



DEBLURRING OPTIMIZATION THROUGH SEPARABLE BLUR KERNEL

Lu Fang

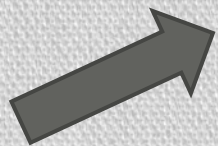
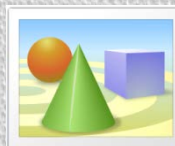
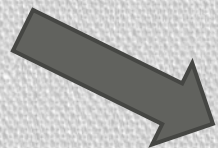
Univ. of Science and Tech. of China

Outline

- **Background Introduction**
- **Pre-analysis of Separable Blur Kernel**
- **Proposed Deblurring Optimization Scheme**
 - ✧ **Random Trajectory Perturbation (RTP)**
 - ✧ **Trajectory Scale Searching (TSS)**
- **Experimental Results and Discussions**

Motivation

More and more pictures ...



flickr™



Bad quality pictures



Out of focus



Blur



Noise

Camera Motion Induced Image Blur

- Convolution Model



Blurred image



Latent sharp image



Blur kernel

$$B = K \otimes I + N$$

\otimes : convolution operator

Image Deblurring Problem

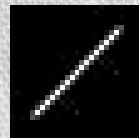
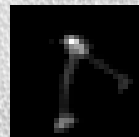
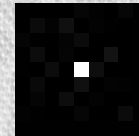
- Severely **ill-posed** problem
 - ✧ **No unique** solution



Blurred image



Possible solutions



Related Work

• Image Priors

- ✧ Krishnan et al., CVPR, 2011
 - Ratio of L1 norm to the L2 norm on the high frequencies
- ✧ Xu et al., CVPR, 2013
 - Generalized and mathematically sound L0 sparse expression
- ✧ Liu et al., CVPR, 2008
 - Color, gradient and spectrum information
- ✧ Joshi et al., CVPR, 2008
 - Utilize sharp edges for PSFs estimation
- ✧ Yuan et al., TOG, 2007
 - Use a noisy but clear image as prior

Related Work

- **Kernel Priors**

- ✧ Xu et al., ICCP, 2012

- Use depth information to help kernel estimation

- ✧ Joshi et al., TOG, 2010

- Use inertial measurement sensors to recover the true trajectory of camera during exposure

- ✧ Gupta et al., ECCV, 2010

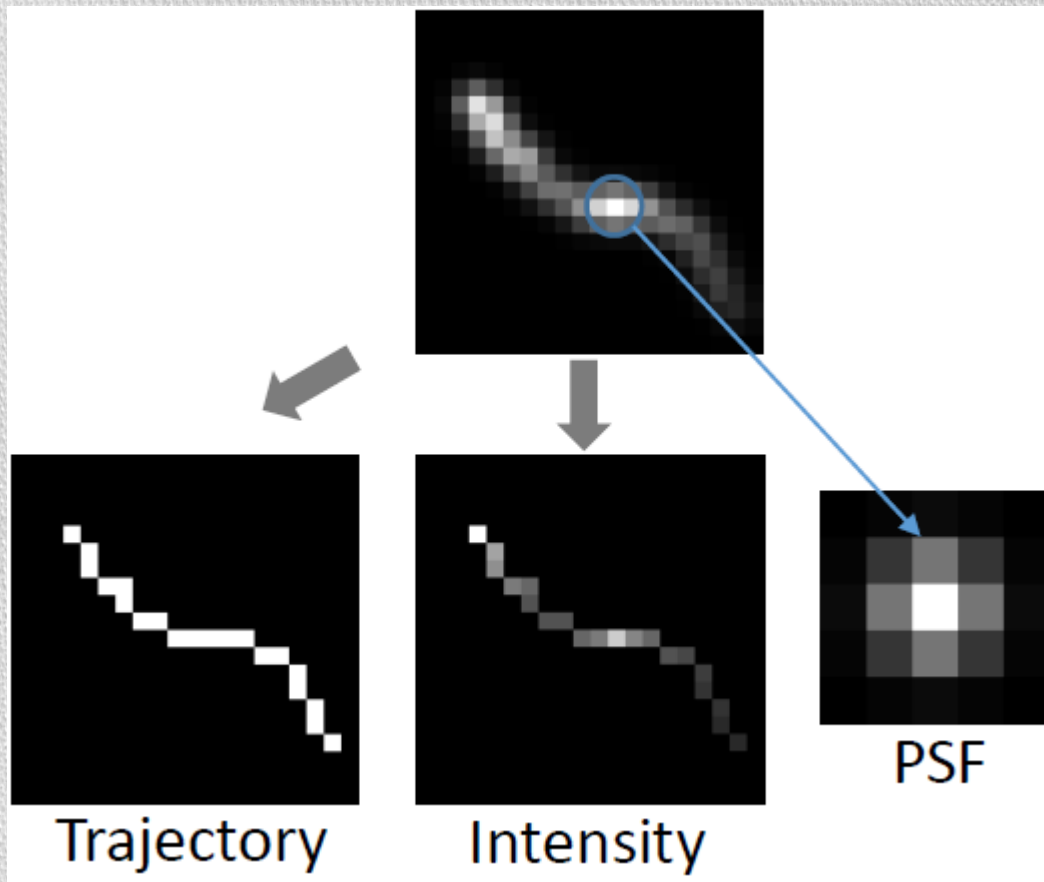
- Model camera motion by motion density function

- ✧ Whyte et al., IJCV, 2012

- Model camera rotation motion as opposed to translation

Our Contribution

- **Separable** Blur Kernel



Trajectory

- *projection of camera shake in 2D image plane*

Intensity

- *staying time of shaking camera in every position*

Point Spread Function

- *decided by camera focus, scene depth and camera motion at the perpendicular direction of image plane*

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Pre-analysis: One Component Degraded Kernel

- Investigate the characteristics of three components



Blurry image



Original image



Ground Truth
Kernel

correlation

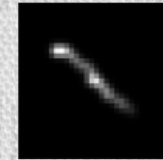
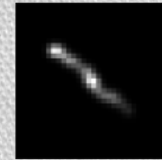
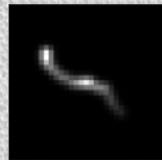
0.9

0.8

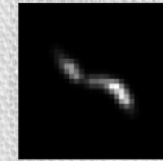
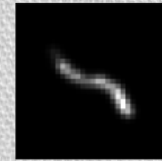
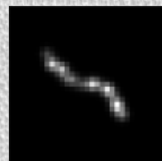
0.7

0.6

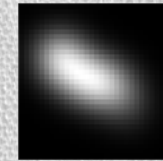
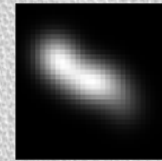
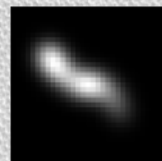
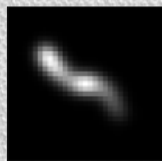
trajectory-
degraded



intensity-
degraded

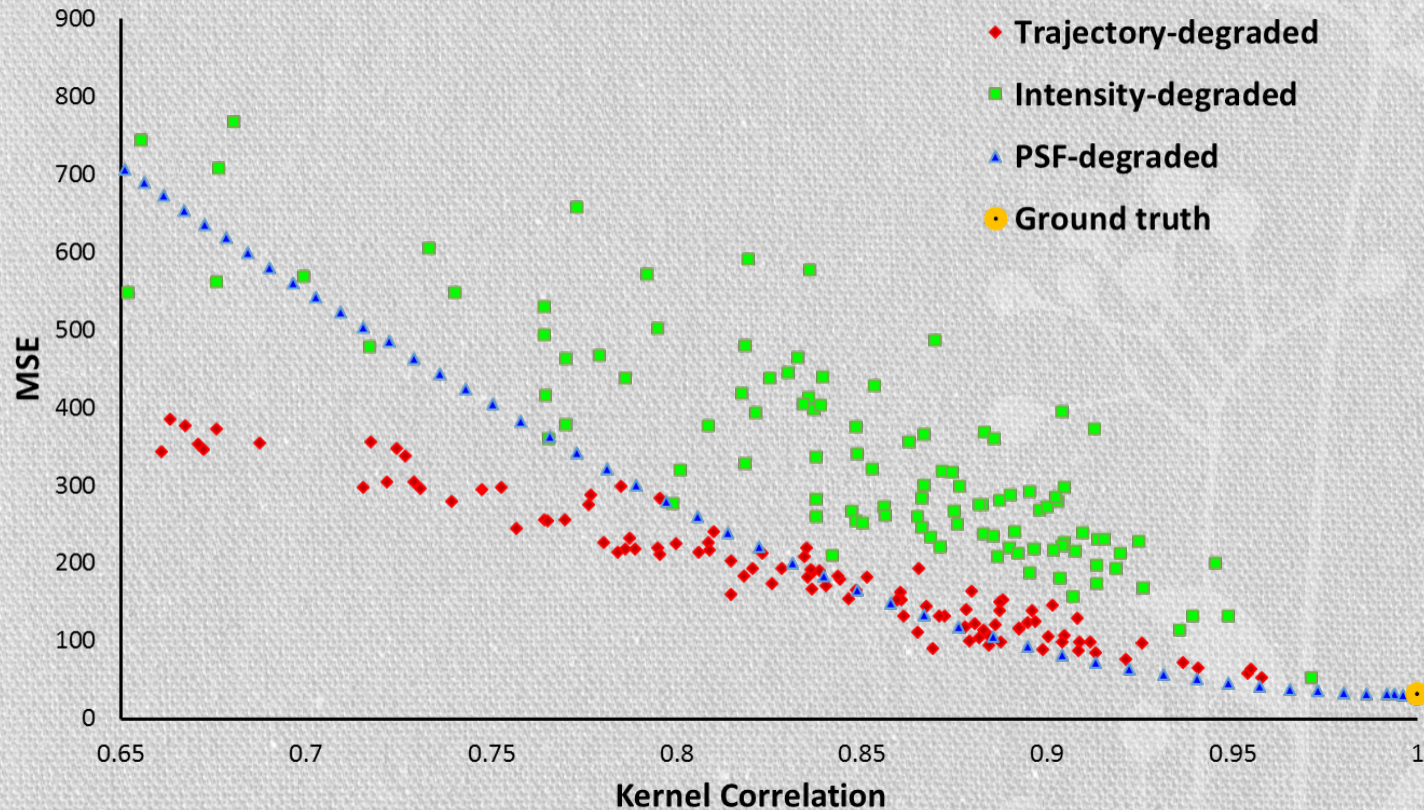


psf-
degraded



Pre-analysis: OCD Kernel Performance

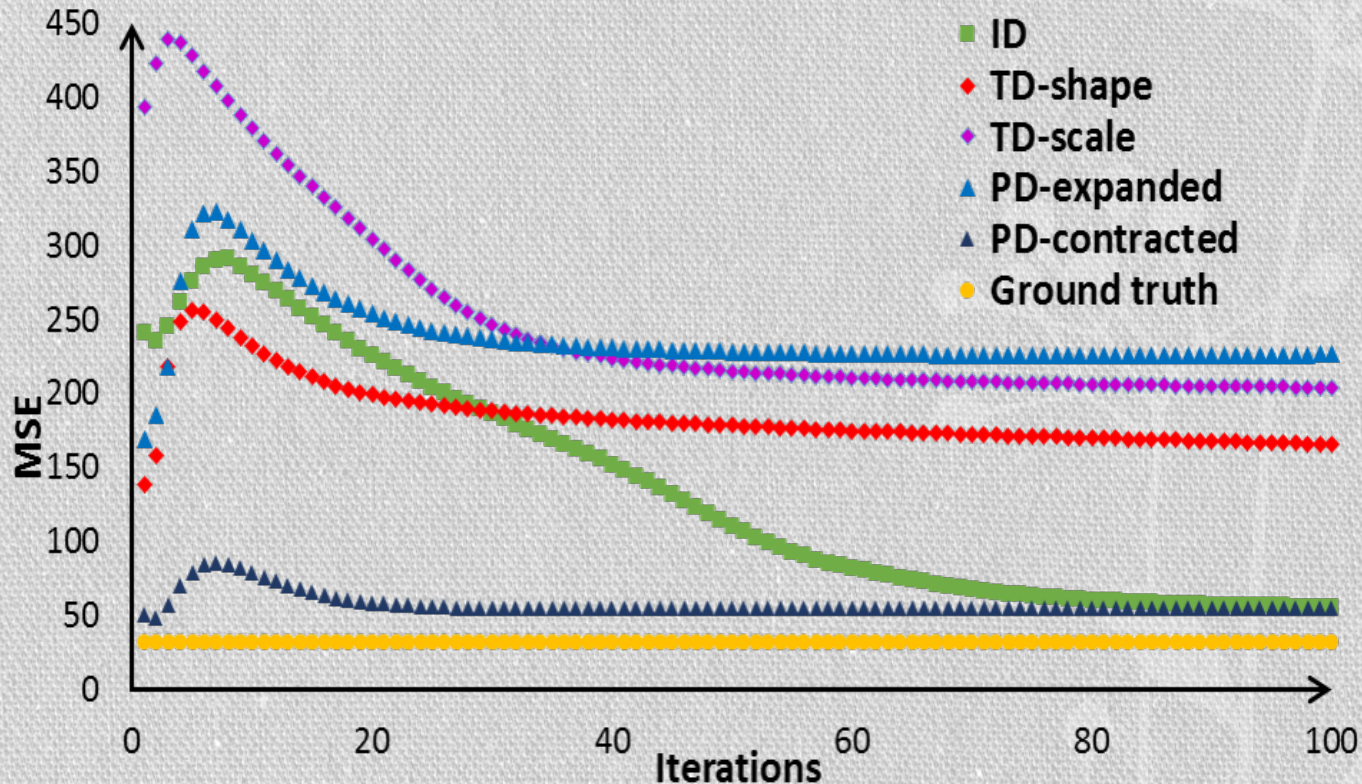
- MSE of deblurred image using one-component degraded (OCD) kernel



- A **smaller kernel correlation** always leads to a **larger MSE**
- Due to monotone increase or decrease of **PSF**, the distribution of its MSEs (**blue** curve) appears **less flexible**
- Degradation in **intensity** (**green** color) results in a relatively **larger distortion**

Pre-analysis: OCD Kernel Optimization

- MSEs of blind deblurred images, with OCD kernels being initialization



- TD kernels in both shape (Red) and scale (Magenta) forms fail to converge with almost immutable large MSE of deblurred images
- ID kernel (Green) can facilely be optimized - the MSE decreases distinctly
- A contracted PD kernel (Cyan) tends to cause much less distortion

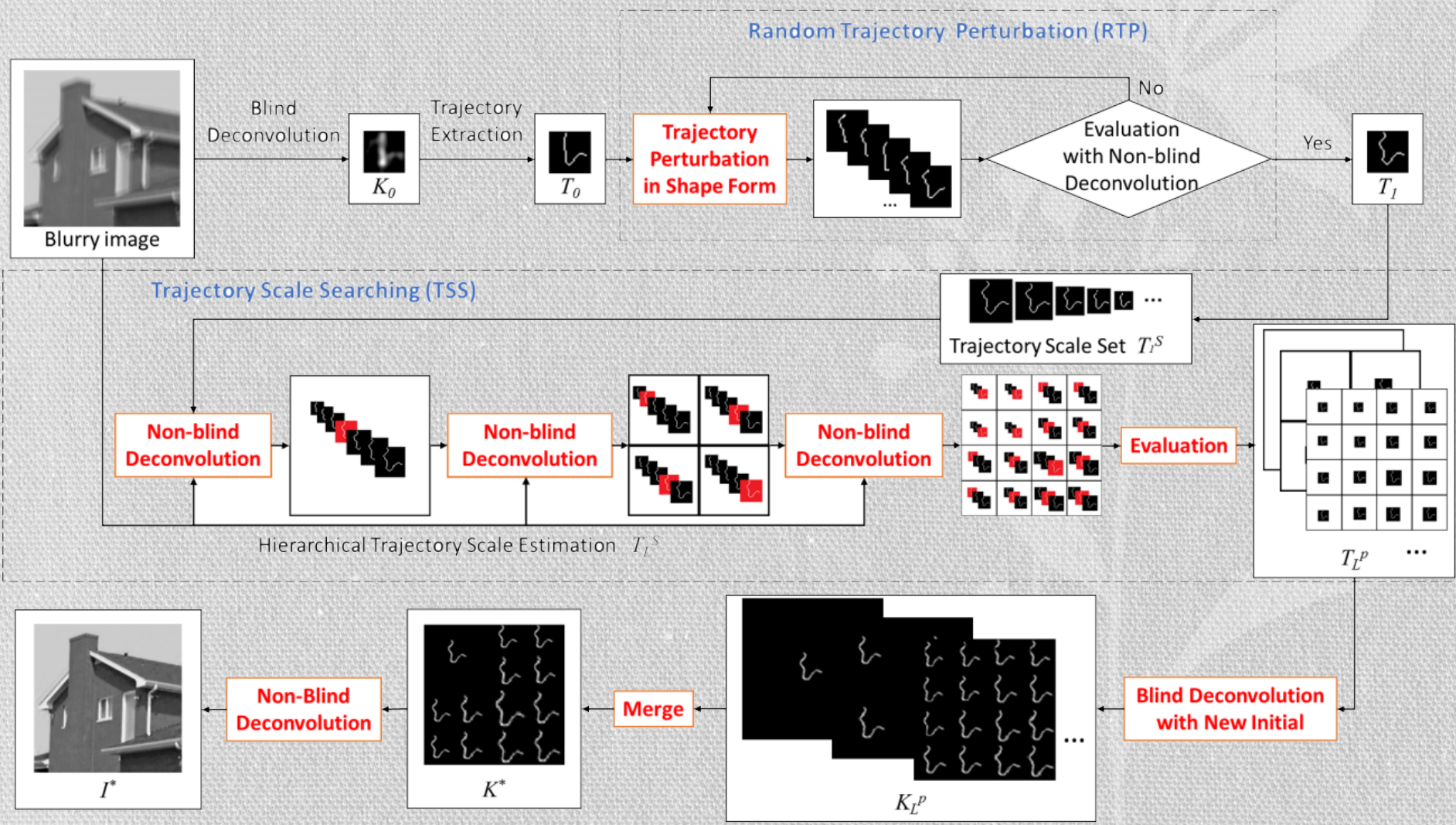
Pre-analysis: Conclusions

- Regardless of severe distortion in **intensity** component, it can be **simply optimized**
- With the good performance in deblurred result, **contracted PSF** component can serve as a good **initialization** for kernel optimization
- **Trajectory** component plays a **crucial** role in intractability of kernel optimization
 - ✧ which falls into **local minimum** once the shape or scale is improperly estimated, and can hardly be corrected

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Proposed Deblurring Optimization Scheme

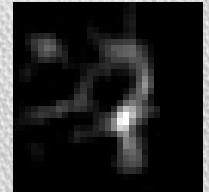


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Random Trajectory Perturbation

Why?



A poor kernel with bad trajectory

- Poor kernel with bad trajectory

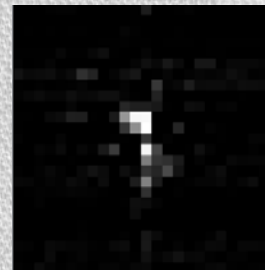
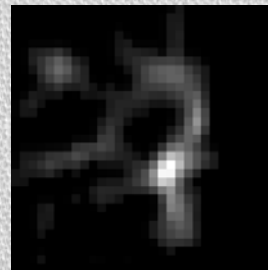
- ✧ Bifurcations

- ✧ Noisy points

- ✧ Broken kernel

- ✧ Inaccurate trajectory

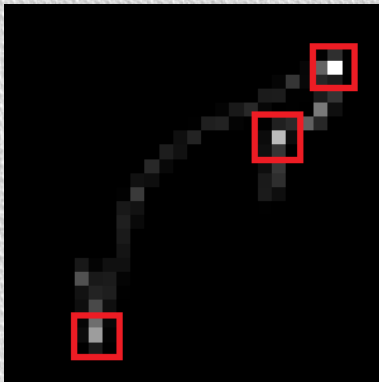
- ✧ ...



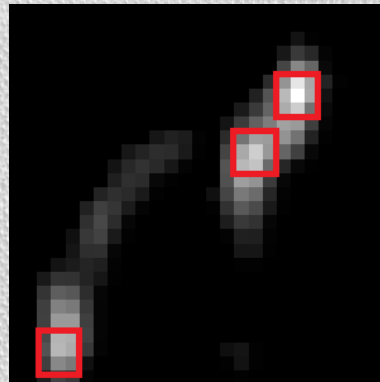
...

RTP: Trajectory Extraction

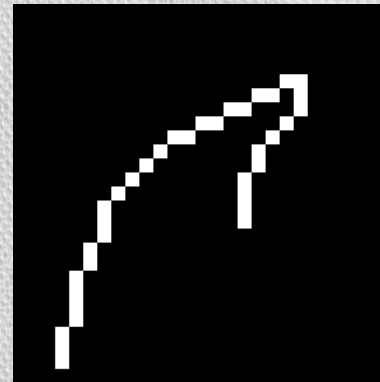
□ Vip Node



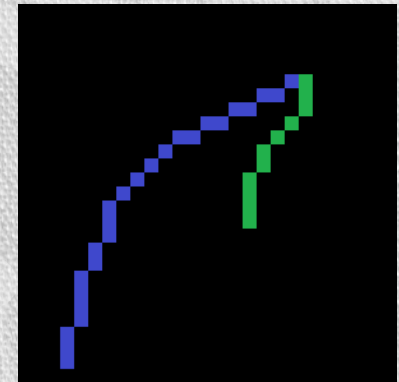
Ground truth kernel



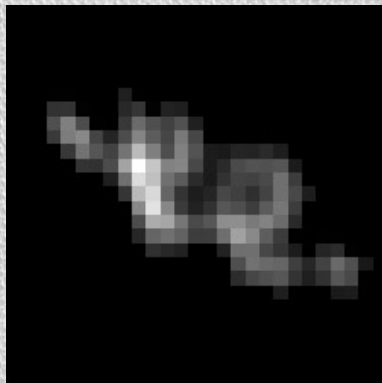
Initial kernel



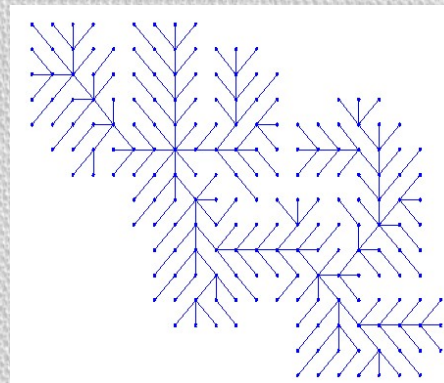
Trajectory



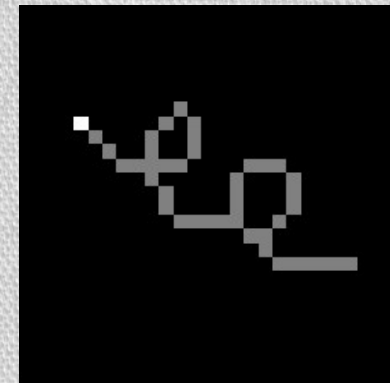
Sub segment



Kernel



Energy-tree-structure

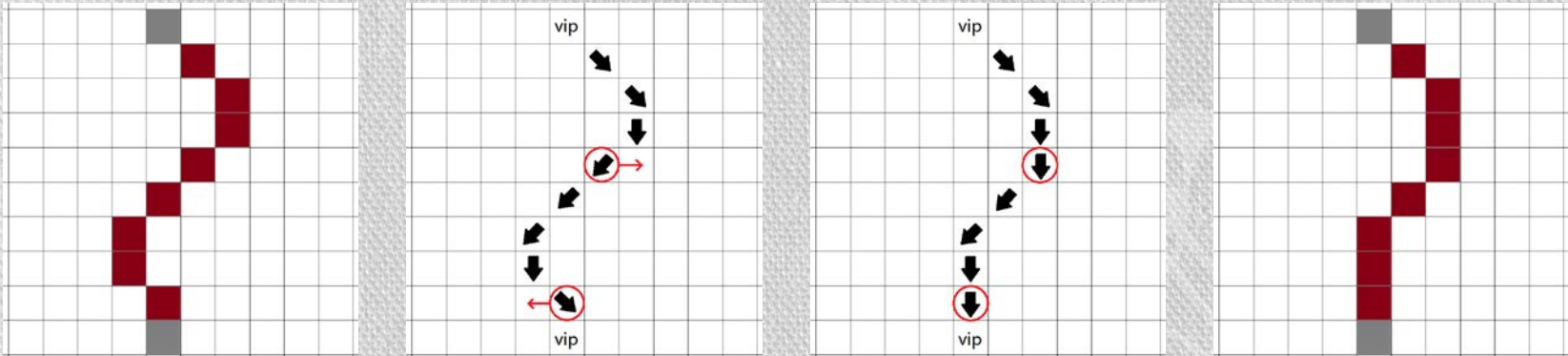


Trajectory

Iterative ordered region-growing process

RTP: Hierarchical Perturbation

- Using a sequence of vectors to represent trajectory
- Pair variation to maintain vip nodes



Trajectory
Extraction

K_0

T_0

Trajectory
perturbation
in shape form

T_{best}

T_1

No

Non-blind
Evaluation

Yes

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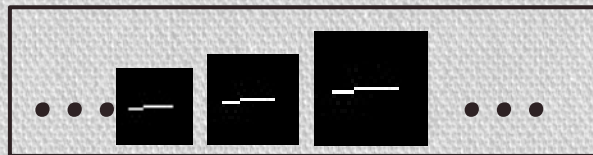
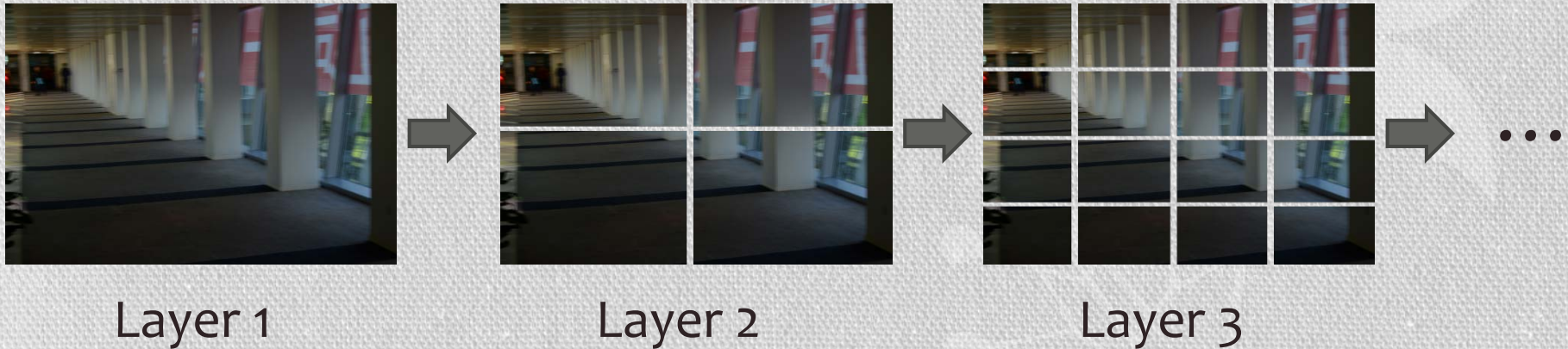
Trajectory Scale Searching

- Why ?
- Spatially-variant Blur kernel

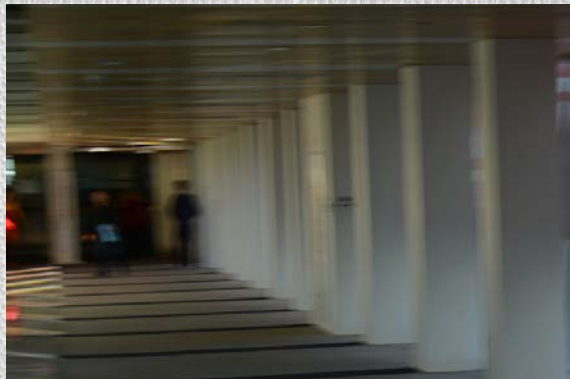


TSS: Non-uniform Scaling

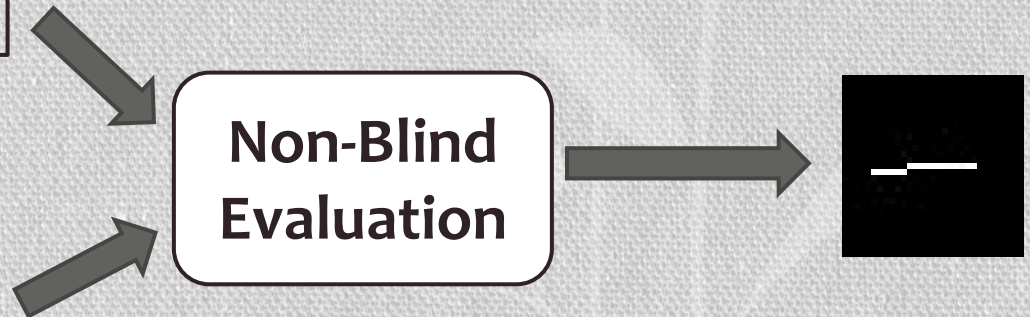
- Quad tree Segmentation



Different sizes of trajectory



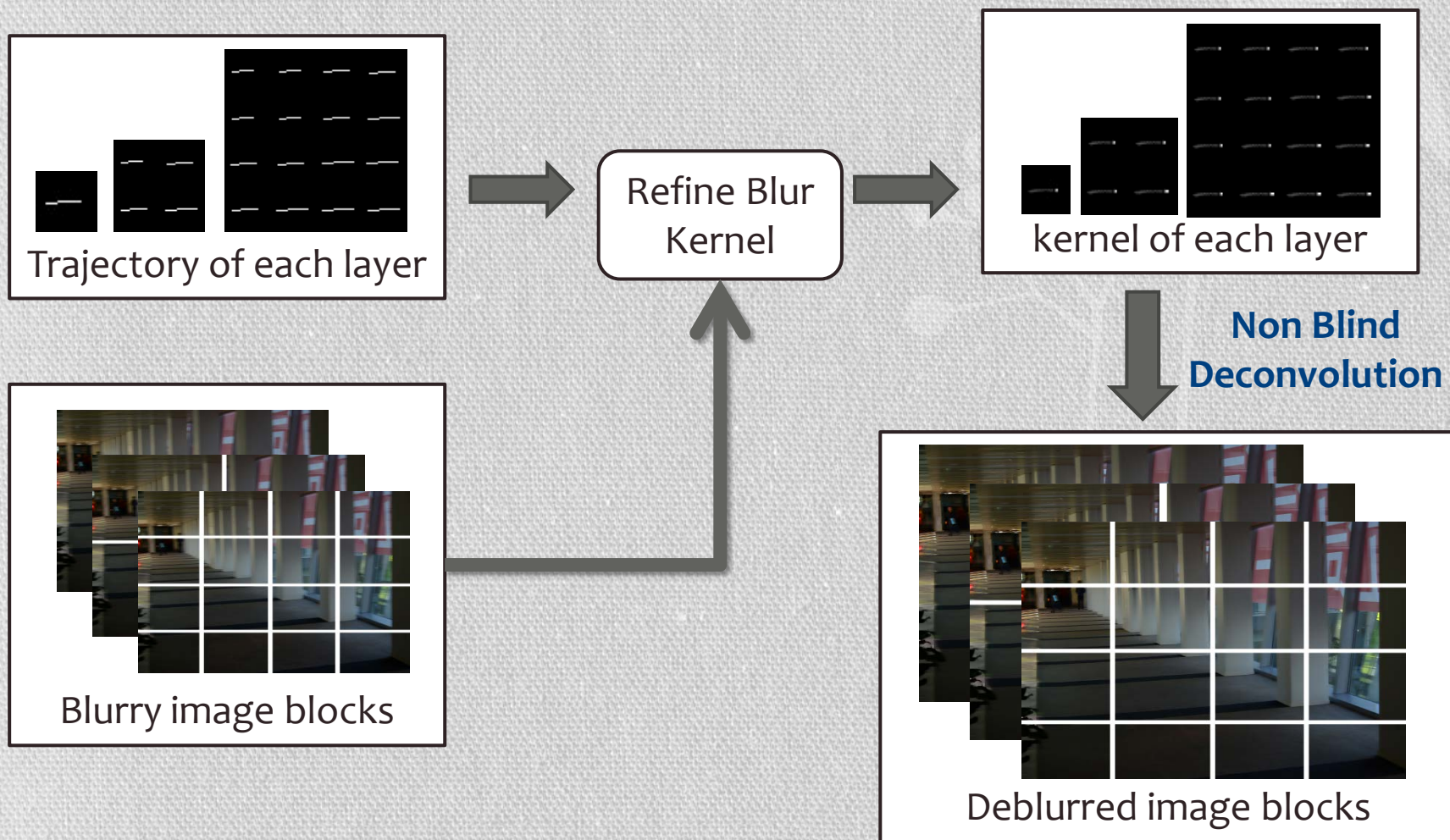
Blurry image block



- Trajectory scale searching within every blurry image block

Blind Deconvolution with New Initial

- Refine blur kernel aided by corrected trajectory



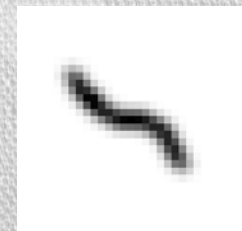
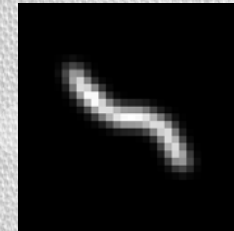
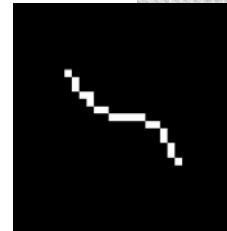
Blind Deconvolution with New Initial

$$K_p^* = \arg \min_{K_p, I_p} \left\| \nabla B_p - \nabla I_p \otimes K_p \right\|_2^2$$

$$+ \lambda_1 \frac{\|\nabla I_p\|_1}{\|\nabla I_p\|_2} + \lambda_2 \|W \circ K_p\|_1$$

s.t. $W = 1 - G(T_p^*),$

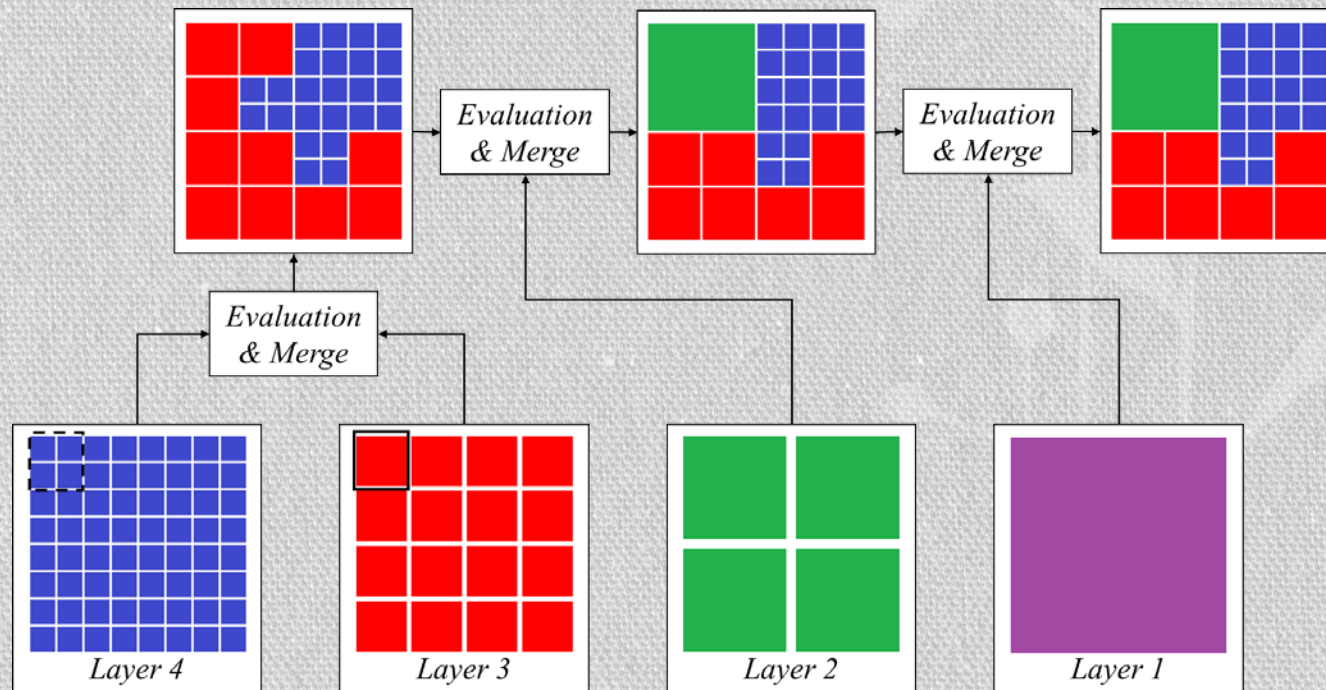
non-statistical
penalty term



T_p

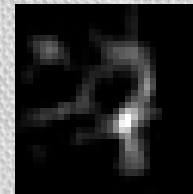
$G(T_p)$

$1 - G(T_p)$

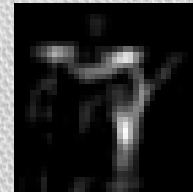


Discussions of Proposed Scheme

- Provide conventional deblurring schemes a chance to jump out the local minimum through trajectory perturbation



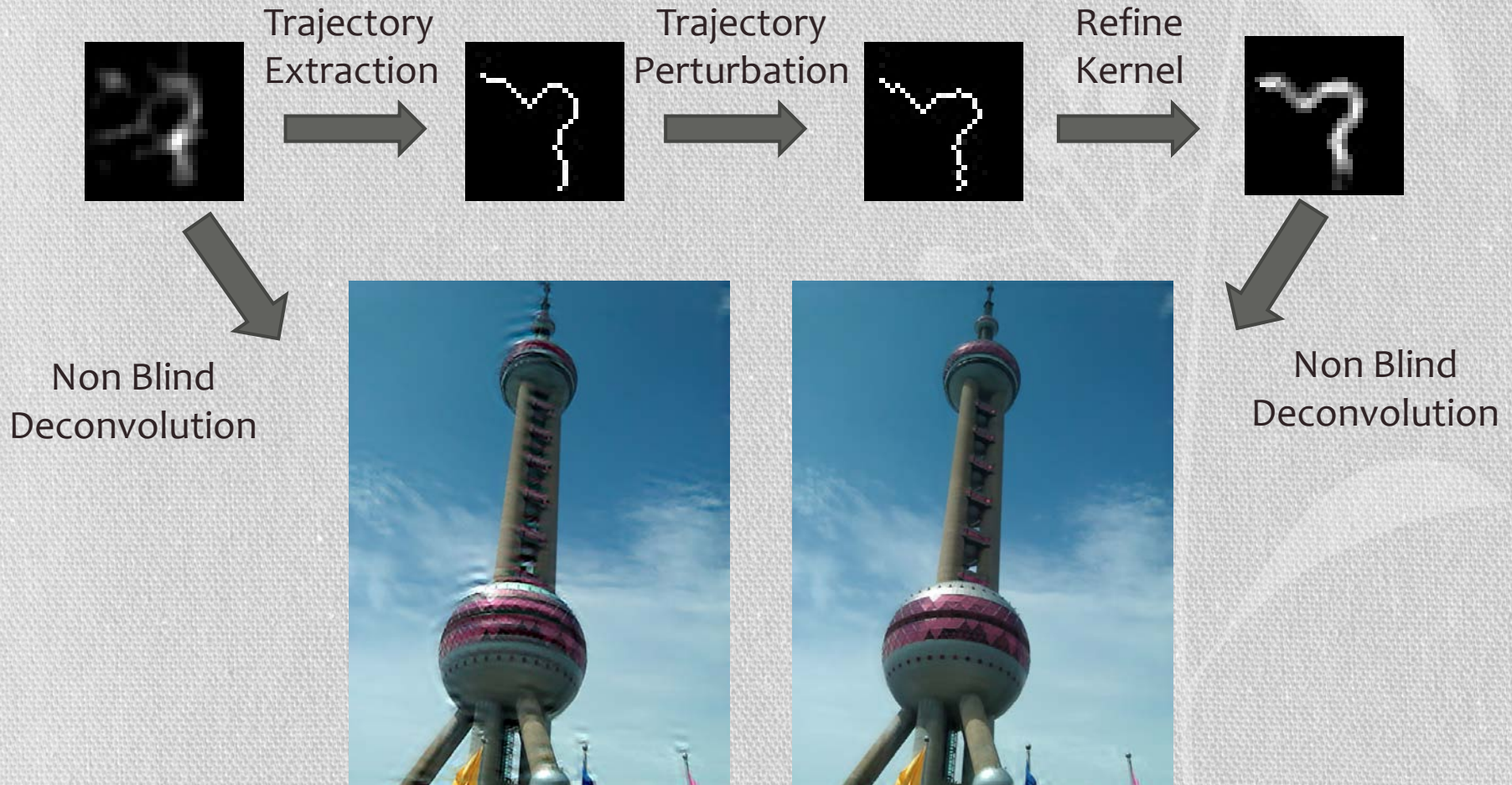
Kernel size = 31 px



Kernel size = 35 px

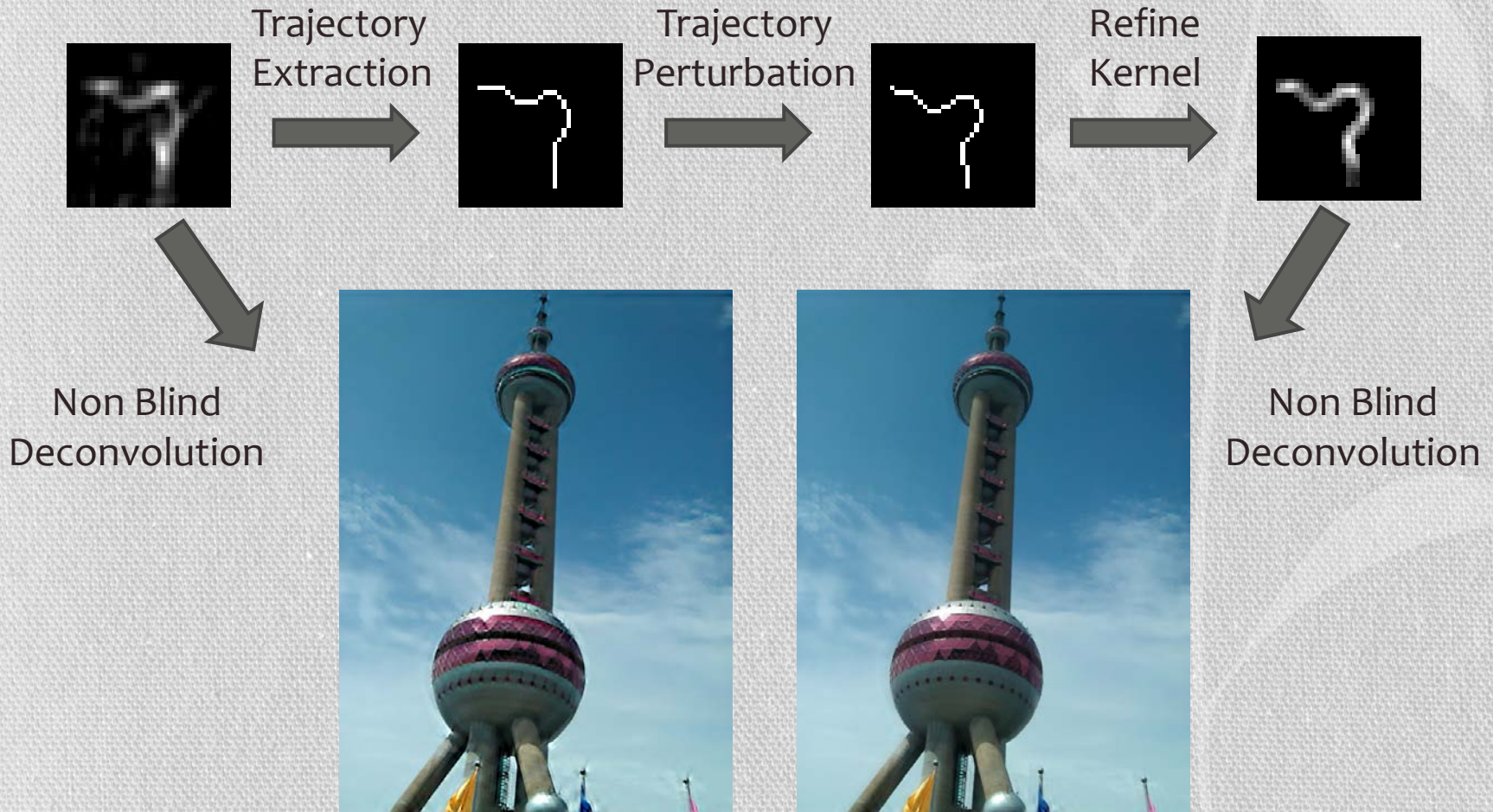
Discussions of Proposed Scheme

- Does **NOT** rely on the initial kernel



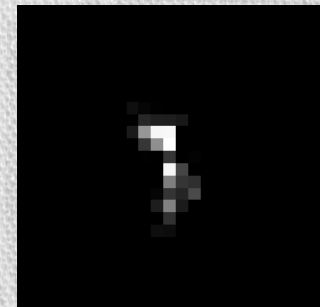
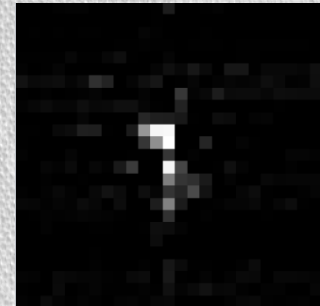
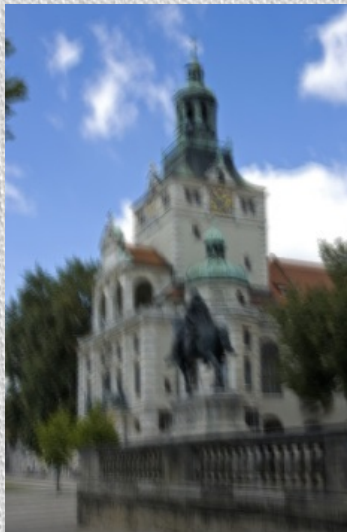
Discussions of Proposed Scheme

- Another initial kernel



Discussions of Proposed Scheme

- Suppress noisy points



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Real-world Blurry Image



Deblurred Image



Xu, Li, Shicheng Zheng, Jiaya Jia. "Unnatural Io sparse representation for natural image deblurring." *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2013. 31

Deblurred Image



Whyte, Oliver, Josef Sivic, Andrew Zisserman, Jean Ponce. "Non-uniform deblurring for shaken images." *International journal of computer vision(IJCV)*, Vol.98, No.2, pp.168-186, 2012. 32

Deblurred Image



Our



Blurry Image



Jia



Whyte



Our

Real-world Blurry Image



Deblurred Image



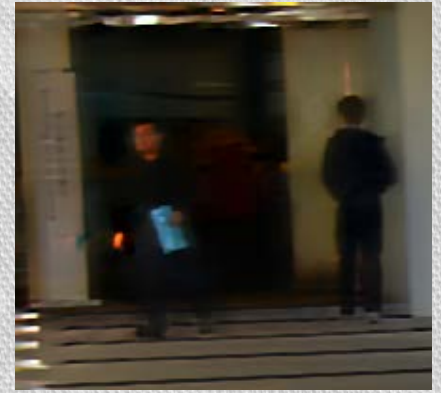
Blurry



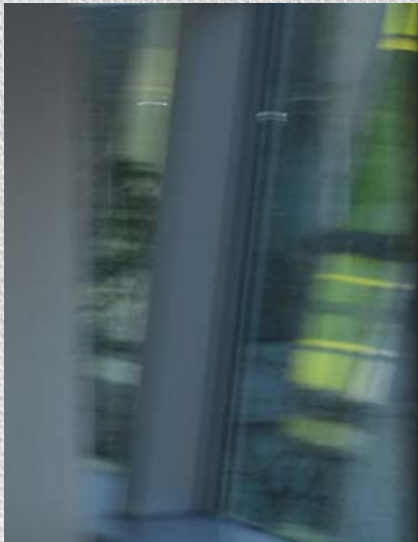
Jia



Whyte



Our



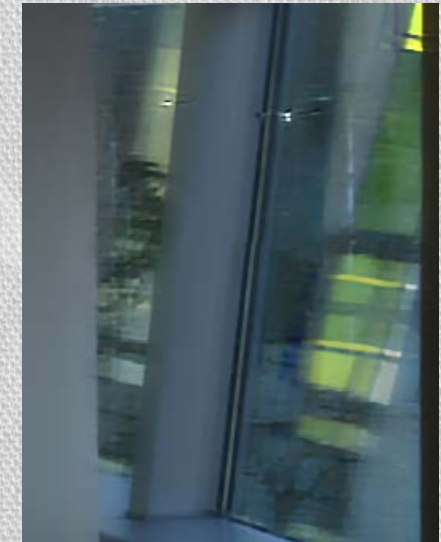
Blurry



Jia



Whyte

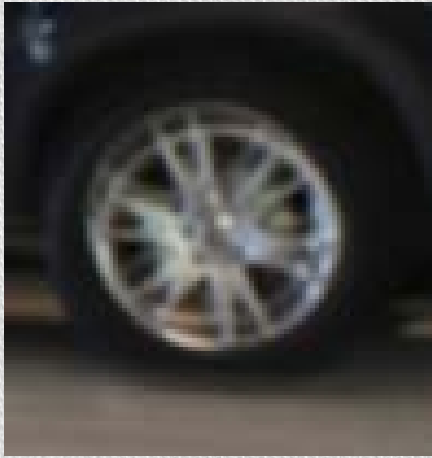


Our

Real-world Blurry Image



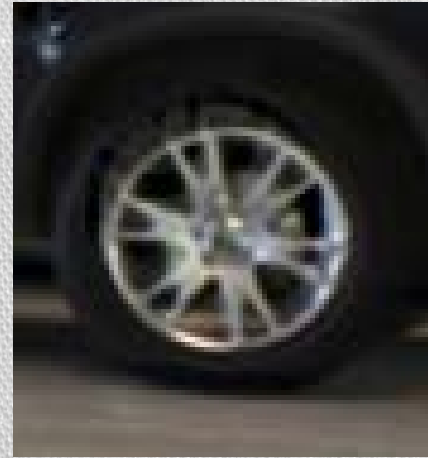
Deblurred Image



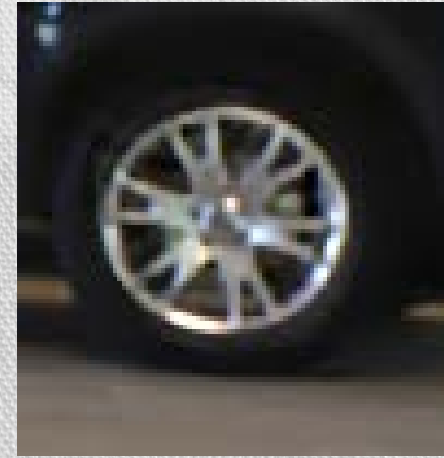
Blurry



Jia



Whyte



Our



Blurry



Jia



Whyte



Our

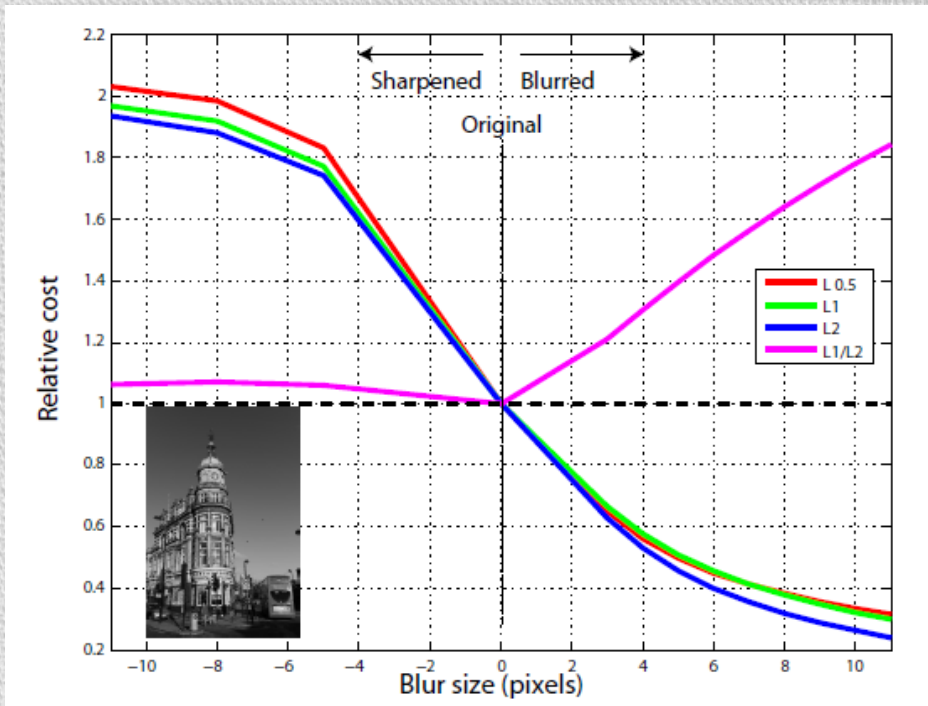
Thank You!

Q & A

Deblurring system

- Why using L1 norm / L2 norm

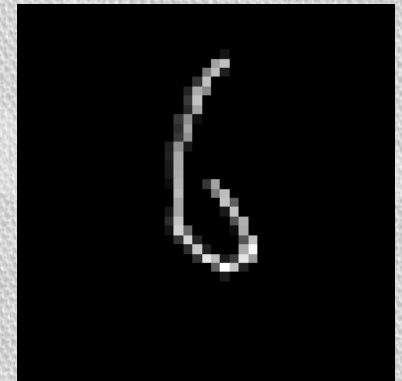
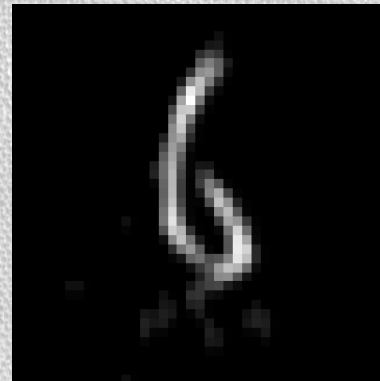
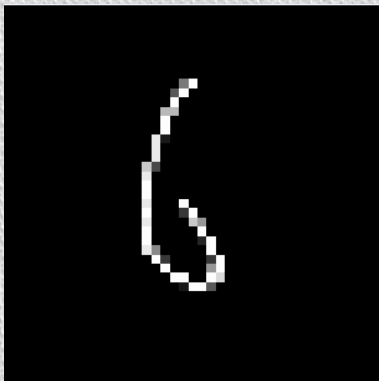
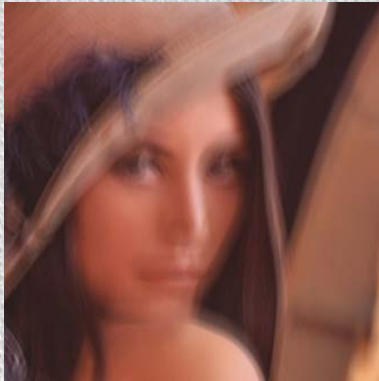
$$\min_{K, I} \left\| \nabla B - \nabla I \otimes K \right\|_2^2 + \lambda_1 \frac{\left\| \nabla I \right\|_1}{\left\| \nabla I \right\|_2} + \lambda_2 \left\| W \bullet K \right\|_1$$



L1 norm / L2 norm is a normalized version of L1 norm and scale invariant. Compared with other regularizer, it has better performance.

Discussions of Proposed Scheme

- Optimize bad trajectory kernel (**no bifurcations**)



Blurry

Krishnan

Jia

Our