\ &= (272,\ 277) \end{aligned}$$

$$I(p) = \begin{bmatrix} \text{red} \\ \text{green} \\ \text{blue} \end{bmatrix} = \begin{bmatrix} 12 \\ 43 \\ 61 \end{bmatrix}$$

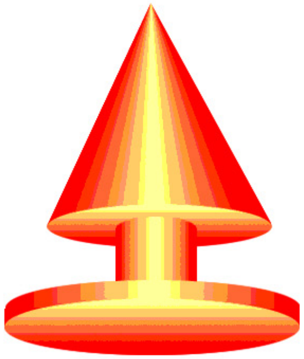
Sampling and Quantization



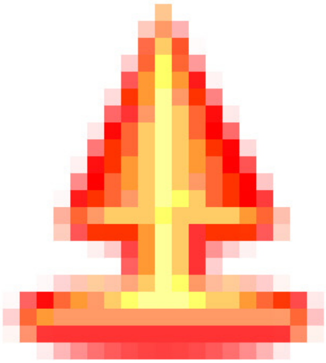
real image



sampled

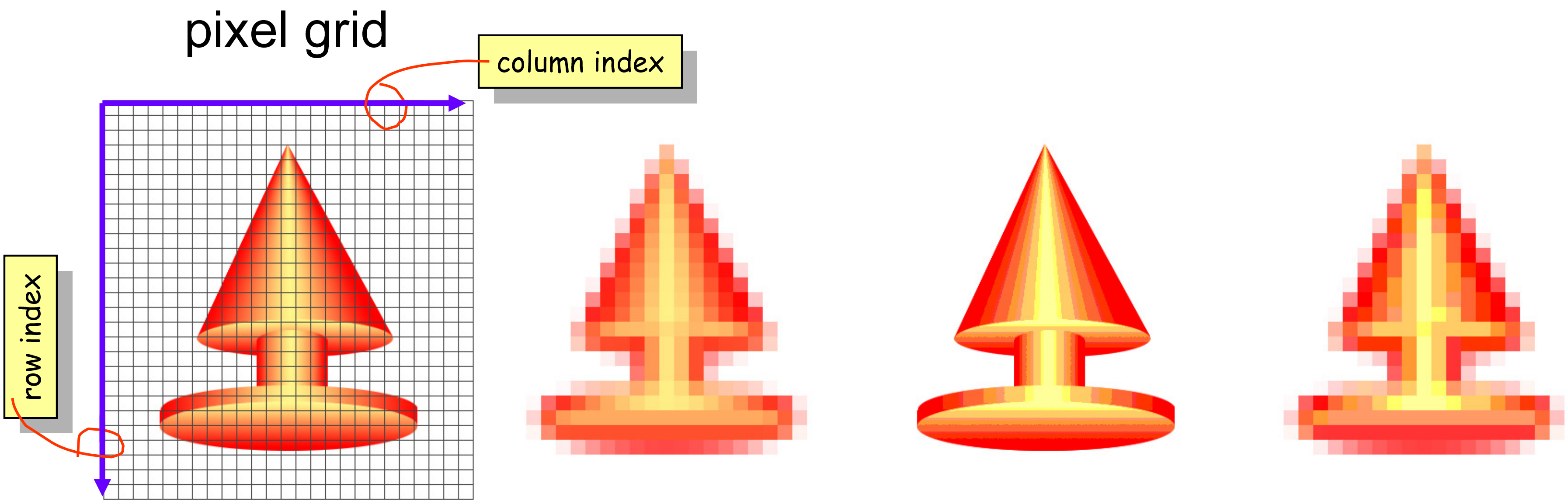


quantized



sampled & quantized

Sampling and Quantization



real image

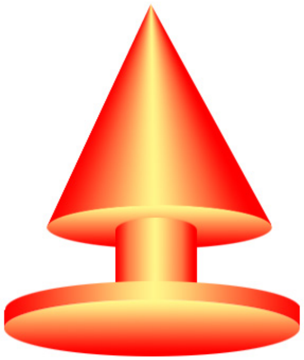
sampled

quantized

sampled & quantized

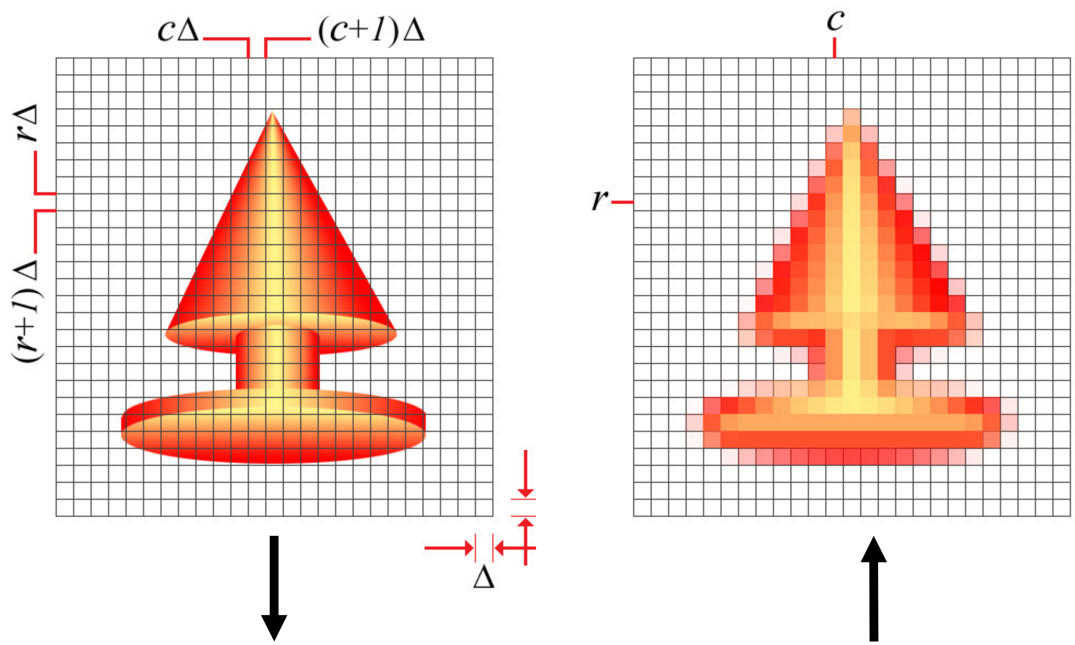
Sampling

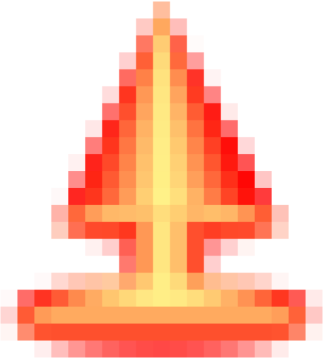
Take the average within each square.



$I_C(\rho,\chi)$

continuous image





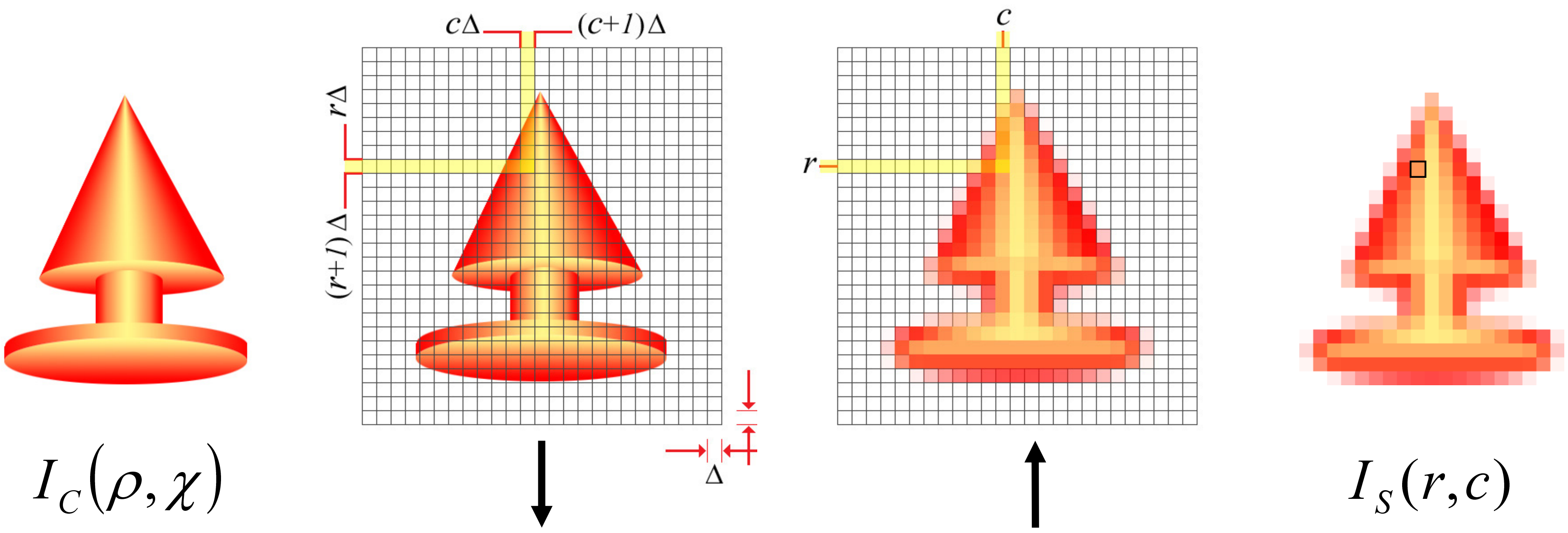
$I_S(r,c)$

sampled image

$$I_S(r,c) = \frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

Sampling

Take the average within each square.



$I_C(\rho,\chi)$

continuous image

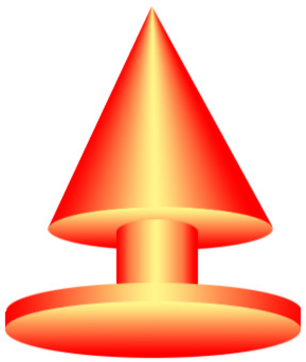
$$I_S(r,c)=\frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta}I_C(\rho,\chi)\delta\rho\delta\chi$$

$I_S(r,c)$

sampled image

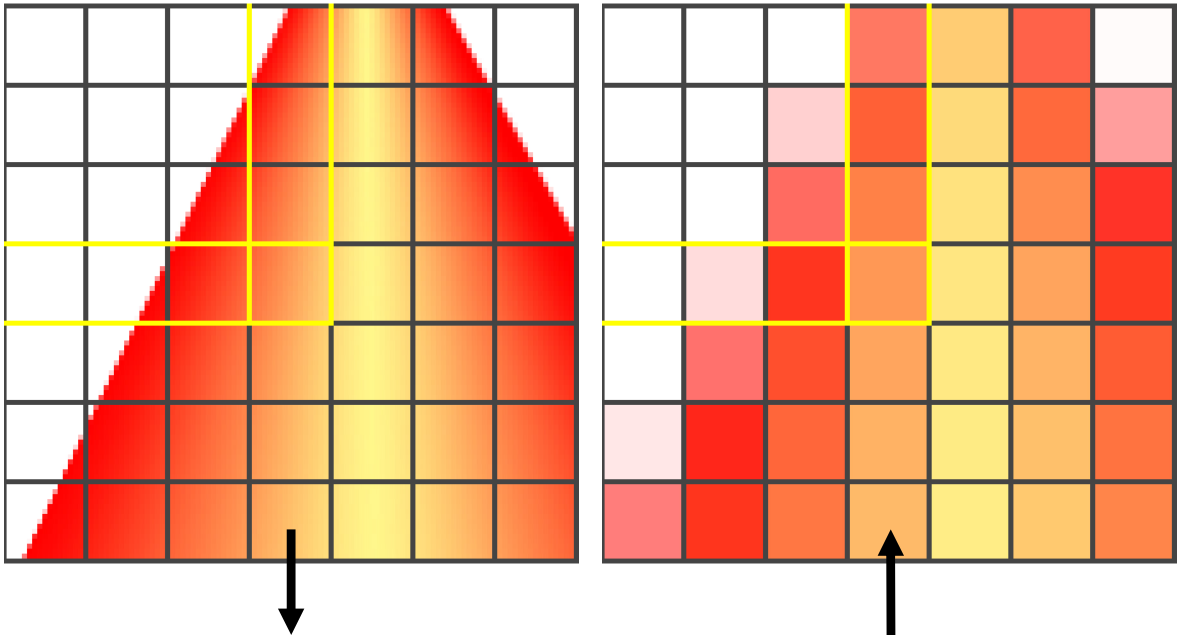
Sampling

Take the average within each square.



$I_C(\rho,\chi)$

continuous image



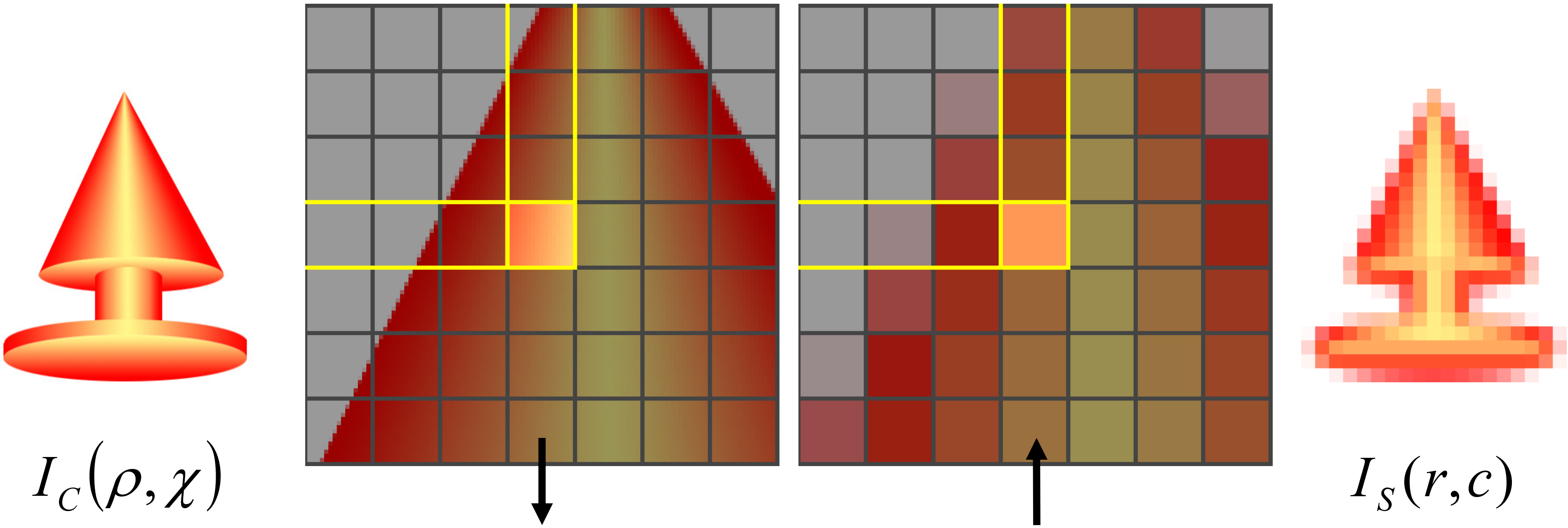
$$I_S(r,c)=\frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\delta\rho\delta\chi$$

$I_S(r,c)$

sampled image

Sampling

Take the average within each square.



$I_C(\rho,\chi)$

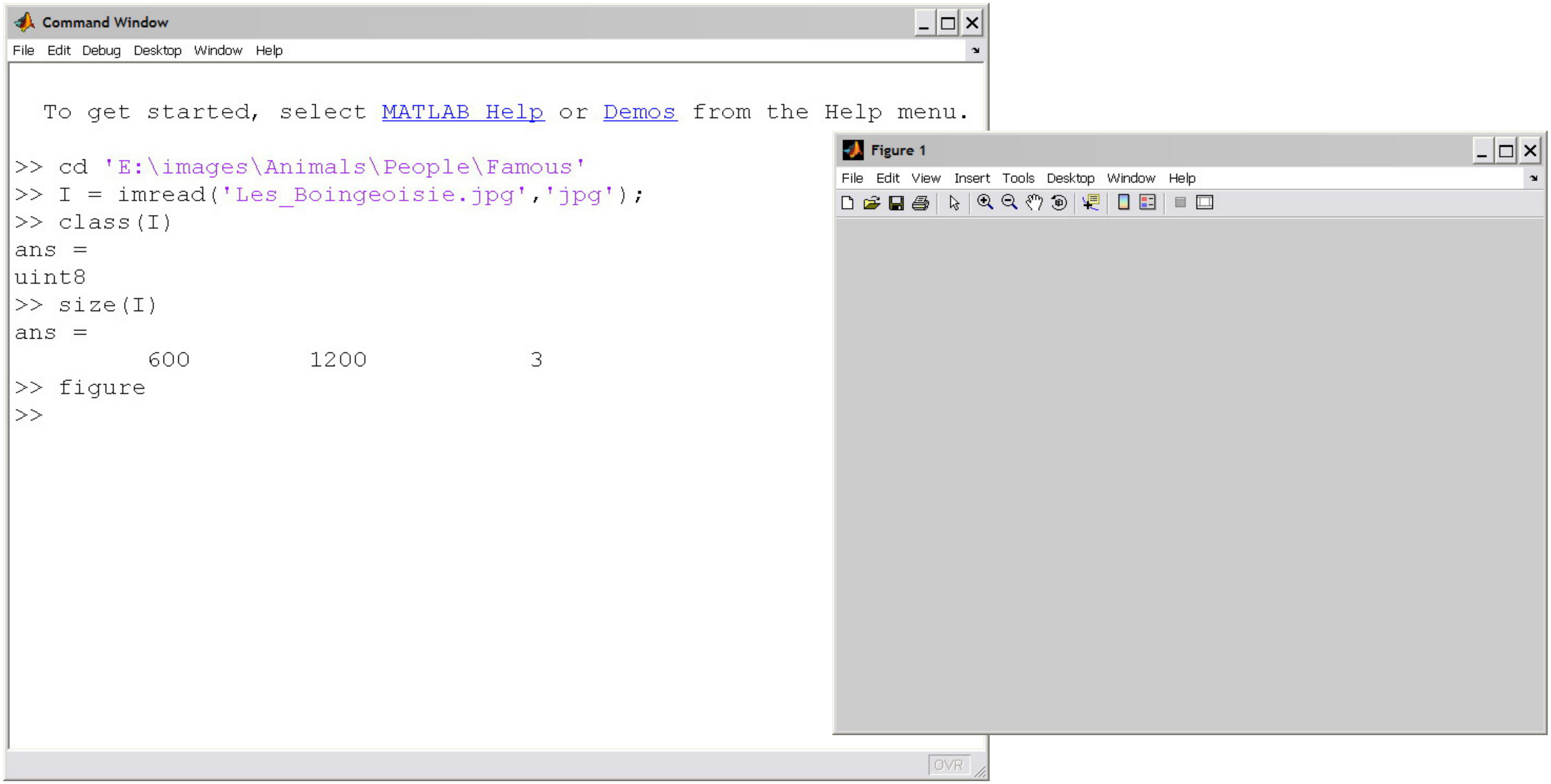
continuous image

$I_S(r,c)$

sampled image

$$I_S(r,c)=\frac{1}{\Delta^2}\int_{r\Delta}^{(r+1)\Delta}\int_{c\Delta}^{(c+1)\Delta} I_C(\rho,\chi)\,\delta\rho\,\delta\chi$$

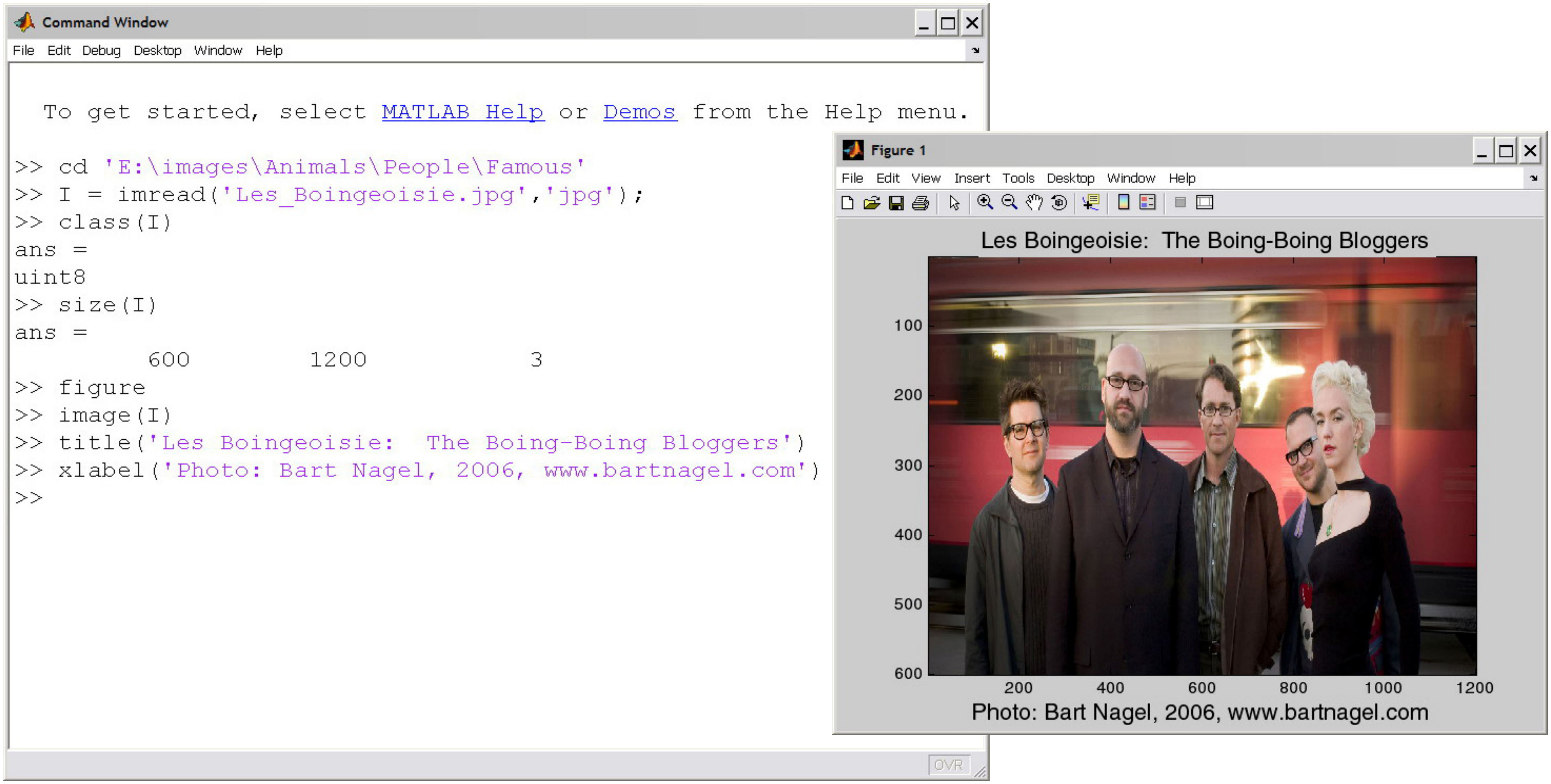
Read a Truecolor Image into Matlab


Command Window
File Edit Debug Desktop Window Help
Figure 1
File Edit View Insert Tools Desktop Window Help
OVR

```
  To get started, select MATLAB Help or Demos from the Help menu.

>> cd 'E:\images\Animals\People\Famous'
>> I = imread('Les_Boingeoisie.jpg','jpg');
>> class(I)
ans =
uint8
>> size(I)
ans =
         600         1200           3
>> figure
>>
```

Read a Truecolor Image into Matlab



Command Window
File Edit Debug Desktop Window Help
Figure 1
File Edit View Insert Tools Desktop Window Help
Les Boingeoisie: The Boing-Boing Bloggers
100
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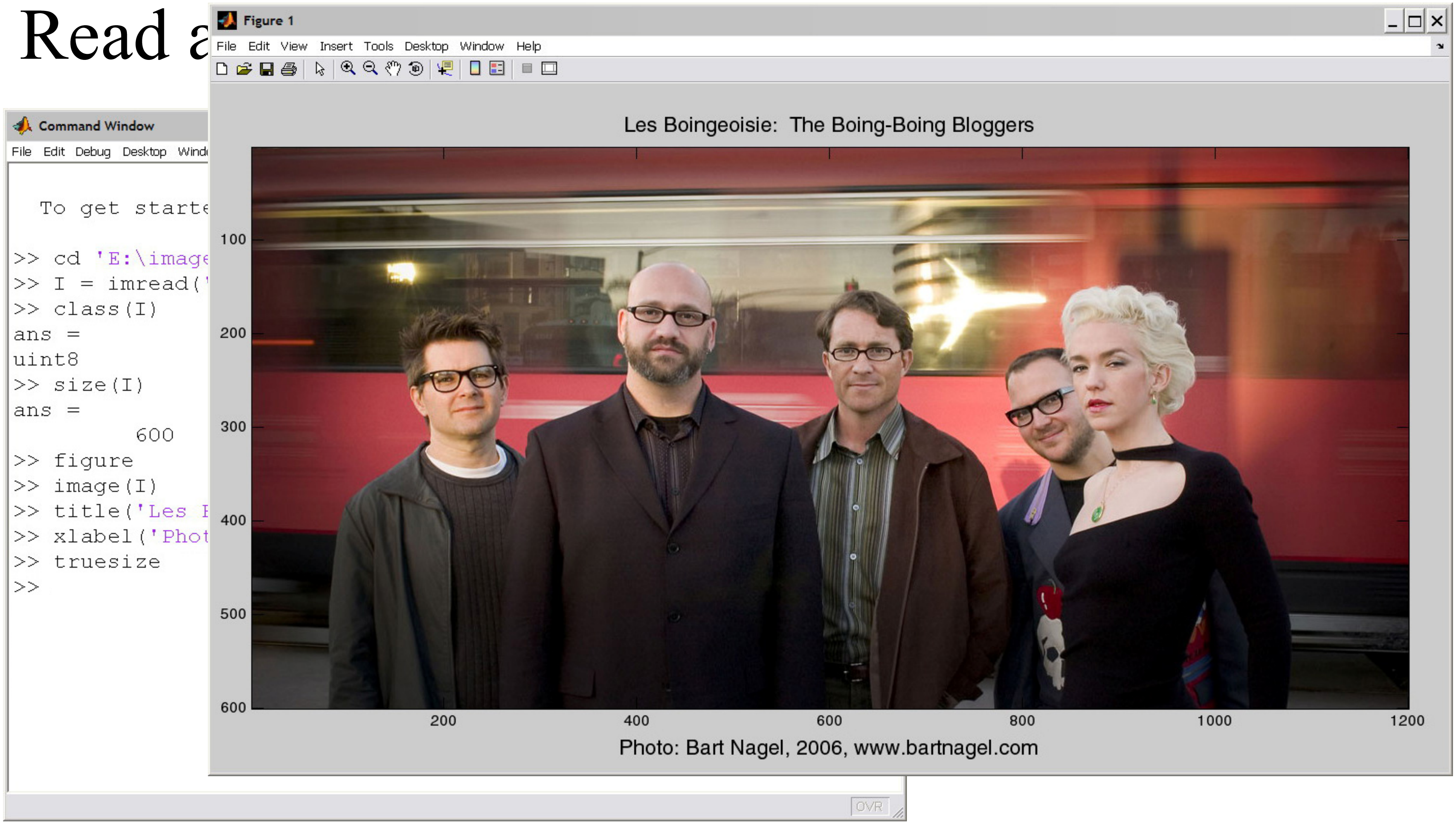
1200
Photo: Bart Nagel, 2006, www.bartnagel.com
OVR

```
  To get started, select MATLAB Help or Demos from the Help menu.

>> cd 'E:\images\Animals\People\Famous'
>> I = imread('Les_Boingeoisie.jpg','jpg');
>> class(I)
ans =
uint8
>> size(I)
ans =
         600        1200           3
>> figure
>> image(I)
>> title('Les Boingeoisie:  The Boing-Boing Bloggers')
>> xlabel('Photo: Bart Nagel, 2006, www.bartnagel.com')
>>
```

Read a


Command Window
File Edit Debug Desktop Wind
Figure 1
File Edit View Insert Tools Desktop Window Help
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OVR

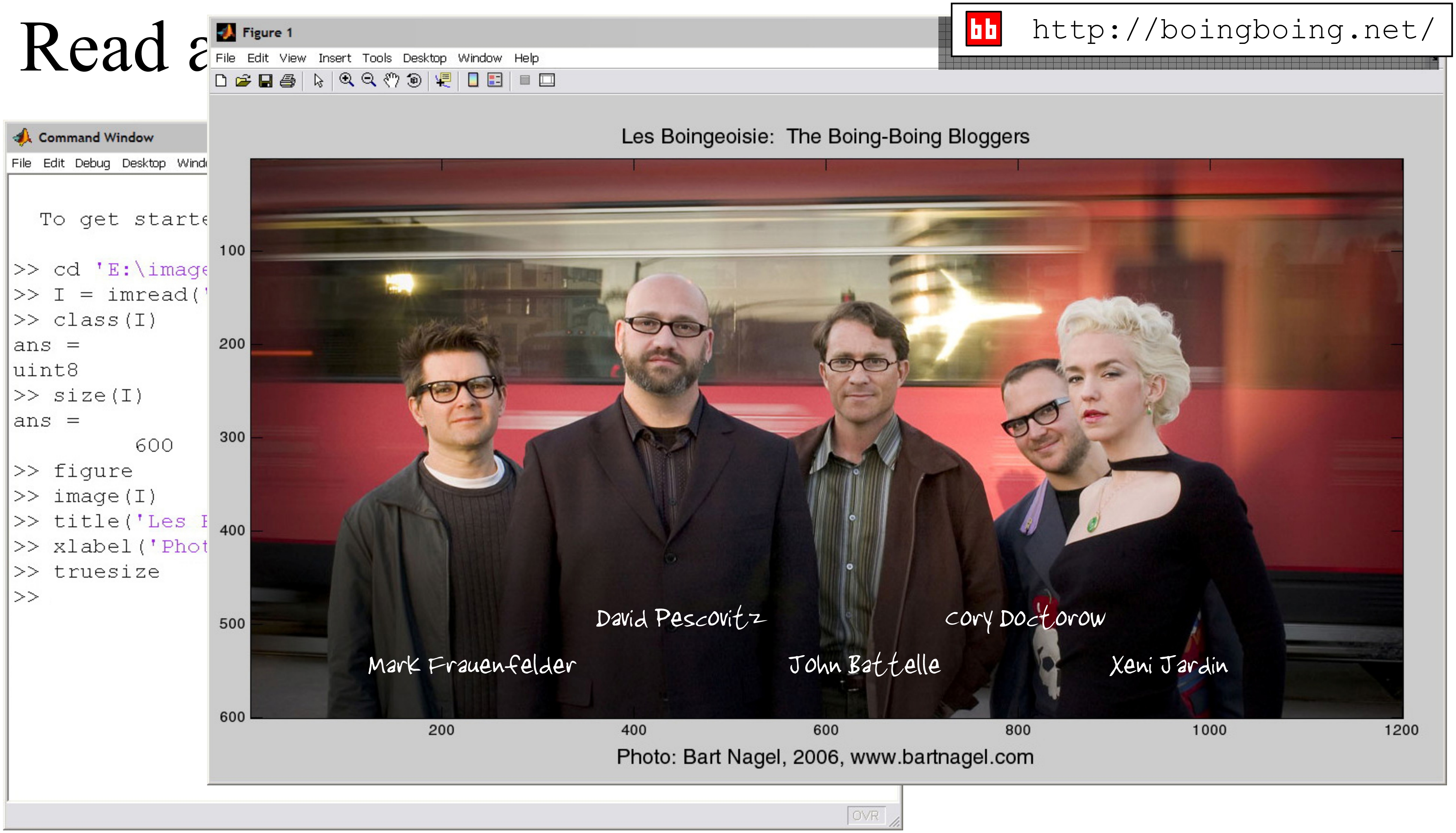
```
  To get starte

>> cd 'E:\image
>> I = imread('
>> class(I)
ans =
uint8
>> size(I)
ans =
         600
>> figure
>> image(I)
>> title('Les B
>> xlabel('Phot
>> truesize
>>
```

Les Boingeoisie: The Boing-Boing Bloggers

Photo: Bart Nagel, 2006, www.bartnagel.com

Read a



```
 To get starte

>> cd 'E:\image
>> I = imread('
>> class(I)
ans =
uint8
>> size(I)
ans =
         600
>> figure
>> image(I)
>> title('Les B
>> xlabel('Phot
>> truesize
>>
```

Command Window
File Edit Debug Desktop Wind
OVR
Figure 1
File Edit View Insert Tools Desktop Window Help
http://boingboing.net/
Les Boingeoisie: The Boing-Boing Bloggers
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600
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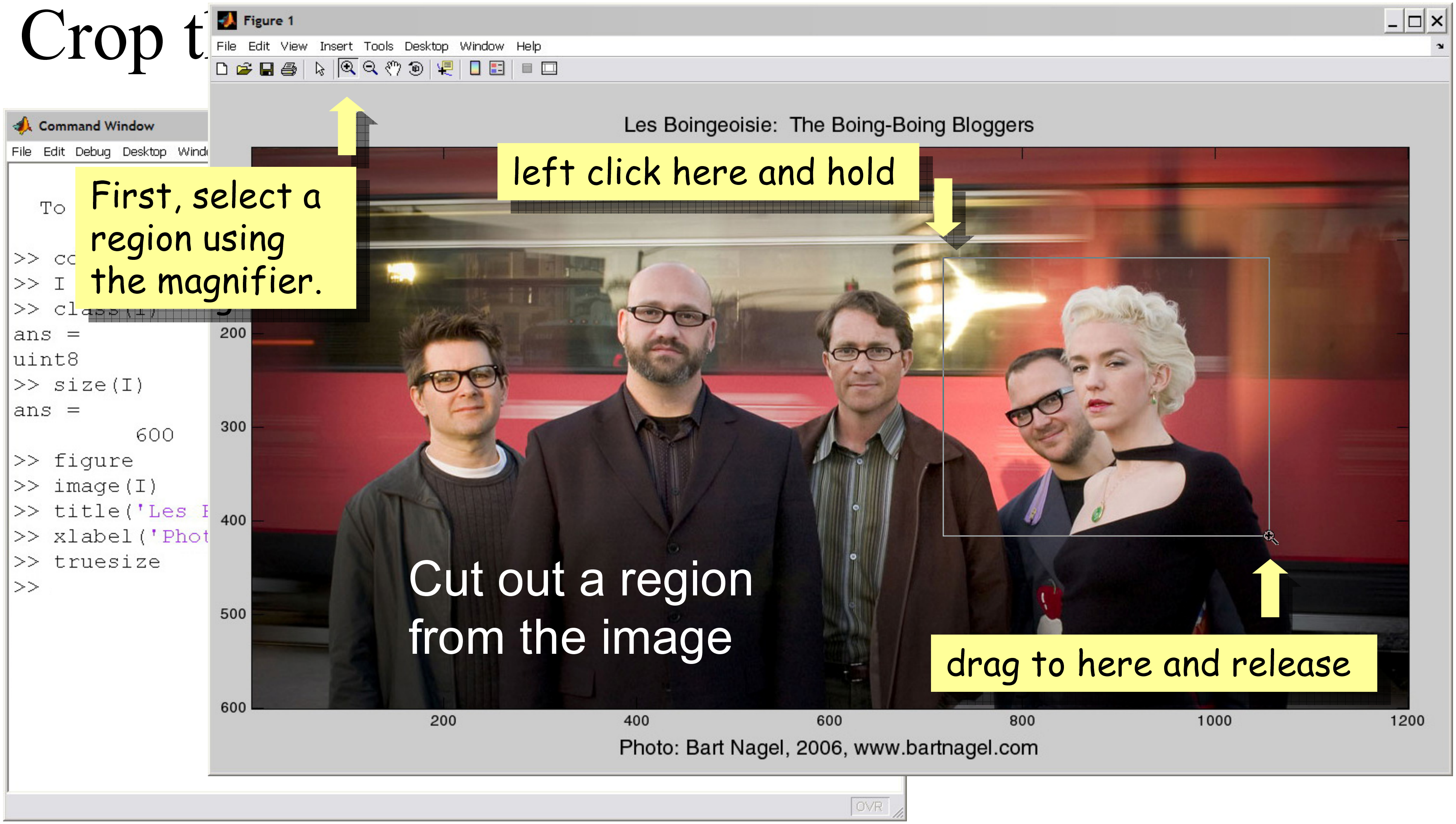
1200
Photo: Bart Nagel, 2006, www.bartnagel.com
David Pescovitz
Cory Doctorow
Mark Frauenfelder
John Battelle
Xeni Jardin

Crop t


Command Window
File Edit Debug Desktop Wind
Figure 1
File Edit View Insert Tools Desktop Window Help
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OVR

```
  To
>> co
>> I
>> class(I)
ans =
uint8
>> size(I)
ans =
        600
>> figure
>> image(I)
>> title('Les I
>> xlabel('Phot
>> truesize
>>
```

Les Boingeoisie: The Boing-Boing Bloggers

Photo: Bart Nagel, 2006, www.bartnagel.com

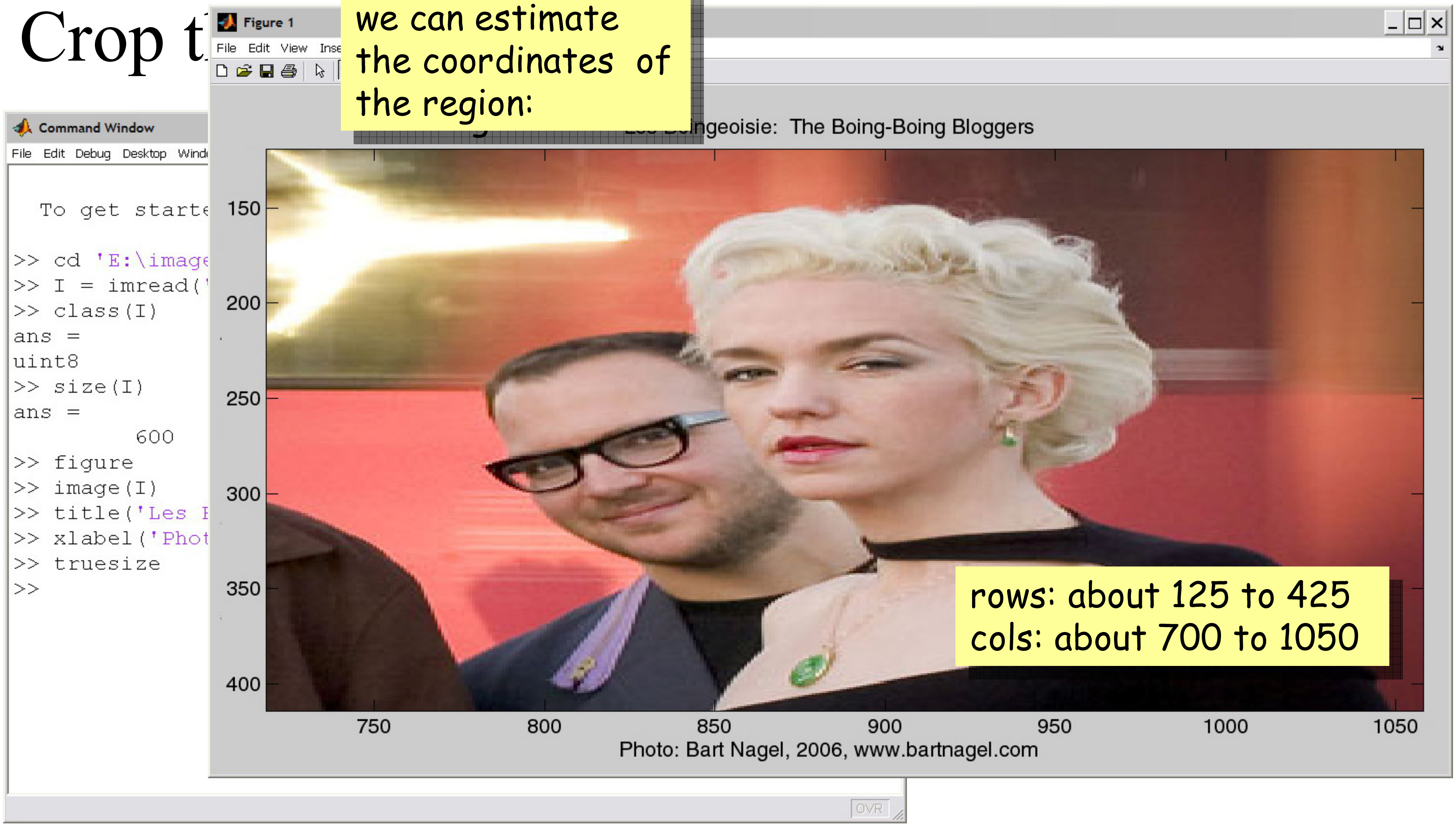
First, select a region using the magnifier.

left click here and hold

drag to here and release

Cut out a region from the image

Crop t


Command Window
File Edit Debug Desktop Wind
Figure 1
File Edit View Inse
ngeoisie: The Boing-Boing Bloggers
150
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350
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750
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850
900
950
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1050
Photo: Bart Nagel, 2006, www.bartnagel.com
OVR

```
  To get starte

>> cd 'E:\image
>> I = imread('
>> class(I)
ans =
uint8
>> size(I)
ans =
         600
>> figure
>> image(I)
>> title('Les B
>> xlabel('Phot
>> truesize
>>
```

From this close-up we can estimate the coordinates of the region:

rows: about 125 to 425
cols: about 700 to 1050

Crop t

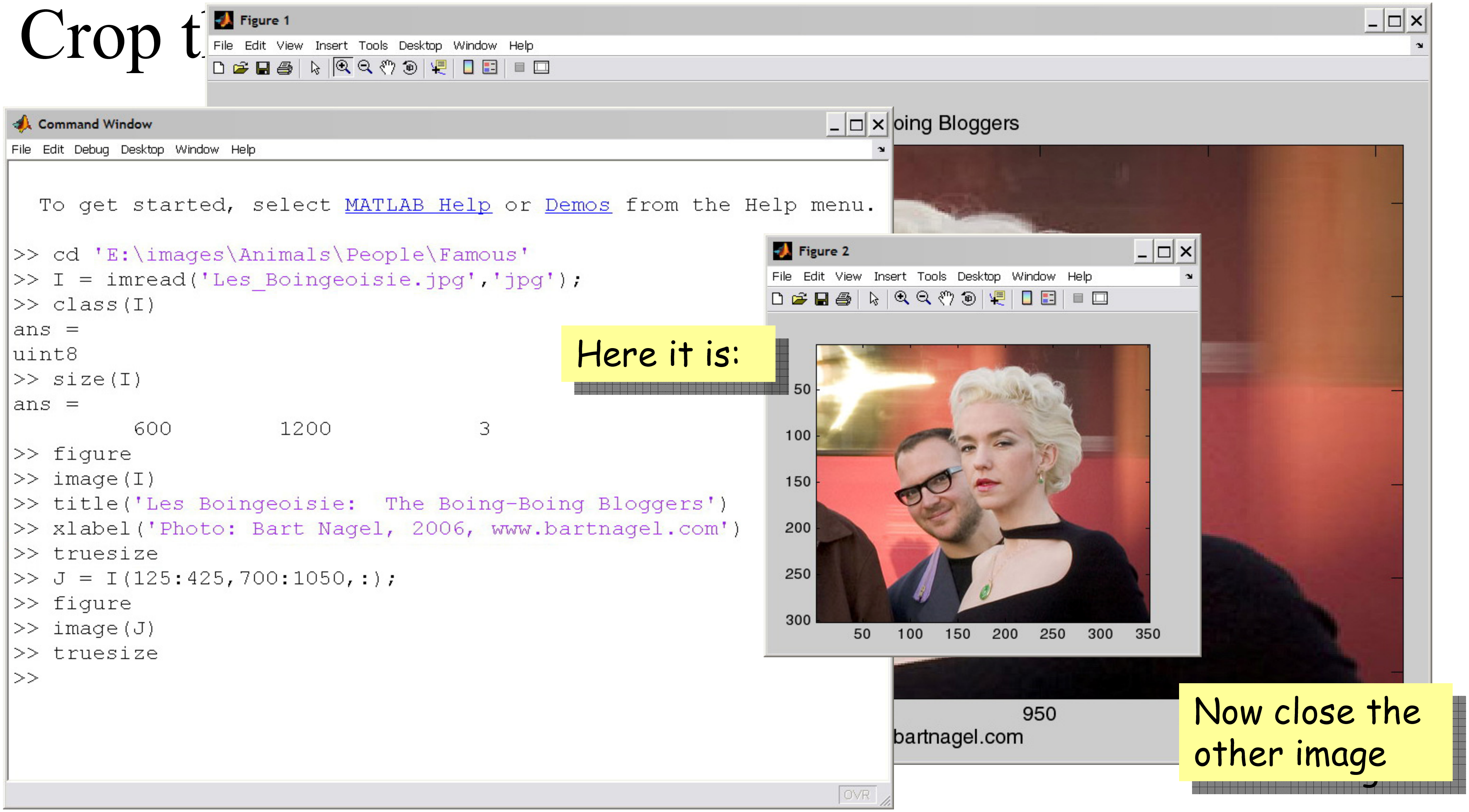

Figure 1
File Edit View Insert Tools Desktop Window Help
oing Bloggers
950
bartnagel.com
Command Window
File Edit Debug Desktop Window Help
OVR
Figure 2
File Edit View Insert Tools Desktop Window Help
50
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200
250
300
50
100
150
200
250
300
350

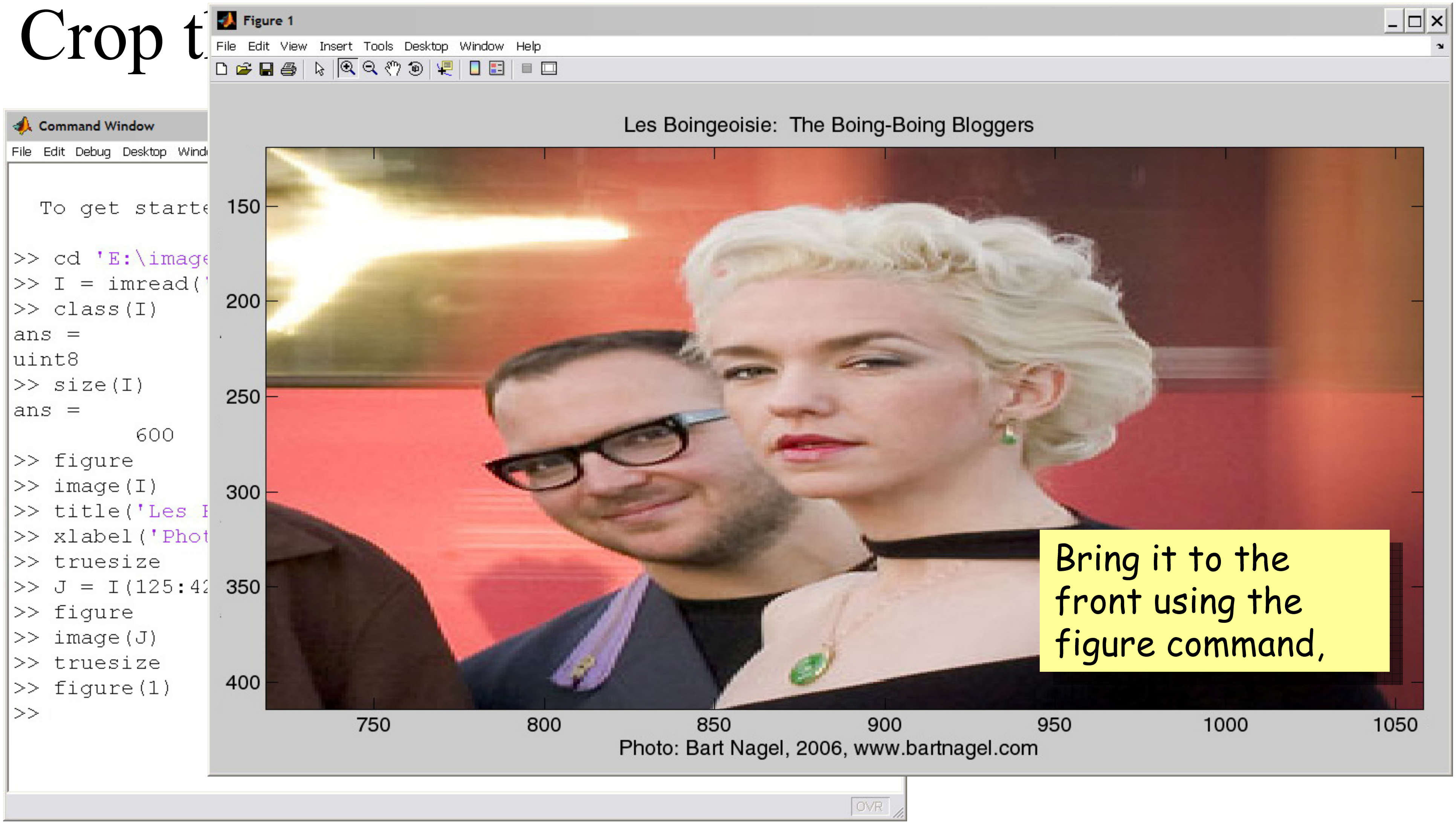
```
  To get started, select MATLAB Help or Demos from the Help menu.

>> cd 'E:\images\Animals\People\Famous'
>> I = imread('Les_Boingeoisie.jpg','jpg');
>> class(I)
ans =
uint8
>> size(I)
ans =
         600         1200            3
>> figure
>> image(I)
>> title('Les Boingeoisie:  The Boing-Boing Bloggers')
>> xlabel('Photo: Bart Nagel, 2006, www.bartnagel.com')
>> truesize
>> J = I(125:425,700:1050,:);
>> figure
>> image(J)
>> truesize
>>
```

Here it is:

Now close the other image

Crop t


Command Window
File Edit Debug Desktop Wind
Figure 1
File Edit View Insert Tools Desktop Window Help
150
200
250
300
350
400
750
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850
900
950
1000
1050
OVR

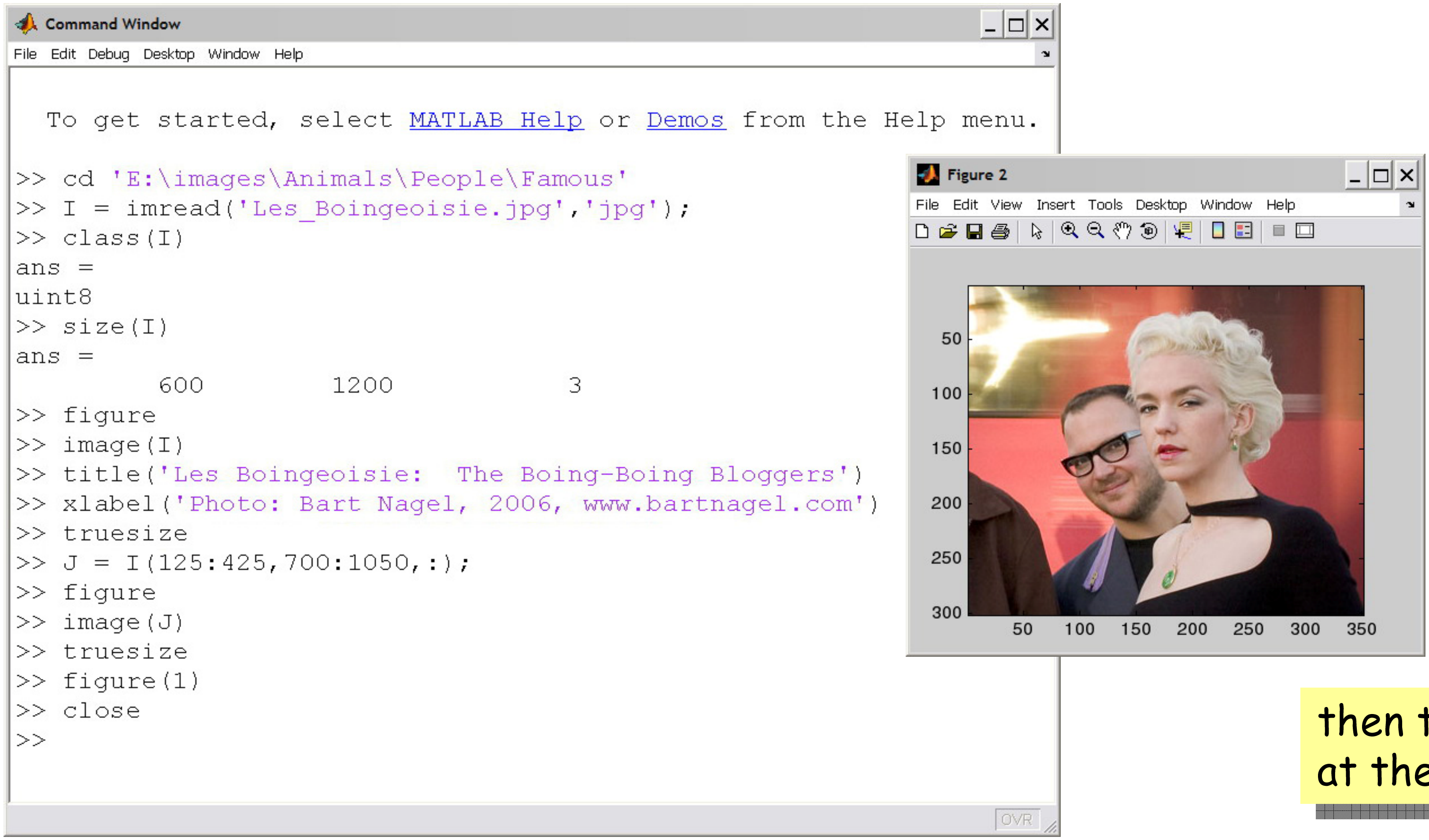
```
  To get starte

>> cd 'E:\image
>> I = imread('
>> class(I)
ans =
uint8
>> size(I)
ans =
         600
>> figure
>> image(I)
>> title('Les B
>> xlabel('Phot
>> truesize
>> J = I(125:42
>> figure
>> image(J)
>> truesize
>> figure(1)
>>
```

Les Boingeoisie: The Boing-Boing Bloggers

Photo: Bart Nagel, 2006, www.bartnagel.com

Bring it to the front using the figure command,

Crop the Image



```
  To get started, select MATLAB Help or Demos from the Help menu.

>> cd 'E:\images\Animals\People\Famous'
>> I = imread('Les_Boingeoisie.jpg','jpg');
>> class(I)
ans =
uint8
>> size(I)
ans =
         600         1200           3
>> figure
>> image(I)
>> title('Les Boingeoisie:  The Boing-Boing Bloggers')
>> xlabel('Photo: Bart Nagel, 2006, www.bartnagel.com')
>> truesize
>> J = I(125:425,700:1050,:);
>> figure
>> image(J)
>> truesize
>> figure(1)
>> close
>>
```

Command Window
File Edit Debug Desktop Window Help
OVR
Figure 2
File Edit View Insert Tools Desktop Window Help
50
100
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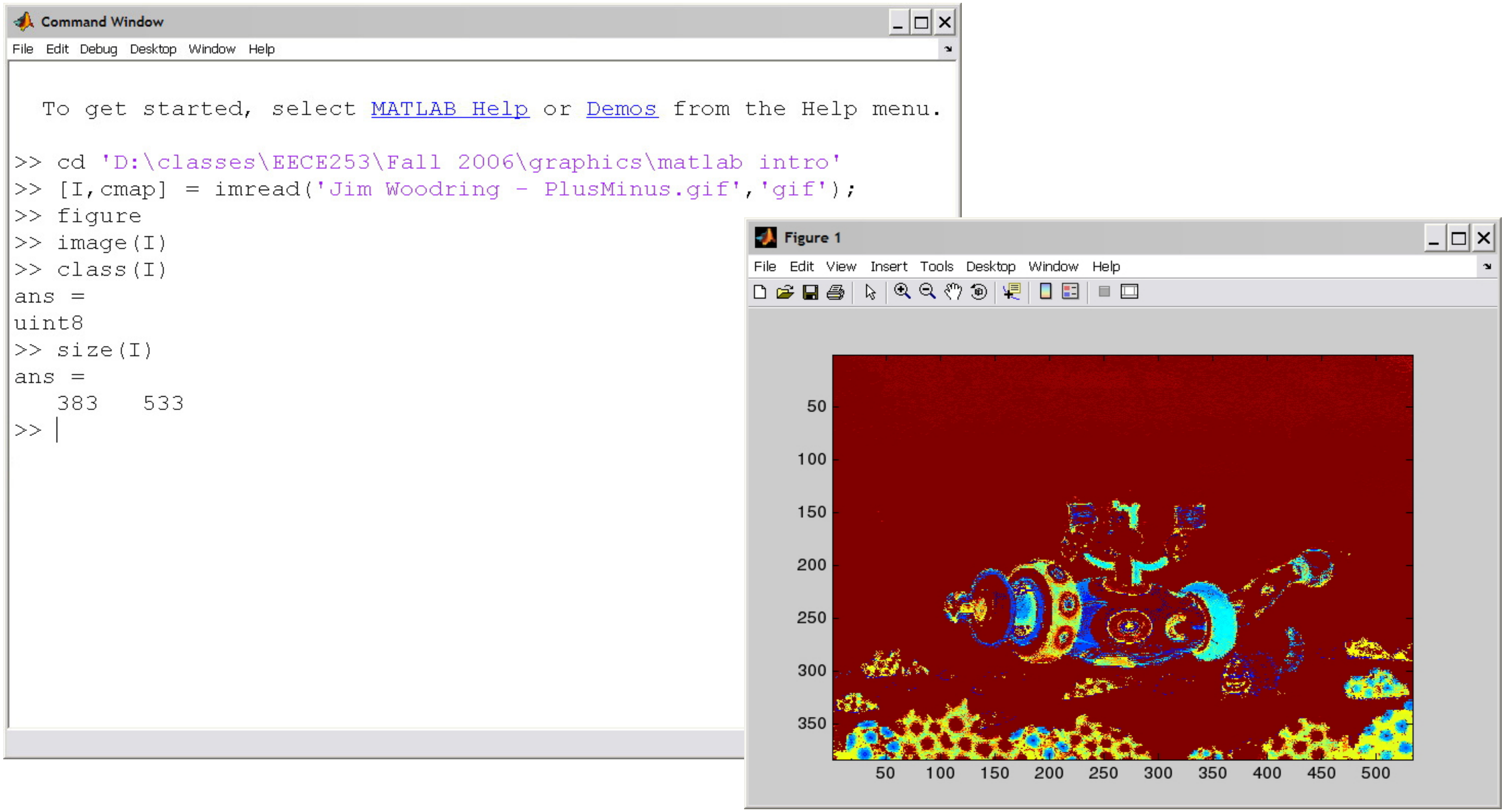
300
50
100
150
200
250
300
350

then type 'close' at the prompt.

Read a Colormapped Image into Matlab


Command Window
File Edit Debug Desktop Window Help
Figure 1
File Edit View Insert Tools Desktop Window Help
50
100
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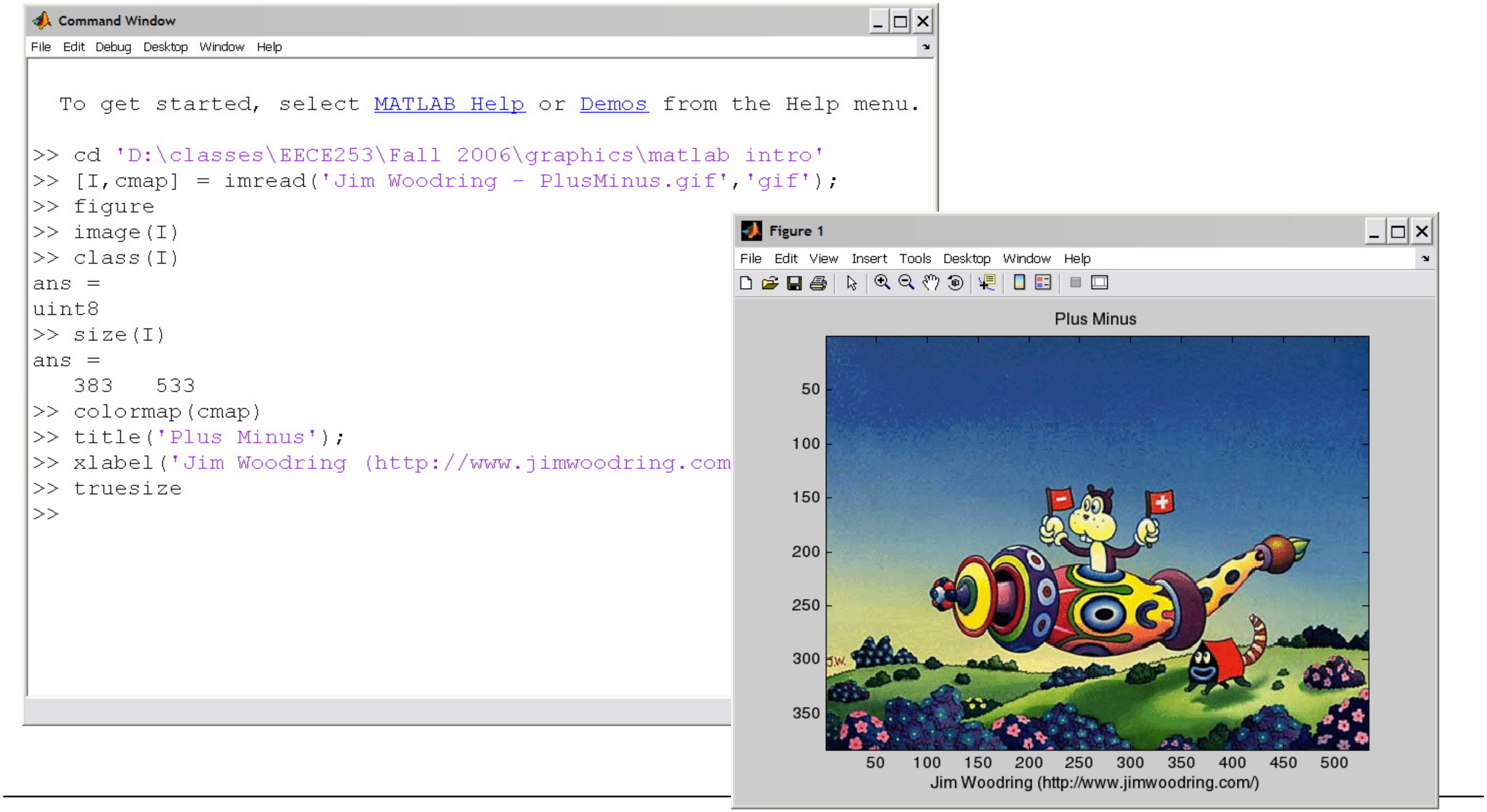
200
250
300
350
50
100
150
200
250
300
350
400
450
500

```
  To get started, select MATLAB Help or Demos from the Help menu.

>> cd 'D:\classes\EECE253\Fall 2006\graphics\matlab intro'
>> [I,cmap] = imread('Jim Woodring - PlusMinus.gif','gif');
>> figure
>> image(I)
>> class(I)
ans =
uint8
>> size(I)
ans =
   383   533
>> 
```

Read a Colormapped Image into Matlab


Command Window
File Edit Debug Desktop Window Help
Figure 1
File Edit View Insert Tools Desktop Window Help
Plus Minus
50
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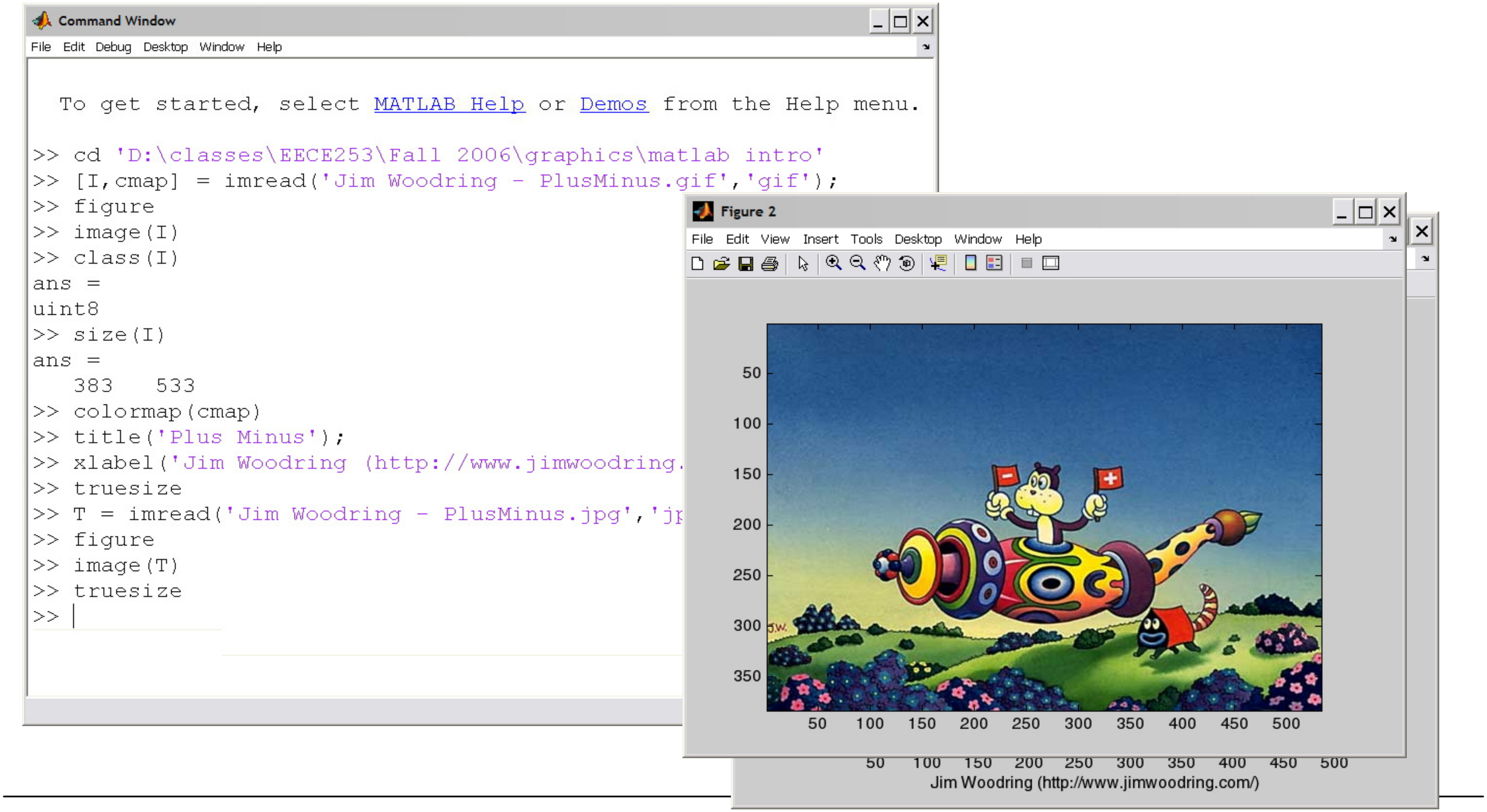
50 100 150 200 250 300 350 400 450 500
Jim Woodring (http://www.jimwoodring.com/)

```
  To get started, select MATLAB Help or Demos from the Help menu.

>> cd 'D:\classes\EECE253\Fall 2006\graphics\matlab intro'
>> [I,cmap] = imread('Jim Woodring - PlusMinus.gif','gif');
>> figure
>> image(I)
>> class(I)
ans =
uint8
>> size(I)
ans =
   383   533
>> colormap(cmap)
>> title('Plus Minus');
>> xlabel('Jim Woodring (http://www.jimwoodring.com
>> truesize
>>
```

Colormapped vs. Truecolor in Matlab



```
  To get started, select MATLAB Help or Demos from the Help menu.

>> cd 'D:\classes\EECE253\Fall 2006\graphics\matlab intro'
>> [I,cmap] = imread('Jim Woodring - PlusMinus.gif','gif');
>> figure
>> image(I)
>> class(I)
ans =
uint8
>> size(I)
ans =
   383   533
>> colormap(cmap)
>> title('Plus Minus');
>> xlabel('Jim Woodring (http://www.jimwoodring.
>> truesize
>> T = imread('Jim Woodring - PlusMinus.jpg','jp
>> figure
>> image(T)
>> truesize
>> |
```

Command Window
File Edit Debug Desktop Window Help
Figure 2
File Edit View Insert Tools Desktop Window Help
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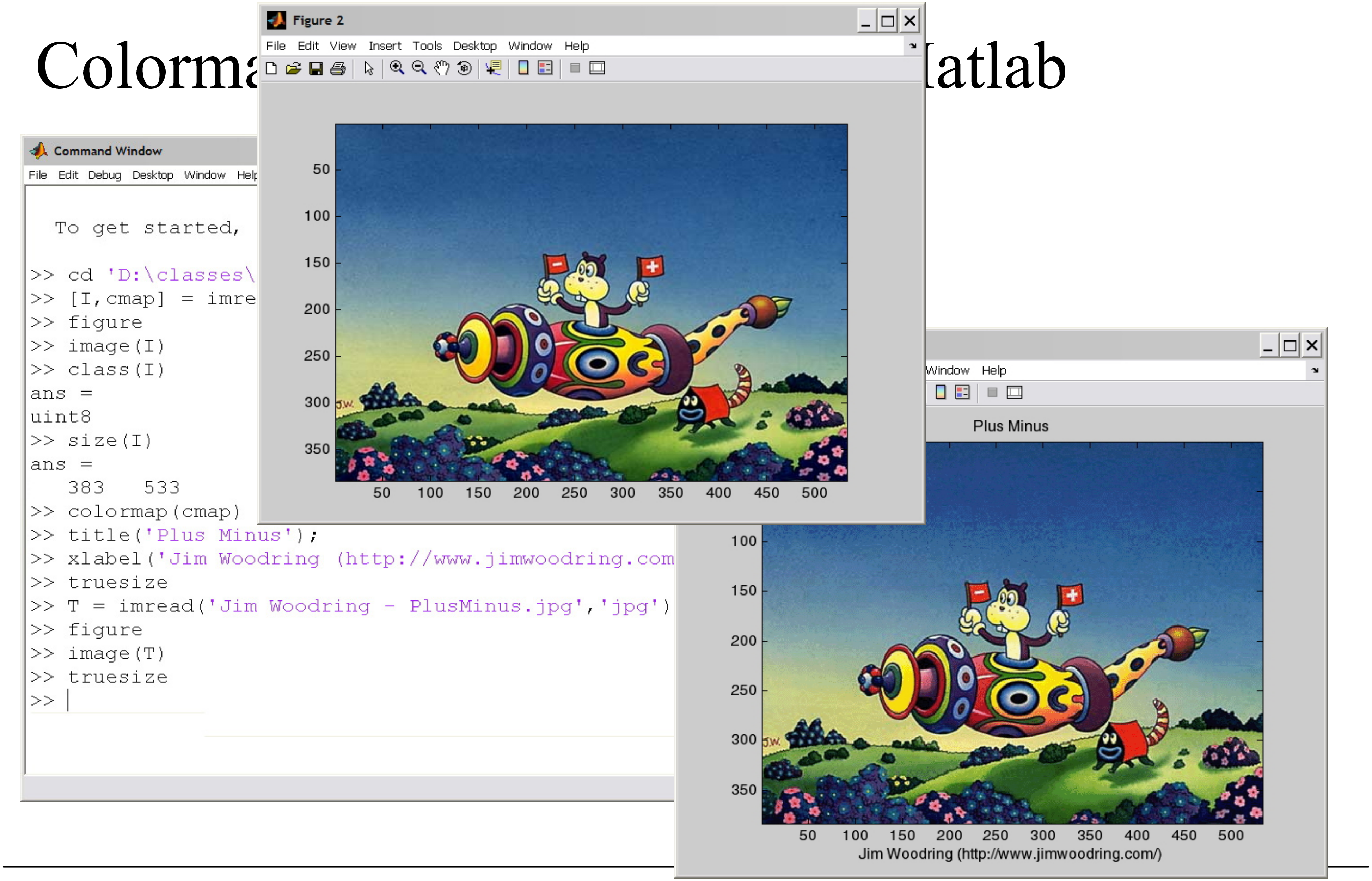
50 100 150 200 250 300 350 400 450 500
50 100 150 200 250 300 350 400 450 500
Jim Woodring (http://www.jimwoodring.com/)

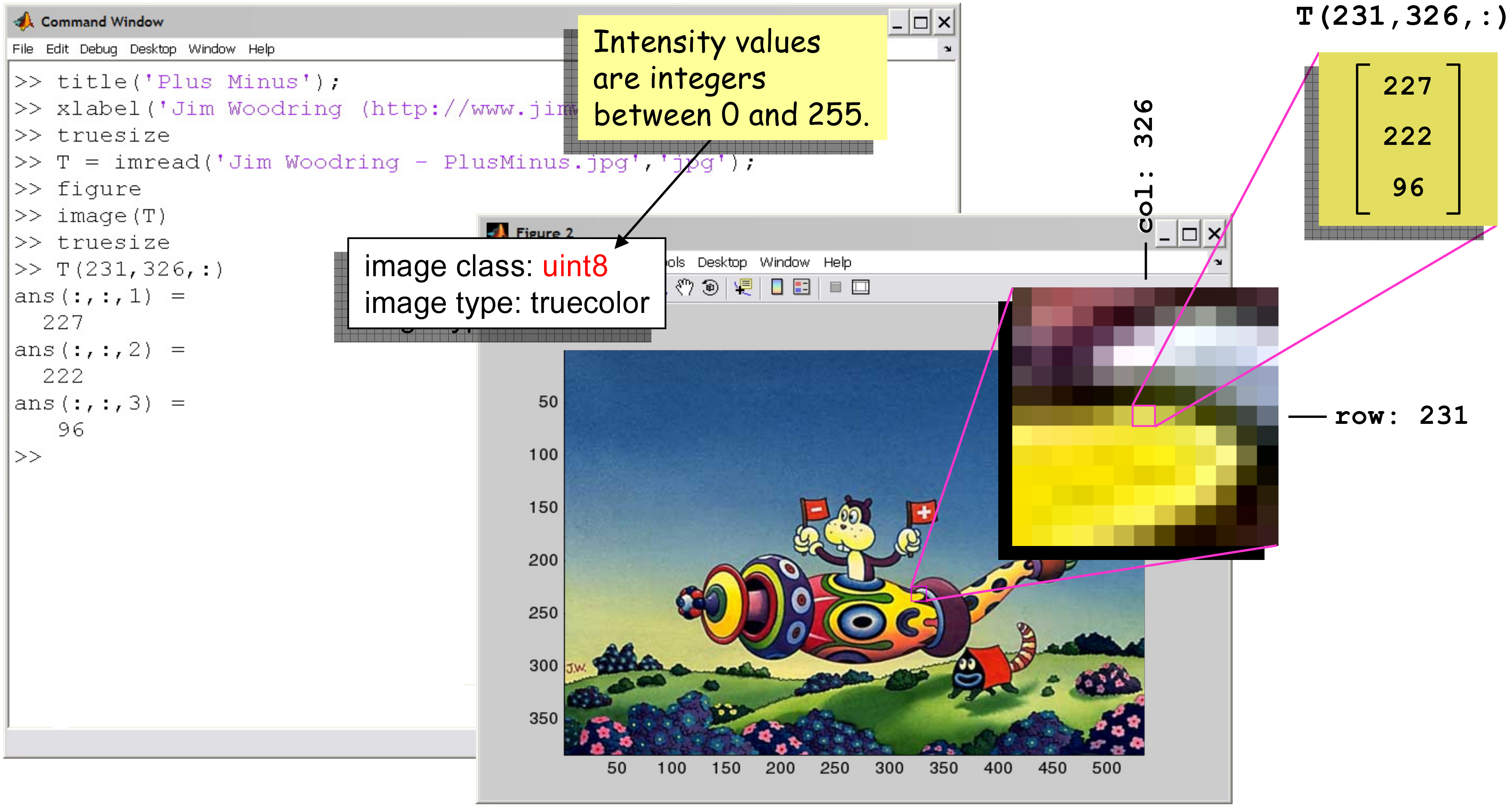
Colorma atlab



```
  To get started,

>> cd 'D:\classes\
>> [I,cmap] = imre
>> figure
>> image(I)
>> class(I)
ans =
uint8
>> size(I)
ans =
   383   533
>> colormap(cmap)
>> title('Plus Minus');
>> xlabel('Jim Woodring (http://www.jimwoodring.com
>> truesize
>> T = imread('Jim Woodring - PlusMinus.jpg','jpg')
>> figure
>> image(T)
>> truesize
>>
```

Colormapped vs. Truecolor in Matlab



```
>> title('Plus Minus');
>> xlabel('Jim Woodring (http://www.jim
>> truesize
>> T = imread('Jim Woodring - PlusMinus.jpg','jpg');
>> figure
>> image(T)
>> truesize
>> T(231,326,:)
ans(:,:,1) =
   227
ans(:,:,2) =
   222
ans(:,:,3) =
    96
>>
```

Intensity values are integers between 0 and 255.

image class: uint8
image type: truecolor

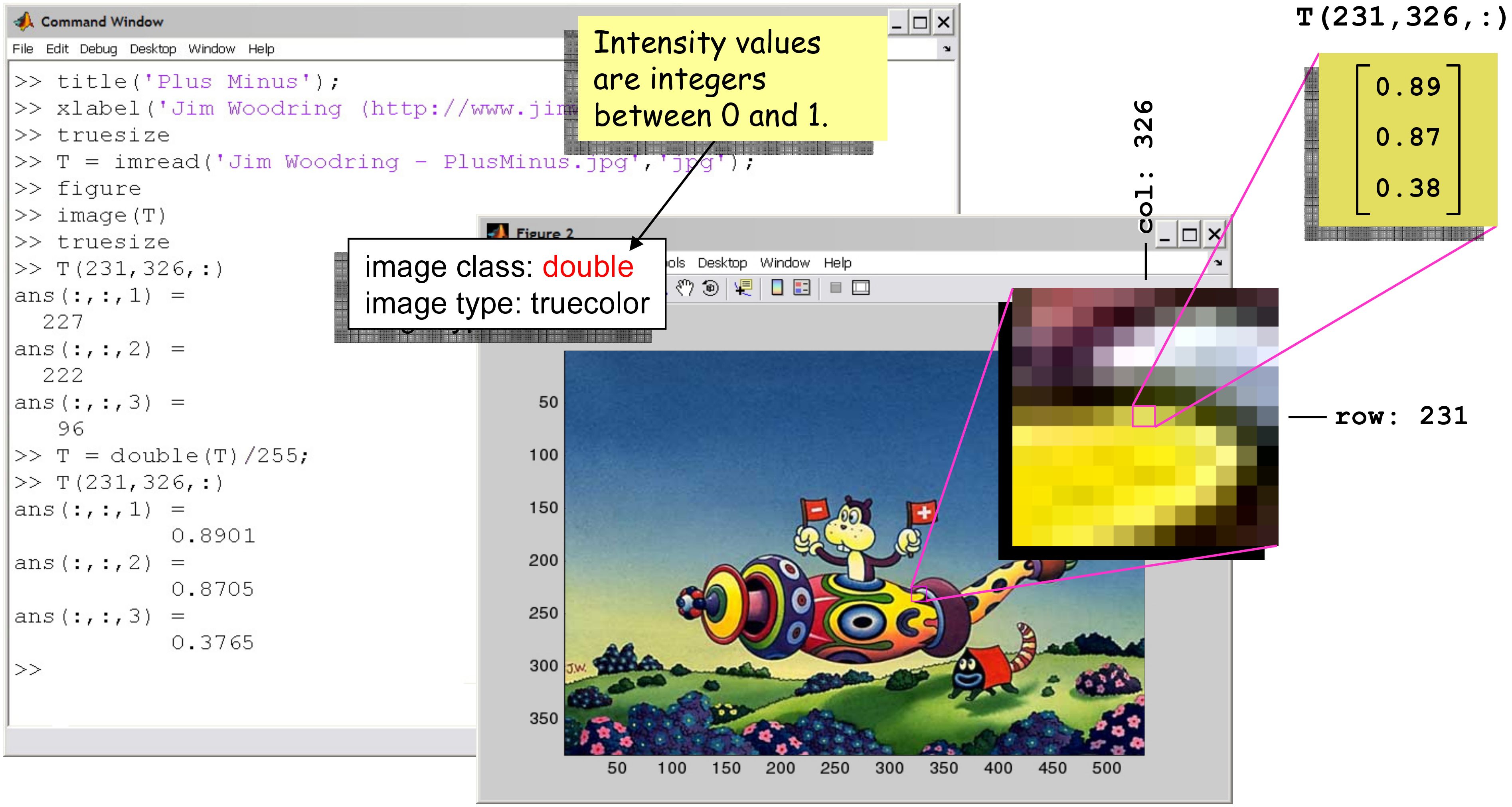
T(231,326,:)

$$\begin{bmatrix} 227 \\ 222 \\ 96 \end{bmatrix}$$

col: 326

row: 231

Colormapped vs. Truecolor in Matlab



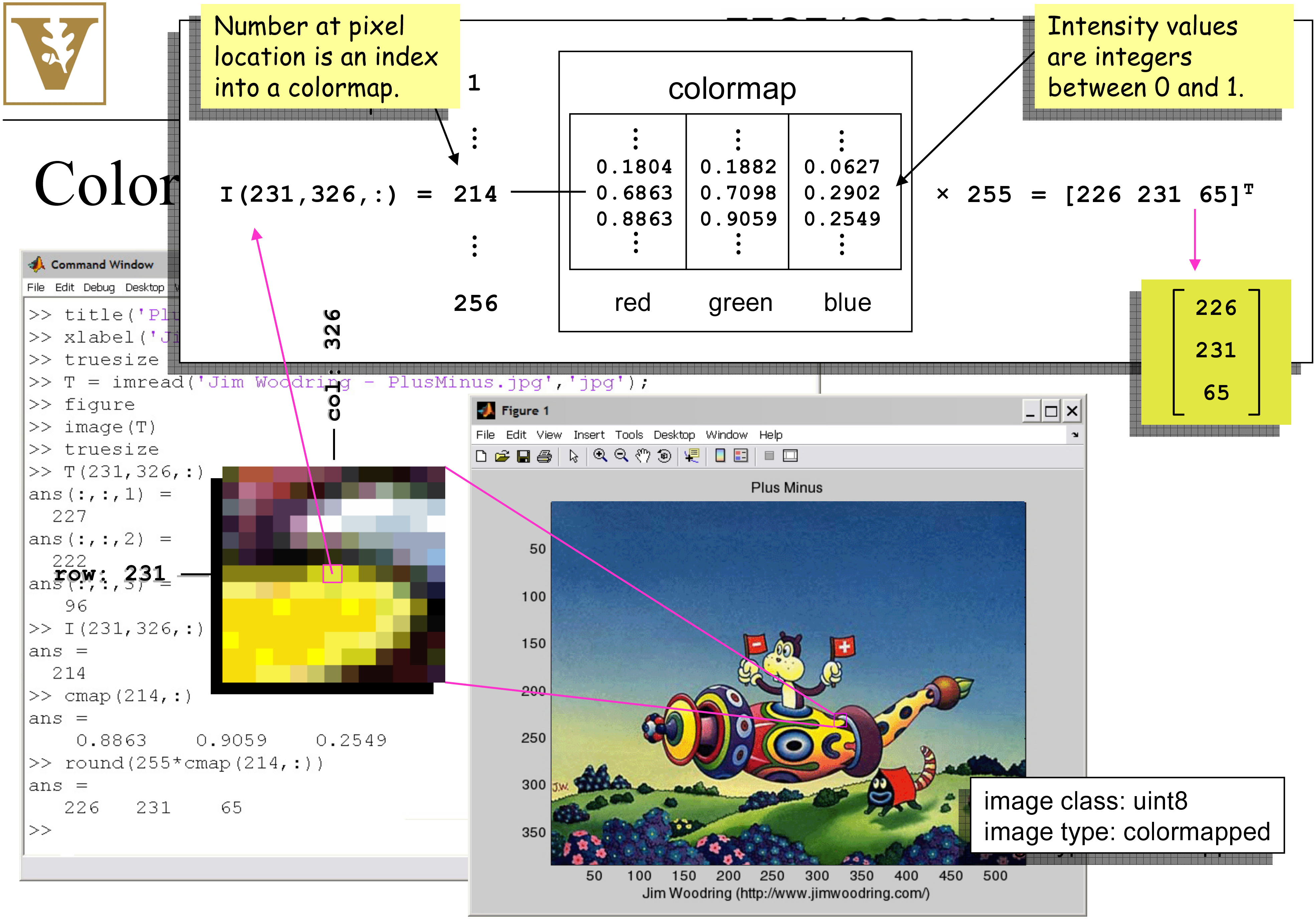
```
>> title('Plus Minus');
>> xlabel('Jim Woodring (http://www.jim
>> truesize
>> T = imread('Jim Woodring - PlusMinus.jpg','jpg');
>> figure
>> image(T)
>> truesize
>> T(231,326,:)
ans(:,:,1) =
   227
ans(:,:,2) =
   222
ans(:,:,3) =
    96
>> T = double(T)/255;
>> T(231,326,:)
ans(:,:,1) =
            0.8901
ans(:,:,2) =
            0.8705
ans(:,:,3) =
            0.3765
>>
```

Intensity values are integers between 0 and 1.

image class: double
image type: truecolor

$$\begin{bmatrix} 0.89 \\ 0.87 \\ 0.38 \end{bmatrix}$$

Color



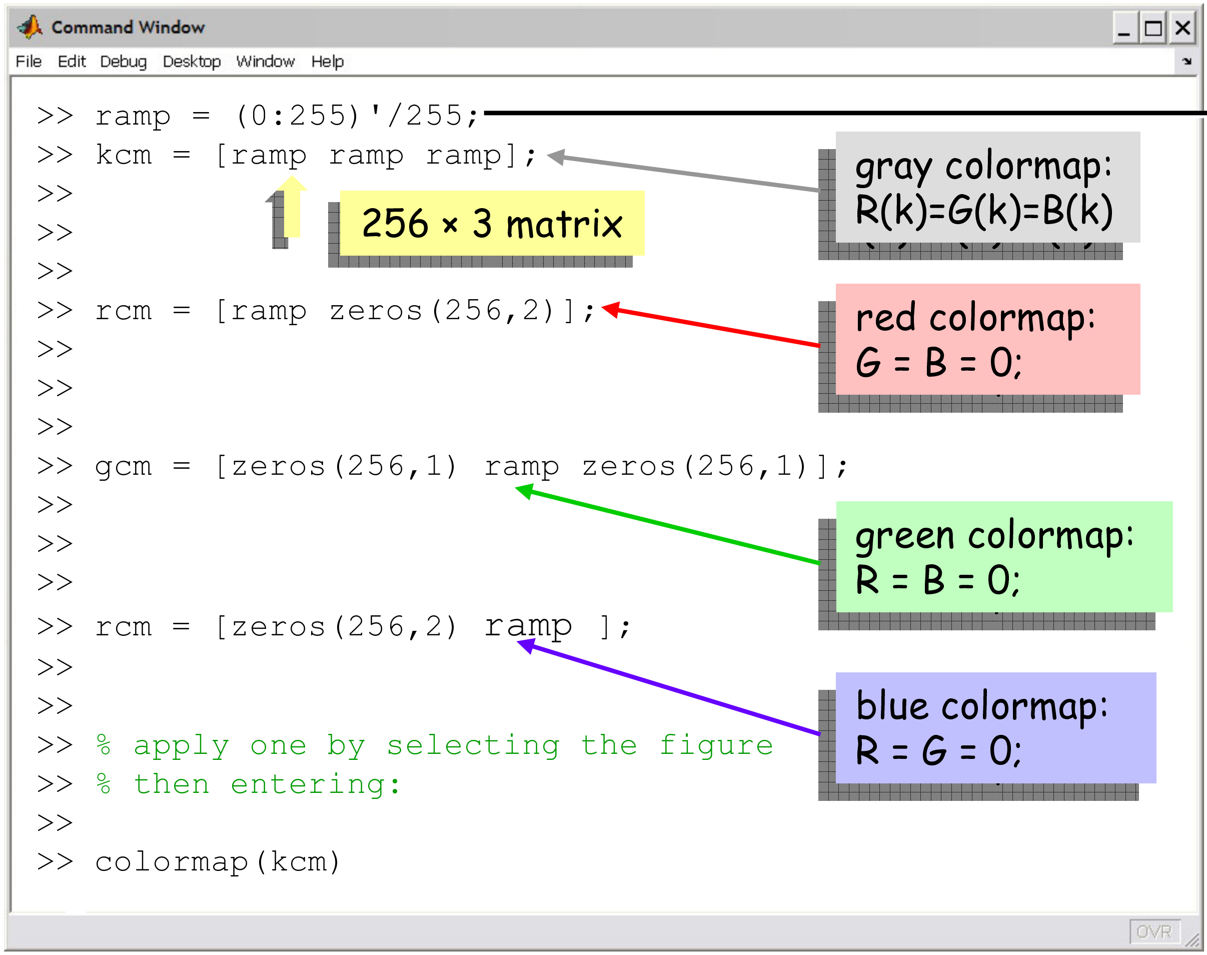
Number at pixel location is an index into a colormap.

Intensity values are integers between 0 and 1.

```
>> title('Pl
>> xlabel('Ji
>> truesize
>> T = imread('Jim Woodring - PlusMinus.jpg','jpg');
>> figure
>> image(T)
>> truesize
>> T(231,326,:)
ans(:,:,1) =
  227
ans(:,:,2) =
  222
ans(:,:,3) =
  96
>> I(231,326,:)
ans =
  214
>> cmap(214,:)
ans =
    0.8863    0.9059    0.2549
>> round(255*cmap(214,:))
ans =
   226   231    65
>>
```

image class: uint8
image type: colormapped

How to Make Colormaps



```
>> ramp = (0:255)'/255;
>> kcm = [ramp ramp ramp];
>>
>>
>>
>> rcm = [ramp zeros(256,2)];
>>
>>
>>
>> gcm = [zeros(256,1) ramp zeros(256,1)];
>>
>>
>>
>> rcm = [zeros(256,2) ramp ];
>>
>>
>> % apply one by selecting the figure
>> % then entering:
>>
>> colormap(kcm)
```

256 × 3 matrix

gray colormap:
R(k)=G(k)=B(k)

red colormap:
G = B = 0;

green colormap:
R = B = 0;

blue colormap:
R = G = 0;

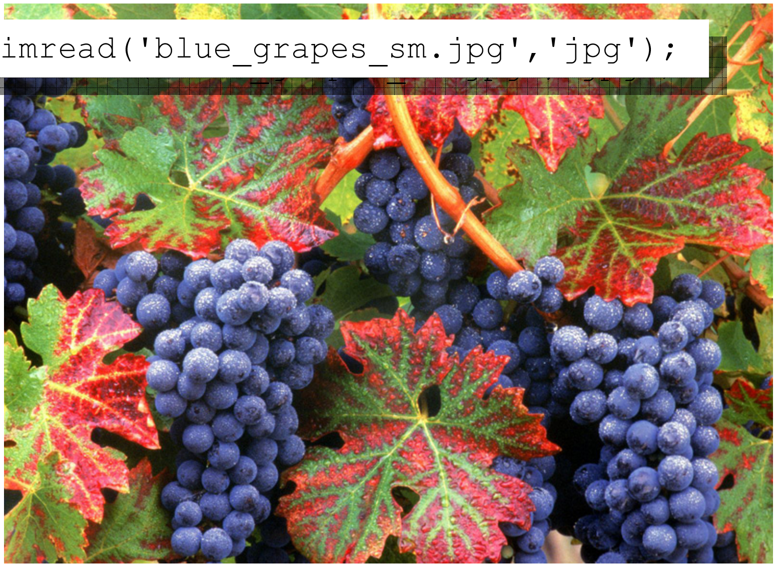
```
0
0.0039
0.0078
0.0118
0.0157
  ⋮

0.9843
0.9882
0.9922
0.9961
1.0000
```

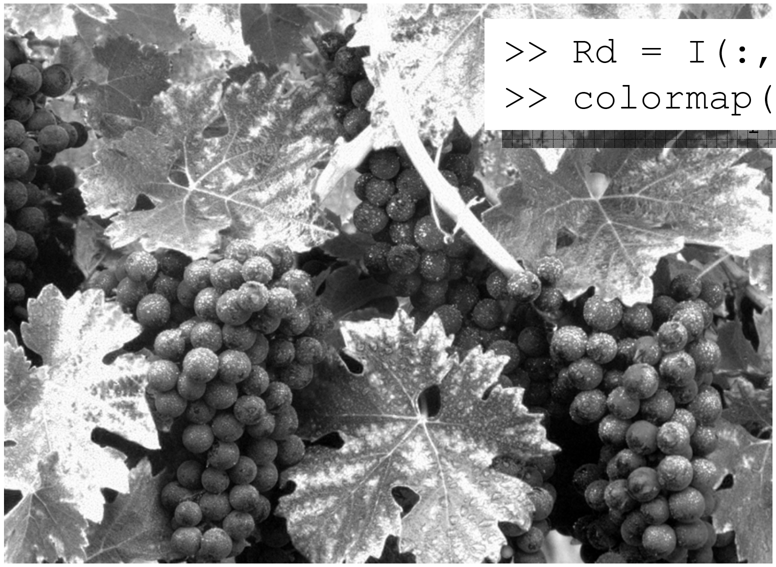
This code, 0:255 , generates a 1 row by 256 element vector of class double that contains numbers 0 through 255 inclusive.

This, (0:255)' , has the same contents and class but is a 256 row by 1 column vector. The apostrophe (') is the matrix transpose operator.

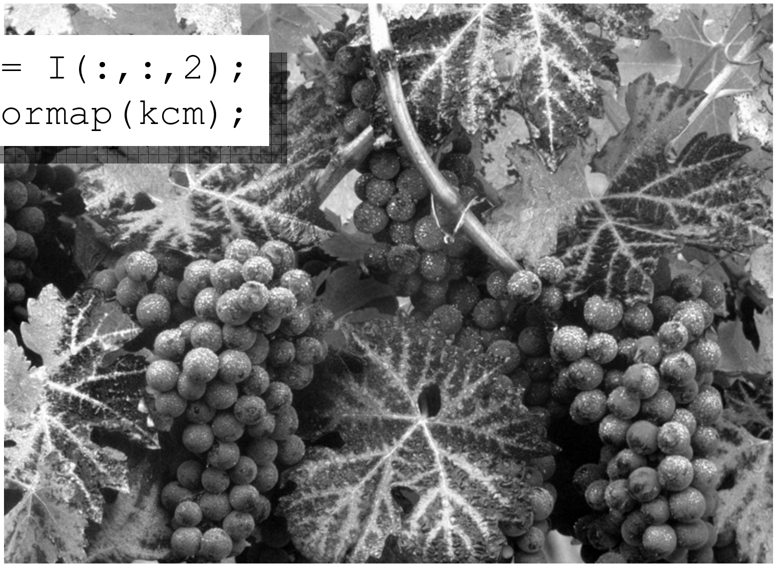
R, G, & B bands of a truecolor image displayed with grayscale colormaps



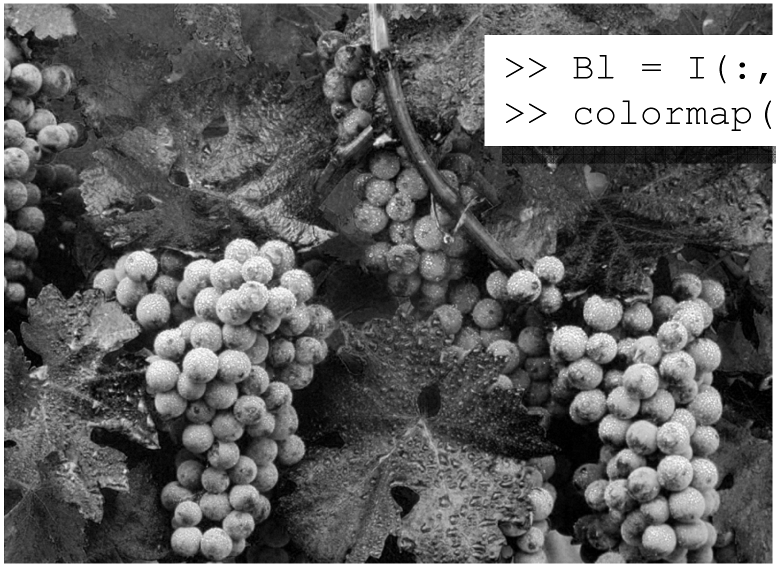
```
>> I = imread('blue_grapes_sm.jpg','jpg');
```



```
>> Rd = I(:,:,1);
>> colormap(kcm);
```



```
>> Gn = I(:,:,2);
>> colormap(kcm);
```

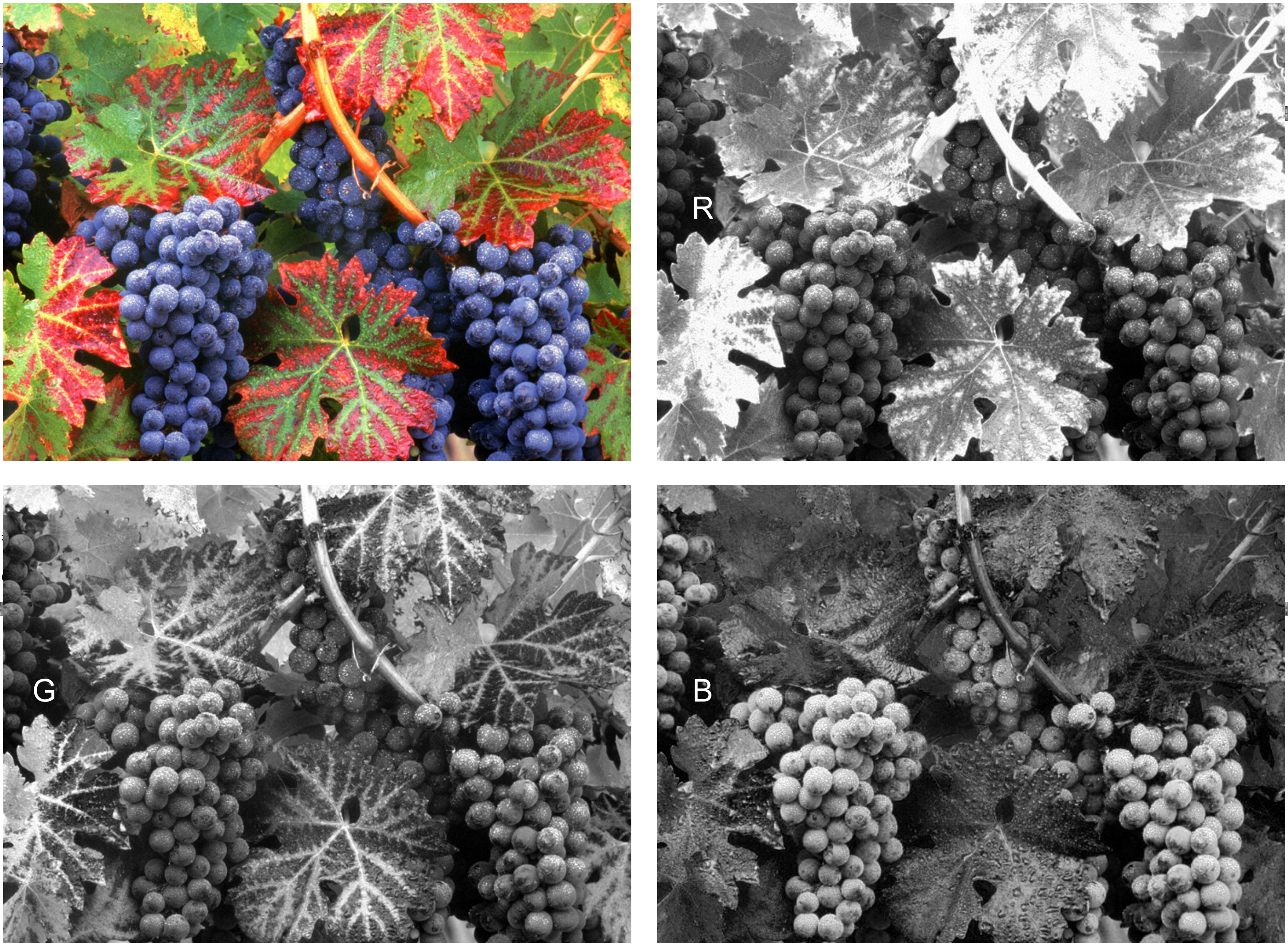


```
>> Bl = I(:,:,3);
>> colormap(kcm);
```

R, G, & B bands of a truecolor image displayed with grayscale colormaps

```
>> I = 
```

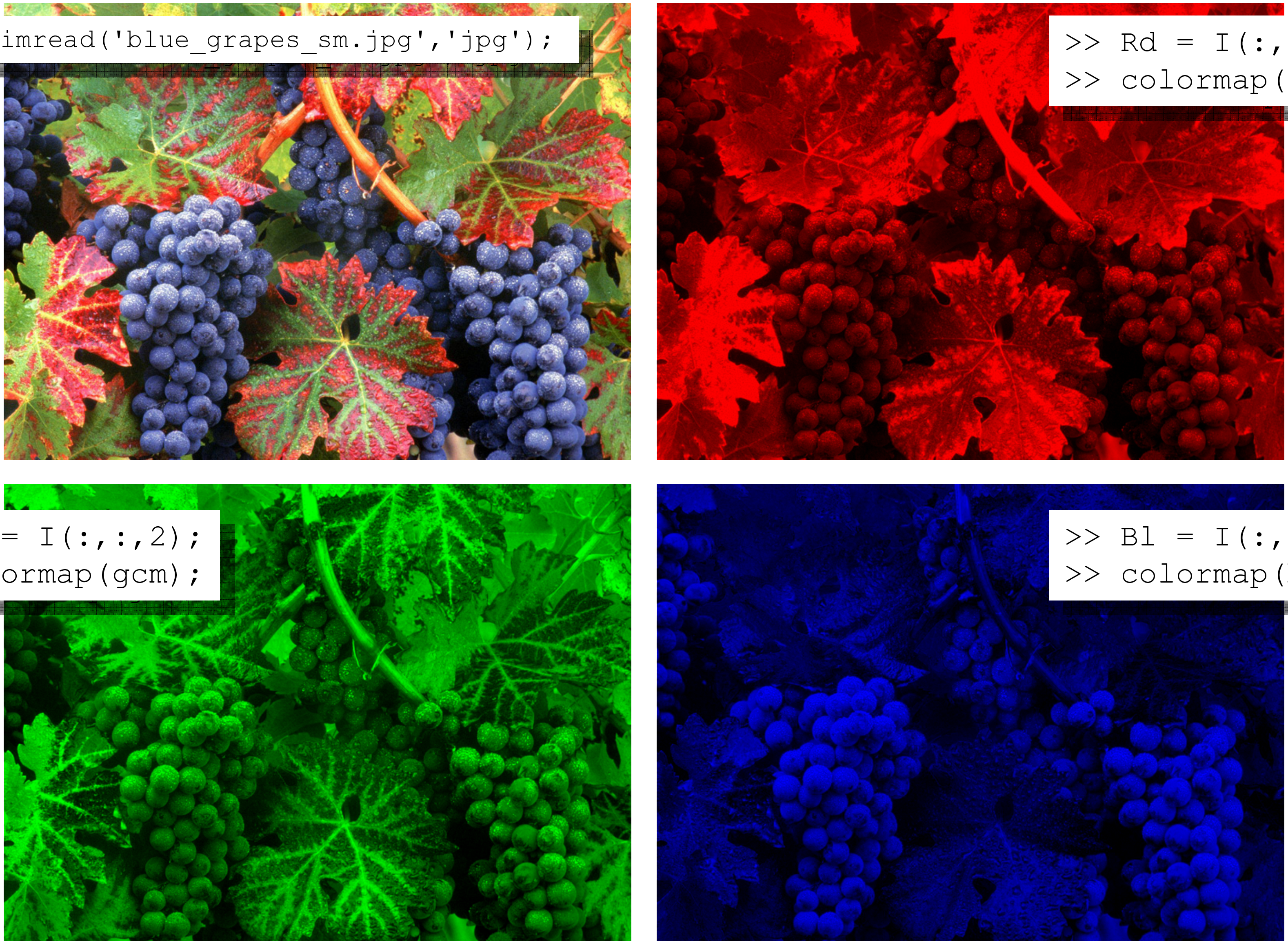
```
:,1);
kcm);
```



```
>> Gn =
>> col
```

```
:,3);
kcm);
```

R, G, & B bands of a truecolor image displayed with tinted colormaps



```
>> I = imread('blue_grapes_sm.jpg','jpg');
```

```
>> Rd = I(:,:,1);
>> colormap(rcm);
```

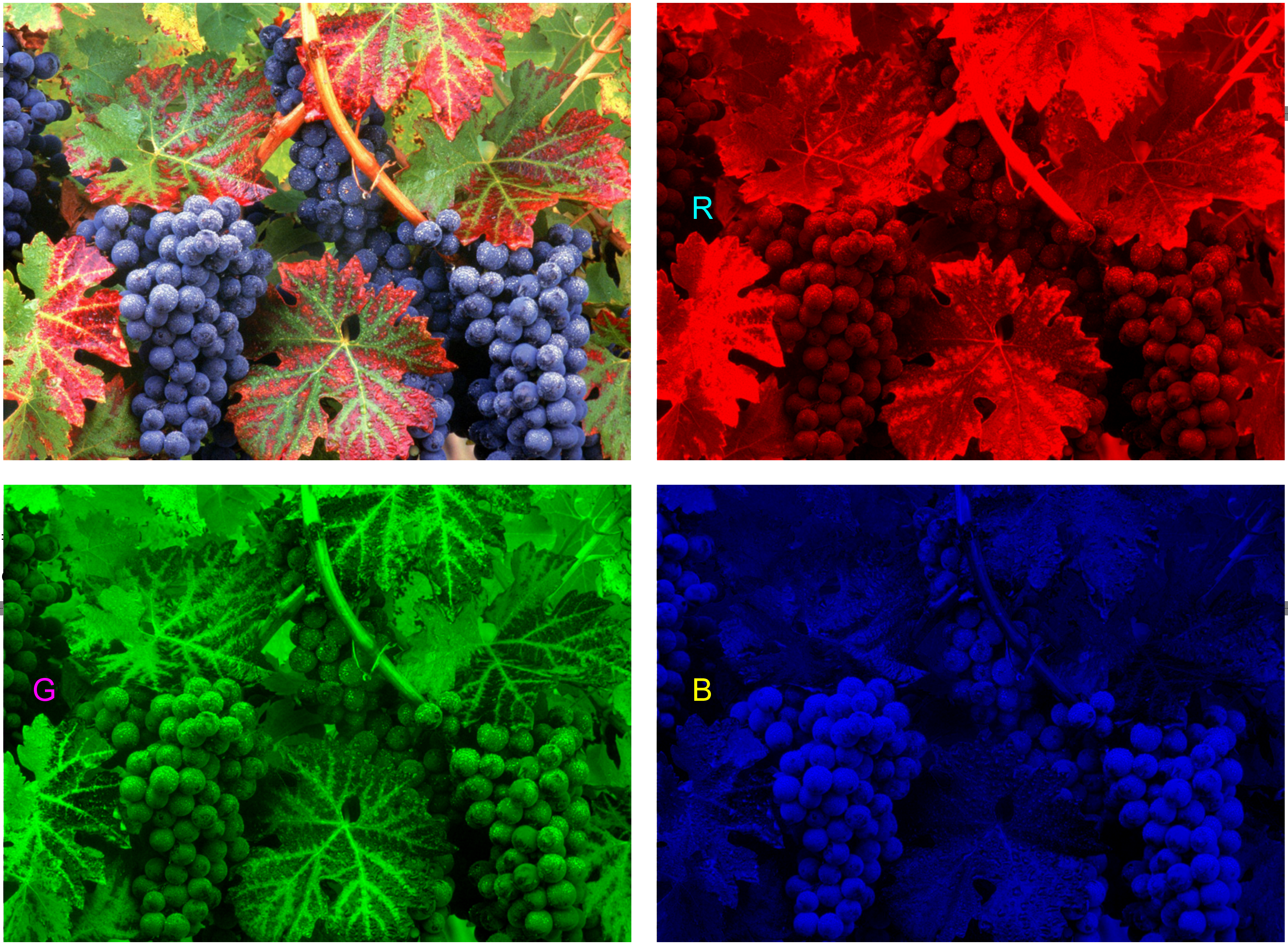
```
>> Gn = I(:,:,2);
>> colormap(gcm);
```

```
>> Bl = I(:,:,3);
>> colormap(bcm);
```

R, G, & B bands of a truecolor image displayed with tinted colormaps

```
>> I = 
```

```
:,1);
rcm);
```



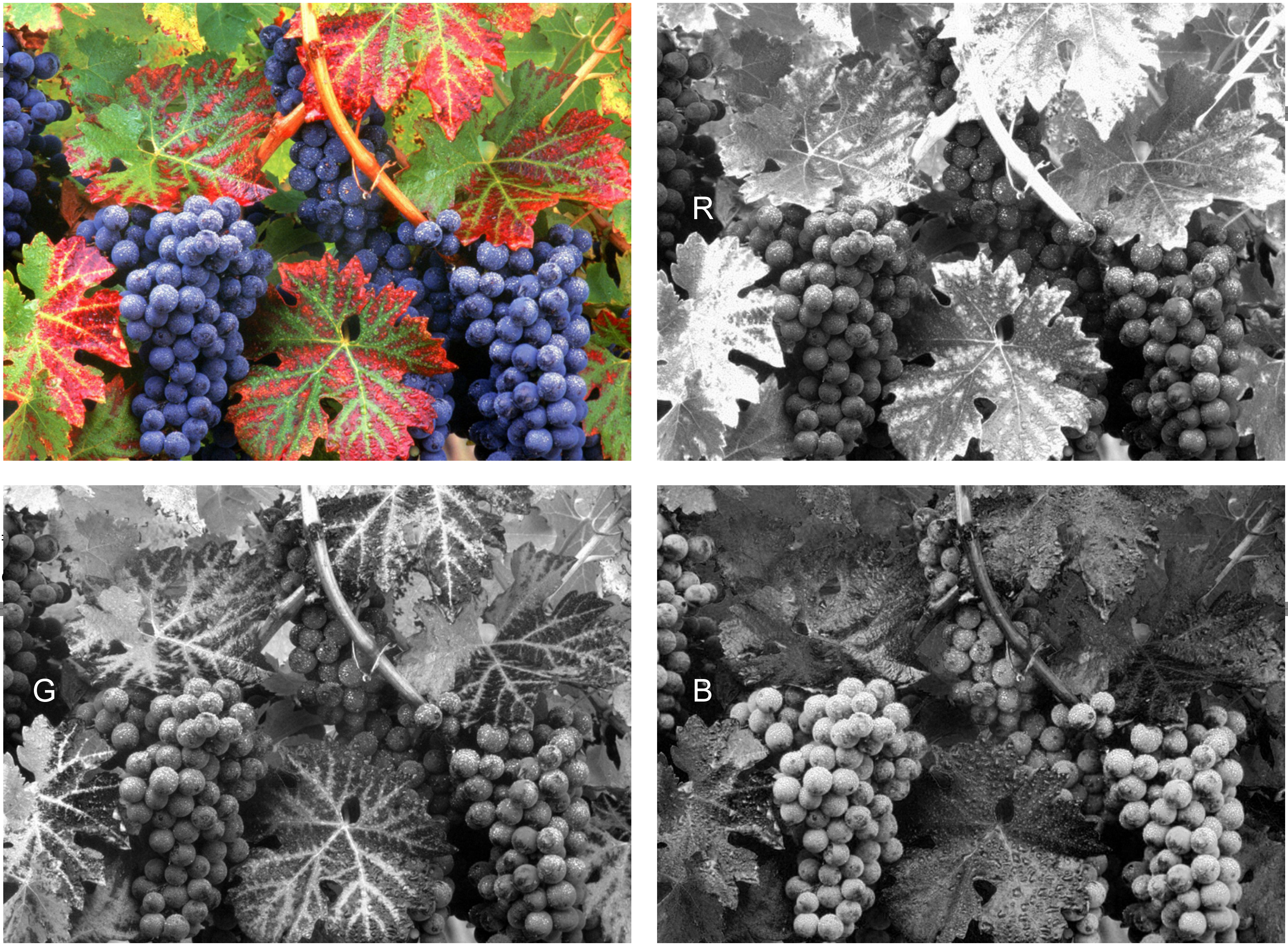
```
>> Gn 
>> col
```

```
:,3);
bcm);
```

R, G, & B bands of a truecolor image displayed with grayscale colormaps

```
>> I = 
```

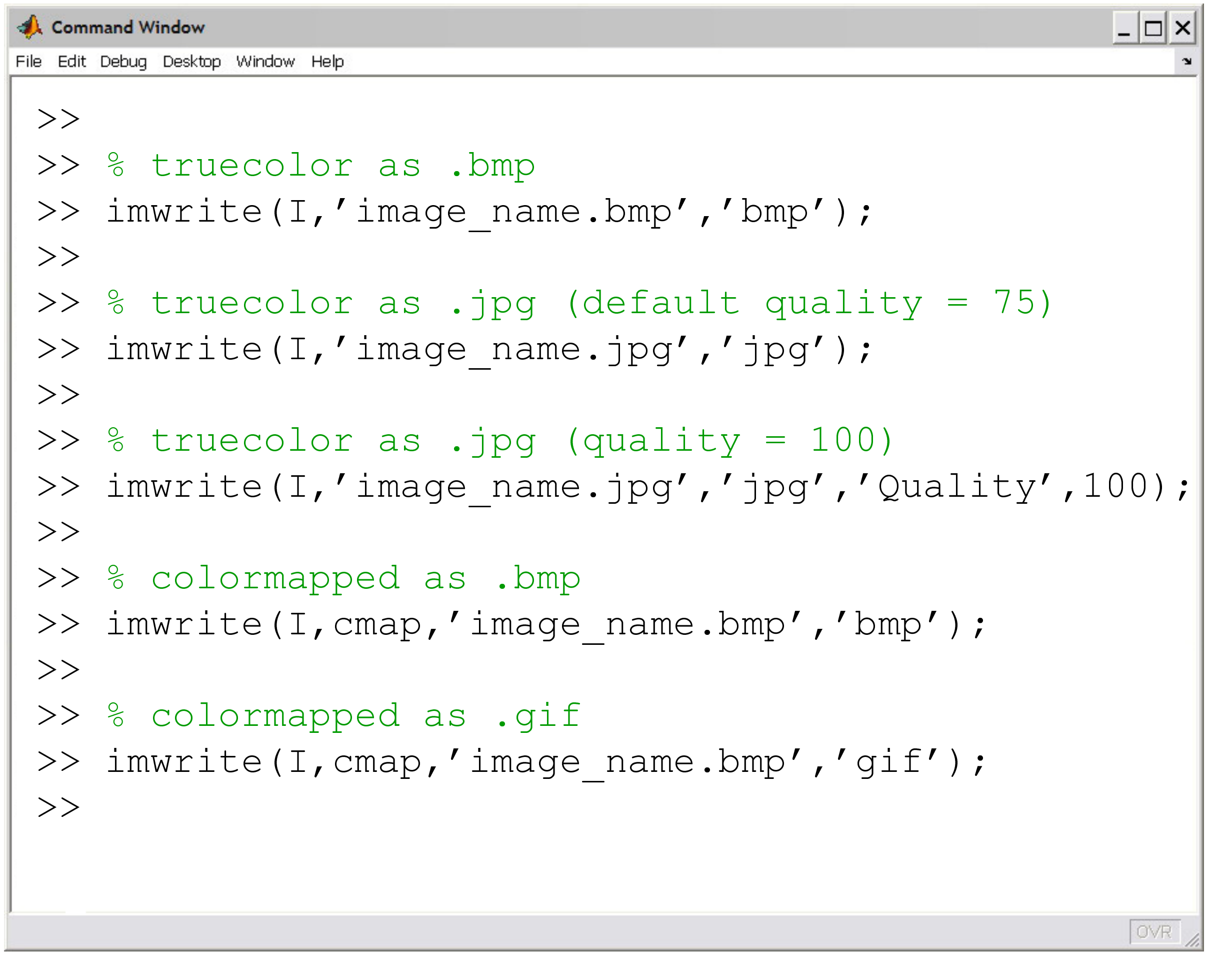
```
:,1);
kcm);
```



```
>> Gn 
>> col
```

```
:,3);
kcm);
```

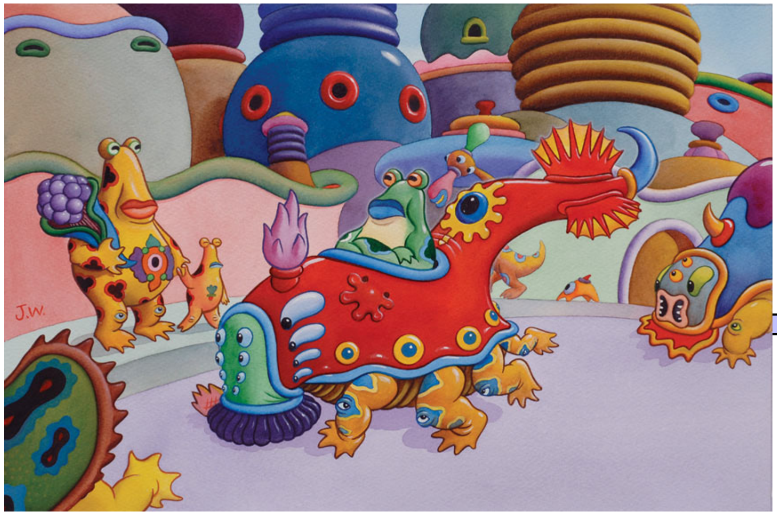
Saving Images as Files



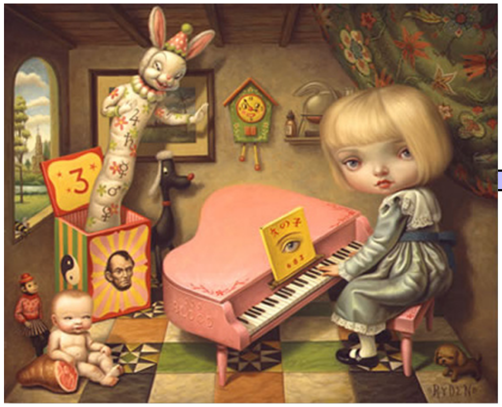
```
>>
>> % truecolor as .bmp
>> imwrite(I,’image_name.bmp’,’bmp’);
>>
>> % truecolor as .jpg (default quality = 75)
>> imwrite(I,’image_name.jpg’,’jpg’);
>>
>> % truecolor as .jpg (quality = 100)
>> imwrite(I,’image_name.jpg’,’jpg’,’Quality’,100);
>>
>> % colormapped as .bmp
>> imwrite(I,cmap,’image_name.bmp’,’bmp’);
>>
>> % colormapped as .gif
>> imwrite(I,cmap,’image_name.bmp’,’gif’);
>>
```

Assuming that
  ‘I’ contains the image of the correct class,
that
  ‘cmap’ is a colormap,
and that
  ‘image_name’ is the file-name that you want.

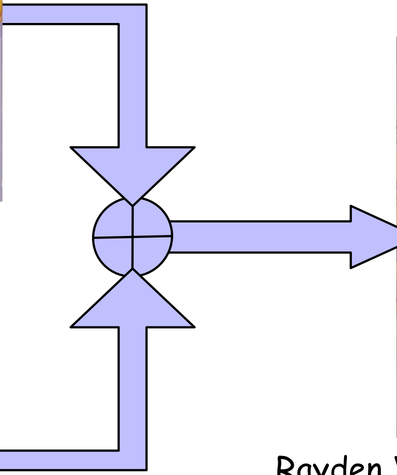
Double Exposure: Adding Two Images

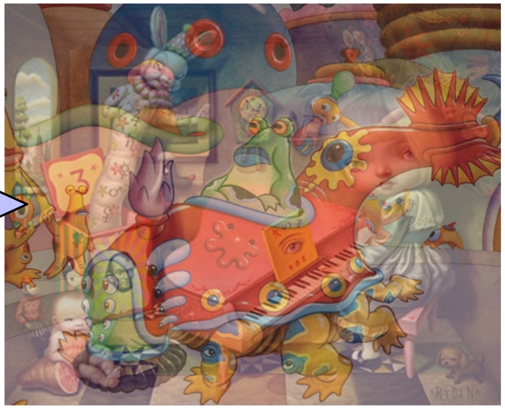


Jim Woodring - Bumperillo



Mark Rayden – The Ecstasy of Cecelia





Rayden Woodring – The Ecstasy of Bumperillo (?)

Double Exposure: Adding Two Images

Example
Matlab Code

```
>> cd 'D:\Classes\EECE253\Fall 2006\Graphics\matlab intro'
>> JW = imread('Jim Woodring - Bumperillo.jpg','jpg');
>> figure
>> image(JW)
>> truesize
>> title('Bumperillo')
>> xlabel('Jim Woodring')
>> MR = imread('Mark Ryden - The Ecstasy of Cecelia.jpg','jpg');
>> figure
>> image(MR)
>> truesize
>> title('The Ecstasy of Cecelia')
>> xlabel('Mark Ryden')
>> [RMR,CMR,DMR] = size(MR);
>> [RJW,CJW,DJW] = size(JW);
>> rb = round((RJW-RMR)/2);
>> cb = round((CJW-CMR)/2);
>> JWplusMR = uint8((double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:))+double(MR))/2);
>> figure
>> image(JWplusMR)
>> truesize
>> title('The Ecstasy of Bumperillo')
>> xlabel('Jim Woodring + Mark Ryden')
```

Double Exposure: Adding Two Images

Example Matlab Code

```
>> cd 'D:\Classes\EECE253\Fall 2006\Graphics\matlab intro'
>> JW = imread('Jim Woodring - Bumperillo.jpg','jpg');
>> figure
>> image(JW)
>> truesize
>> title('Bumperillo')
>> xlabel('Jim Woodring')
>> MR = imread('Mark Ryden - The Ecstasy of Cecelia.jpg','jpg');
>> figure
>> image(MR)
>> truesize
>> title('The Ecstasy of Cecelia')
>> xlabel('Mark Ryden')
>> [RMR,CMR,DMR] = size(MR);
>> [RJW,CJW,DJW] = size(JW);
>> rb = round((RJW-RMR)/2);
>> cb = round((CJW-CMR)/2);
>> JWplusMR = uint8((double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:))+double(MR))/2);
>> figure
>> image(JWplusMR)
>> truesize
>> title('The Ecstasy of Bumperillo')
>> xlabel('Jim Woodring + Mark Ryden')
```

Cut a section out of the middle of the larger image the same size as the smaller image.

Double Exposure: Adding Two Images

Example Matlab Code

```
>> cd 'D:\Classes\EECE253\Fall 2006\Graphics\matlab intro'
>> JW = imread('Jim Woodring - Bumperillo.jpg','jpg');
>> figure
>> image(JW)
>> truesize
>> title('Bumperillo')
>> xlabel('Jim Woodring')
>> MR = imread('Mark Ryden - The Ecstasy of Cecelia.jpg','jpg');
>> figure
>> image(MR)
>> truesize
>> title('The Ecstasy of Cecelia')
>> xlabel('Mark Ryden')
>> [RMR,CMR,DMR] = size(MR);
>> [RJW,CJW,DJW] = size(JW);
>> rb = round((RJW-RMR)/2);
>> cb = round((CJW-CMR)/2);
>> JWplusMR = uint8((double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:))+double(MR))/2);
>> figure
>> image(JWplusMR)
>> truesize
>> title('The Ecstasy of Bumperillo')
>> xlabel('Jim Woodring + Mark Ryden')
```

Note that the images are averaged, pixelwise.

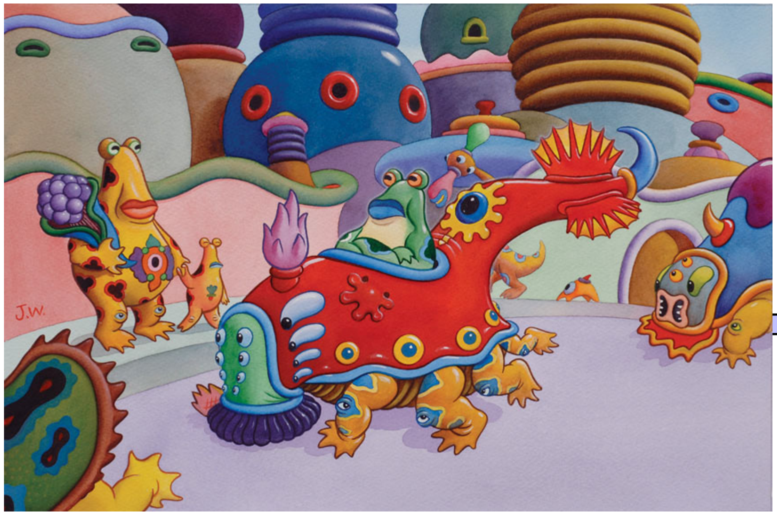
Double Exposure: Adding Two Images

Example Matlab Code

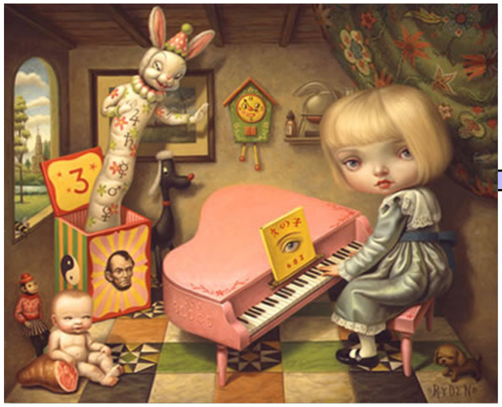
```
>> cd 'D:\Classes\EECE253\Fall 2006\Graphics\matlab intro'
>> JW = imread('Jim Woodring - Bumperillo.jpg','jpg');
>> figure
>> image(JW)
>> truesize
>> title('Bumperillo')
>> xlabel('Jim Woodring')
>> MR = imread('Mark Ryden - The Ecstasy of Cecelia.jpg','jpg');
>> figure
>> image(MR)
>> truesize
>> title('The Ecstasy of Cecelia')
>> xlabel('Mark Ryden')
>> [RMR,CMR,DMR] = size(MR);
>> [RJW,CJW,DJW] = size(JW);
>> rb = round((RJW-RMR)/2);
>> cb = round((CJW-CMR)/2);
>> JWplusMR = uint8((double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:))+double(MR))/2);
>> figure
>> image(JWplusMR)
>> truesize
>> title('The Ecstasy of Bumperillo')
>> xlabel('Jim Woodring + Mark Ryden')
```

Note the data class conversions.

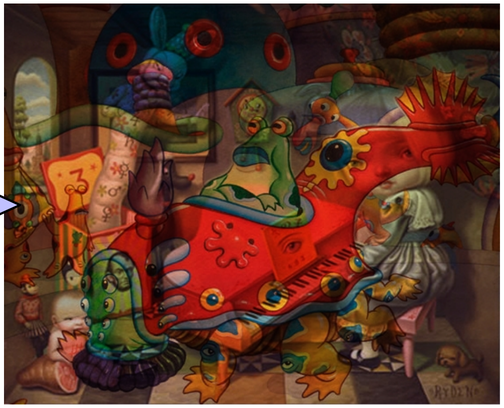
Intensity Masking: Multiplying Two Images



Jim Woodring - Bumperillo



Mark Rayden – The Ecstasy of Cecelia



Rayden Woodring – Bumperillo Ecstasy (?)

Intensity Masking: Multiplying Two Images

Example Matlab Code

```
>> JW = imread('Jim Woodring - Bumperillo.jpg','jpg');
>> MR = imread('Mark Ryden - The Ecstasy of Cecelia.jpg','jpg');
>> [RMR,CMR,DMR] = size(MR);
>> [RJW,CJW,DJW] = size(JW);
>> rb = round((RJW-RMR)/2);
>> cb = round((CJW-CMR)/2);
>> JWplusMR = uint8((double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:))+double(MR))/2);
>> figure
>> image(JWplusMR)
>> truesize
>> title('The Extacsy of Bumperillo')
>> xlabel('Jim Woodring + Mark Ryden')
>> JWtimesMR = double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:)).*double(MR);
>> M = max(JWtimesMR(:));
>> m = min(JWtimesMR(:));
>> JWtimesMR = uint8(255*(double(JWtimesMR)-m)/(M-m));
>> figure
>> image(JWtimesMR)
>> truesize
>> title('EcstasyBumperillo')
```

Intensity Masking: Multiplying Two Images

Example Matlab Code

```
>> JW = imread('Jim Woodring - Bumperillo.jpg','jpg');
>> MR = imread('Mark Ryden - The Ecstasy of Cecelia.jpg','jpg');
>> [RMR,CMR,DMR] = size(MR);
>> [RJW,CJW,DJW] = size(JW);
>> rb = round((RJW-RMR)/2);
>> cb = round((CJW-CMR)/2);
>> JWplusMR = uint8((double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:))+double(MR))/2);
>> figure
>> image(JWplusMR)
>> truesize
>> title('The Extacsy of Bumperillo')
>> xlabel('Jim Woodring + Mark Ryden')
>> JWtimesMR = double(JW(rb:(rb+RMR-1),cb:(cb+CMR-1),:)).*double(MR);
>> M = max(JWtimesMR(:));
>> m = min(JWtimesMR(:));
>> JWtimesMR = uint8(255*(double(JWtimesMR)-m)/(M-m));
>> figure
>> image(JWtimesMR)
>> truesize
>> title('EcstasyBumperillo')
```

Note that the images are multiplied, pixelwise.

Note how the image intensities are scaled back into the range 0-255.

Pixel Indexing in Matlab

"IP_Function" is some arbitrary image processing function that you or someone else has written.

"For" loops in Matlab are inefficient, whereas Matlab's native indexing procedures are very fast.

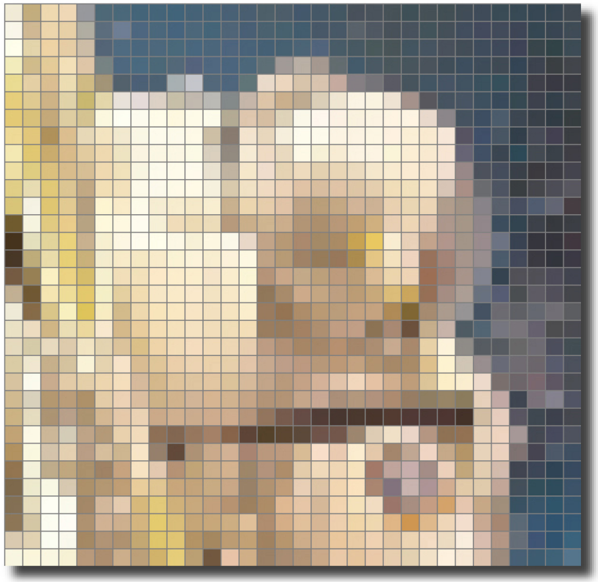
Rather than

```
for r = 1:R
   for c = 1:C
      J(r,c,:) = IP_Function(I(r,c,:));
   end
end
```

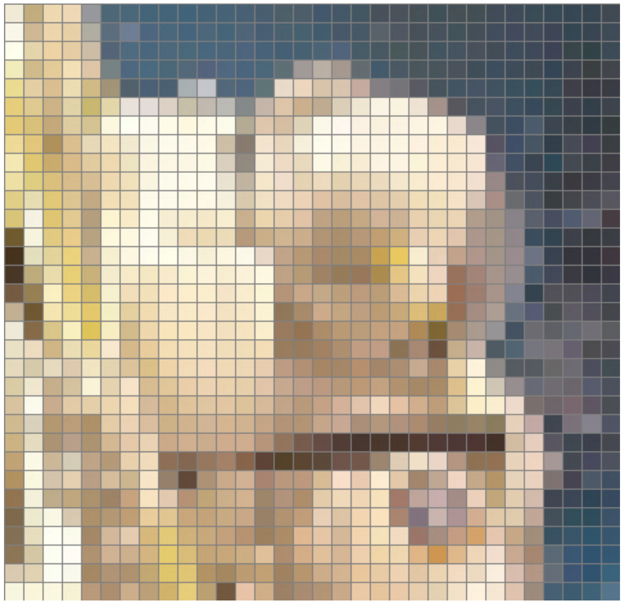
use, if possible

```
J = IP_Function(I);
```

But, sometimes that is not possible.
For example, if the output, *J*, is decimated with respect to the input, *I*, the above will not work (unless, of course, it is done within IP_function).



Pixel Indexing in Matlab

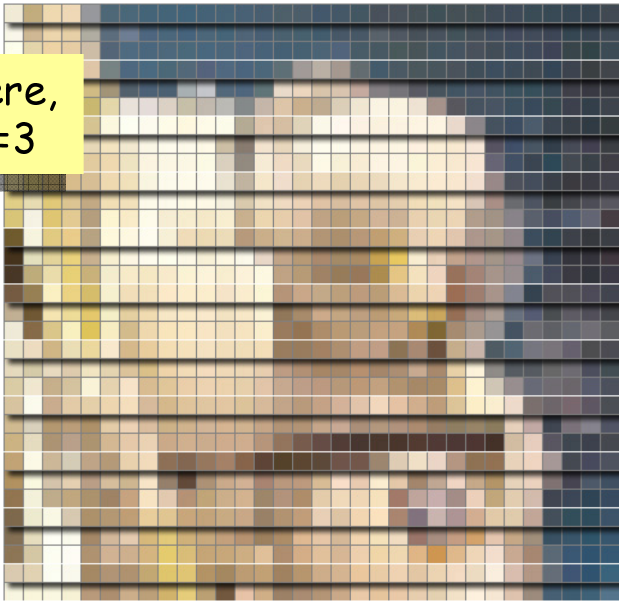


```
r = 1:n:R;
```

```
I(r,:,:)
```

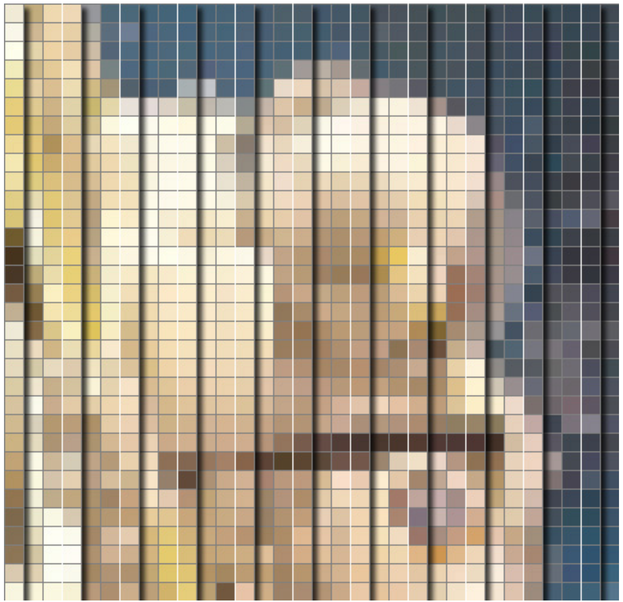
```
c = 1:n:C;
```

```
I(:,c,:)
```



Here, n=3

$r = [1\ 4\ 7\ 10\ 13\ 16\ 19\ 22\ 25\ 28\ 31]$

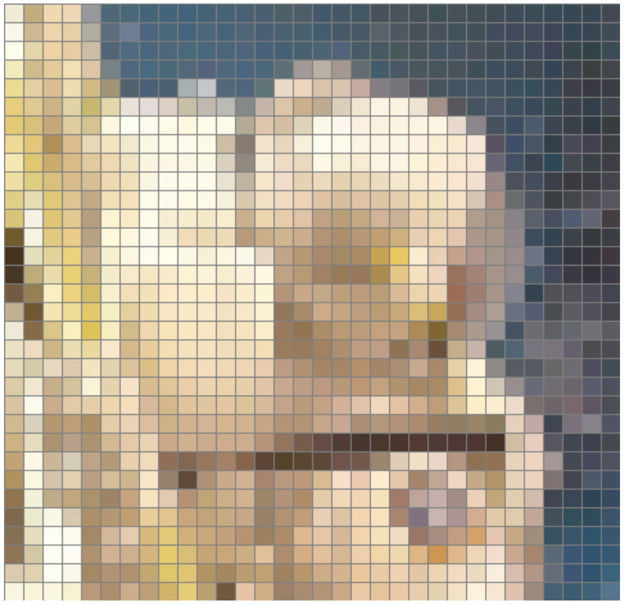


$c = [1\ 4\ 7\ 10\ 13\ 16\ 19\ 22\ 25\ 28\ 31]$

To decimate the above image by a factor of *n*, create a vector, **r**, that contains the index of every *n*th row, and a similar vector, **c**.

Pixel Indexing in Matlab

This is called, 'vectorizing'.

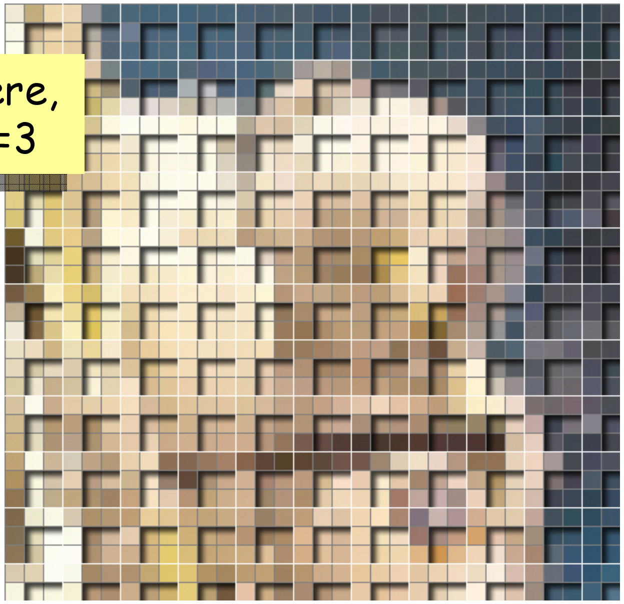


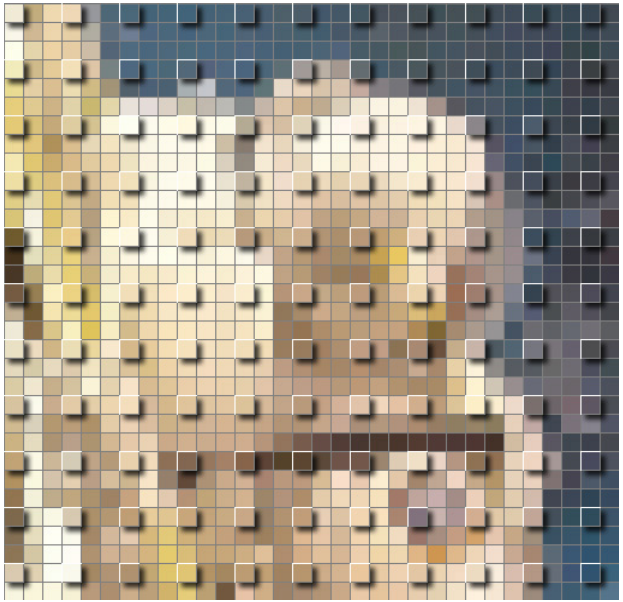
Take the pixels indexed by both *r* and *c*.

↓

```
I(r,c)
```

Here, n=3

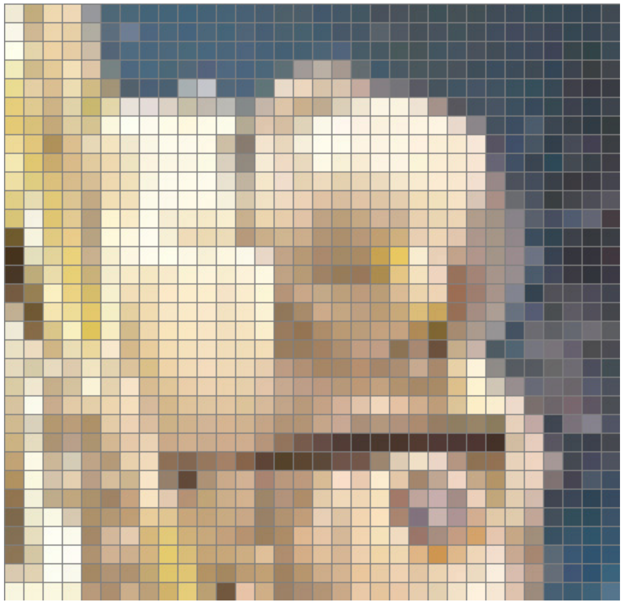




Then, vectors **r** and **c** used as index arguments for image *I* select every *n*th column in every *n*th row.

Pixel Indexing in Matlab

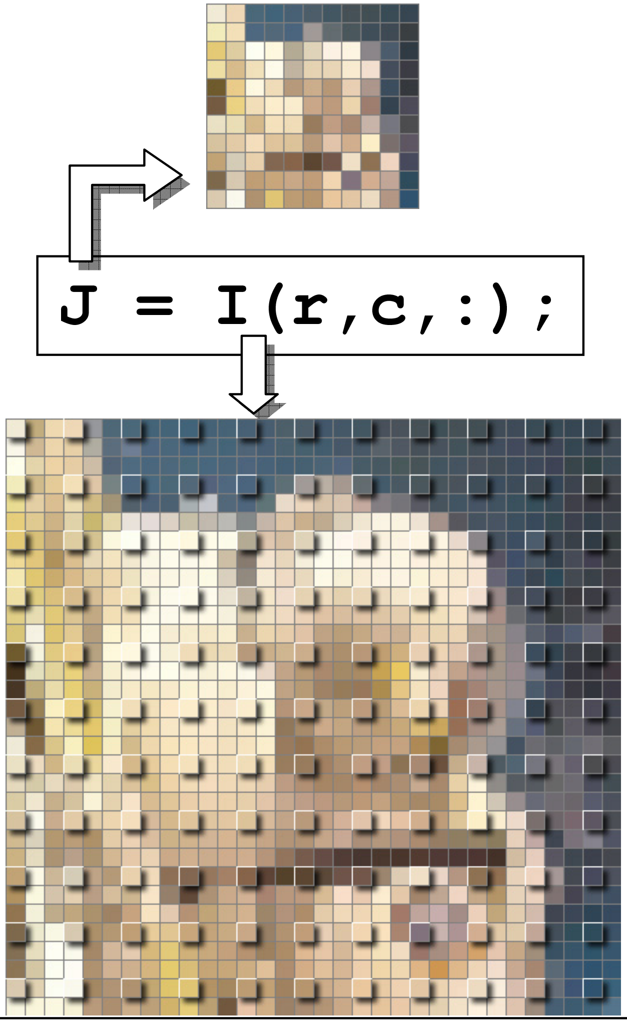
Here, n=3



image, `I`

```
r = 1:n:R;
```

```
c = 1:n:C;
```



```
J = I(r,c,:);
```

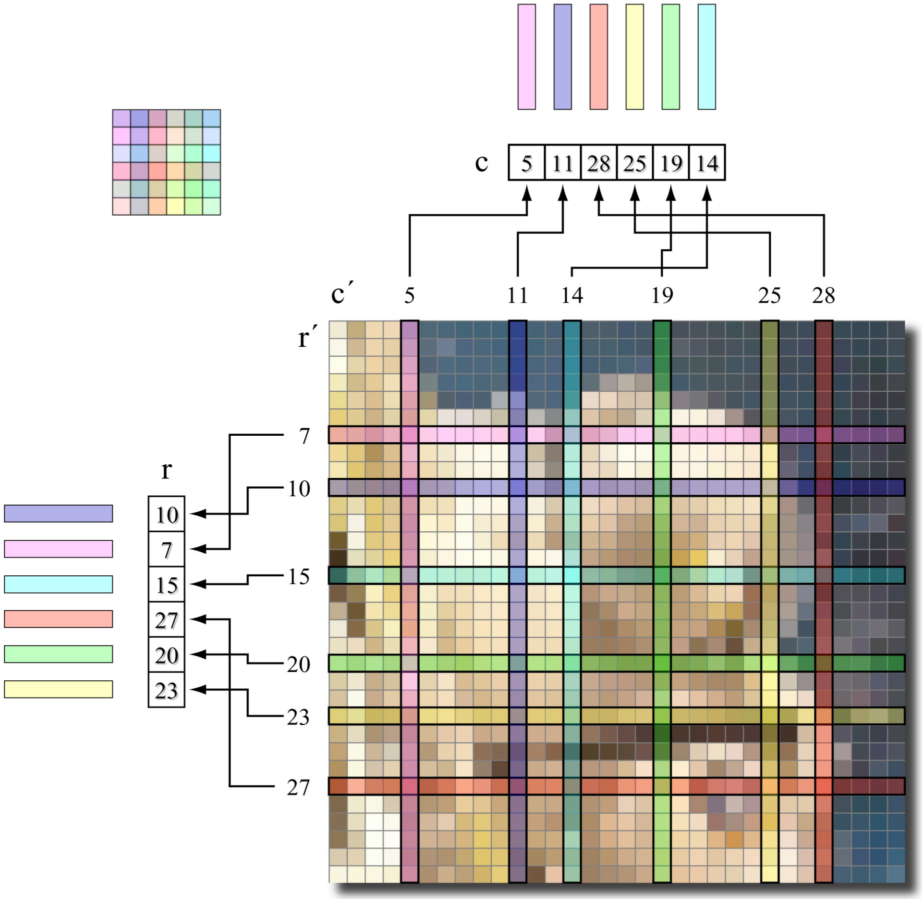
Pixel Indexing in Matlab

Indexing in Matlab is fully general.

If `I` is R x C x B, vectors **r** and **c** can contain any numbers $1 \le r_k \le R$ and $1 \le c_k \le C$.

The numbers can be in any order and can be repeated within **r** and **c.**

The result of `I(r,c)` is an ordinal shuffling of the pixels from I as indexed by **r** and **c**.



Whenever possible, avoid using 'for' loops; vectorize instead.

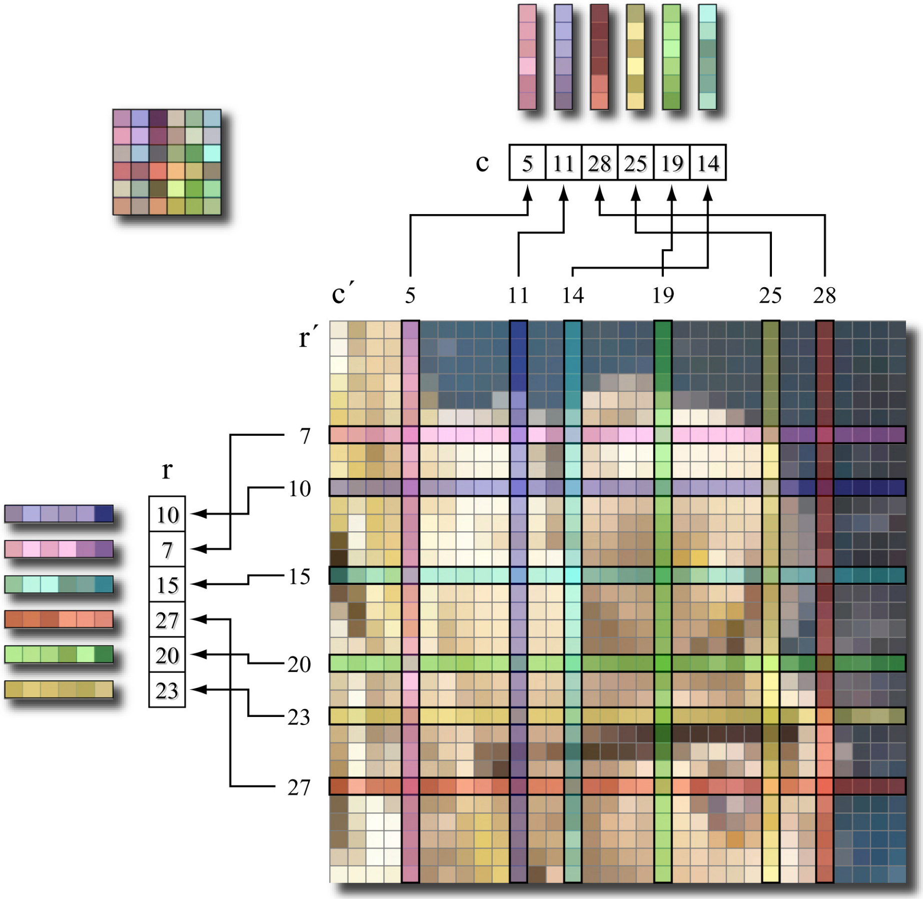
Pixel Indexing in Matlab

Indexing in Matlab is fully general.

If `I` is R x C x B, vectors **r** and **c** can contain any numbers $1 \leq r_k \leq R$ and $1 \leq c_k \leq C$.

The numbers can be in any order and can be repeated within **r** and **c.**

The result of `I(r,c)` is an ordinal shuffling of the pixels from I as indexed by **r** and **c**.



Whenever possible, avoid using 'for' loops; vectorize instead.

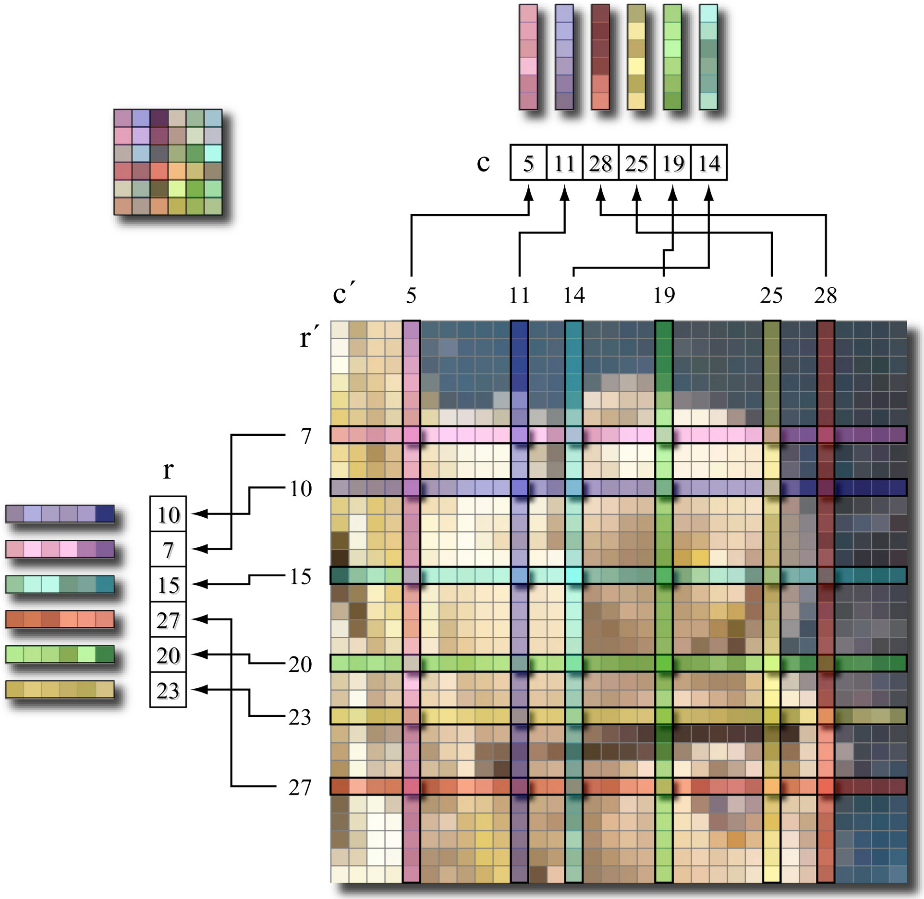
Pixel Indexing in Matlab

Indexing in Matlab is fully general.

If `I` is R x C x B, vectors **r** and **c** can contain any numbers $1 \le r_k \le R$ and $1 \le c_k \le C$.

The numbers can be in any order and can be repeated within **r** and **c.**

The result of `I(r,c)` is an ordinal shuffling of the pixels from I as indexed by **r** and **c**.



Whenever possible, avoid using 'for' loops; vectorize instead.

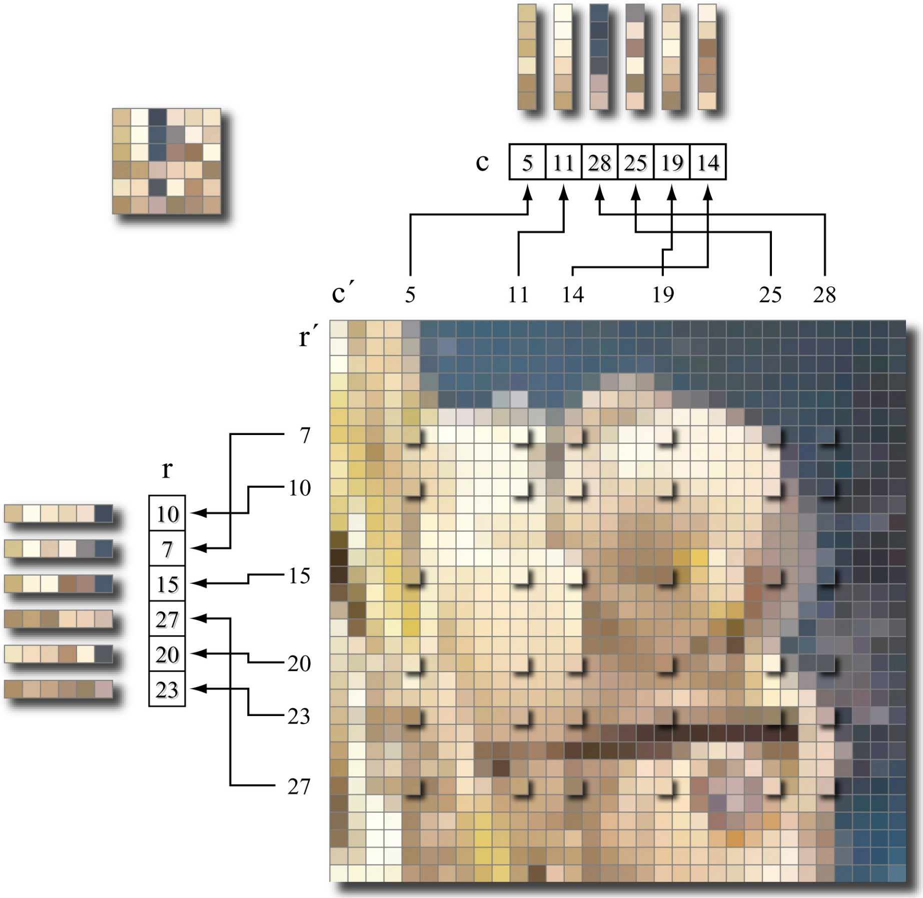
Pixel Indexing in Matlab

Indexing in Matlab is fully general.

If `I` is R x C x B, vectors **r** and **c** can contain any numbers $1 \leq r_k \leq R$ and $1 \leq c_k \leq C$.

The numbers can be in any order and can be repeated within **r** and **c.**

The result of `I(r,c)` is an ordinal shuffling of the pixels from I as indexed by **r** and **c**.



Whenever possible, avoid using 'for' loops; vectorize instead.

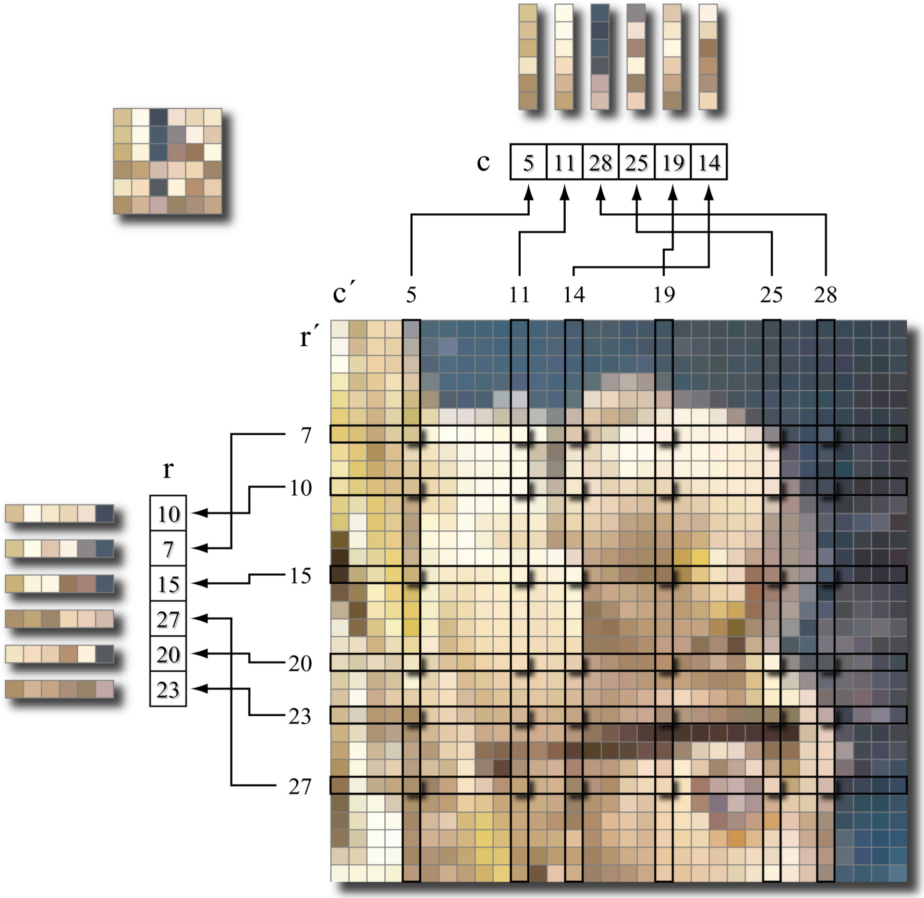
Pixel Indexing in Matlab

Indexing in Matlab is fully general.

If `I` is R x C x B, vectors **r** and **c** can contain any numbers $1 \le r_k \le R$ and $1 \le c_k \le C$.

The numbers can be in any order and can be repeated within **r** and **c.**

The result of `I(r,c)` is an ordinal shuffling of the pixels from I as indexed by **r** and **c**.



Whenever possible,
avoid using 'for' loops;
vectorize instead.

Pixel Indexing in Matlab

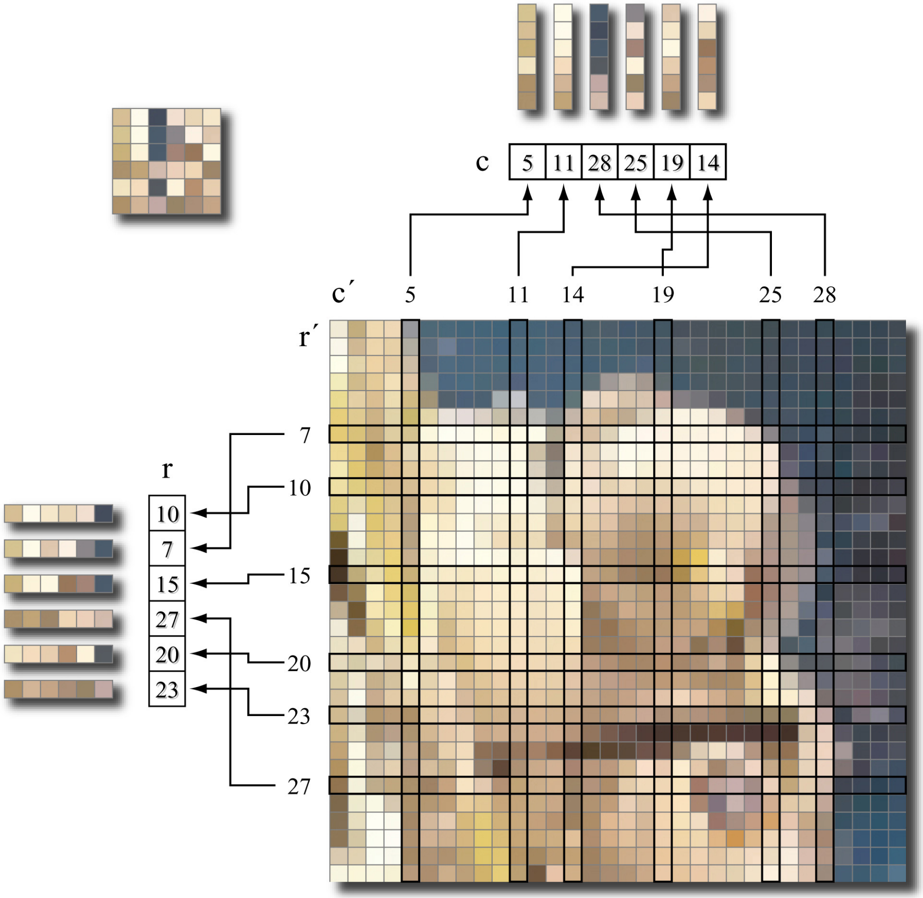
Indexing in Matlab is fully general.

If `I` is R x C x B, vectors **r** and **c** can contain any numbers $1 \leq r_k \leq R$ and $1 \leq c_k \leq C$.

The numbers can be in any order and can be repeated within **r** and **c.**

The result of `I(r,c)` is an ordinal shuffling of the pixels from I as indexed by **r** and **c**.

Whenever possible, avoid using 'for' loops; vectorize instead.


c
5
11
28
25
19
14
c′
5
11
14
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