

**A Gentle Introduction
to Bilateral Filtering
and its Applications**

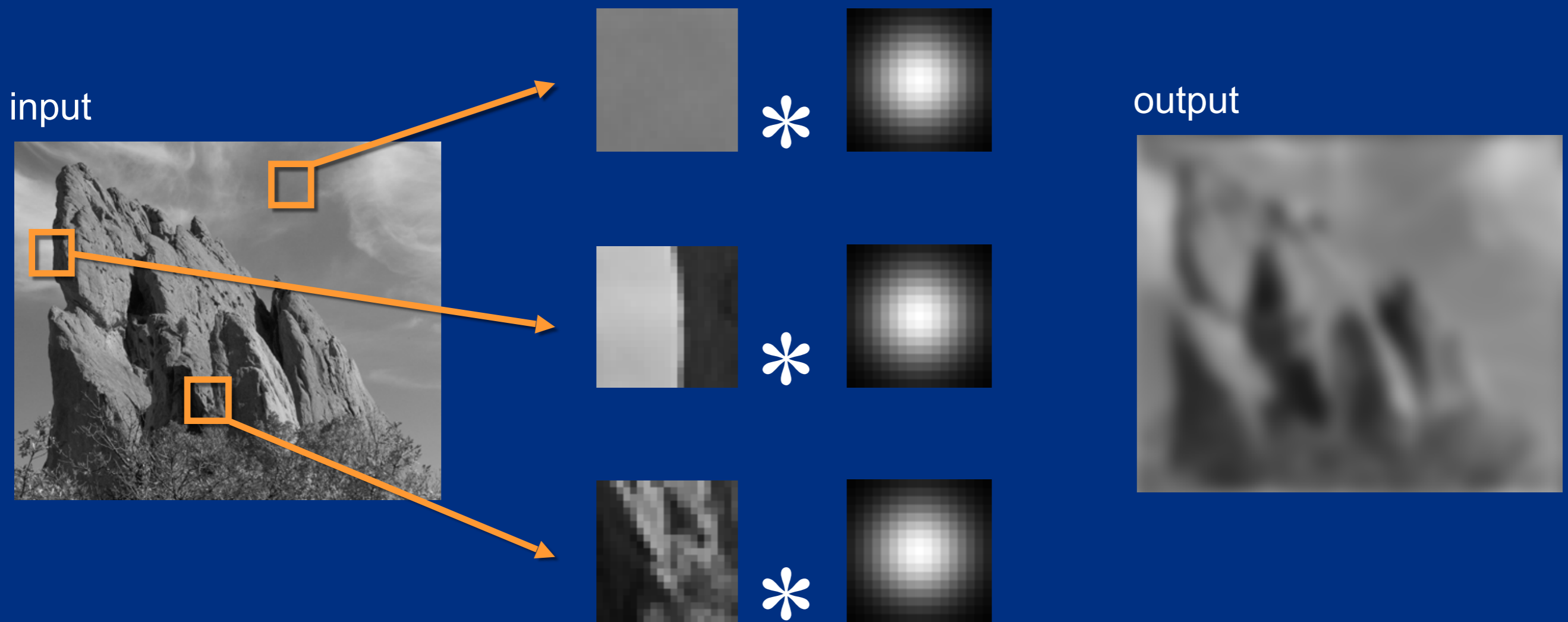


SIGGRAPH2007

**“Fixing the Gaussian Blur”:
the Bilateral Filter**

Sylvain Paris – MIT CSAIL

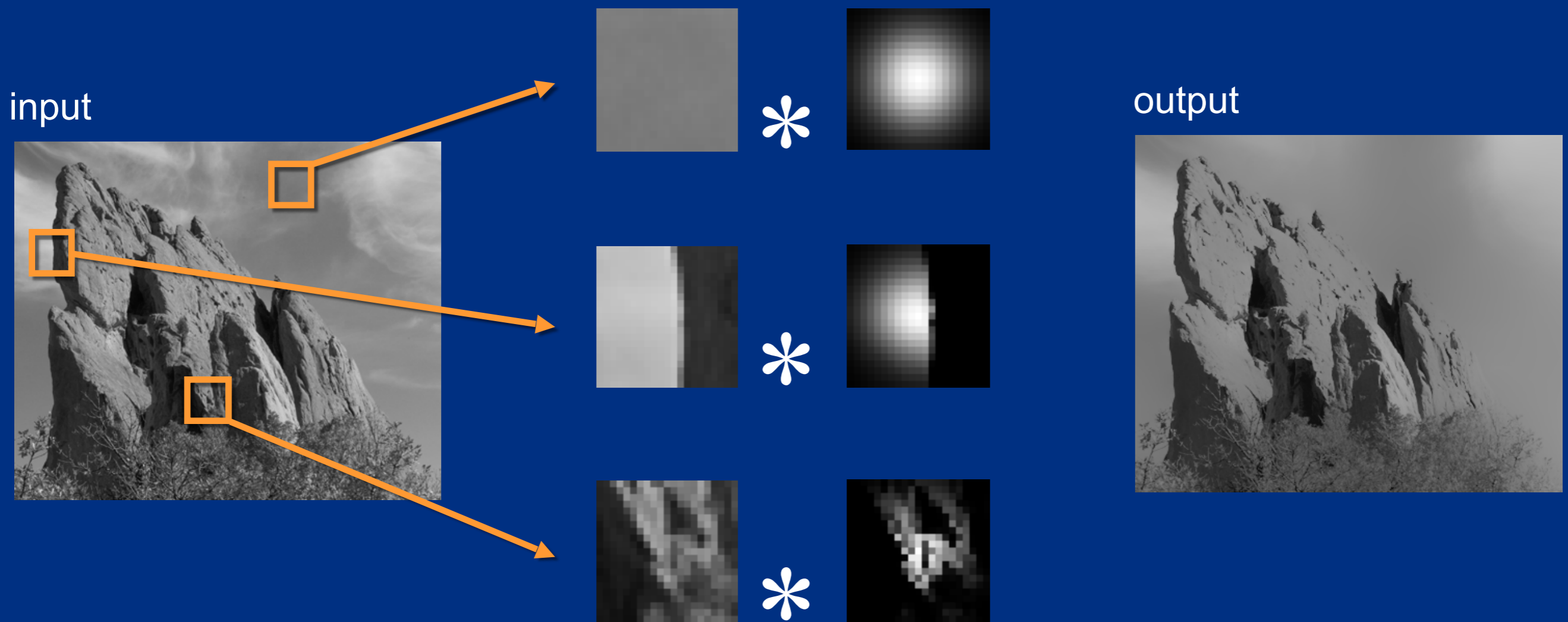
Blur Comes from Averaging across Edges



Same Gaussian kernel everywhere.

Bilateral Filter [Aurich 95, Smith 97, Tomasi 98]

No Averaging across Edges



The kernel shape depends on the image content.

Bilateral Filter Definition: an Additional Edge Term

Same idea: weighted average of pixels.

$$BF[I]_p = \overset{\text{new}}{\frac{1}{W_p}} \sum_{q \in S} \overset{\text{not new}}{G_{\sigma_s}(\|p - q\|)} \overset{\text{new}}{G_{\sigma_r}(|I_p - I_q|)} I_q$$

normalization factor *space* weight *range* weight

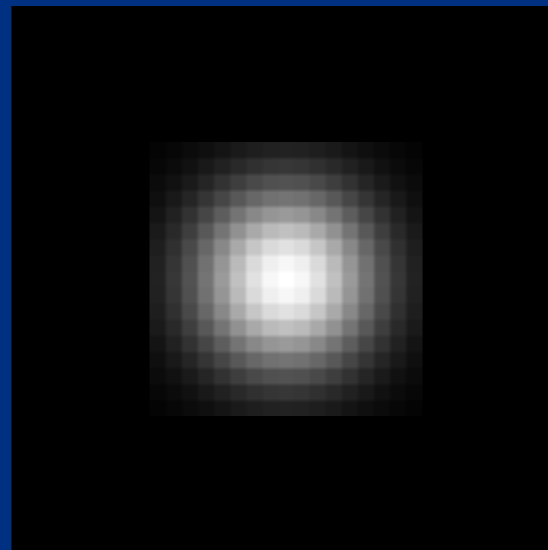
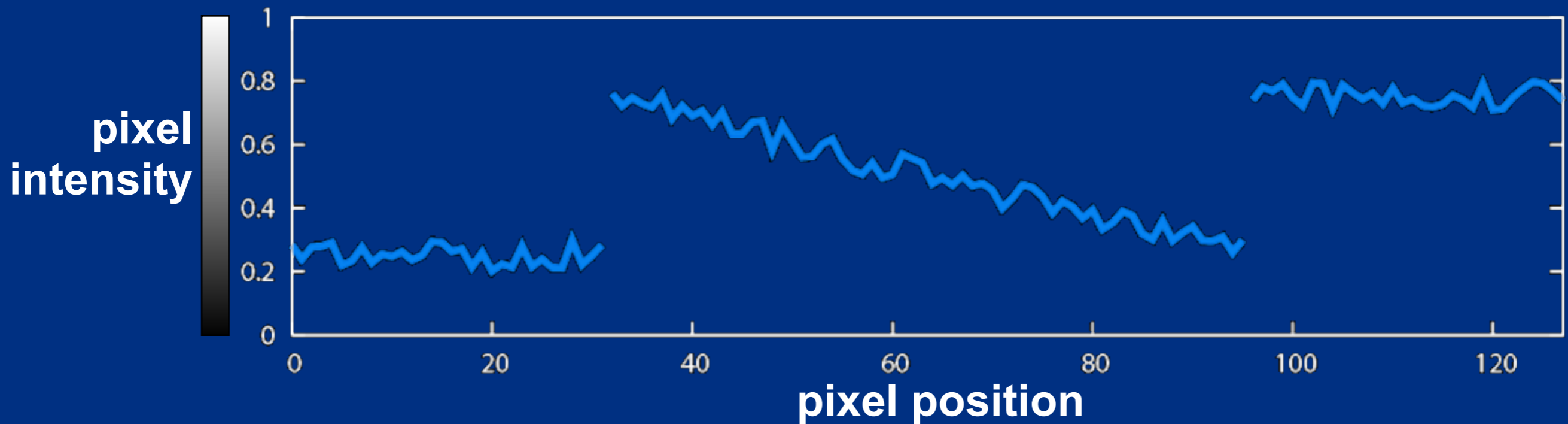


Illustration a 1D Image

- 1D image = line of pixels

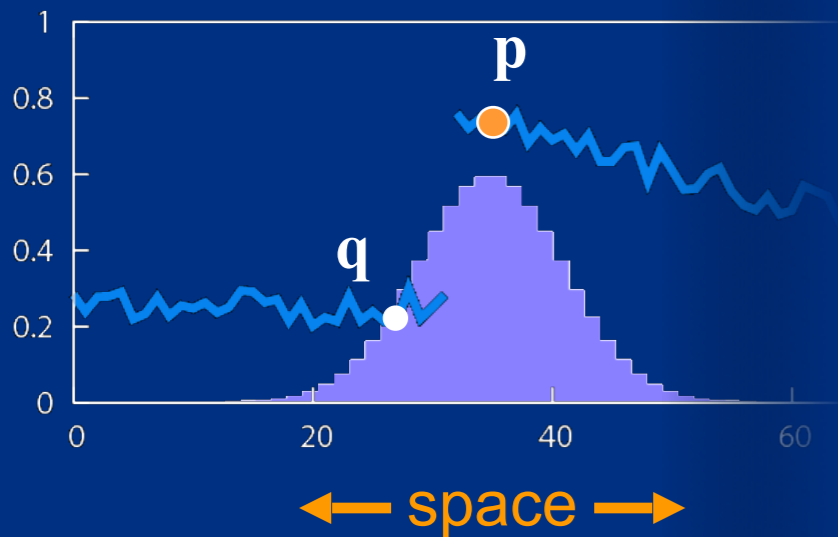


- Better visualized as a plot



Gaussian Blur and Bilateral Filter

Gaussian blur

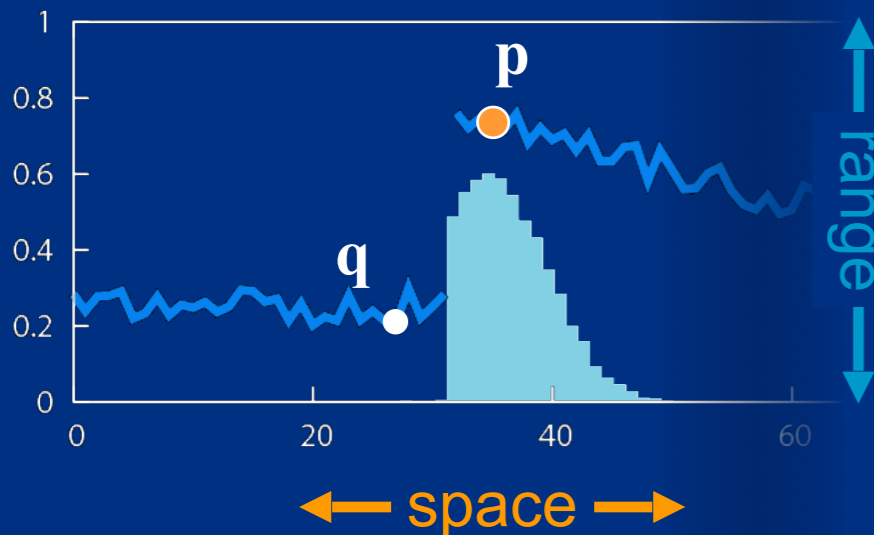


$$GB[I]_p = \sum_{q \in S} G_{\sigma}(\|p - q\|) I_q$$

space

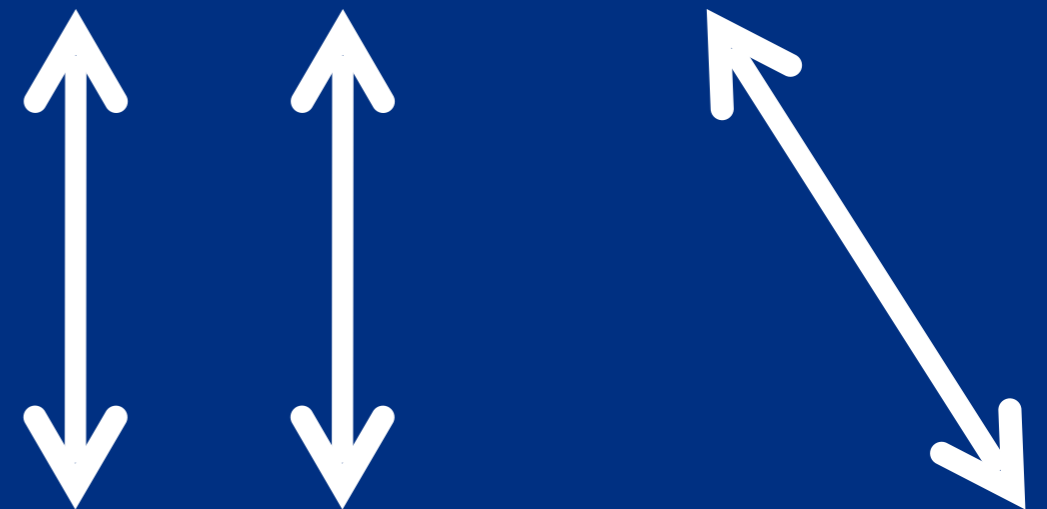
Bilateral filter

[Aurich 95, Smith 97, Tomasi 98]



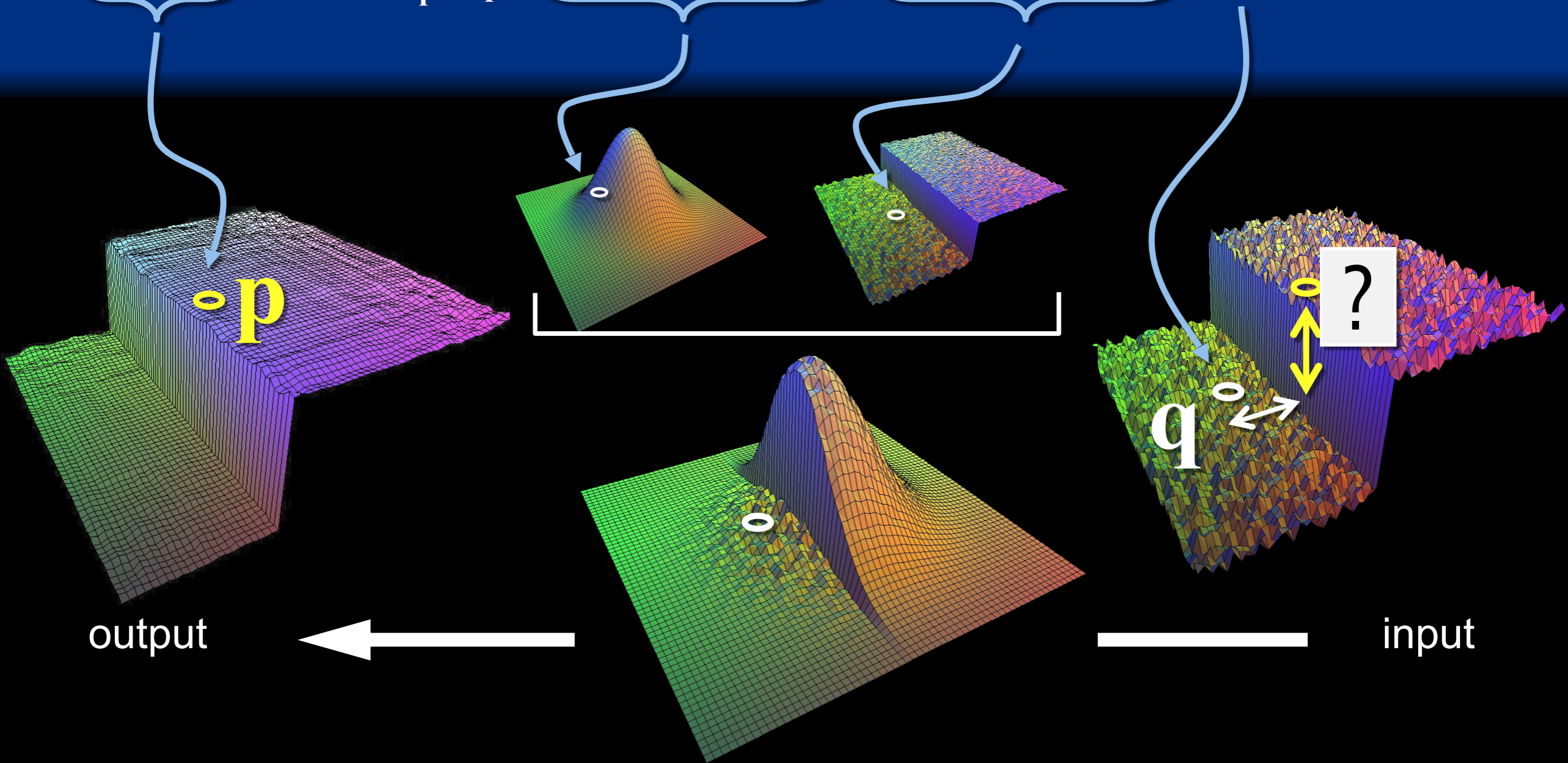
$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_s}(\|p - q\|) G_{\sigma_r}(|I_p - I_q|) I_q$$

normalization space range




Bilateral Filter on a Height Field

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in \mathcal{S}} \underbrace{G_{\sigma_s}(\|\mathbf{p} - \mathbf{q}\|)}_{\text{spatial}} \underbrace{G_{\sigma_r}(|I_p - I_q|)}_{\text{range}} I_q$$



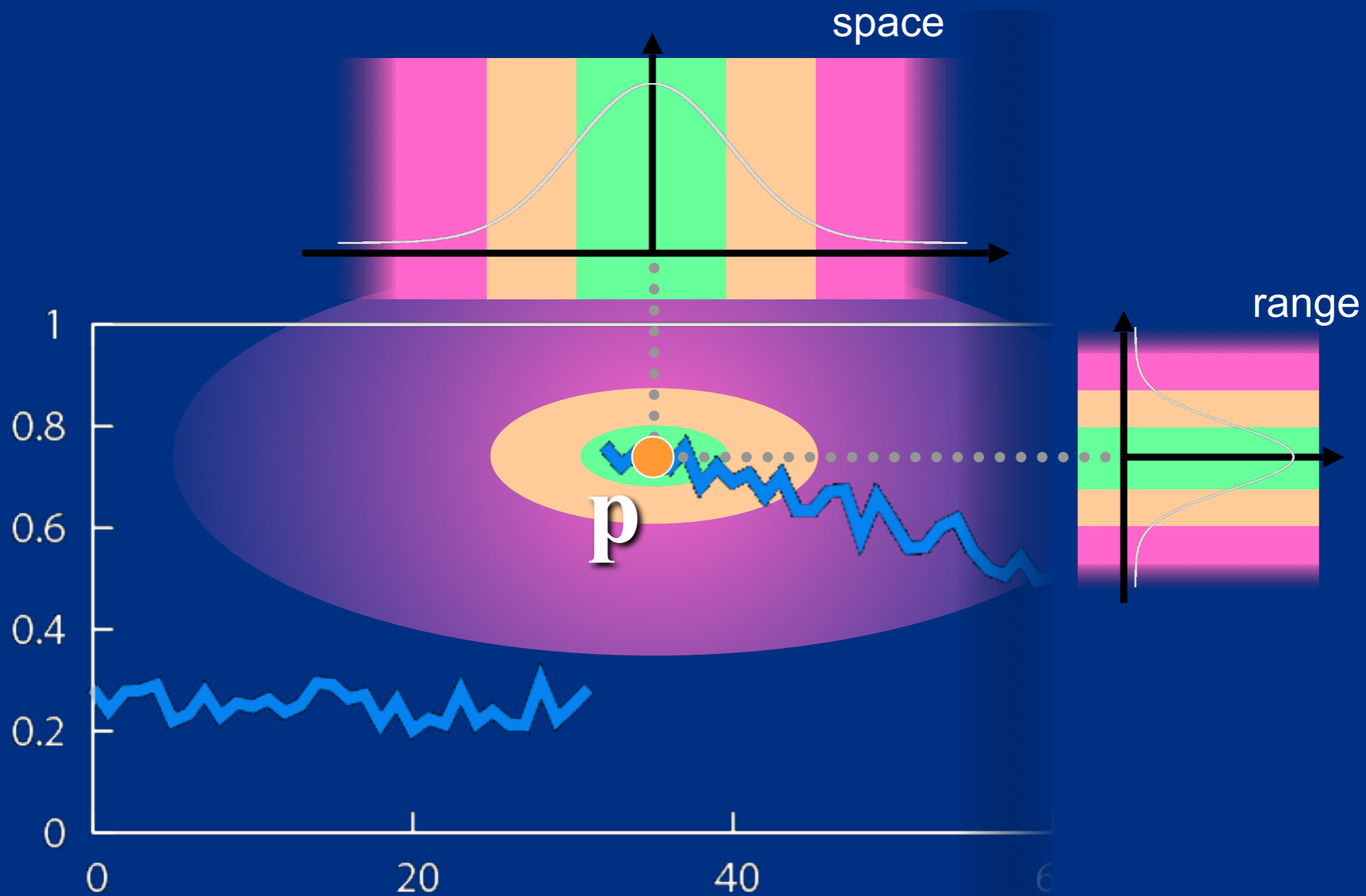
Space and Range Parameters

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_s}(\|\mathbf{p} - \mathbf{q}\|) G_{\sigma_r}(|I_p - I_q|) I_q$$


- space σ_s : spatial extent of the kernel, size of the considered neighborhood.
- range σ_r : “minimum” amplitude of an edge

Influence of Pixels

Only pixels close in space and in range are considered.



Exploring the Parameter Space



input

$$\sigma_r = 0.1$$

$$\sigma_r = 0.25$$

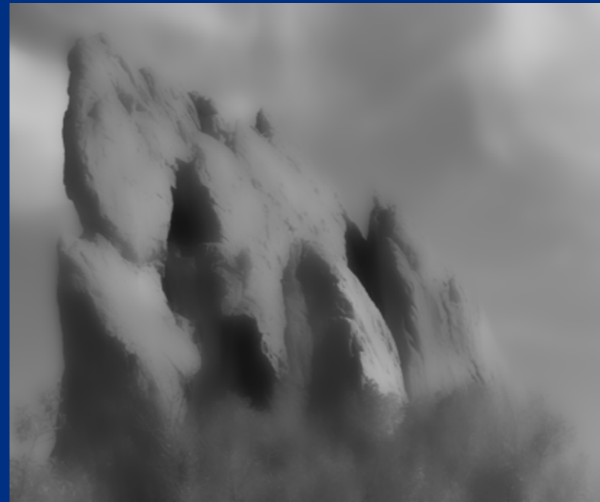
$$\sigma_r = \infty$$

(Gaussian blur)

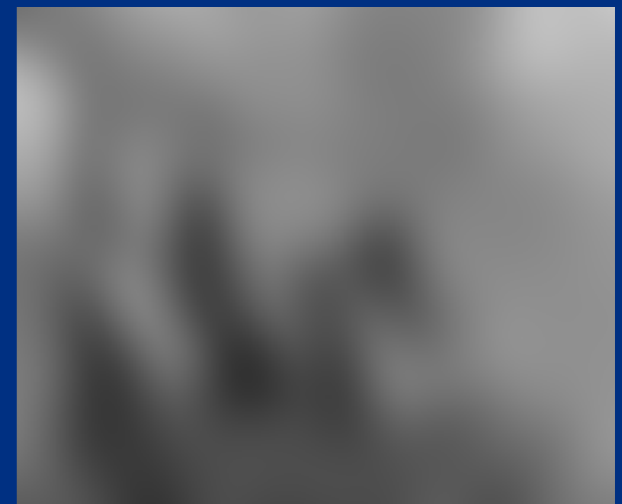
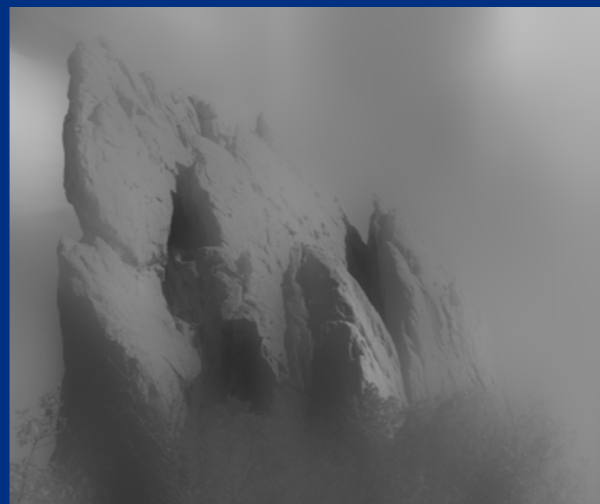
$$\sigma_s = 2$$



$$\sigma_s = 6$$



$$\sigma_s = 18$$



Varying the Range Parameter



input

$\sigma_s = 2$

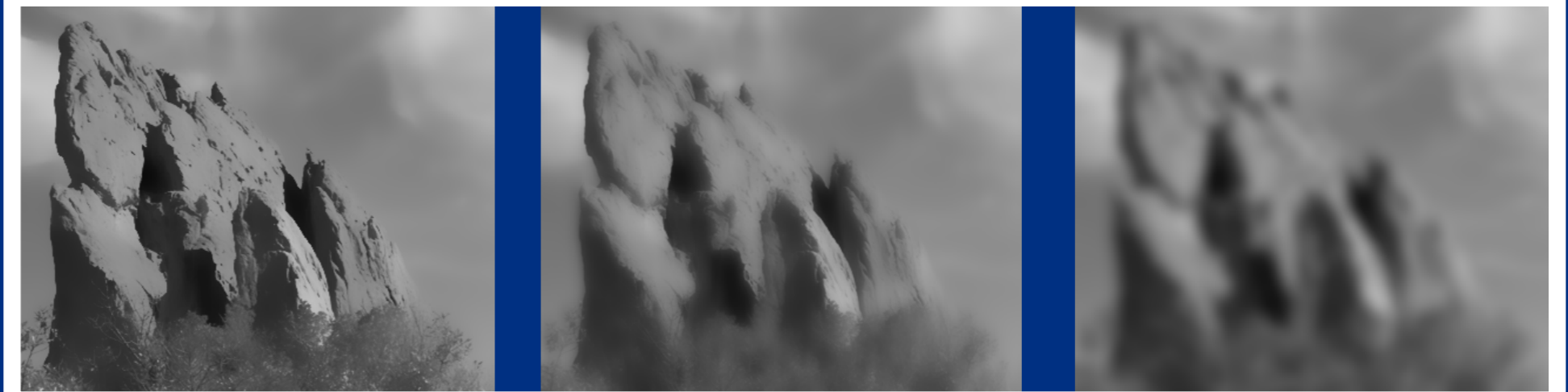
$\sigma_r = 0.1$

$\sigma_r = 0.25$

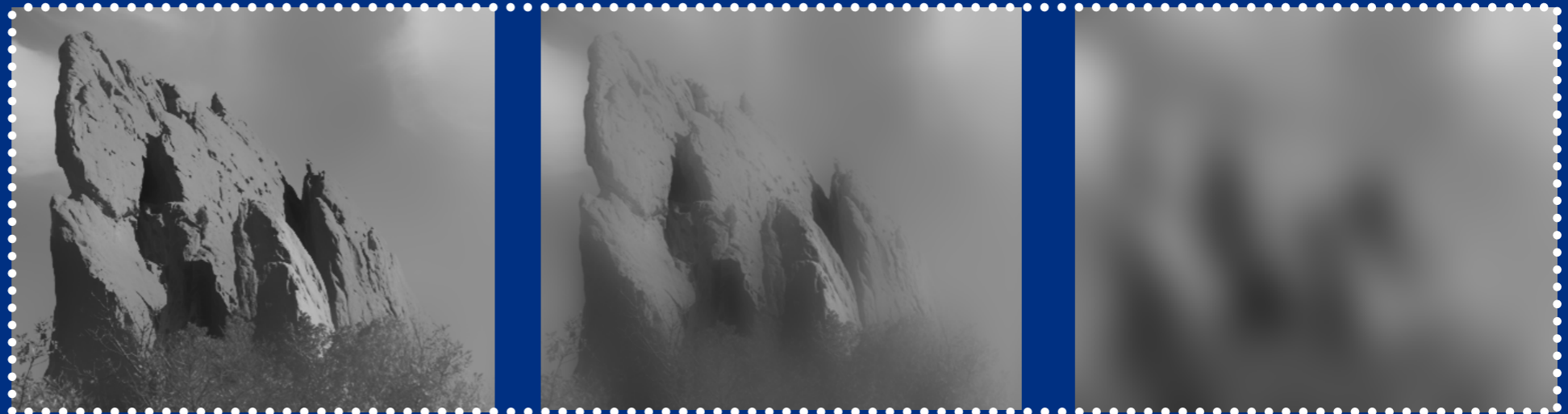
$\sigma_r = \infty$
(Gaussian blur)



$\sigma_s = 6$



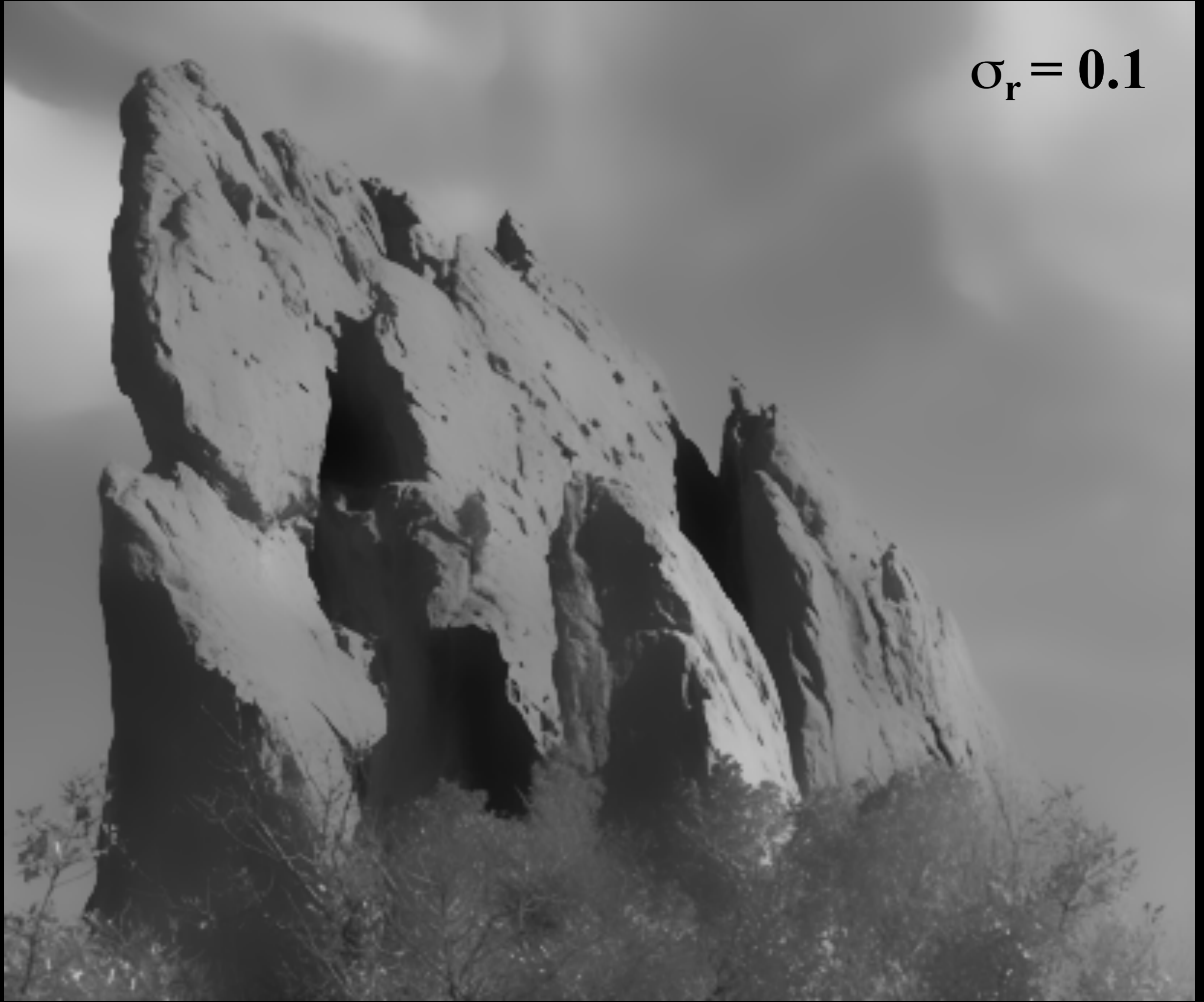
$\sigma_s = 18$



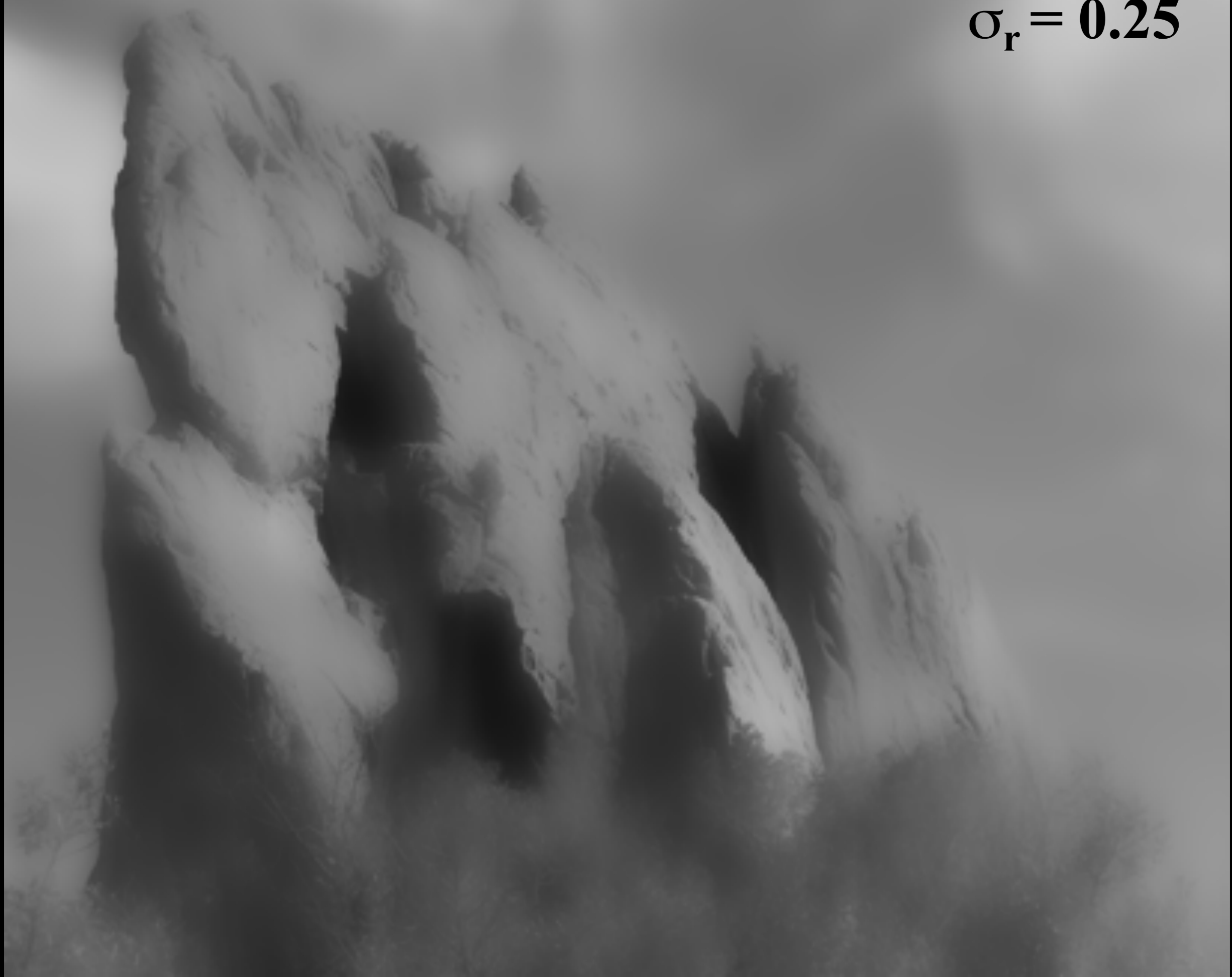
input



$$\sigma_r = 0.1$$



$$\sigma_r = 0.25$$



$$\sigma_r = \infty$$

(Gaussian blur)

Varying the Space Parameter



input

$\sigma_r = 0.1$

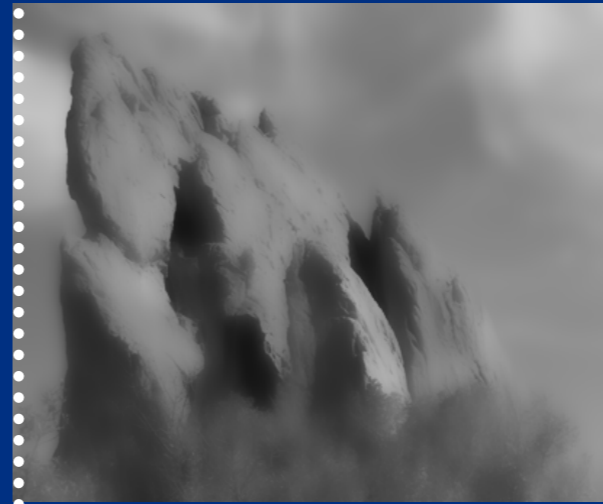
$\sigma_r = 0.25$

$\sigma_r = \infty$
(Gaussian blur)

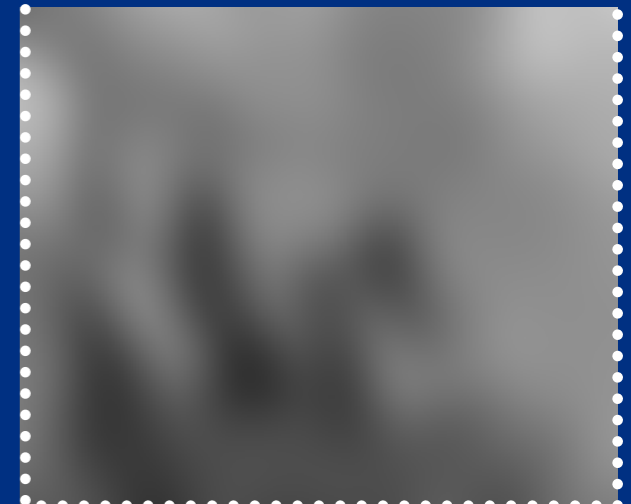
$\sigma_s = 2$



$\sigma_s = 6$



$\sigma_s = 18$



input



$$\sigma_s = 2$$



$$\sigma_s = 6$$



$\sigma_s = 18$

