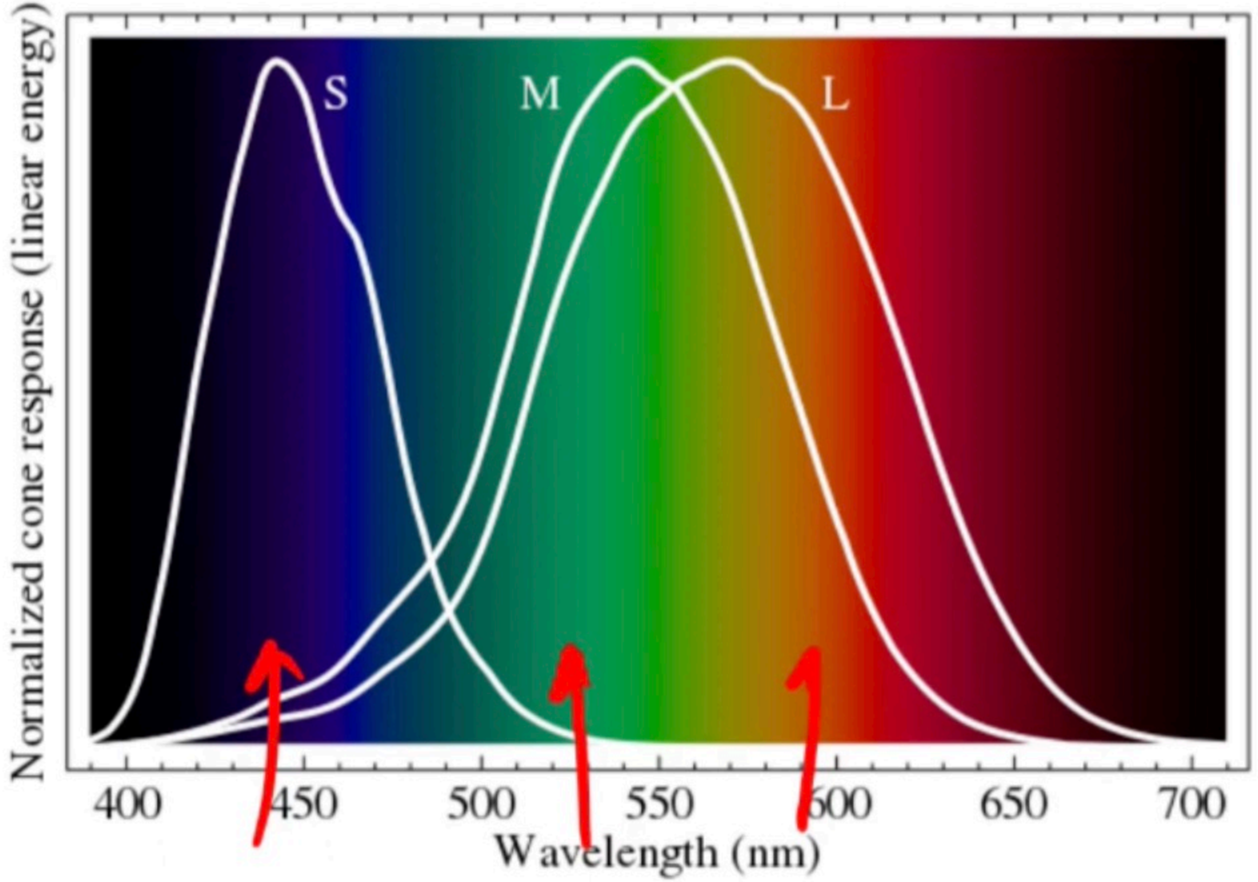
On Colour

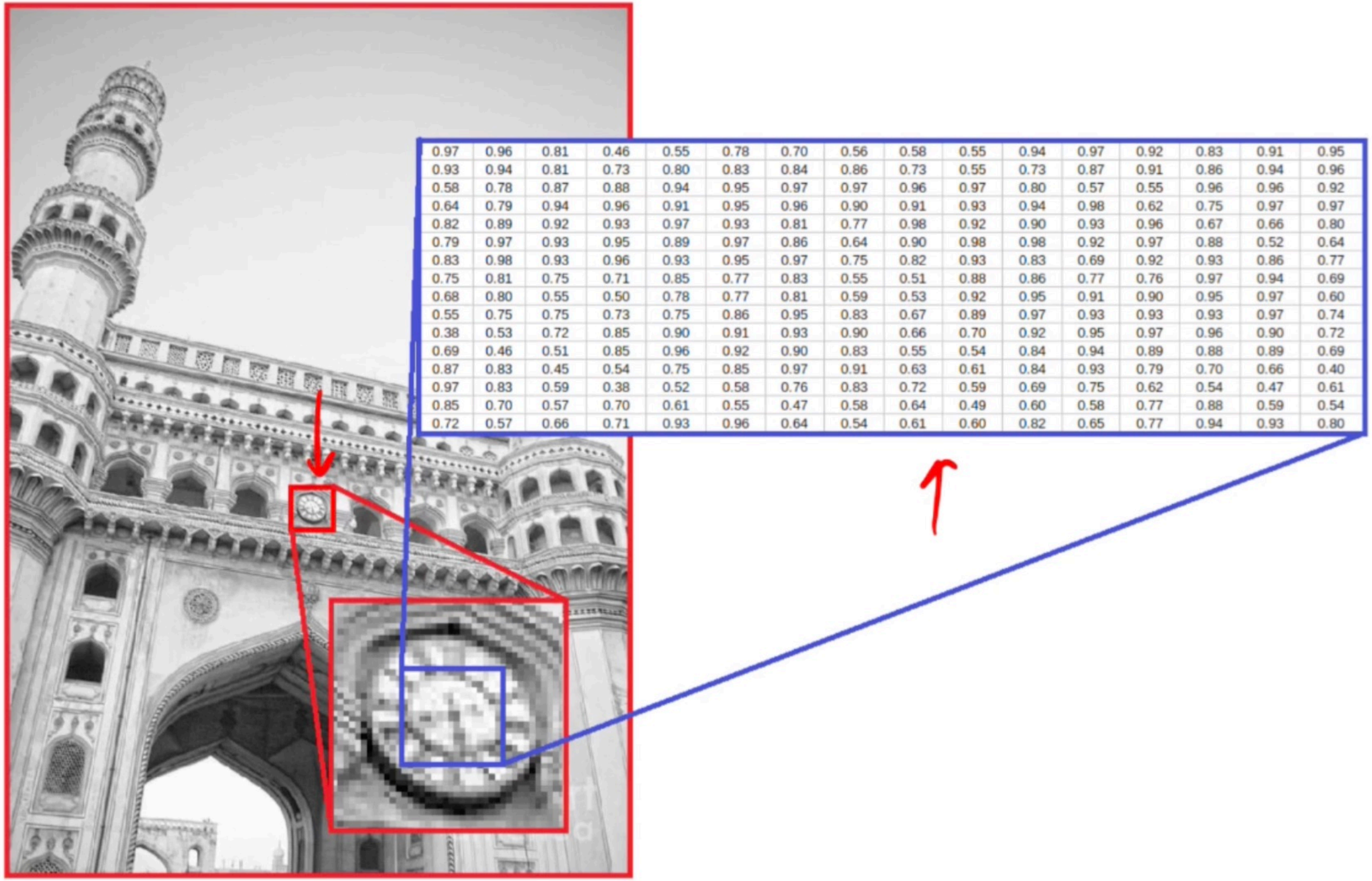
If visible light spectrum is VIBGYOR, why RGB colour representation?



Credit: Derek Hoiem, UIUC

- Long (red), Medium (green), and Short (blue) cones, plus intensity rods
- Fun facts
  - "M" and "L" on the X-chromosome $\Longrightarrow$ men are more likely to be colour blind!
  - Some animals have 1 (night animals), 2 (e.g., dogs), 4 (fish, birds), 5 (pigeons, some reptiles/amphibians), or even 12 (mantis shrimp) types of cones

Image as a Matrix

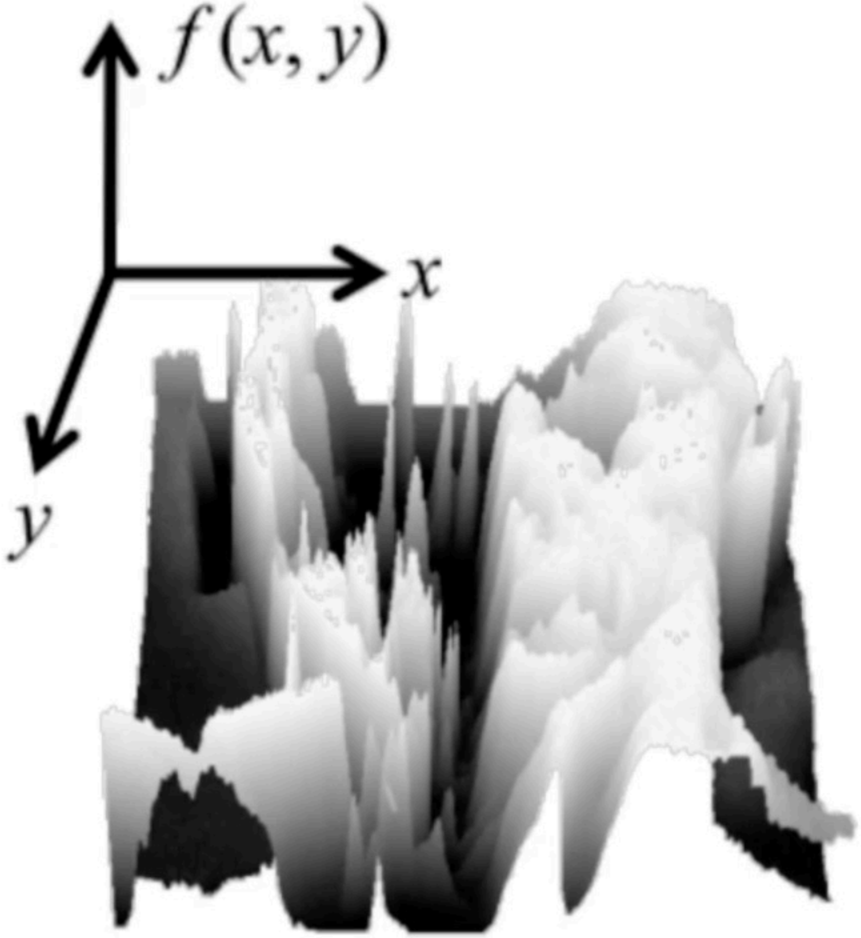


0.97	0.96	0.81	0.46	0.55	0.78	0.70	0.56	0.58	0.55	0.94	0.97	0.92	0.83	0.91	0.95
0.93	0.94	0.81	0.73	0.80	0.83	0.84	0.86	0.73	0.55	0.73	0.87	0.91	0.86	0.94	0.96
0.58	0.78	0.87	0.88	0.94	0.95	0.97	0.97	0.96	0.97	0.80	0.57	0.55	0.96	0.96	0.92
0.64	0.79	0.94	0.96	0.91	0.95	0.96	0.90	0.91	0.93	0.94	0.98	0.62	0.75	0.97	0.97
0.82	0.89	0.92	0.93	0.97	0.93	0.81	0.77	0.98	0.92	0.90	0.93	0.96	0.67	0.66	0.80
0.79	0.97	0.93	0.95	0.89	0.97	0.86	0.64	0.90	0.98	0.98	0.92	0.97	0.88	0.52	0.64
0.83	0.98	0.93	0.96	0.93	0.95	0.97	0.75	0.82	0.93	0.83	0.69	0.92	0.93	0.86	0.77
0.75	0.81	0.75	0.71	0.85	0.77	0.83	0.55	0.51	0.88	0.86	0.77	0.76	0.97	0.94	0.69
0.68	0.80	0.55	0.50	0.78	0.77	0.81	0.59	0.53	0.92	0.95	0.91	0.90	0.95	0.97	0.60
0.55	0.75	0.75	0.73	0.75	0.86	0.95	0.83	0.67	0.89	0.97	0.93	0.93	0.93	0.97	0.74
0.38	0.53	0.72	0.85	0.90	0.91	0.93	0.90	0.66	0.70	0.92	0.95	0.97	0.96	0.90	0.72
0.69	0.46	0.51	0.85	0.96	0.92	0.90	0.83	0.55	0.54	0.84	0.94	0.89	0.88	0.89	0.69
0.87	0.83	0.45	0.54	0.75	0.85	0.97	0.91	0.63	0.61	0.84	0.93	0.79	0.70	0.66	0.40
0.97	0.83	0.59	0.38	0.52	0.58	0.76	0.83	0.72	0.59	0.69	0.75	0.62	0.54	0.47	0.61
0.85	0.70	0.57	0.70	0.61	0.55	0.47	0.58	0.64	0.49	0.60	0.58	0.77	0.88	0.59	0.54
0.72	0.57	0.66	0.71	0.93	0.96	0.64	0.54	0.61	0.60	0.82	0.65	0.77	0.94	0.93	0.80

- Common to use one byte per value: 0 = black, 255 = white
- One such matrix for every channel in colour images

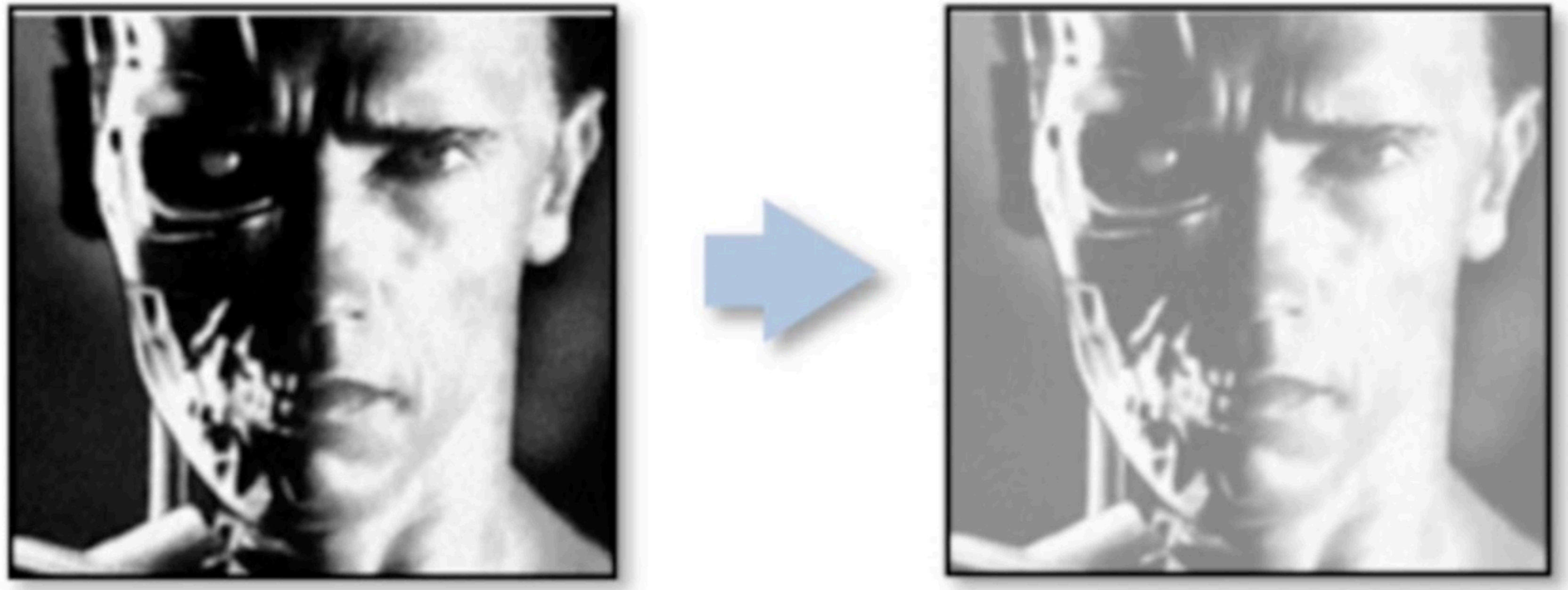
Image as a Function

- We can think of a (grayscale) image as a function $f : \mathbb{R}^2 \to \mathbb{R}$, giving the intensity at position (x, y)
- A digital image is a discrete (sampled, quantized) version of this function



Credit: Noah Snavely, Cornell Univ

Image Transformations

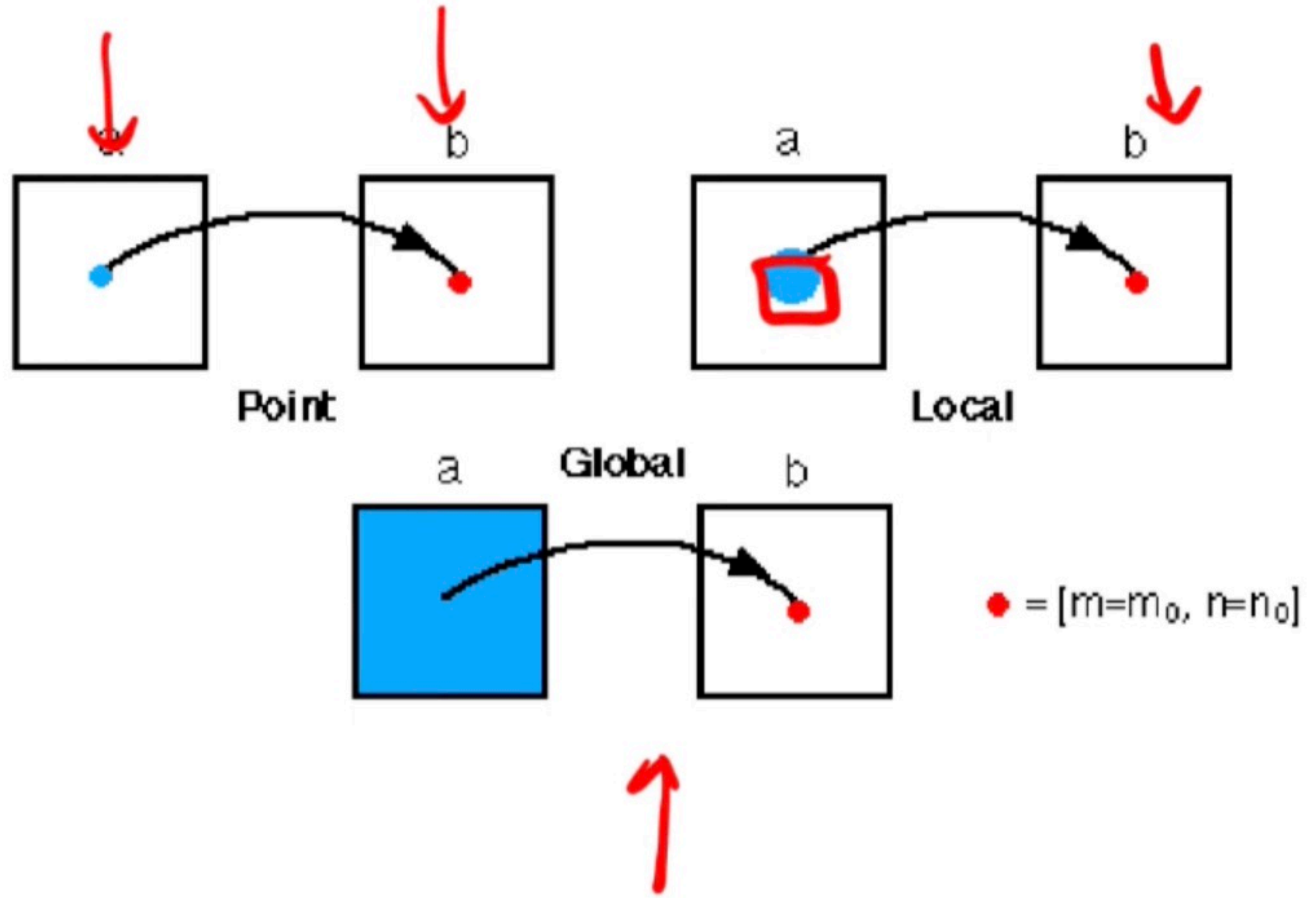


$$\hat{I}(x, y) = I(x, y) + 20$$

$$\hat{I}(x, y) = I(-x, y)$$

Image Processing Operations

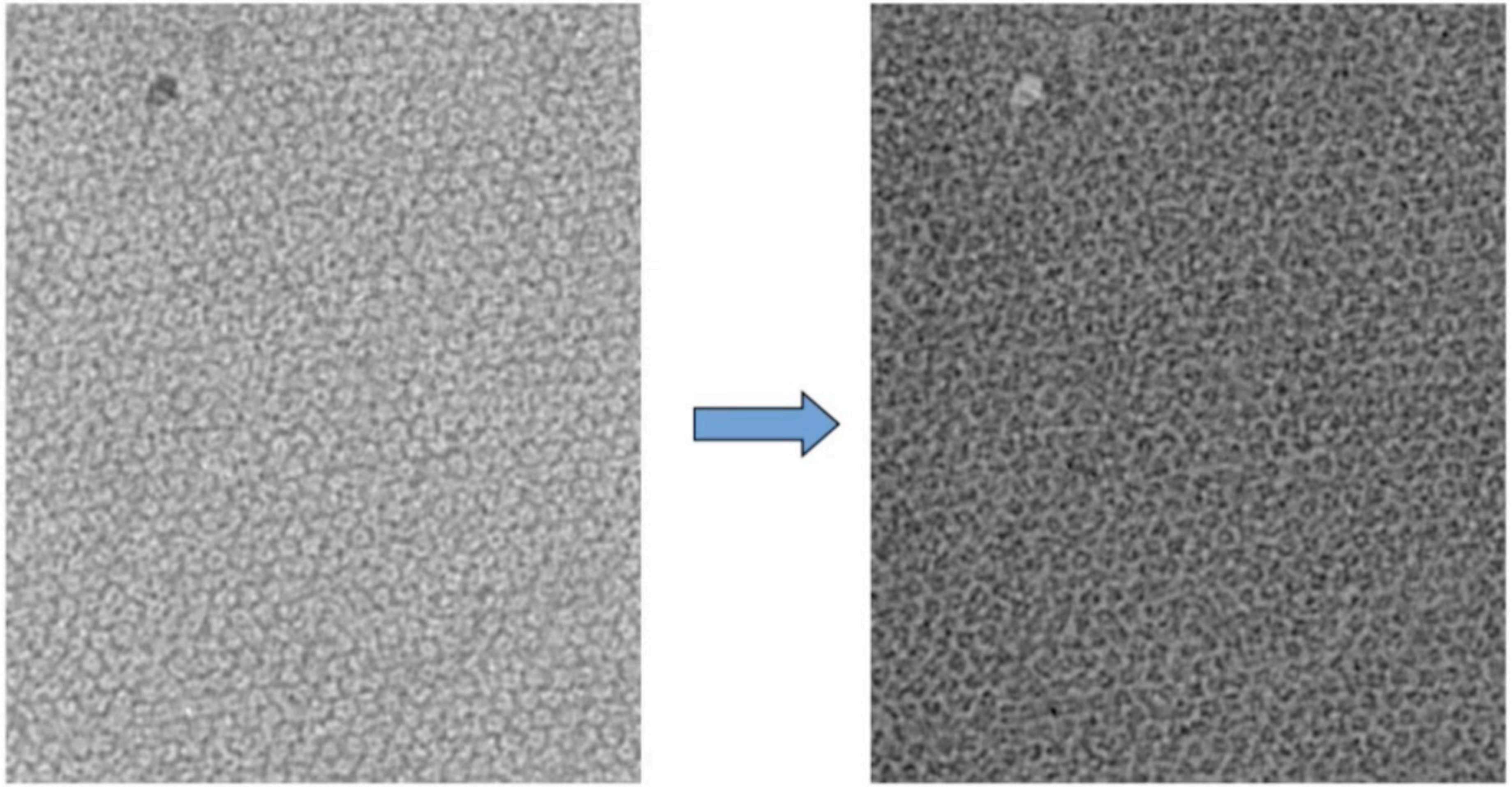
- Point Operations
  - Output value at (m_0, n_0) is dependent only on the input value at the same coordinate
  - *Complexity/pixel:* Constant
- Local Operations
  - Output value at (m_0, n_0) is dependent on input values in a $\boxed{p \times p}$ neighborhood of that same coordinate
  - *Complexity/pixel:* p^2
- Global Operations
  - Output value at (m_0, n_0) is dependent on on all the values in the input $N \times N$ image
  - *Complexity/pixel:* N^2



Point Operations: Example

- Image Enhancement:
  Reversing the contrast

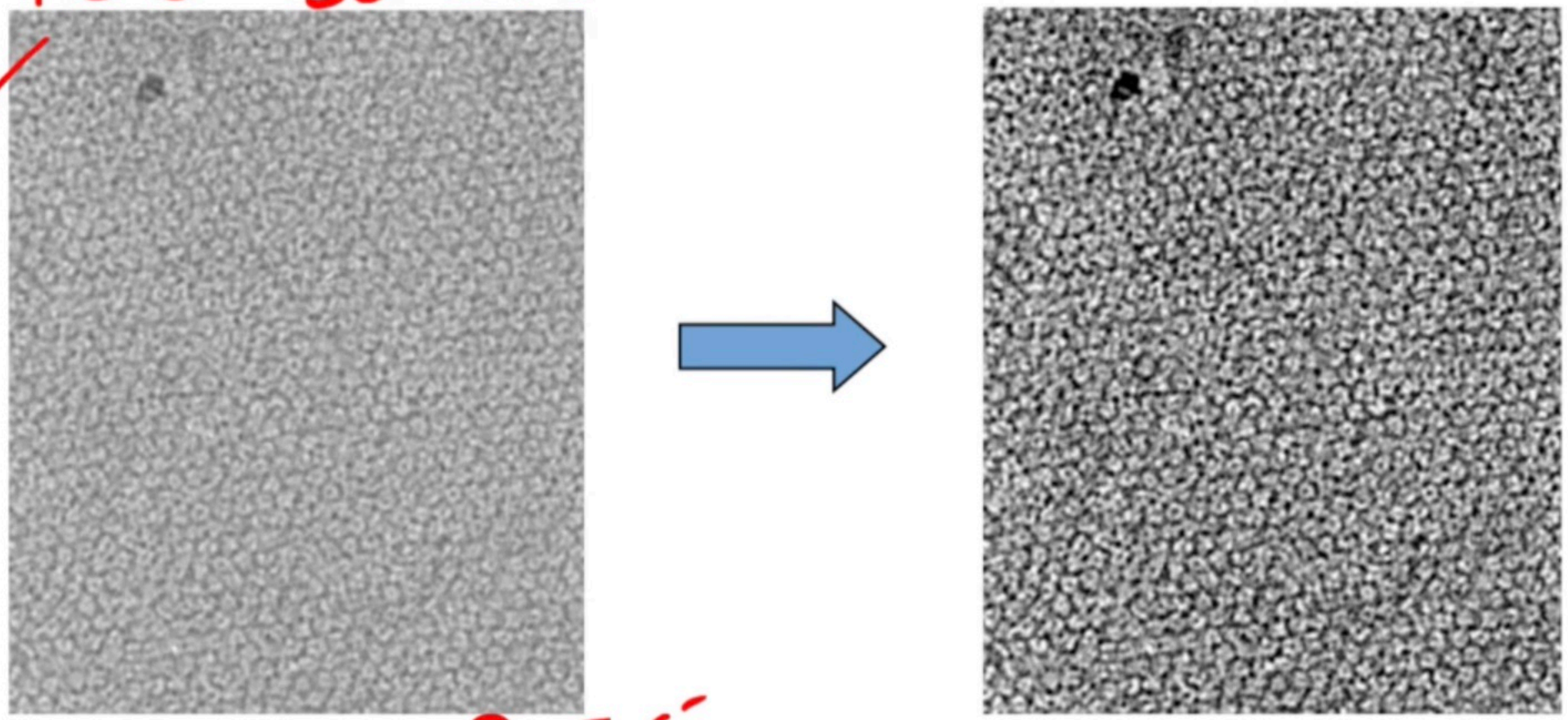
- How?



$$\hat{I}(m_0, n_0) = \overset{255}{I_{MAX}} - I(m_0, n_0) + \overset{0}{I_{MIN}}$$

Point Operations: Another Example

100 150 200



- Image Enhancement: Stretching the contrast
- How?

2.55

Linear Contrast Stretching

$$\hat{I}(m_0, n_0) = \left(I(m_0, n_0) - \min_{x,y} I(x,y) \right) * \left(\overbrace{(I_{MAX} - I_{MIN}) / (\max_{x,y} I(x,y) - \min_{x,y} I(x,y))}^{2.55} \right) + \overset{0}{I_{MIN}}$$

How Useful are Point Operations?

- A single point (or pixel)'s intensity is influenced by multiple factors, and may not tell us everything
  - Light source strength and direction
  - Surface geometry, material and nearby surfaces
  - Sensor capture properties
  - Image representation and colour
- Given a camera and a still scene, how do you reduce noise using point operations?
- Take many images, and average them!
- You need local operations otherwise. What is the local operation?

Local Operation Examples: Moving Average

3

I

3

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	0	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	0	0	0	0	0	0	0
0	0	90	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

	0								

Credit: Steve Seitz, Univ of Washington

Local Operation Examples: Moving Average

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	0	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	0	0	0	0	0	0	0
0	0	90	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

	0	10	20						

Credit: Steve Seitz, Univ of Washington

Local Operation Examples: Moving Average

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	0	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	0	0	0	0	0	0	0
0	0	90	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

	0	10	20	30	30	30	20	10	
	0	20	40	60	60	60	40	20	
	0	30	60	90	90	90	60	30	
	0	30	50	80	80	90	60	30	
	0	30	50	80	80	90	60	30	
	0	20	30	50	50	60	40	20	
	10	20	30	30	30	30	20	10	
	10	10	10	0	0	0	0	0	

Credit: Steve Seitz, Univ of Washington

Local Operation Examples: Moving Average

$$\hat{I}(x,y) = \sum_{i=x-k}^{x+k} \sum_{j=y-k}^{y+k} I(i,j) * \frac{1}{(2k+1)^2}$$

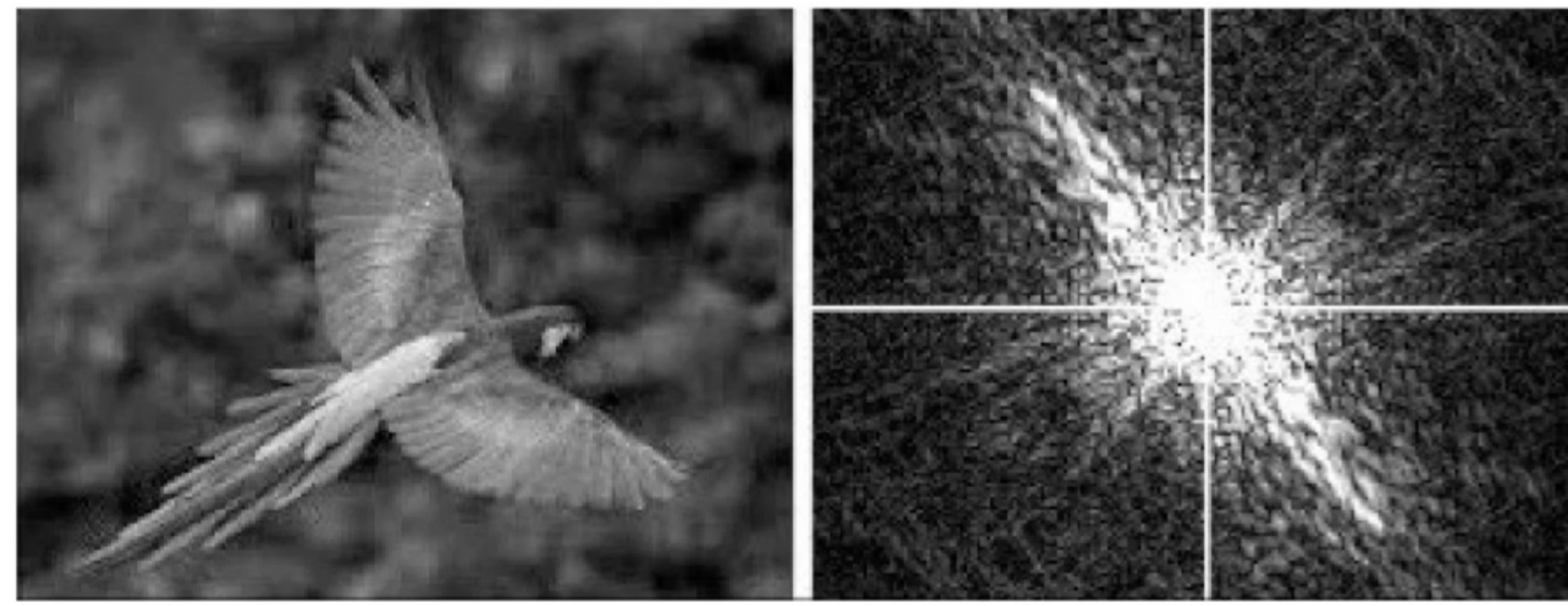
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	90	~~0~~	90	90	90	0	0
0	0	0	90	90	90	90	90	0	0
0	0	0	0	0	0	0	0	0	0
0	0	~~90~~	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

	0	10	20	30	30	30	20	10	
	0	20	40	60	60	60	40	20	
	0	30	60	90	90	90	60	30	
	0	30	50	80	80	90	60	30	
	0	30	50	80	80	90	60	30	
	0	20	30	50	50	60	40	20	
	10	20	30	30	30	30	20	10	
	10	10	10	0	0	0	0	0	

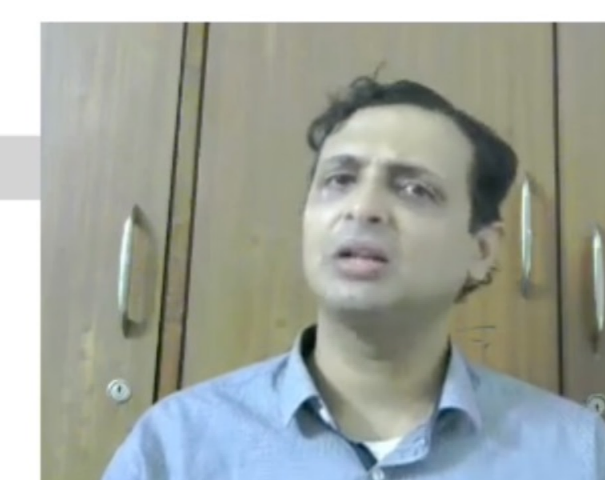
Credit: Steve Seitz, Univ of Washington

Global Operations: Examples

- Image coordinate transformations, e.g. Fourier transform
- We will see more of this later



Credit: Mathworks MATLAB Toolbox



this what is known as a Fourier transform we will
see this in a slightly later lecture but there are