SIGGRAPH2007

A Gentle Introduction to Bilateral Filtering and its Applications

SIGGRAPH2007

Limitation?

Pierre Kornprobst (INRIA)

0:20

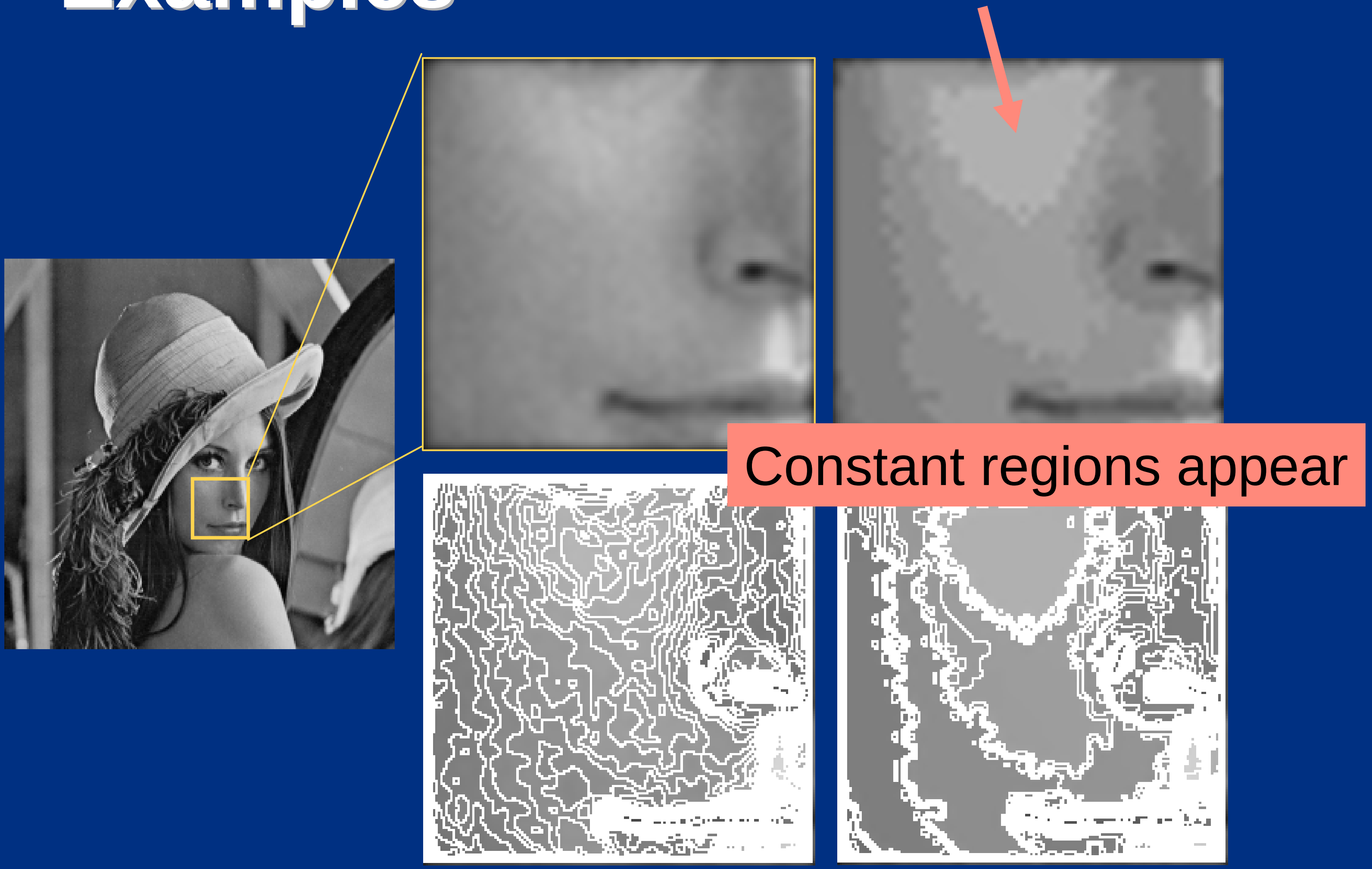
Examples

Soft texture is removed

Input

Bilateral filter

Examples



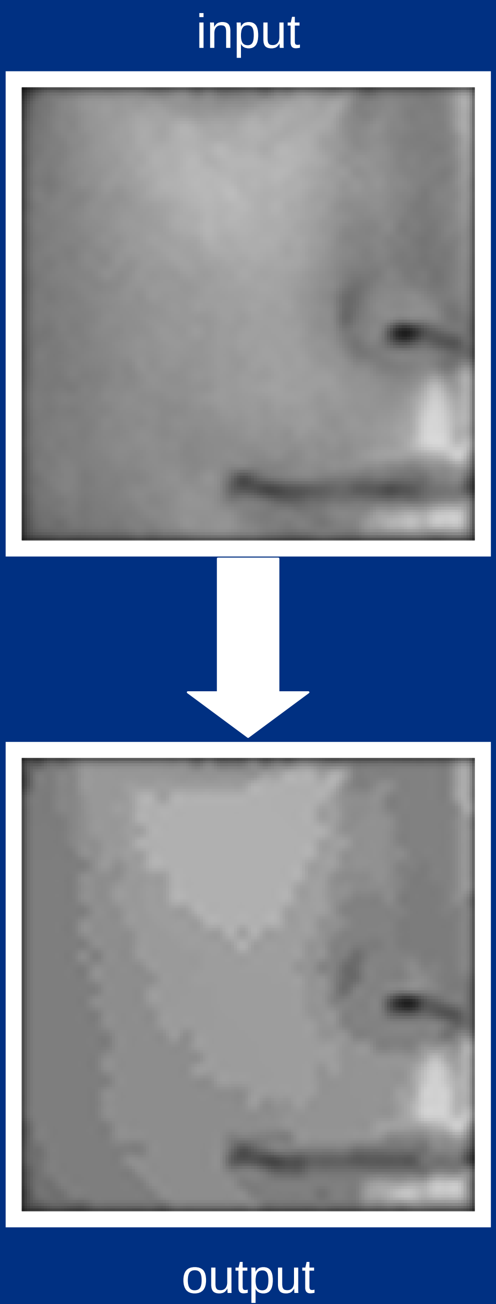
Input

Bilateral filter

[Buades, Coll, Morel, 2005]

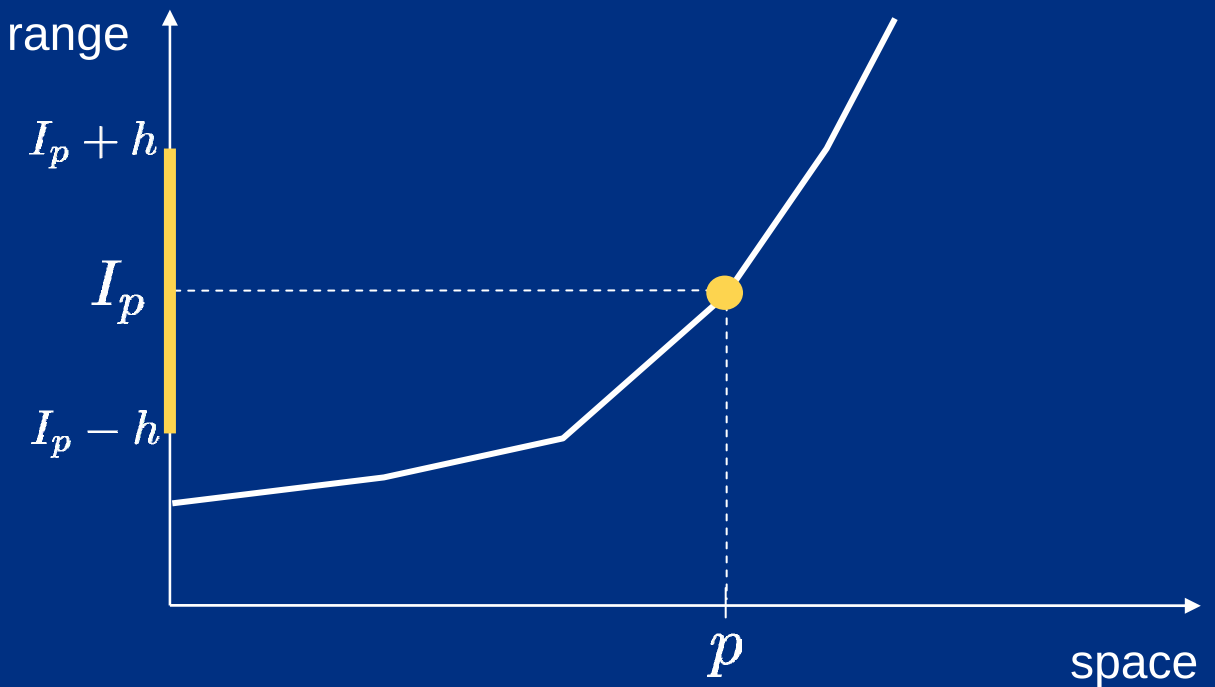
Staircase effect

- Bilateral filter tends to remove texture, create flat intensity regions and new contours
- Questions
  - Why does it occur?
  - Can this be an advantage?
  - Otherwise, can we solve this problem?



Why?

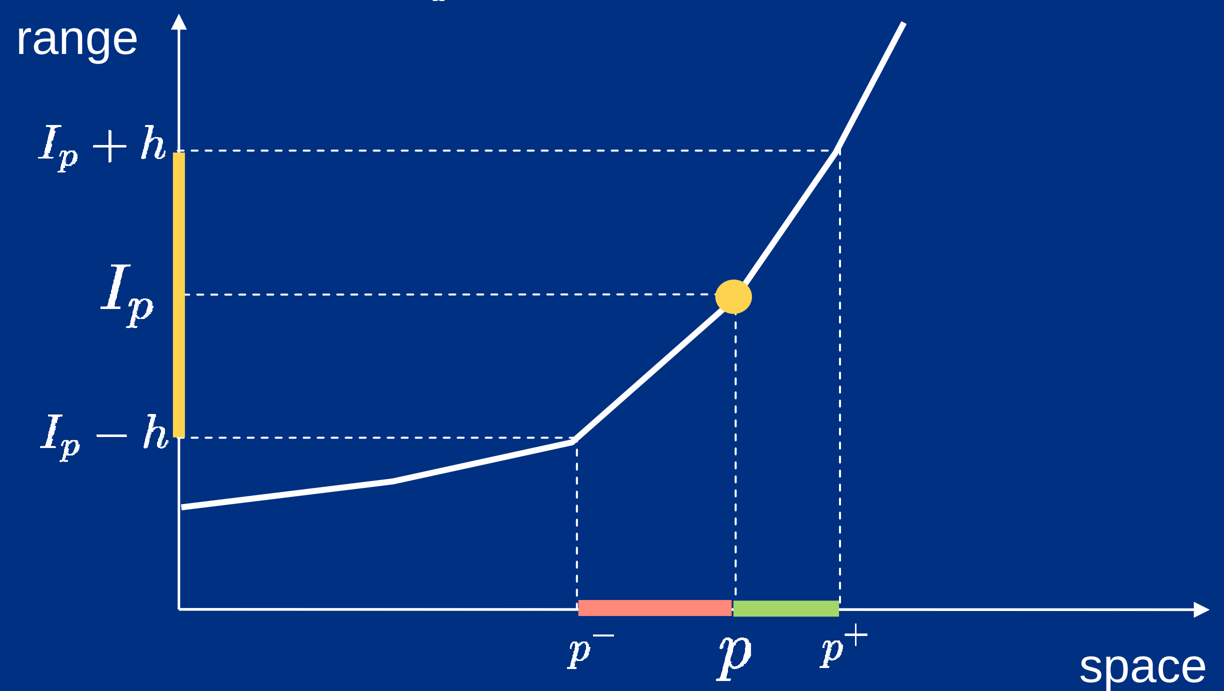
$$BF[I] = \frac{1}{W} \sum_{q \in S} G_{\sigma_s}(p-q) G_{\sigma_r}(I_p - I_q) I_q$$



- Bilateral filter is a weighted average of intensities and…

Why?

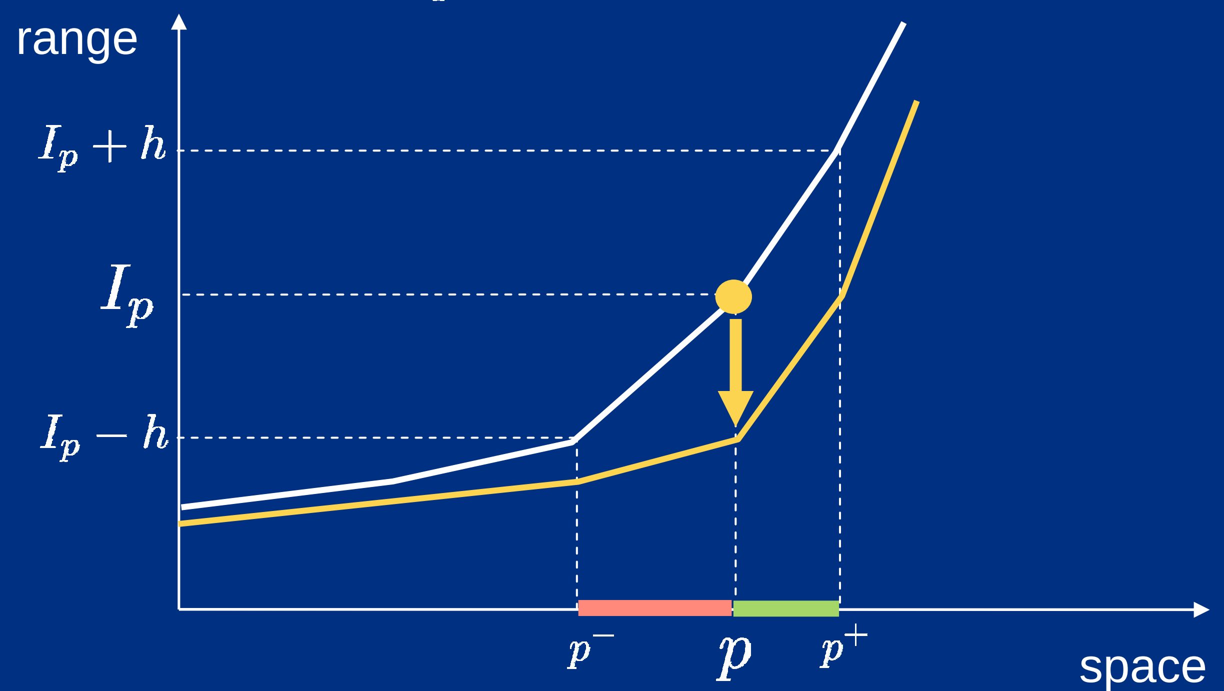
$$BF[I] = \frac{1}{W} \sum_{q \in S} G_{\sigma_s}(p - q) G_{\sigma_r}(I_p - I_q) I_q$$



- The number of points q satisfying I_p-h<I_q<I_p is larger than the number satisfying I_p<I_q<I_p+h.

Why?

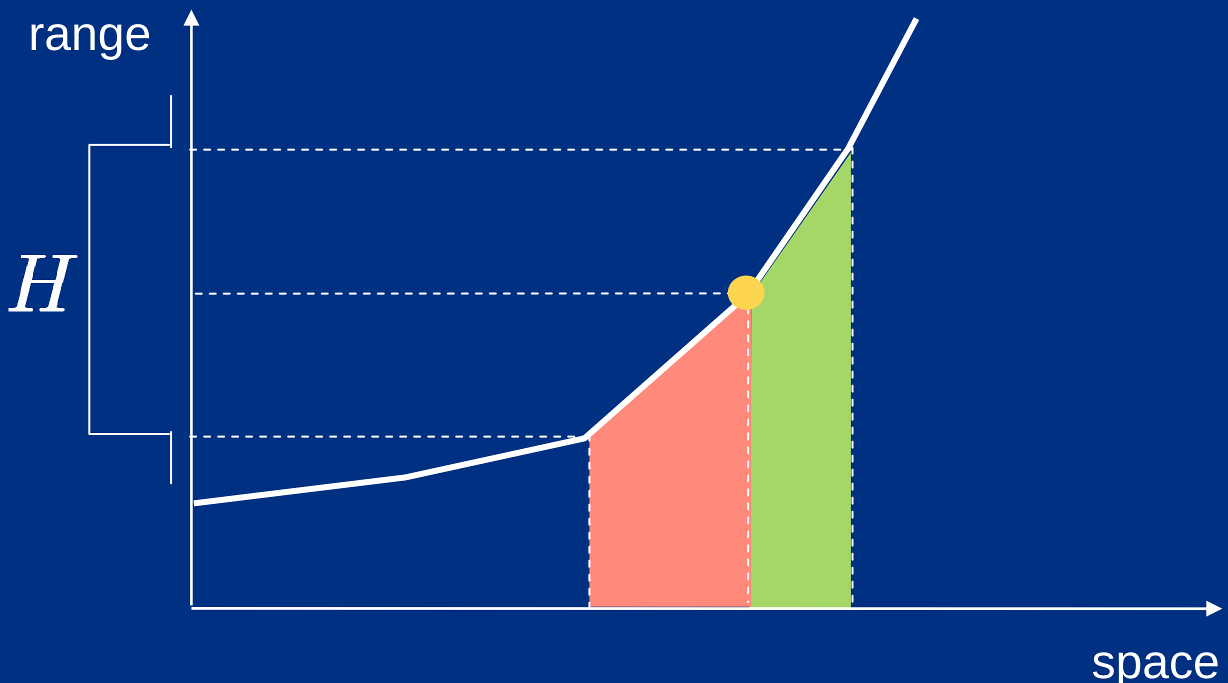
$$BF[I] = \frac{1}{W} \sum_{q \in S} G_{\sigma_s}(p-q) G_{\sigma_r}(I_p - I_q) I_q$$



- Thus the average value is smaller than I_p, enhancing that part of the signal.

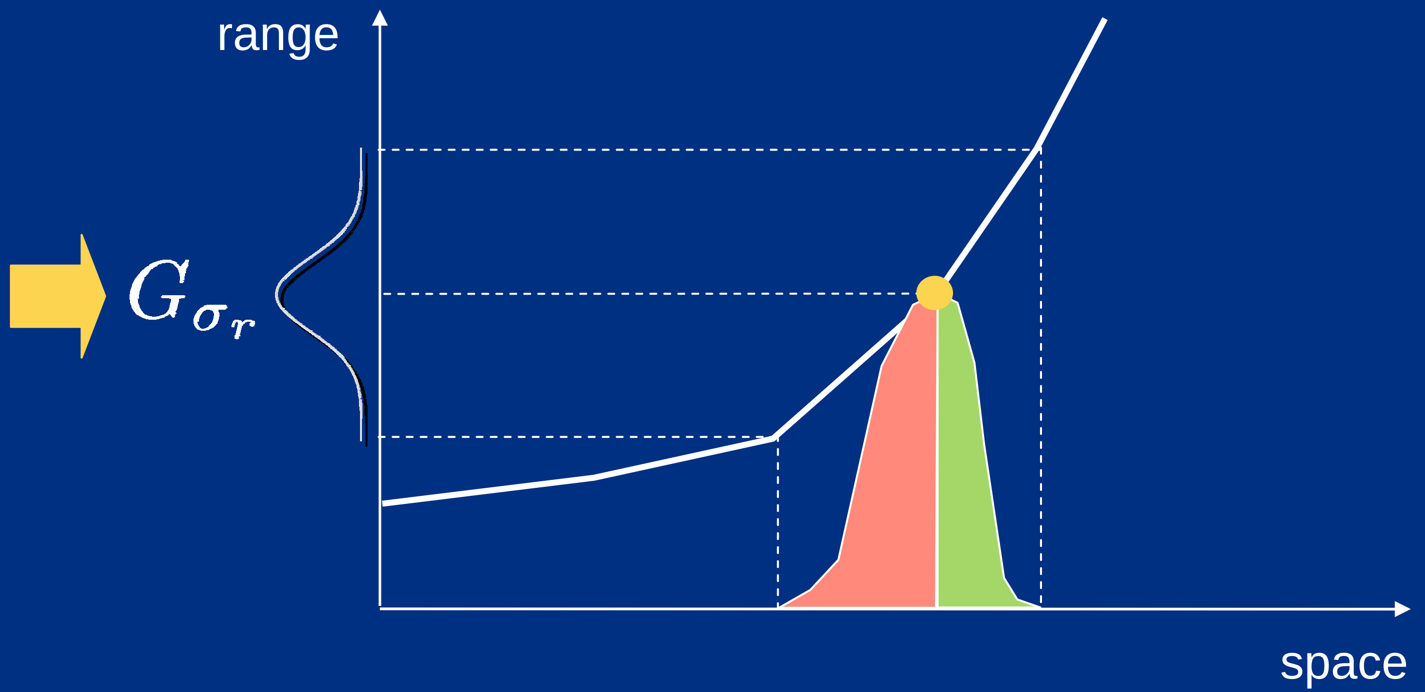
Note: Of course, opposite reasoning the the concave case

And Gaussians don't change anything



$$BF[I] = \frac{1}{W} \sum_{q \in S} \qquad H\left(I_p - I_q\right) I_q$$

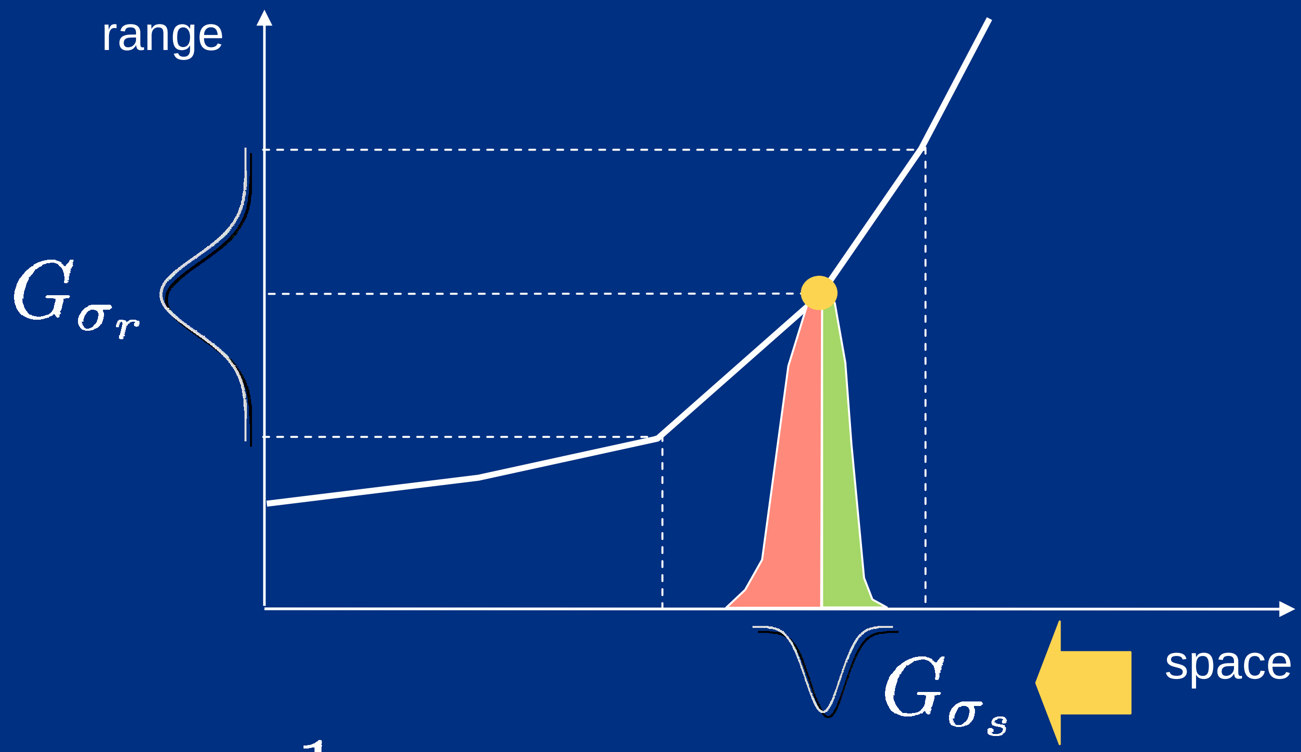
And Gaussians don't change anything



$$BF[I] = \frac{1}{W} \sum_{q \in S}$$

$$G_{\sigma_r}(I_p - I_q) I_q$$

And Gaussians don't change anything



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

[Winnemöller, Olsen, Gooch, 2006]

So… Can this be an advantage?

- Yes! Since we obtain cartoon-like pictures, let us do cartoons!...

Input

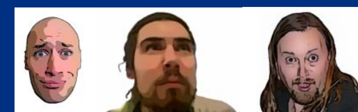
Output

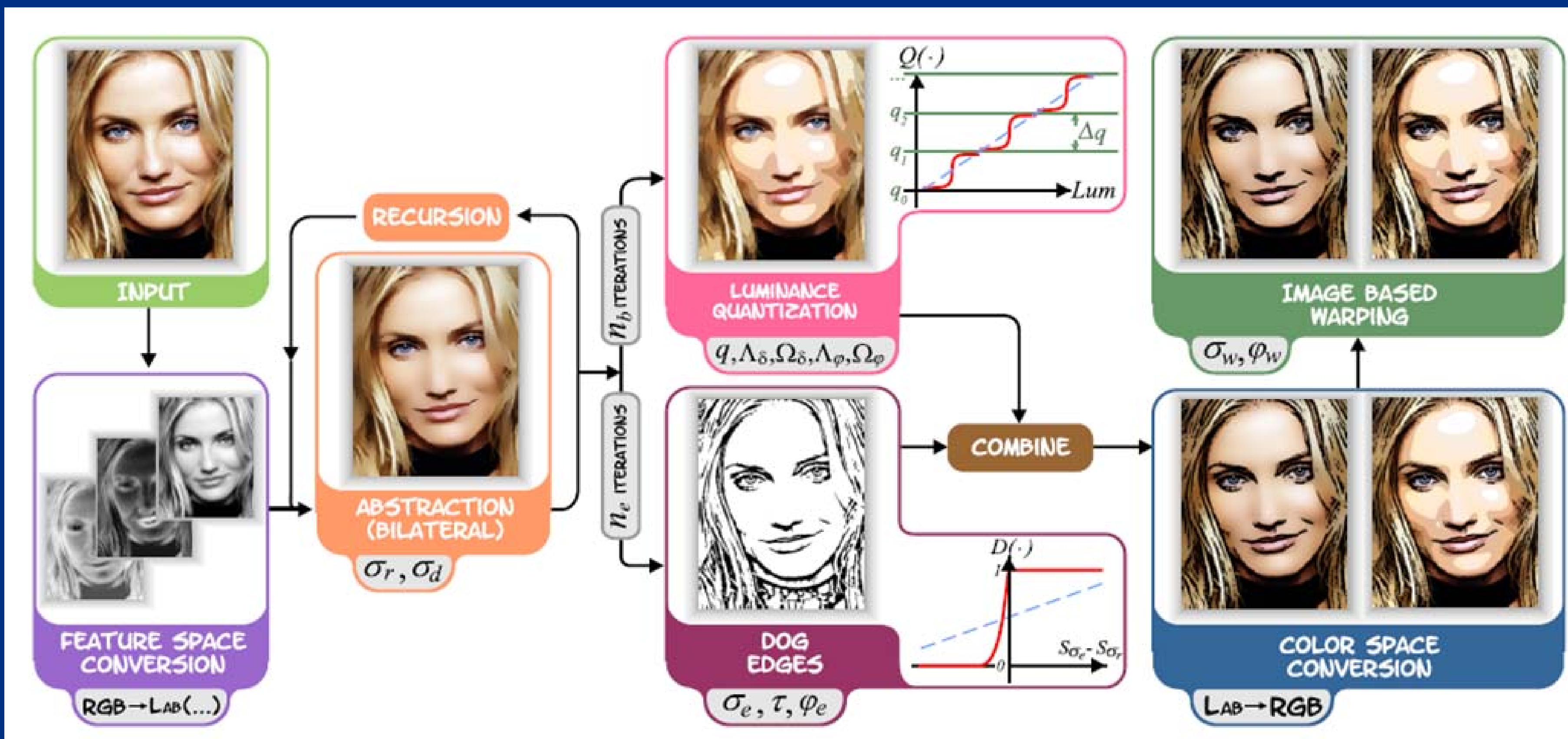
[Winnemöller, Olsen, Gooch, 2006]

I said cartoons?

Few words about the approach

[Winnemoller, Olsen, Gooch, 2006]





[Winnemöller, Olsen, Gooch, 2006]

And you can do more!

- Real-time video abstraction

- To know more

  http://www.cs.northwestern.edu/~holger/Research/VideoAbstraction/

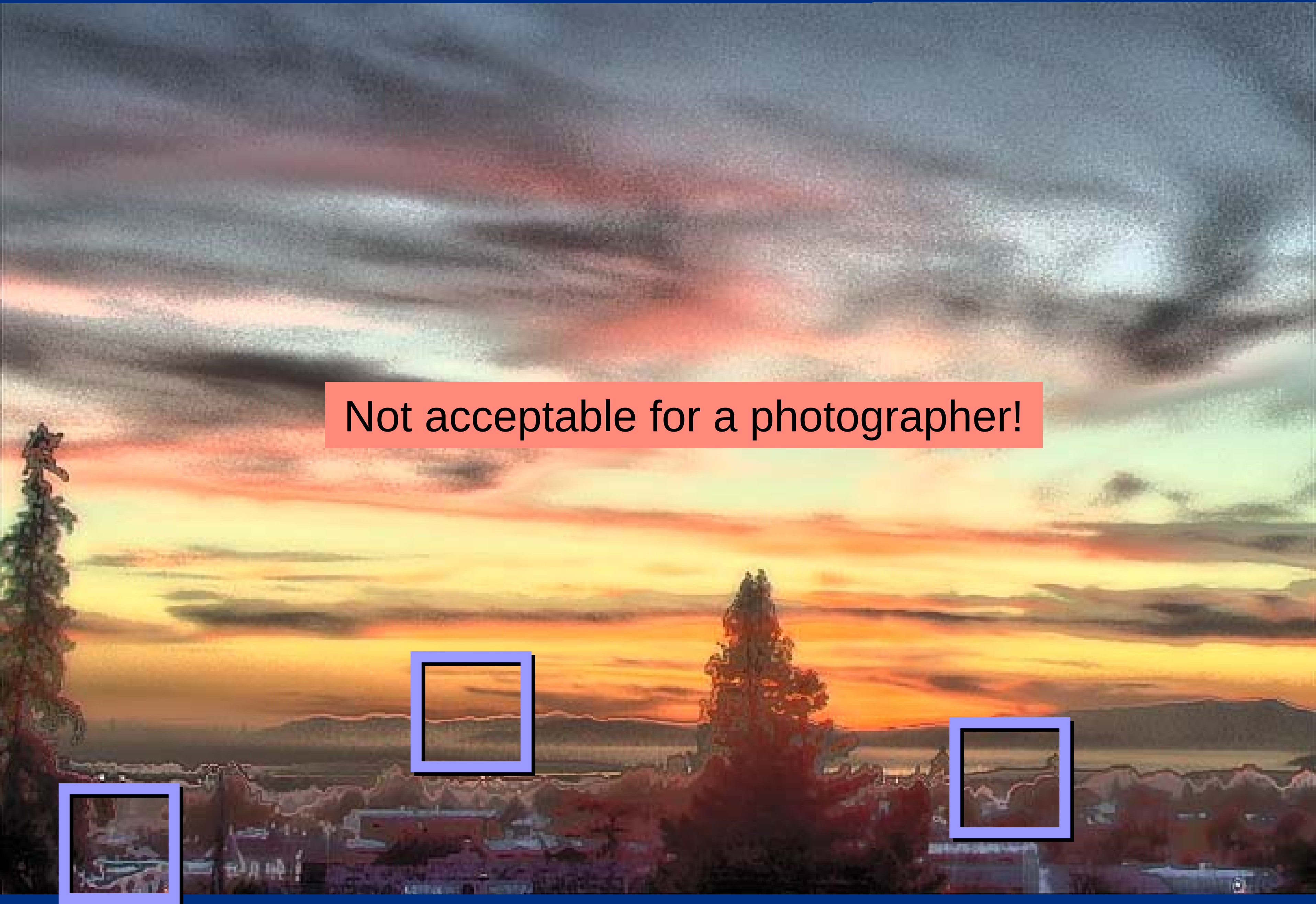
You want to see some example?

But…

- We don't always want to have this kind of rendering
- When bilateral filter is used some side effects car appear

HDR input

Tone mapping with look transfer [Bae, Paris and Durand, 2006]



Result **without** correcting the BF output

Can we avoid this defect?

Yes!

Solution 1

"Gradient manipulation"

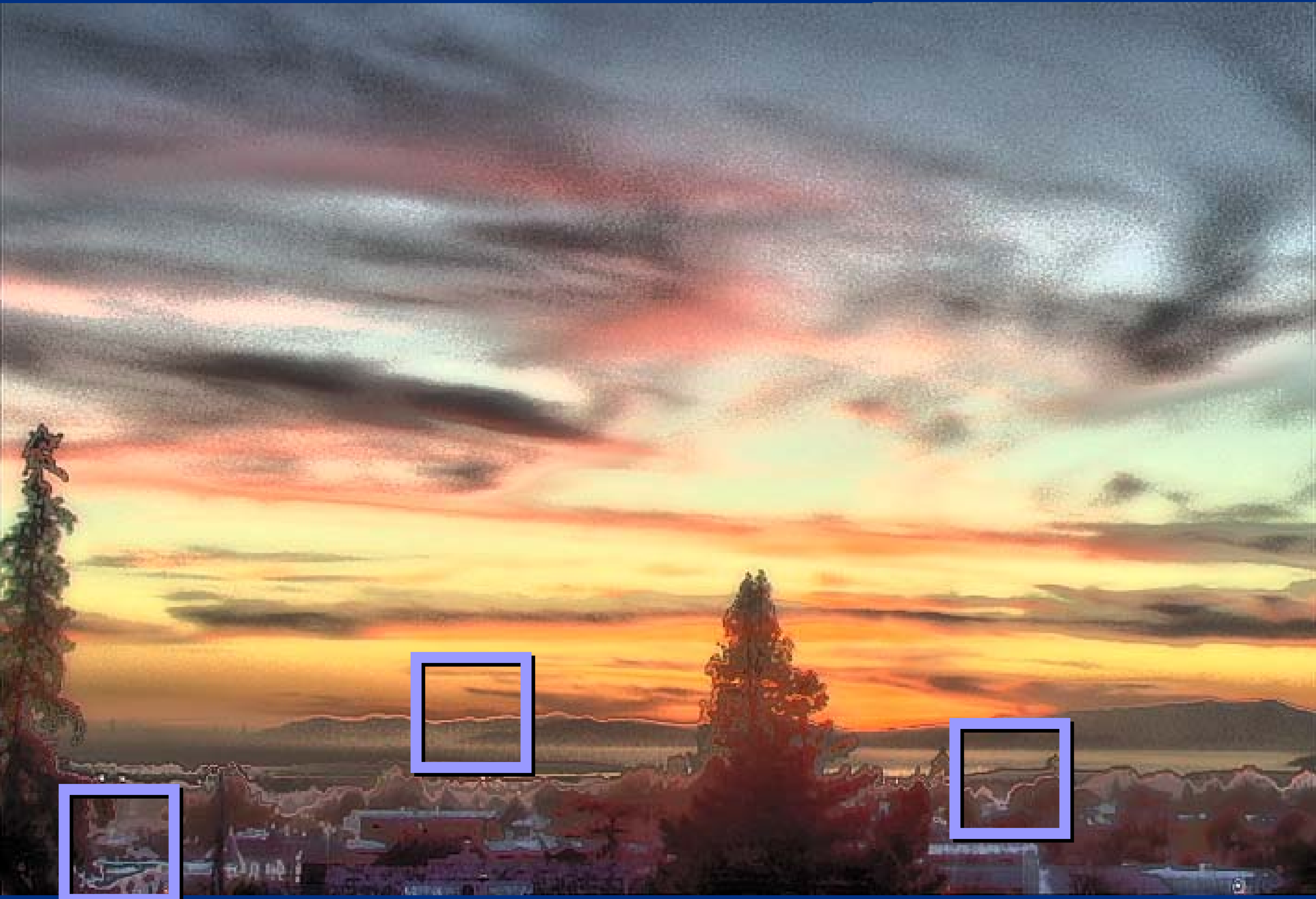
[Bae, Paris and Durand, 2006]

Goal of the paper was to control photographic look and transfer a "look" from a model photo

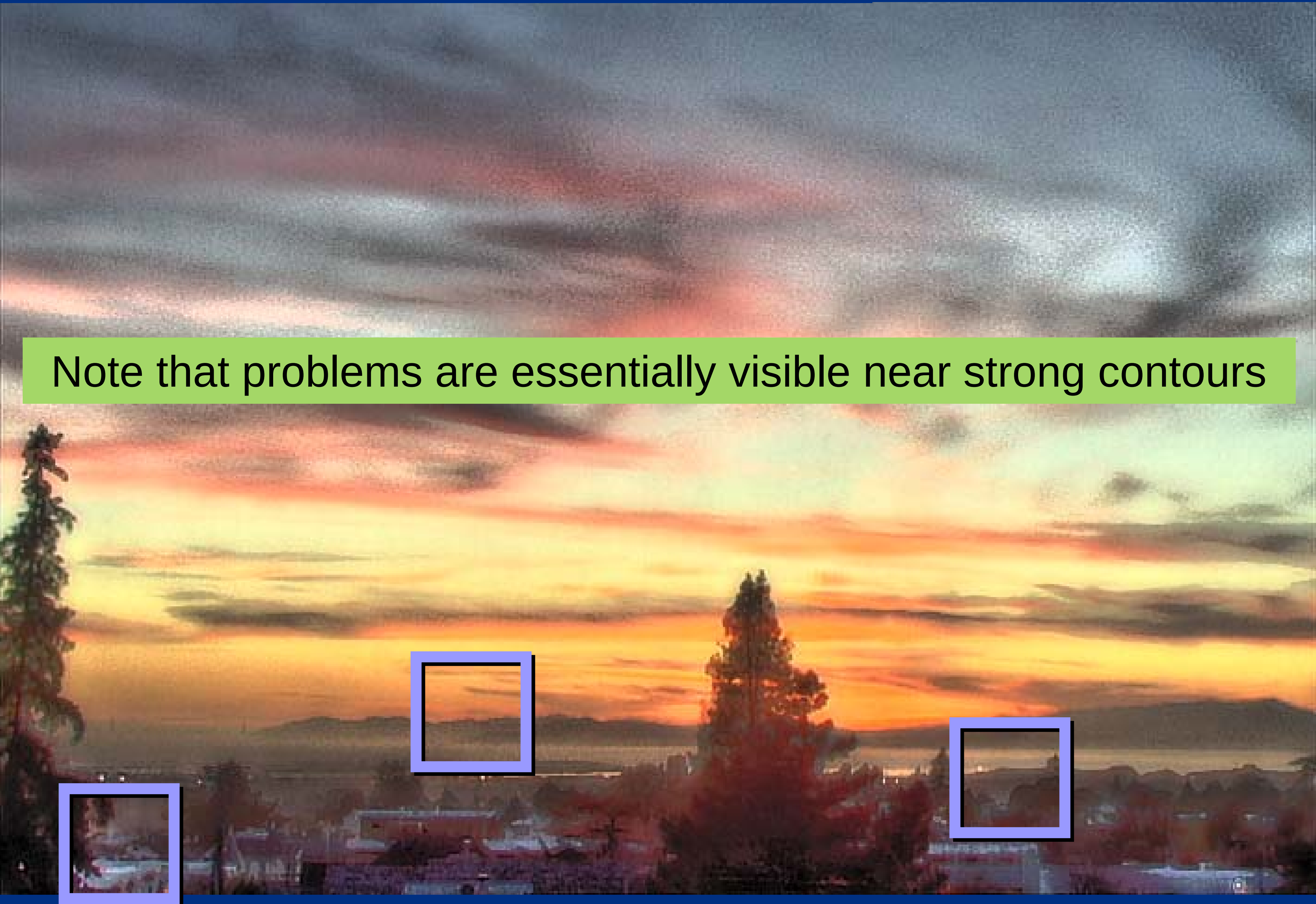
1. In the **gradient domain**:
   - Compare gradient amplitudes of input and current
   - Prevent increase
2. Solve the **Poisson equation**

See [Perez etal, 2003] on Poisson image editing
See [Agarwala, 2007] on solving Poisson equation for large images

Tone mapping with look transfer [Bae, Paris and Durand, 2006]



Result **without** correcting the BF output



Result **with** corrected BF output

Edge Blending

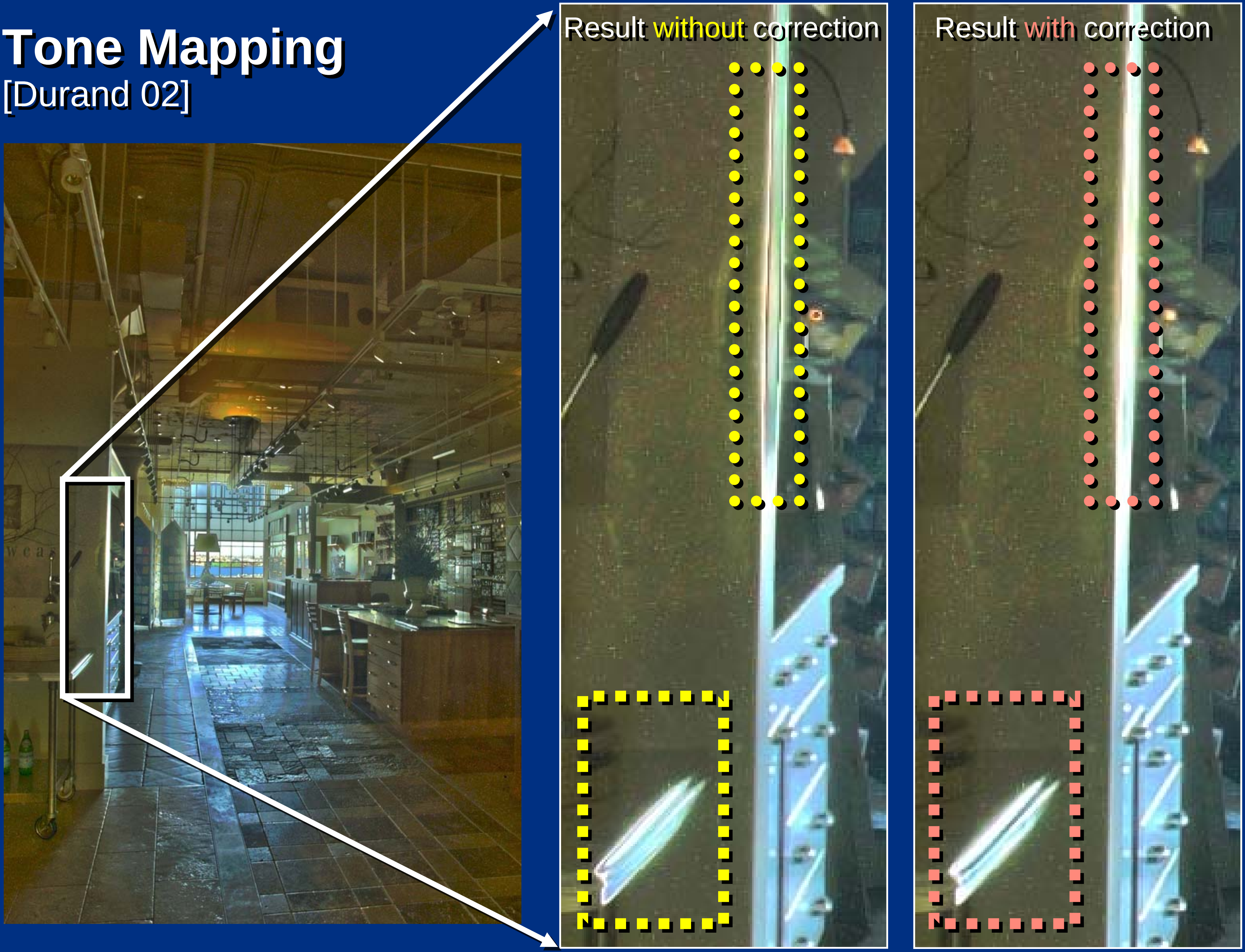
Solution 2

[Durand and Dorsey, 2002] *Goal of the paper was the display of high-dynamic-range images*

- With a single iteration, staircase effects is visible only at edges.
- Edges detected with normalization factor (see also [Smith and Brady, 1997])
- Blend edges with smoothed version of input to counteract staircase effect

(Combination between BF and Gaussian results at strong contours locations)

Tone Mapping
[Durand 02]



“Linear interpolation”

Solution 3

[Buades, Coll, Morel, 2005]

Goal of the paper was to establish the link between integral formulations and differential operators

- We saw that bilateral filter behaves like Perona-Malik and thus creates flat zones
- They proposed to replace the simple average by a linear regression
- How?

“Linear interpolation”

- Bilateral filter can be expressed by

$$\inf_{i} \sum_{q \in S} G_{\sigma_s}(q-p) G_{\sigma_r}(I_q - I_p)(I_q - i)^2$$

- If you derive, you obtain

$$i = \frac{\sum_{q \in \Omega} G_{\sigma_s}(p-q) G_{\sigma_r}(I_p - I_q) I_q}{\sum_{q \in \Omega} G_{\sigma_s}(p-q) G_{\sigma_r}(I_p - I_q)}$$

“Linear interpolation”

- Bilateral filter can be expressed by

$$\inf_{i} \sum_{q \in S} G_{\sigma_s}(q-p) G_{\sigma_r}(I_q - I_p)(I_q \underline{- i})^2$$

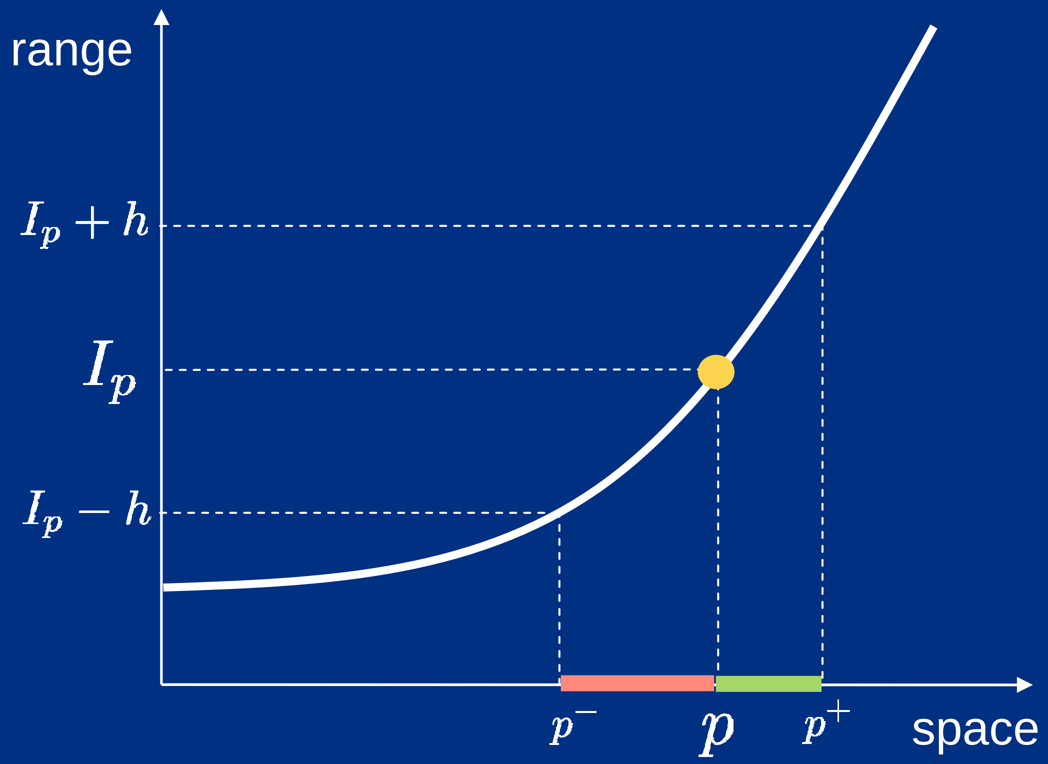
- [Buades, Coll, Morel, 2005] changed the constant model by an affine model

$$\inf_{a,b,c} \sum_{q \in S} G_{\sigma_s}(q-p) G_{\sigma_r}(I_q - I_p)(I_q \underline{- a q_1 - b q_2 - c})^2$$

- New value at *p* will be $a p_1 + b p_2 + c$

"Linear interpolation"

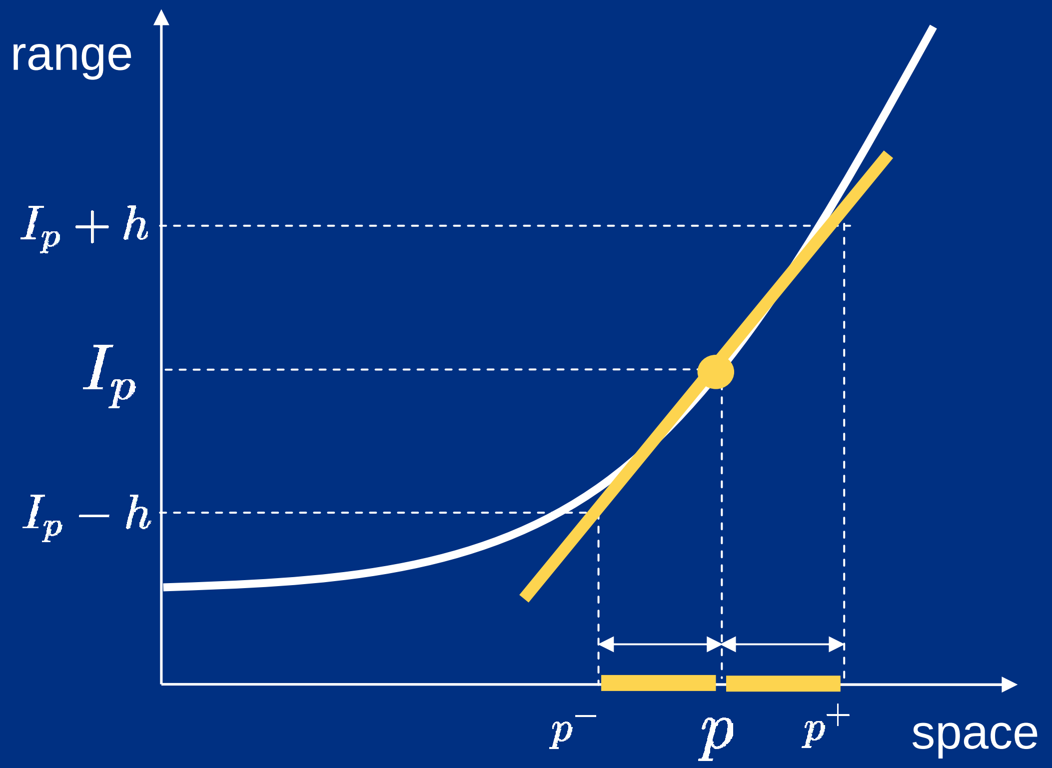
Geometrical interpretation



- Remember, the problem was that lower values were more taken into consideration

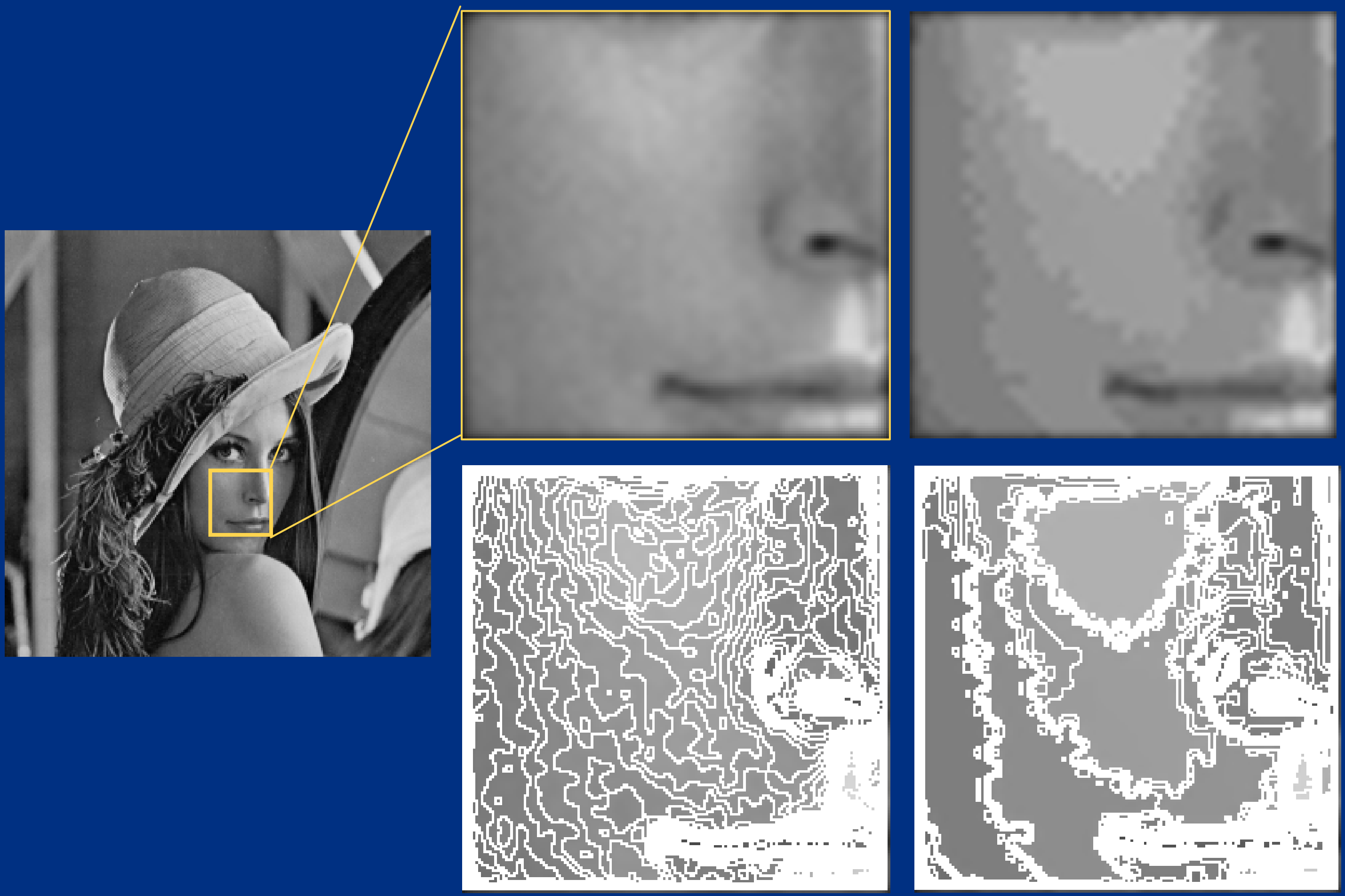
“Linear interpolation”

Geometrical interpretation



- Now, left and right-hand side parts have the same influence

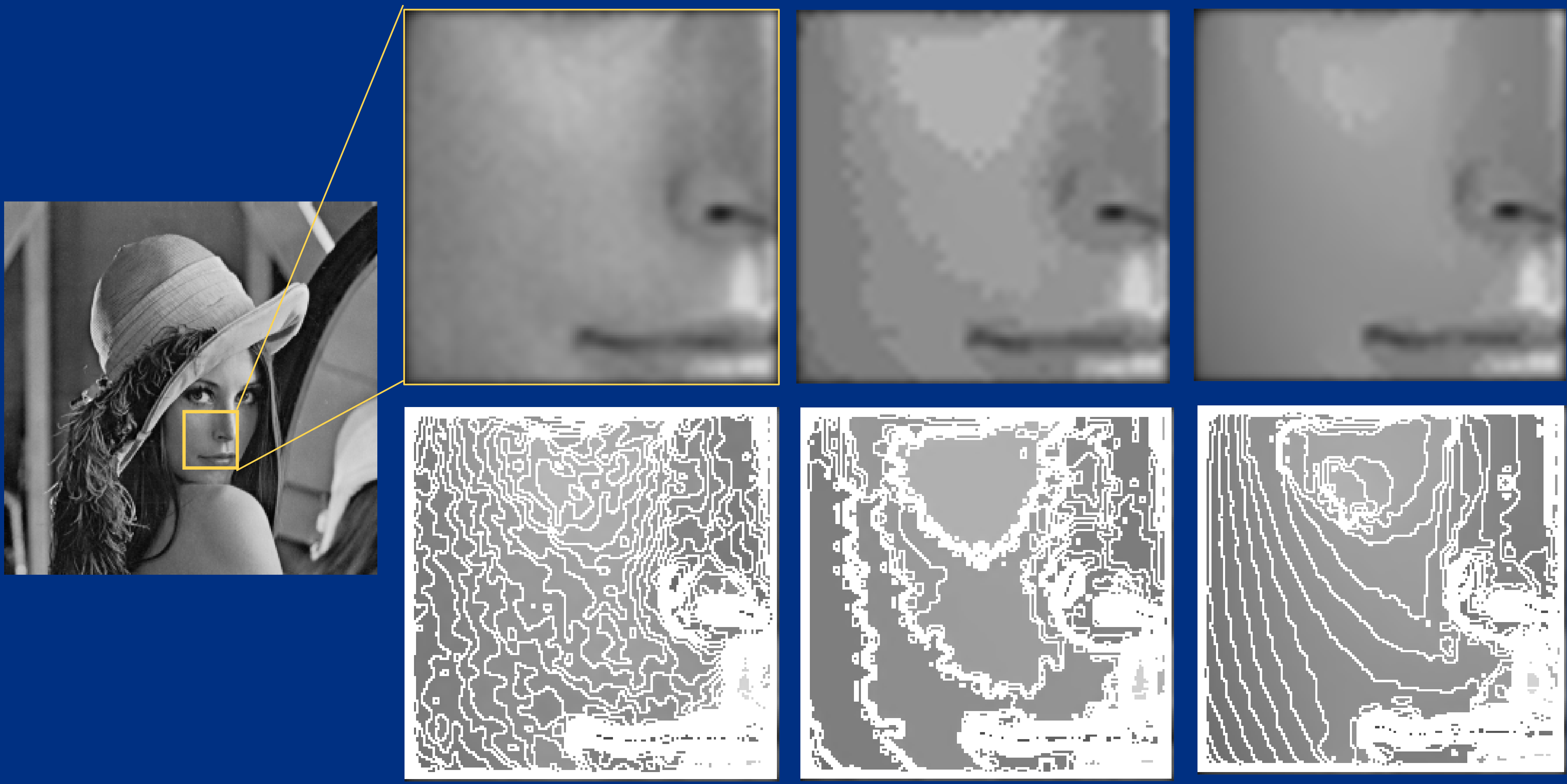
Staircase effect



Input

Bilateral filter

With linear interpolation…



Input | Bilateral filter | modified

[Buades, Coll, Morel, 2005]

Also…

- This new operator is also related to differential operators, i.e., PDEs!

- In this paper, you will also find extensions of bilateral filter, called non local filter.

$$G_{\sigma_r}(I_q - I_p) \longrightarrow \sum_v G(v)|I_{q+v} - I_{p+v}|^2$$

Average when similar intensities

Average when similar patch around (correlation of neighborhood)

[Buades, Coll, Morel, 2005]

How to choose?

- Two methods which correct afterward defects of bilateral filter, mainly visible on boundaries.

  Efficient

  Correction of an existing problem

- One method which solves the problem by adapting the bilateral filter.

  Directly address the problem

  Computationally expensive

Summary

- Bilateral filter produces staircase effect
- It has been used as a tool for many applications such as texture extraction
- By itself, it has some interest too!
- Staircase effect can be controlled
- The link with PDEs is again appearing

Questions?

Pierre.kornprobst@inria.fr
http://pierre.kornprobst.googlepages.com/