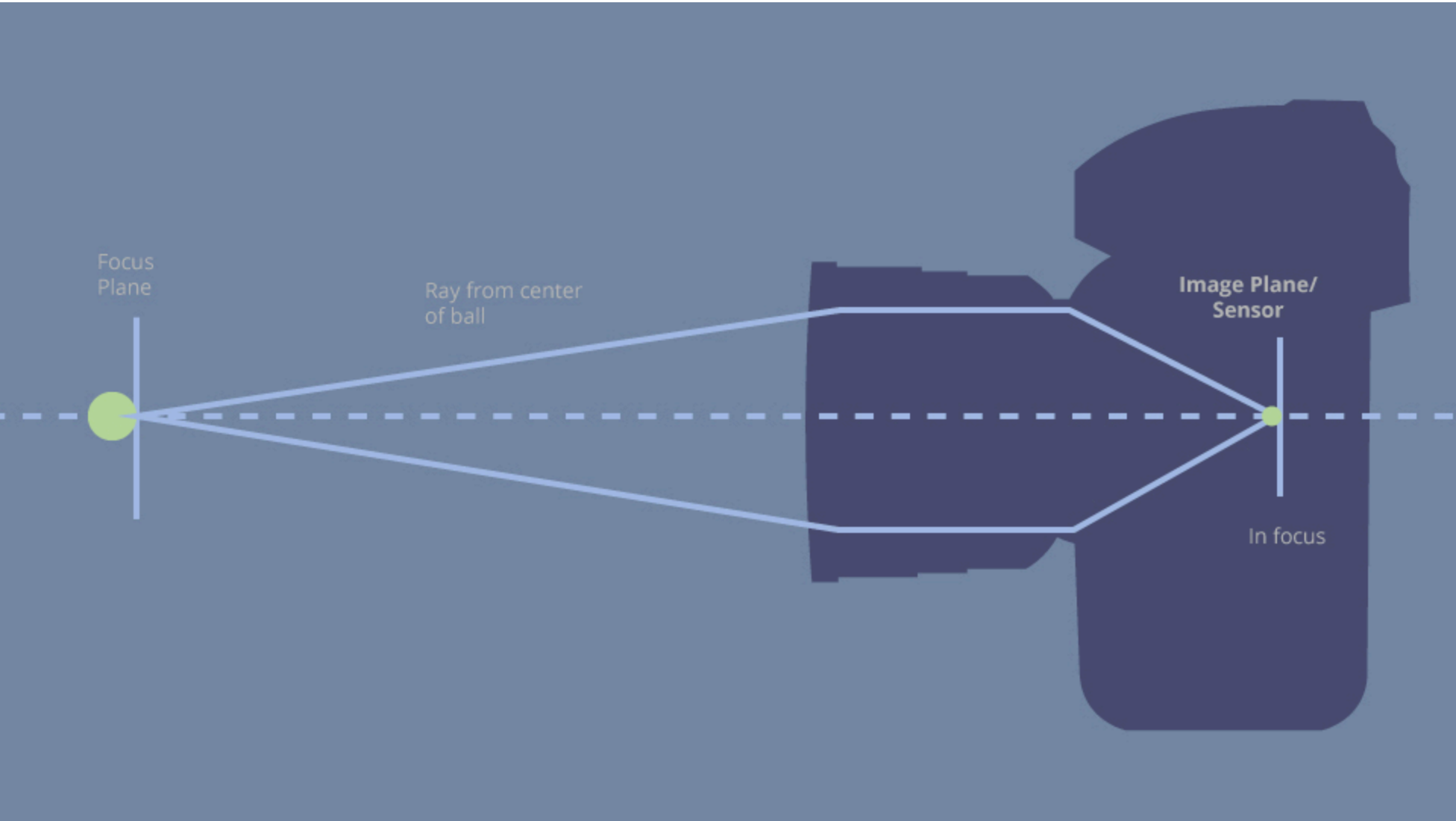
图像去模糊

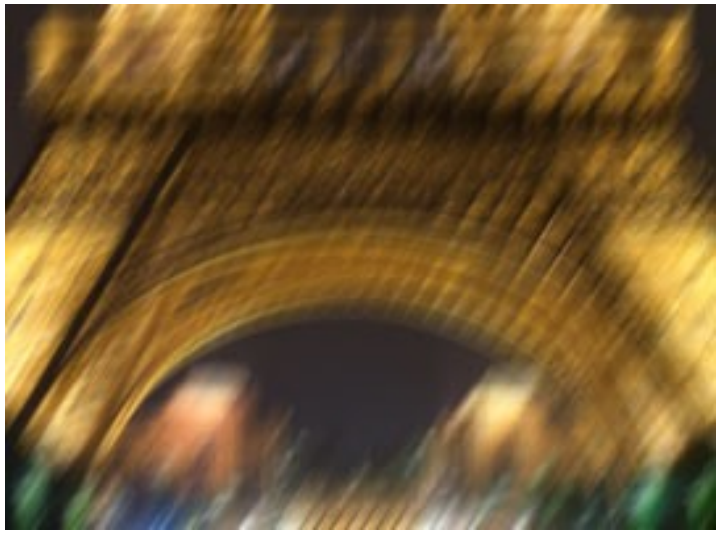
章国锋/周晓巍

图像模糊的原因


Focus
Plane
Ray from center
of ball
Image Plane/
Sensor
In focus

图像模糊的原因

- 相机抖动
  - 拍摄时相机不稳
  - 全部画面被模糊



图像模糊的原因

- 相机抖动
  - 拍摄时相机不稳
  - 全部画面被模糊
- 物体的运动
  - 部分物体运动
  - 不同区域模糊不同

图像去模糊

- 利用硬件来去模糊
  - 三脚架
  - 不便携

图像去模糊

- 利用硬件来去模糊
  - 光学防抖
  - 结合IMU等传感器信息
  - 专业稳定设备
  - 总而言之：贵！

Steadycam

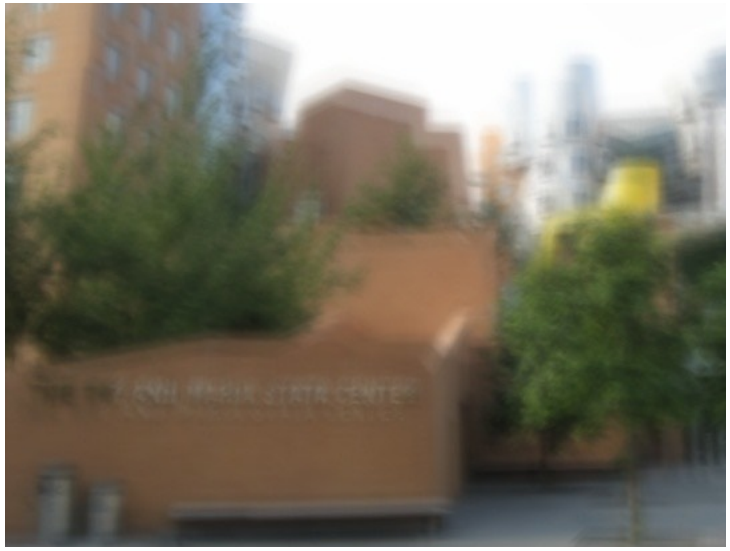
图像去模糊

- 不修改硬件？
  - 设计算法去模糊
  - 计算摄影学所关心的

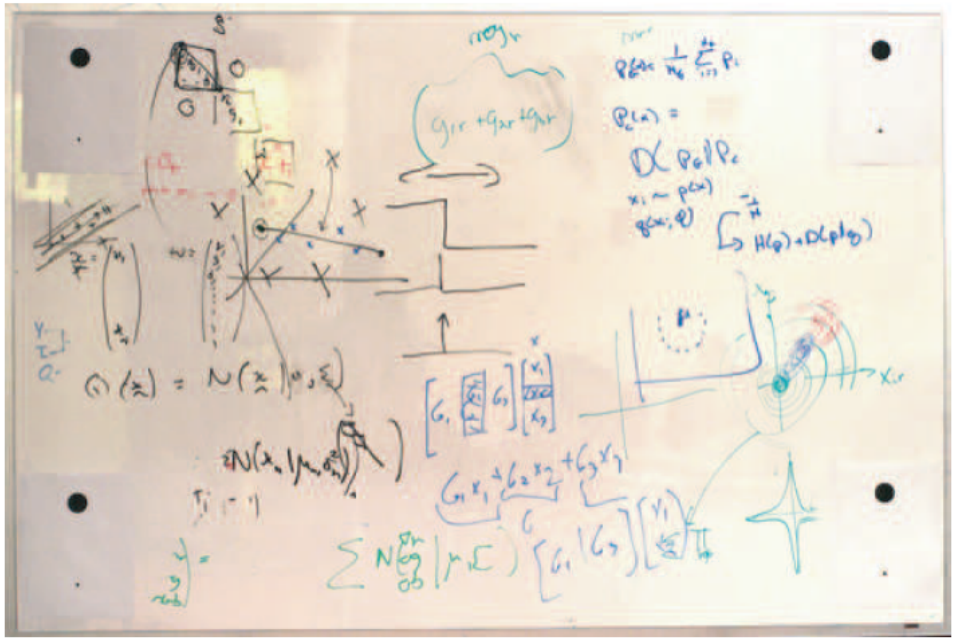
Steadycam


Adobe® Creative Cloud™
Photoshop® CC

如何用数学模型描述？



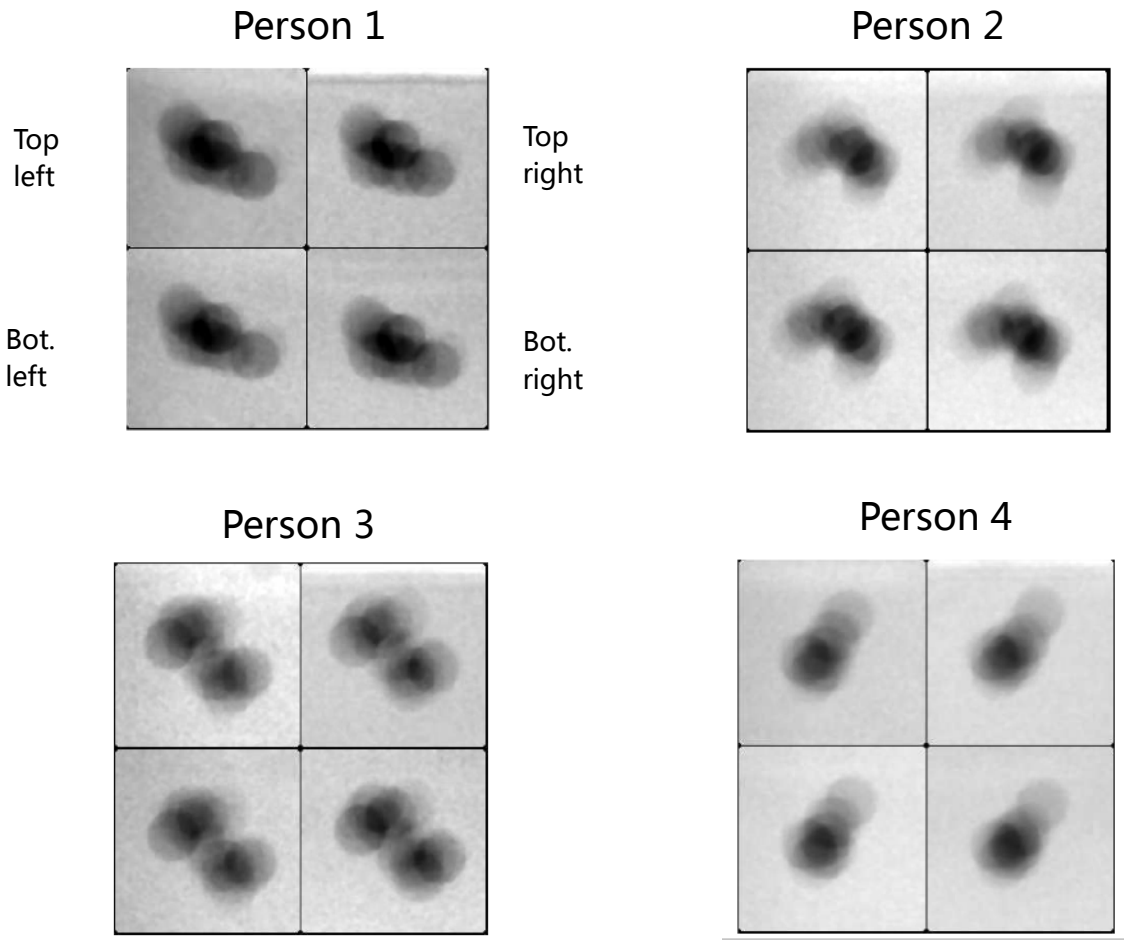
模糊的卷积模型



手持相机拍摄带有四个点标志的白板，曝光时间1秒钟

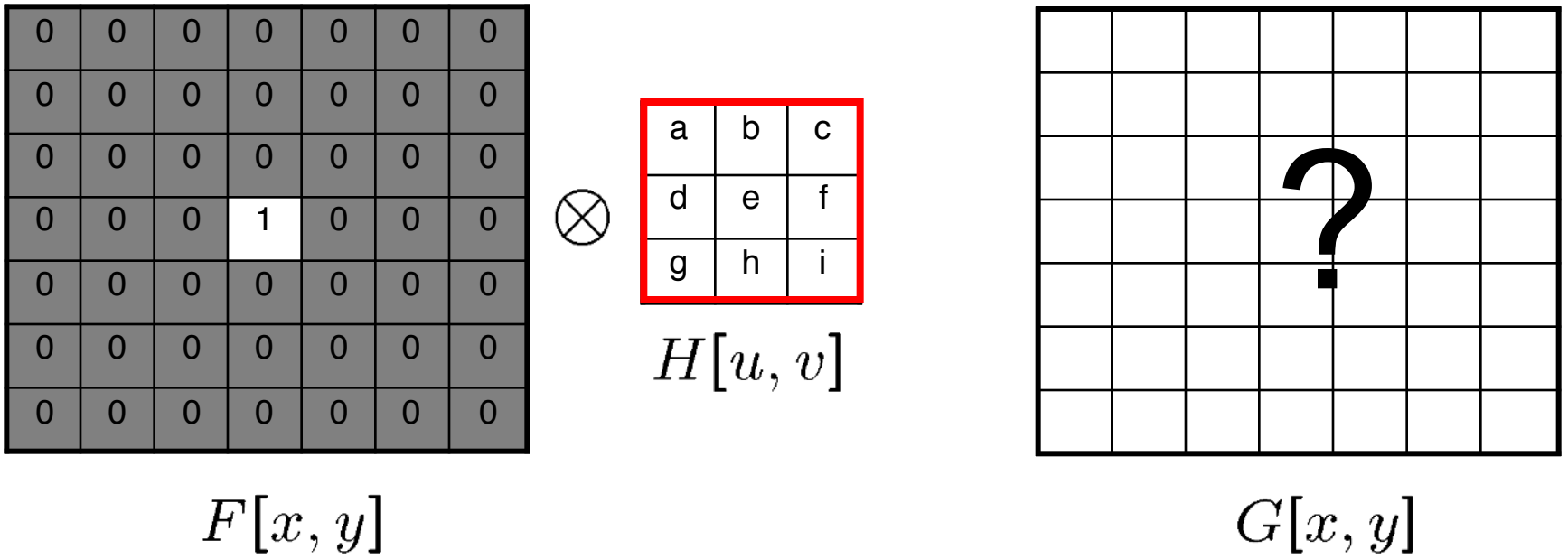
模糊的卷积模型

四个角模糊基本相同



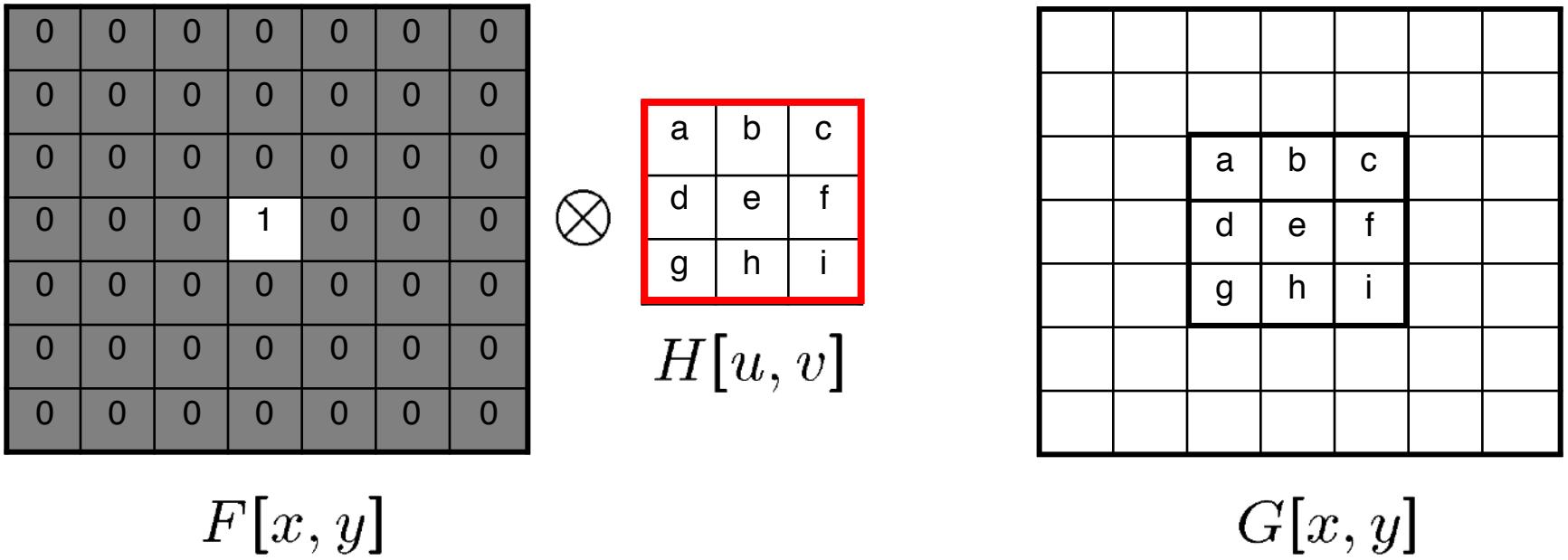
模糊的卷积模型

What is the result of filtering the impulse signal (image) *F* with the arbitrary kernel *H*?

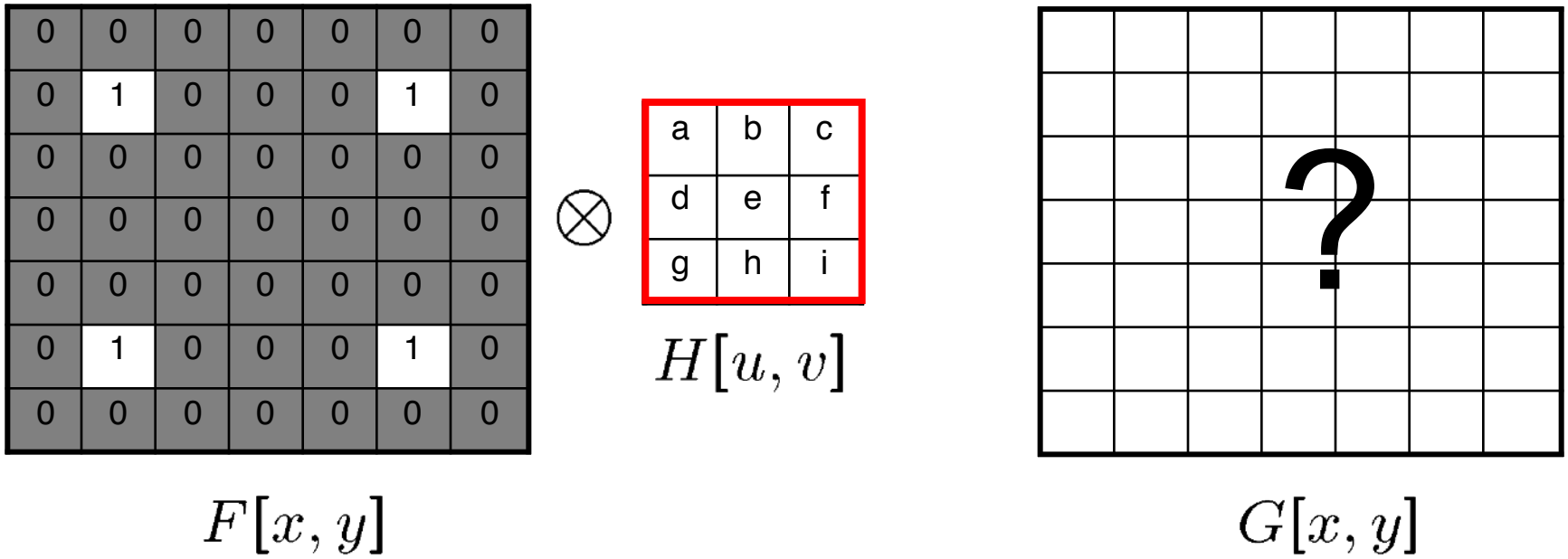


模糊的卷积模型

What is the result of filtering the impulse signal (image) *F* with the arbitrary kernel *H*?



模糊的卷积模型

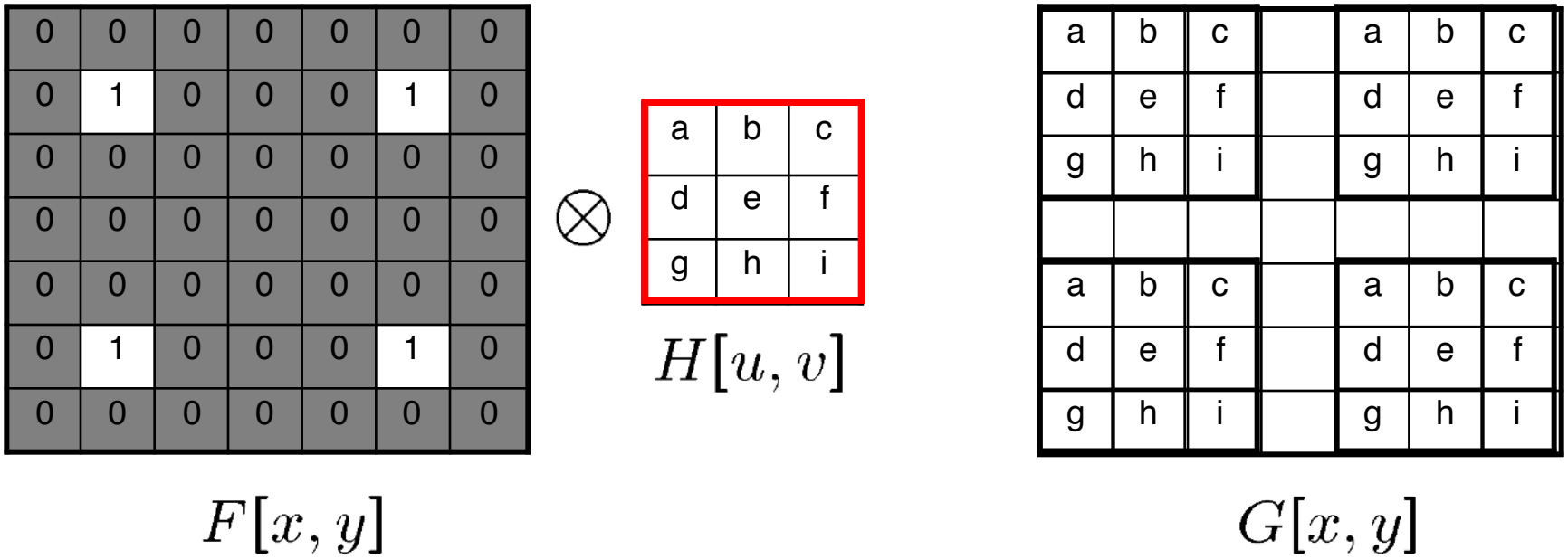


$F[x, y]$

$H[u, v]$

$G[x, y]$

模糊的卷积模型

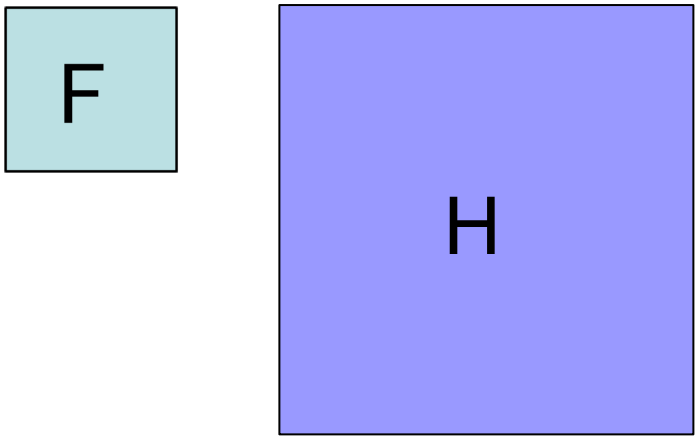

0 0 0 0 0 0 0
0 1 0 0 0 1 0
0 0 0 0 0 0 0
0 0 0 0 0 0 0
0 0 0 0 0 0 0
0 1 0 0 0 1 0
0 0 0 0 0 0 0
a b c
d e f
g h i
$F[x, y]$
$H[u, v]$
a b c a b c
d e f d e f
g h i g h i
a b c a b c
d e f d e f
g h i g h i
$G[x, y]$

模糊的卷积模型

$$G[i,j] = \sum_{u=-k}^{k} \sum_{v=-k}^{k} H[u,v]F[i-u,j-v]$$

$$G = H \star F$$

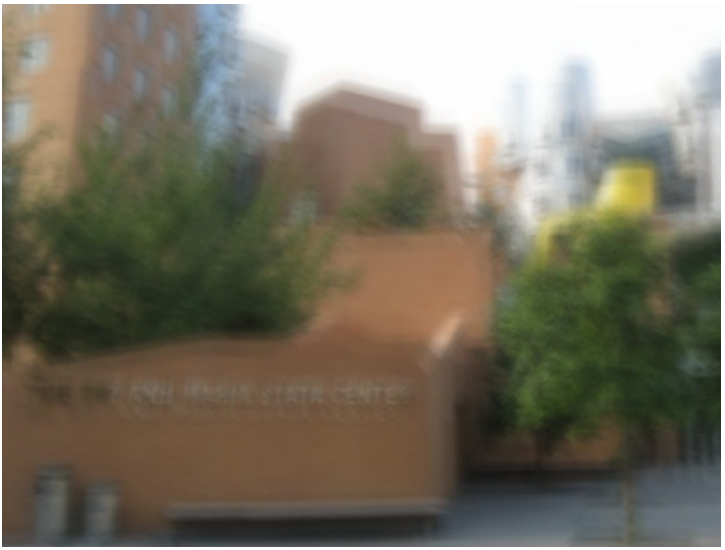
卷积操作



Slide credit: Kristen Grauman

模糊的卷积模型

- 假设场景是静态的，并进行针孔成像
  - 没有物体运动，没有失焦，只有抖动



模糊图像
（拍摄的）

=

清晰图像
（要求解的）

⊗

模糊核

卷积算子

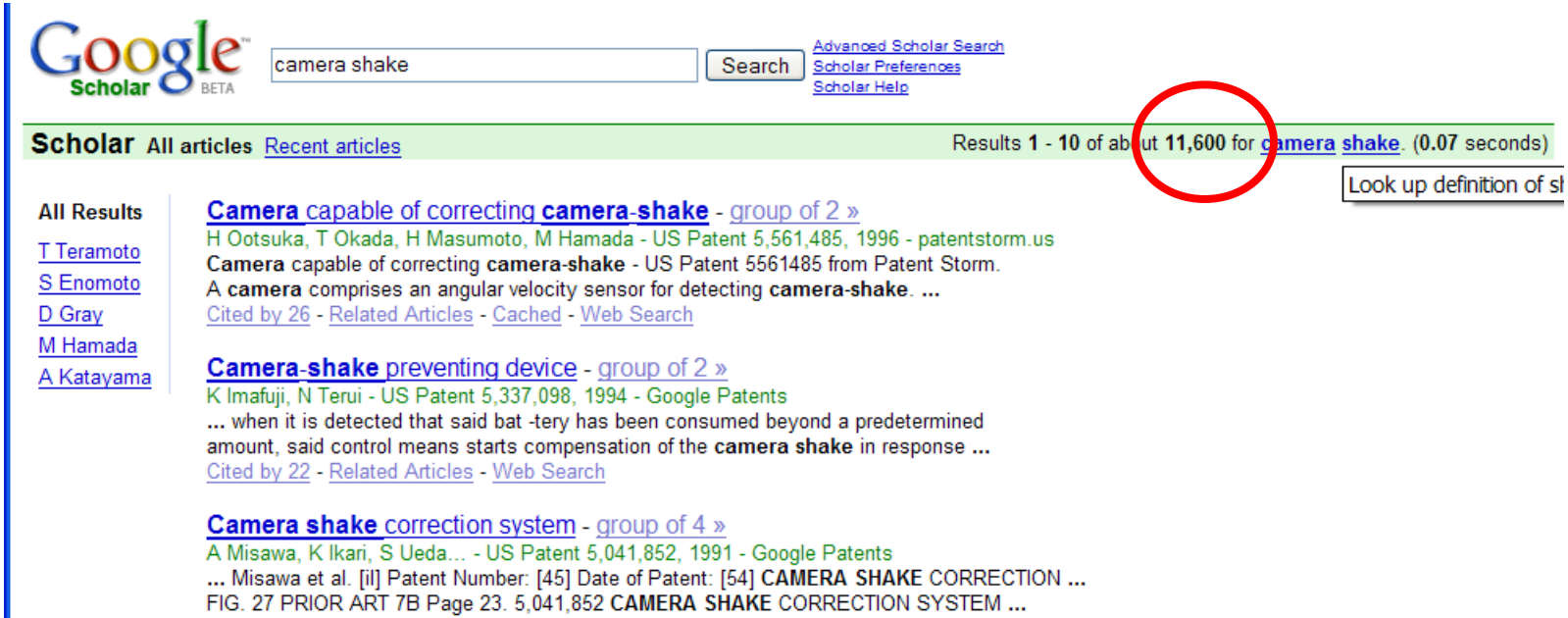
解卷积——盲与非盲

- 非盲去卷积
  (Non-blind, NBID)

- 盲去卷积
  (Blind, BID)

NBID

- 是一个经典的问题
  - Trott, T., “**The Effect of Motion of Resolution”**, *Photogrammetric Engineering,* Vol. 26, pp. 819-827, 1960.
  - Slepian, D., “**Restoration of Photographs Blurred by Image Motion”**, *Bell System Tech.,* Vol. 46, No. 10, pp. 2353-2362, 1967.



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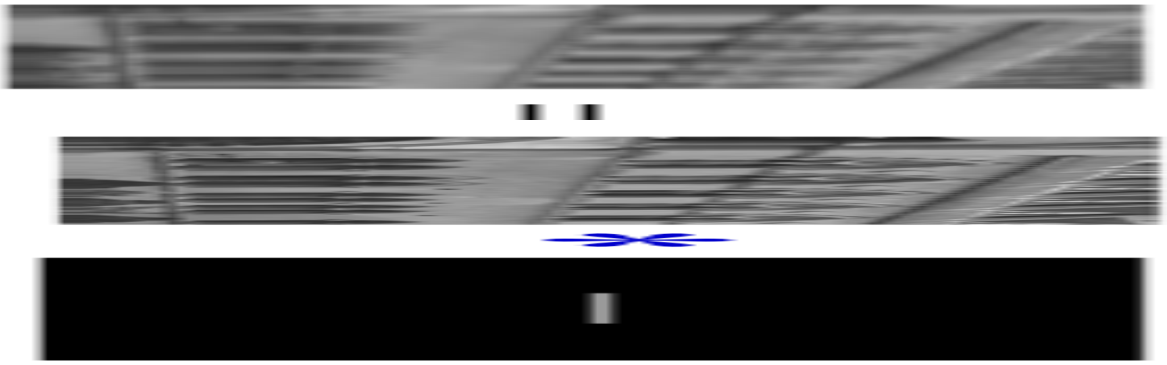
  - Slepian, D., “**Restoration of Photographs Blurred by Image Motion”**, *Bell System Tech.,* Vol. 46, No. 10, pp. 2353-2362, 1967.
- 多数基于简单的模型
  - 频域解卷积
  - 贝叶斯模型 (Richard, 1972. Lucy, 1974.)
  - 对卷积核要求高

NBID基本模型

- J: 拍摄到的图像
- I: 需要求解的图像
- K: 卷积核



频域解卷积

- 空域的卷积 = 频域的乘积

- 空域解卷积 = 频域的除法

Richardson-Lucy

- 一种常用的空域迭代去卷积方法

example, W_i indicates either the ith location in the array W or the value associated with the ith location. The unsubscripted letter refers to the entire array or the value associated with the array as in $W=\sum_i W_i$. The double-subscripted $W_{i,j}$ in two dimensions is interpreted similarly to W_i in one dimension. In the approximation formulas, a subscript r appears, which is the number of the iteration.

DISCUSSION

Given the degraded image H, the point spread function S, and the requirement to find the original image W. Bayes's theorem comes readily to mind. In the notation

This results in an iterative procedure where the initial $P_0(W_i)$ is estimated. An estimation often used is Bayes's postulate (also known as the equidistribution of ignorance), which assumes a uniform distribution so that $P_0(W_i)=1/I$ or $W_{i,0}=W/I$.

Equation (4) can be reduced to a more easily workable form by $P(W_i)=W_i/W$ and $P(H_k)=H_k/H=H_k/W$, since the restoration is a conservative process and $W=H$, and also $P(H_k|W_i)=P(S_{i,k})=S_{i,k}/S$,

$$S=\sum_j S_j, \quad j=\{1,J\}.$$

Then Eq. (4) becomes

Richardson-Lucy

- 迭代算法：

- 直观解释
  - 用当前估计的清晰图像进行卷积
  - 与模糊图像比较得到差异 → 当前估计的误差
  - 将误差补偿到估计图像

Richardson-Lucy

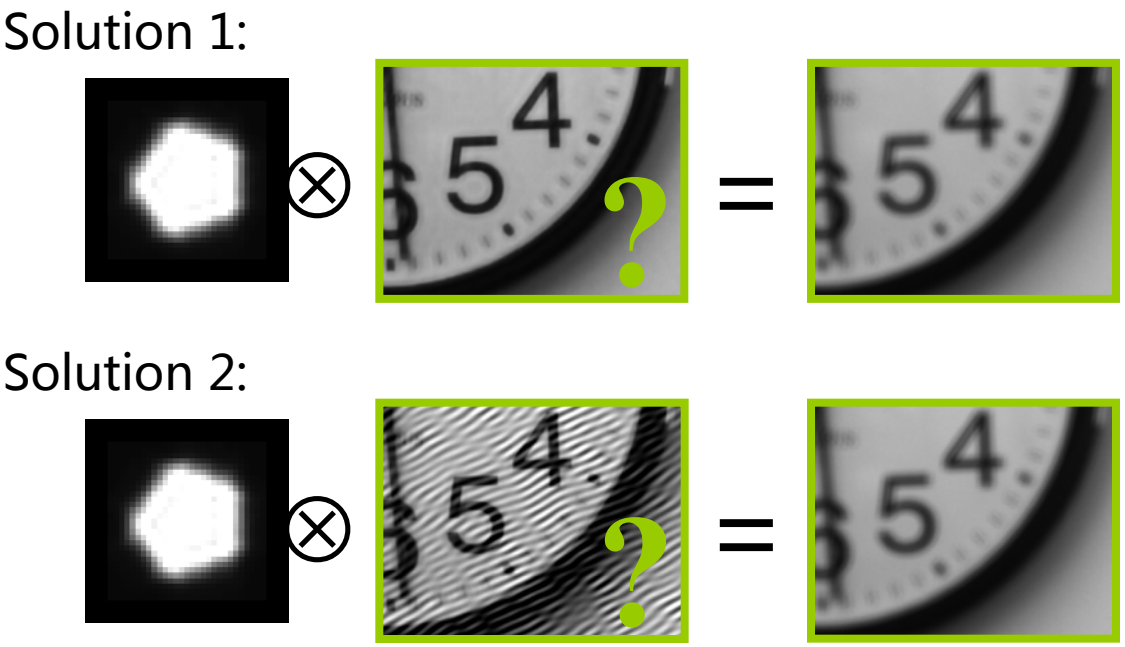
- 一种常用的空域迭代去卷积方法
  - 基于贝叶斯模型进行的最大似然估计
  - 缺点：噪音、Ringing Artifacts

Input

Richardson-Lucy

NBID是个病态问题

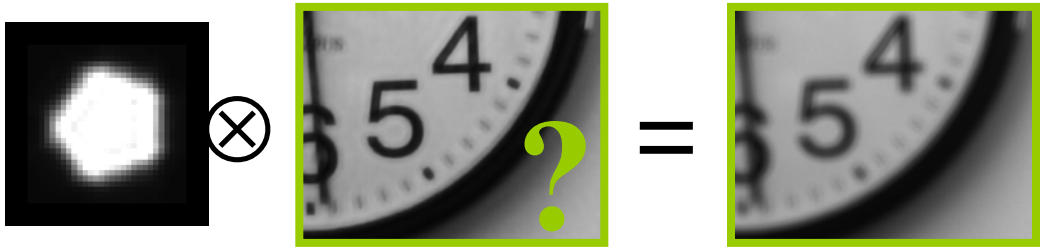
- 解并不唯一



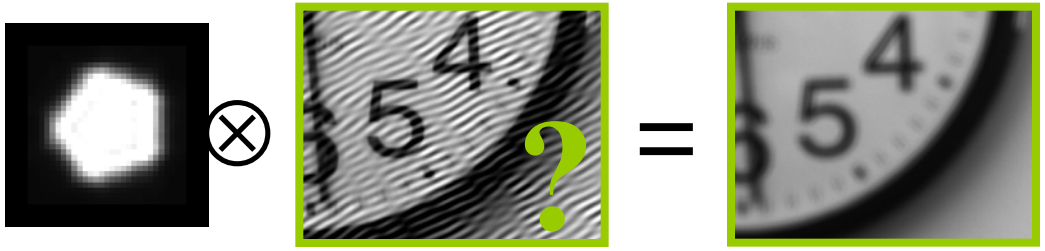
NBID是个病态问题

- 解并不唯一
- 好的解要“自然”

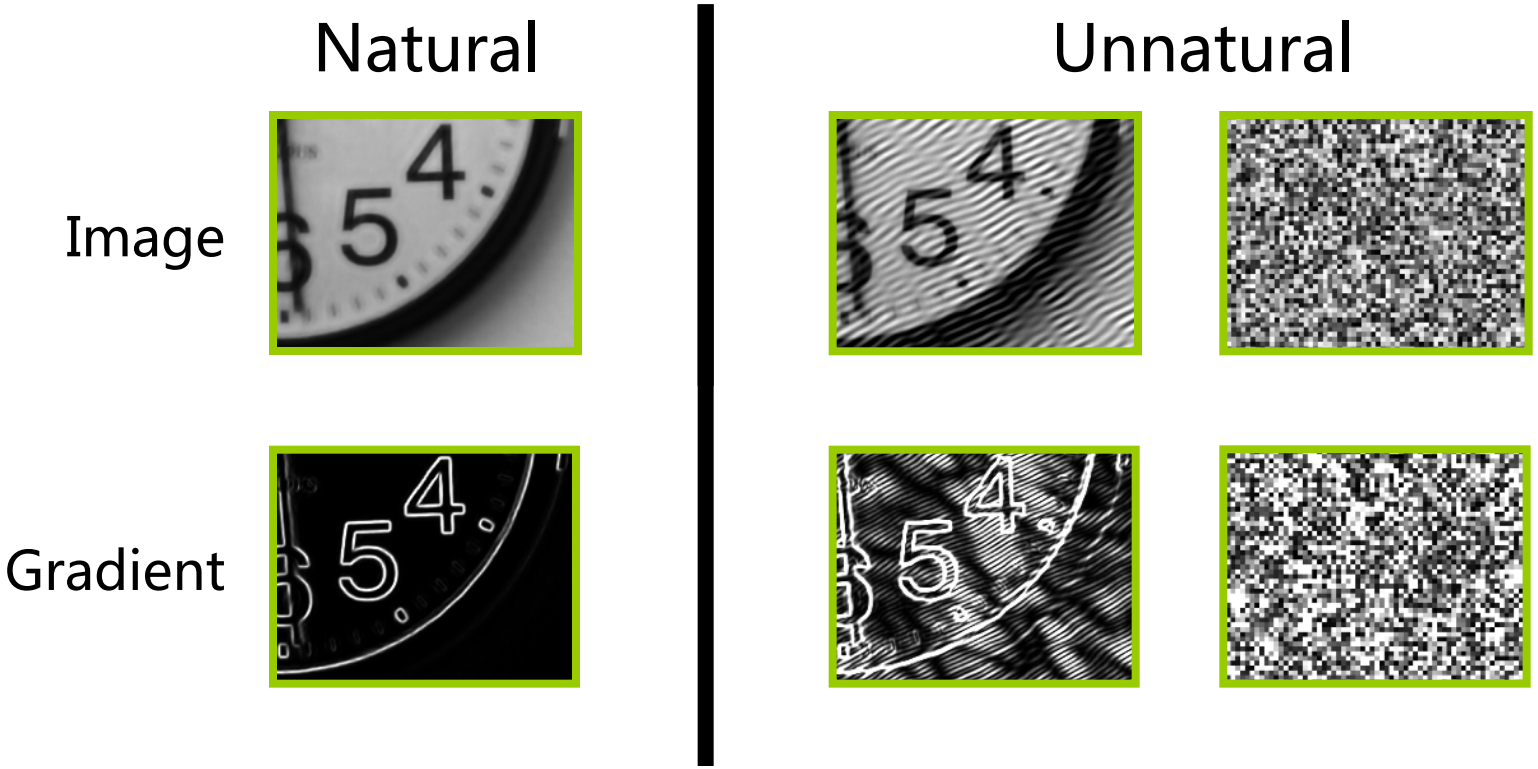
Solution 1:



Solution 2:



自然图片有什么特点？



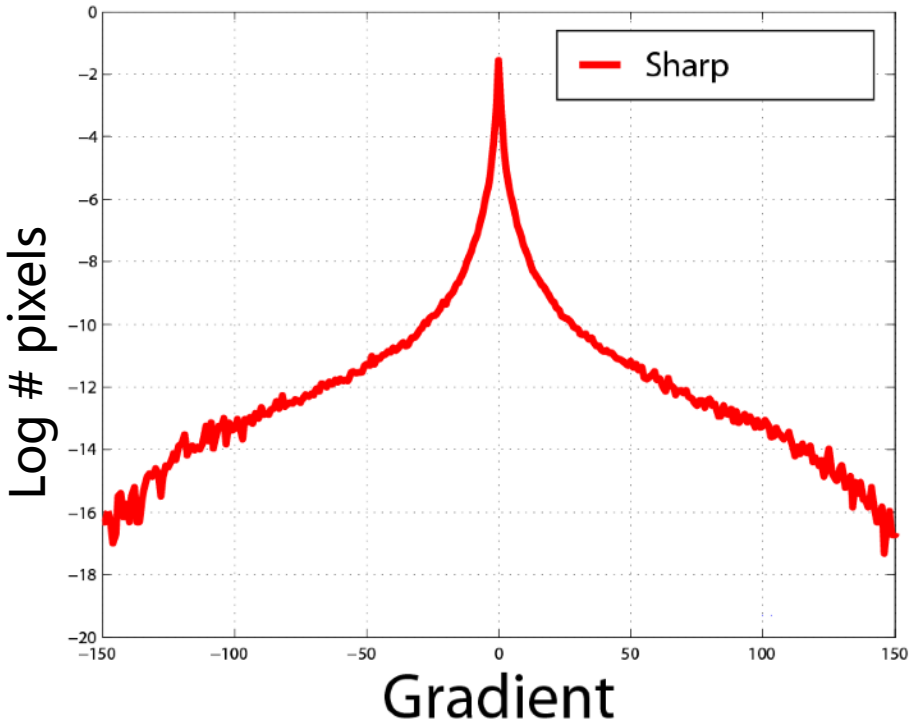
Natural images have sparse gradients

➡ put a penalty on gradients

Slide adapted from Anat Levin

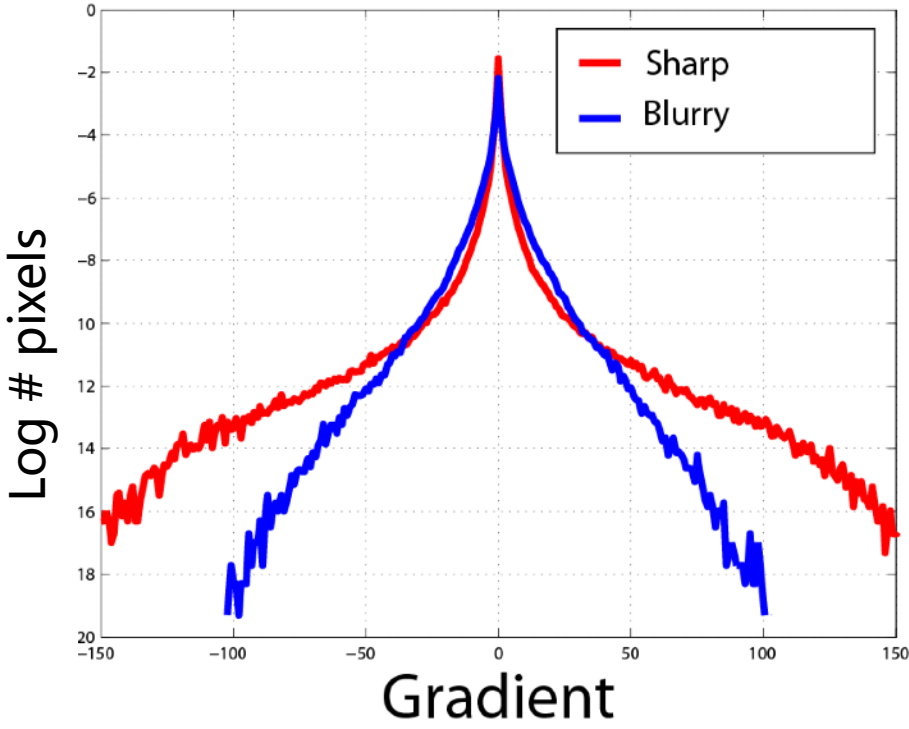
自然图像的统计特性

- 图像梯度的直方图具有明显的重尾分布 (Heavy-tail distribution)



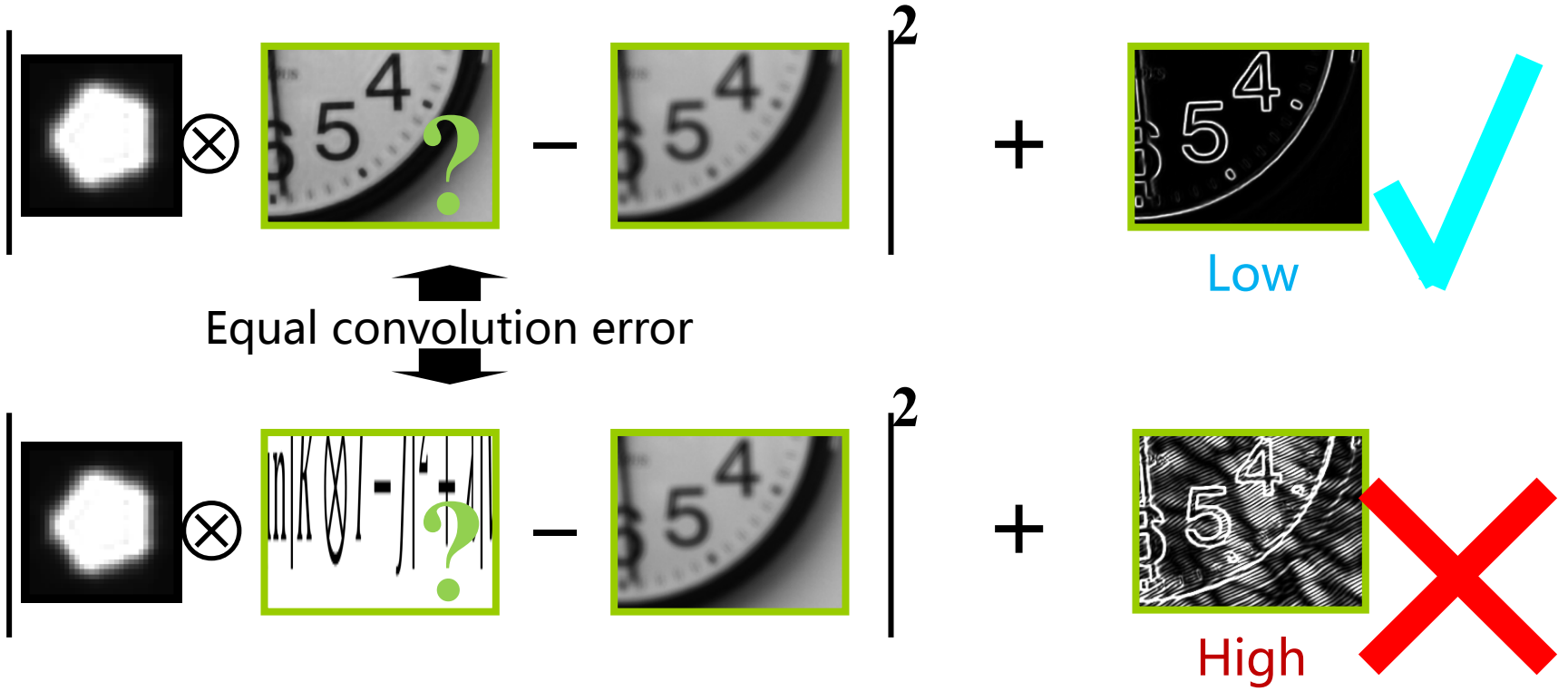
模糊图像呢？

- 并不会出现重尾分布



带先验非盲去卷积

$$\min_{I} \left| K \otimes I - J \right|^2 + \lambda \left| \nabla I \right|^k$$



(Non blind) deconvolution code available online: http://groups.csail.mit.edu/graphics/CodedAperture/

R-L vs. Prior

$$\min_I \left| K \otimes I - J \right|^2 + \lambda \left| \nabla I \right|^k$$

k=2

"spread" gradients

k=1

"localizes" gradients

Richardson-Lucy

Gaussian prior

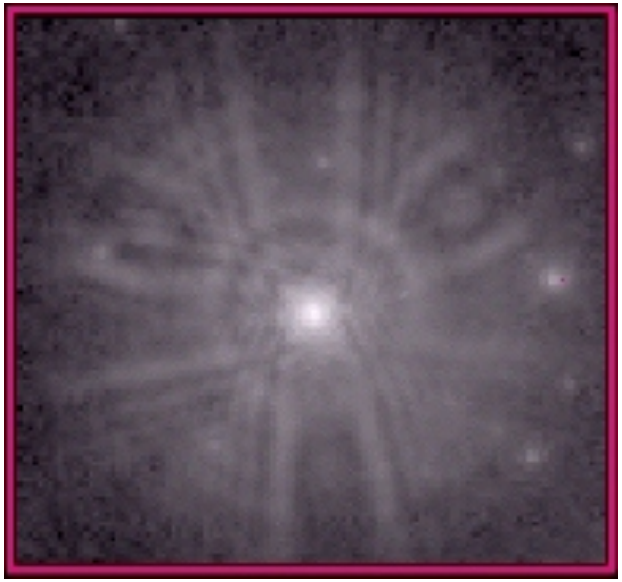
Sparse prior

Slide adapted from Anat Levin

NBID的应用

- 哈勃太空望远镜
  - 升空时反射镜存在缺陷
  - 最初使用去卷积方法消除问题

Image of star



NBID的应用

- 哈勃太空望远镜
  - 升空时反射镜存在缺陷
  - 最初使用去卷积方法消除问题

Before and after corrective optics

http://en.wikipedia.org/wiki/Hubble_Space_Telescope

Blind Image Deconvolution (BID)

- 卷积核也未知
- 显然更加困难
  - 需要更多先验知识！

Removing Camera Shake from a Single Photograph

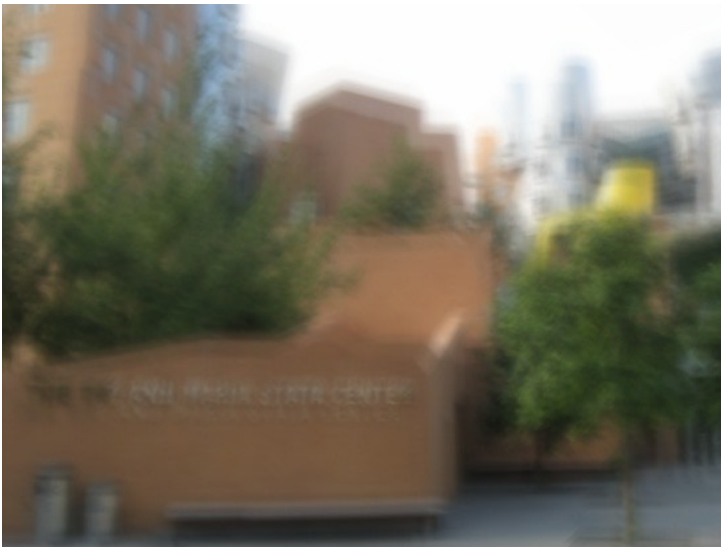
Rob Fergus, Barun Singh, Aaron Hertzmann,
Sam T. Roweis and William T. Freeman

SIGGRAPH 2006

Massachusetts Institute of Technology
and
University of Toronto

哪些信息是已知的？

- 图像的卷积模糊模型



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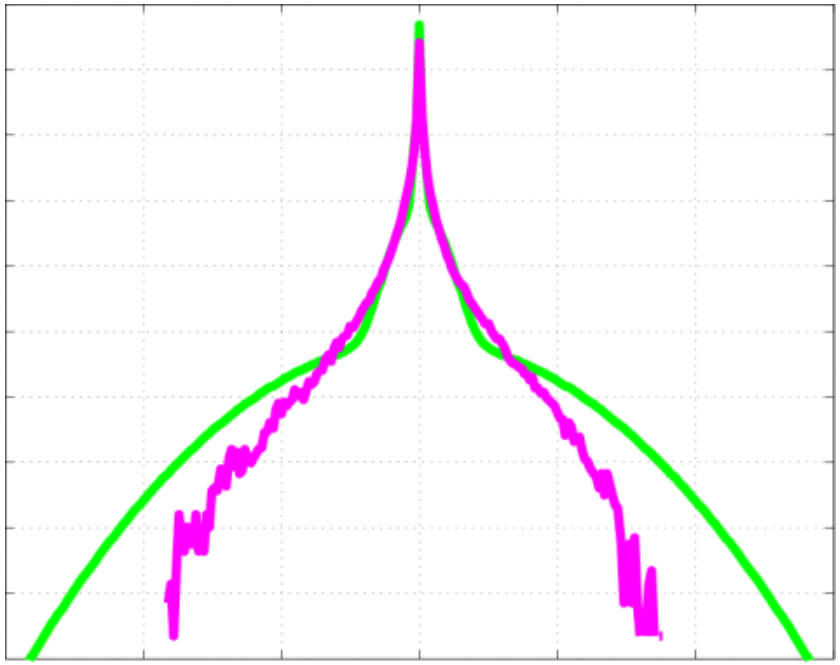
⊗

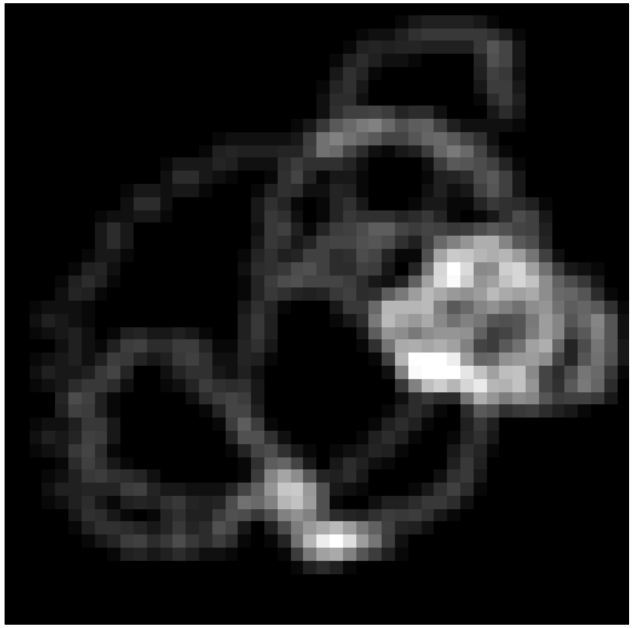
哪些信息是已知的？

- 图像的卷积模糊模型
- 图像梯度的先验信息
  - 重尾分布



哪些信息是已知的？

- 图像的卷积模糊模型
- 图像梯度的先验信息
  - 重尾分布
- 模糊核的先验信息
  - 非负且稀疏



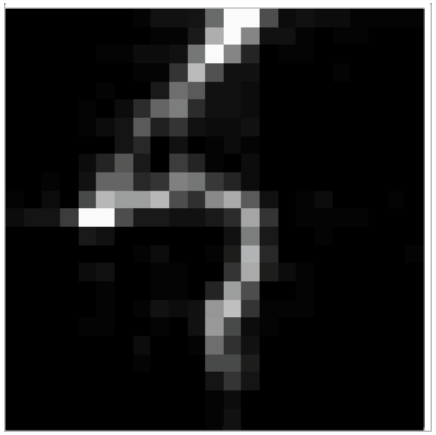
人造数据的结果

原始图片

求解得到的图片

Ground-Truth 模糊核

求解出的模糊核



Blurry image

Matlab `deconvblind`

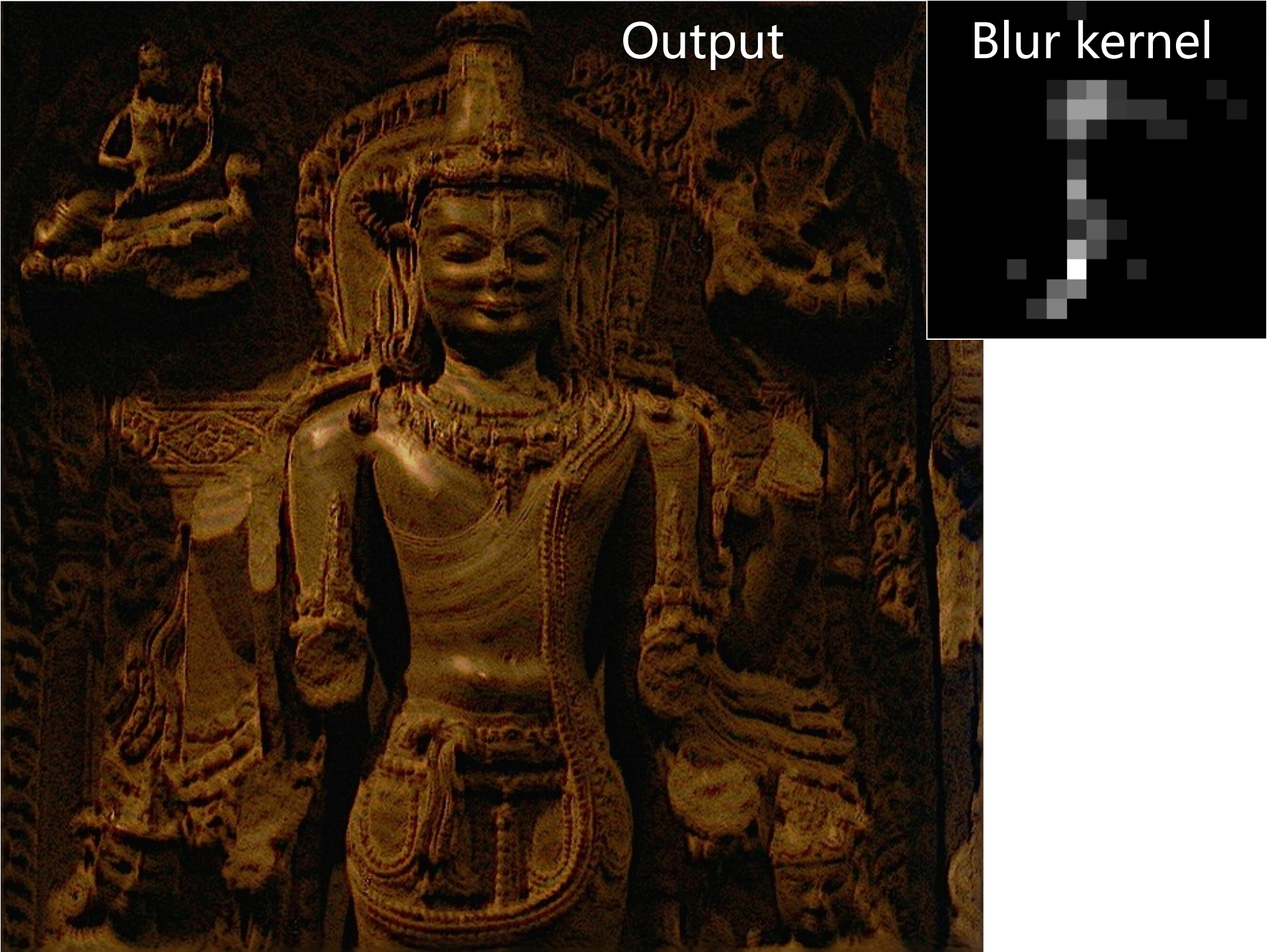
Blurry image

Deblurring output

True sharp image

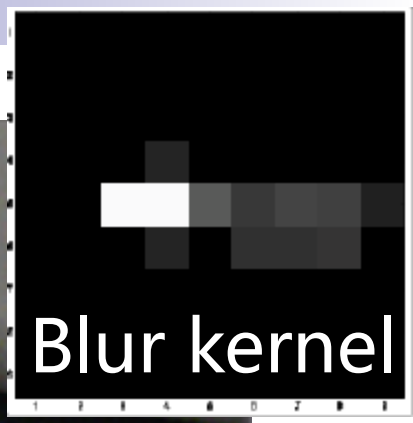
真实数据结果

Original photograph


Output
Blur kernel

Original photograph

Output



真实数据结果

- 结果并不完美
  - 相机类型等等并不知道，无法修正Gamma
  - 噪音模型很单纯
  - 最后的去卷积使用了简单的R-L
  - ……
- 启发了其后一大批的工作

小结

- 相机抖动模糊的模型是什么？
  - 图像卷积
- BID和NBID的区别是什么？
  - 卷积核是否已知
- 解卷积这种病态问题要如何处理？
  - 需要发现先验知识来约束解

运动模糊 vs. 相机抖动

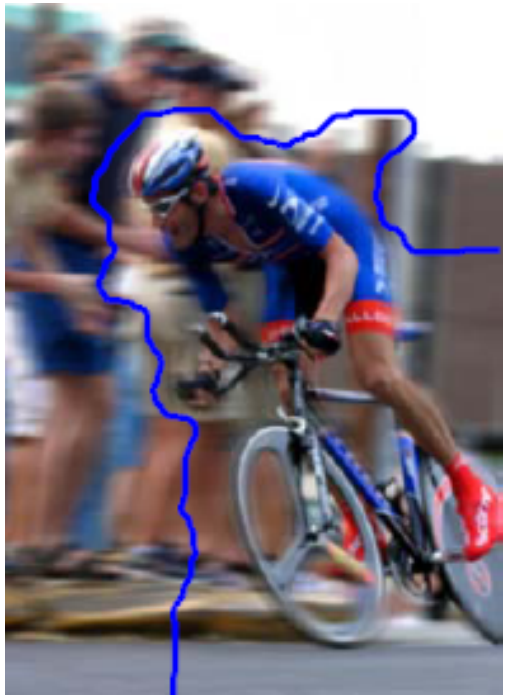
- 相机抖动
  - 全局一致的模糊

运动模糊 vs. 相机抖动

- 相机抖动
  - 全局一致的模糊

- 运动模糊
  - 不同物体
    模糊模式不同
  - 分层处理，
    假定层内模糊一致
    (A. Levin, 2006)

Input & Segmentation



Deblurred image

运动模糊 vs. 相机抖动

- 相机抖动
  - 通常是由于不良的拍摄条件导致

运动模糊 vs. 相机抖动

- 相机抖动
  - 通常是由于不良的拍摄条件导致
  - 希望消除

运动模糊 vs. 相机抖动

- 相机抖动
  - 通常是由于不良的拍摄条件导致
  - 希望消除
- 运动模糊
  - 有时是为了画面效果

运动模糊 vs. 相机抖动

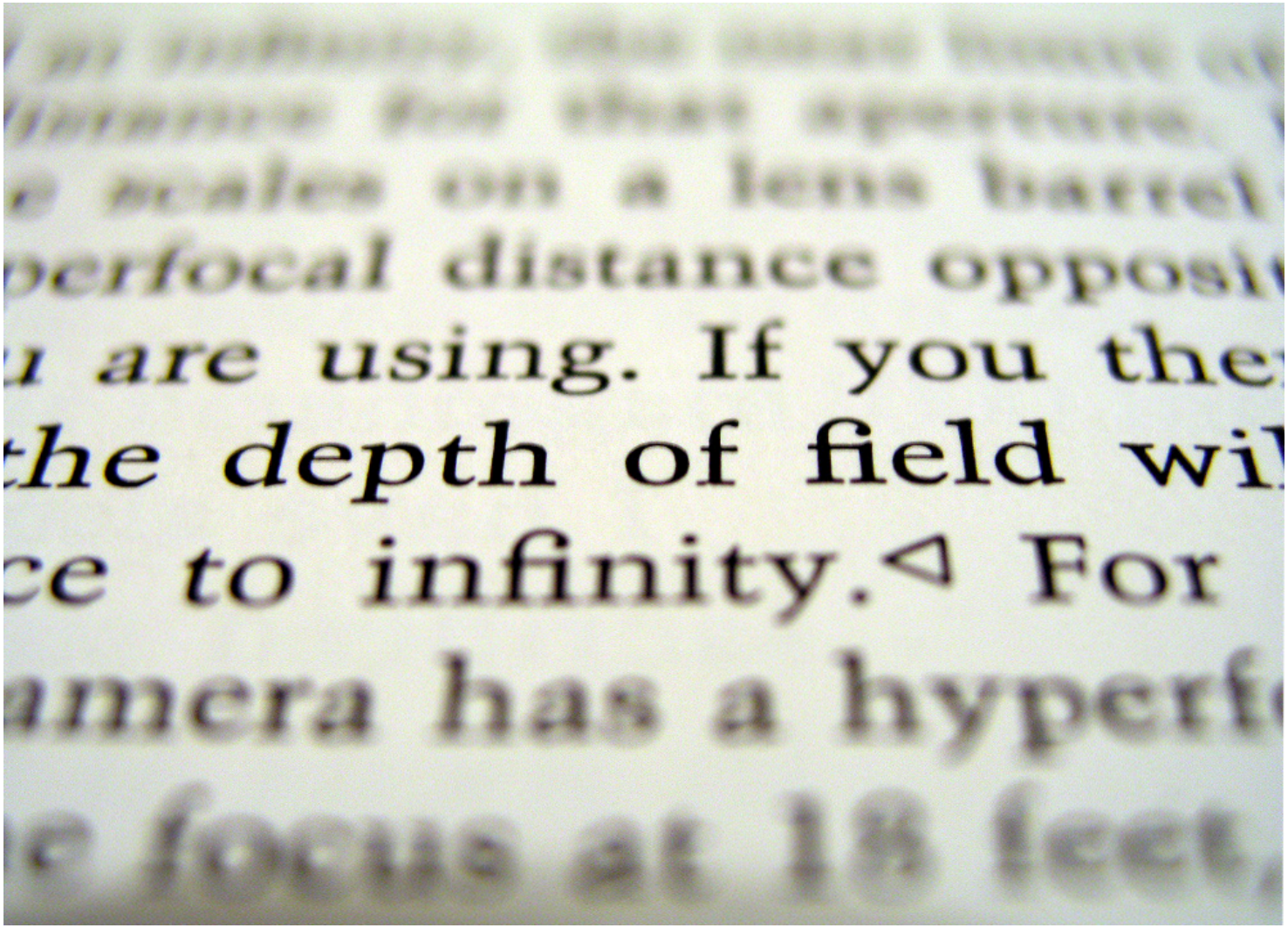
- 相机抖动
  - 通常是由于不良的拍摄条件导致
  - 希望消除
- 运动模糊
  - 有时是为了画面效果
  - 不一定需要消除

Light Painting

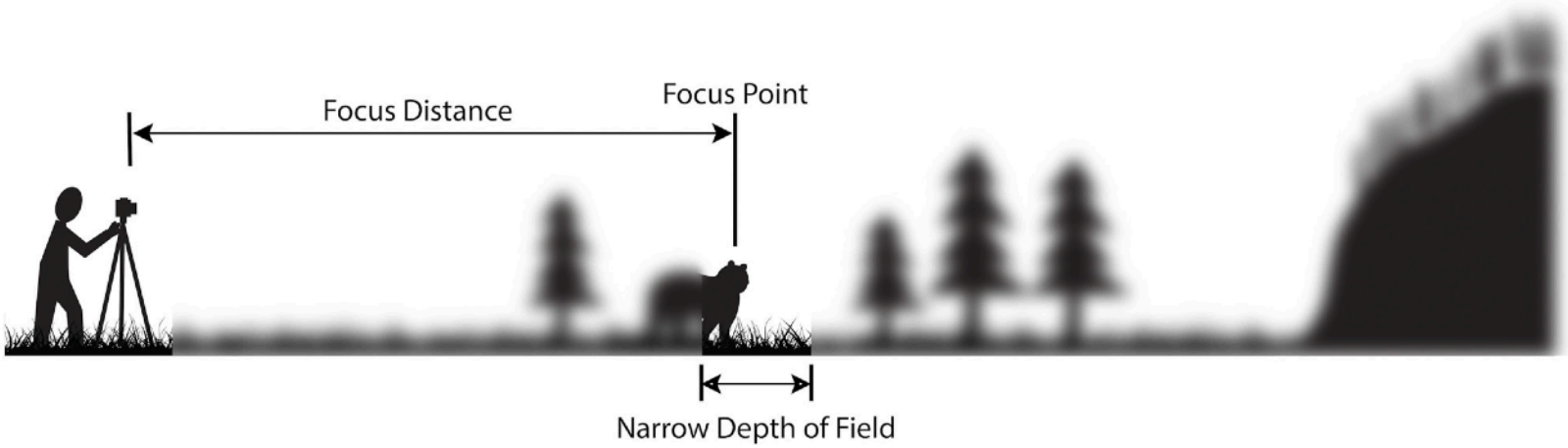
图像模糊的原因

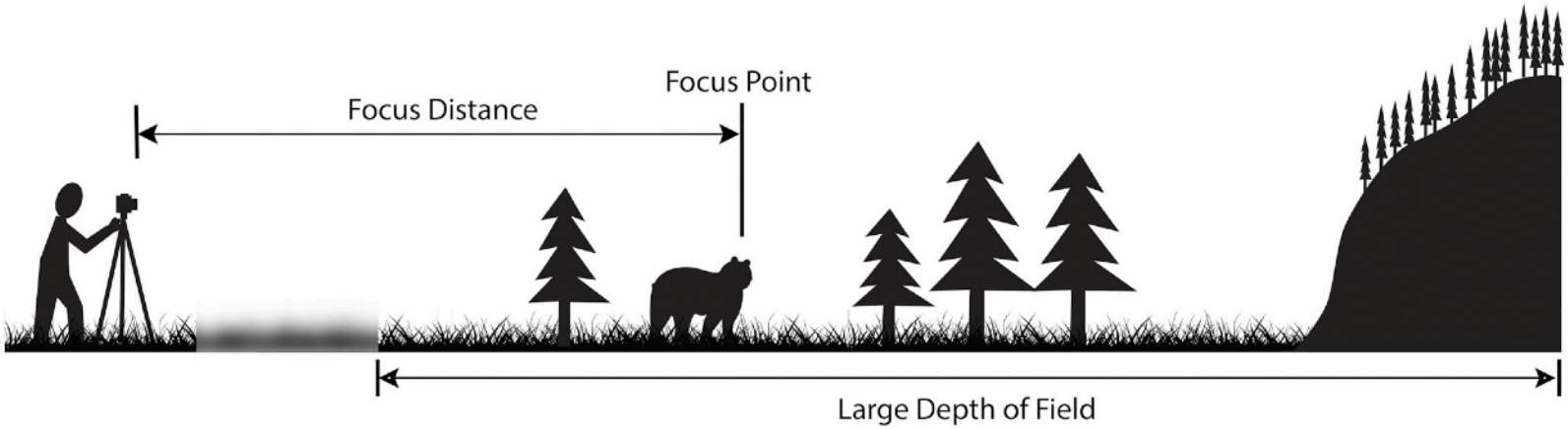
- 相机抖动
  - 拍摄时相机不稳
  - 全部画面被模糊
- 物体的运动
  - 部分物体运动
  - 不同区域模糊不同
- 镜头失焦
  - 大光圈小景深时的效果
  - 深度不同模糊程度不同

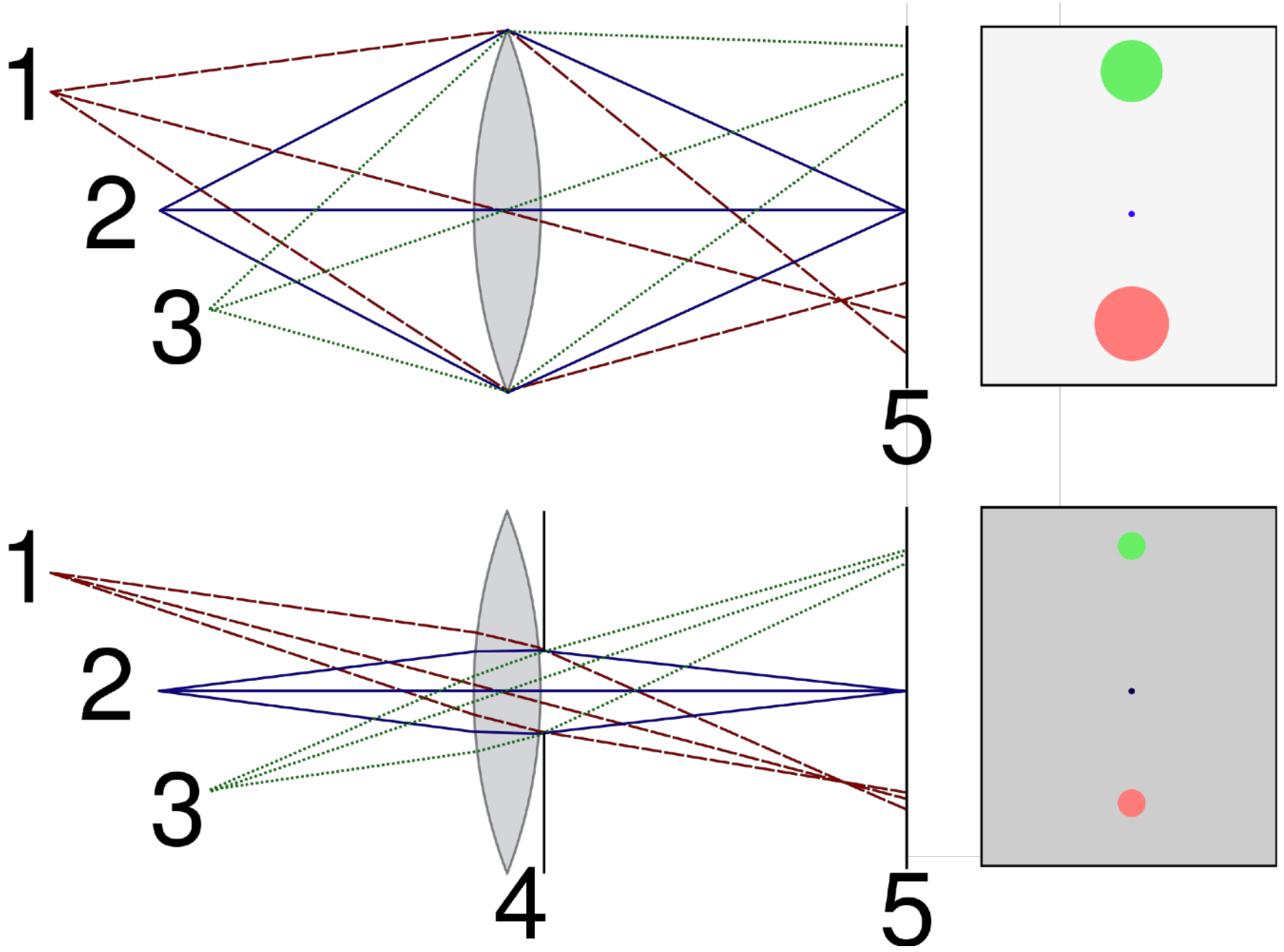
景深


perfocal distance
are using. If you
the depth of field
ce to infinity.◁ For
amera has a

景深跟哪些因素有关


Focus Distance
Focus Point
Narrow Depth of Field


Focus Distance
Focus Point
Large Depth of Field


1
2
3
5
1
2
3
4
5

如何减小景深

- 大光圈
- 长焦距
- 距离近
- 背景远

镜头失焦

- 模糊核与深度有关

镜头失焦

- 模糊核与深度有关
  - 需要求解原始图像、深度、模糊核
  - 假定模糊核关于深度的模型已知?
    - Depth from focus/defocus
    - 另一个研究领域（Depth from X）

手机人像模式如何实现的？