图像增强

Image Enhancement

动机/目标：　提高图像质量（视觉感受）

途径：分析图像质量下降/视觉感受不好的原因，对症下药

学习方法：
- 避免单纯学习算法（如同死背“验方”）
- 学会分析图像特性（如同诊断）
- 掌握算法的构思（动机）（如同掌握各味药的药性）
- 学会根据图像特性设计（组合）算法（如同调配中药方）

图像质量因素1：灰度分布不合理

充分使用灰度动态范围
（不浪费灰度区间）

曝光不足
图像过暗

✗没有充分利用高灰度区间

曝光过度
图像过亮

✗没有充分利用低灰度区间

逆光

图像明暗对比过大

✗ 只利用了少量的灰度

图像质量因素2：噪声

抑制噪声
（提高信噪比）

图像质量因素3：模糊

增强细节，提高对比度


注意安全

图像质量问题的分类以及应对方法

图像灰度分布不合理 ⟵ 灰度映射

图像噪声干扰 ⟵ 噪声抑制

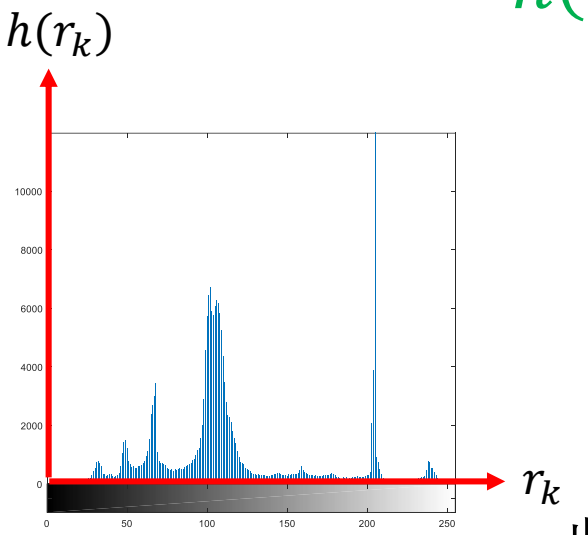
图像模糊/低对比度 ⟵ 细节增强/对比度增强

灰度映射
(灰度直方图变换)


BACK
FUNC
PLAY
MENU
/OK
MASTER
MIN
FinePix
MASTER
MIN
MAX

灰度直方图（Gray Histogram）

$$h(r_k) = n_k$$



cardinality in a set

$$n_k = \underset{(x,y)}{card}\{I(x,y) = r_k\}$$ (灰度等于r_k的像素总数)

$$r_k = [0, K-1]$$ (图像灰度范围)

$$\sum_k h(r_k) = \sum_k n_k = n$$ (图像面积)

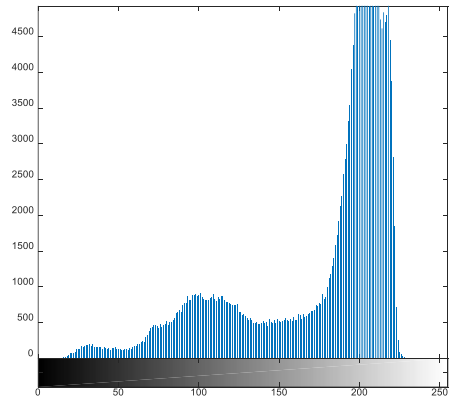
归一化直方图(normalized histogram)：$p(r_k) = \dfrac{h(r_k)}{n} = \dfrac{n_k}{n}$

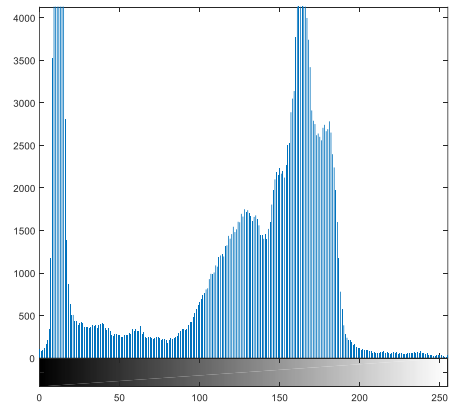
$$0 \le p(r_k) \le 1$$

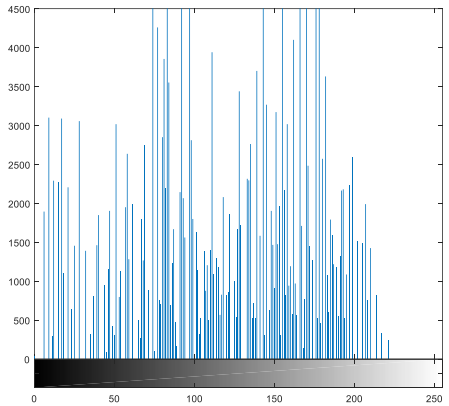
$$\sum_k p(r_k) = 1$$

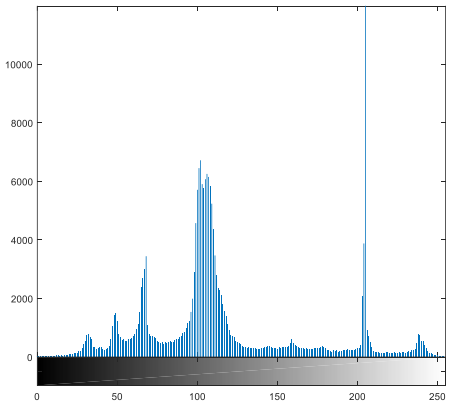
理解灰度直方图

直方图的“峰” -> 灰度聚类（存在大量像素具备相近的灰度）

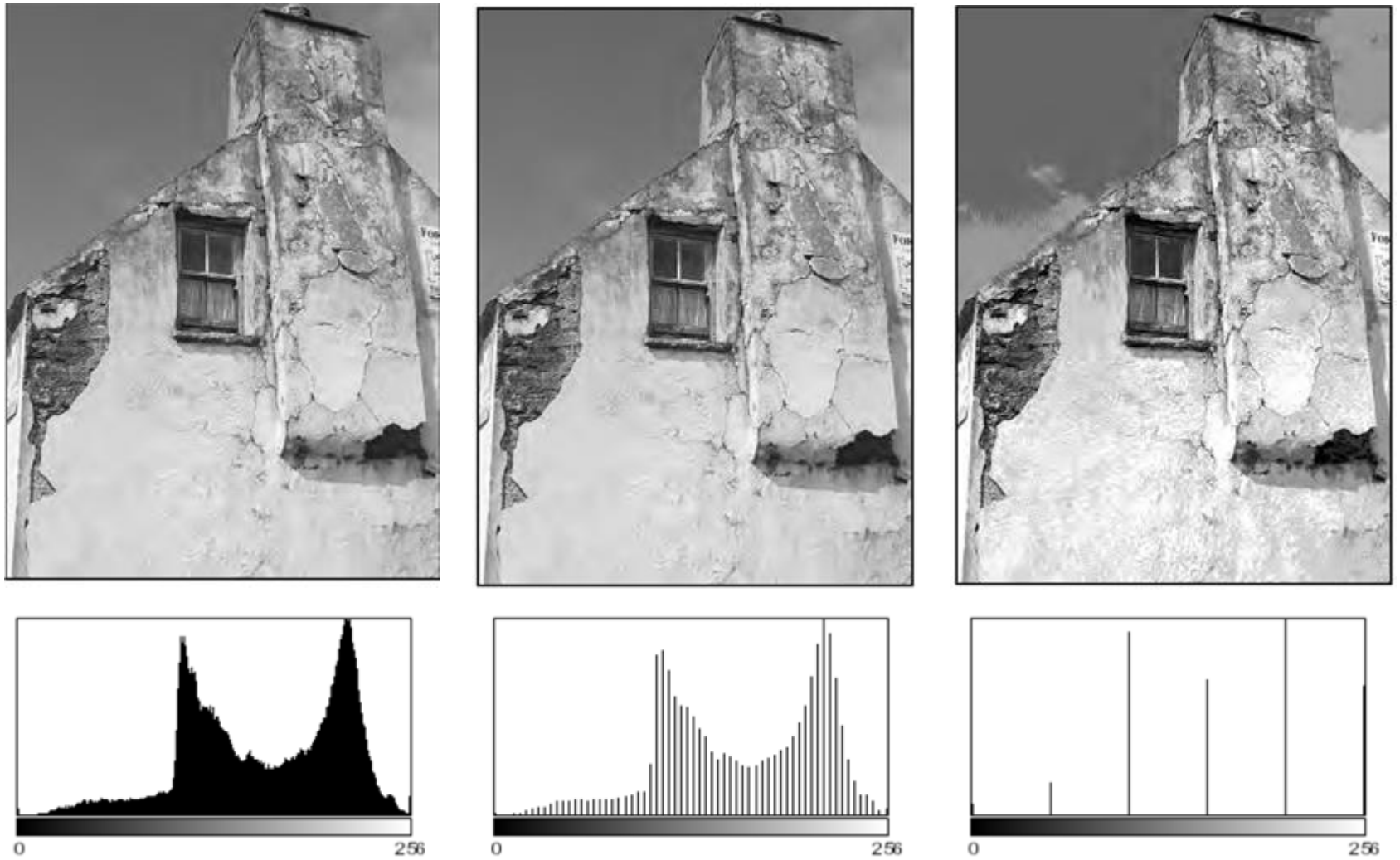




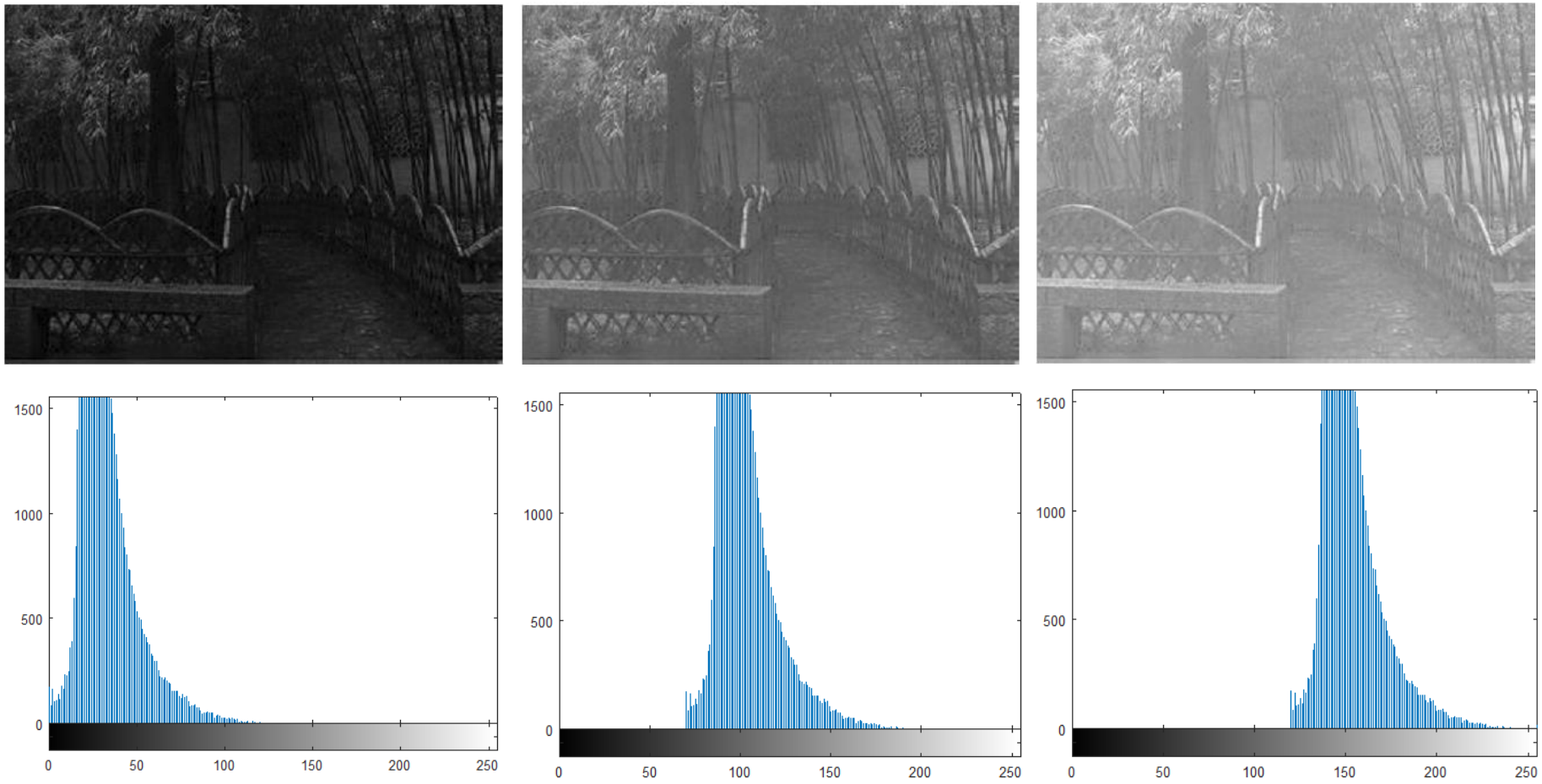




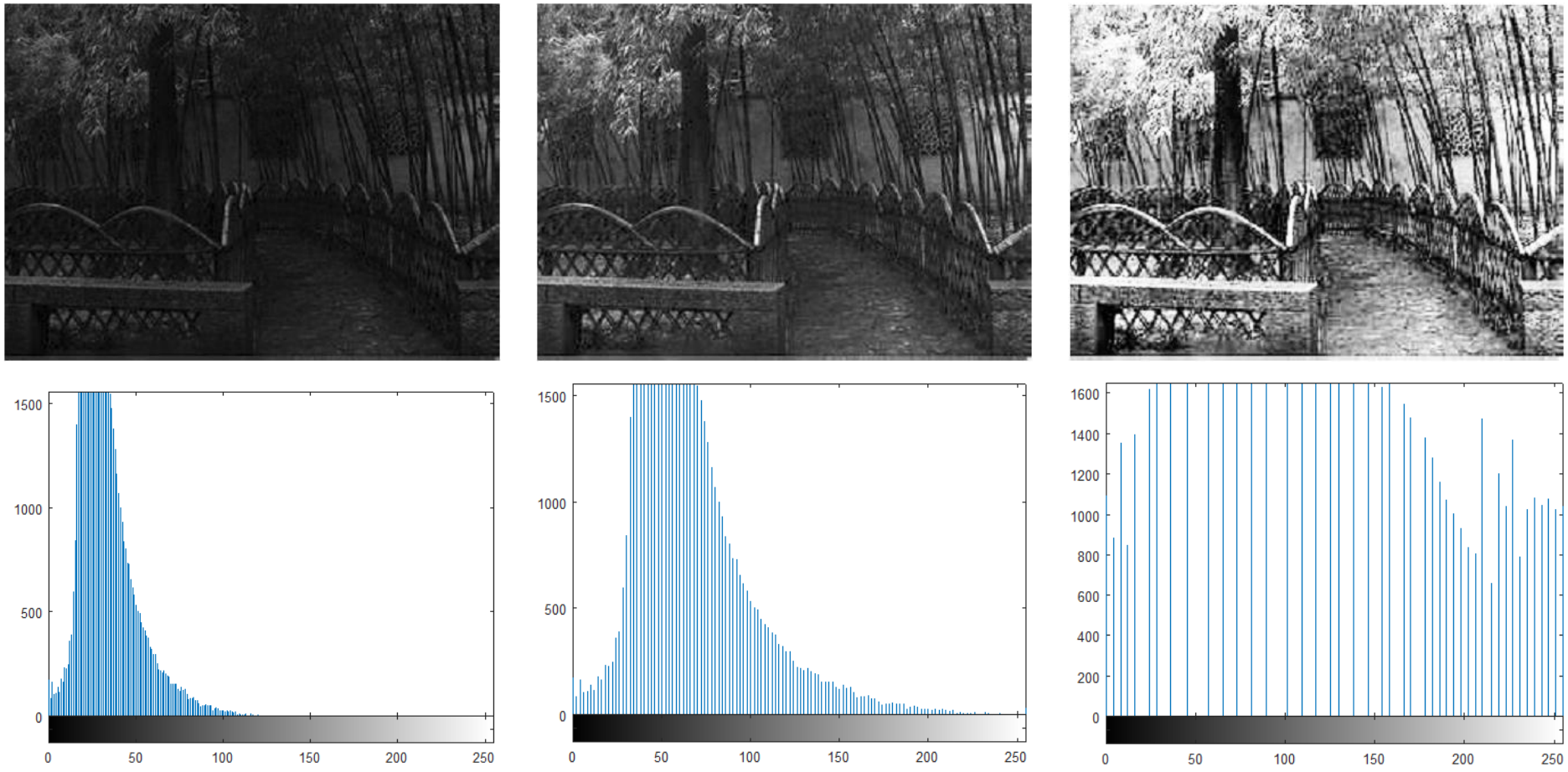
视觉特性：有效灰度级与视觉质量



视觉特性：灰度范围与视觉质量



视觉特性：灰度分布与视觉质量



最大限度均匀覆盖灰度范围

以牺牲有效灰度级为价值，增大覆盖灰度范围，且提高分布的均匀性

灰度映射（Gray mapping）

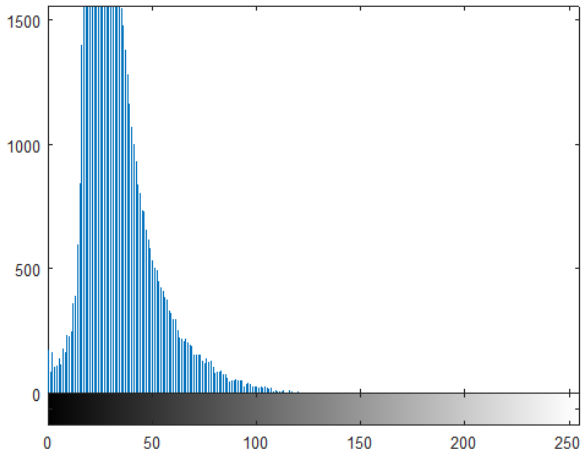
$$s = T(r)$$

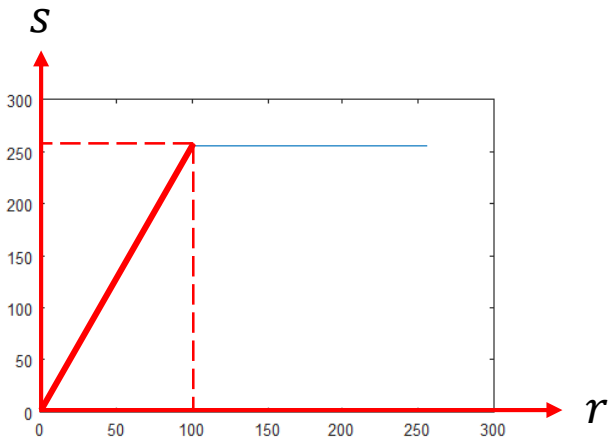
原始图像灰度r

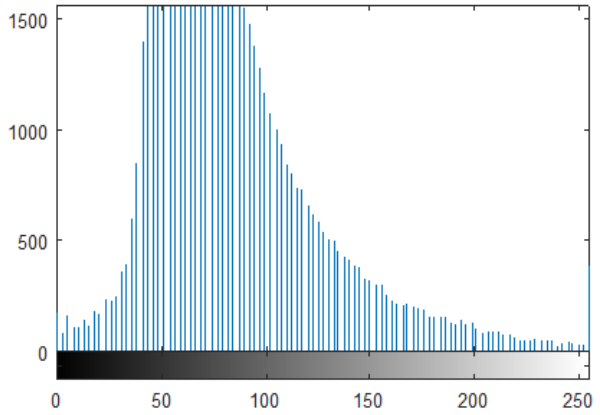
目标图像灰度s

- 灰度映射函数是单调函数

灰度分段线性映射


1500
1000
500
0
0
50
100
150
200
250


s
300
250
200
150
100
50
0
0
50
100
150
200
250
300
r


1500
1000
500
0
0
50
100
150
200
250

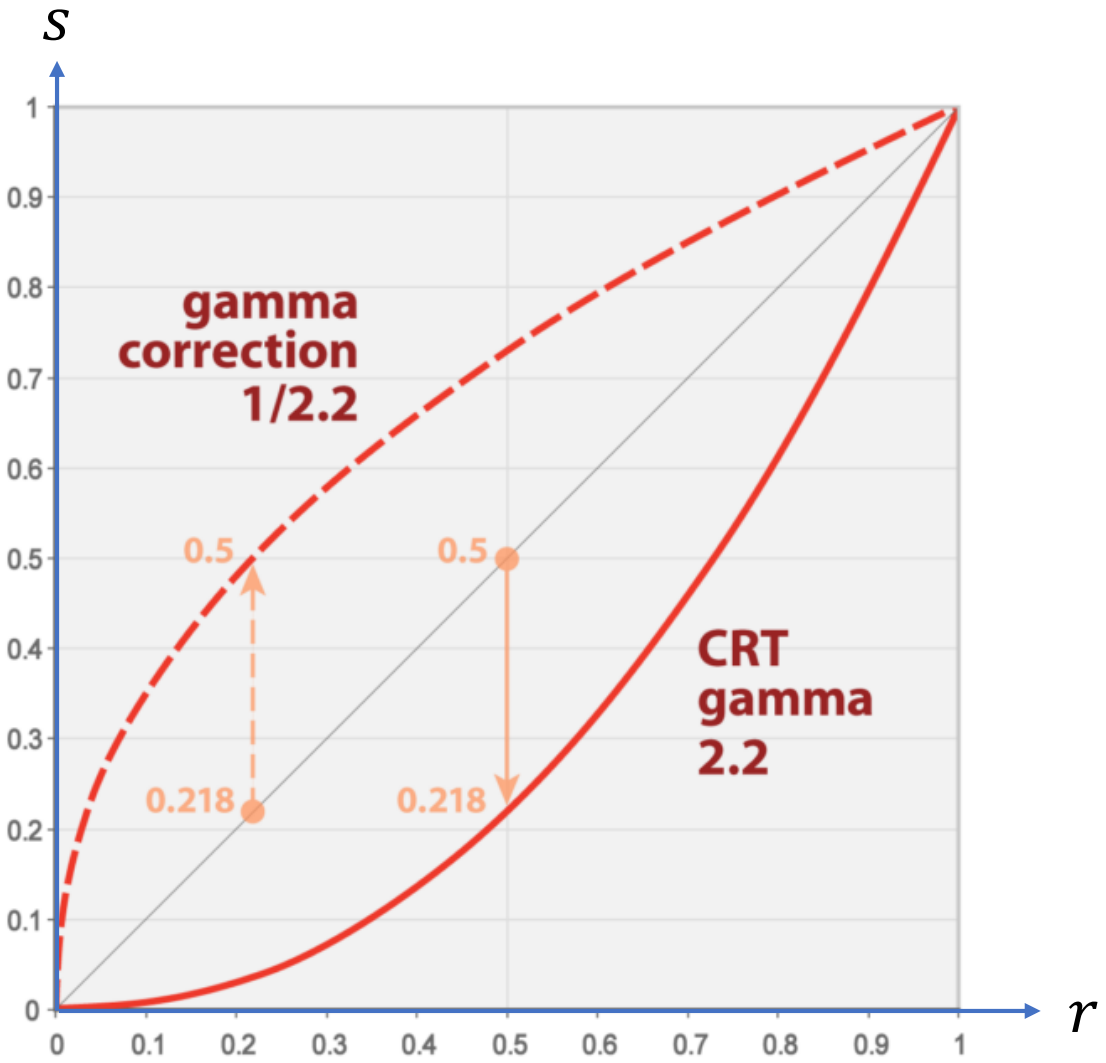
伽玛校正（Gamma Correction）

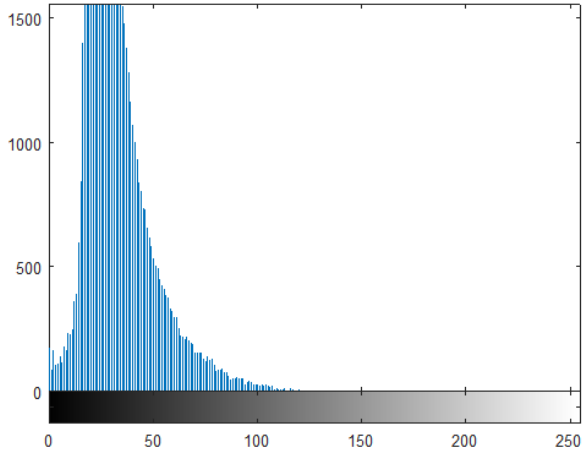
$$s = r^{\gamma}$$

$$s = T(r)$$

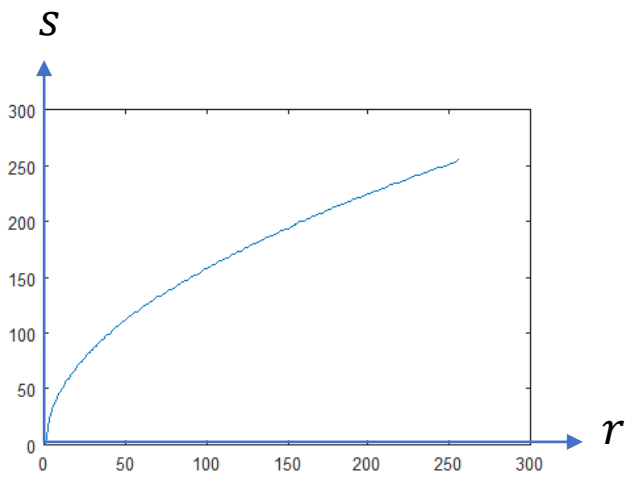
$T'(r) > 1 \rightarrow$ 灰度范围拉伸

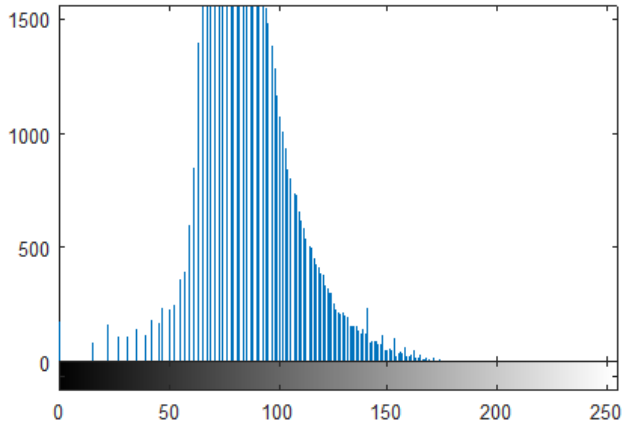
$T'(r) < 1 \rightarrow$ 灰度范围压缩

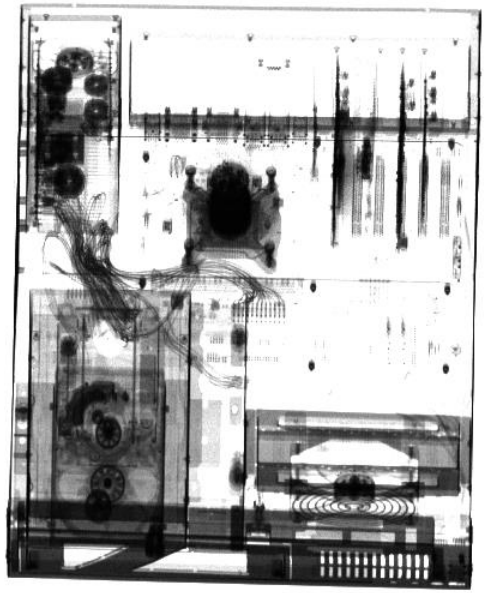


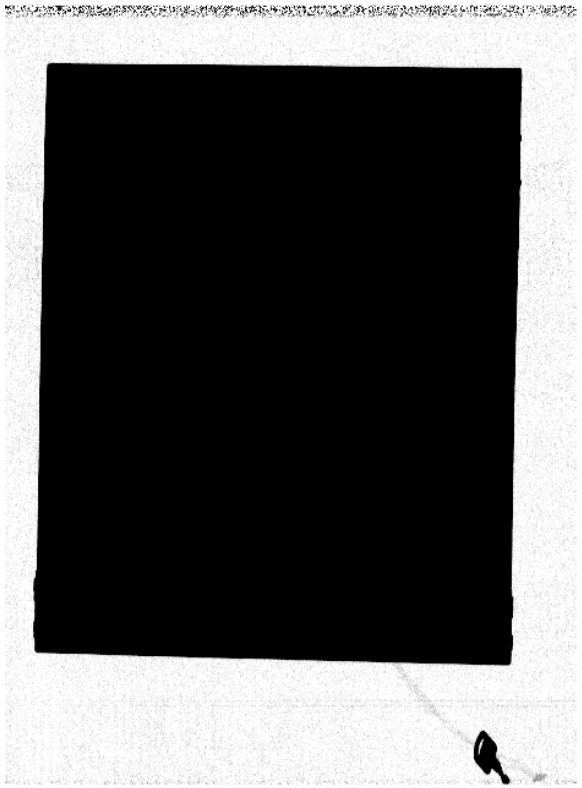

1500
1000
500
0
0
50
100
150
200
250

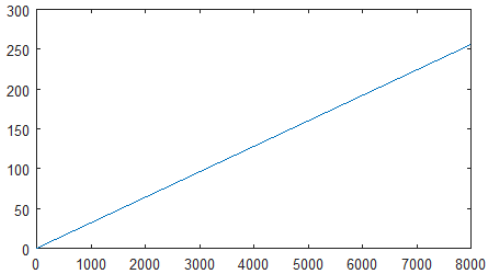
$$s = r^{0.5}$$

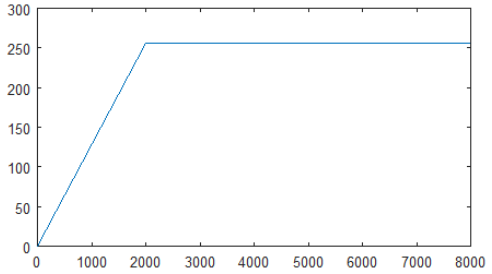

s
300
250
200
150
100
50
0
0
50
100
150
200
250
300
r

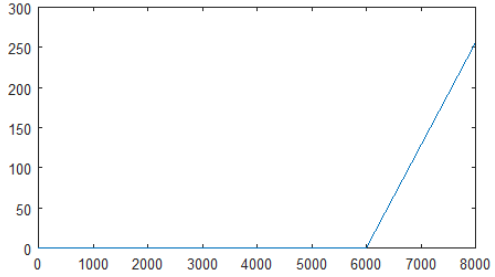

1500
1000
500
0
0
50
100
150
200
250

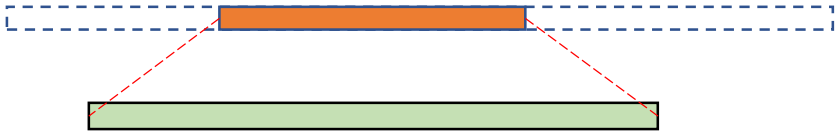












分段线性映射（图像灰度范围大于显示范围）

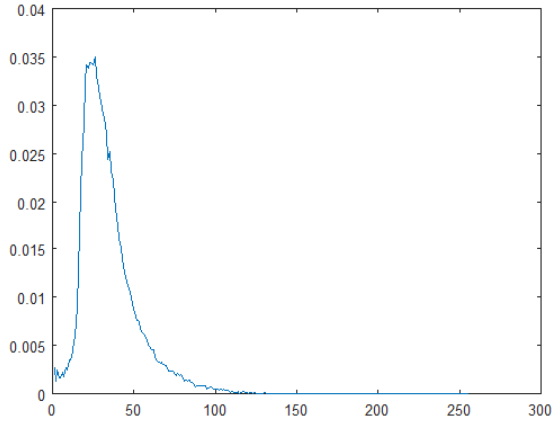
灰度窗调整（窗宽窗位调整）

累积直方图（Cumulative Histogram）

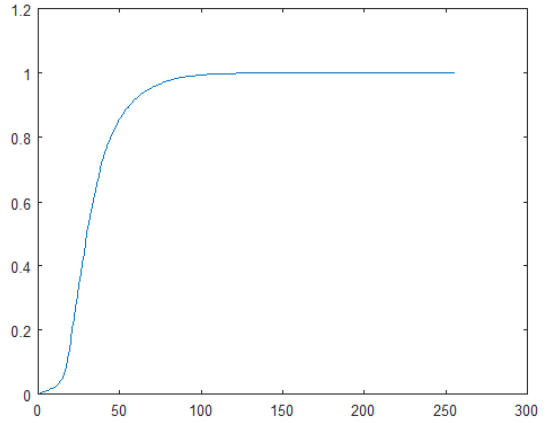
$$H(k) = \sum_{i=1}^{k} p(i) \qquad k = [1, K]$$

$$H(k) = \begin{cases} p(1) & (k = 1) \\ H(k-1) + p(k) & otherwise \end{cases}$$

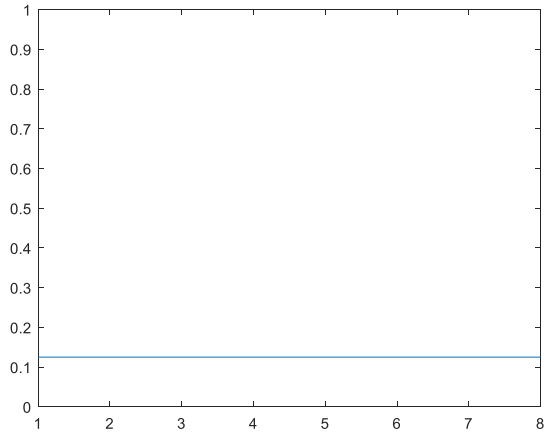
$p(k)$



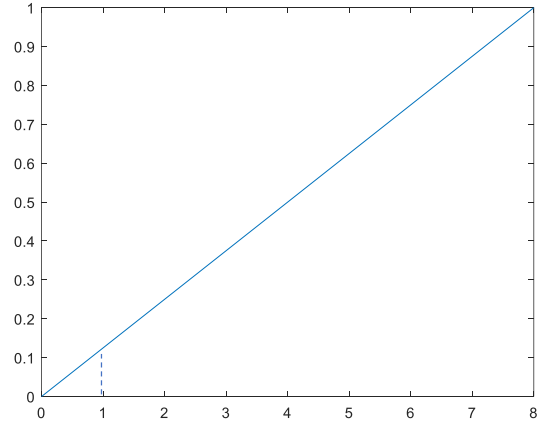
$H(k)$



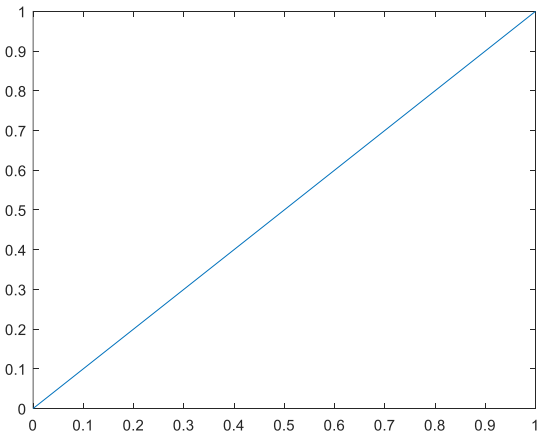
$p(k)$



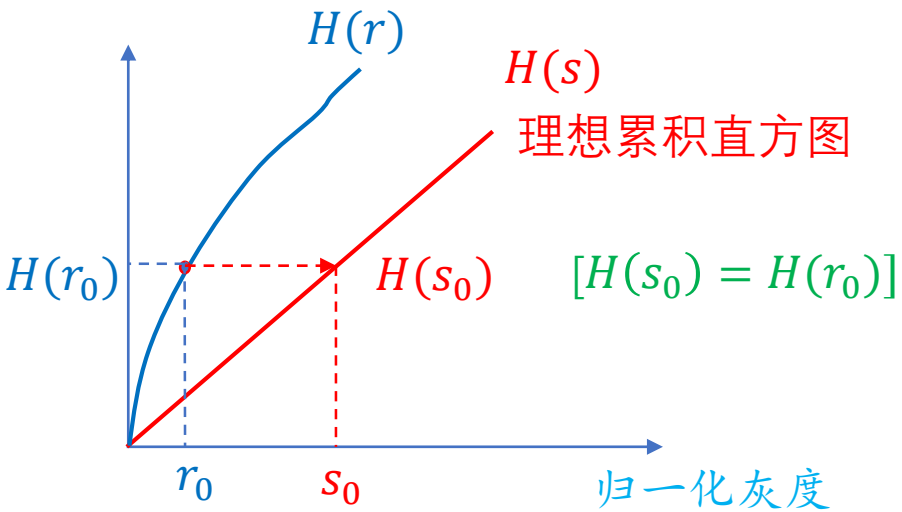
$H(k)$



$H(k)$

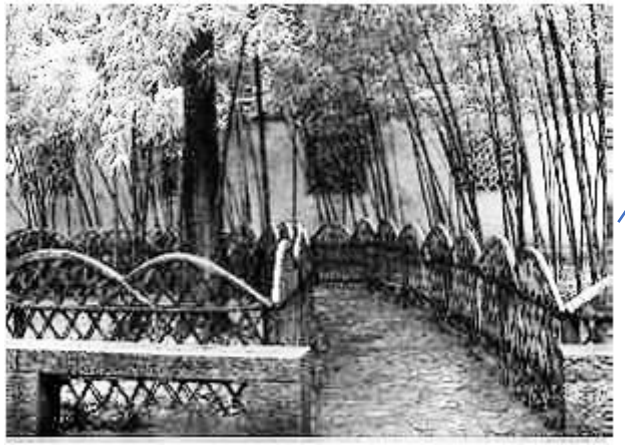


直方图均衡算法原理

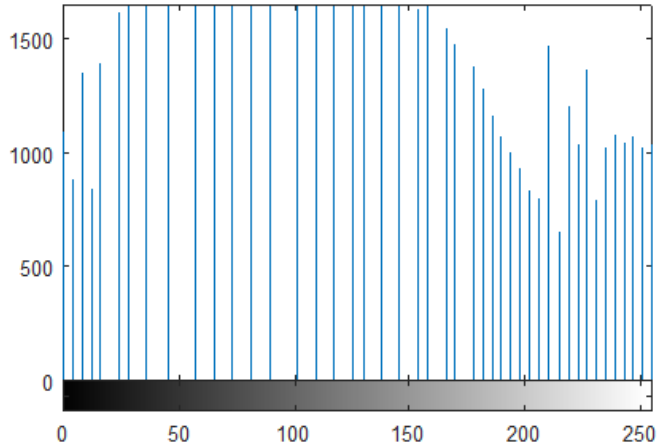


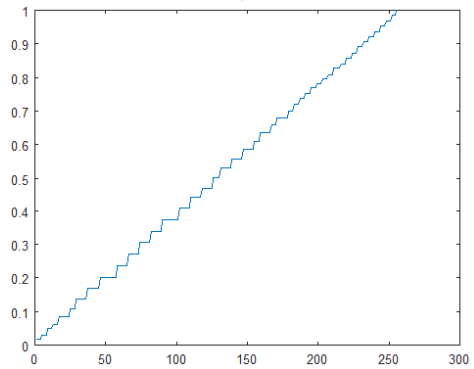
累积直方图（局部）

因为理想累积直方图$H(s) = s \rightarrow s = H(r)$



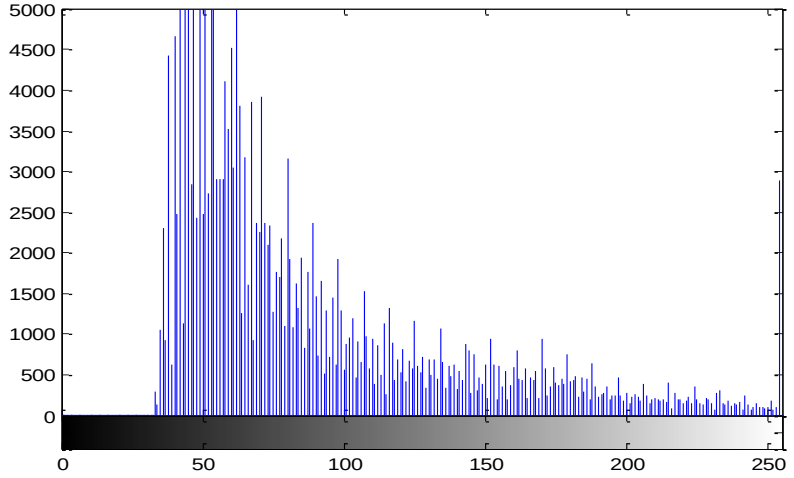
灰度直方图

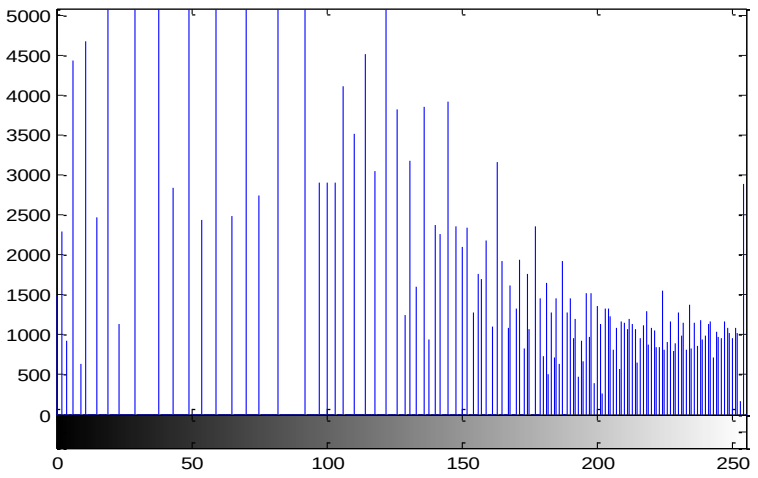




累积灰度直方图

灰度	0	1	2	3	4	5	6	7	[0,7]
k	1	2	3	4	5	6	7	8	[1,8]
p(k)	0.05	0.10	0.35	0.30	0.10	0.05	0.05	0.00	
H(k)	0.05	0.15	0.50	0.80	0.90	0.95	1.00	1.00	
s	0.05	0.15	0.50	0.80	0.90	0.95	1.00	1.00	
S	0.4	1.2	4.0	6.4	7.2	7.6	8.0	8.0	
	0	1	4	6	7	8	8	8	[1,8]
灰度	0	0	3	5	6	7	7	7	[0,7]


5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250


5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250

图像平滑（噪声抑制）
Denoising

图像平滑方法分类

- 空间域
  - 线性方法（线性滤波器）
    - ✓均值滤波器, 高斯滤波器, 维纳滤波器, …
  - 非线性方法
    - ✓中值滤波器, 全变分, 非局部均值, 双边滤波, 非均匀扩散, …
  - 结合线性与非线性方法
- 基于形态学运算的方法
- 基于模糊理论的方法
- 基于人工神经网络的方法
- 基于统计的方法
- 变换域的方法
  - 小波域, 主成份分析（PCA）, …

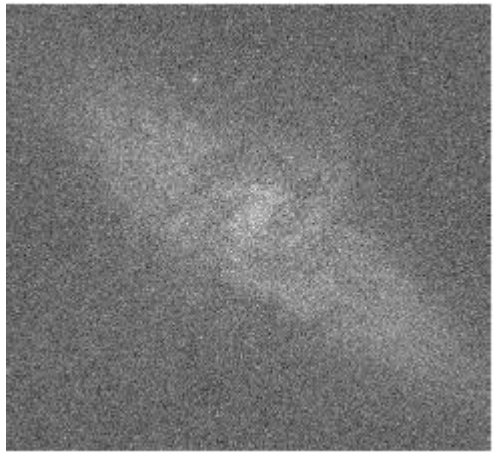
图像平均（Image Averaging）

原始图像（无噪声的理想图像）: I

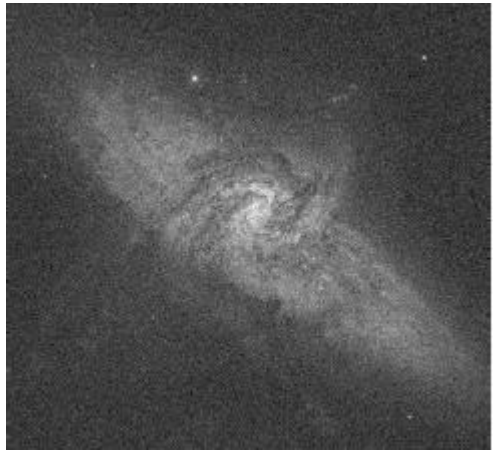
采样图像（包含噪声）: $I(t)$, (t=1,...,N)

$I(t) = I + n(t)$　　$n(t)$ → 服从高斯分布

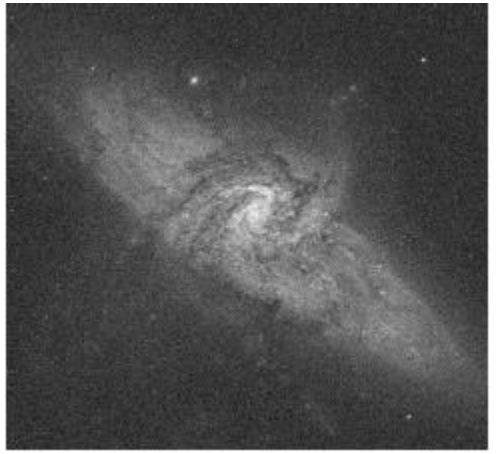
$$\hat{I} = \frac{1}{N}\sum_{t=1}^{N} I(t) = I + \frac{1}{N}\sum_{t=1}^{N} n(t)$$



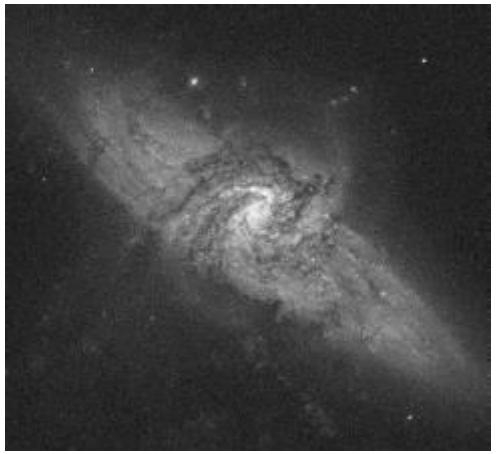
sample



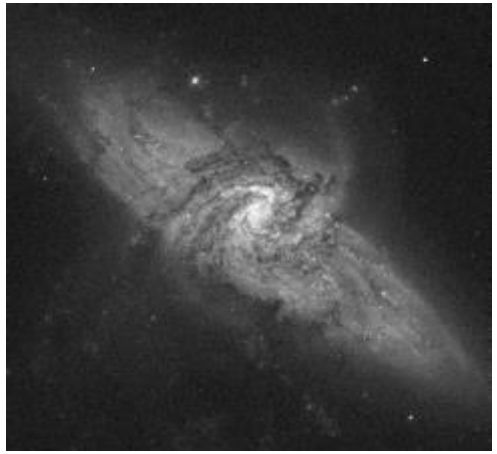
8 frames averaging



16 frames averaging



64frames averaging



128frames averaging


2007-11-22 07:13:52
Camera 03


2007-11-22 07:13:53
Camera 03


2007-11-22 07:13:53
Camera 03

邻域像素的平均

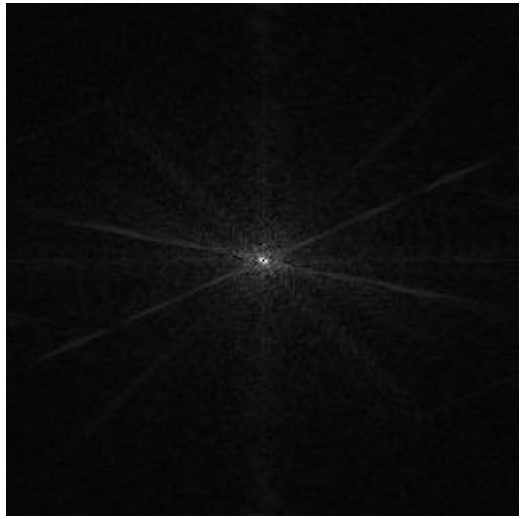
$$\hat{I}(x,y) = \frac{1}{(2W+1)^2} \sum_{i=-W}^{W} \sum_{j=-W}^{W} I(x+i, y+j)$$

加权平均

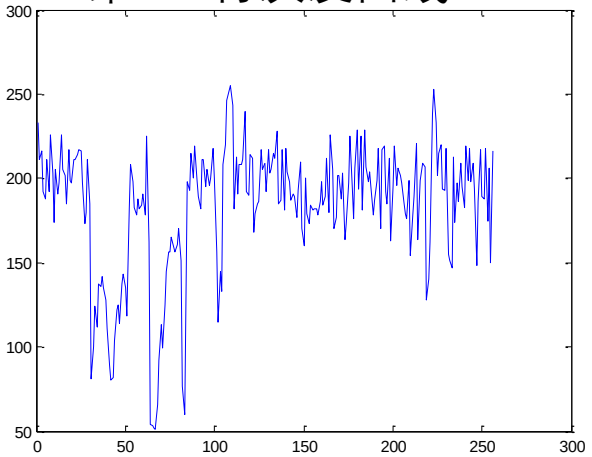
$$\hat{I}(x,y) = \sum_{i=-W}^{W} \sum_{j=-W}^{W} h(i,j) I(x-i, y-j)$$

灰度图像

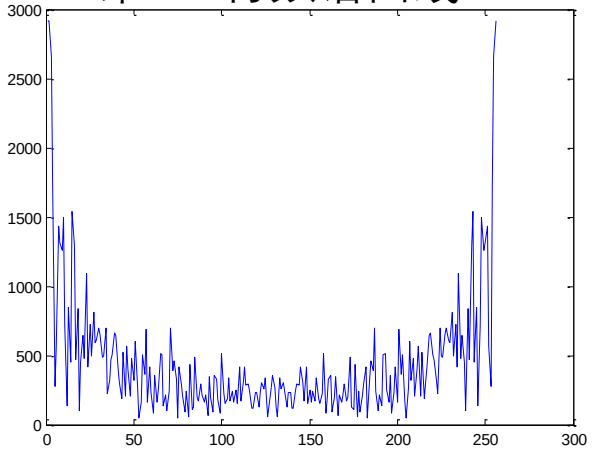
频谱图像



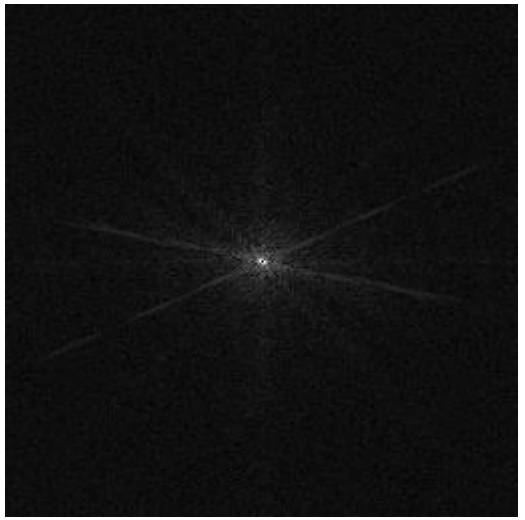
第256行灰度曲线

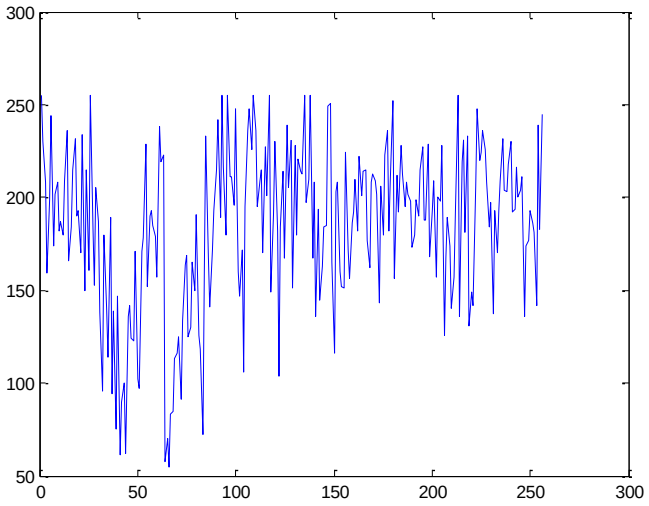


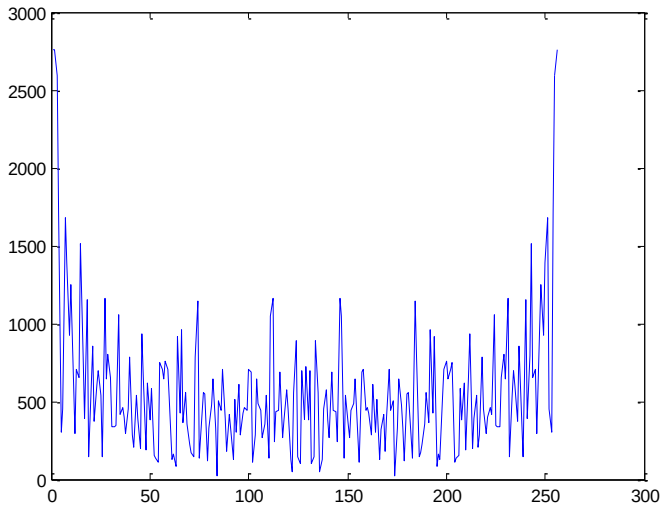
第256行频谱曲线



频谱特性



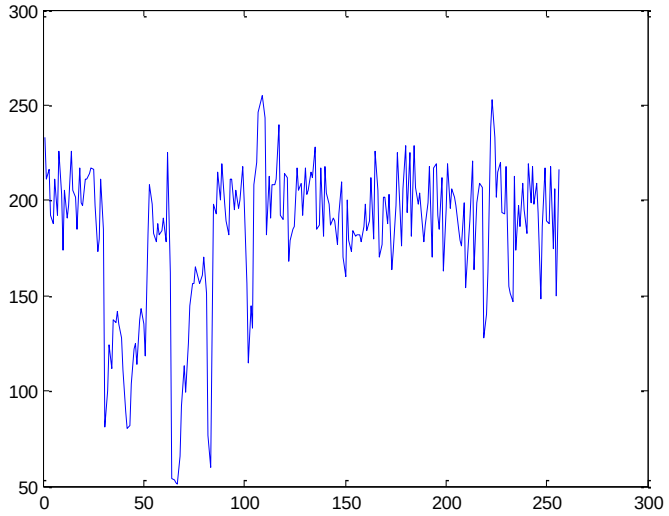

300
250
200
150
100
50
0
50
100
150
200
250
300

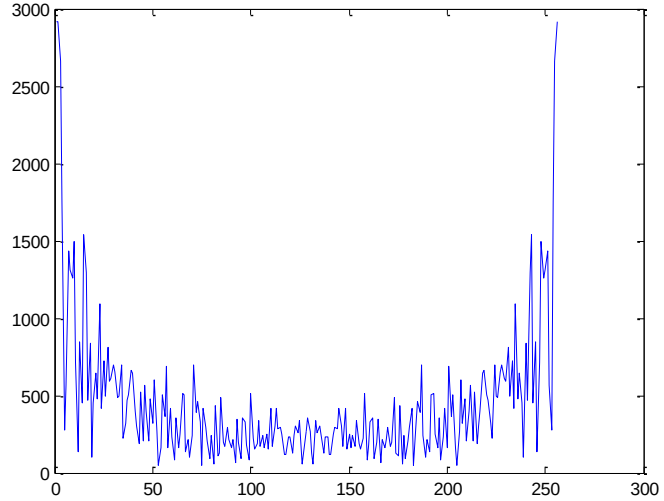

3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300

灰度

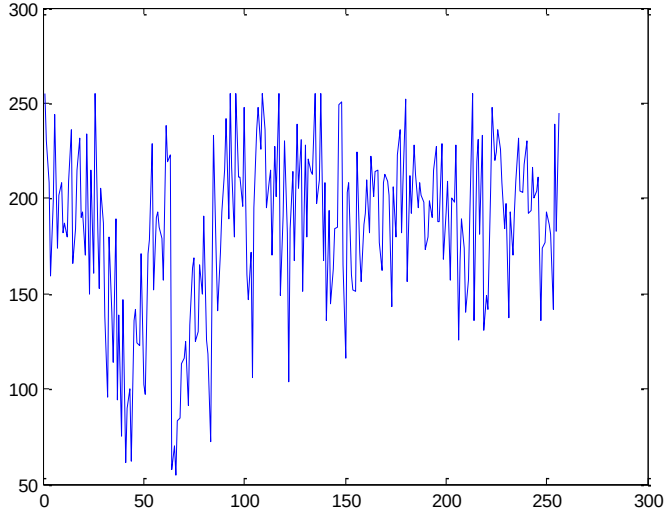
频谱

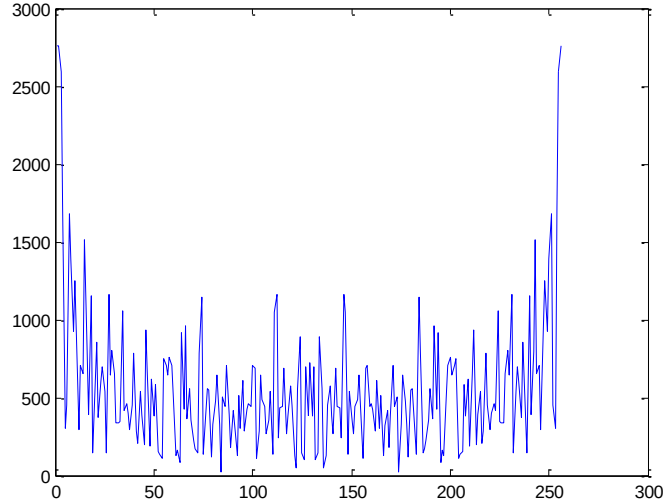
原始图像





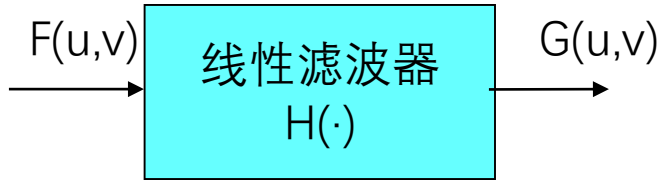
加噪声后图像





低通滤波器（Lowpass Filter）

$$G(u,v) = H(u,v)\,F(u,v)$$



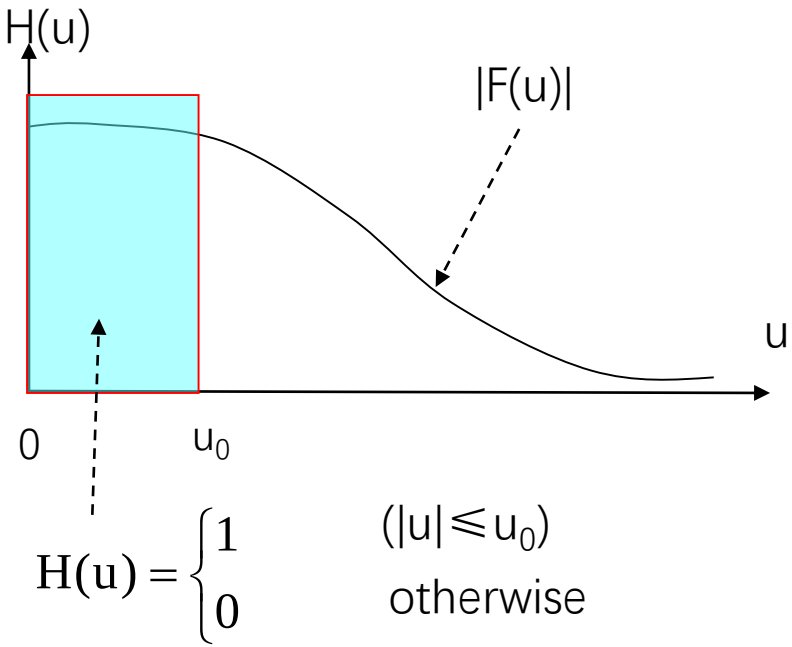
H(u,v) : 传递函数

F(u,v) : 输入图像的频域特性

G(u,v) : 输出图像的频域特性

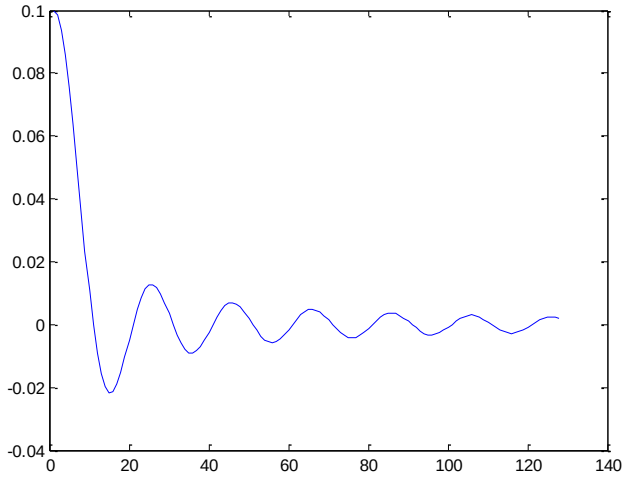
$$g(x,y) = h(x,y) * f(x,y)$$

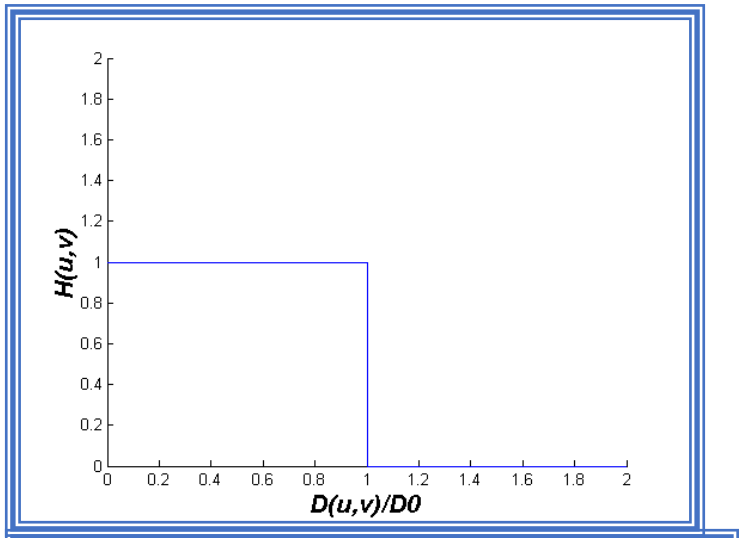
h(x,y) : 点扩展函数（Point Spread Function）

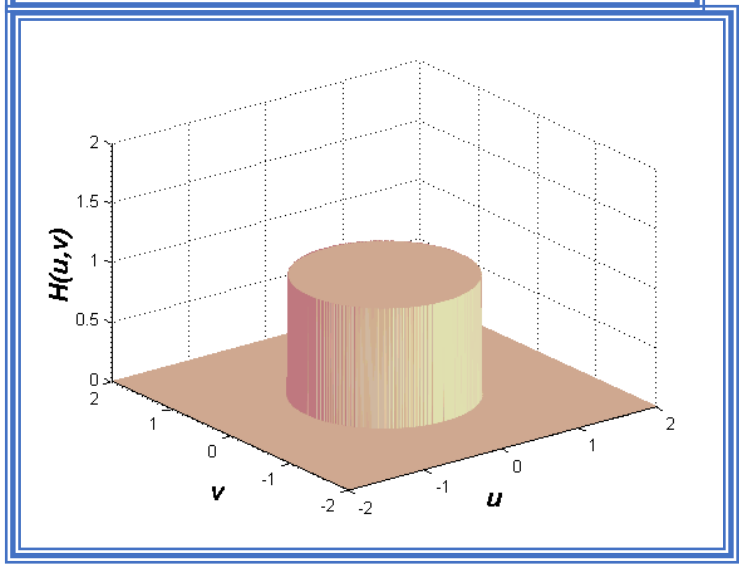


理想低通滤波器（Ideal Lowpass Filter)

点扩展函数h(r)



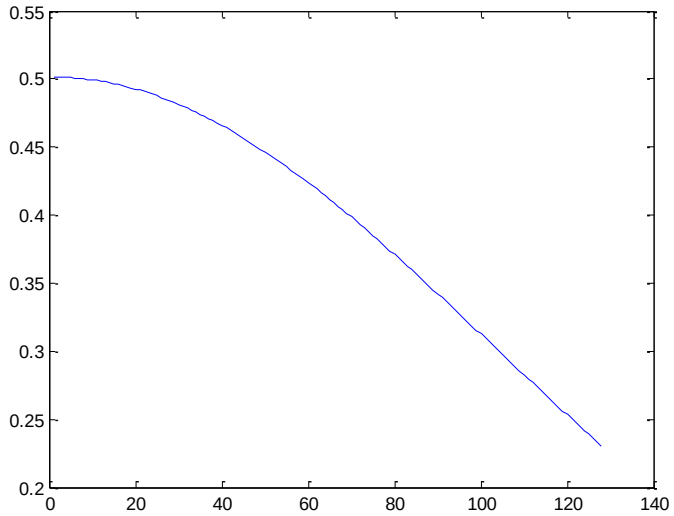


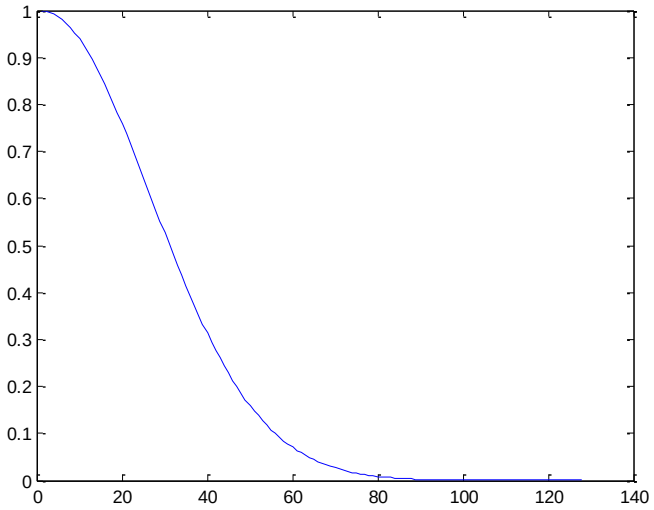


高斯滤波器(Gaussian Lowpass Filter)

$$h(x) = \sqrt{2\pi}\sigma A e^{-2\pi^2\sigma^2 x^2}$$

$$H(u) = Ae^{-u^2/2\sigma^2}$$





均值濾波器（Averaging filter）

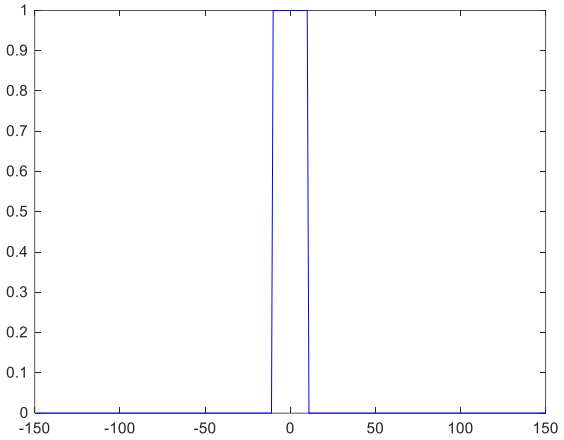
$$h(x)=\begin{cases}1 & (-a/2\le x\le a/2)\\ 0 & otherwise\end{cases}$$

$$H(u)=\int_{-a/2}^{a/2}e^{-j2\pi ux}dx$$

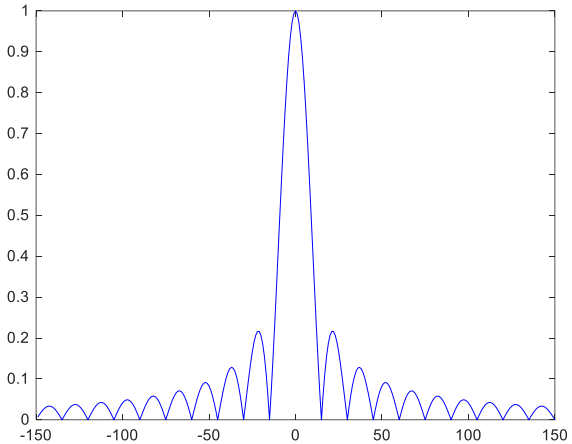
$$=\frac{e^{-j\pi au}-e^{j\pi au}}{-j2\pi u}$$

$$=\frac{\sin(\pi au)}{\pi u}$$

$h(x)$



$|H(u)|$

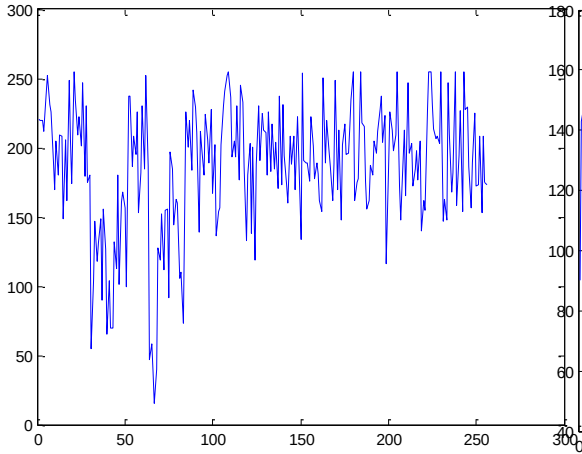


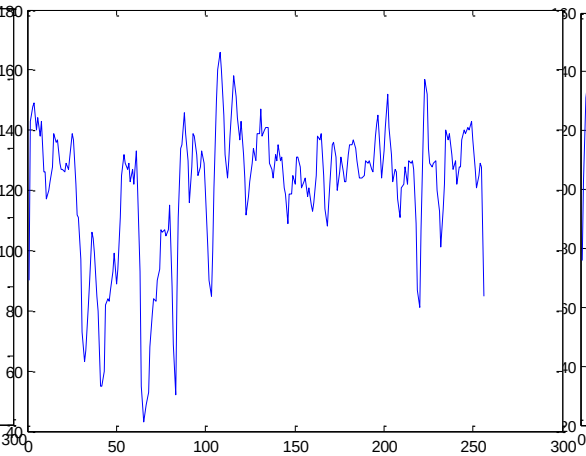
均值滤波器

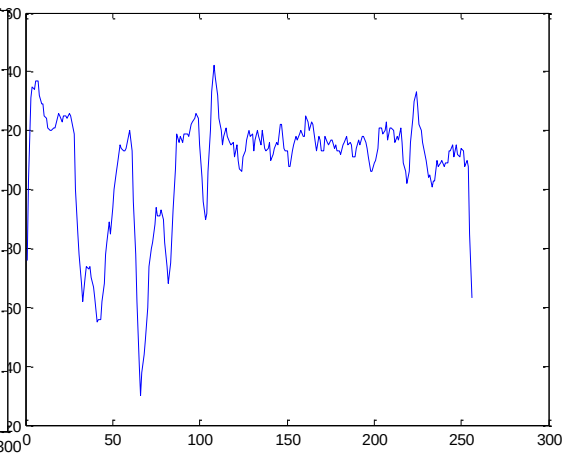
输入图像

3x3

5x5





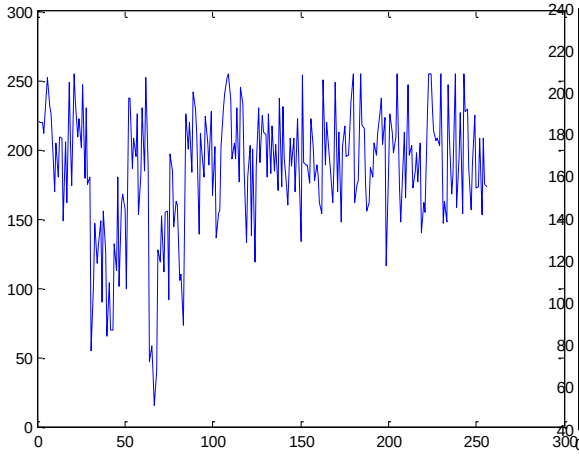


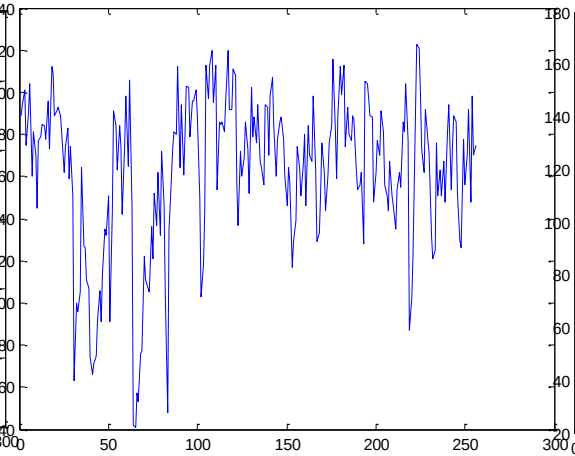
高斯滤波器

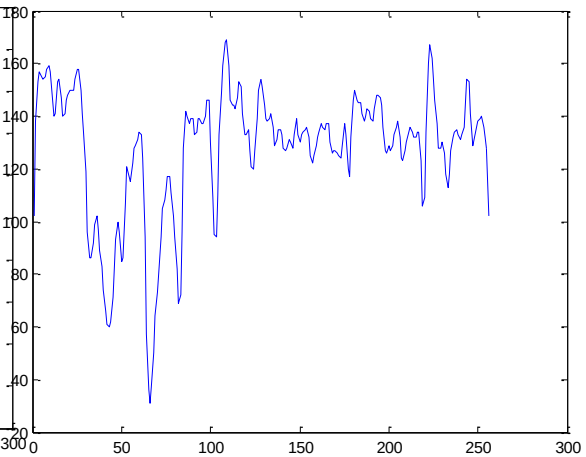
输入图像

σ=0.5

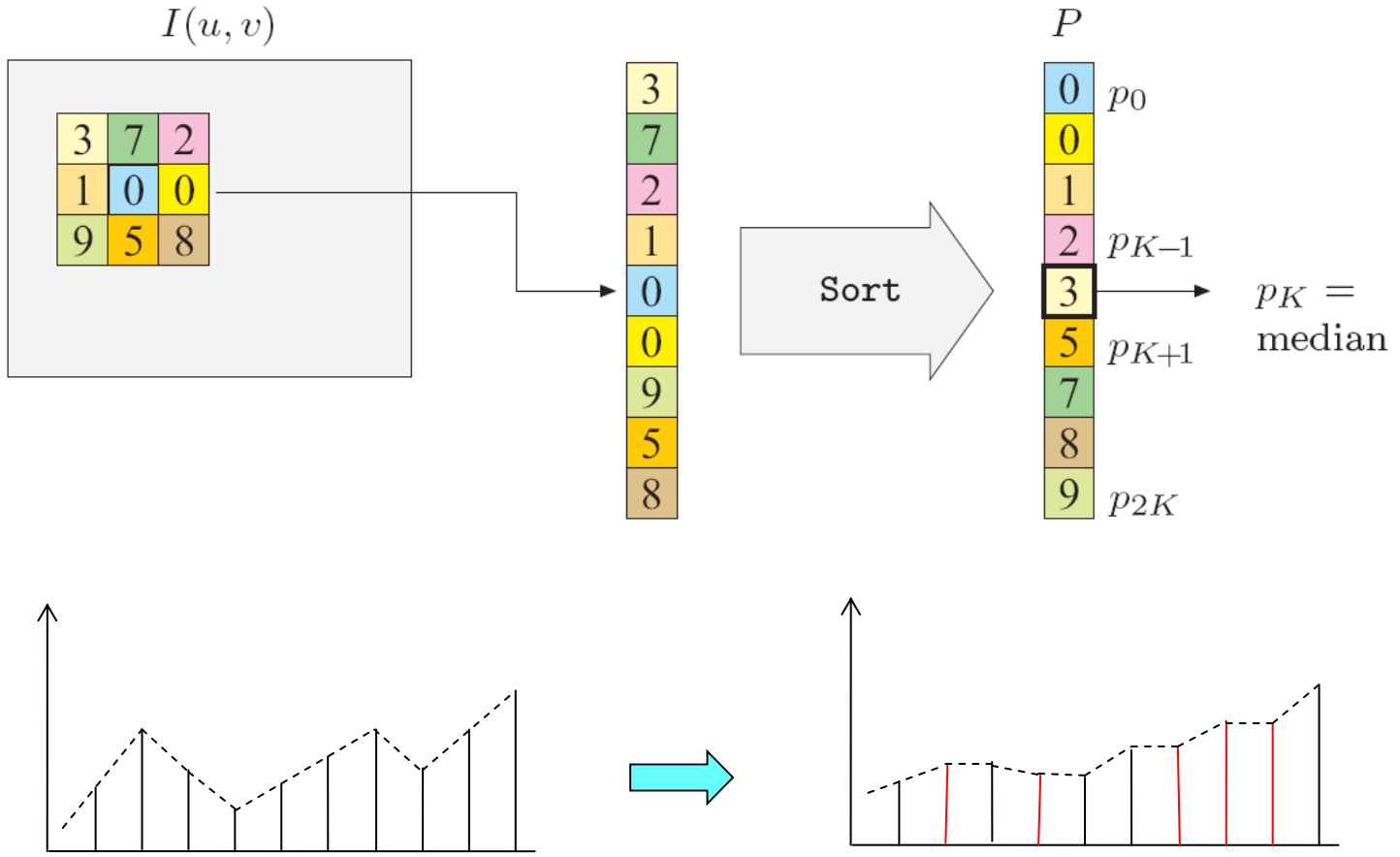
σ=1.0







中值滤波器（Median Filter）

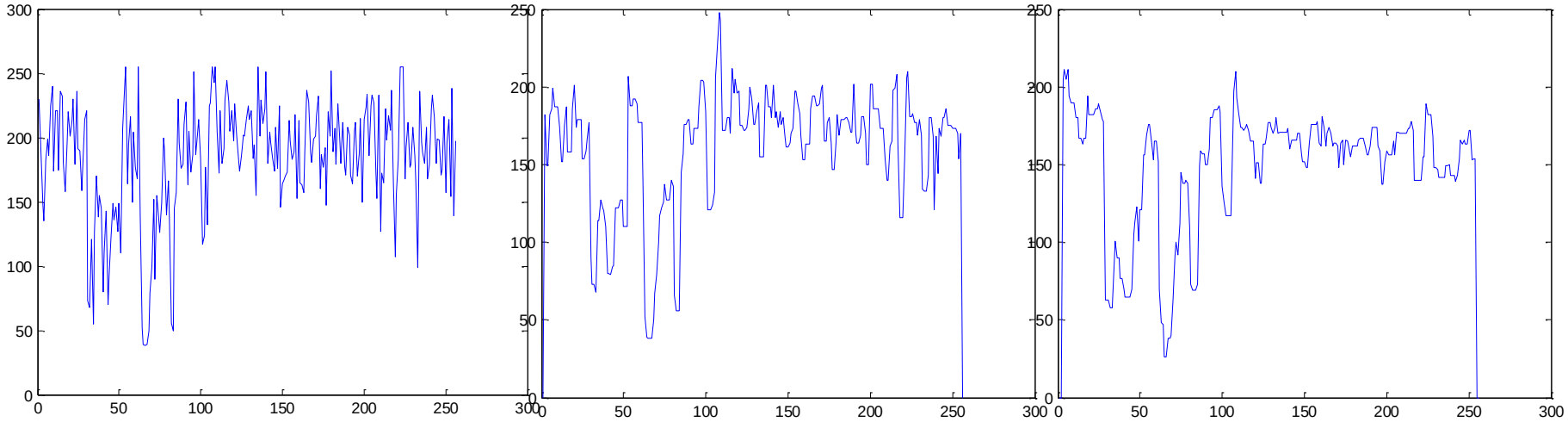


中值滤波器

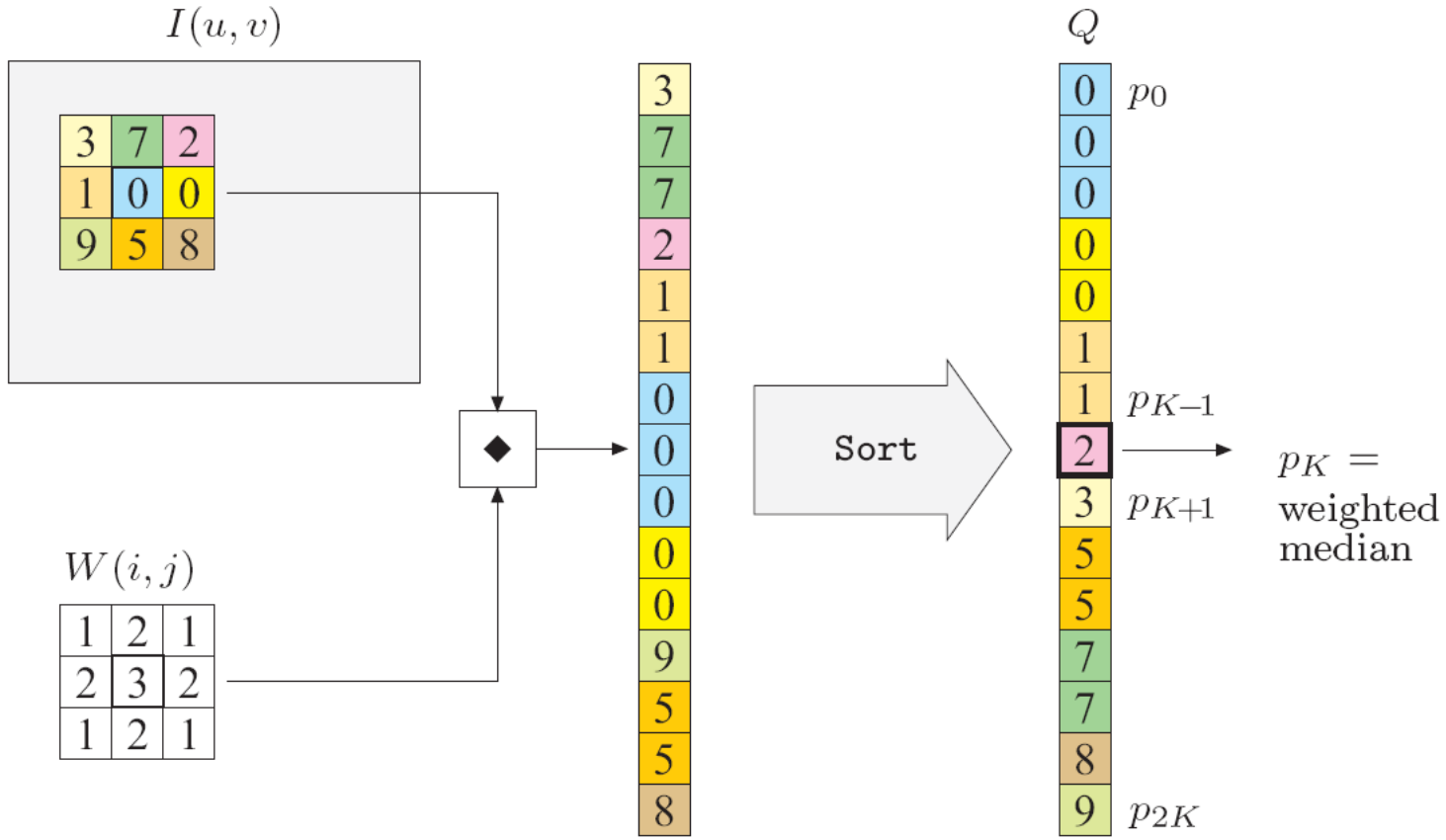
输入图像

3x3 窗口输出图像

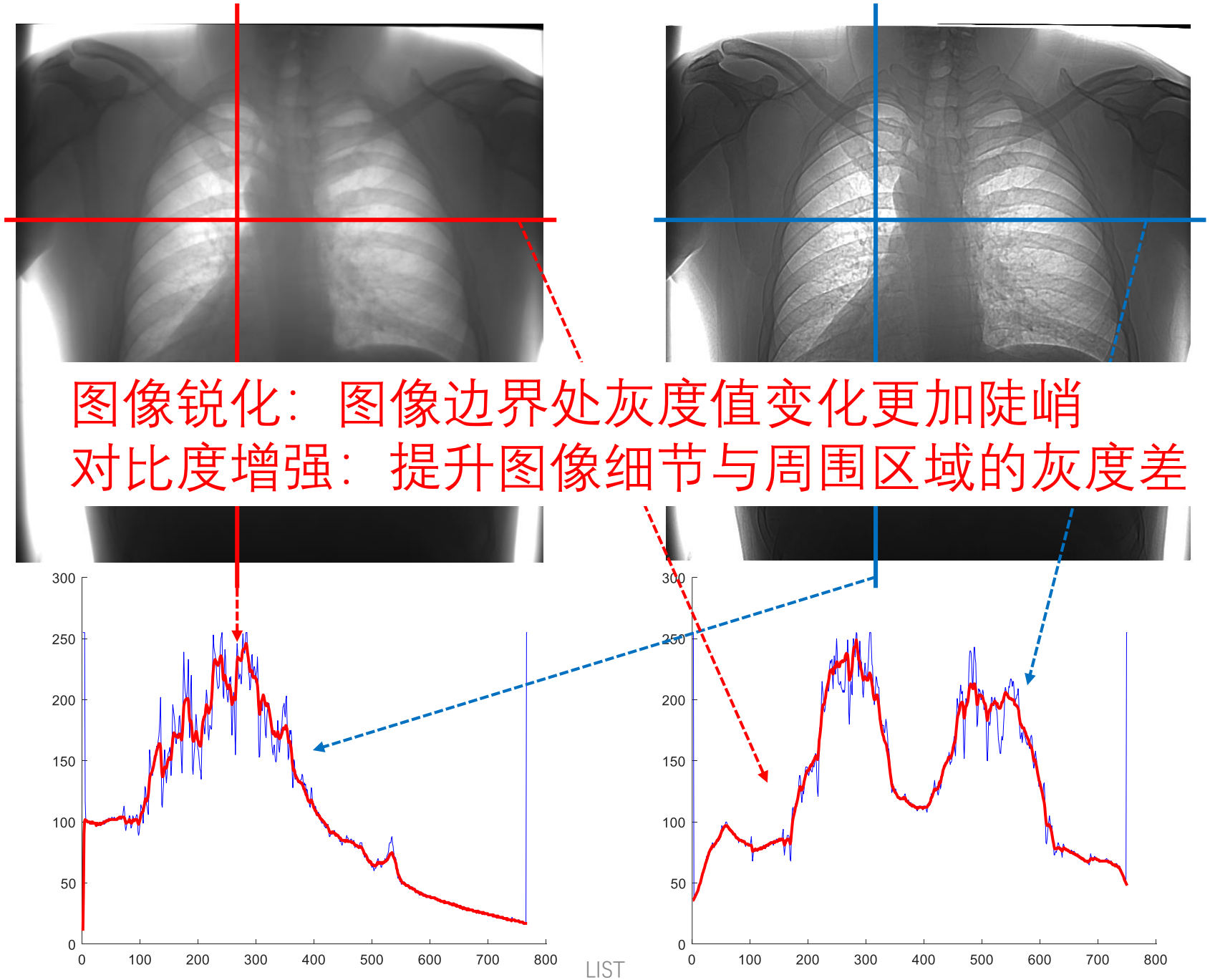
5x5 窗口输出图像

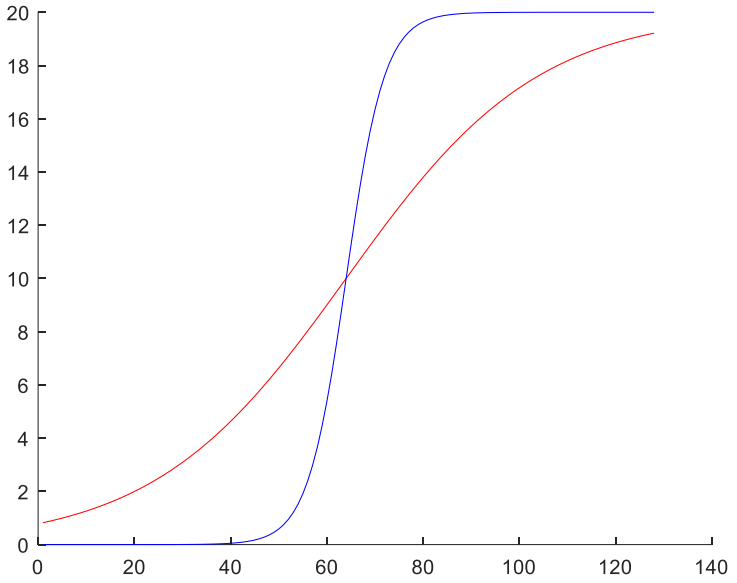


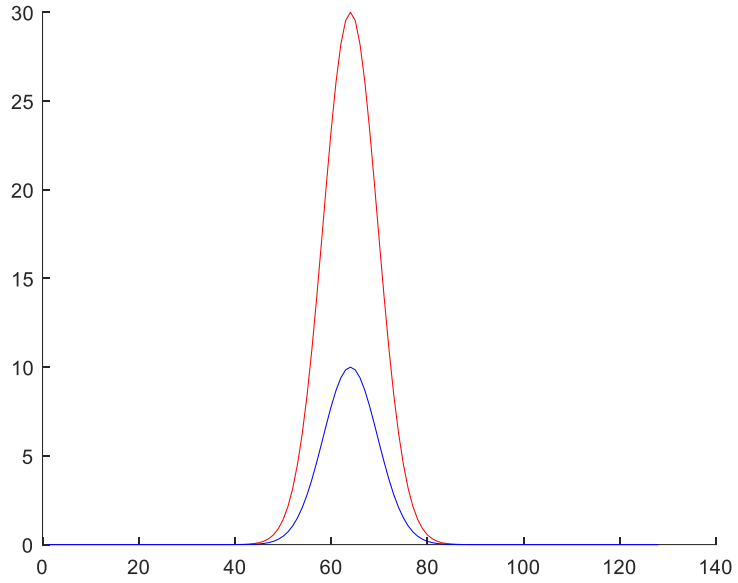
加权中值滤波器（Weighted Median Filter）

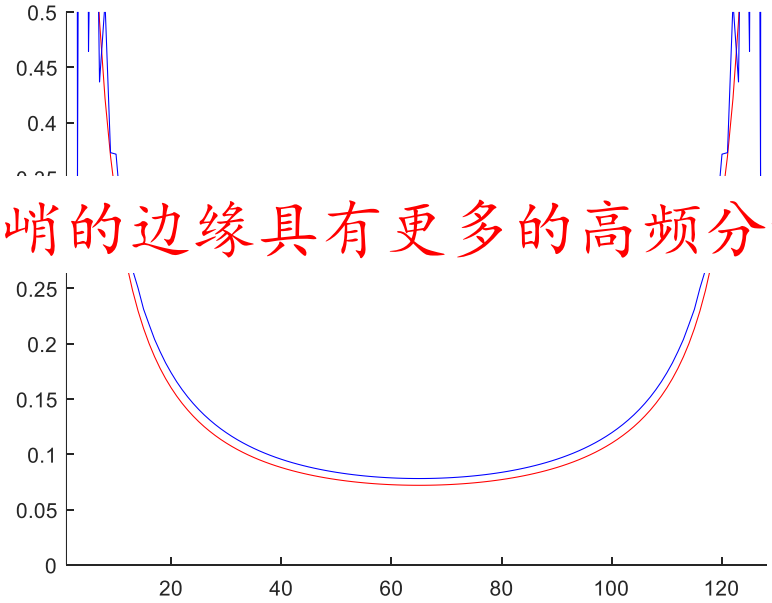


图像锐化 & 对比度增强
Image Sharpening
Contrast Enhancement

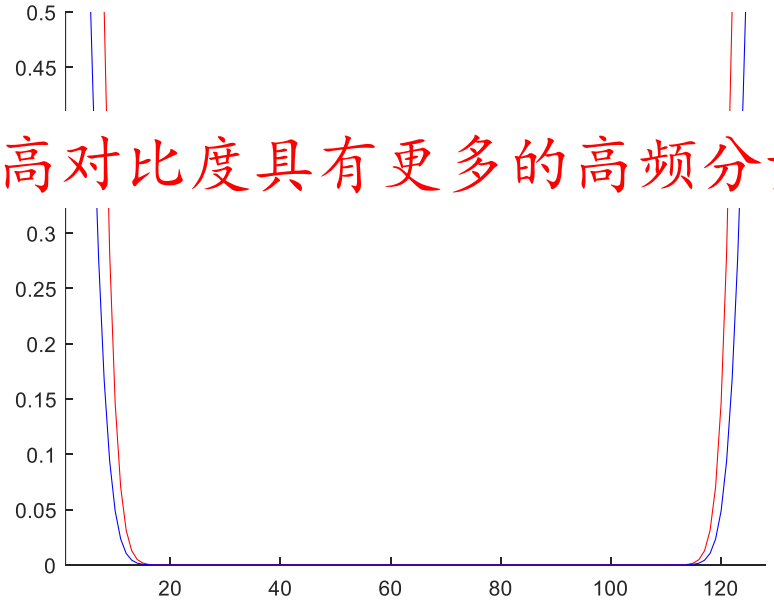

图像锐化：图像边界处灰度值变化更加陡峭
对比度增强：提升图像细节与周围区域的灰度差
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800





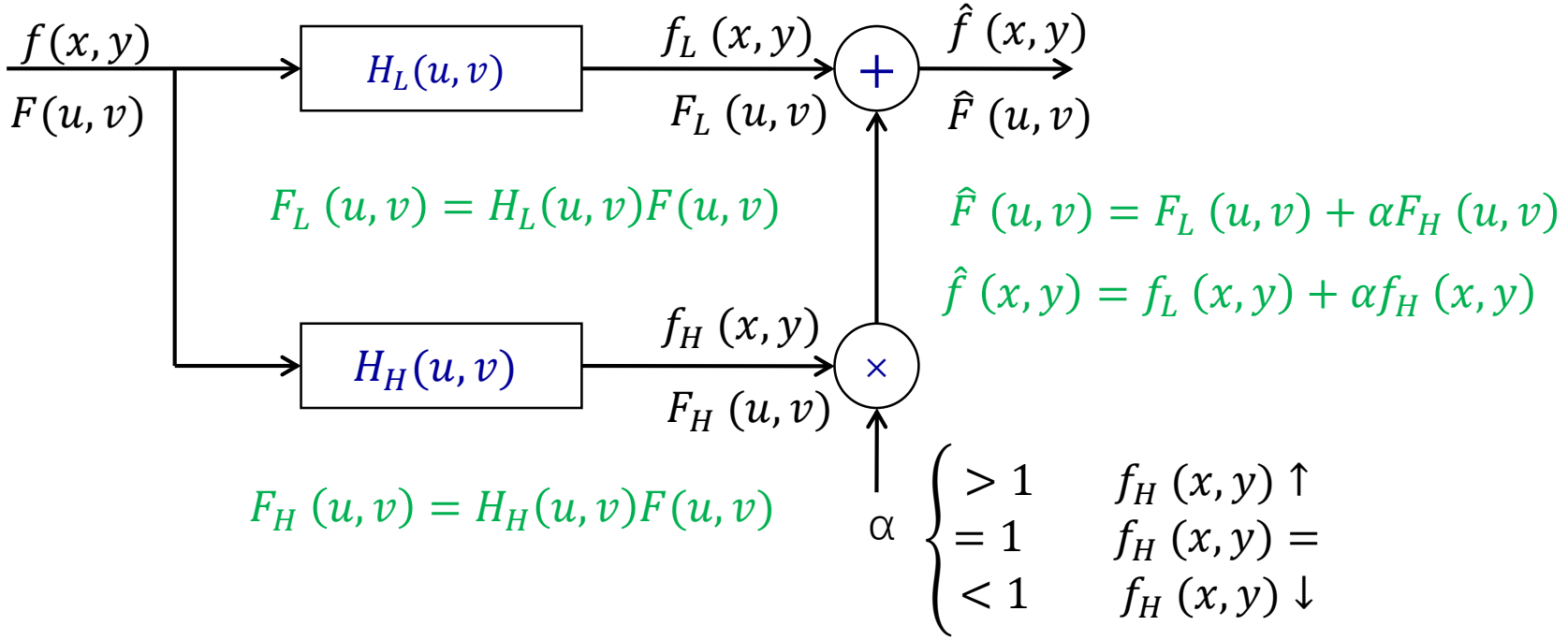


陡峭的边缘具有更多的高频分量

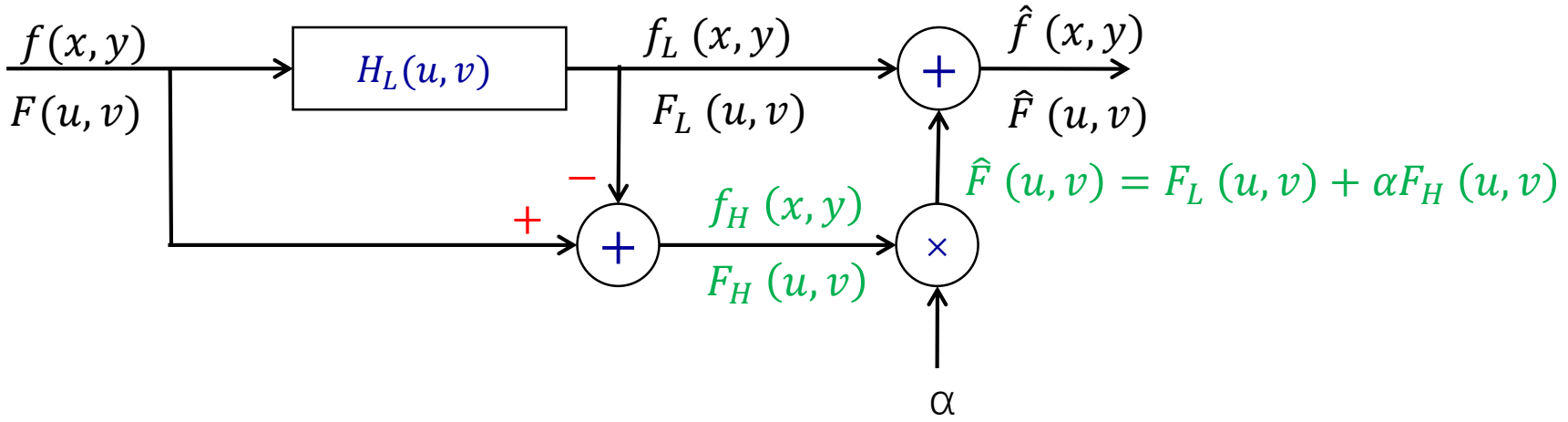


高对比度具有更多的高频分量

Unsharp Masking

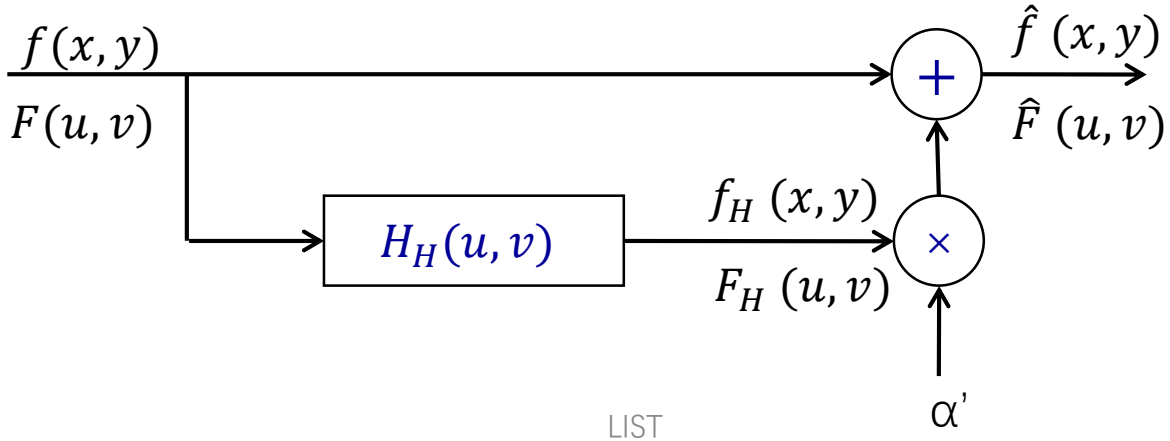


$H_L(u,v) + H_H(u,v) = 1 \rightarrow \ H_H(u,v) = 1 - H_L(u,v)$



记 $\alpha = \alpha' + 1 \ \rightarrow \hat{F}\ (u,v) = H_L(u,v)F(u,v) + H_H(u,v)F(u,v) + \alpha' H_H(u,v)F(u,v)$

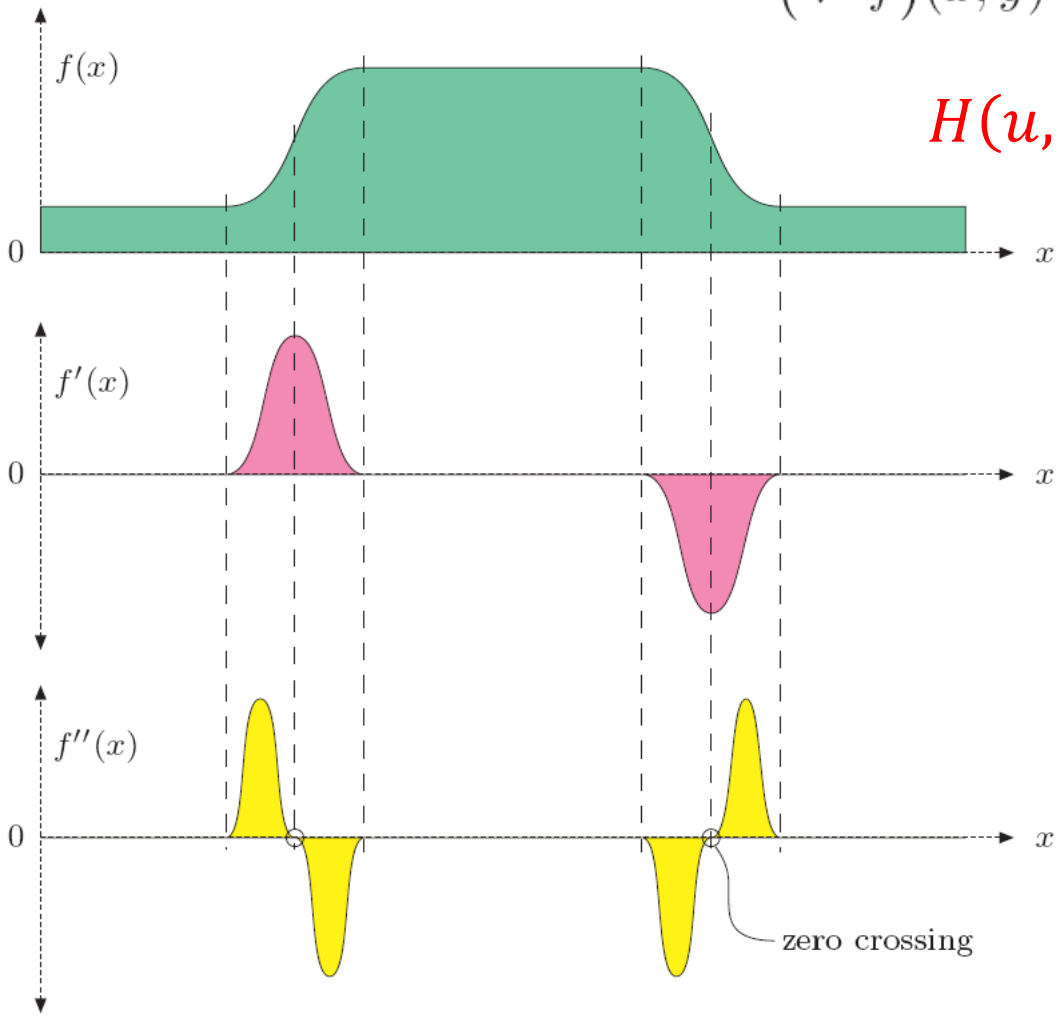
$\hat{F}\ (u,v) = \ [1 + \alpha' H_H(u,v)]F(u,v)$

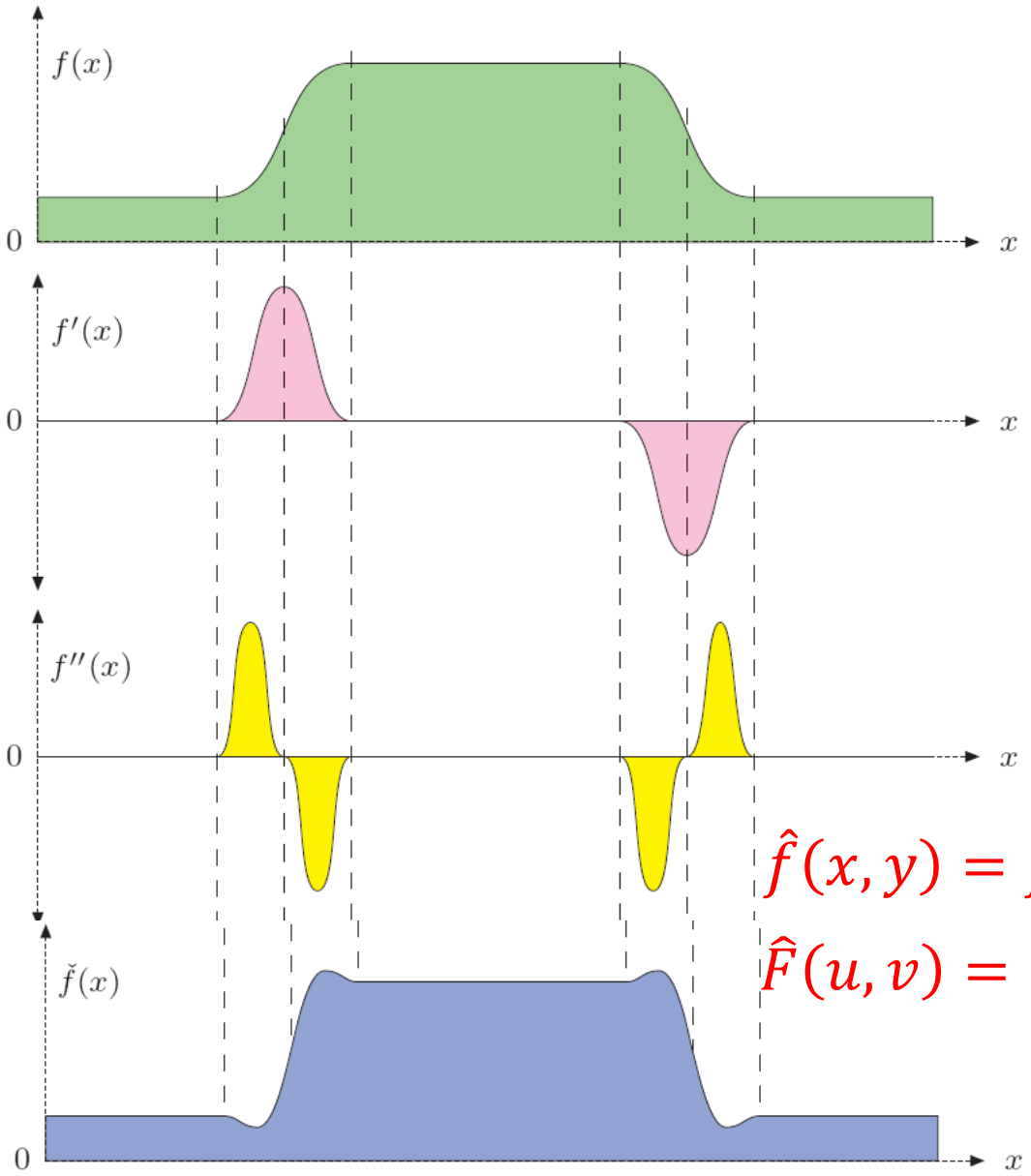


Laplacian

$$(\nabla^2 f)(x,y) = \frac{\partial^2 f}{\partial^2 x}(x,y) + \frac{\partial^2 f}{\partial^2 y}(x,y)$$

$$H(u,v) = -(u^2 + v^2)$$

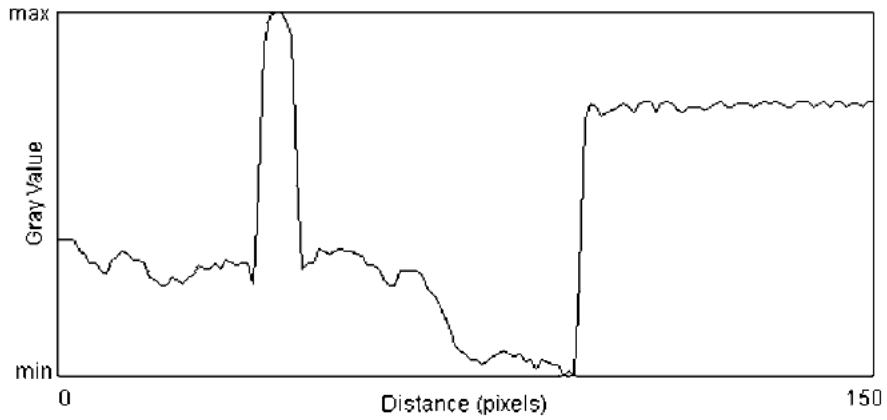




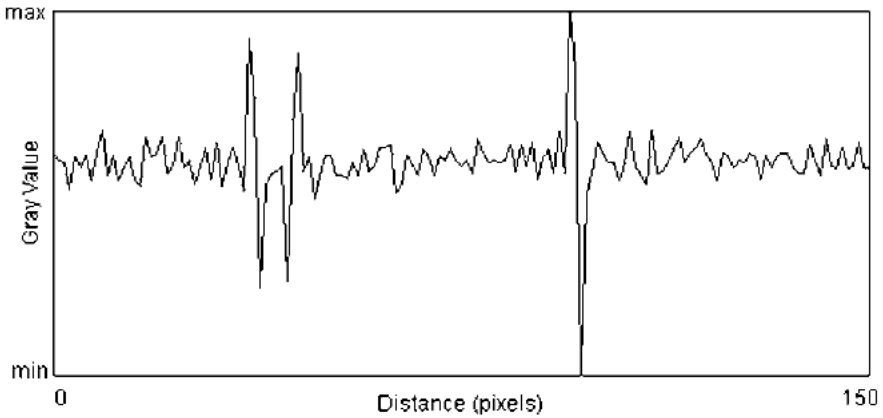
$$\hat{f}(x,y) = f(x,y) - \alpha\nabla^2 f(x,y)$$

$$\hat{F}(u,v) = [1 + \alpha(u^2 + v^2)]F(u,v)$$

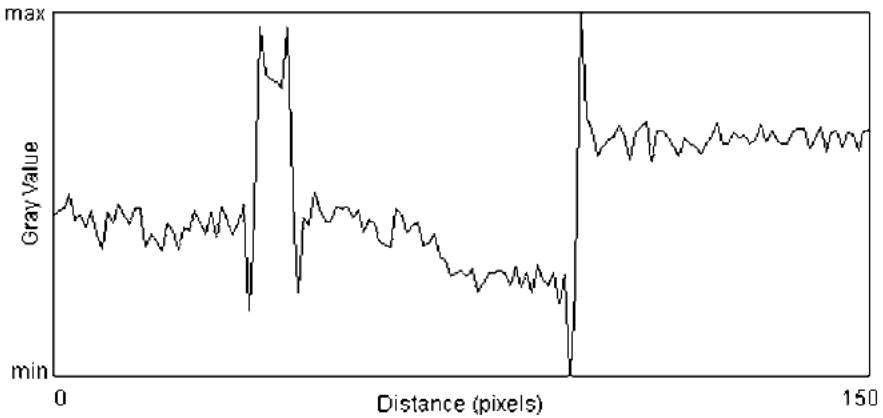
f



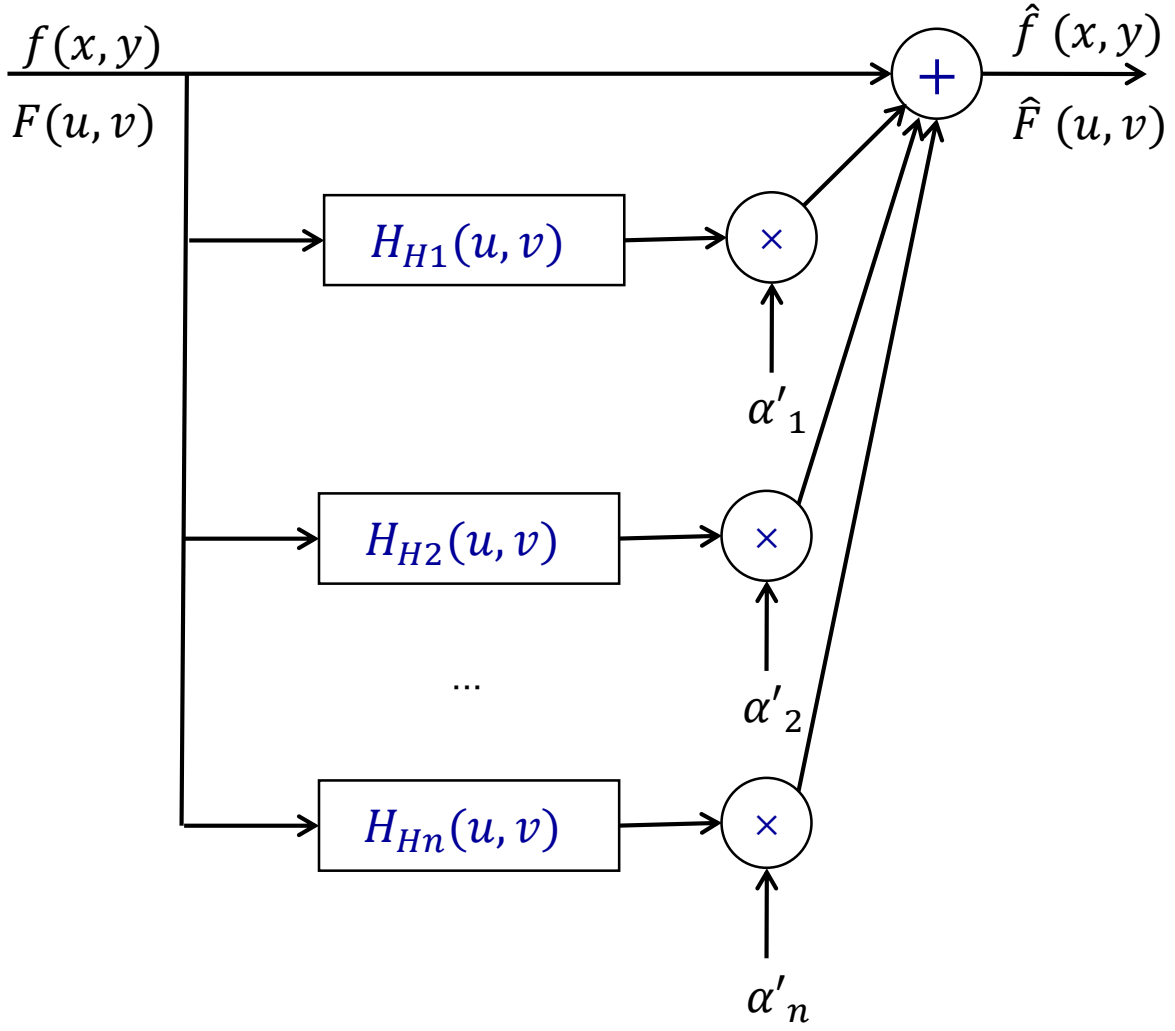
$\nabla^2 f$



$f - \nabla^2 f$



多分辨Unsharp Masking



同态滤波器（Homomorphic Filter)

Retinex　对比度增强算法

光反射模型：　$I(x,y) = L(x,y)R(x,y)$

反射系数（高频，有效信息）

光源（低频，无效信息）

$$logI(x,y) = logL(x,y) + logR(x,y)$$