# Bitmapped Images

## Multimedia Techniques & Applications

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# Outline

- Overview
- Image compression
- Image manipulation
- Geometrical transformations

# Overview

- Record the value of every pixel in the image
- **Image size** is the main cost for the simplicity

- Images created from external devices are usually in a bitmapped fashion
  - Digital cameras
  - Scanners


digital camera


scanner

# Resolution

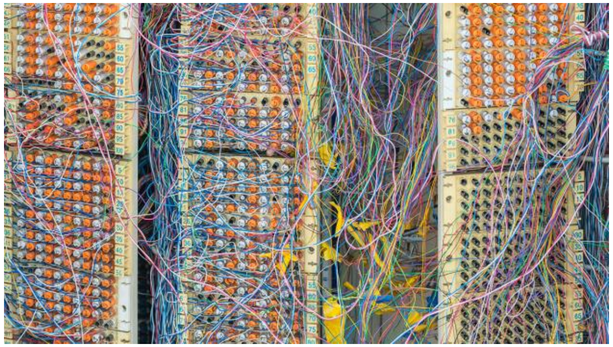
- A measure of **how finely** a device approximates continuous images using finite pixels
  - Closely related to sampling rates
- Two ways of specifying resolution
  - **Printers and scanners: number of dots per unit**
    - Dots per inch (dpi)
    - Ex: consumer printer (600 dpi), book production (1200 – 2700 dpi), scanners (300 dpi – 3600 dpi)
  - **Video: size of a frame measured in pixels**
    - Ex: 640 x 480, 768 x 576
    - Can translate into the form of dpi if you know the physical dimension of the display device

# Image Compression

# Image Compression

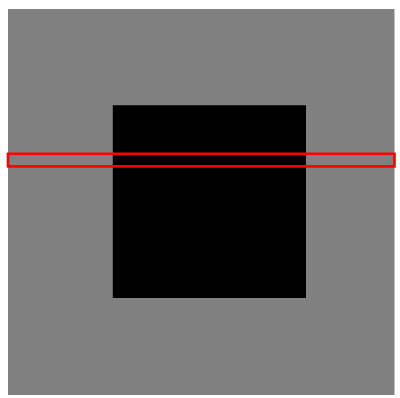
- **Motivation**
  - Faithfully store all pixel values of an image takes lots of memory space
  - Human eyes can tolerate some minor errors in images
    - Digital representation is an approximation itself

- **Assumption**
  - Images are usually **smooth** and have some **spatial coherence**



# Compression Methods

- Spend some computation efforts to earn saving in space
- The effectiveness depends on the content of the compressed image
  - **Image size can become bigger after applying compression**
  - Definitely true, otherwise, any data can be compressed into one byte

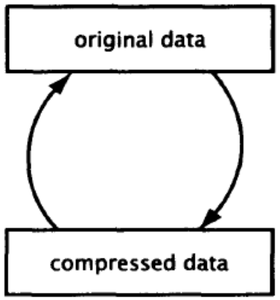


128 bytes ➔ 6 bytes
for a row (RLE)

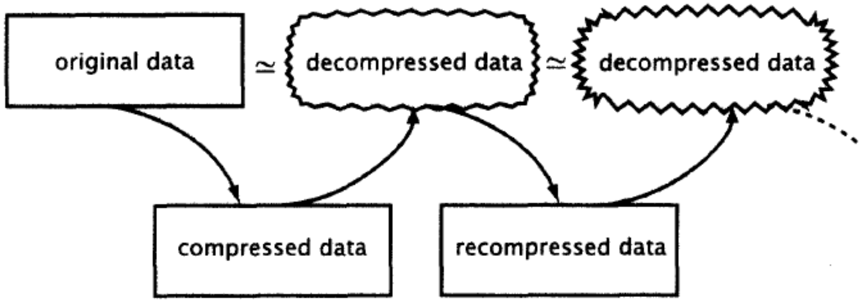
128 bytes ➔256 bytes
for a row (RLE)

# Compression Methods (cont.)

- **Lossless compression**
  - No information will lose during a compression/decompression cycle
  - Ex: run-length encoding (RLE),
    variable-length coding

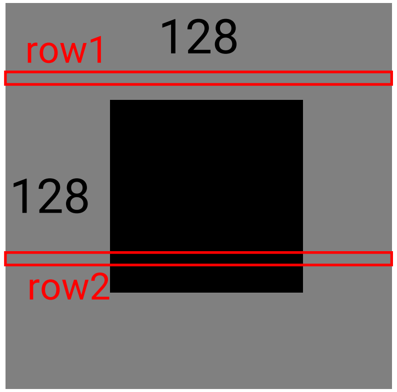



- **Lossy compression**
  - Discard some information during the compression process and the information can **never** be recovered
  - Ex: JPEG



# Run-Length Encoding (RLE)

- The simplest compression technique
- Each time store a value, followed by a **count** to indicate a number of consecutive pixels of that value
- Example
  - RLE for row1: *128 128*
    - 128 bytes (raw) v.s. **2 bytes** (using short)
  - RLE for row2: *128 32 0 64 128 32*
    - 128 bytes (raw) v.s. **6 bytes** (using short)



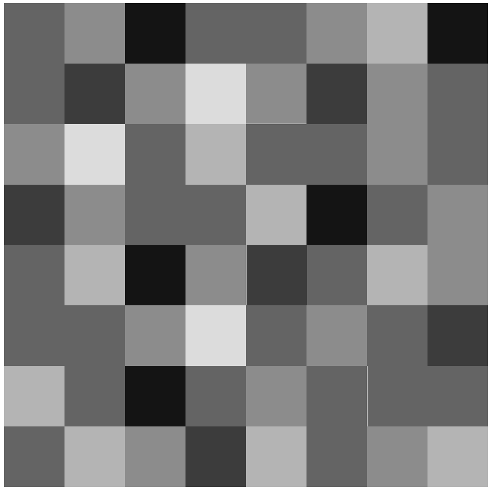
# Huffman Coding

- The best-known variable length coding
- **Lossless** compression
- Example:

Assume an 8 x 8 image containing 6 different pixel intensities

We can count their occurrence:

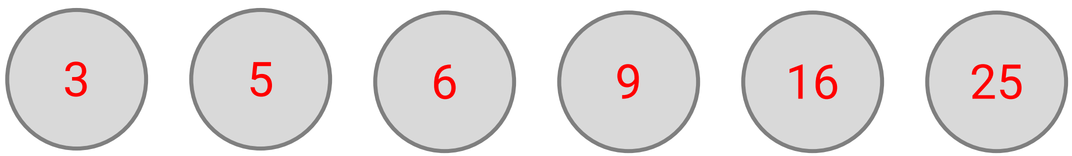
| intensity | 20 | 60 | 100 | 140 | 180 | 220 |
|---|---|---|---|---|---|---|
| occurrence | 5 | 6 | 25 | 16 | 9 | 3 |



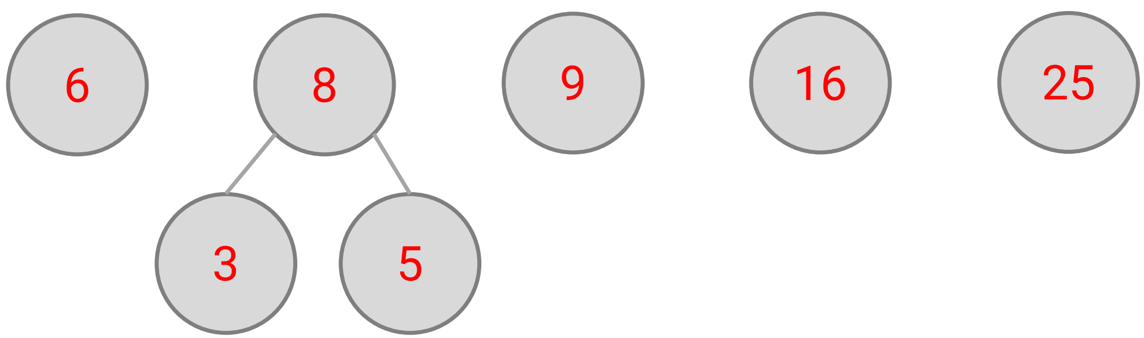
# Huffman Coding (cont.)

- **Algorithm**
  - Build a Huffman tree
    - Sort the occurrence of intensity

| | | | | | |
|---|---|---|---|---|---|
| 20 | 60 | 100 | 140 | 180 | 220 |
| 5 | 6 | 25 | 16 | 9 | 3 |



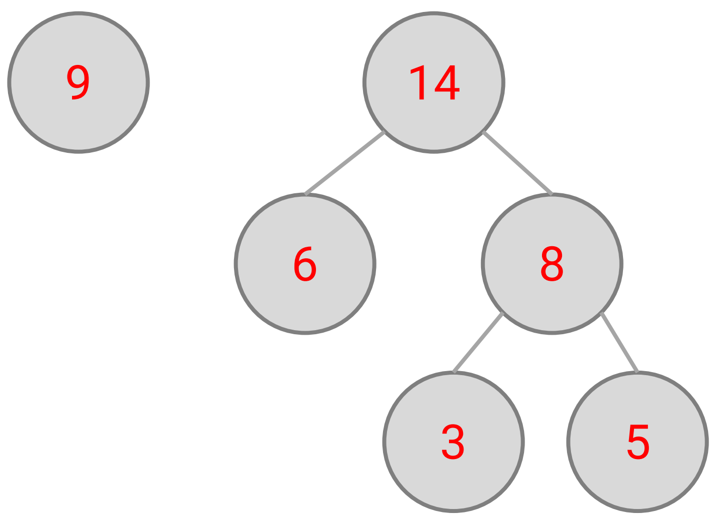

    - Merge the two with the smallest occurrence, and sort again



# Huffman Coding (cont.)

- **Algorithm**
  - Build a Huffman tree
    - Keep doing …

| | | | | | |
|---|---|---|---|---|---|
| 20 | 60 | 100 | 140 | 180 | 220 |
| 5 | 6 | 25 | 16 | 9 | 3 |



# Huffman Coding (cont.)

- **Algorithm**
  - Build a Huffman tree
    - Keep doing …

| | | | | | |
|---|---|---|---|---|---|
| 20 | 60 | 100 | 140 | 180 | 220 |
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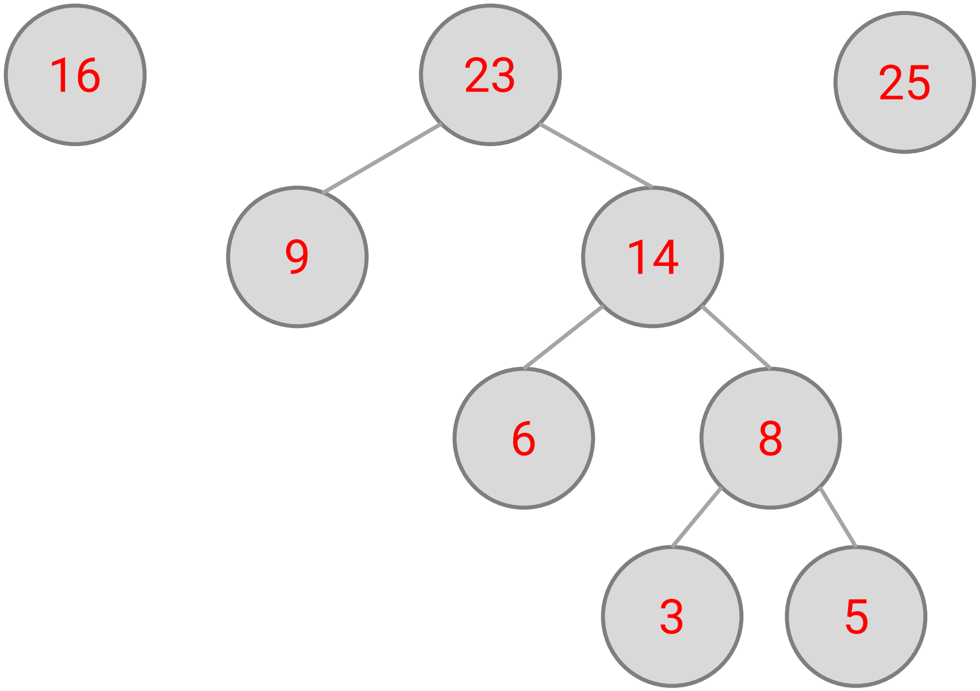
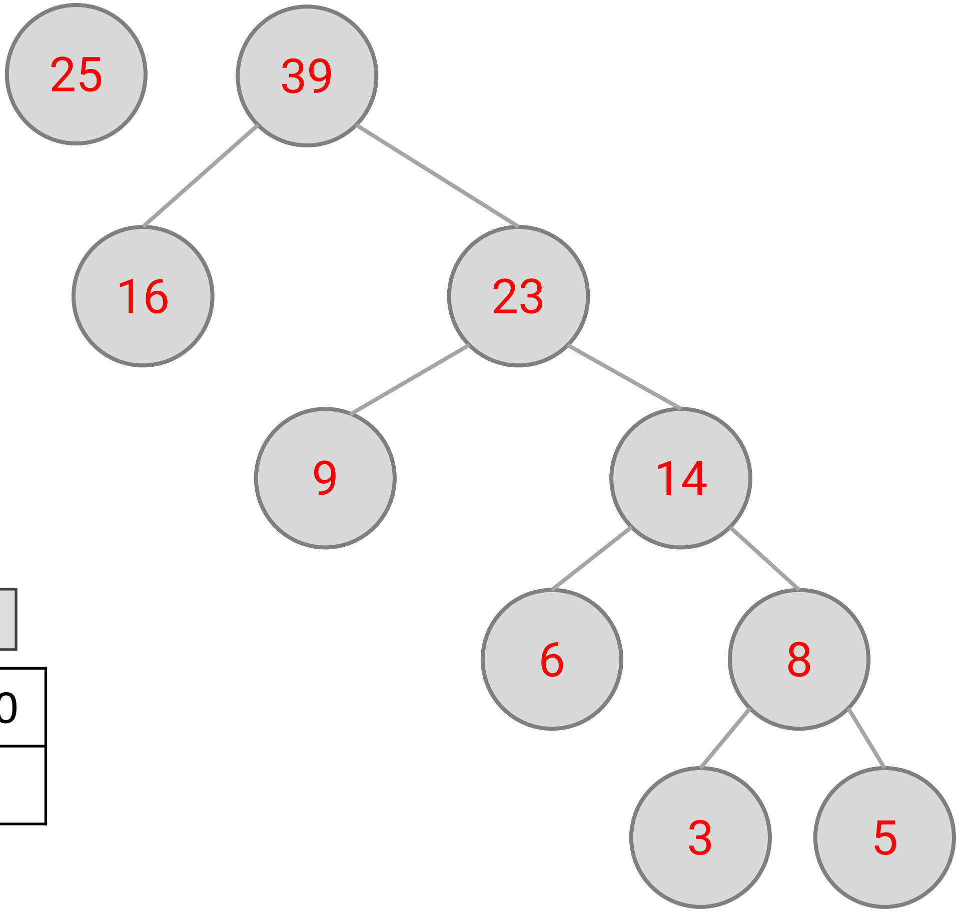


# Huffman Coding (cont.)

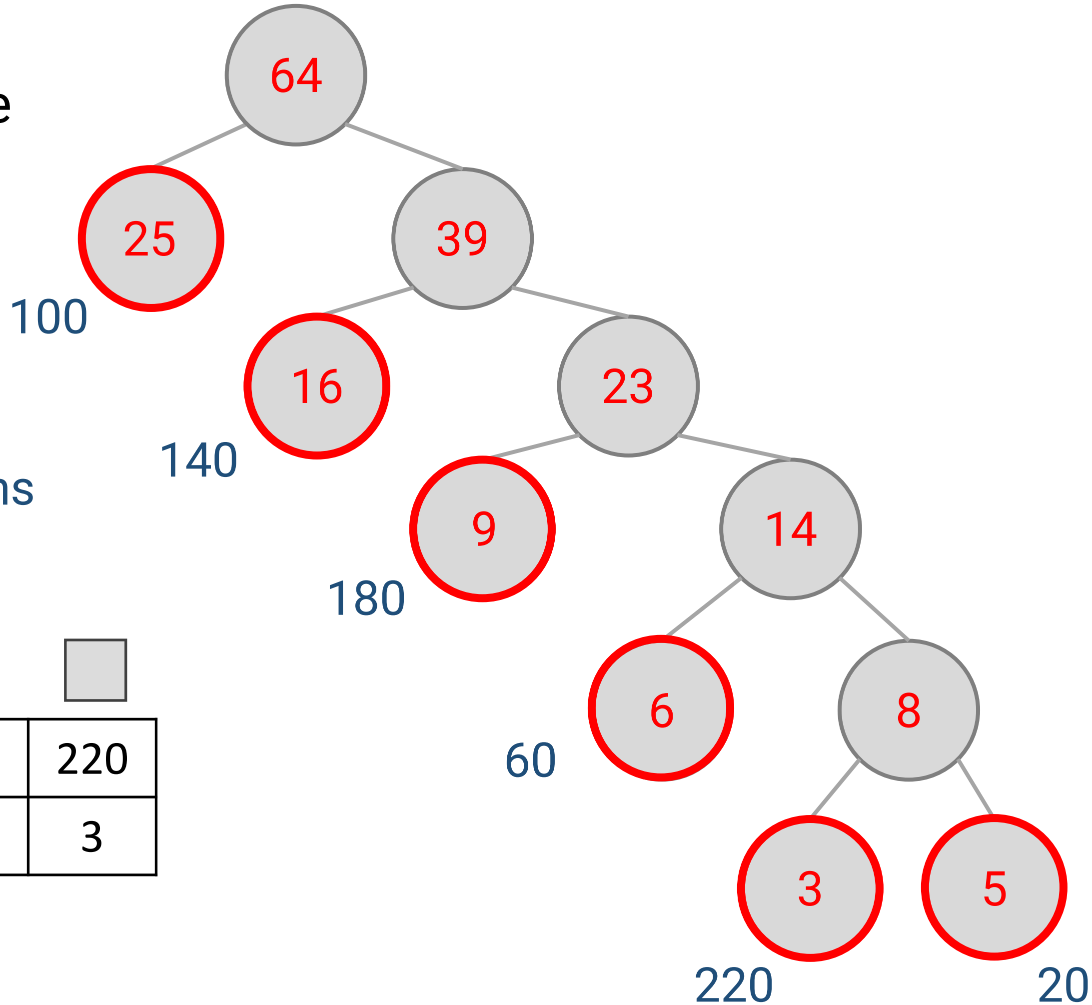
- **Algorithm**
  - Build a Huffman tree
    - Keep doing …




| | | | | | |
|---|---|---|---|---|---|
| 20 | 60 | 100 | 140 | 180 | 220 |
| 5 | 6 | 25 | 16 | 9 | 3 |

# Huffman Coding (cont.)

- **Algorithm**
  - Build a Huffman tree
    - Keep doing …

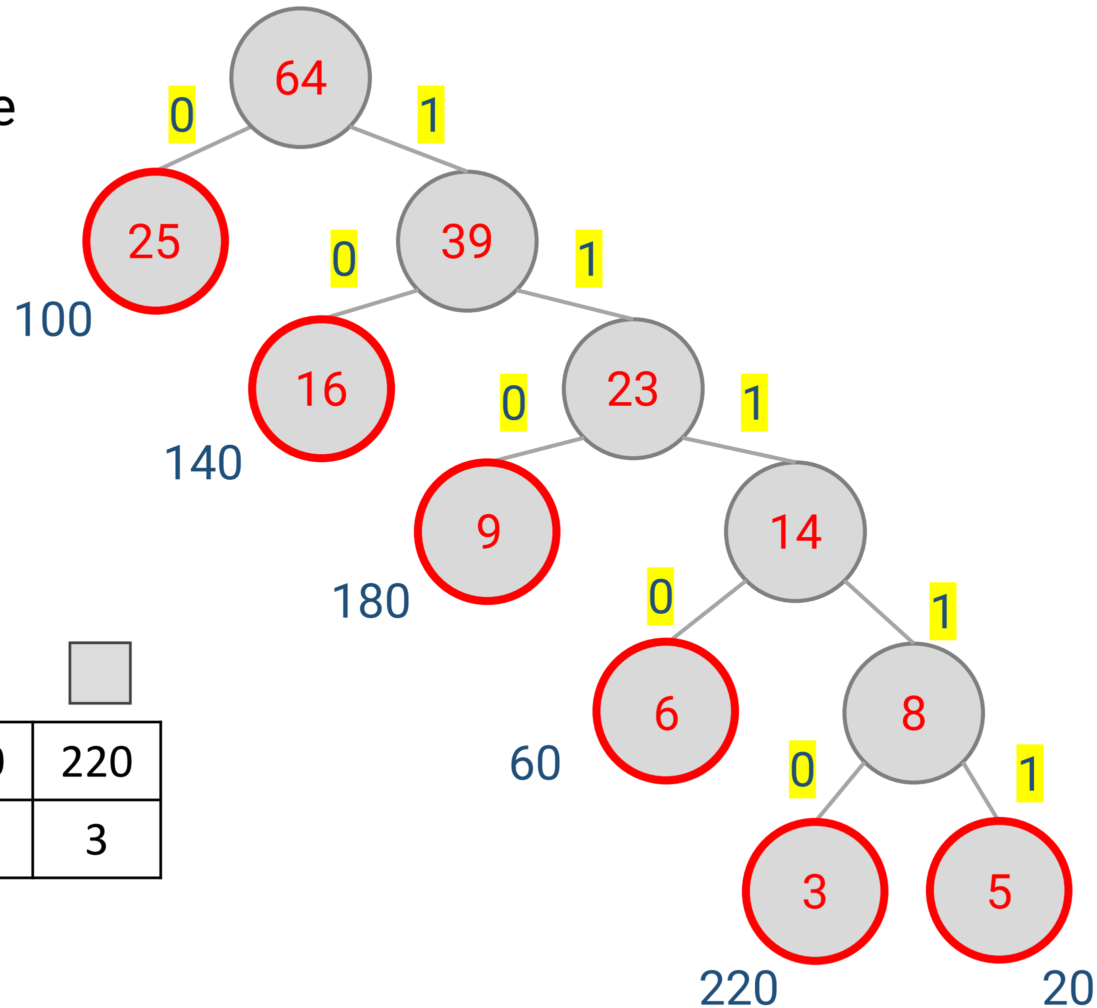



Once we have done, the leaf nodes are the initial data items

| | | | | | |
|---|---|---|---|---|---|
| 20 | 60 | 100 | 140 | 180 | 220 |
| 5 | 6 | 25 | 16 | 9 | 3 |

# Huffman Coding (cont.)

- **Algorithm**
  - Build a Huffman tree
  - Label the code (from root)




| 20 | 60 | 100 | 140 | 180 | 220 |
|---|---|---|---|---|---|
| 5 | 6 | 25 | 16 | 9 | 3 |

# Huffman Coding (cont.)

- **Algorithm**
  - Build a Huffman tree
  - Label the code (from root)
  - We will obtain

    100: 0

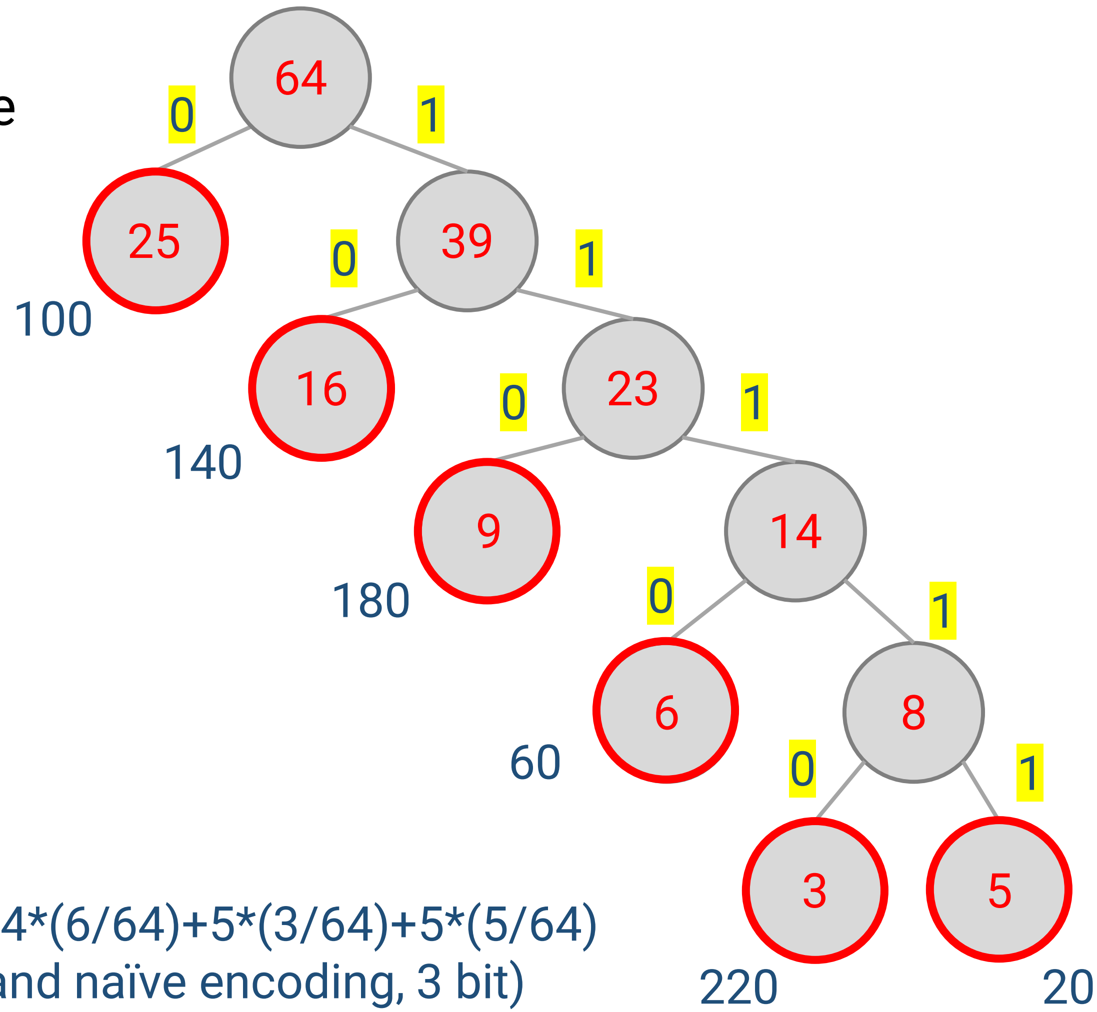
    140: 10

    180: 110

    60: 1110

    220: 11110

    20: 11111

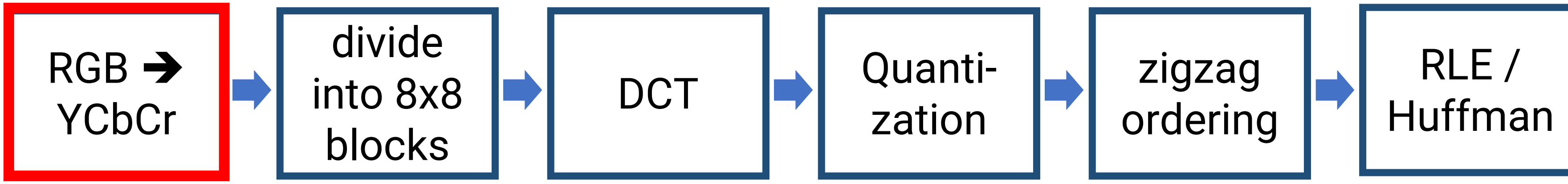



Average number of bit per data:
1*(25/64)+2*(16/64)+3*(9/64)+4*(6/64)+5*(3/64)+5*(5/64)
= **2.31** (compared to raw, 8 bit, and naïve encoding, 3 bit)

# JPEG Compression

- JPEG is the most important **lossy** compression technique, which stands for ***Joint Photographic Experts Group***
    - Related file formats: *.jpg / *.jpeg / *.jpe / *.jfif / *.jfi / *.jif
- It works because image data can tolerate a certain amount of data loss

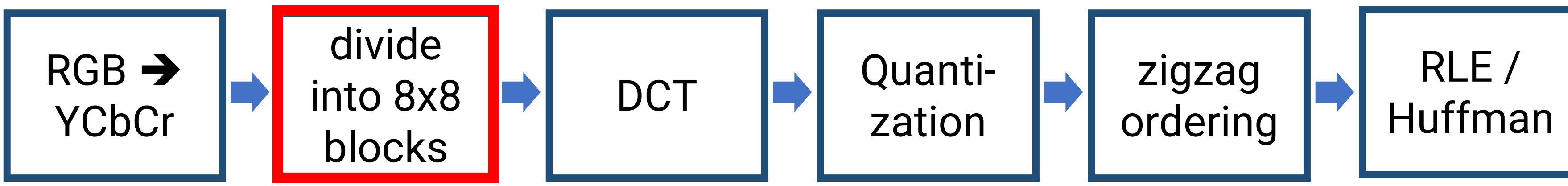
# JPEG Compression (cont.)



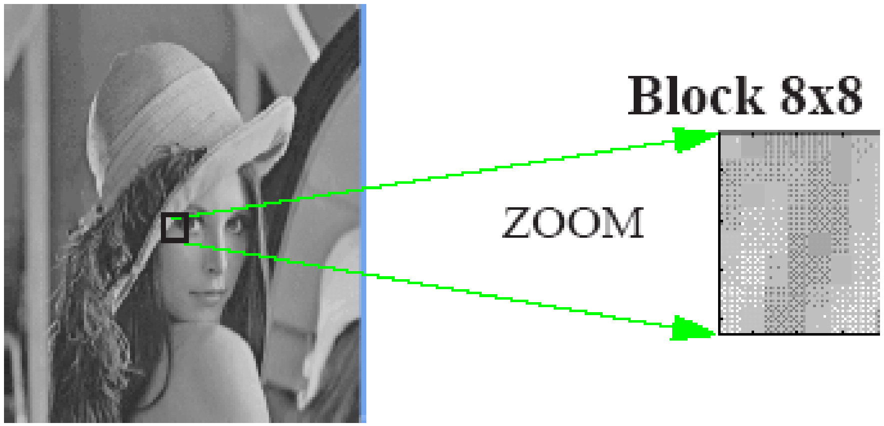

- **RGB → YCbCr**
  - People are more sensitive to intensity (Y) and less sensitive to color (Cb, Cr)
  - Cb and Cr are lower frequency and have more spatial coherence
  - Compress Cb and Cr; while keep Y as it is

RGB Y Cb Cr

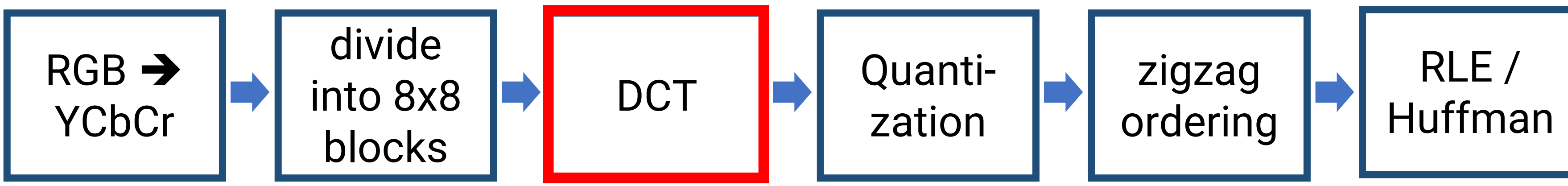
# JPEG Compression (cont.)




- **Divide into 8x8 blocks (for Cb & Cr)**
  - The entire image is too difficult to compress
  - Small image block has higher coherence

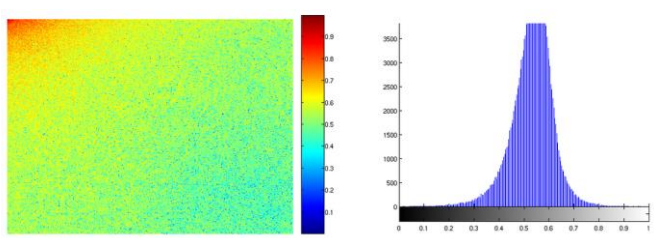


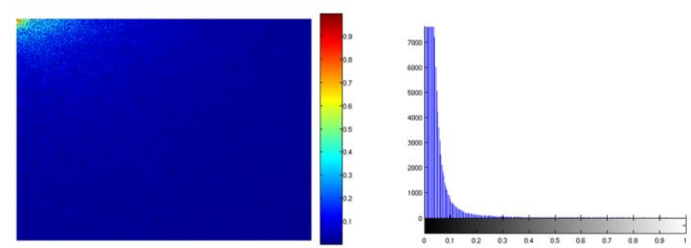
# JPEG Compression (cont.)



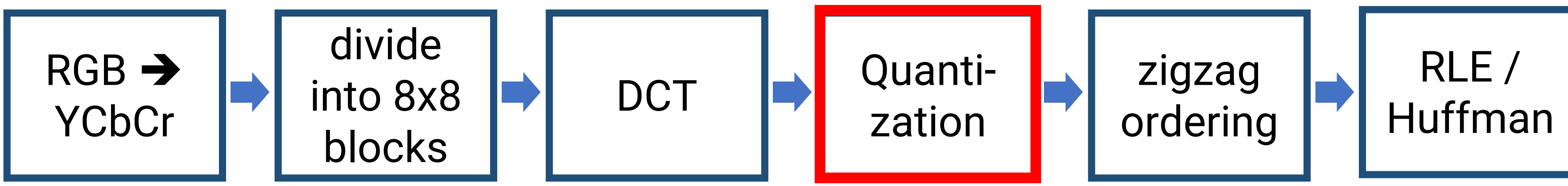

- **Discrete Cosine Transform (DCT)**
  - A method for transforming a waveform into its frequency domain
  - The DCT of an image block is the coefficients of different cosines of the image block


image


DFT result

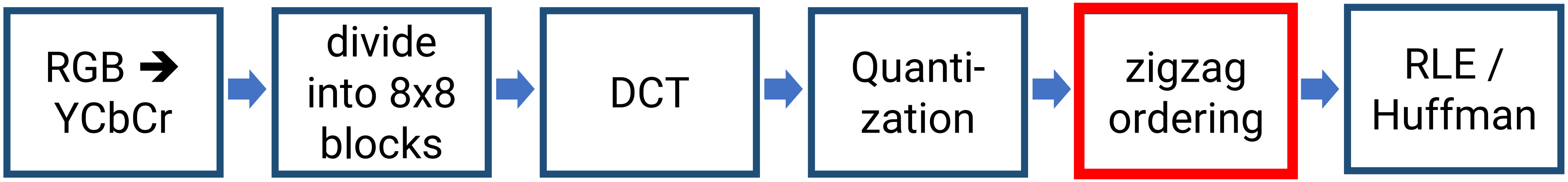

DCT result

# JPEG Compression (cont.)

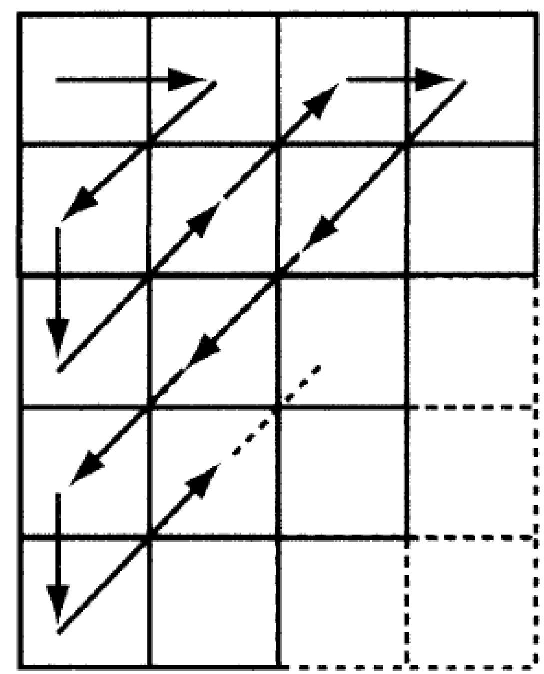



- **Quantization**
  - Human are less sensitive to high-frequency signal
  - Use fewer bits for high-frequency signals in the DCT result and vice versa
  - **This step is the reason of lossy compression**
  - After this step, many components will end up with zero coefficients

# JPEG Compression (cont.)



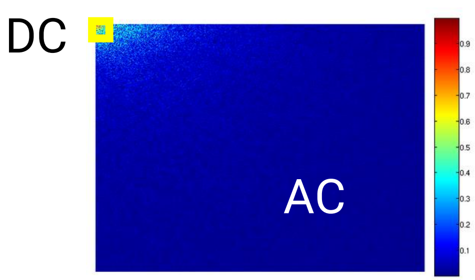

- **Zigzag ordering**
  - For later Huffman encoding
  - Result in a longer zero sequence



# JPEG Compression (cont.)

RGB ➔ YCbCr → divide into 8x8 blocks → DCT → Quanti-zation → zigzag ordering → **RLE / Huffman**

- **RLE / Huffman encoding**
  - Different strategy for DC and AC term
  - The DC components of different blocks are encoded using Huffman algorithm
  - The AC components within a block are encoded using RLE



# JPEG Compression (cont.)

- The decompression of JPEG data is done by reversing the compression process
- We can control the degree of compression by altering the amount of quantization
- JPEG compression usually achieves very high compression rate for natural images (5% of the original size)

# Image Manipulation

# Image Manipulation

- **Motivations**
  - Correct deficiencies in an image (e.g., noise, red-eye)
  - Create images that are difficult or impossible to make naturally (e.g., glow)

- Type of image manipulations
  - Pixel **point** processing
  - Pixel **group** processing

# Pixel Point Processing

- Compute a pixel's new value solely on the basis of its old value

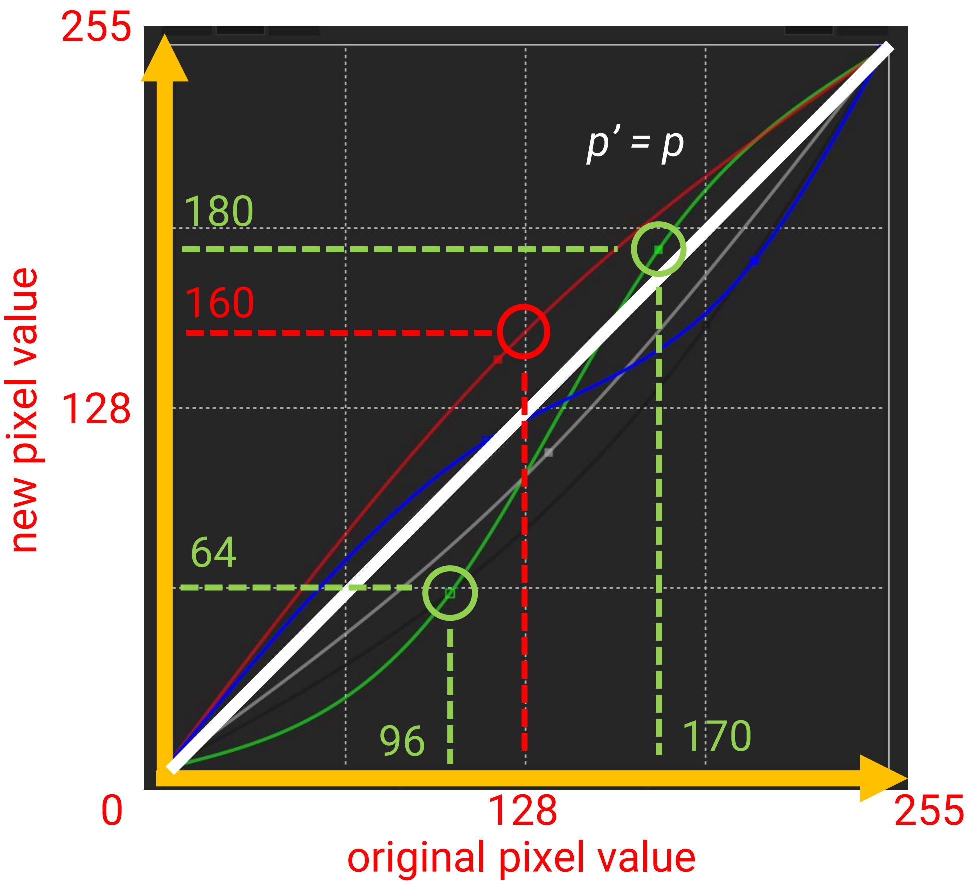
mapping function

$$p' = \boxed{f}(p)$$

- Some examples
  - Adjustment of brightness
  - Adjustment of contrast
  - Change the black and white levels

# Color Curve

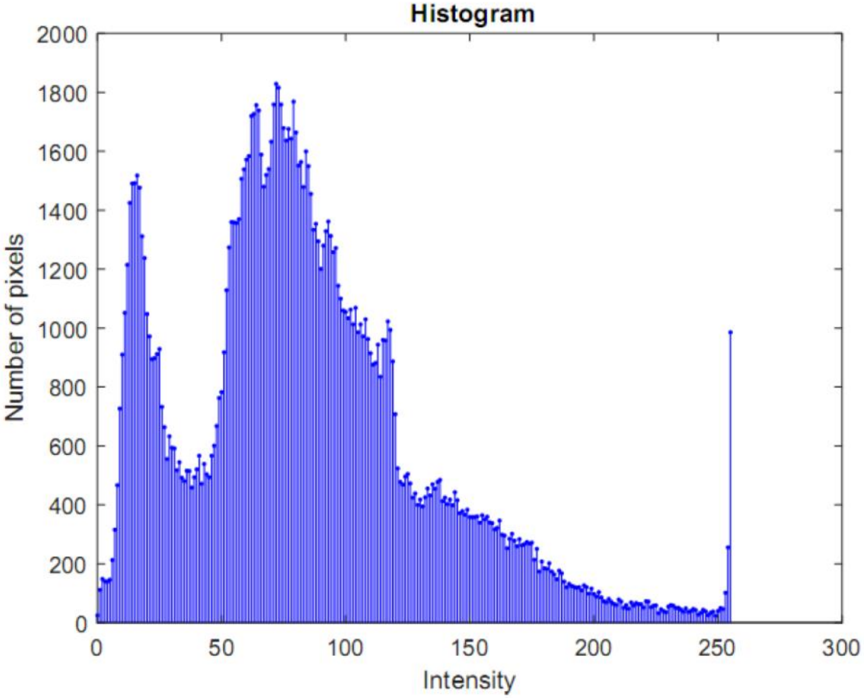
- The operations can be considered generally as altering the mapping function ***f***
- **Color curve**



# Histogram

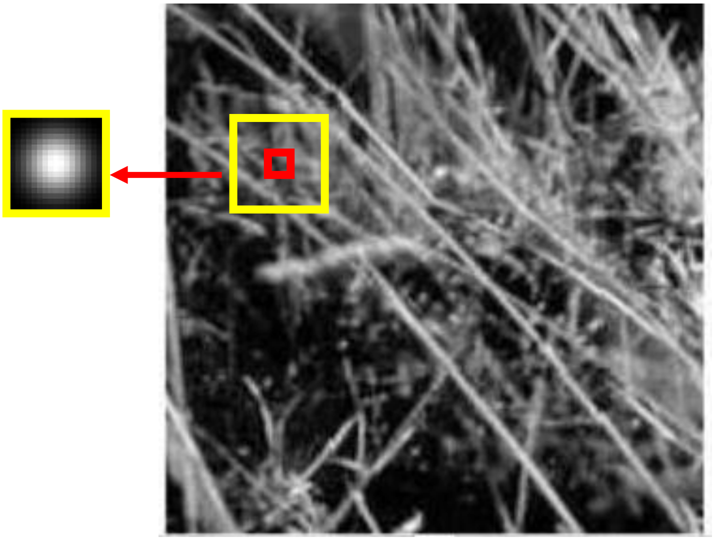
- An approximate representation of the **distribution** of numerical data

Intensity Image



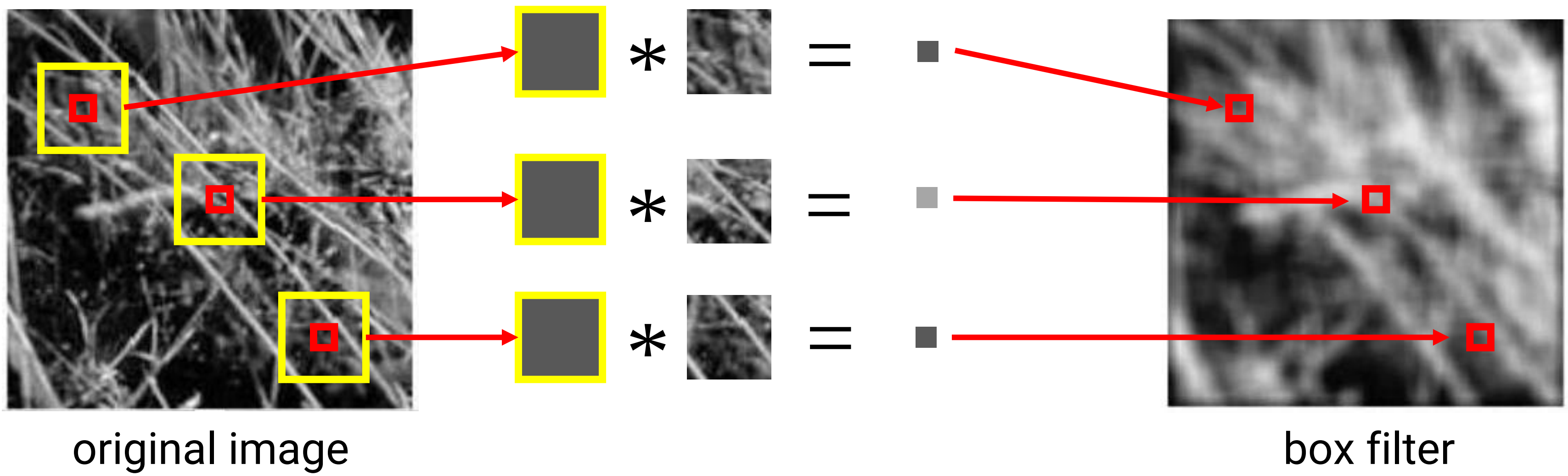
# Pixel Group Processing

- Compute each pixel's new value as a function not just of its old value, but also of **the values of neighboring pixels**
- Usually related to **filtering**
  - For a pixel of an image, specify a two-dimensional array of weights of its neighbors
  - Several types of filters
    - Smoothing
    - Sharpening
    - Detecting edge



# Box Filter

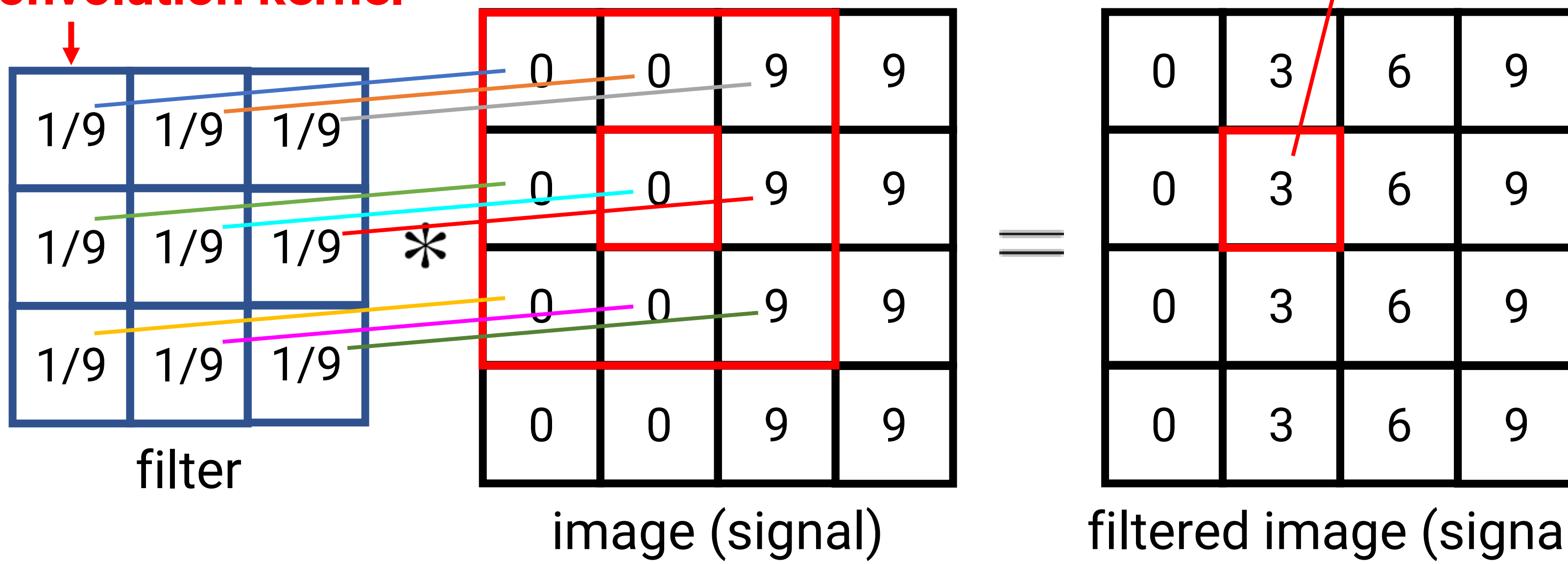
- Each neighbor has the same weight

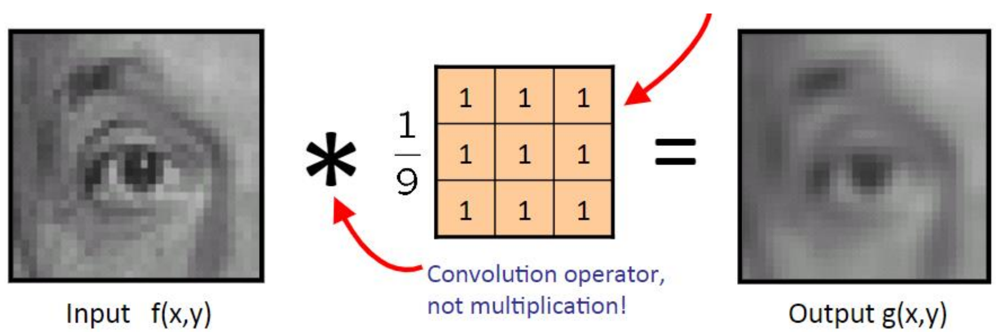


# Box Filter (cont.)

**convolution mask**
**convolution kernel**

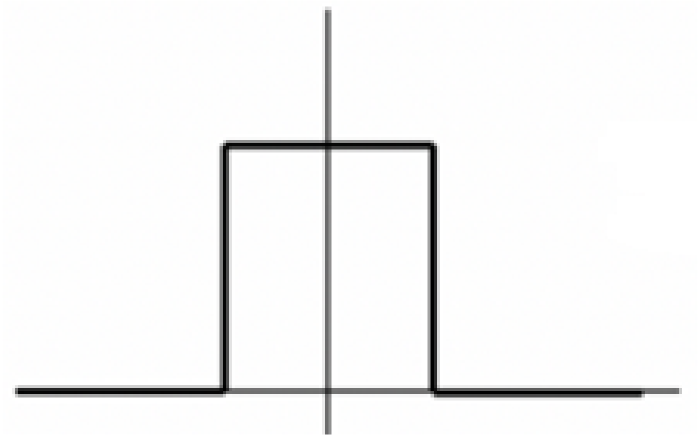
(1/9*0+1/9*0+1/9*0+
1/9*0+1/9*0+1/9*0+
1/9*9+1/9*9+1/9*9)



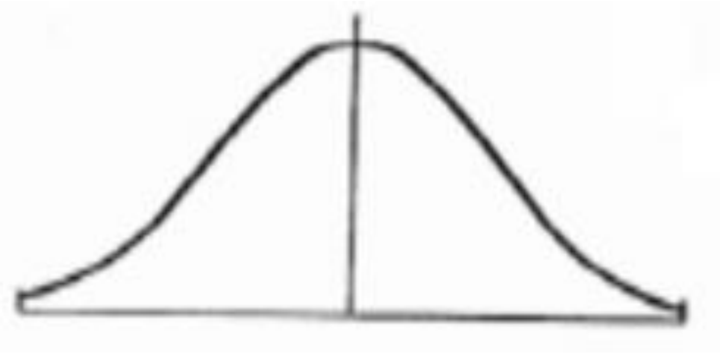



# Box Filter (cont.)

- 1D visualization of kernel weight



box filter



gaussian filter

# Gaussian Filter

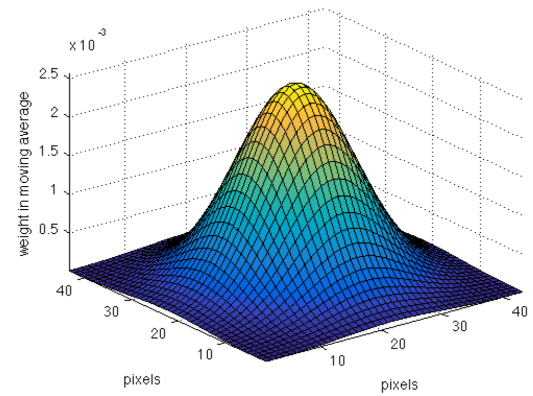
- The weight of neighbor falls exponentially with its distance to the filtered pixel
  - Standard deviation α controls the speed of decreasing

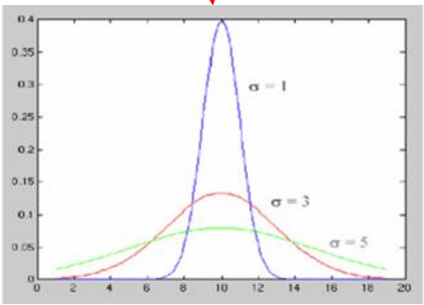
distance

$$g(x,y) = \boxed{\frac{1}{2\pi\sigma^2}} e^{-\frac{\boxed{x^2+y^2}}{2\sigma^2}}$$

standard deviation

normalization (sum of weight = 1)

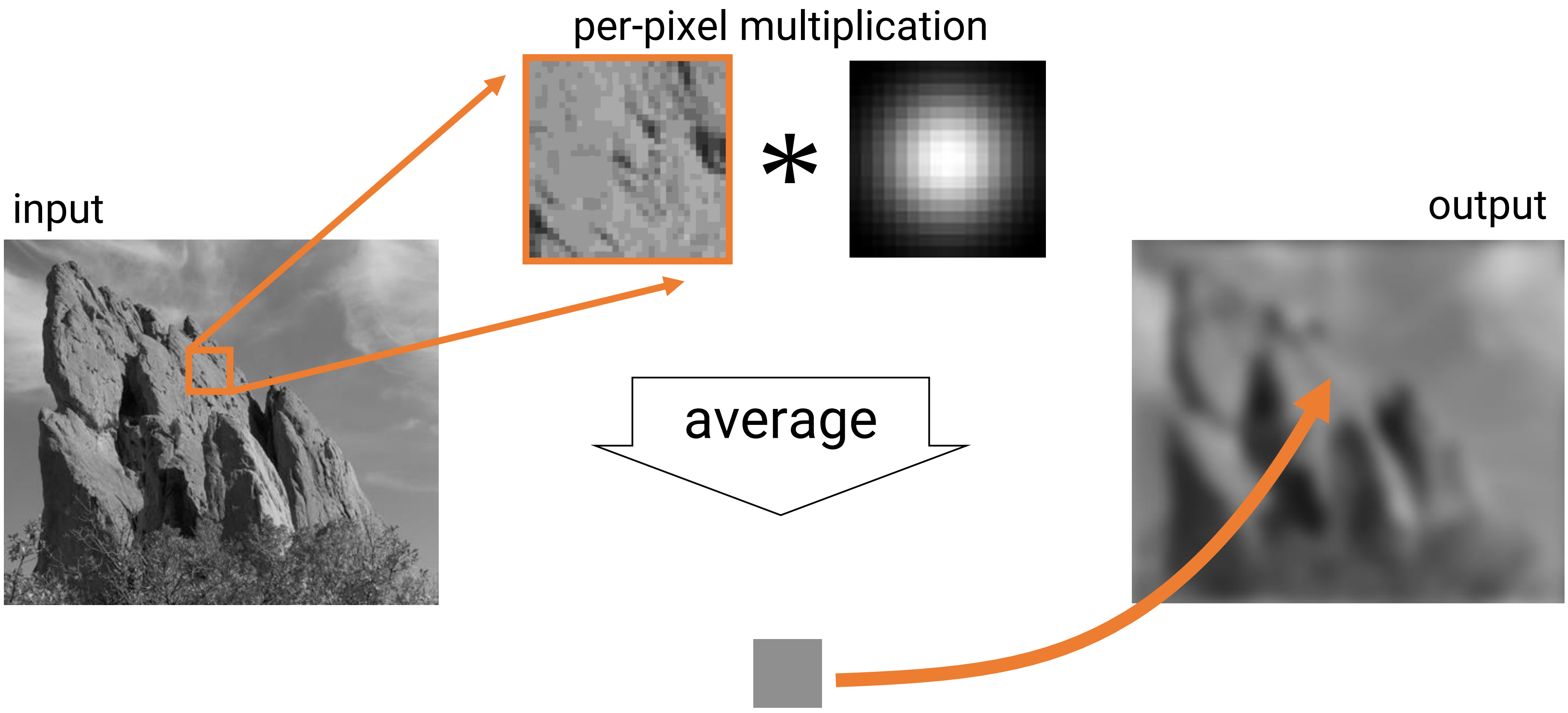


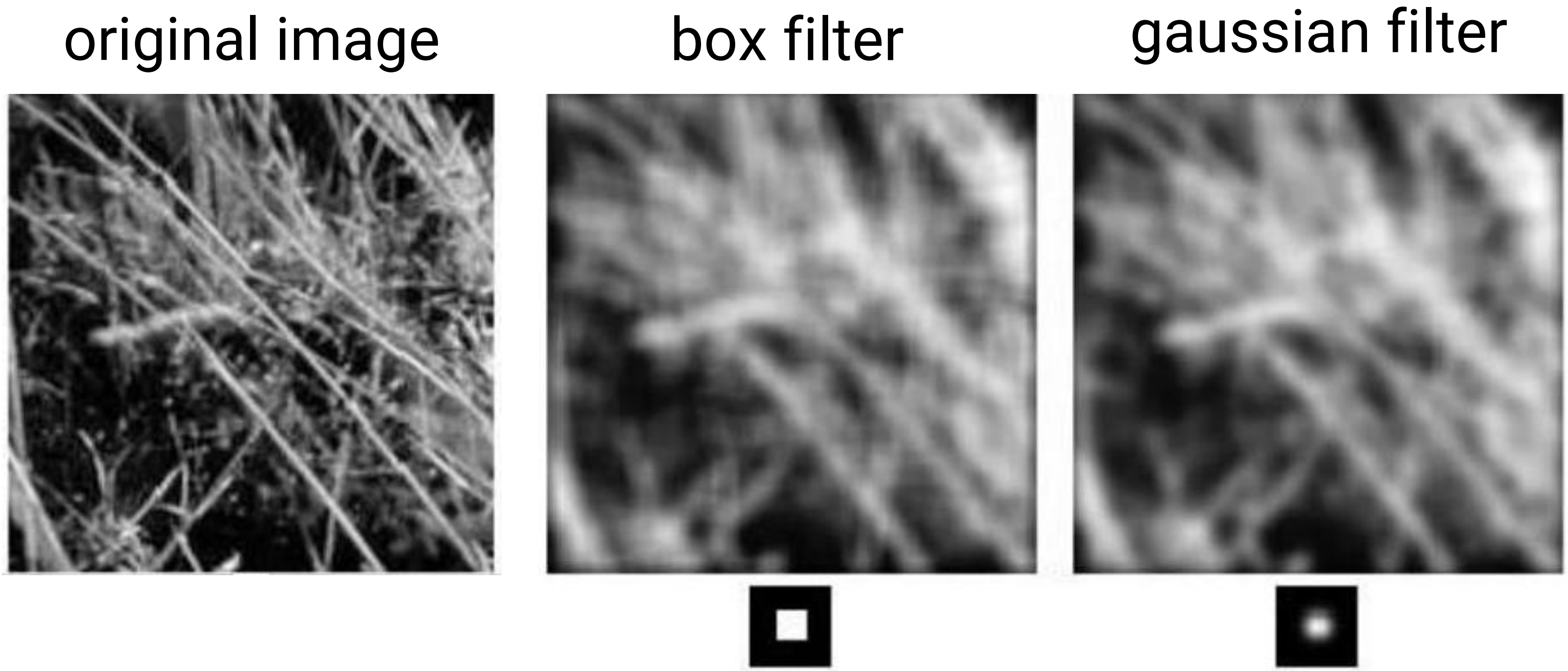

$\frac{1}{273}$

| | | | | |
|---|---|---|---|---|
| 1 | 4 | 7 | 4 | 1 |
| 4 | 16 | 26 | 16 | 4 |
| 7 | 26 | 41 | 26 | 7 |
| 4 | 16 | 26 | 16 | 4 |
| 1 | 4 | 7 | 4 | 1 |

# Gaussian Filter (cont.)



# Box Filter v.s. Gaussian Filter



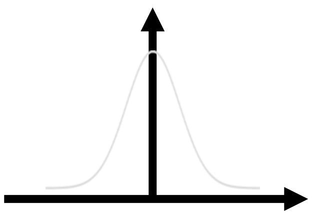
# Bilateral Filter

- Properties of Gaussian filter

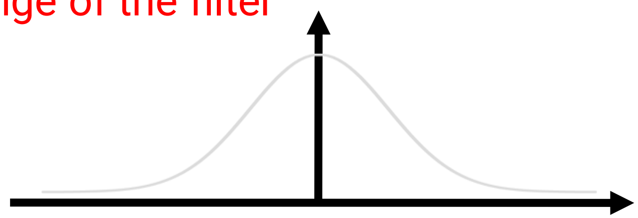
$$g(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

range of the filter

input



small $\sigma$



large $\sigma$

limited smoothing

strong smoothing

# Bilateral Filter (cont.)

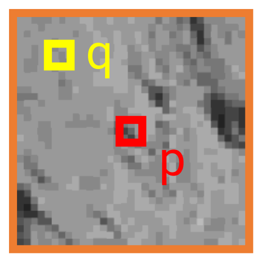
- Problems of Gaussian filter
  - Does smooth images
  - But smoothes too much: **edges are blurred**
  - Only spatial distance matters
  - No edge term

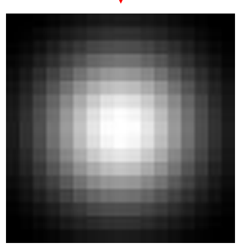
input

output

spatial distance

$$GB[I]_{\mathbf{p}} = \sum_{\mathbf{q}\in S} G_{\sigma}(\|\mathbf{p}-\mathbf{q}\|)\, I_{\mathbf{q}}$$

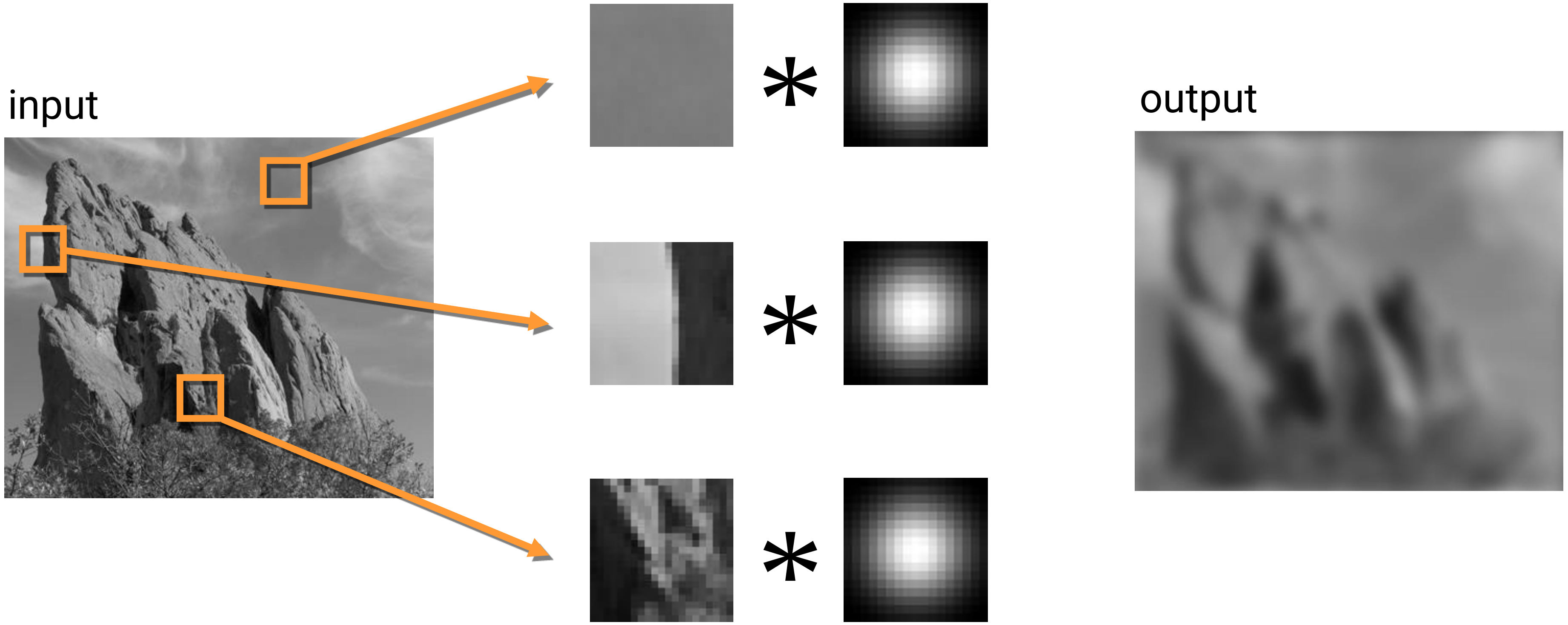


$$g(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

# Bilateral Filter (cont.)

- Problems of Gaussian filter
  - Same Gaussian kernel everywhere



# Bilateral Filter (cont.)

- Combine another Gaussian weight computed by **intensity difference** (**edge preserving**)

spatial distance

$$GB[I]_{\mathbf{p}} = \sum_{\mathbf{q} \in S} G_{\sigma}(\| \mathbf{p} - \mathbf{q} \|) I_{\mathbf{q}}$$

↓

$$BF[I]_{\mathbf{p}} = \frac{1}{W_{\mathbf{p}}} \sum_{\mathbf{q} \in S} G_{\sigma_{\mathrm{s}}}(\| \mathbf{p} - \mathbf{q} \|) G_{\sigma_{\mathrm{r}}}(| I_{\mathbf{p}} - I_{\mathbf{q}} |) I_{\mathbf{q}}$$

spatial distance

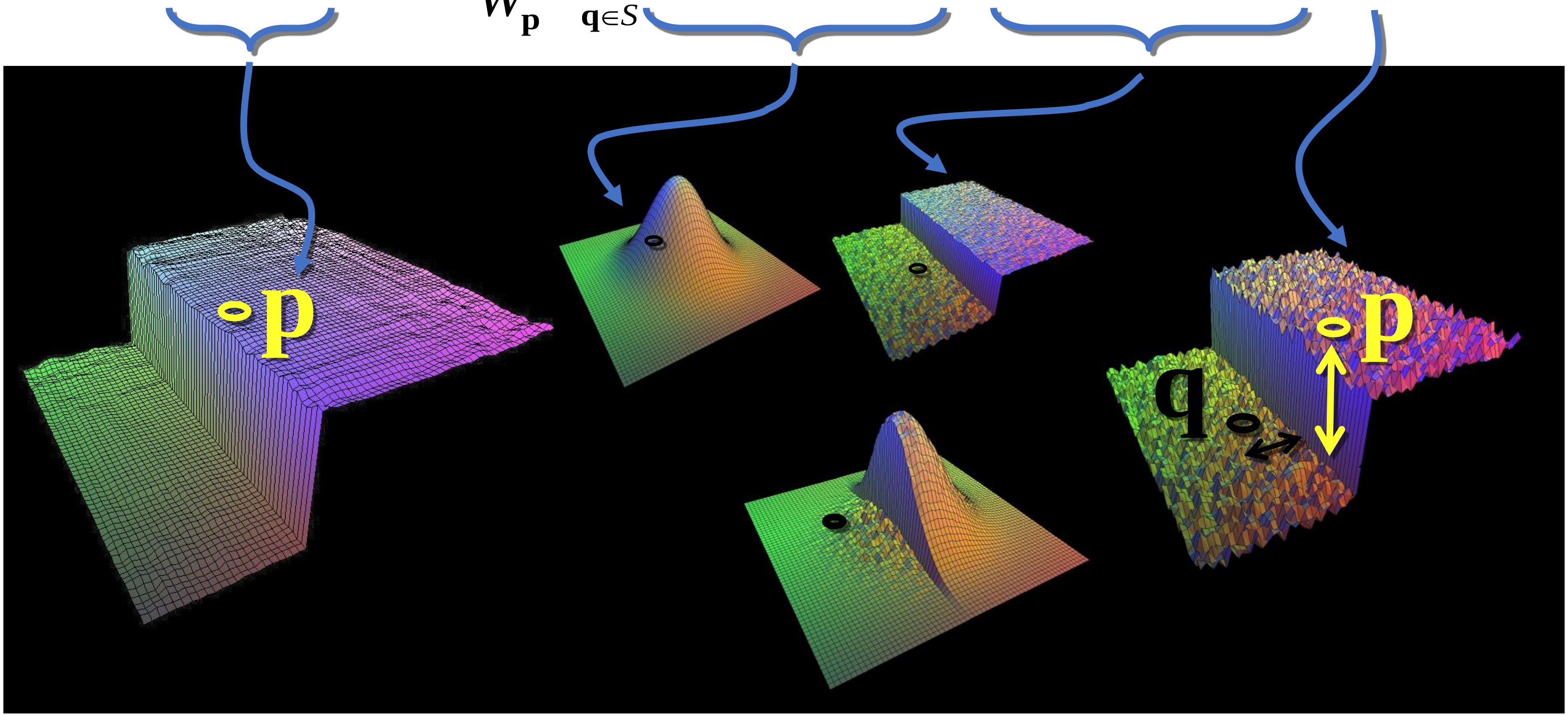
range (intensity) distance

**NEW!**

# Bilateral Filter (cont.)

- Visualization

$$BF[I]_{\mathbf{p}} = \frac{1}{W_{\mathbf{p}}} \sum_{\mathbf{q} \in S} G_{\sigma_s}(\| \mathbf{p} - \mathbf{q} \|) \; G_{\sigma_r}(| I_{\mathbf{p}} - I_{\mathbf{q}} |) \; I_{\mathbf{q}}$$



# Bilateral Filter (cont.)

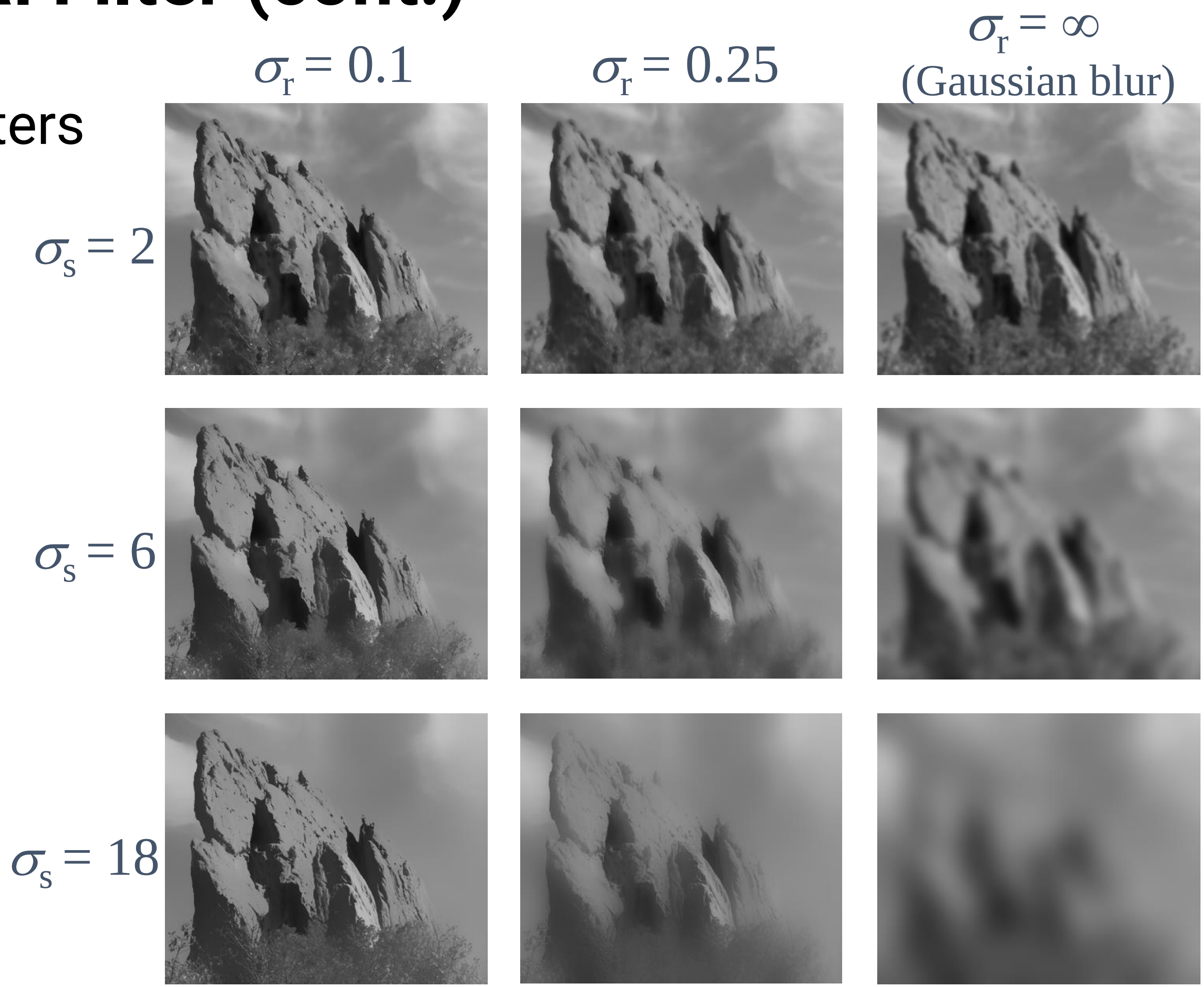
- Parameters

$$BF[I]_{\mathbf{p}} = \frac{1}{W_{\mathbf{p}}} \sum_{\mathbf{q} \in S} G_{\sigma_{\mathrm{s}}}\left(\| \mathbf{p} - \mathbf{q} \|\right) G_{\sigma_{\mathrm{r}}}\left(| I_{\mathbf{p}} - I_{\mathbf{q}} |\right) I_{\mathbf{q}}$$

- **Spatial sigma $\sigma_s$ :** spatial extent of the kernel, size of the considered neighborhood
- **Range sigma $\sigma_r$ :** “minimum” amplitude of an edge

# Bilateral Filter (cont.)

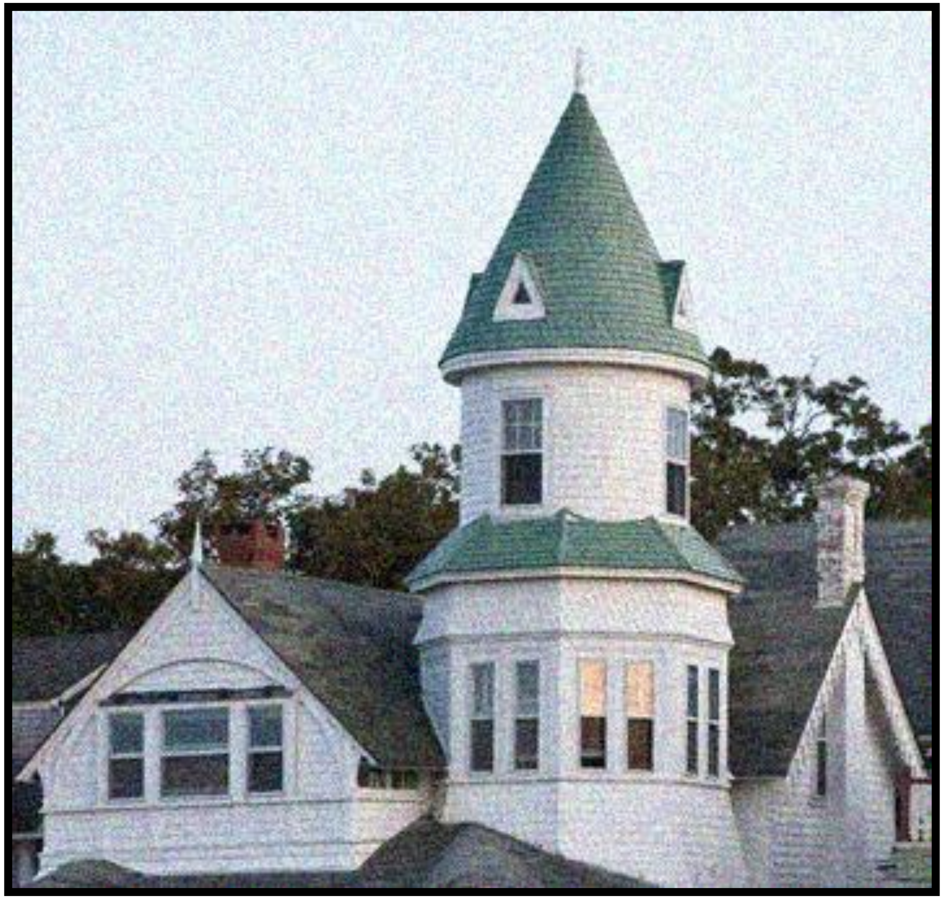
- Parameters




input

# Bilateral Filter Application (cont.)

- Denoising

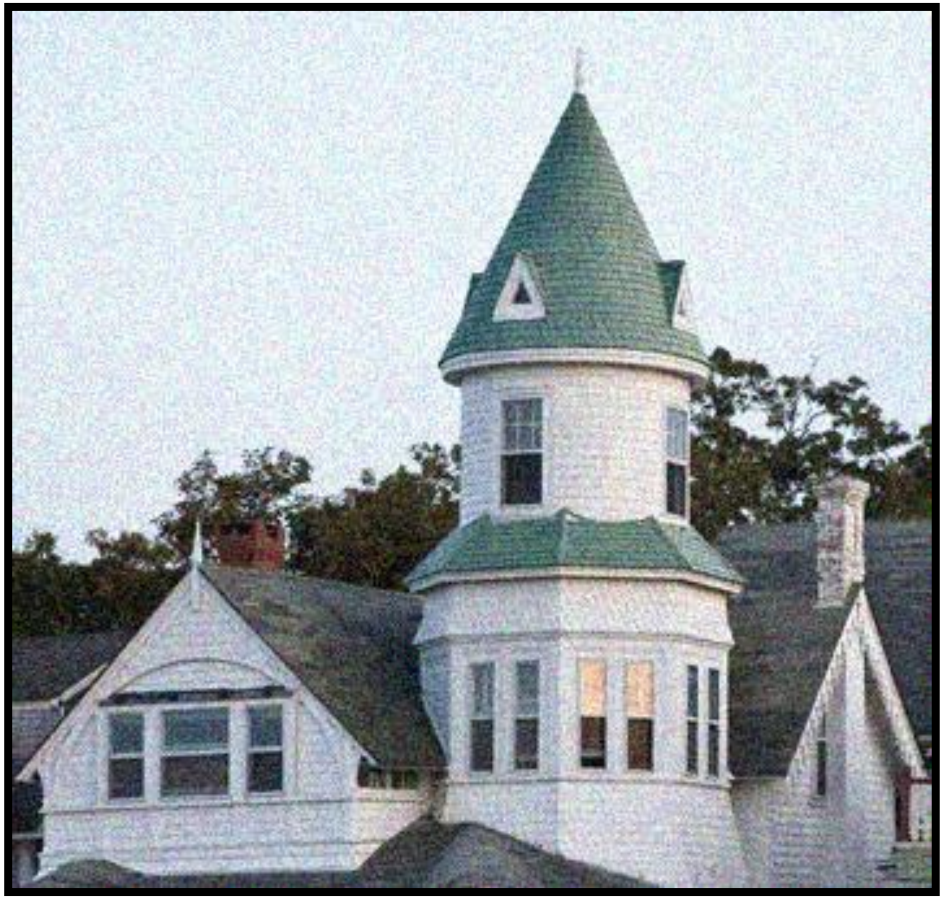


noisy input

Median Filter 5x5

# Bilateral Filter Application (cont.)

- Denoising



noisy input

Bilateral Filter 7x7

# Bilateral Filter Application (cont.)

- Denoising


noisy input


Gaussian Filter


Bilateral Filter

# Sobel Filter

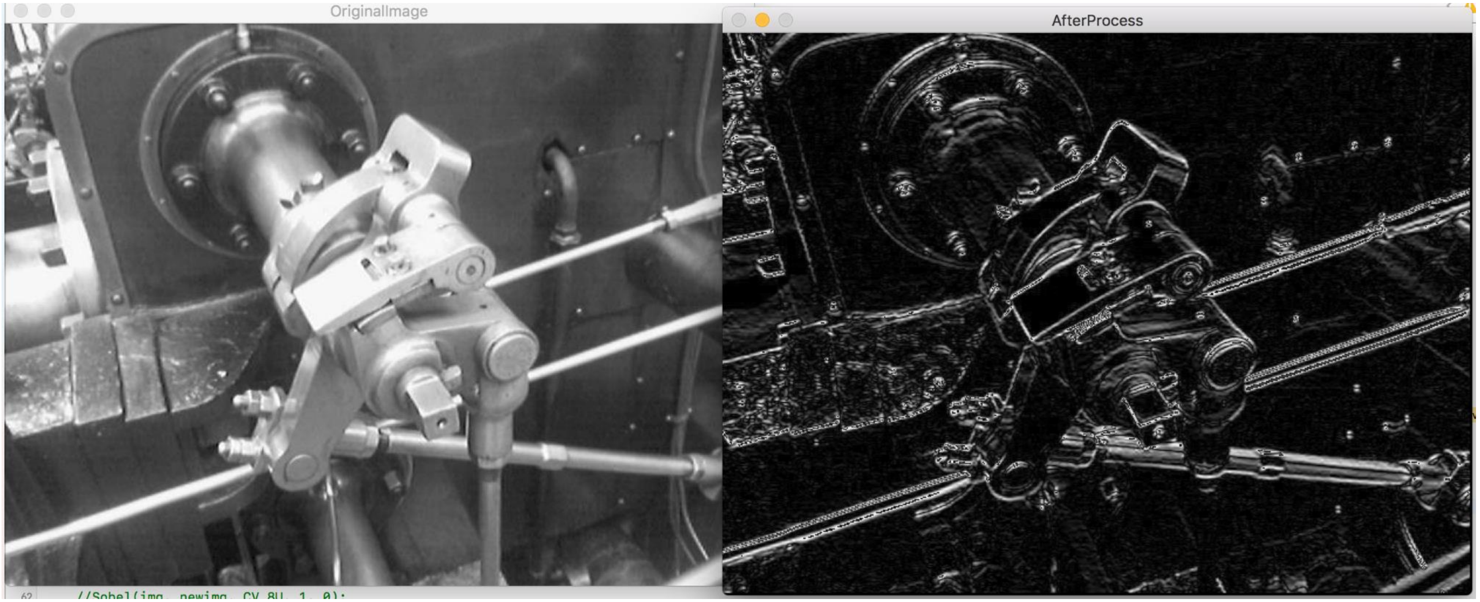
- Negative weights are commonly used for edge detection

| | | |
|---|---|---|
| -1 | 0 | +1 |
| -2 | 0 | +2 |
| -1 | 0 | +1 |

Gx

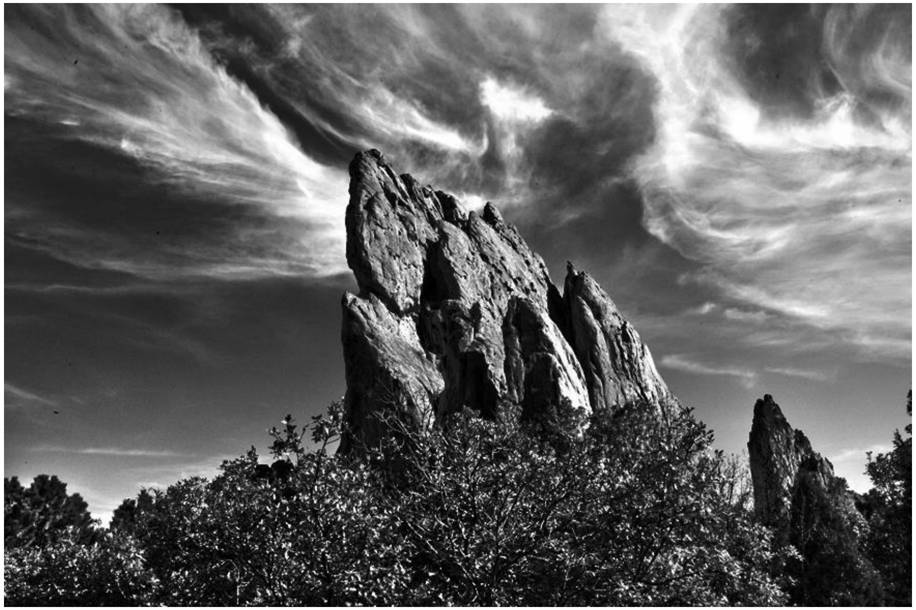
| | | |
|---|---|---|
| +1 | +2 | +1 |
| 0 | 0 | 0 |
| -1 | -2 | -1 |

Gy



# Photographic Style Transfer

- Two-scale Tone Management for Photographic Look, Bae et al. SIGGRAPH 2006



# Photographic Style Transfer (cont.)

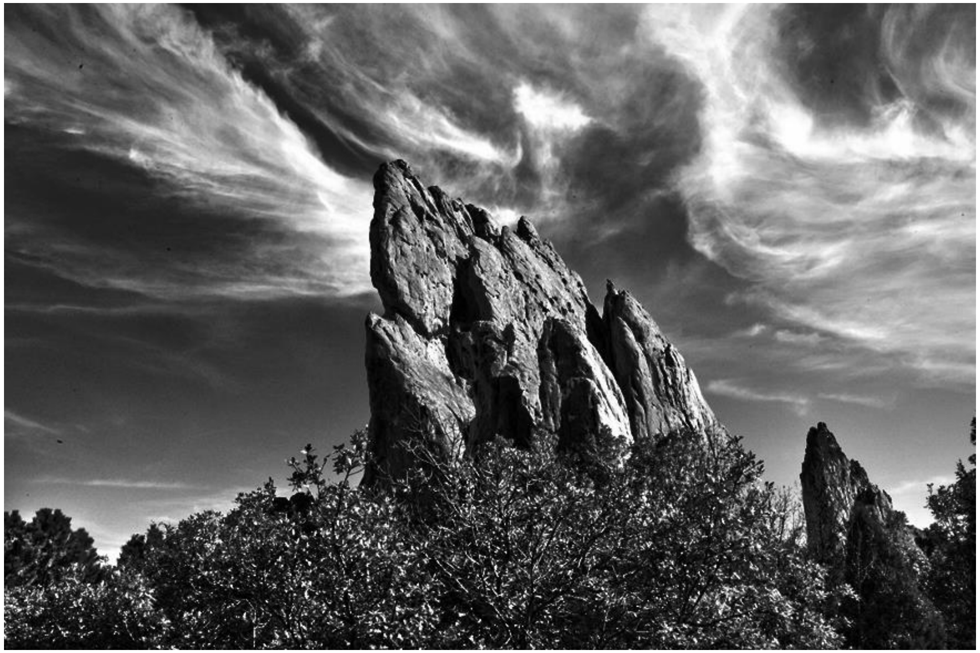
- **Motivation**

Ansel Adams
*Clearing Winter Storm*

An Amateur Photographer

# Photographic Style Transfer (cont.)

- **Motivation**

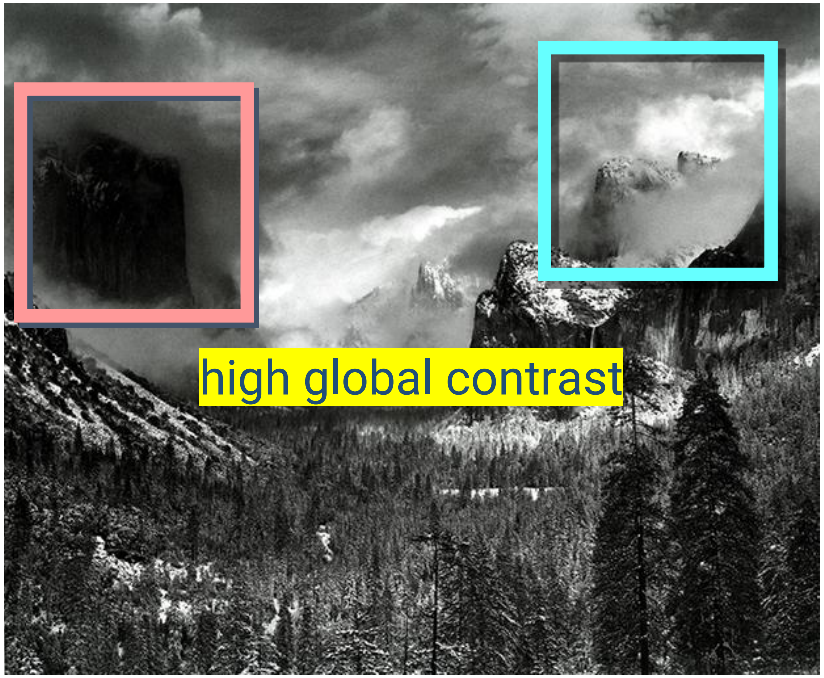


Ansel Adams
*Clearing Winter Storm*

style transferred result
(an imitation of Ansel Adams)

# Photographic Style Transfer (cont.)

- **Observation**
  - Different photographers have different tonal styles
    - Global contrast

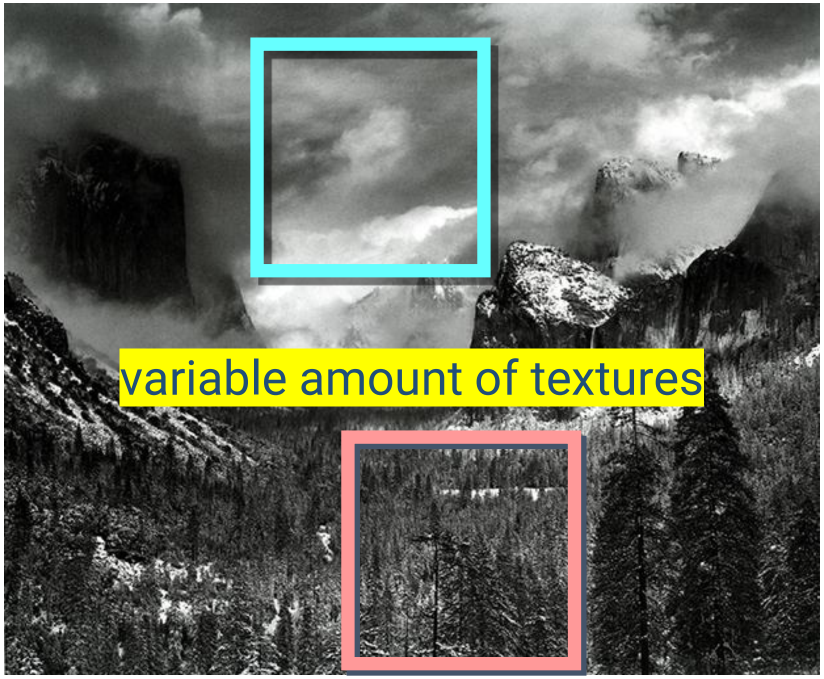




Ansel Adams


Kenro Izu

# Photographic Style Transfer (cont.)

- **Observation**
  - Different photographers have different tonal styles
    - Global contrast
    - Local contrast




Ansel Adams


Kenro Izu

# Photographic Style Transfer (cont.)

- **Goal**
  - Transfer look between photographers

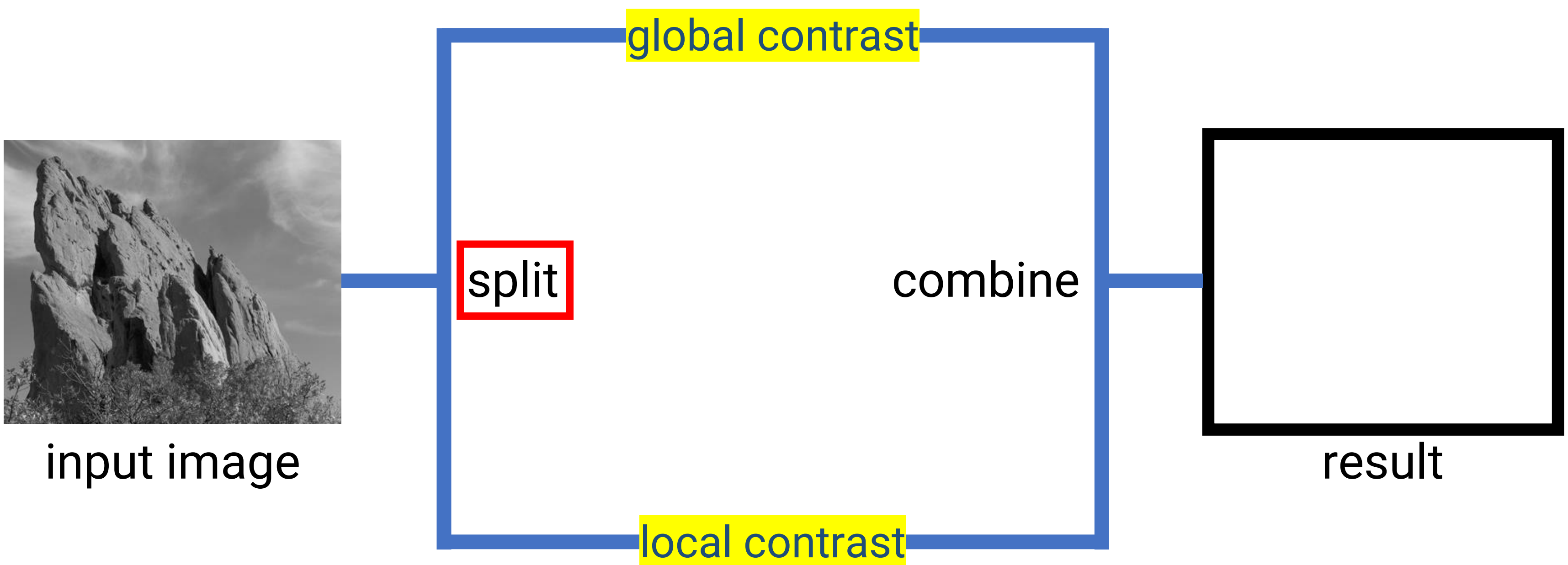
model

input image

result

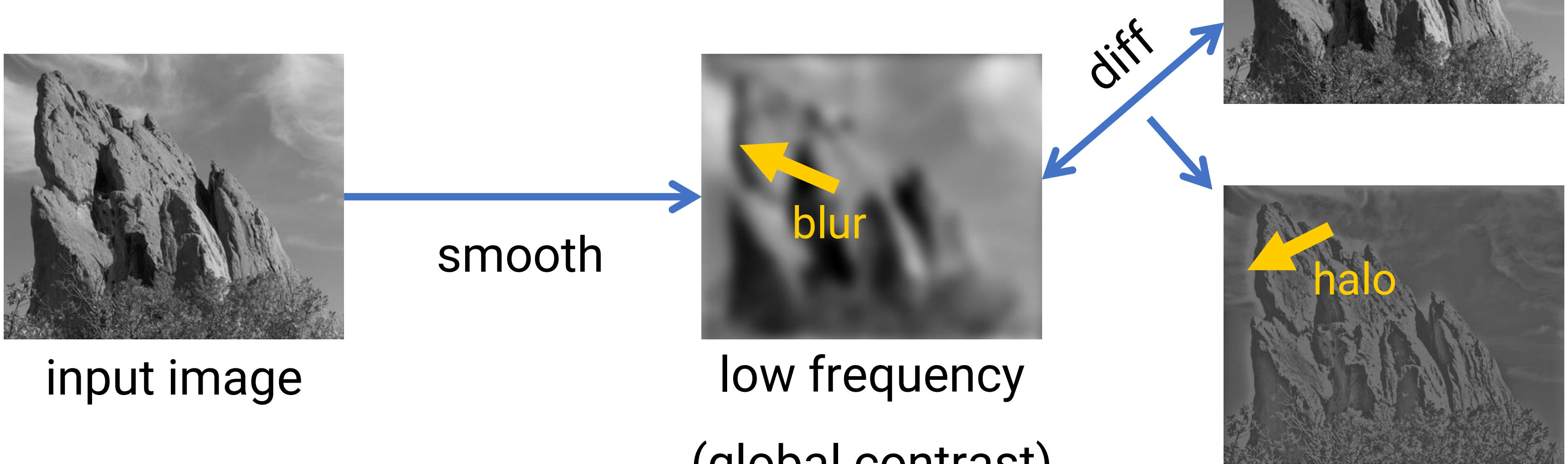
# Photographic Style Transfer (cont.)

- **Algorithm**



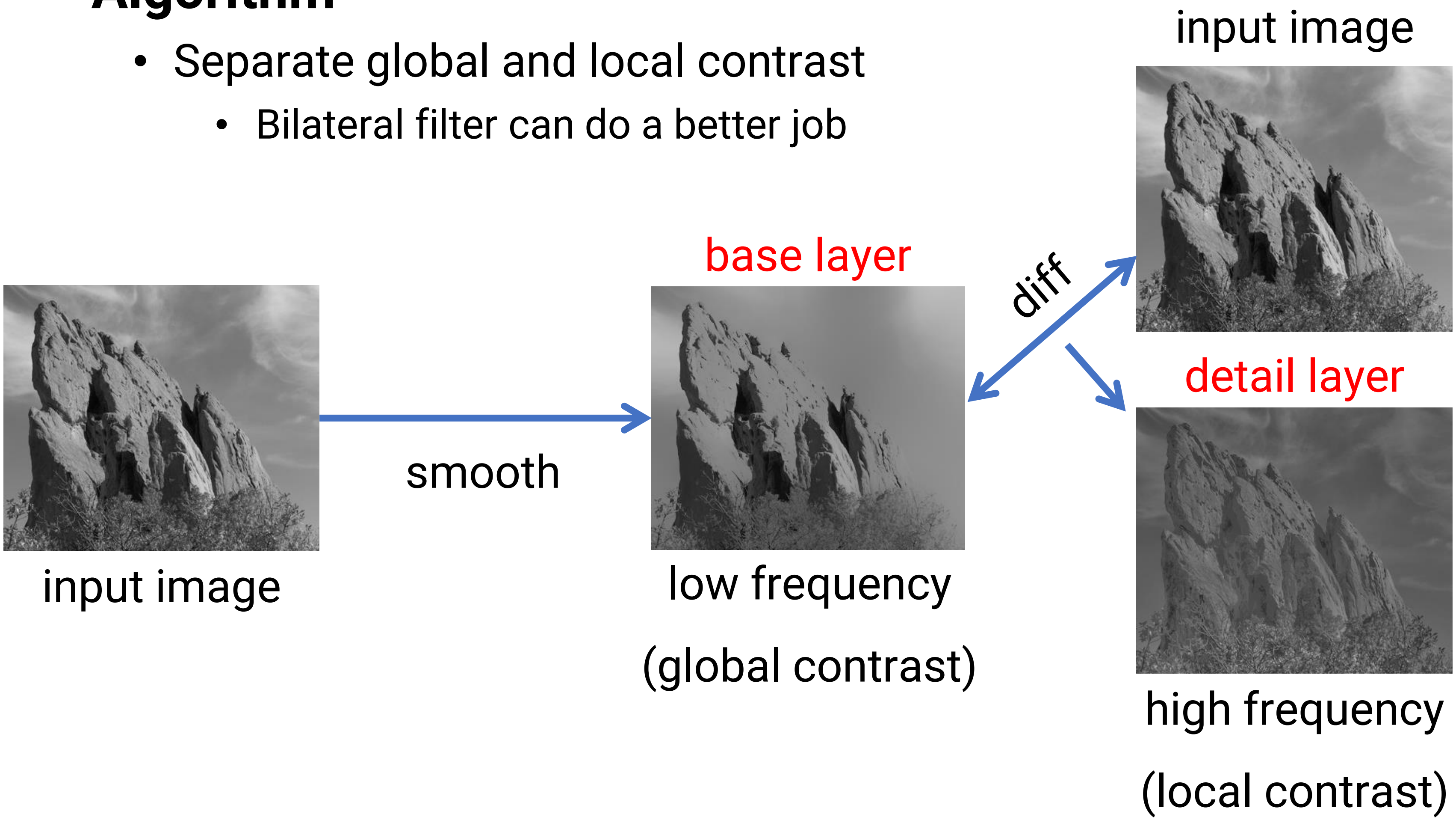
# Photographic Style Transfer (cont.)

- **Algorithm**
  - Separate global and local contrast
    - Gaussian filter produces blurring and halos



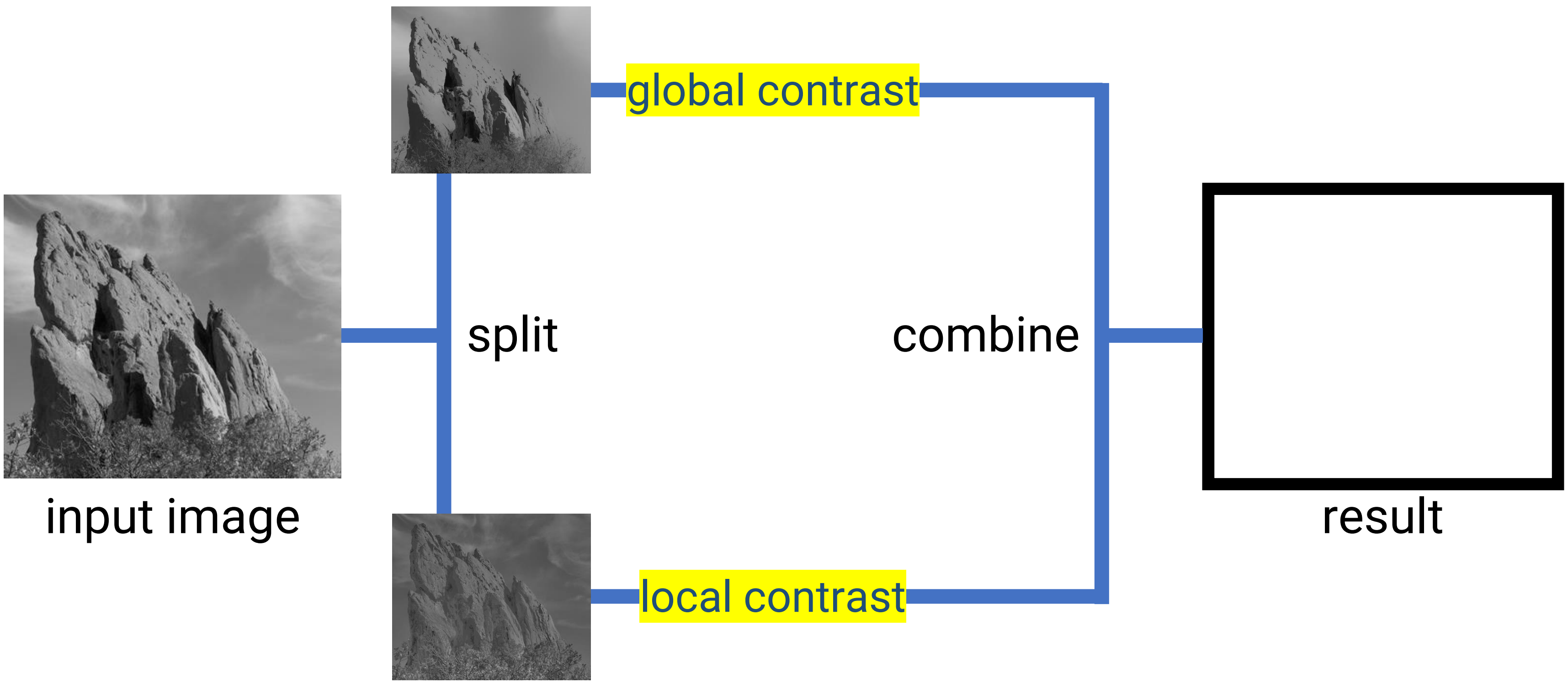
# Photographic Style Transfer (cont.)

- **Algorithm**
  - Separate global and local contrast
    - Bilateral filter can do a better job



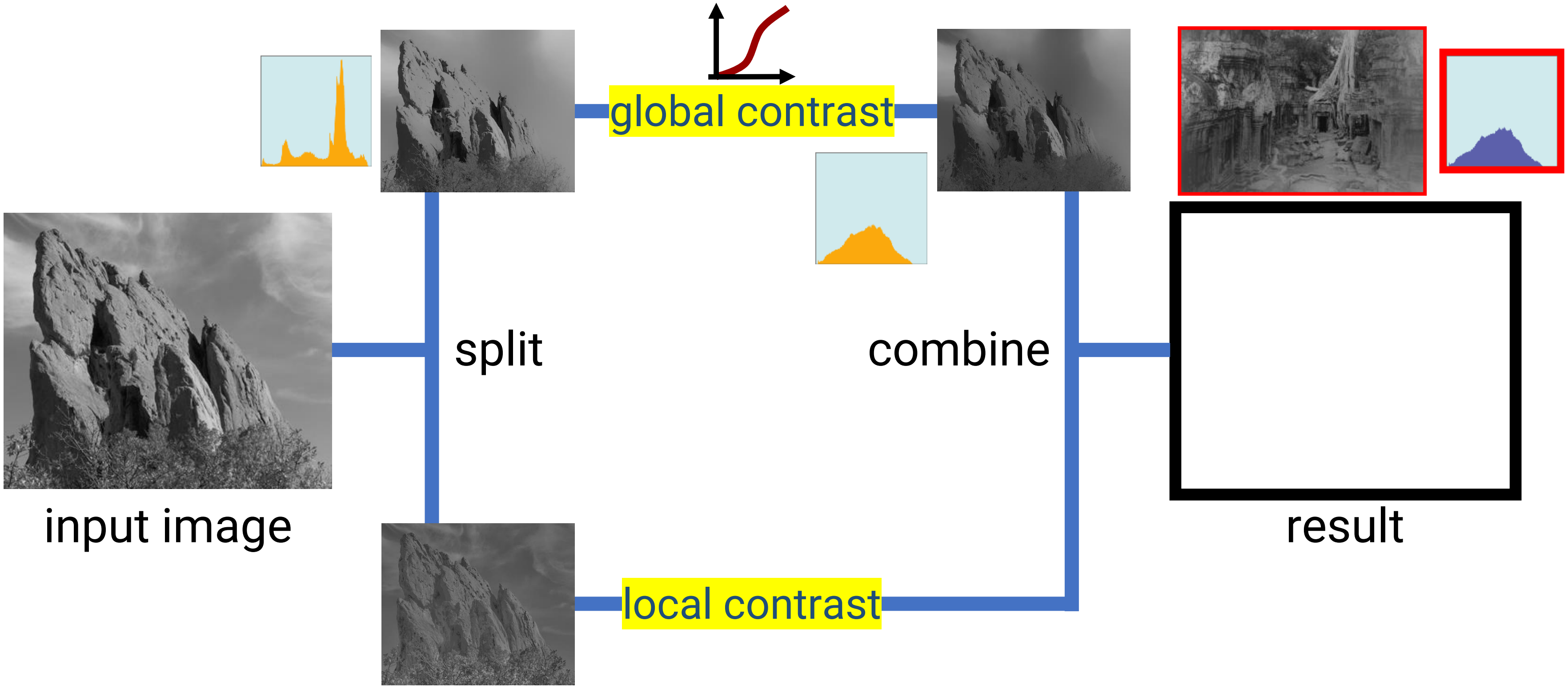
# Photographic Style Transfer (cont.)

- **Algorithm**
  - Separate global and local contrast



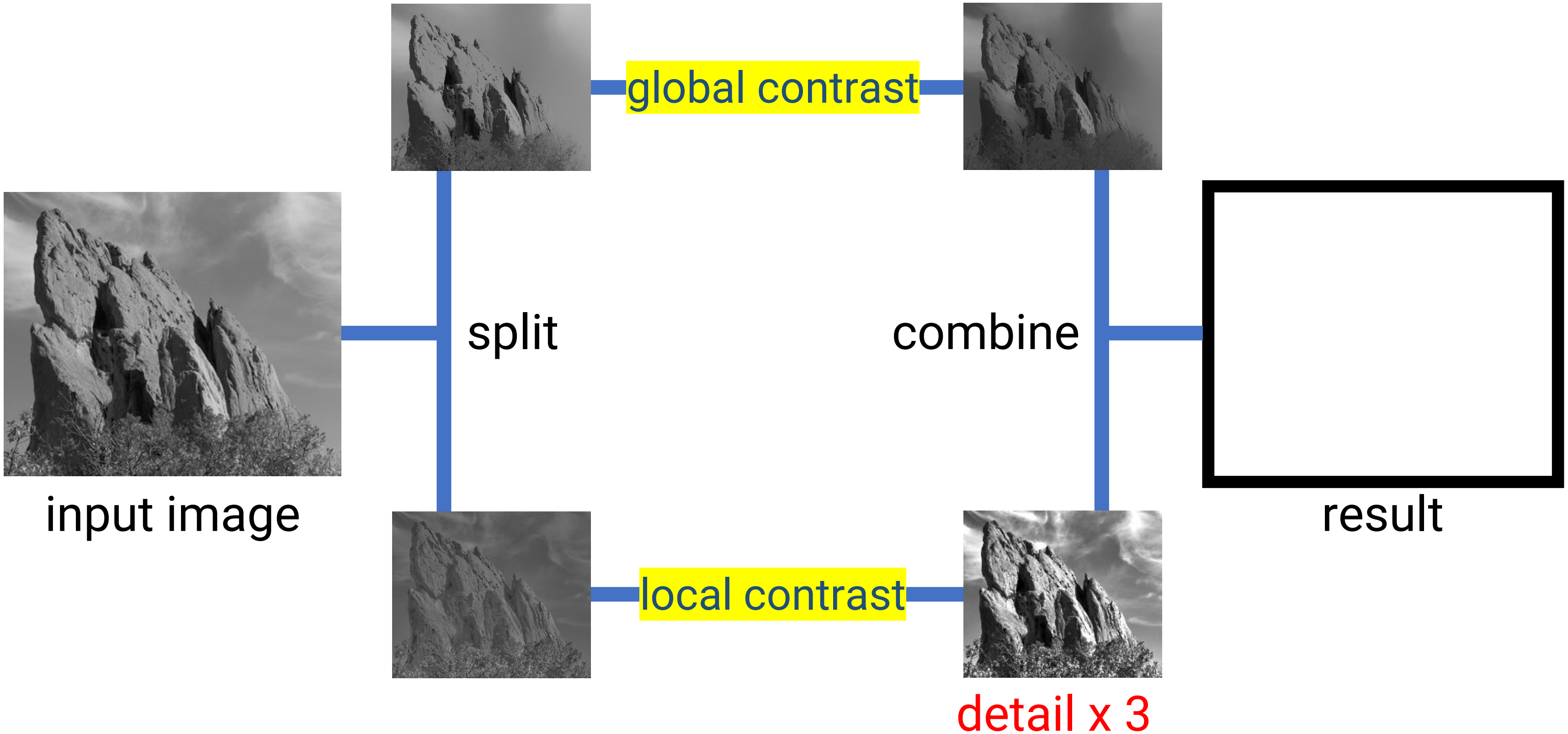
# Photographic Style Transfer (cont.)

- **Algorithm**
  - Adjust global contrast by histogram matching



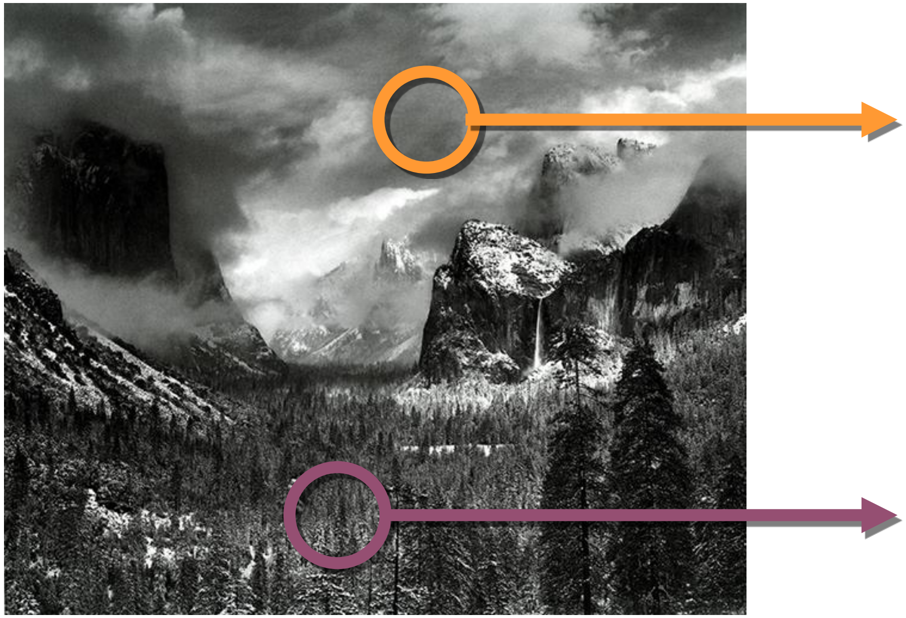
# Photographic Style Transfer (cont.)

- **Algorithm**
  - Adjust local contrast by uniformly scaling



# Photographic Style Transfer (cont.)

- **Algorithm**
  - Sometimes the local contrast is not uniform



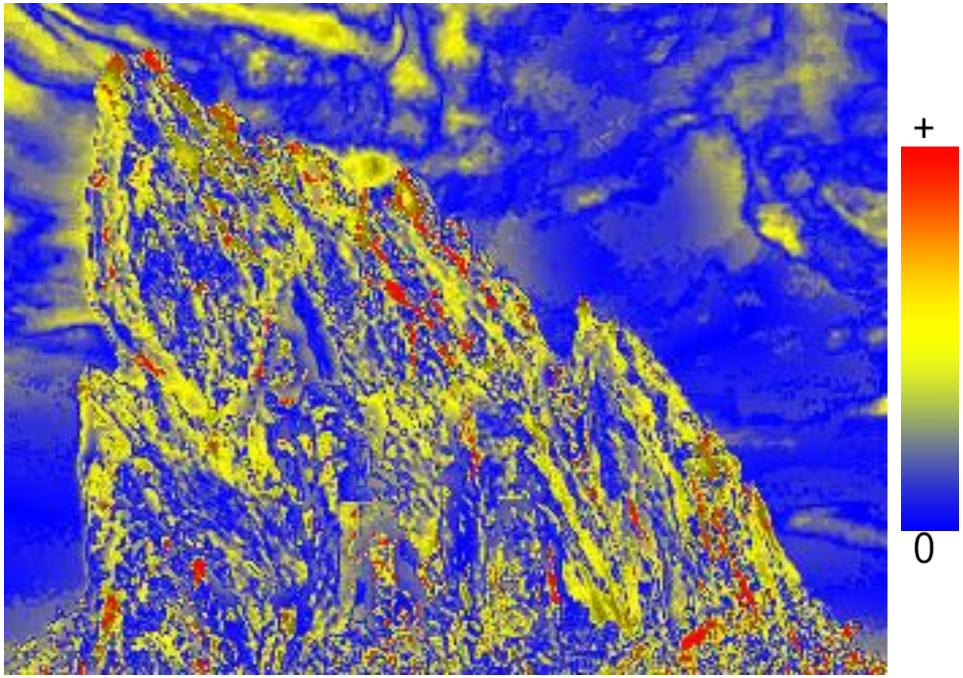
smooth region
⇨ low textureness

textured region
⇨ high textureness

# Photographic Style Transfer (cont.)

- **Algorithm**
    - Textureness computation

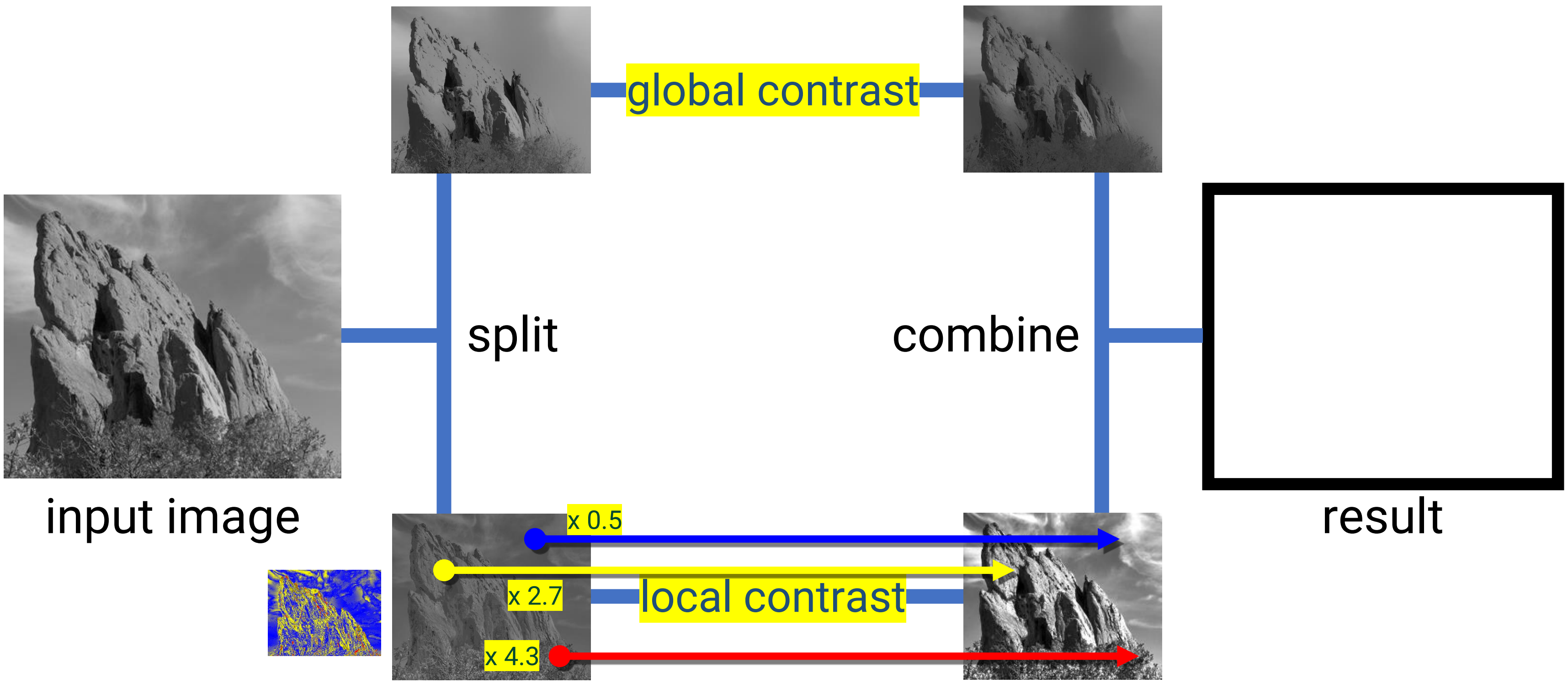
input




textureness

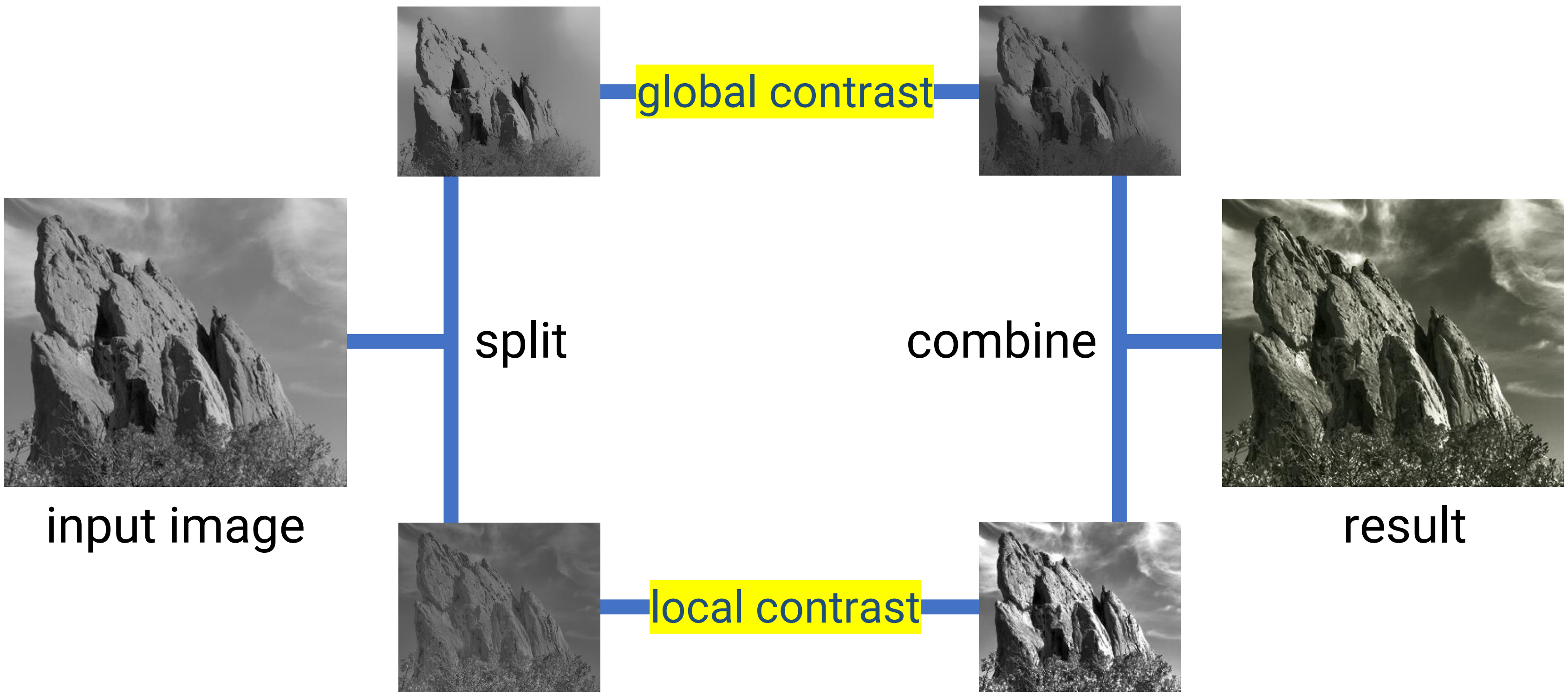
# Photographic Style Transfer (cont.)

- **Algorithm**
  - Non-uniformly increase local contrast based on textureness



# Photographic Style Transfer (cont.)

- **Algorithm**
  - Combine global and local contrast

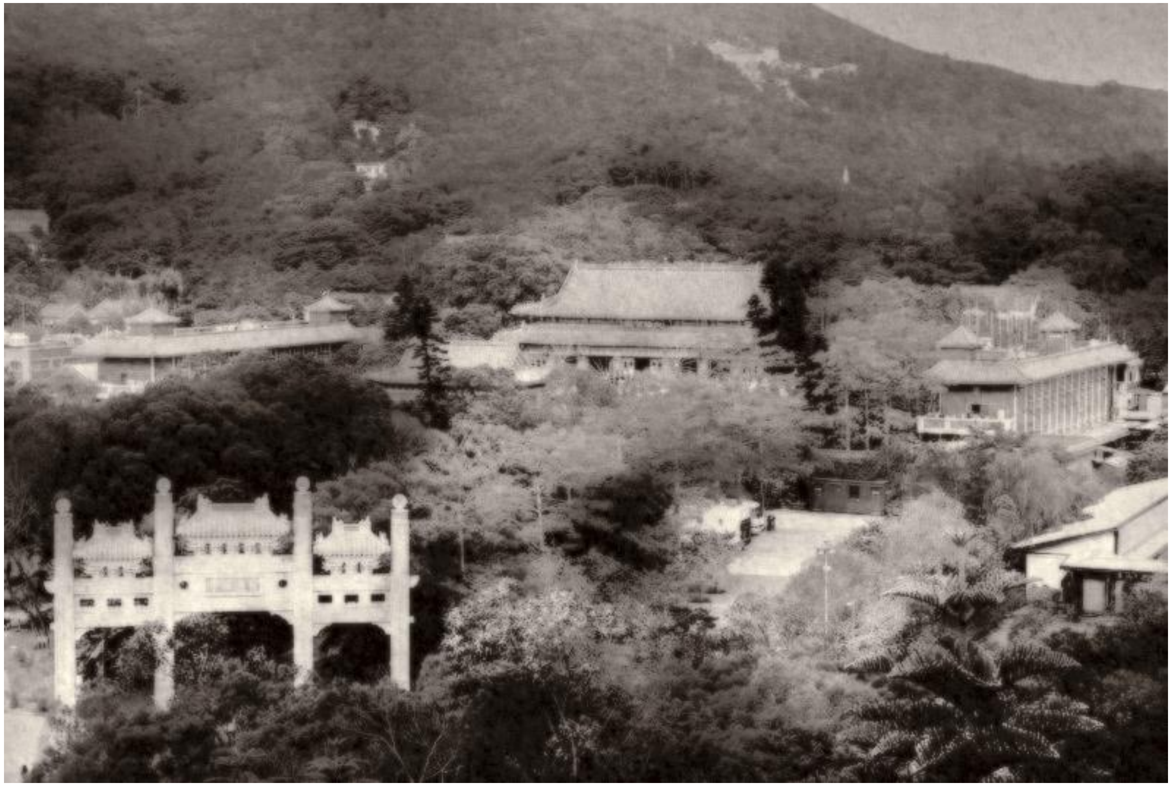


# Photographic Style Transfer (cont.)

- **Results**

# Photographic Style Transfer (cont.)

- **Results**



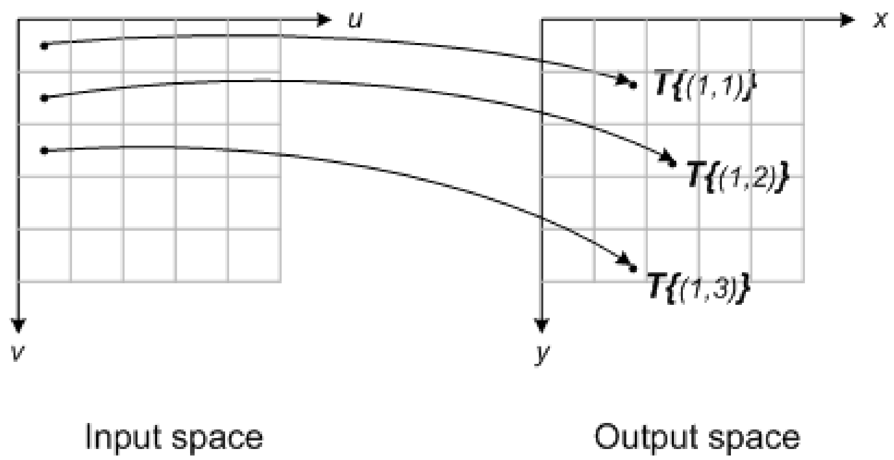
# Geometrical Transformations

# Types of Geometrical Transformations

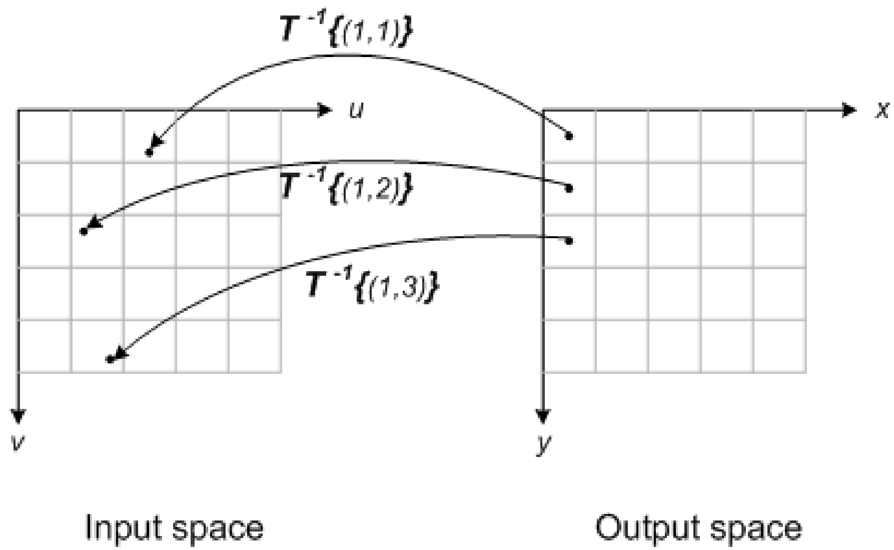
- Scaling
- Translation
- Reflection
- Rotation
- Shearing

- For bitmapped images, we have to **transform every pixel**, and will often require the image to be **resampled**

# Forward Mapping and Inverse Mapping



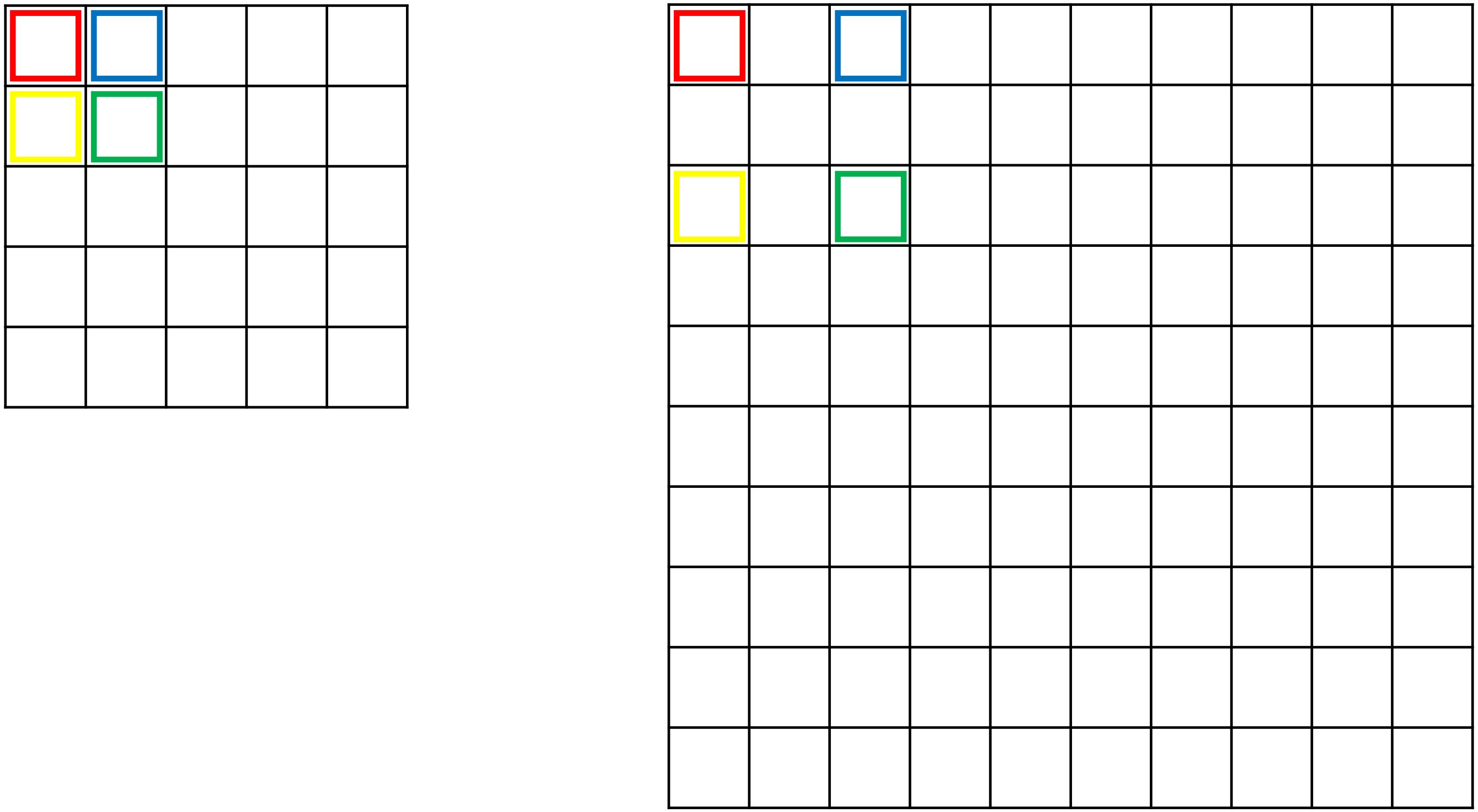

forward mapping




**inverse mapping**

# Forward Mapping and Inverse Mapping

$(x', y') = (2x, 2y)$

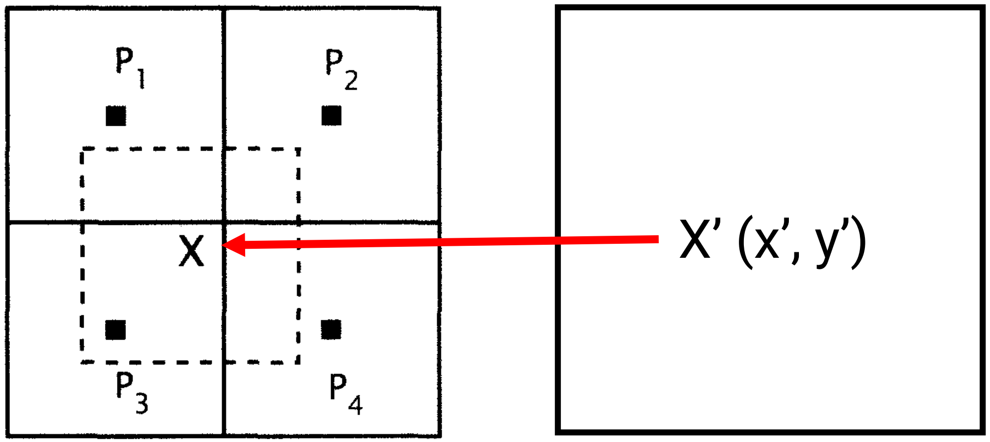


# Image Scaling

- We will use image scaling as an example
- Assume we want to obtain an image which is ***s*** times larger than the original image

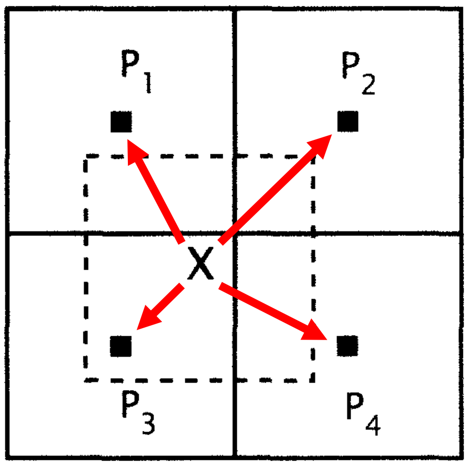
forward mapping $(x', y') = (sx, sy)$

inverse mapping $(x, y) = (x'/s, y'/s)$



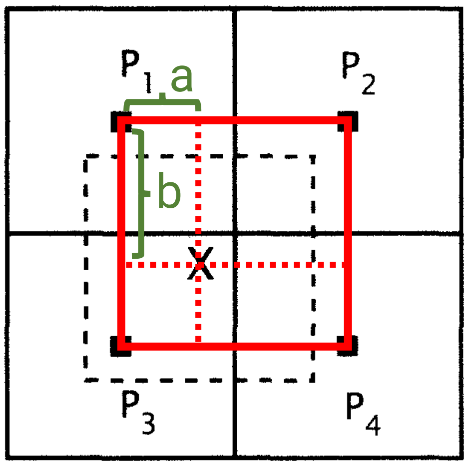
# Image Scaling (cont.)

- Three strategies to obtain an estimation of X



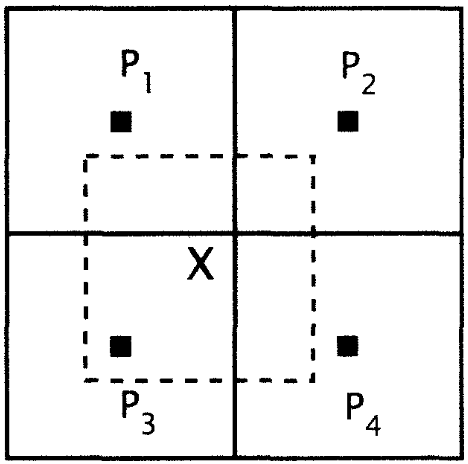

**nearest neighbor**

$P_3$ is closest
Use $P_3$'s pixel value




**bilinear interpolation**

$(1\text{-}a)(1\text{-}b)P_1 + (a)(1\text{-}b)P_2 + (1\text{-}a)(b)P_3 + (a)(b)P_4$

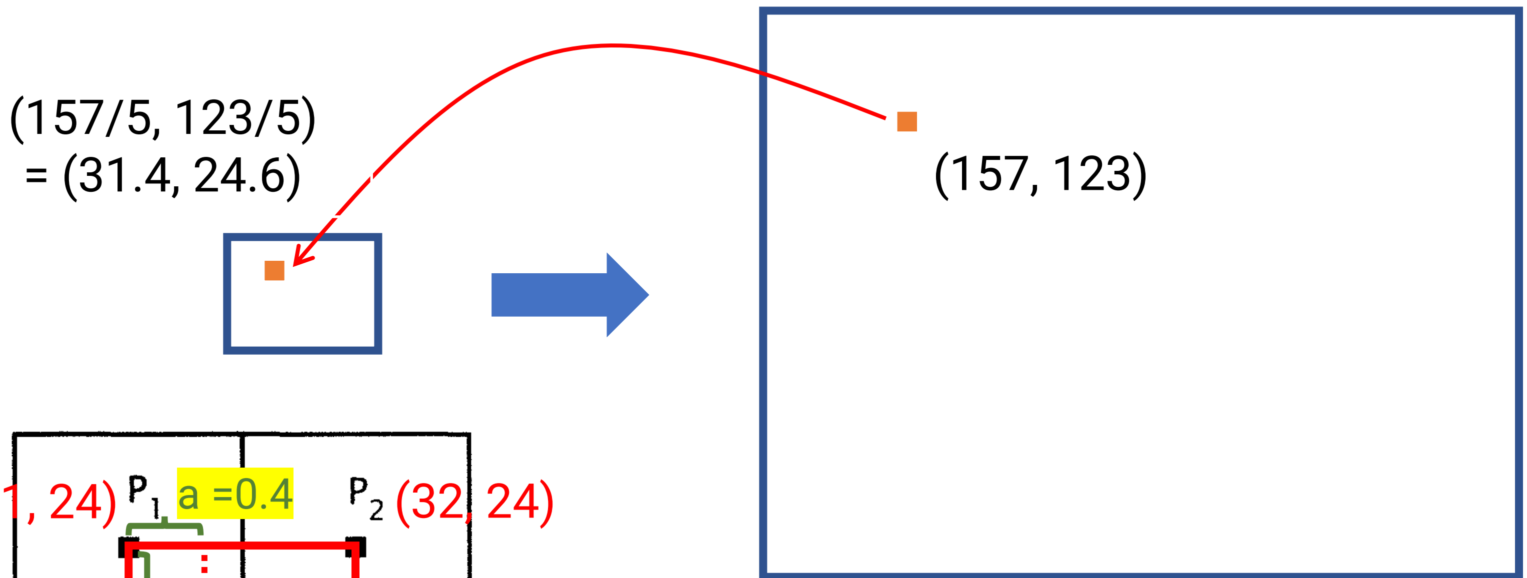


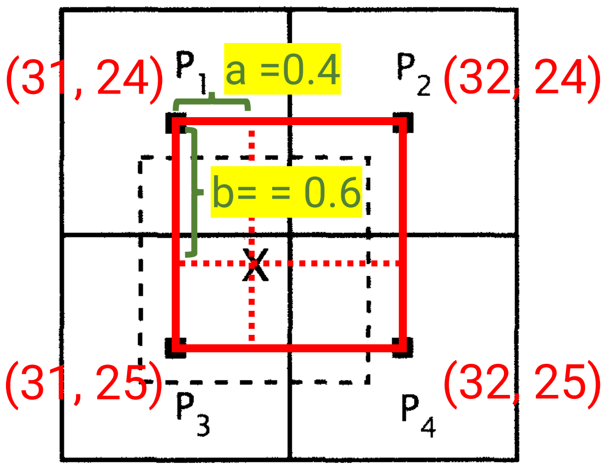

**bicubic interpolation**

using curve to
compute weight
(nonlinear)

# Image Scaling (cont.)

- Example: scale an image from 160 x 120 to 800 x 600




**nearest neighbor: use color of (31,25)**

**bilinear: compute**

$$(1\text{-}a)(1\text{-}b)P_1 + (a)(1\text{-}b)P_2 + (1\text{-}a)(b)P_3 + (a)(b)P_4$$

0.24 0.16 0.36 0.24

# Image Scaling (cont.)

- Example

nearest neighbor

bilinear interpolation

bicubic interpolation

# Image Scaling (cont.)

- Example

nearest neighbor

bilinear interpolation

bicubic interpolation

original  × 10

# Image Scaling (cont.)

- Example

original

nearest neighbor

bilinear interpolation

bicubic interpolation

# Image Scaling (cont.)

- OpenCV

```
void cvResize(
        const CvArr* src,
        const CvArr* dst,
        int interpolation = CV_INTER_LINEAR
);
```

interpolation can be

*CV_INTER_NN, CV_INTER_LINEAR, CV_INTER_CUBIC*