CVPR 2007

Minneapolis

NORTHWESTERN UNIVERSITY

NEC

Soft Edge Smoothness Prior for Alpha Channel Super Resolution

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Prior is needed

- Minimize the reconstruction error
  - Degraded HR → LR input
  - Efficient solution by Back-projection (Irani'93)
- However …
  - SR is under-determined (Baker&Kanade'02, Lin&Shum'04)
  - Image prior is needed for regularization

What kind of prior?

LR input

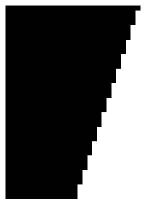
Back-projection

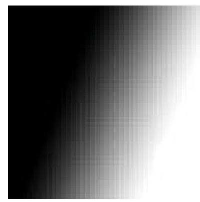
Bicubic interpolation

Smooth edges are preferred

What kind of smoothness?

Hard edge *vs.* Soft edge



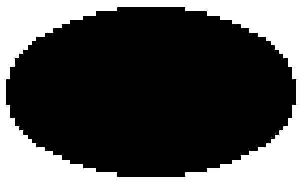


binary value

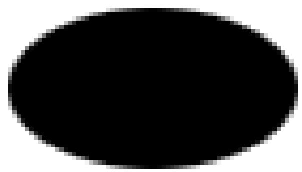
real value

LR input

Hard + Smooth



Soft + Smooth



Soft smoothness is preferred

- Questions
  - How to describe an edge?
  - How to obtain a soft smooth edge?
- Our solutions
  - Alpha channel edge description
  - Soft edge smoothness prior

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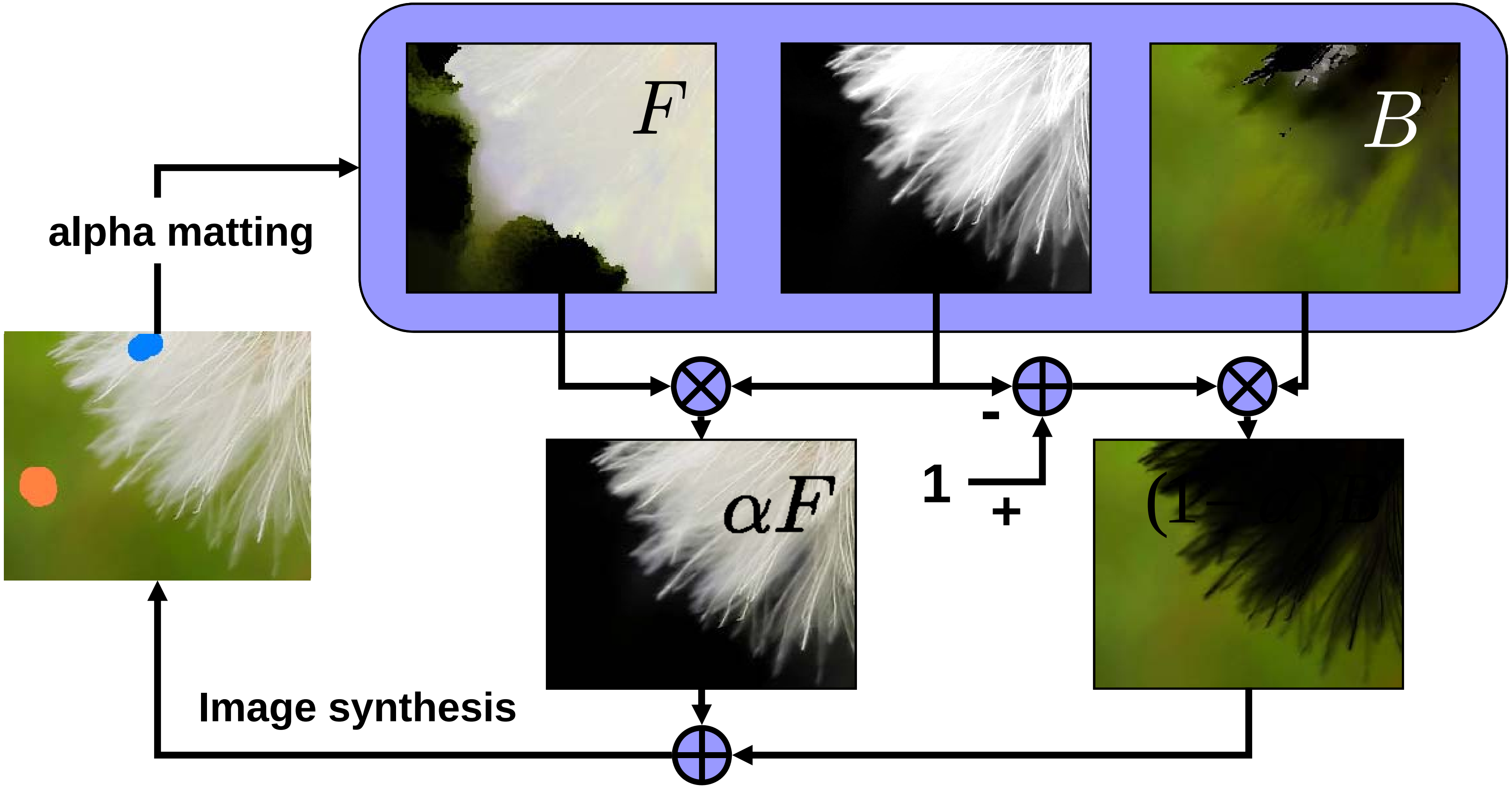
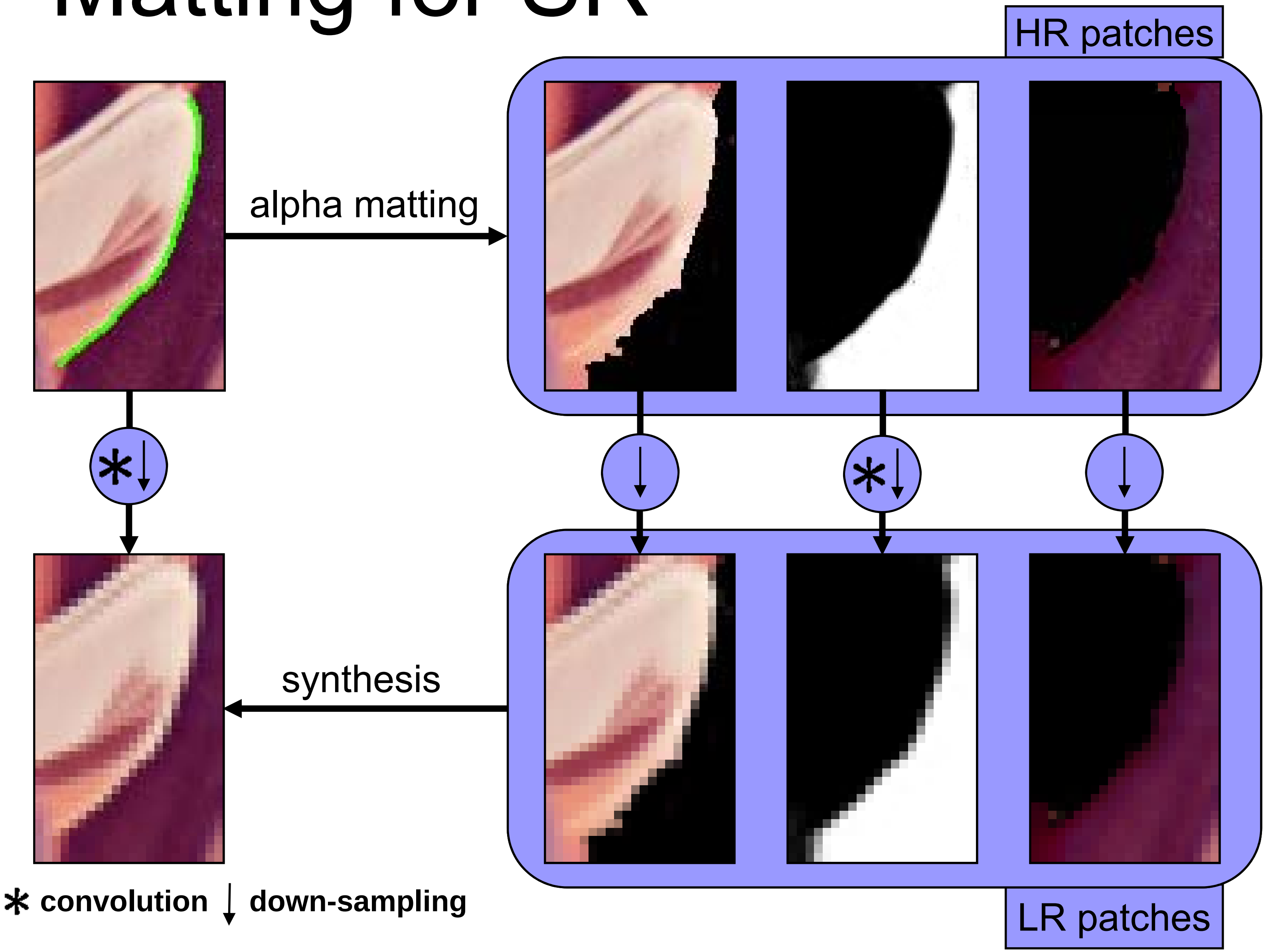
Alpha matting

$$I = \alpha F + (1 - \alpha) B$$

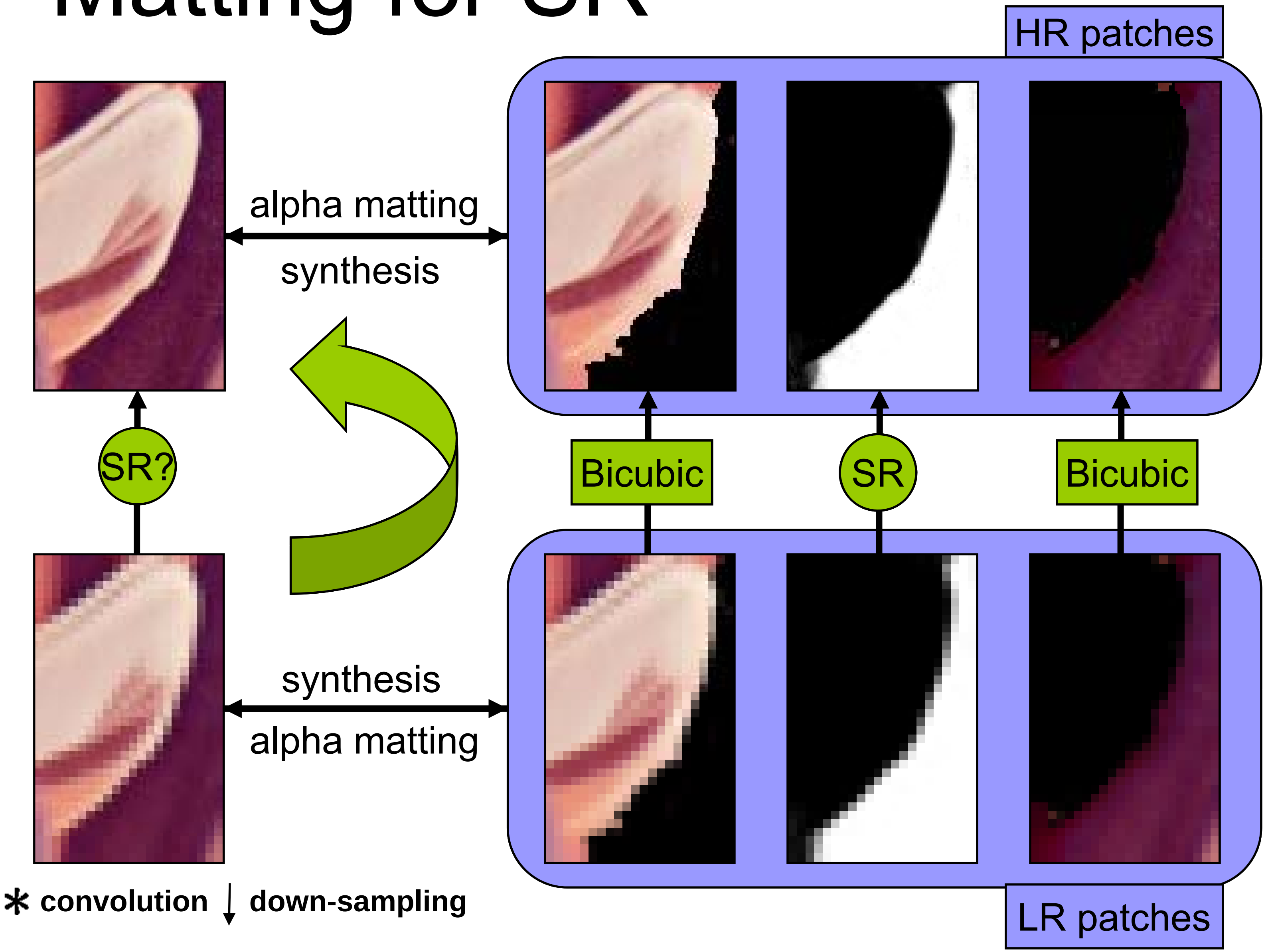


A closed form solution with smoothness assumption (Levin etc. '06)

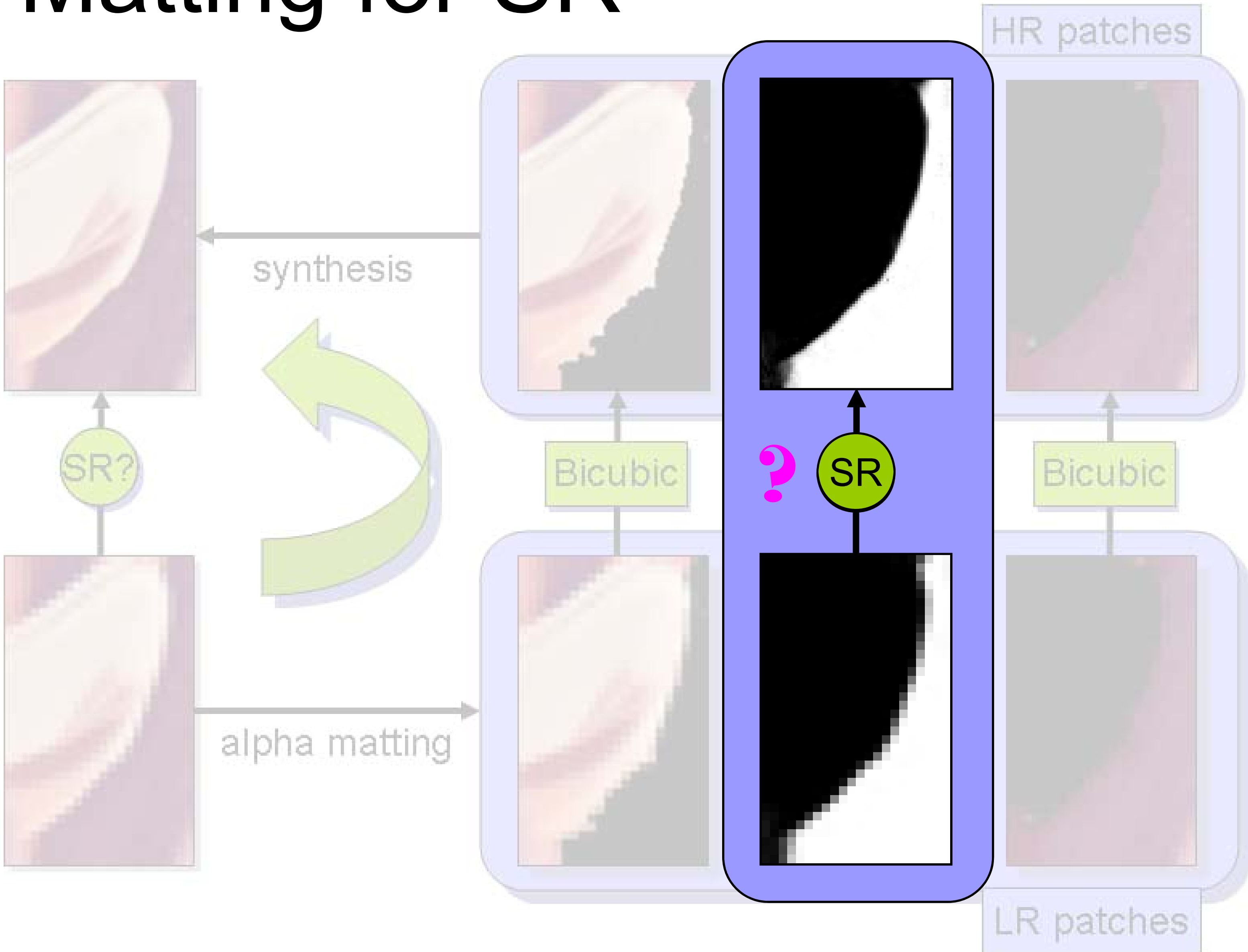
Matting for SR



Matting for SR



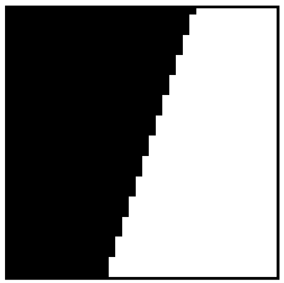
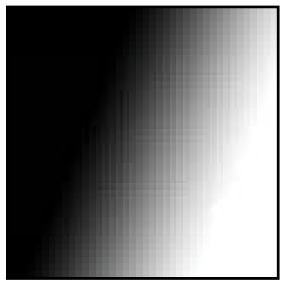
Matting for SR



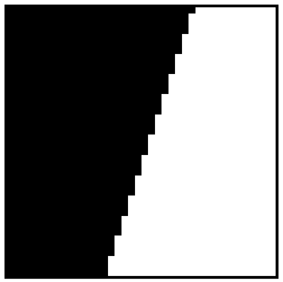
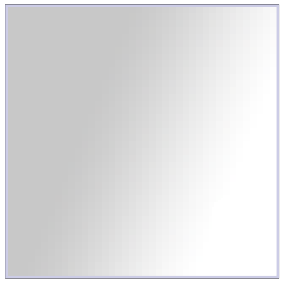
- Questions
  - How to describe an edge?
  - How to obtain a soft smooth edge?
- Our solutions
  - Alpha channel edge description
  - Soft edge smoothness prior

Objective

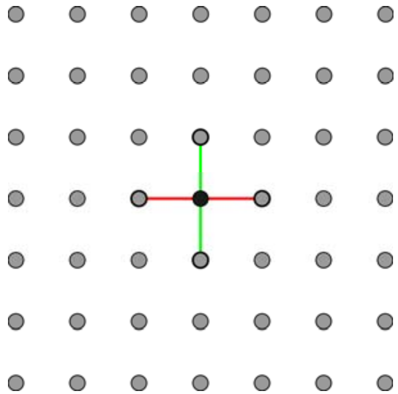
Regularity term prefers soft smooth edge

Geocut	Our method
Hard edge 	**Soft edge** 

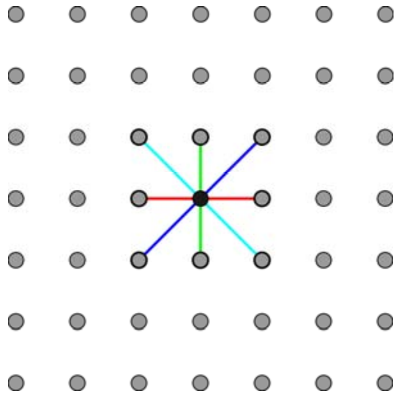
Objective

Geocut	Our method
Hard edge	**Soft edge**
	

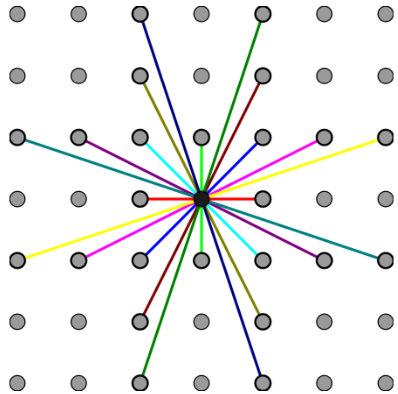
Pixel neighborhood



$$n_{\mathcal{G}} = 2$$

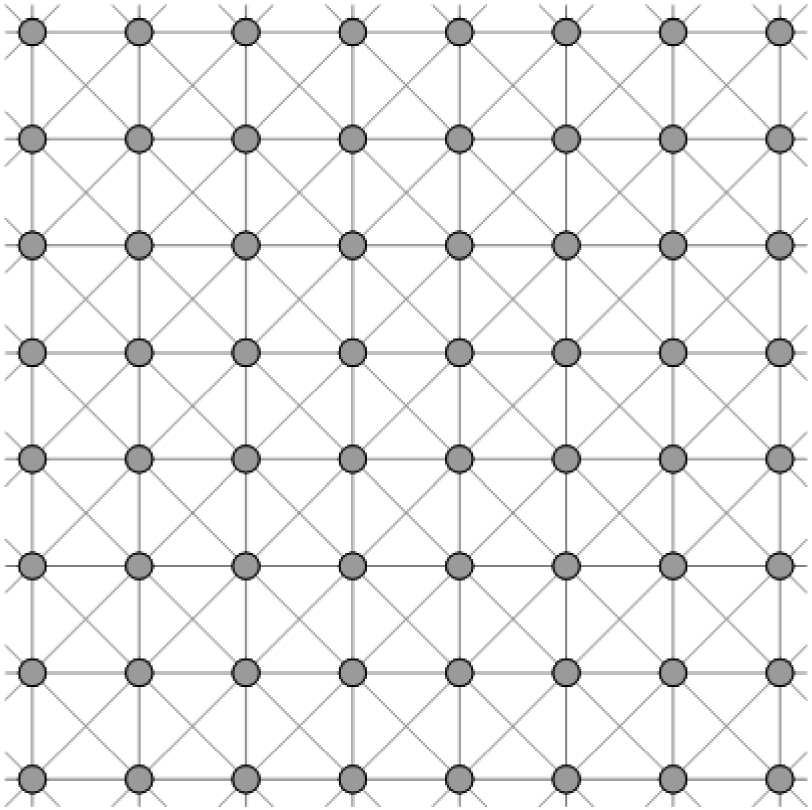


$$n_{\mathcal{G}} = 4$$



$$n_{\mathcal{G}} = 12$$

Image grid graph

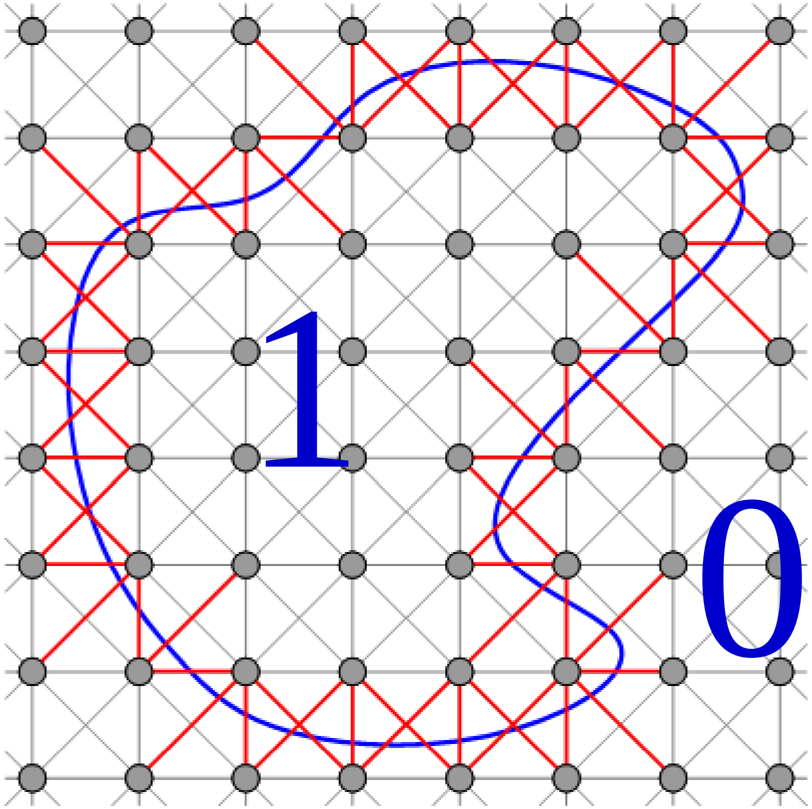


$$\mathcal{G} = \langle V, E \rangle$$

$$n_{\mathcal{G}} = 2$$

Hard edge smoothness

Geocut (Boykov&Kolmogorov'03)



$\mathcal{G} = \langle V, E \rangle$ Curve C

Cut metric: $|C|_{\mathcal{G}} = \sum_{e \in E_C} w_e$

$$= \sum_{1 \le k \le n_{\mathcal{G}}} \left(w_k \sum_{e_{pq} \in N_k} |F_C(p) - F_C(q)| \right)$$

F_C: Binary indication function on grid

$n_{\mathcal{G}}$: Neighborhood order of the image grid

w : Edge weight of the grid graph

N_k: Set of the pixels pairs of order k

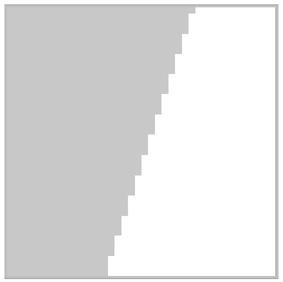
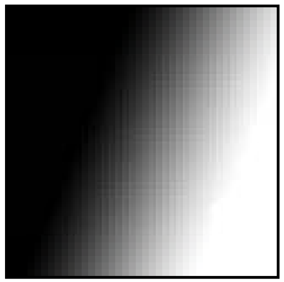
Hard edge smoothness

$$|C|_{\mathcal{G}} \longrightarrow |C|_{\mathcal{E}}$$

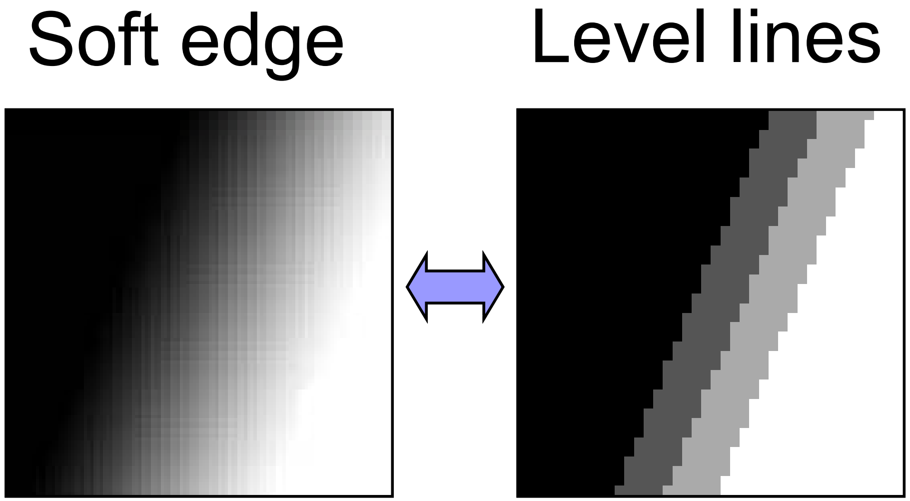
Cut metric　　Euclidean length

- A regularity term prefers hard smooth edge
- Application
  - Segmentation problem
  - Reducing the metrication artifact

Objective

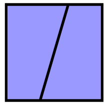
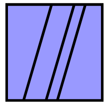
Geocut	Our method
Hard edge	**Soft edge**
	

Soft edge smoothness



Soft edge is equivalent to a set of image level lines

Soft edge smoothness

Geocut 	Our method 
$\min \lvert C\rvert_{\mathcal{E}}$ 	$\min(\frac{1}{n}\sum \lvert l_i\rvert_{\mathcal{E}})$ 
Binary indication function F_C	**Real-valued function** I
Cut metric $\lvert C\rvert_{\mathcal{G}} = \sum_{1\le k\le n_{\mathcal{G}}} \left(w_k \sum_{e_{pq}\in N_k} \lvert F_C(p) - F_C(q)\rvert\right)$	**Soft cut metric** $\lvert I\rvert_{\mathcal{G}} = \sum_{1\le k\le n_{\mathcal{G}}} \left(w_k \sum_{e_{pq}\in N_k} \lvert I(p) - I(q)\rvert\right)$
$\lvert C\rvert_{\mathcal{G}} \to \lvert C\rvert_{\mathcal{E}}$	$\lvert I\rvert_{\mathcal{G}} \to \frac{1}{n}\sum_{1\le i\le n} \lvert l_i\rvert_{\mathcal{E}}$

Soft edge smoothness

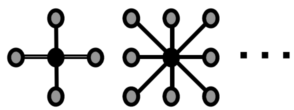
- A regularity term prefers soft smooth edge
- Application
  - Super resolution
  - Reducing the jaggy effect

For SR

- Objective function

$$I^h = \arg\min_{I} \left(||I^l - (I * G) \downarrow ||_2^2 + \lambda |I|_{\mathcal{G}} \right)$$

- Efficient optimization by steepest descent
- Critical parameters

$n_{\mathcal{G}}$ 

λ 

- Two options
  - Alpha channel SR for each edge segment
  - Color channels SR over entire image

Effect of $n_{\mathcal{G}}$

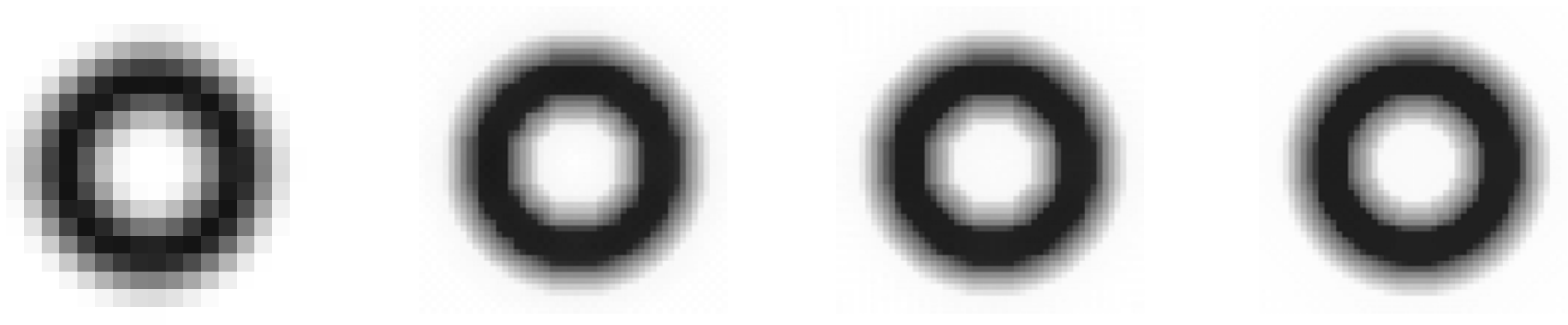
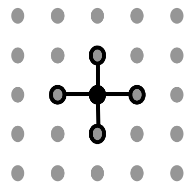


Image size

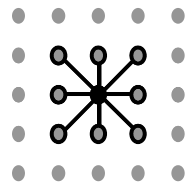
18×18

Zoom factor

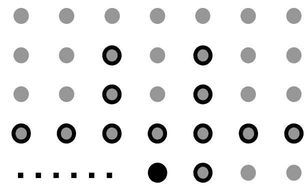
$s = 3$



$n_{\mathcal{G}} = 2$



$n_{\mathcal{G}} = 4$



$n_{\mathcal{G}} = 12$

only upper plane is shown

Effect of λ

$\lambda = 0.01$

Back-projection

$\lambda = 0.001$

$\lambda = 0.1$

$$20 \times 20$$
$$s = 3$$
$$n_{\mathcal{G}} = 12$$

Note: color channels are processed separately

Color channels SR

20 × 20

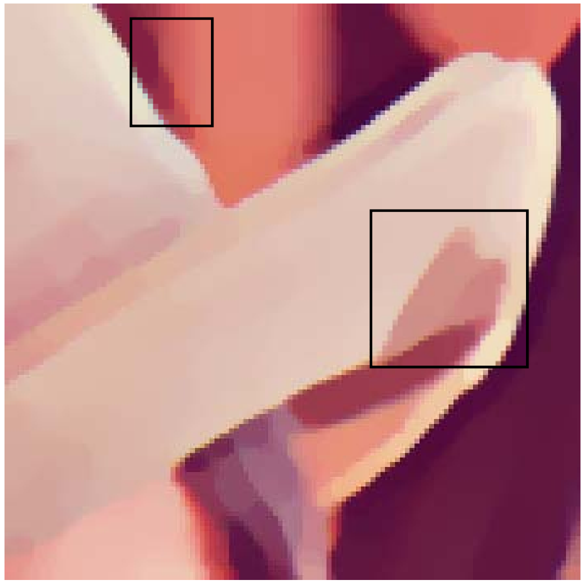
16 × 6

40 × 40

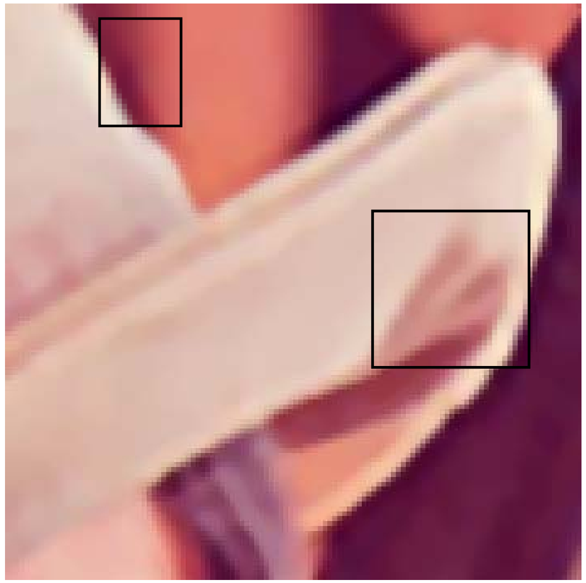
LR input | Our result | Bicubic interpolation

$s = 3 \quad n_{\mathcal{G}} = 12 \quad \lambda = 0.01$

Color channels *vs.* alpha channel

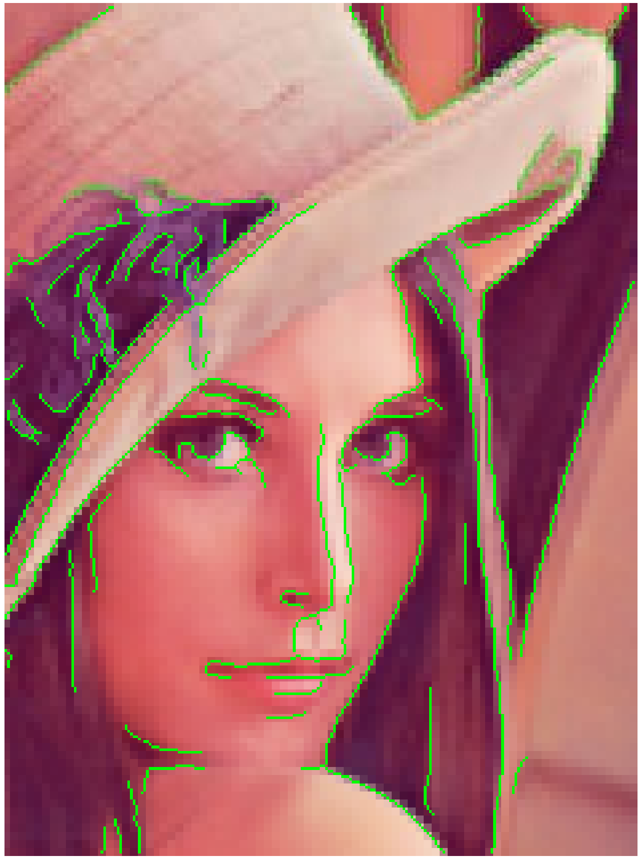


Color channels SR
on the entire image

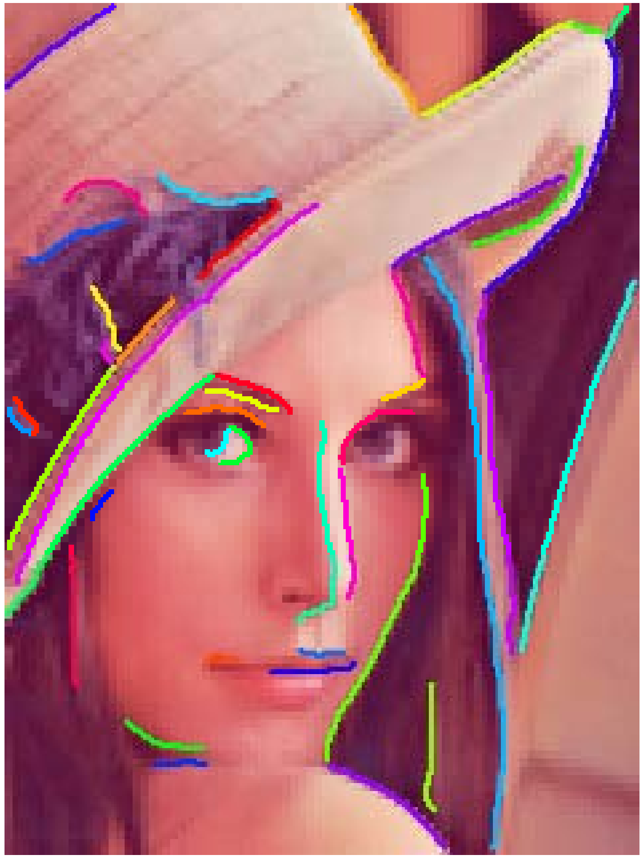


Alpha channel SR
on edge segments

Alpha channel SR

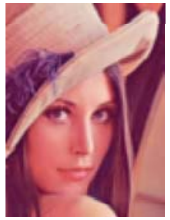


Corner detection (He etc. 04)

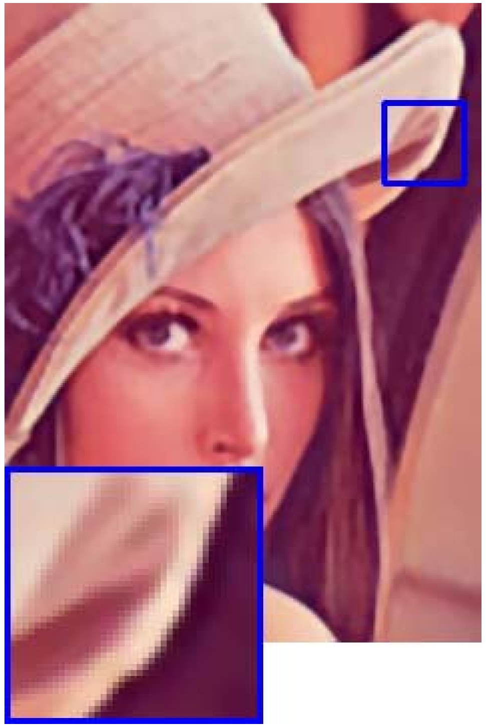


Process each edge segment separately

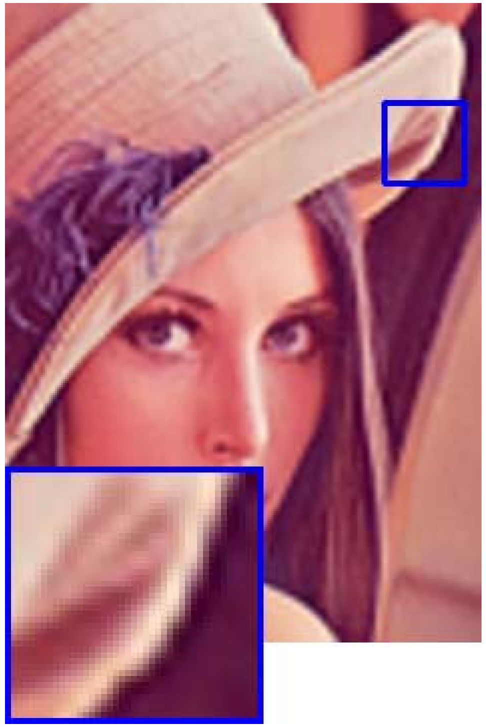
Comparison



Bicubic

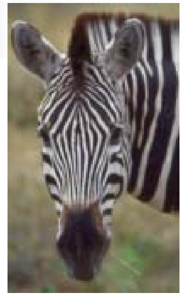


Our method

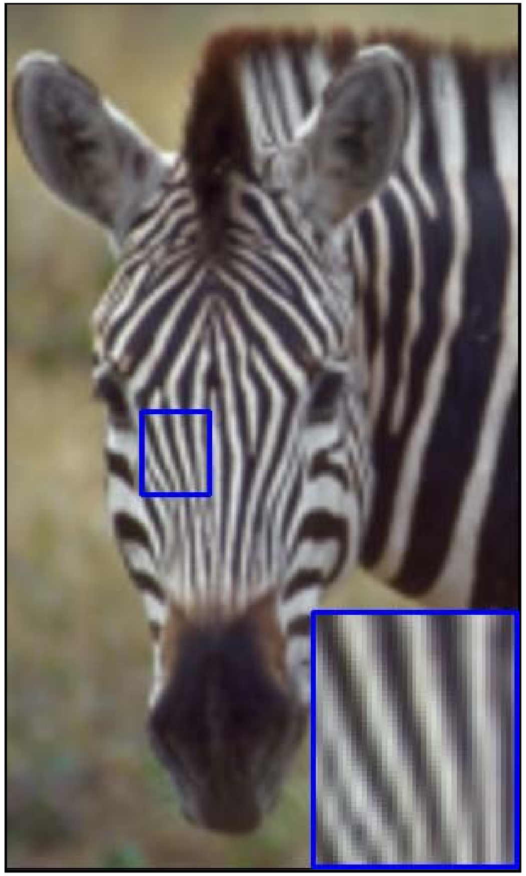


Back-projection

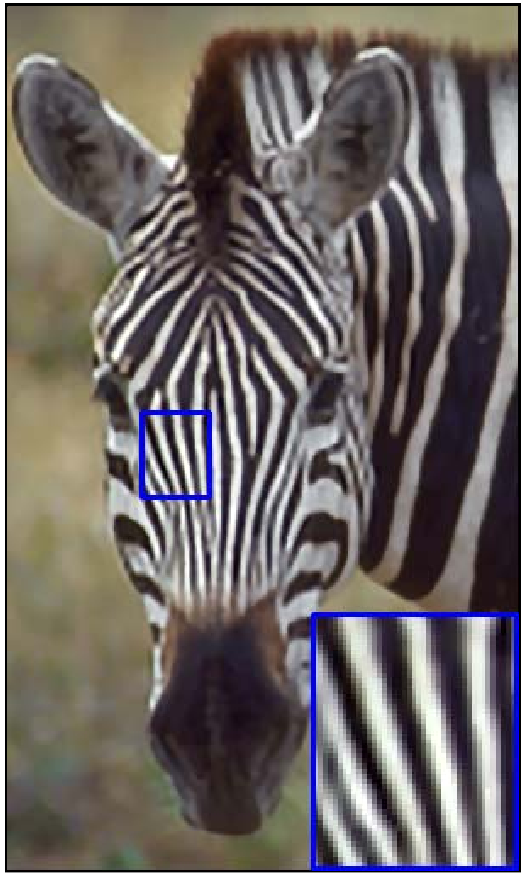
Comparison – reconstruction based



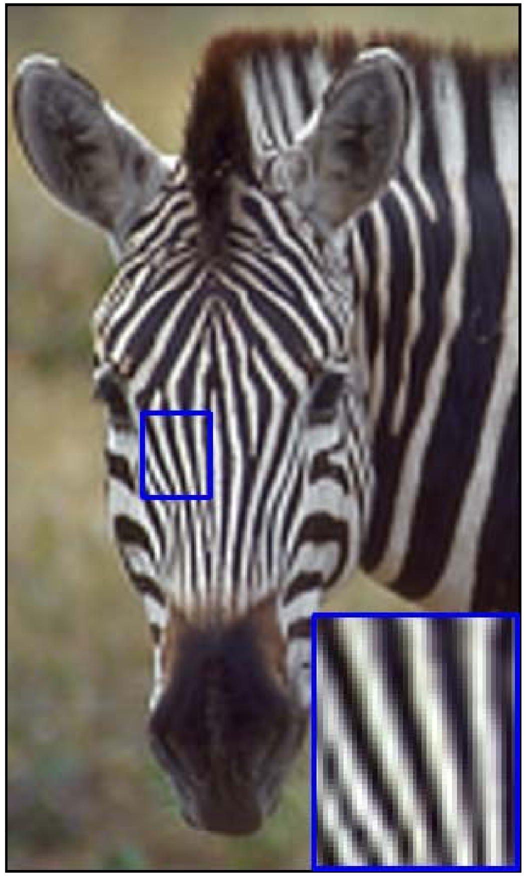
$100 \times 170 \times 3$



Bicubic

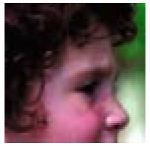


Our method



Back-projection

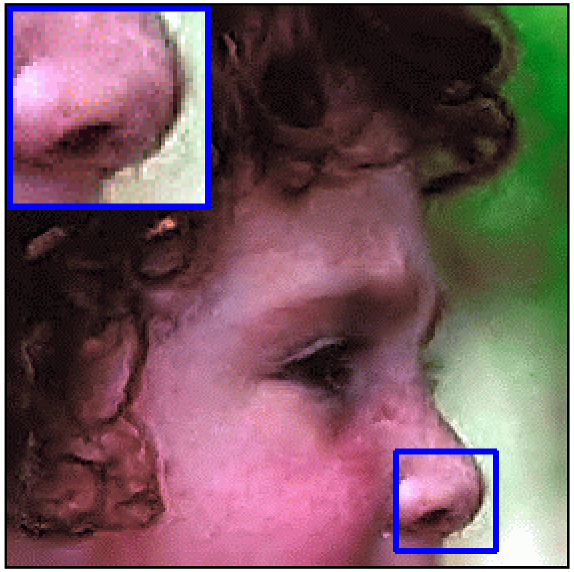
Comparison – exemplar based



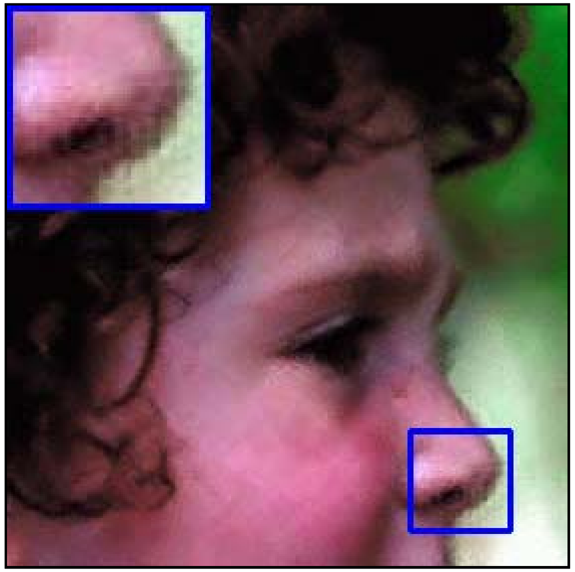
70×70

$\times 4$

Our method



Learning low level vision
(courtesy to Bill Freeman)



Neighbor embedding
(courtesy to Dit-Yan Yeung)

Conclusion

- Soft smoothness prior
  - With specific geometric explanation
  - Applicable to super resolution
- Alpha channel super resolution

- Limitation
  - The smoothness prior may not hold for texture