# Digital Image Processing (CSE/ECE 478)

# Lecture # 03: Spatial Filtering

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# What we have seen so far!

1. Intensity Transformation Functions

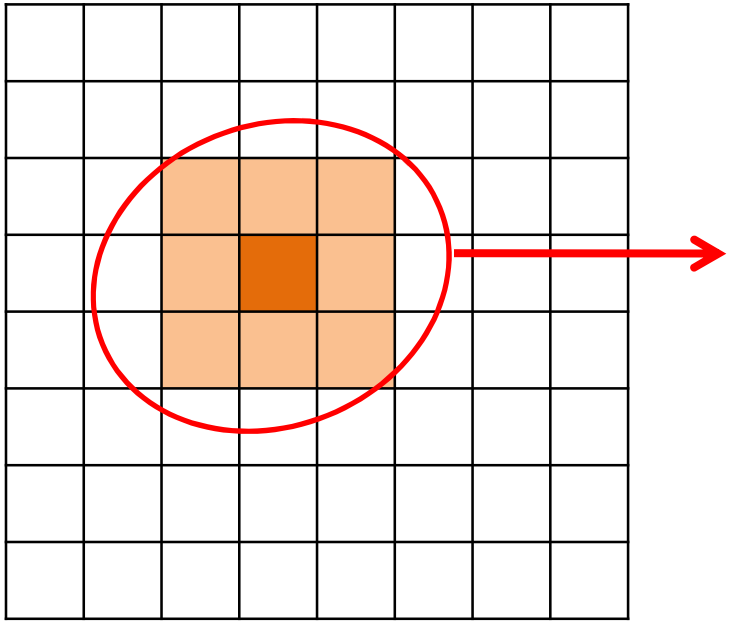
2. Histogram Processing

Spatial Filtering

# The idea of neighbourhood

- 4 neighbours, 8 neighbours
- Focus of this lecture is on spatial filtering
- More when we study morphological operations

# Spatial Filtering



| | | |
|---|---|---|
| f(x-1,y-1) | f(x-1,y) | f(x-1,y+1) |
| f(x,y-1) | f(x,y) | f(x,y+1) |
| f(x+1,y-1) | f(x+1,y) | f(x+1,y+1) |

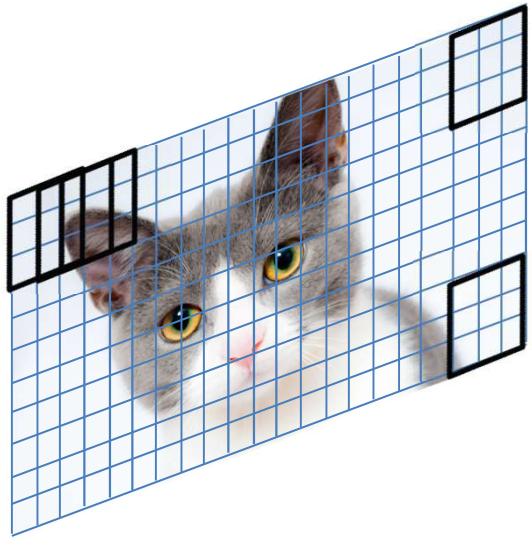
3 × 3 mask

| | | |
|---|---|---|
| w(-1,-1) | w(-1,0) | w(-1,1) |
| w(0,-1) | w(0,0) | w(0,1) |
| w(1,-1) | w(1,0) | w(1,1) |

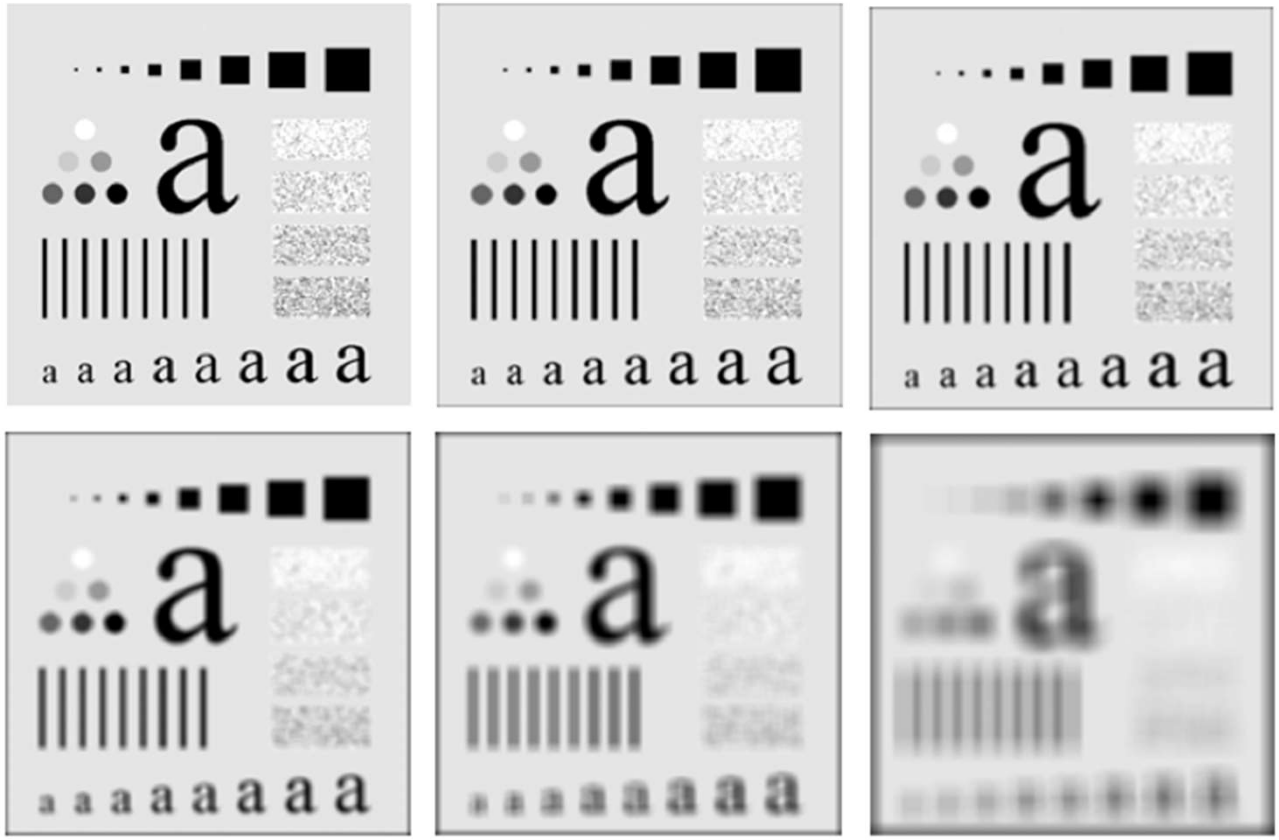
$$g(x.y) = w(-1,-1)f(x-1,y-1) + w(-1,0)f(x-1,y)... \\ + w(0,0)f(x,y) + ... + w(1,1)f(x+1,y+1)$$

# Convolution of Spatial Filter Mask

- Mask is centered around every pixel one by one.
- Zero padding can be done for pixels around edges.
- The special convolution can be replaced by multiplication in Fourier domain.



# Smoothing Linear Filters

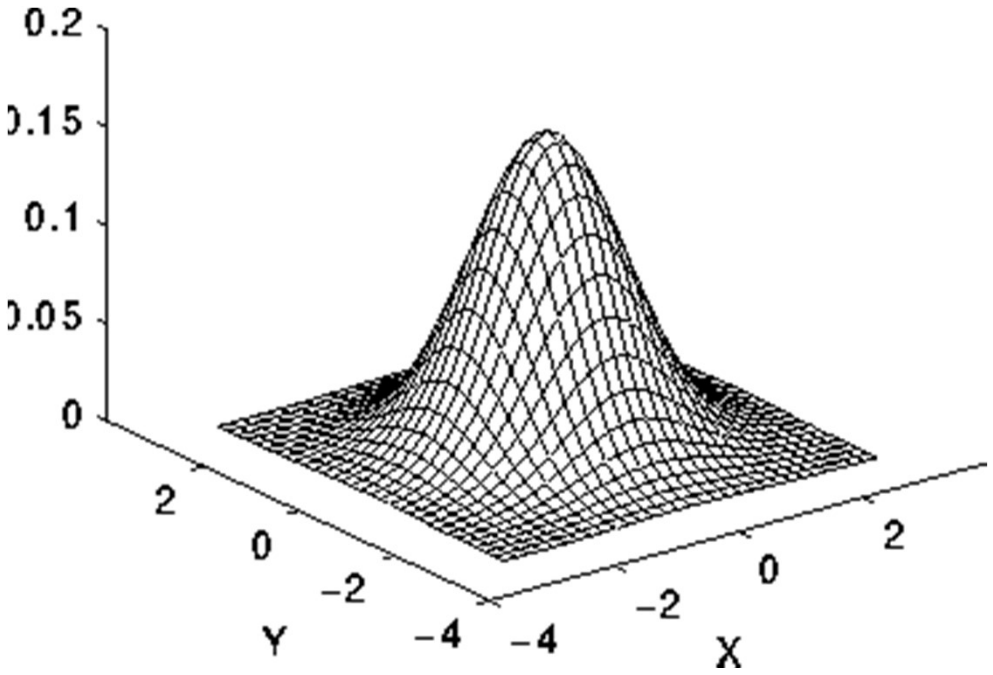


$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Square averaging filter mask size: 3,5,9,15,35

Image Courtesy: Gonzalez and Woods

# Smoothing Gaussian Filters




$$\frac{1}{265}$$

| | | | | |
|---|---|---|---|---|
| 1 | 4 | 6 | 4 | 1 |
| 4 | 16 | 26 | 16 | 4 |
| 6 | 26 | 43 | 26 | 6 |
| 4 | 16 | 26 | 16 | 4 |
| 1 | 4 | 6 | 4 | 1 |

5×5 Gaussian filter, σ=1

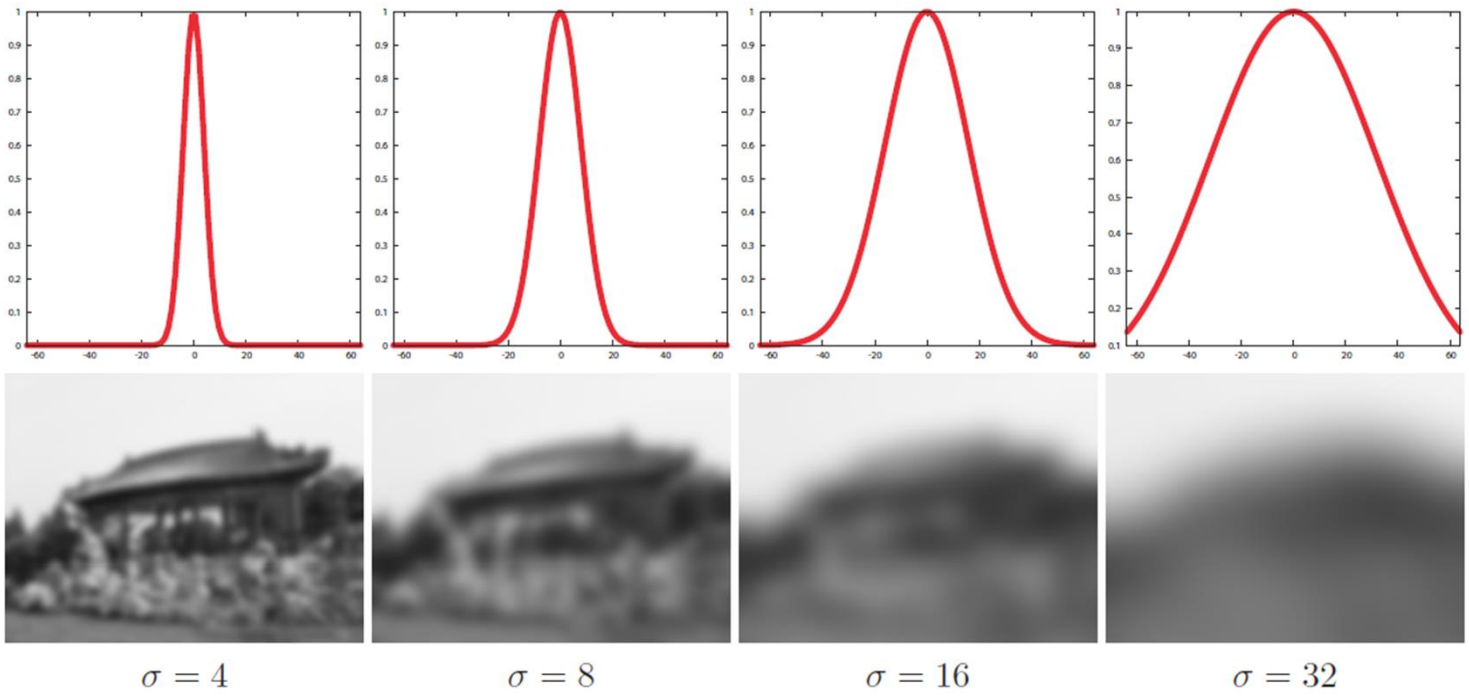
Image Courtesy: Gonzalez and Woods

# Smoothing Gaussian Filters

5×5 Gaussian filter, σ=1

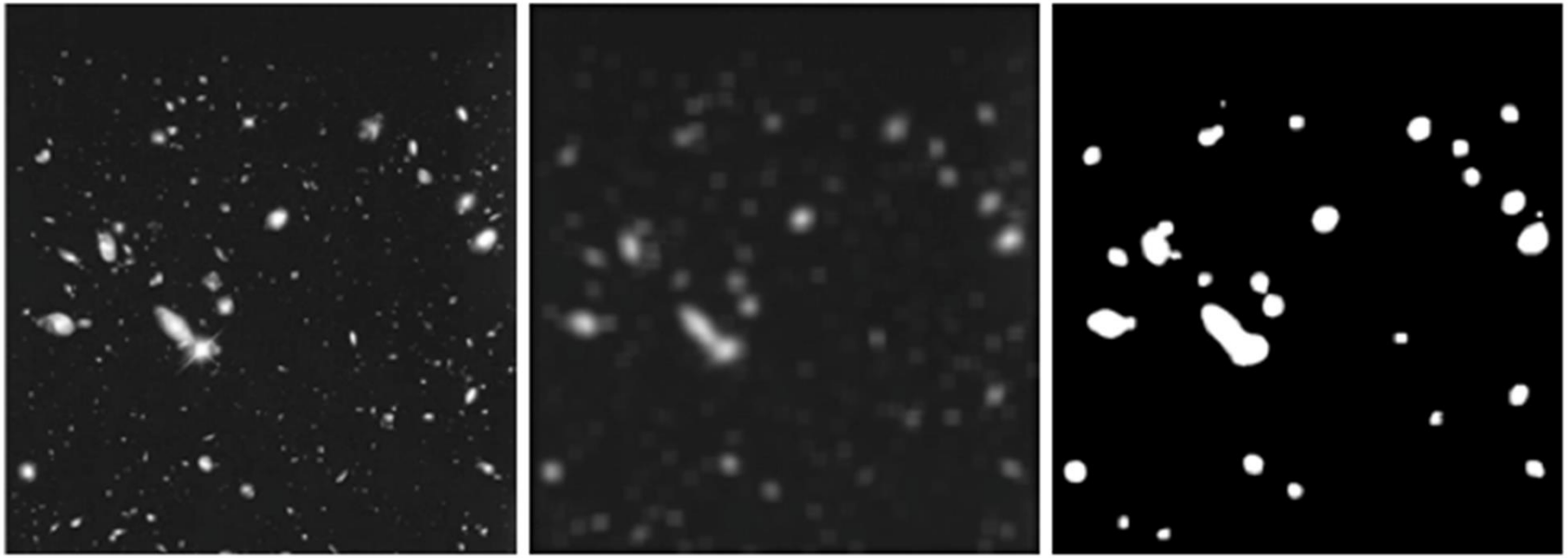
5×5 Gaussian filter, σ=3

# Smoothing Gaussian Filters




Source: Sylvain Paris

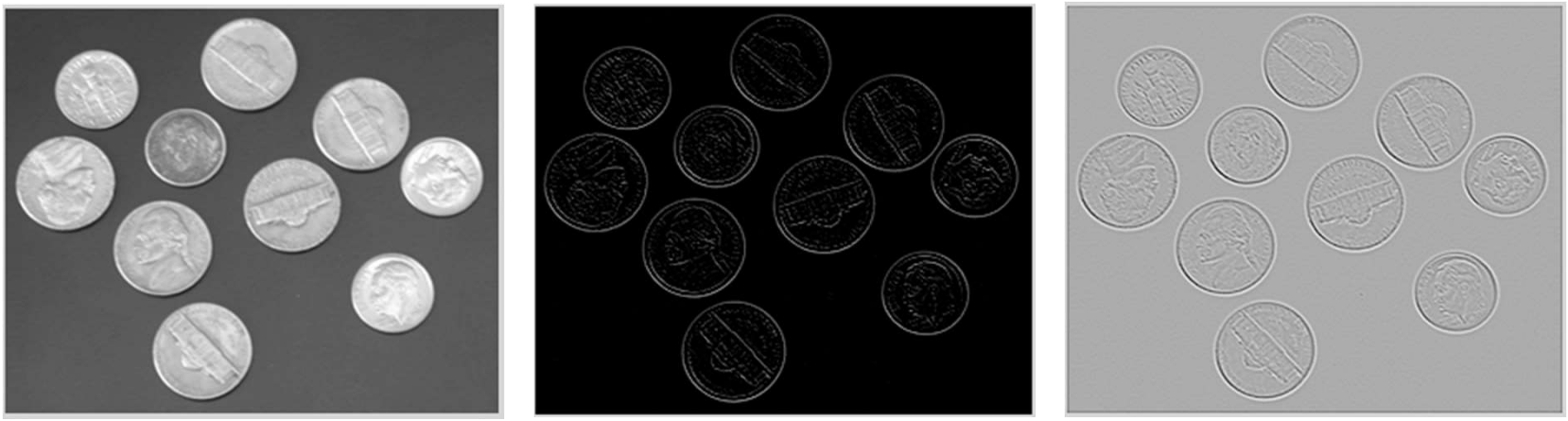
# Smoothing Linear Filters



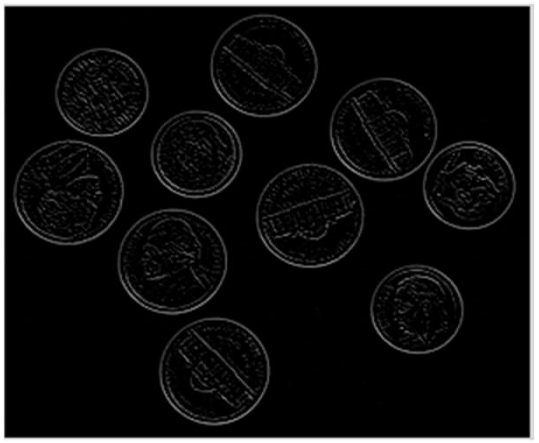
Application for Noise removal using 15×15 mask

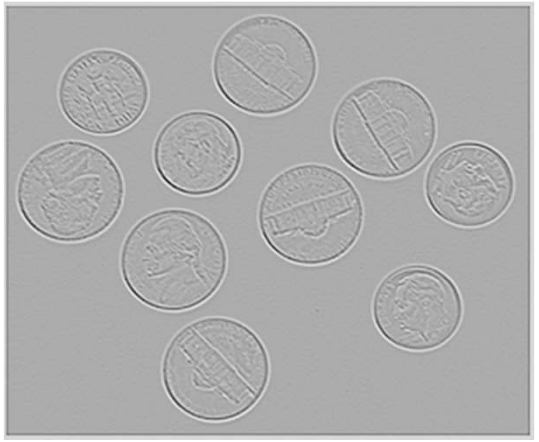
Image Courtesy: Gonzalez and Woods

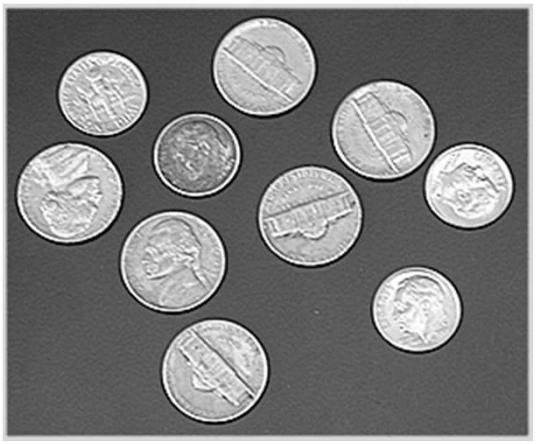
# Sharpening with Laplacian Filters



# Laplacian Filters







# Sharpening with Laplacian Filters

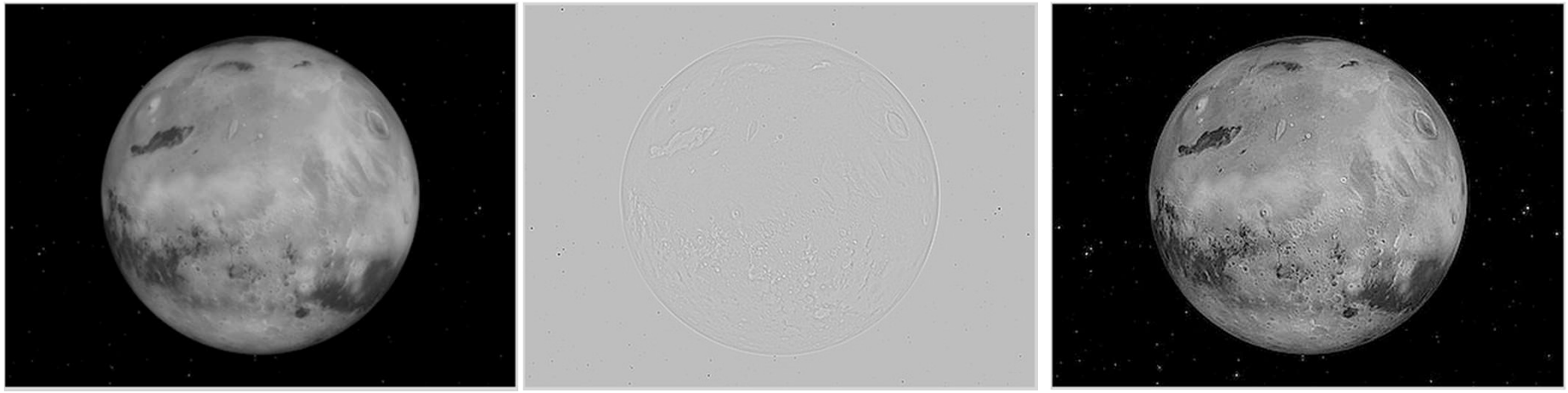
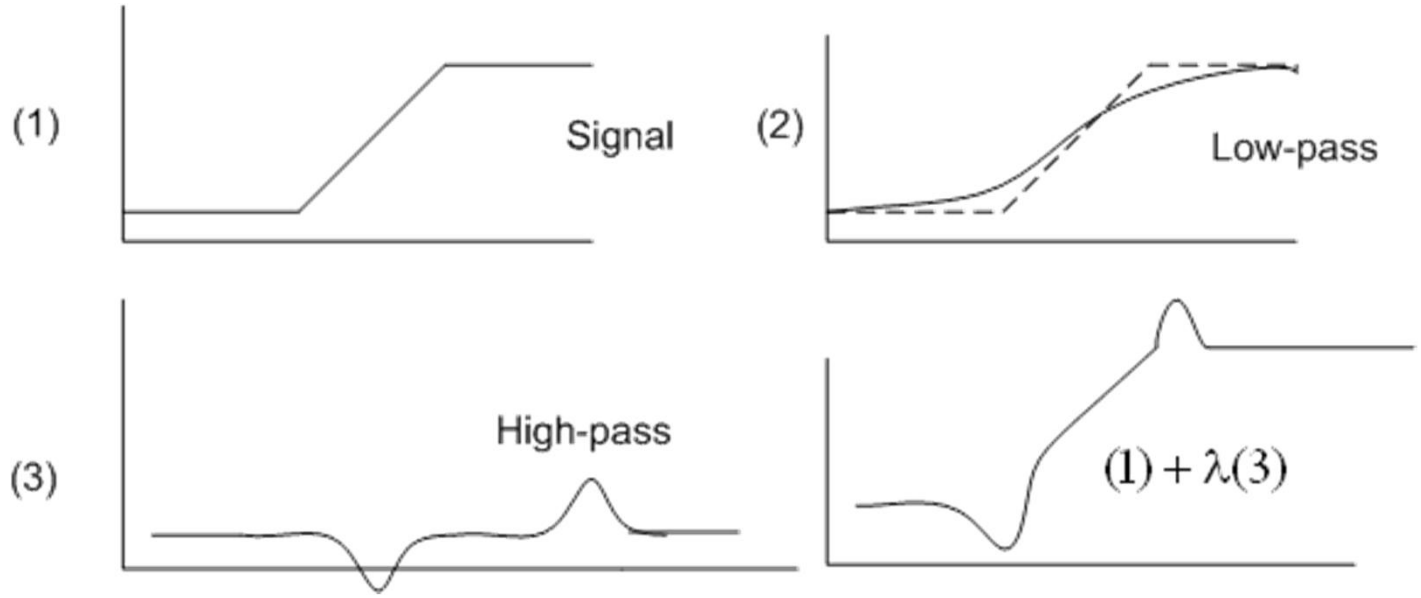


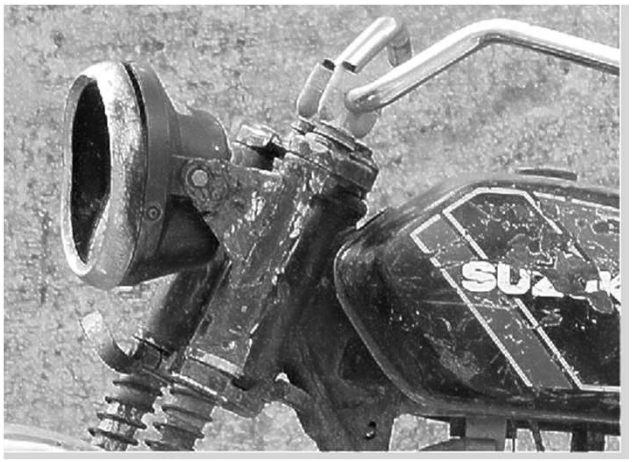
Image Courtesy: NASA

# Unsharp Masking (and Highboost Filtering)

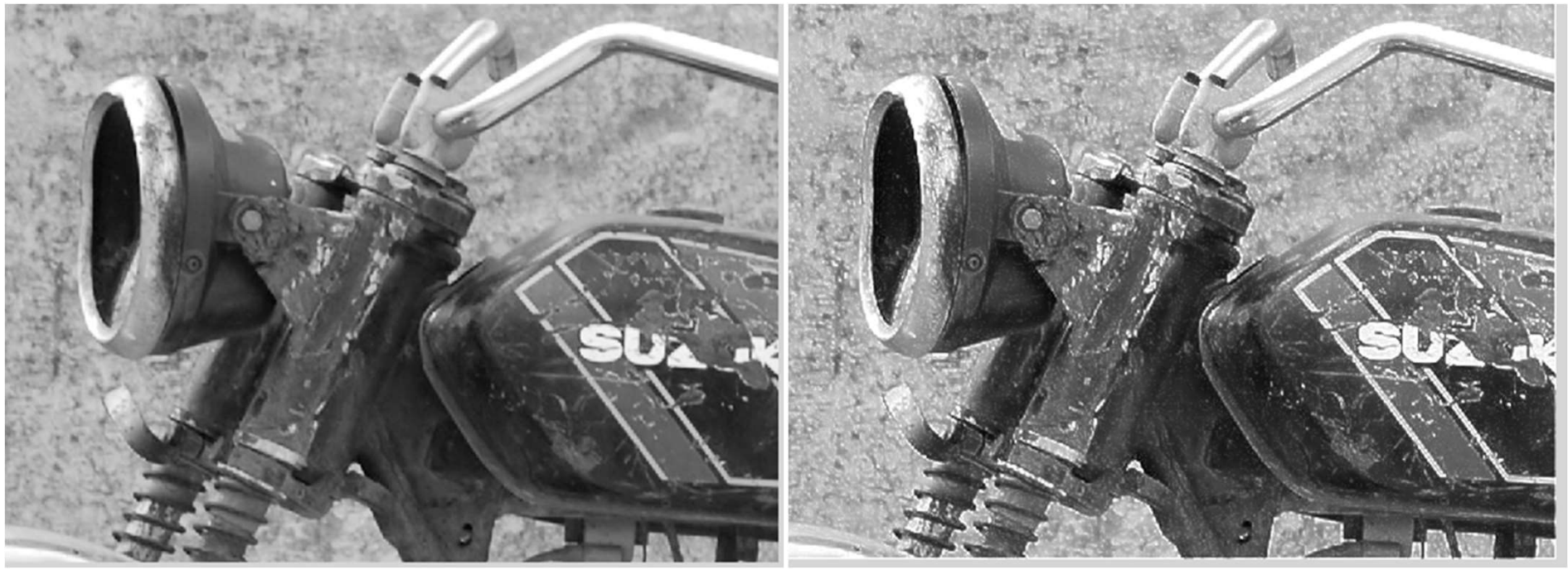



$$g_{mask}(x,y) = f(x,y) - \bar{f}(x,y), \quad g(x,y) = f(x,y) + k * g_{mask}(x,y).$$

# Unsharp Masking (and Highboost Filtering)



# Unsharp Masking (and Highboost Filtering)



# Unsharp Masking (and Highboost Filtering)

# Other Spatial Filters (first order derivative)

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

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

Robert Cross Gradient Operator

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

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

Sobel Gradient Operator

# Other Spatial Filters

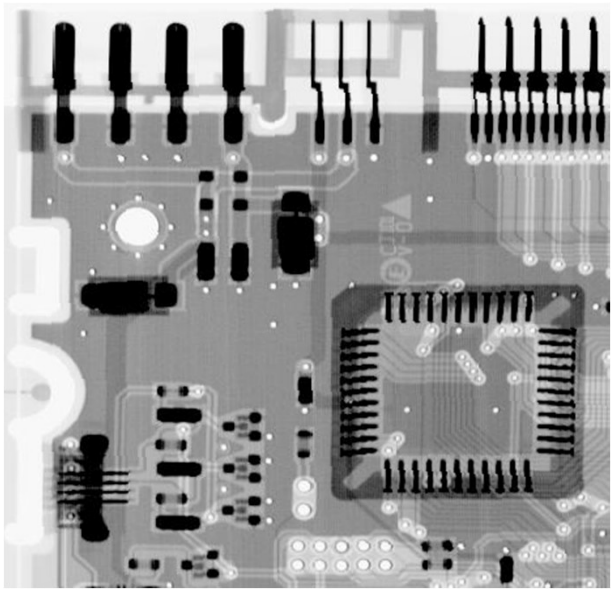
| | |
|---|---|
| +1 | 0 |
| 0 | -1 |

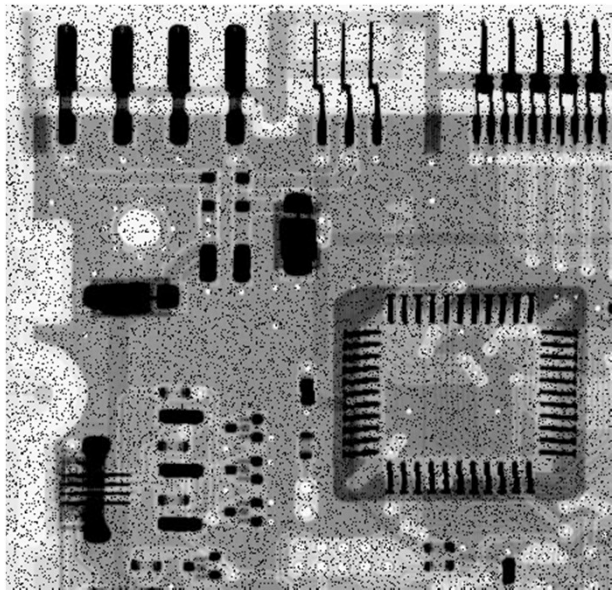
| | |
|---|---|
| 0 | +1 |
| -1 | 0 |

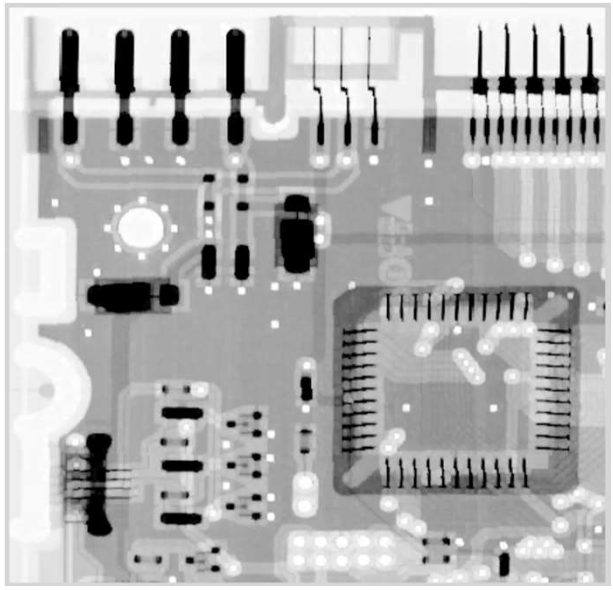
| | | |
|---|---|---|
| -1 | 0 | +1 |
| -2 | 0 | +2 |
| -1 | 0 | +1 |

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

# Other Spatial Filters (non linear)

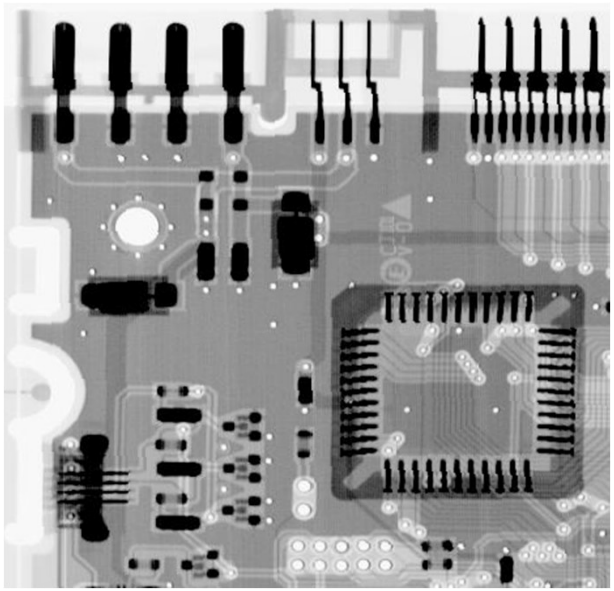


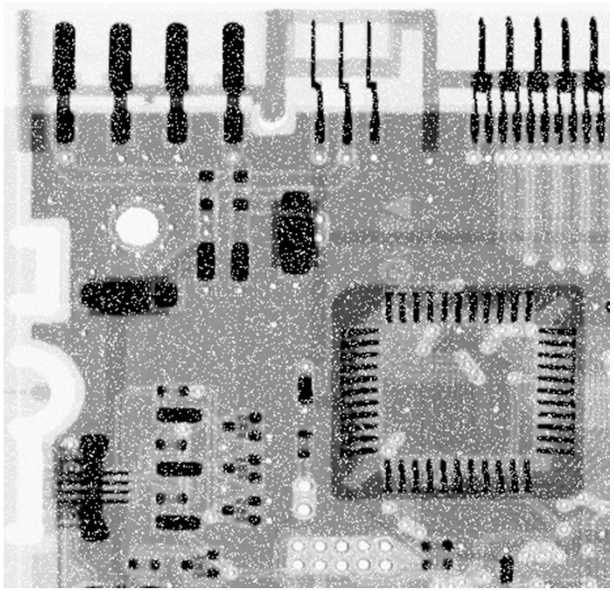


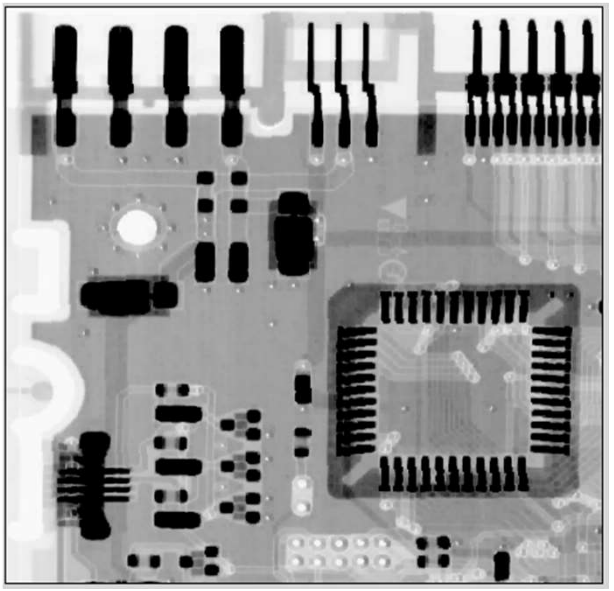


**max filter**

# Other Spatial Filters (non linear)

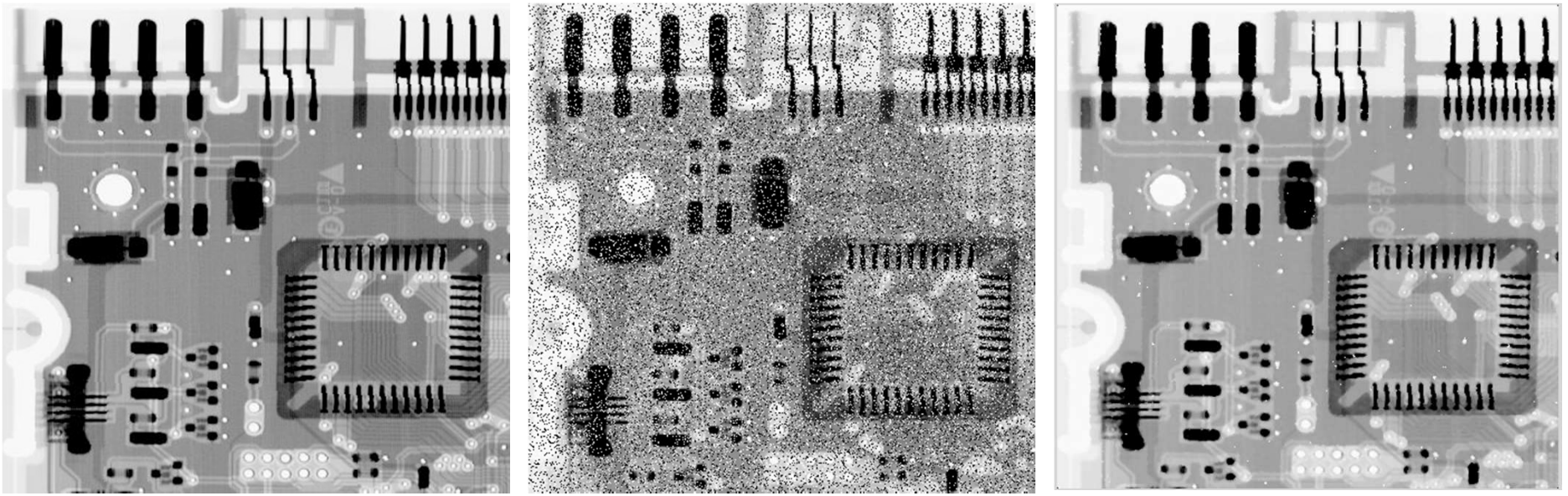






**min filter**

# Other Spatial Filters (median filter – non linear)



max, min, median → also known as order statistic filters

# Other Spatial Filters

- Geometric mean
- Harmonic mean
- Contra harmonic mean
- Mid Point filter
- Alpha trimmed mean filter
- …..

More details when we will study advanced noise removal techniques

# Bilateral Filtering

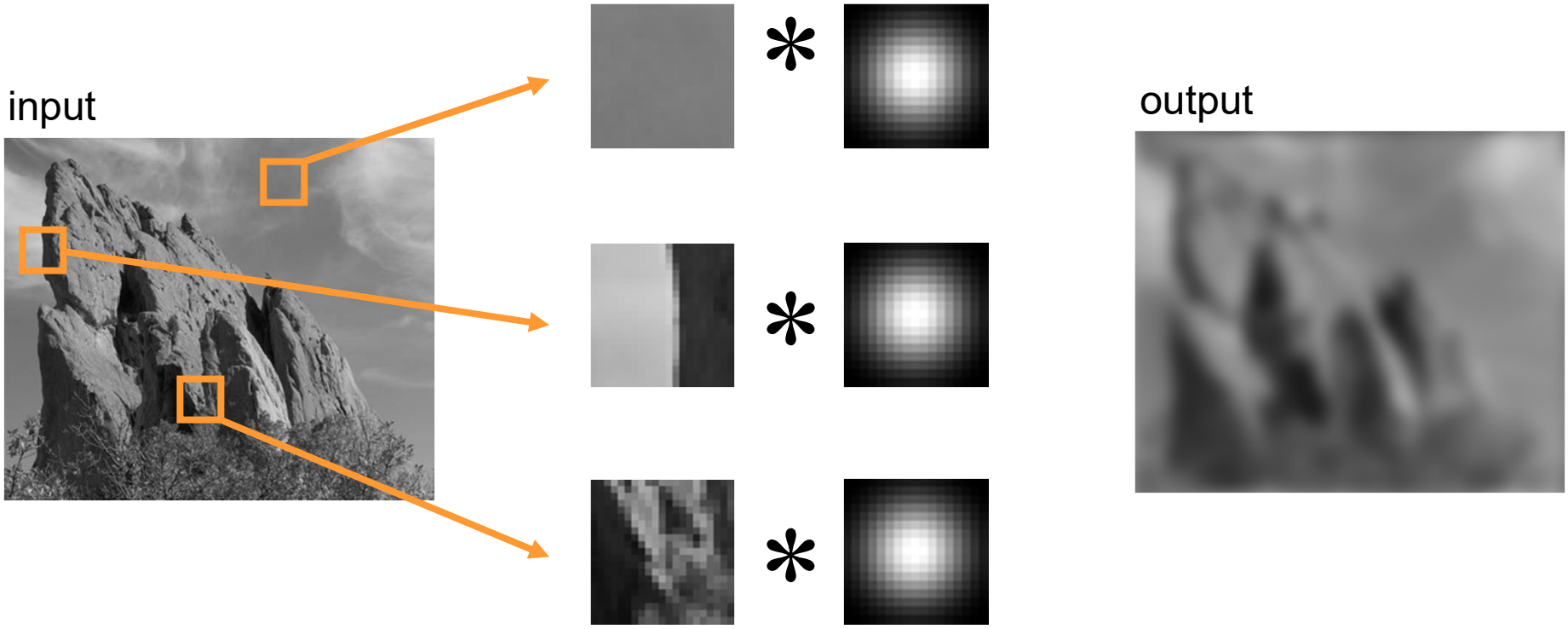
Original image taken from cs.cityu.edu.hk

# Bilateral Filtering

Original image from mfullywoodco.hol.es

# Bilateral Filtering

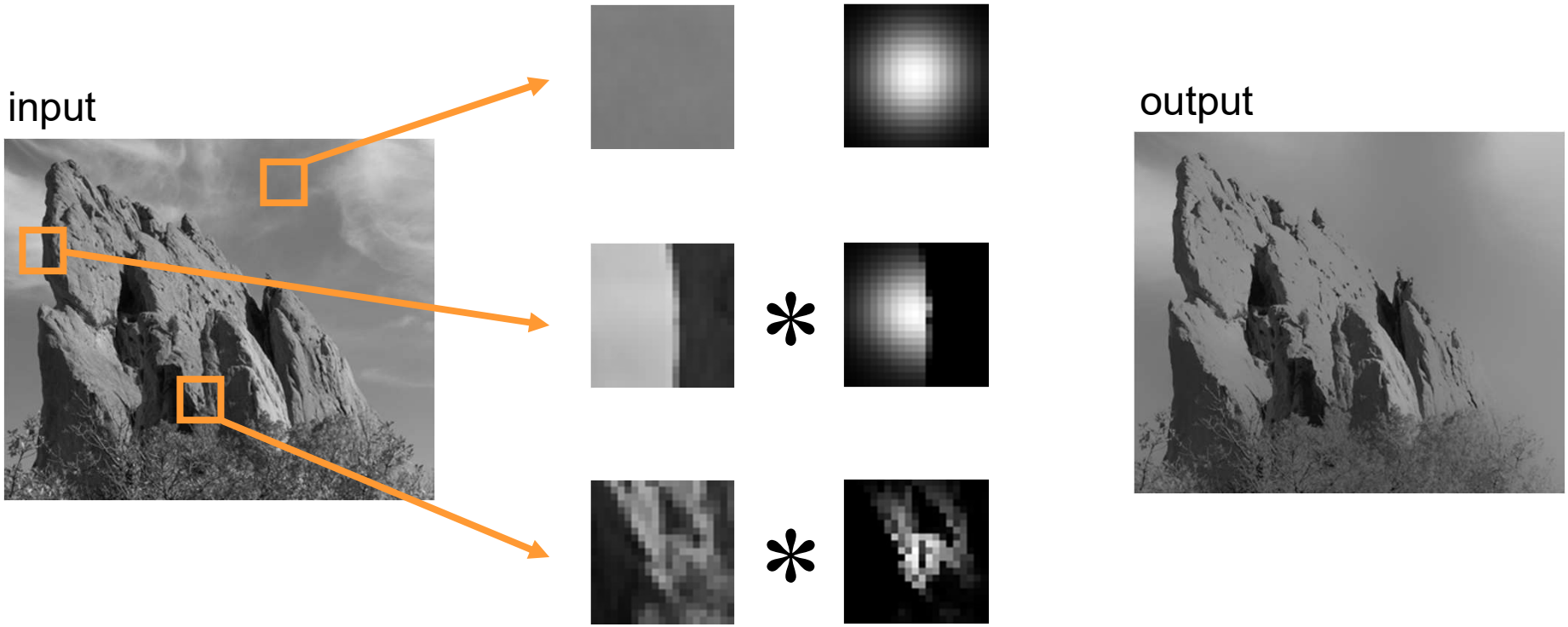
# Usual Gaussian Filtering




Same Gaussian kernel everywhere.

Source: Sylvain Paris

# Bilateral Filtering




The kernel shape depends on the image content.

Source: Sylvain Paris

# Bilateral Filtering

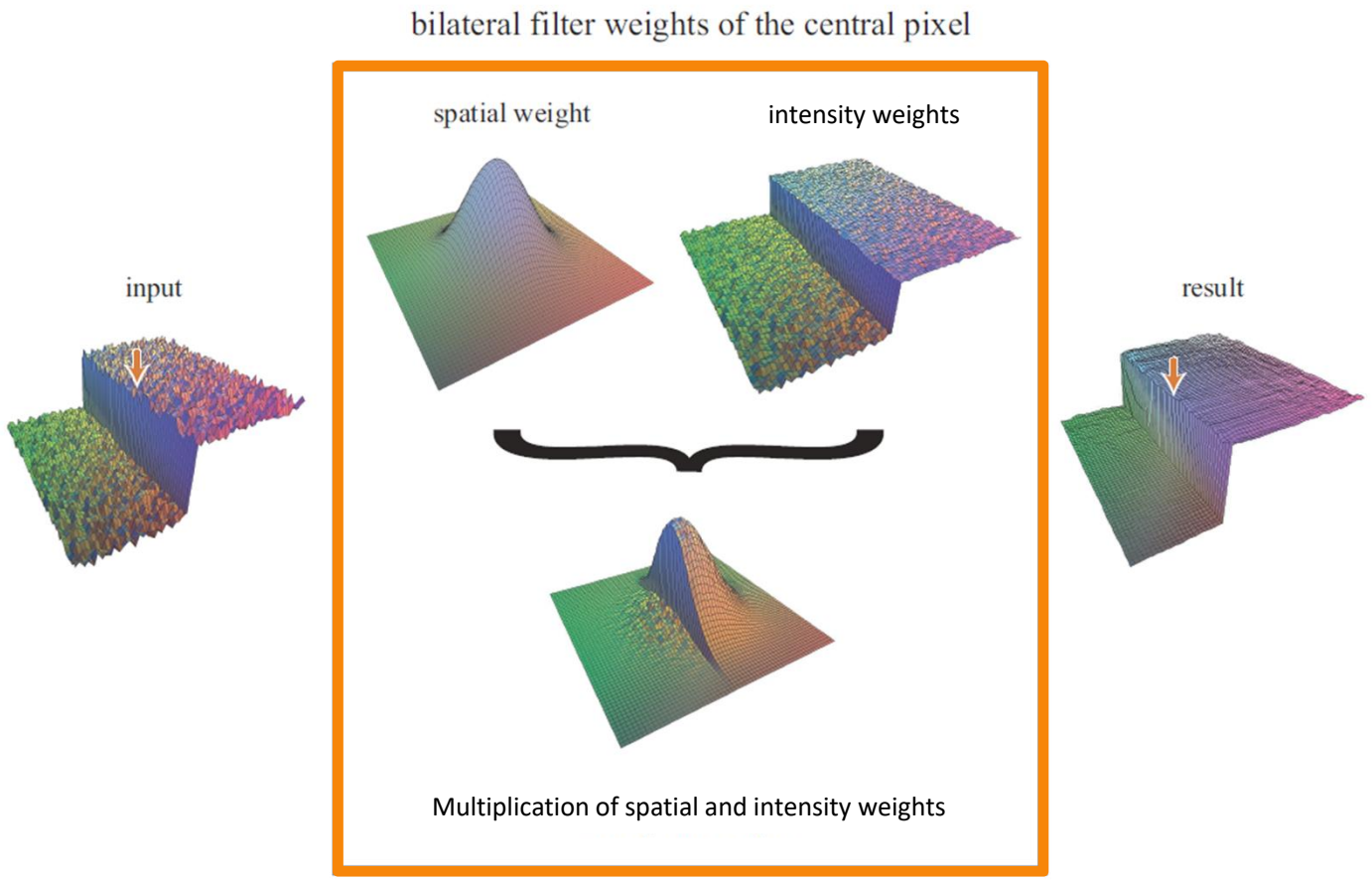
- Bilateral Filter $BF[.]$

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

$$W_{\mathbf{p}} = \sum_{\mathbf{q} \in \mathcal{S}} G_{\sigma_s}(\|\mathbf{p} - \mathbf{q}\|)\, G_{\sigma_r}(I_{\mathbf{p}} - I_{\mathbf{q}})$$

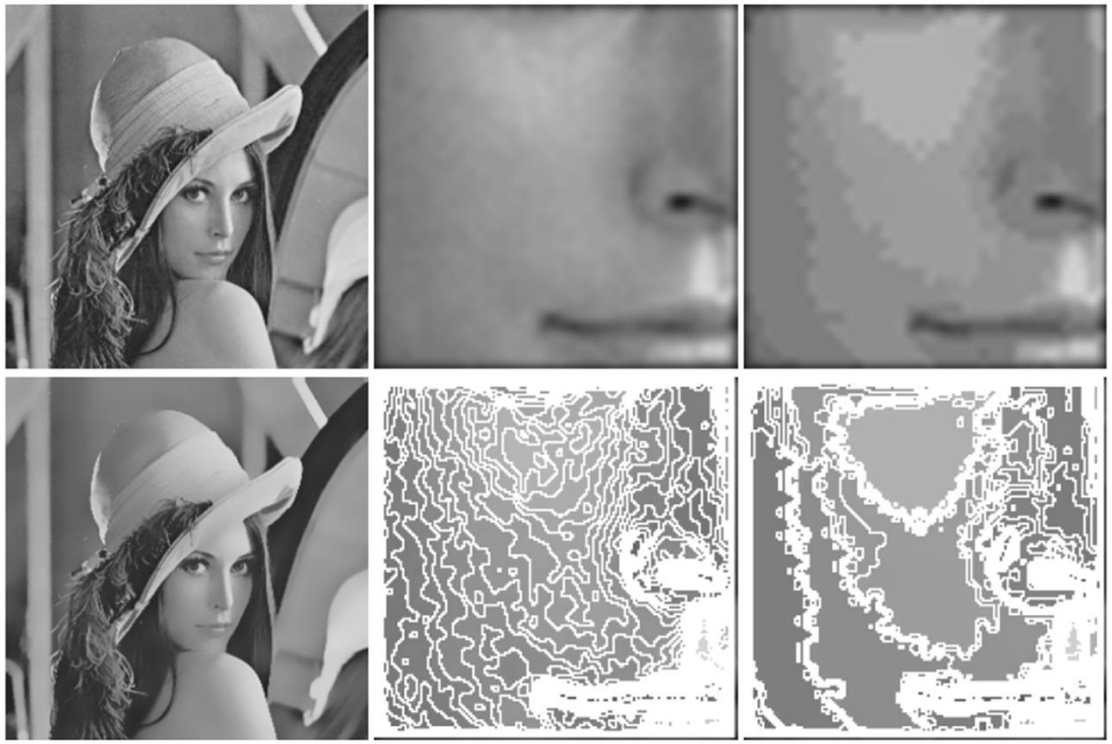
Source: Sylvain Paris

# Bilateral Filtering




Source: Sylvain Paris

# Bilateral Filtering



Source: Sylvain Paris

Noisy input

Bilateral filter 7x7 window

Source: Sylvain Paris

Bilateral filter

Median 3x3

Bilateral filter

Median