Blind Super-Resolution

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** Joint work with Tomer Michaeli* **[ICCV 2013]**

Super-Resolution

- *Classical multi-image SR*
- *Example-based SR*
  - *External*
  - *Internal*

Wrong blur kernel

➔ Bad SR results

Blind Super Resolution

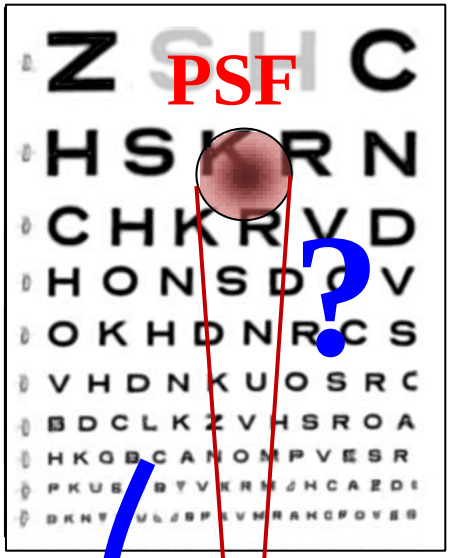
Assumed known

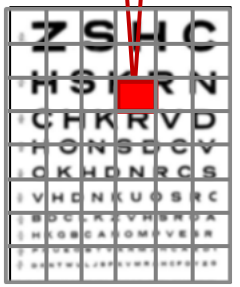
$(h * k) \downarrow_\alpha$

PSF Gaussian

⋮

high-res image h





low-res image l

In this work:

1. The correct blur k is NOT the PSF
2. Recover the optimal SR kernel k directly from the low-res image l

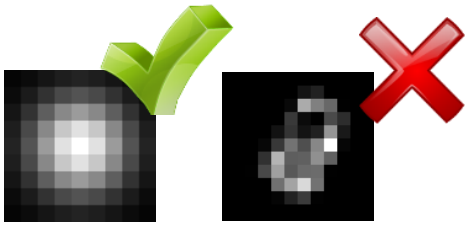
Prior Work on Blind-SR

- **Parametric kernels:**

  [Begin & Ferrie. '04], [Wang et al. '05], [Qiao et al. '06], [He et al. '09]

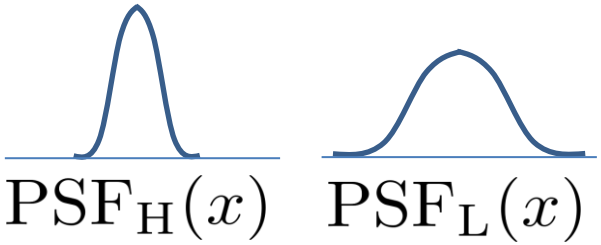
- **Nonparametric kernels with a single peak:**

  [Joshi et al. '08]



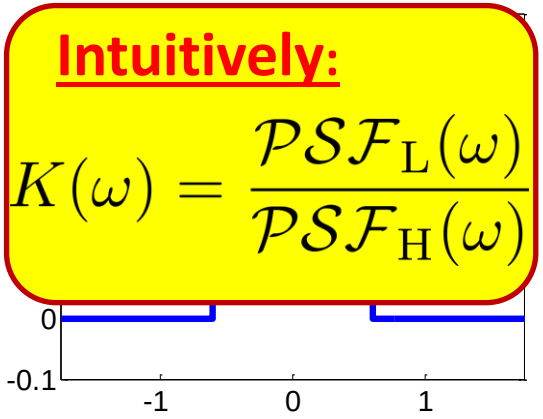
Our goal: General Nonparametric Blind-SR

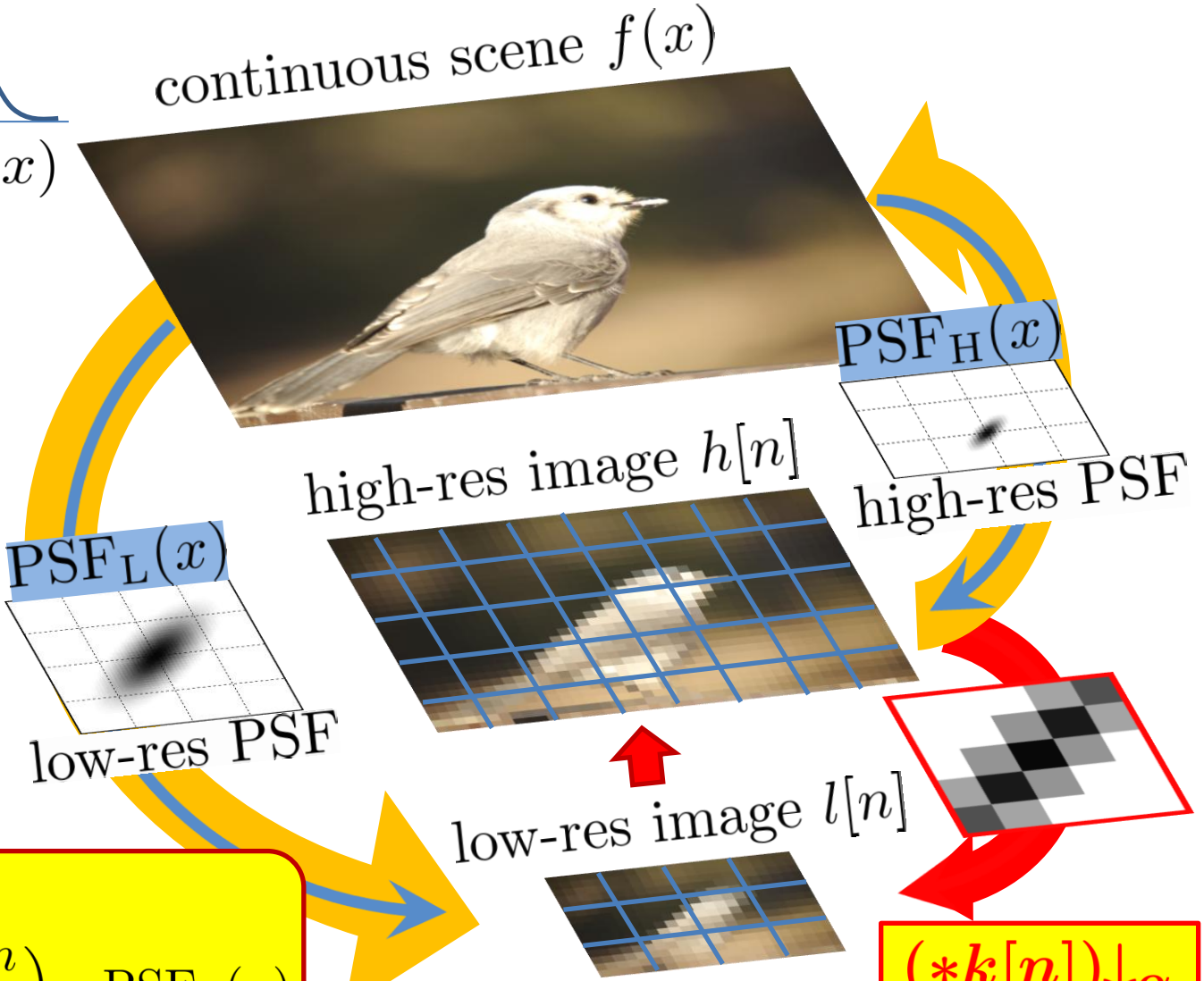
What is the Correct Blur Kernel?



Intuitively:

$$K(\omega) = \frac{\mathcal{PSF}_{\mathrm{L}}(\omega)}{\mathcal{PSF}_{\mathrm{H}}(\omega)}$$





More formally:

$$\sum_m k[m]\,\mathrm{PSF_H}\left(x - \frac{m}{\alpha}\right) = \mathrm{PSF_L}(x)$$

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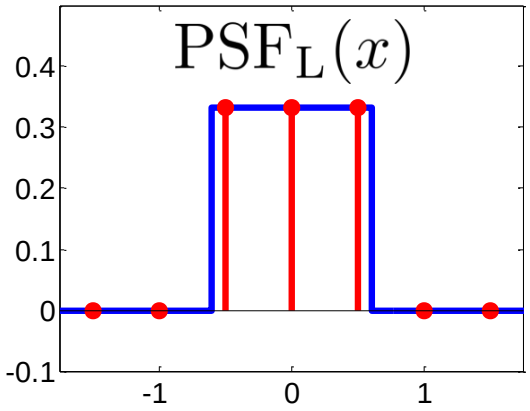
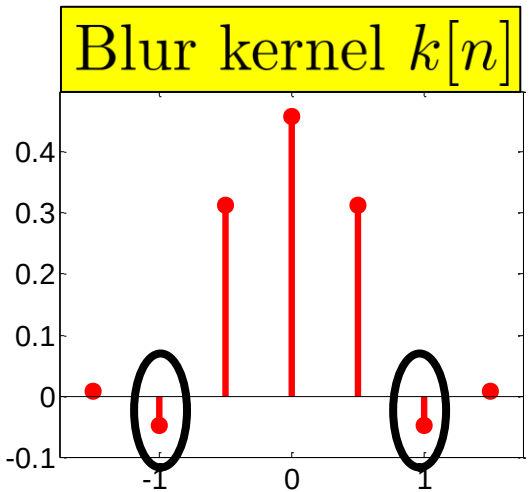
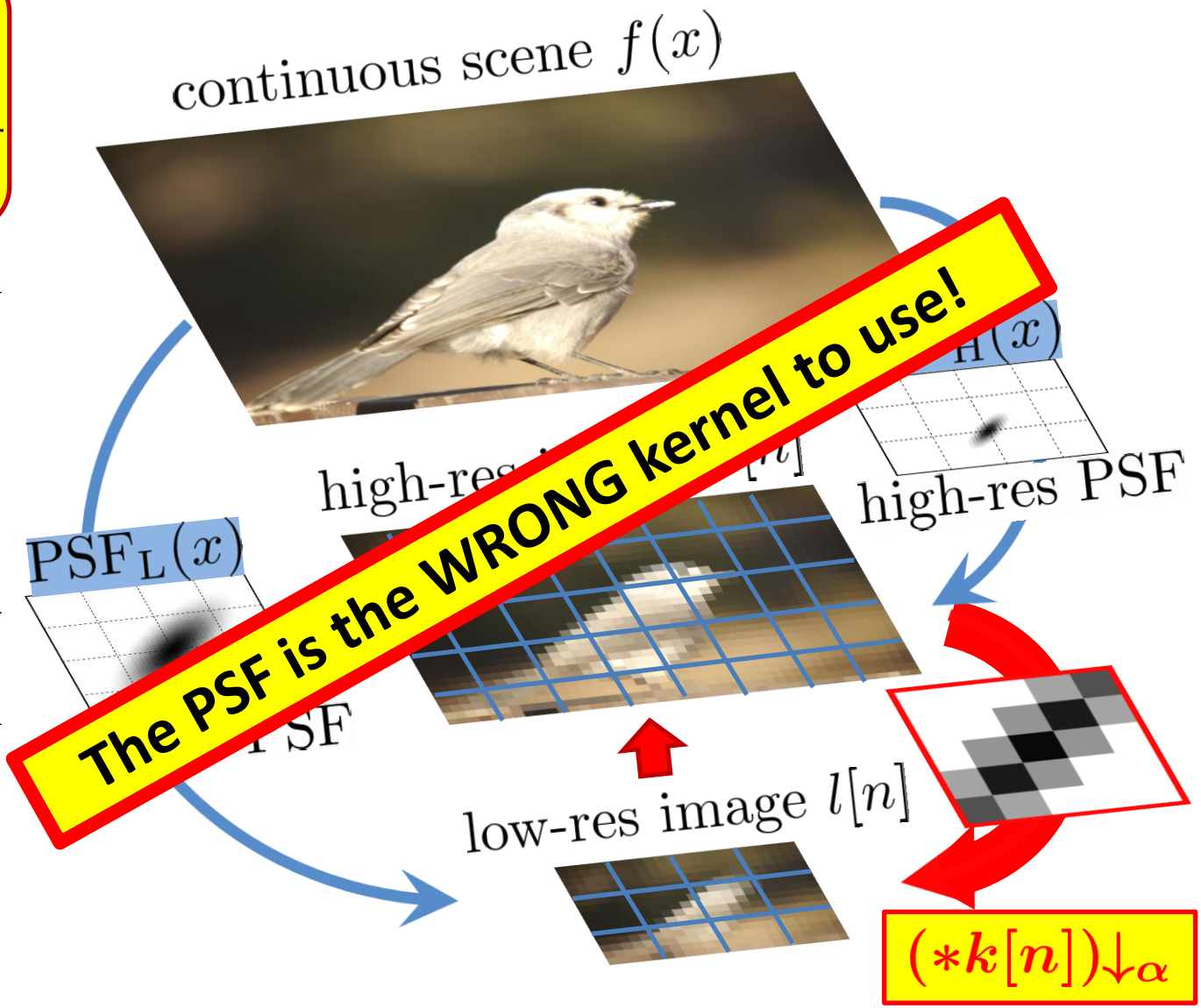






Kernel Recovery

Natural images behave like fractals

➔ **Small patterns recur at different scales:**

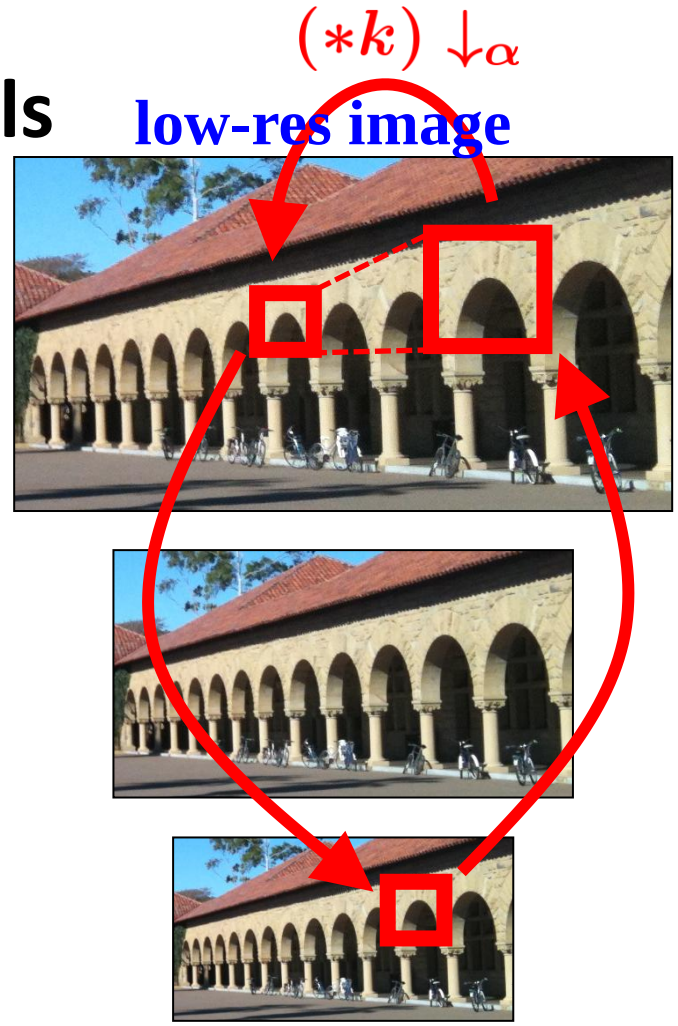
- **Fractal image compression**

  [Barnsley & Sloan `87], ...

- **Single image SR**

  [Glasner,Bagon,Irani `09],

  [Freedman & Fattal `11], …

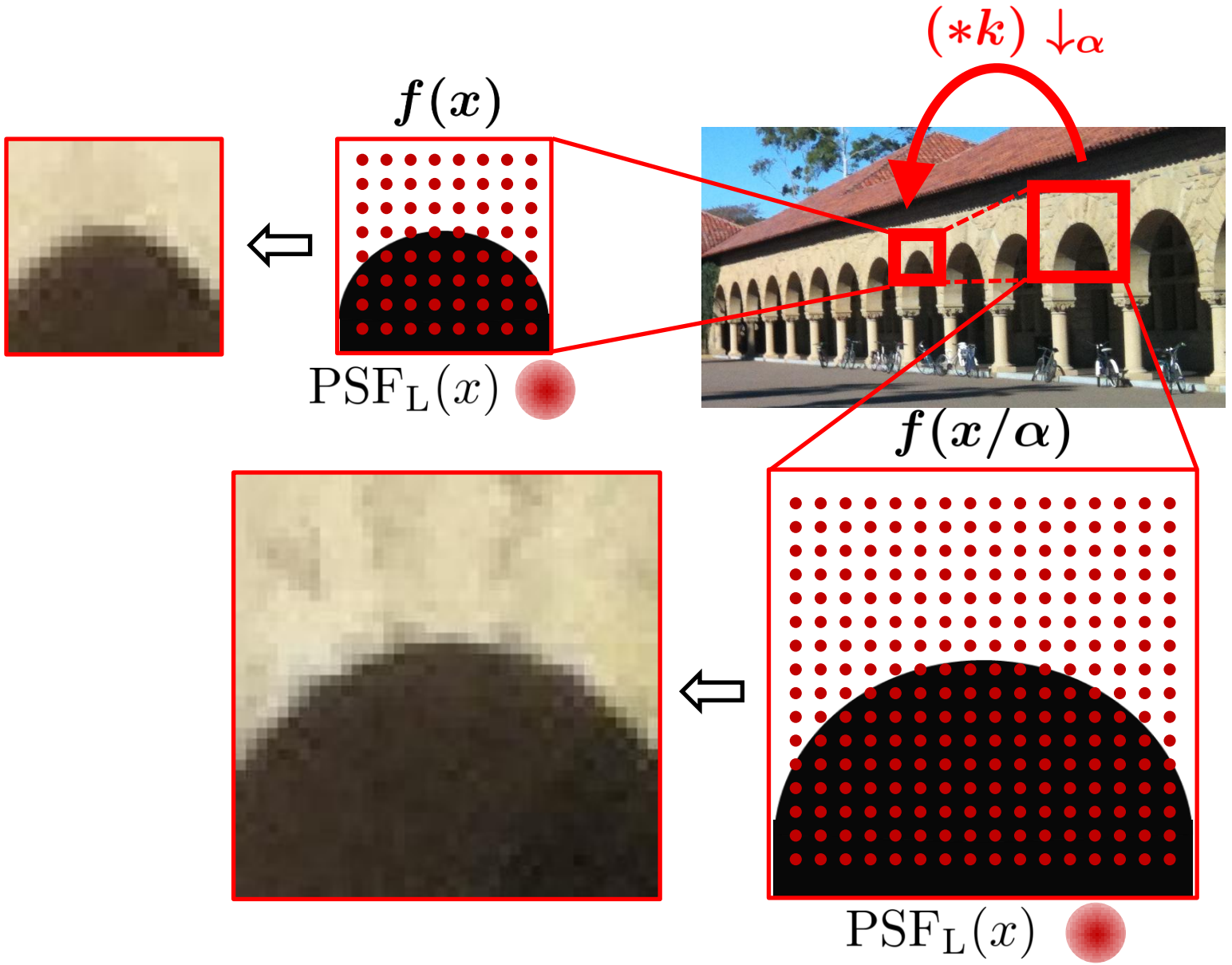


True for most 5x5 patches in any natural image

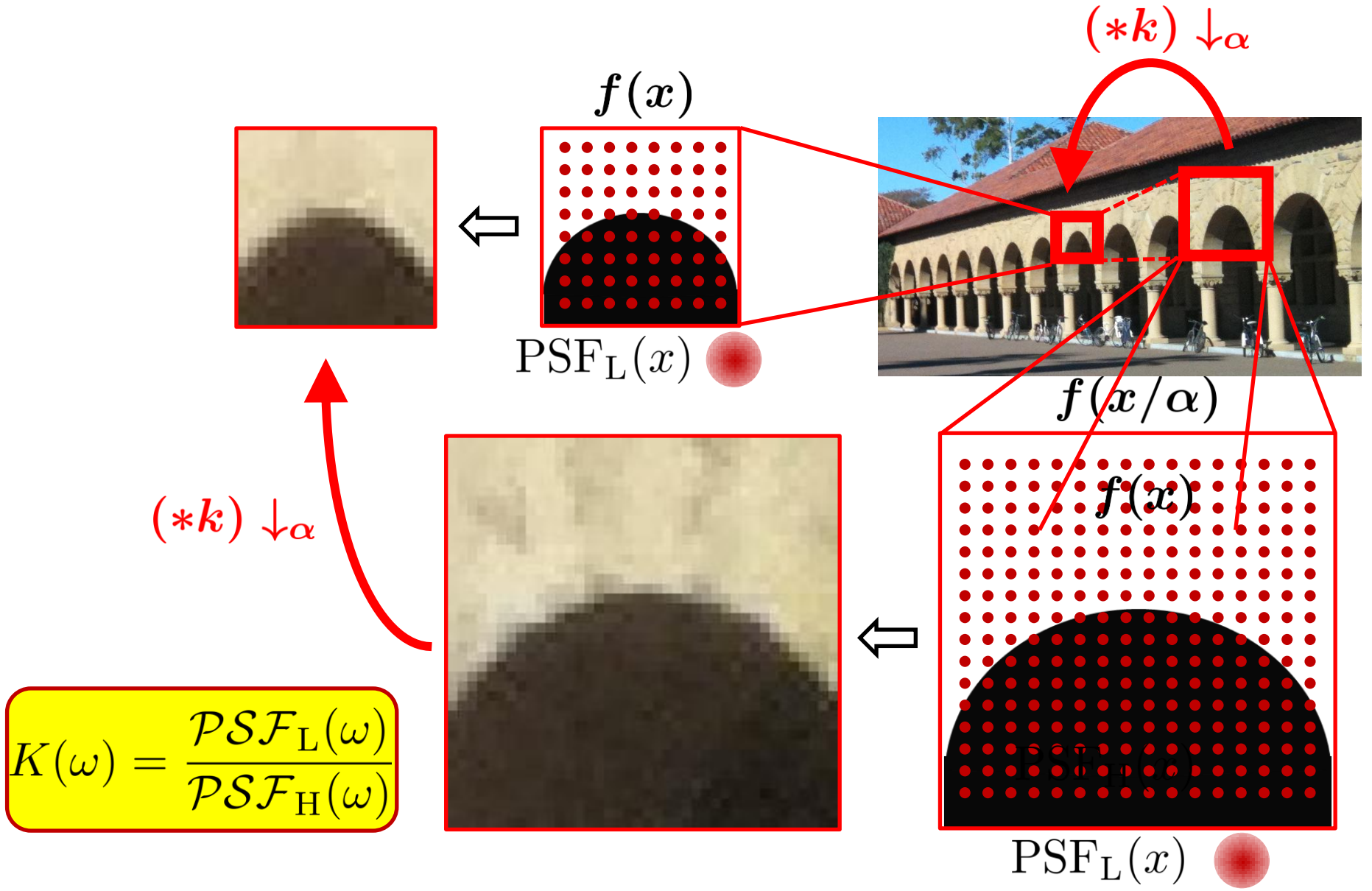
[Glasner,Bagon,Irani 2009]

➔ Recover the unknown SR blur kernel

Kernel Recovery



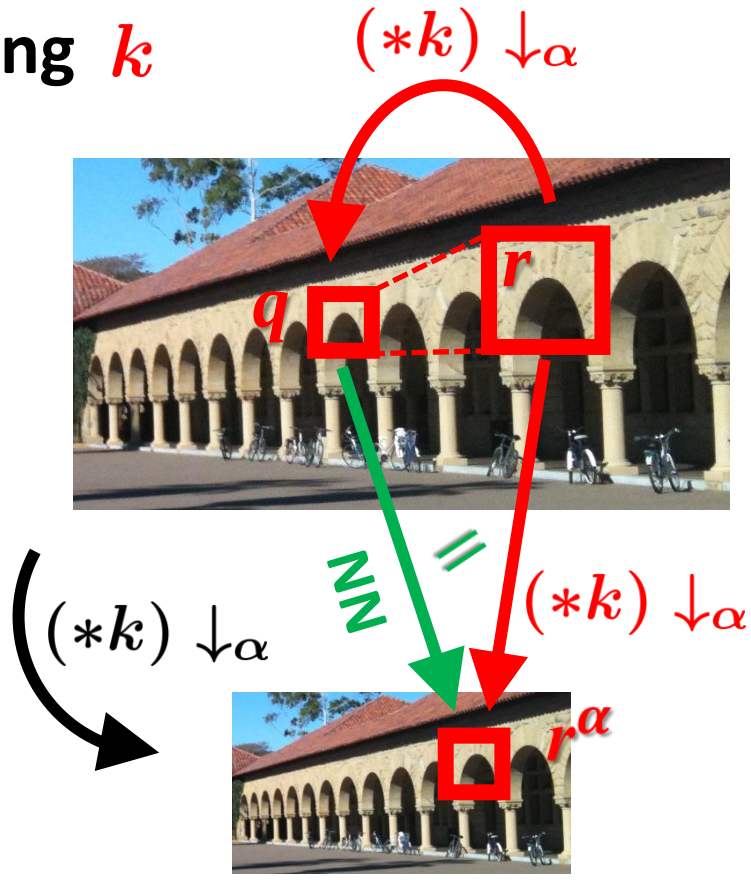
Kernel Recovery



Kernel Recovery

Enough pairs allow recovering k

$$q = (r * k) \downarrow \alpha$$



Algorithm

Initialize $\hat{k} = \delta$

For $t = 1 \ldots T$

1. Down-sample image with $\hat{k}$
2. Find NNs
3. Update $\hat{k}$ using least-squares

End

The optimal kernel k maximizes patch similarity across scales

Kernel Recovery

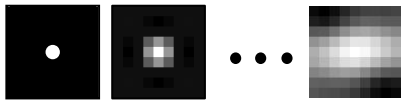
Insensitive to initial guess $\hat{k}$

Robust

Initial

Final

iterations



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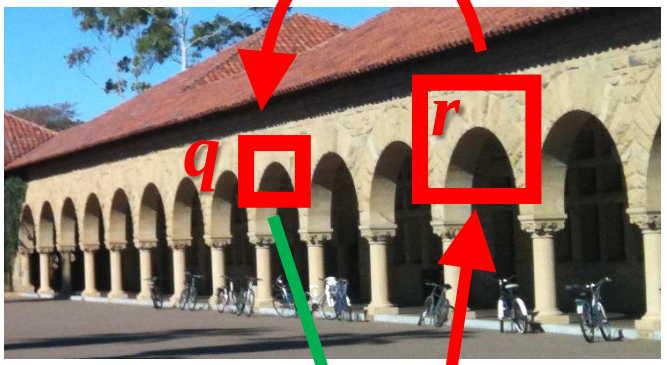


NN

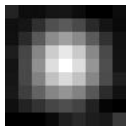
$(*\hat{k}) \downarrow_\alpha$

Results

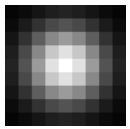
Low-res input image
(generated with ground-truth kernel)

[1] Glasner, Bagon, Irani – ICCV 2009
(Internal example-based SR)

[2] Zeyde, Elad, Protter – LNCS 2012
(External example-based SR)



Recovered kernel



Ground-truth kernel

Default kernel

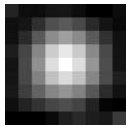
SRx2 with default kernel

Default kernel

[1] Glasner, Bagon, Irani 2009

[2] Zeyde, Elad, Protter 2012

SRx2 with Recovered kernel



Recovered kernel

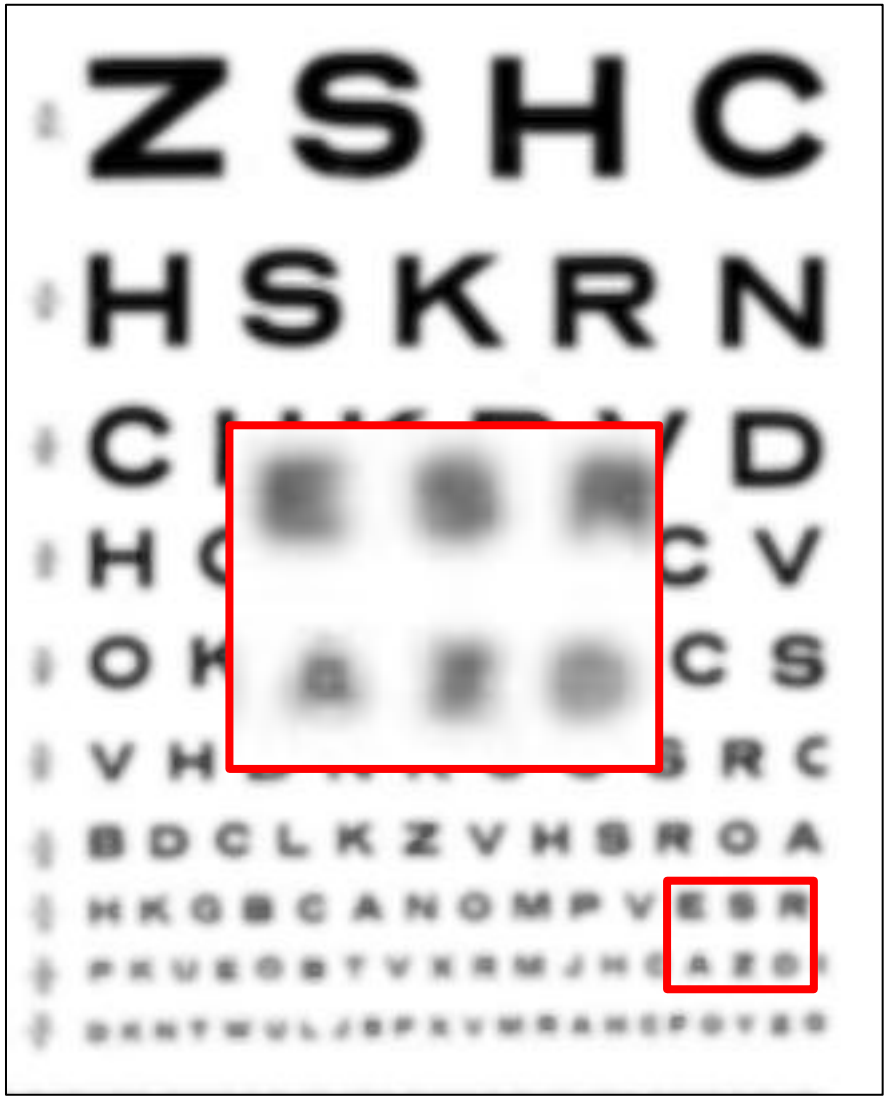
[1] Glasner, Bagon, Irani 2009

[2] Zeyde, Elad, Protter 2012

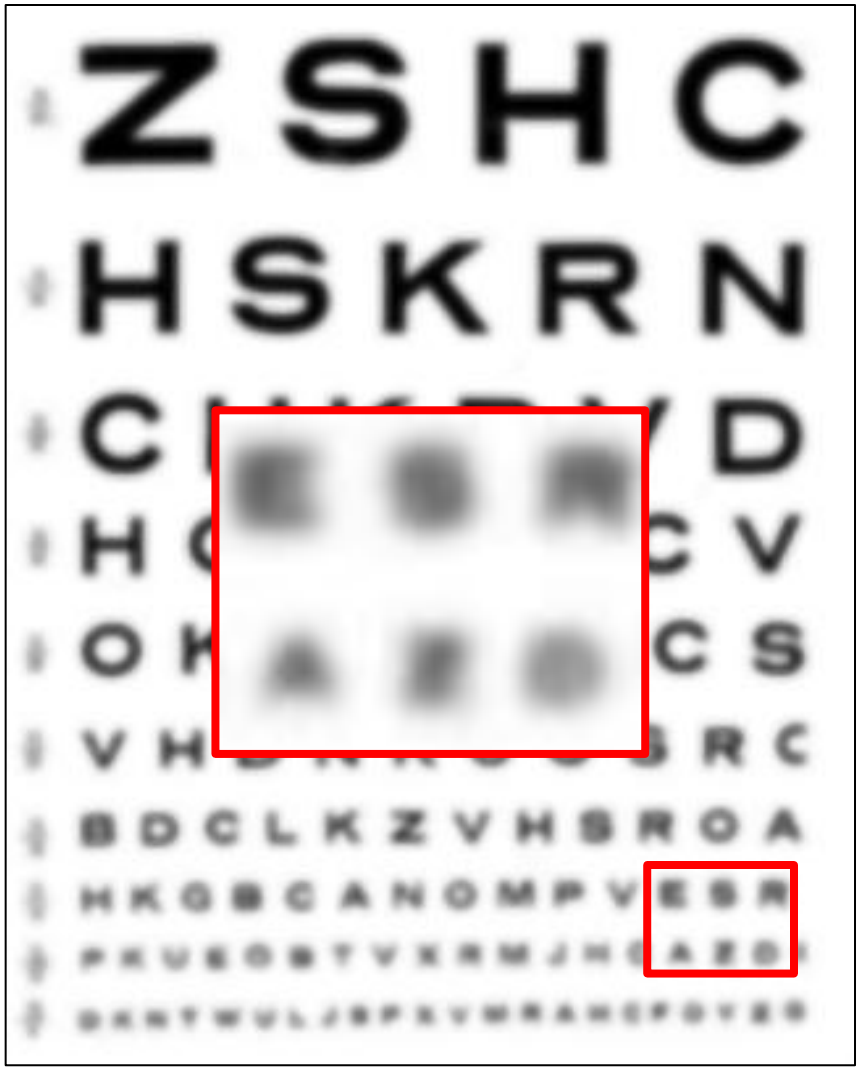
SRx2 with default kernel

Default kernel

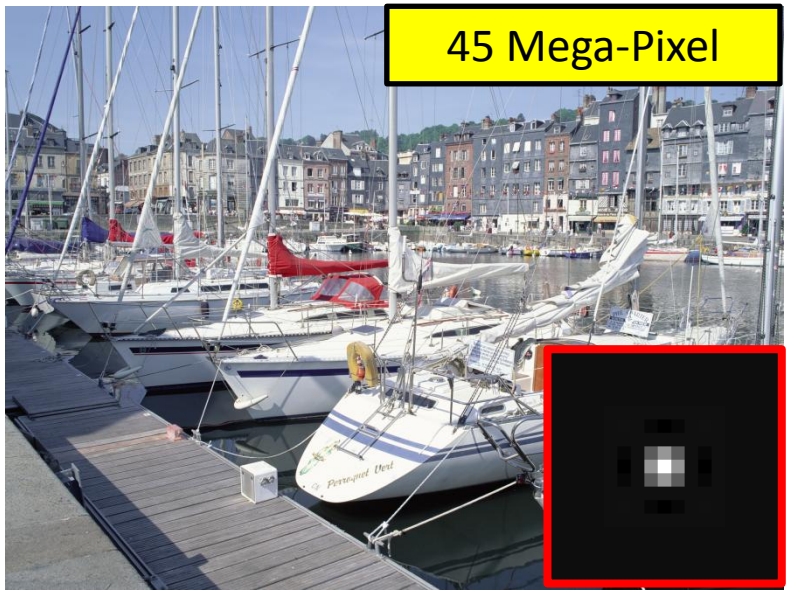
[1] Glasner, Bagon, Irani 2009

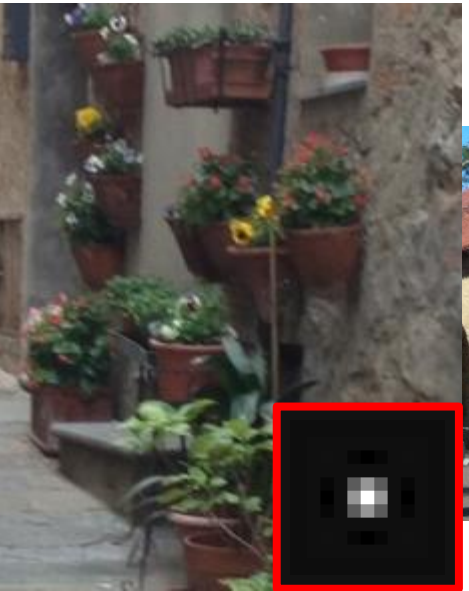


[2] Zeyde, Elad, Protter 2012

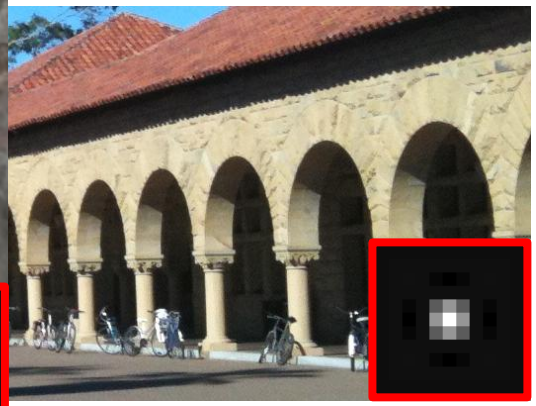


Real (Difficult) Images





iPhone



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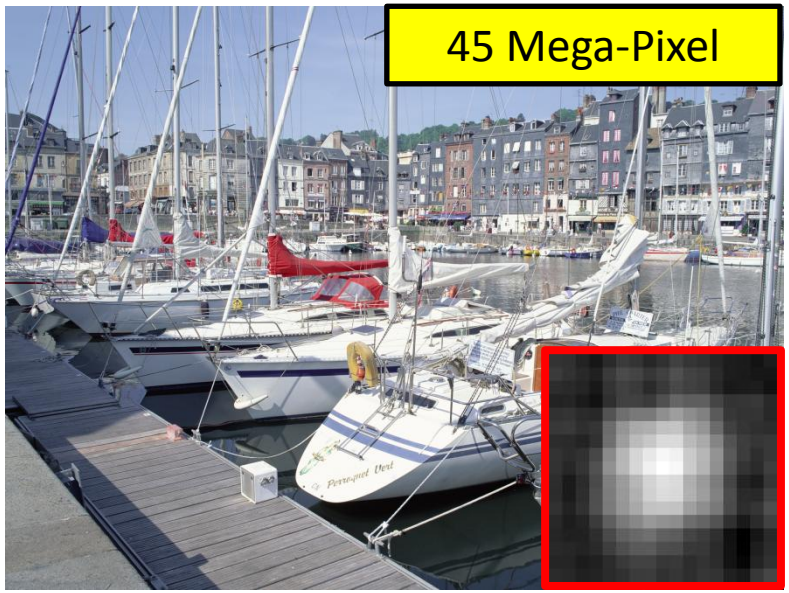

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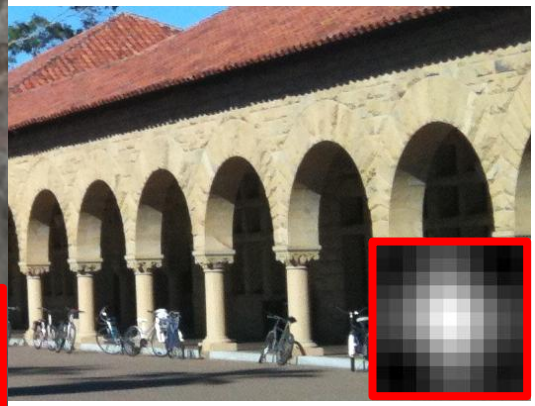

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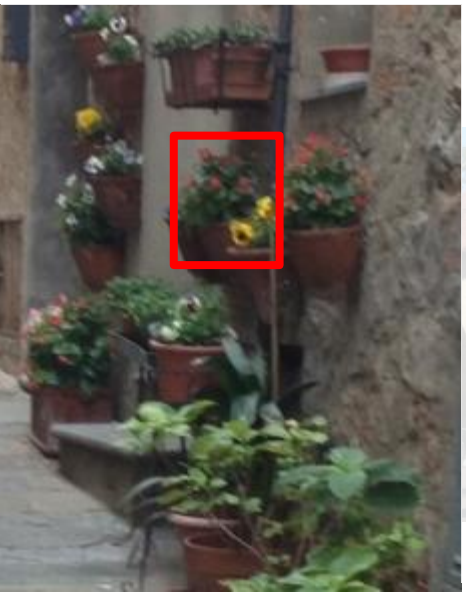

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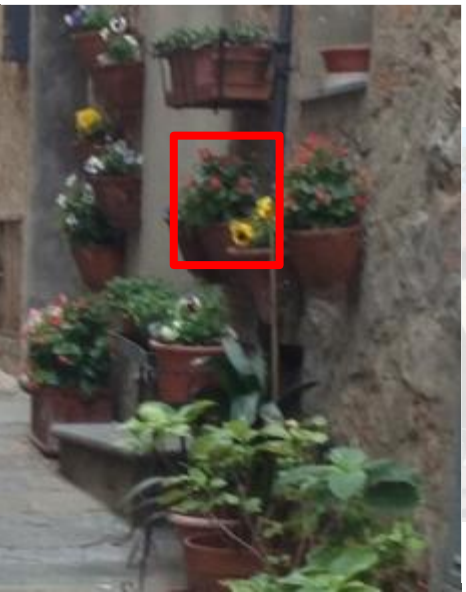


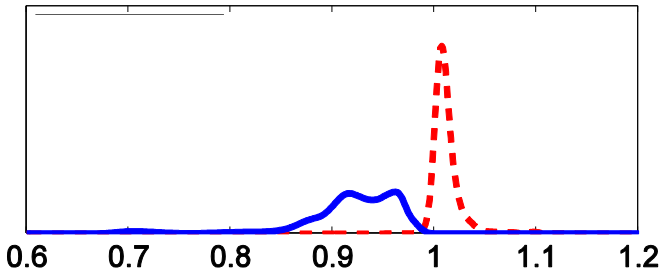
Quantitative Results

Empirical evaluation on hundreds of images (with randomly generated blurs)

Relative error ***w.r.t.*** **ground-truth kernel** $\frac{ERR(Recovered\ kernel)}{ERR(GT\ kernel)}$

Relative error ***w.r.t.*** **default kernel** $\frac{ERR(Recovered\ kernel)}{ERR(Default\ kernel)}$

SR of Glasner *et al.*



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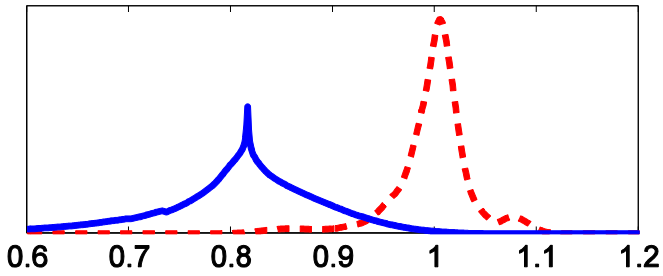

Conclusions

- **The PSF is the WRONG SR blur kernel**
- **Recover the SR kernel from the low-res image**
- **Significant improvement in SR results**

THANK YOU!