Winter in Kraków photographed by Marcin Ryczek

边缘检测 Edge Detection

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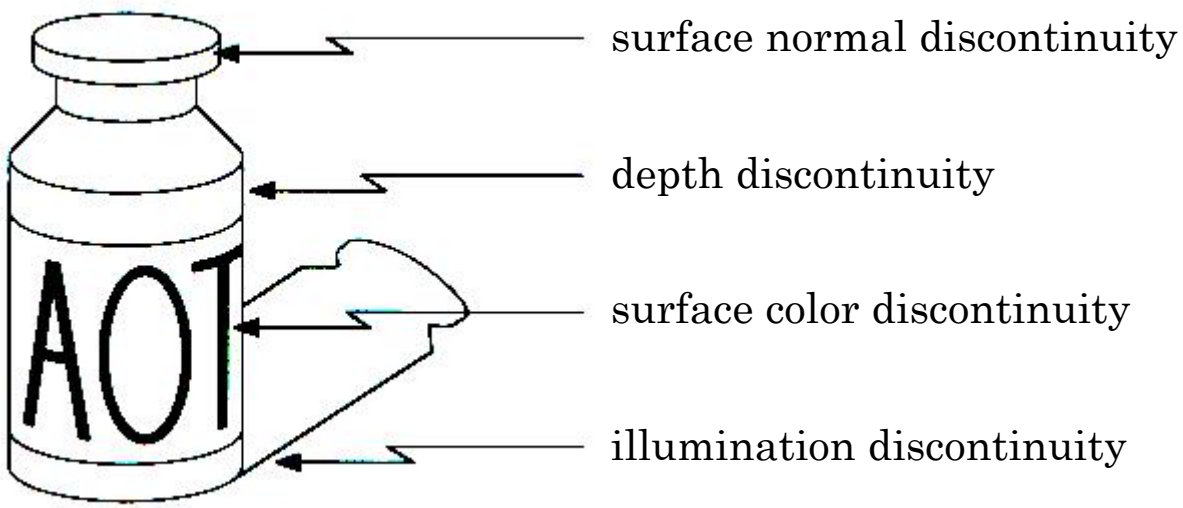
边缘检测 Edge detection

- **检测突变 Goal: Identify sudden changes (discontinuities) in an image**
- **Intuitively, edges carry most of the semantic and shape information from the image 直观上，边缘携带了图像中的语义、形状信息**



Sources: D. Lowe and S. Seitz

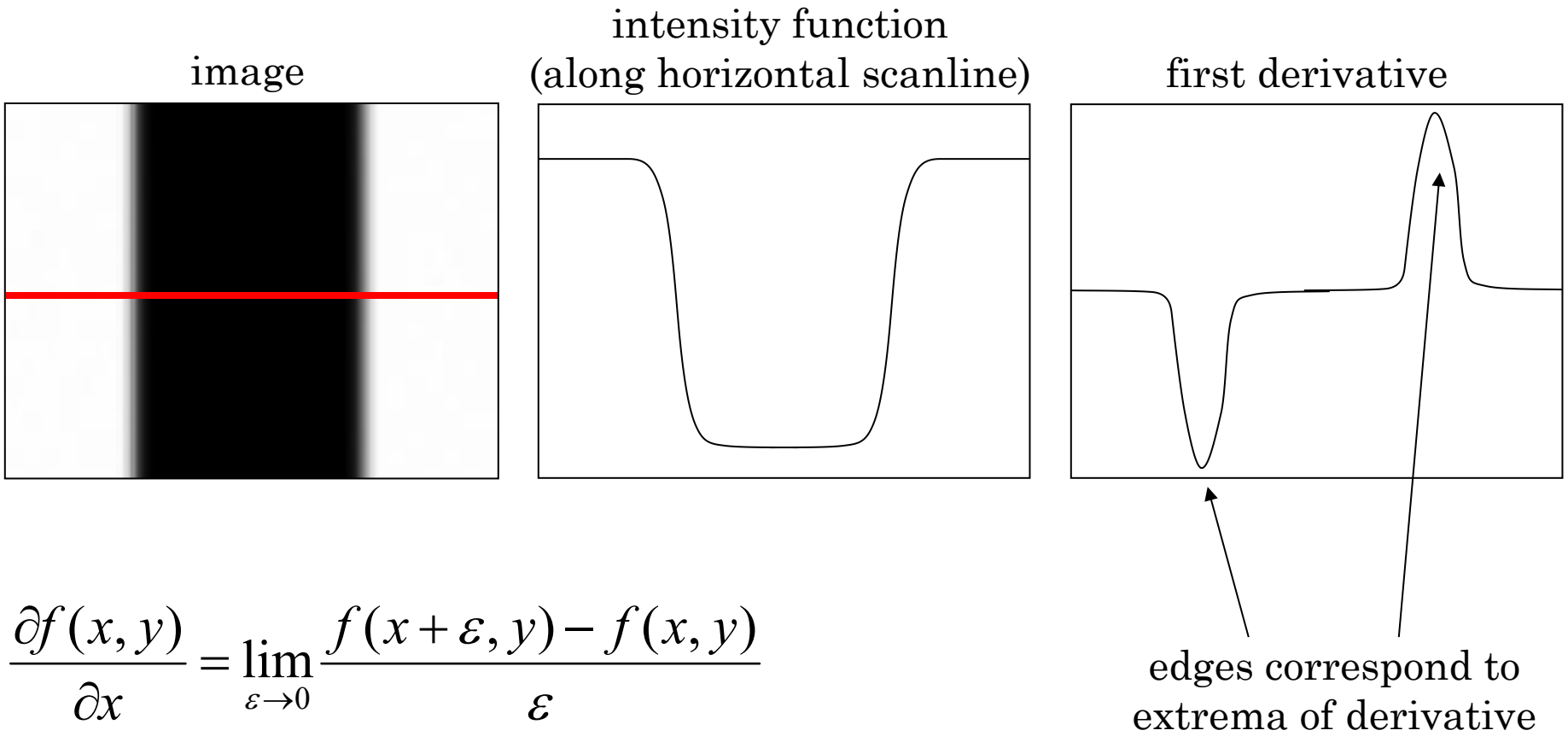
边缘检测 Edge detection

- **Ideal: artist's line drawing**

- **Reality:**

边缘检测 Edge detection

- **An edge is a place of rapid change in the image intensity function**
  - 边缘为图像中亮度函数剧烈变化的地方



$$\frac{\partial f(x,y)}{\partial x} = \lim_{\varepsilon \to 0} \frac{f(x+\varepsilon, y) - f(x,y)}{\varepsilon}$$

卷积微分 Derivatives with convolution

- **二维函数偏导 For 2D function f(x,y), the partial derivative is:**

$$\frac{\partial f(x,y)}{\partial x} = \lim_{\varepsilon \to 0} \frac{f(x+\varepsilon, y) - f(x,y)}{\varepsilon}$$

- **离散形式 For discrete data, we can approximate using finite differences:**

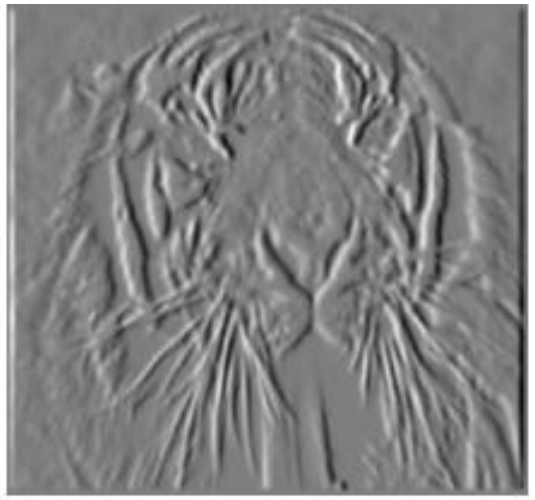
$$\frac{\partial f(x,y)}{\partial x} \approx \frac{f(x+1, y) - f(x,y)}{1}$$

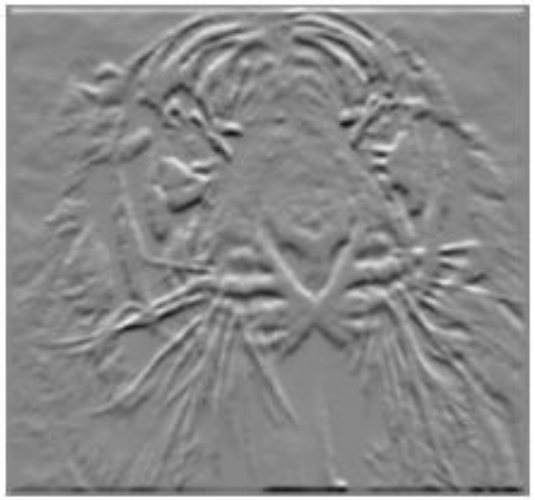
- **滤波器形式? To implement the above as convolution, what would be the associated filter?**

Source: K. Grauman

图像偏微分 Partial derivatives of an image

$$\frac{\partial f(x,y)}{\partial x}$$





$$\frac{\partial f(x,y)}{\partial y}$$

-1	1

-1
1

or

1
-1

Which shows changes with respect to x?

有限差分滤波 Finite difference filters

- **Sobel模板算子**

-1	-2	-1
0	0	0
1	2	1

水平

-1	0	1
-2	0	2
-1	0	1

垂直

0	1	2
-1	0	1
-2	-1	0

-2	-1	0
-1	0	1
0	1	2

对角线

- **Prewitt模板算子**

-1	-1	-1
0	0	0
1	1	1

水平

-1	0	1
-1	0	1
-1	0	1

垂直

0	1	1
-1	0	1
-1	-1	0

-1	-1	0
-1	0	1
0	1	1

对角线

有限差分滤波 Finite difference filters

- **拉普拉斯算子**

- **图像增强**

$$g(x,y) = f(x,y) + c[\nabla^2 f(x,y)]$$

  - 采用(a)或(b)时，c=-1
  - 采用(c)或(d)时，c=1

w=fspecial('laplacian',0)

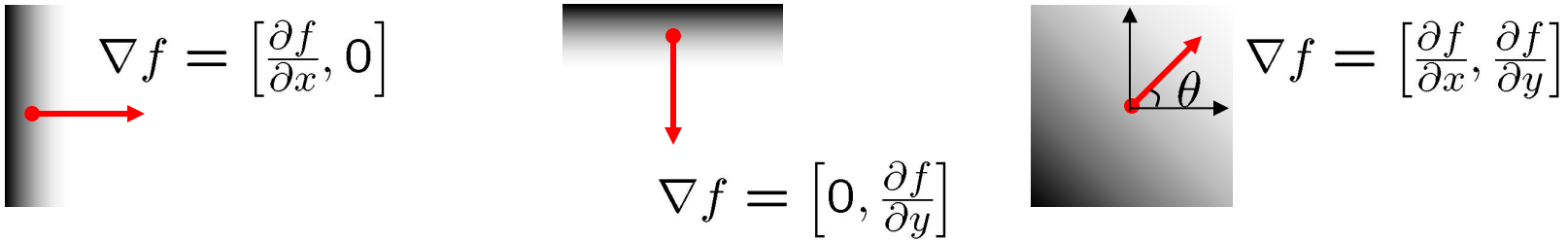
0	1	0	1	1	1
1	−4	1	1	−8	1
0	1	0	1	1	1
0	−1	0	−1	−1	−1
−1	4	−1	−1	8	−1
0	−1	0	−1	−1	−1

a b
c d

FIGURE 3.37
(a) Filter mask used to implement Eq. (3.6-6).
(b) Mask used to implement an extension of this equation that includes the diagonal terms.
(c) and (d) Two other implementations of the Laplacian found frequently in practice.

图像梯度 Image gradient

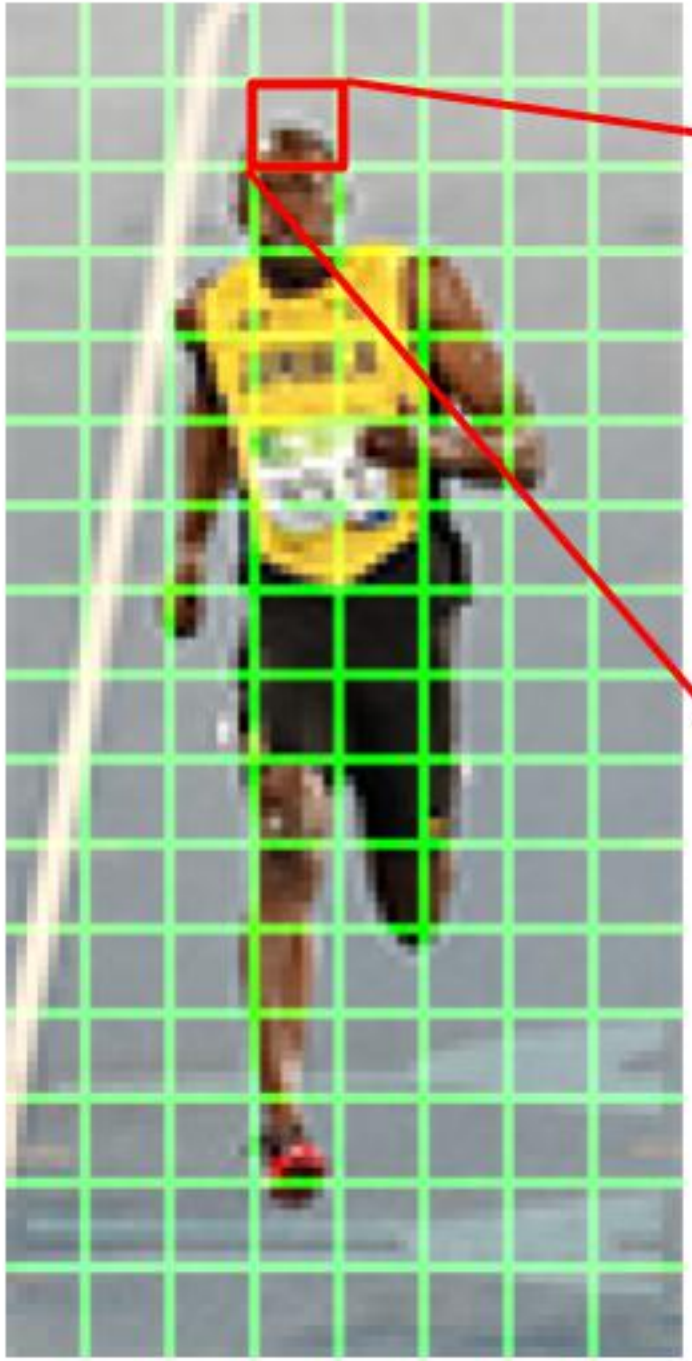
- **图像梯度 The gradient of an image:** $\nabla f = \left[\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right]$



- **The gradient points in the direction of most rapid increase in intensity**
  - How does this direction relate to the direction of the edge?
  - 梯度方向 The gradient direction is given by $\theta = \tan^{-1}\left(\frac{\partial f}{\partial y} / \frac{\partial f}{\partial x}\right)$
  - 梯度幅度 The edge strength is given by the gradient magnitude

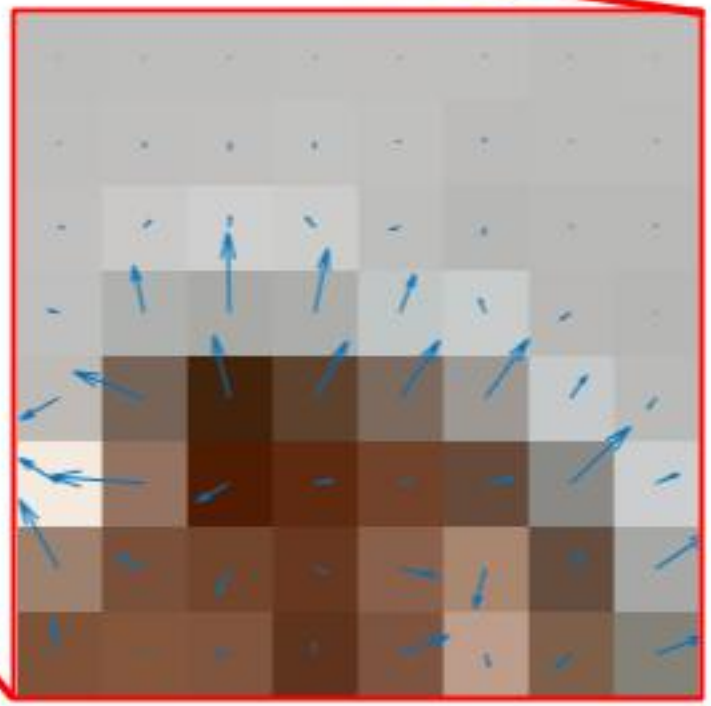
$$\|\nabla f\| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

Source: Steve Seitz



中间：一个网格用箭头表示梯度

右边：这个网格用数字表示的梯度



箭头是梯度的方向

长度是梯度的大小

2	3	4	4	3	4	2	2
5	11	17	13	7	9	3	4
11	21	23	27	22	17	4	6
23	99	165	135	85	32	26	2
91	155	133	136	144	152	57	28
98	196	76	38	26	60	170	51
165	60	60	27	77	85	43	136
71	13	34	23	108	27	48	110

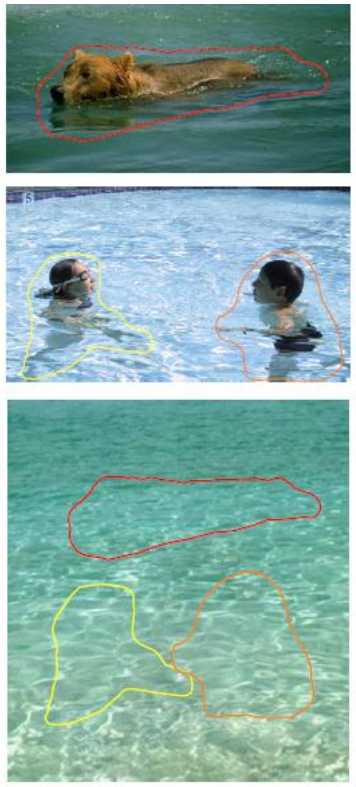
Gradient Magnitude

80	36	5	10	0	64	90	73
37	9	9	179	78	27	169	166
87	136	173	39	102	163	152	176
76	13	1	168	159	22	125	143
120	70	14	150	145	144	145	143
58	86	119	98	100	101	133	113
30	65	157	75	78	165	145	124
11	170	91	4	110	17	133	110

Gradient Direction

Application: Gradient-domain image editing 图像编辑

- **Goal: solve for pixel values in the target region to match gradients of the source region while keeping background pixels the same**



sources/destinations

cloning

seamless cloning

P. Perez, M. Gangnet, A. Blake, Poisson Image Editing, SIGGRAPH 2003

Application: Enhancment

- **拉普拉斯算子**

$$\frac{\partial^2 f}{\partial x^2} = f''(x) = f(x+1) + f(x-1) - 2f(x)$$

思考：为什么这个模板有锐化的性质?

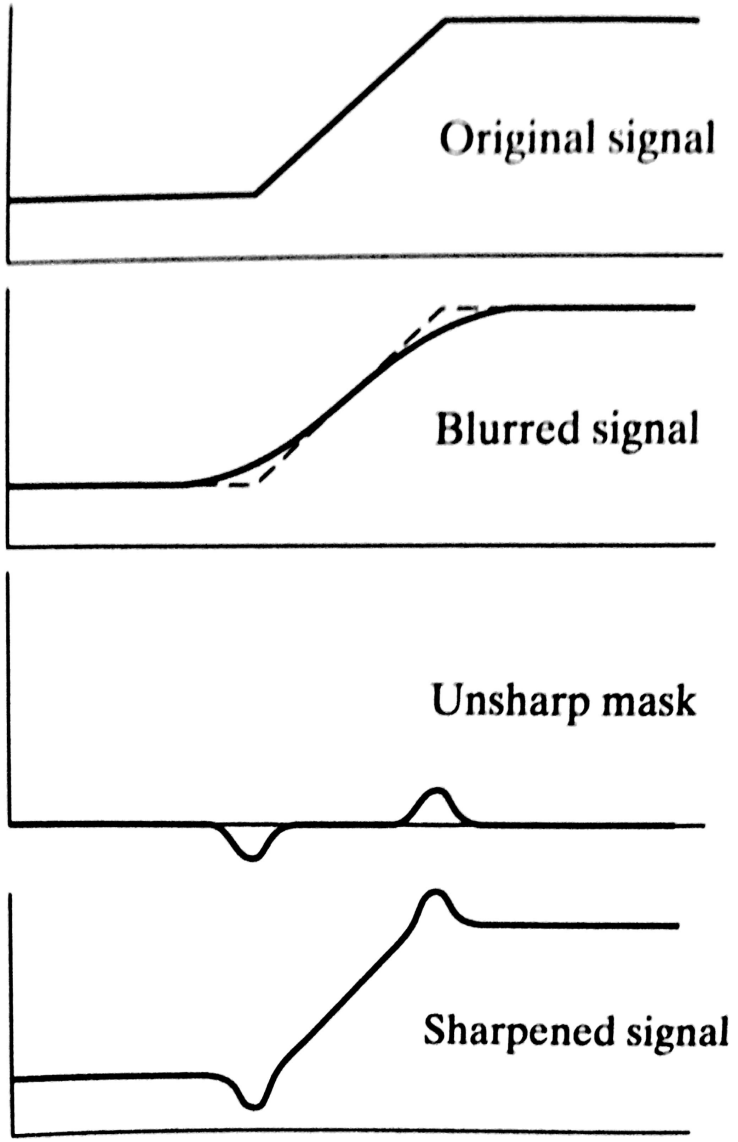
Application: Enhancment

- **Unsharp Masking and Highboost Filtering (图3.39,3.40)**

$$g_{mask}(x,y) = f(x,y) - \bar{f}(x,y)$$

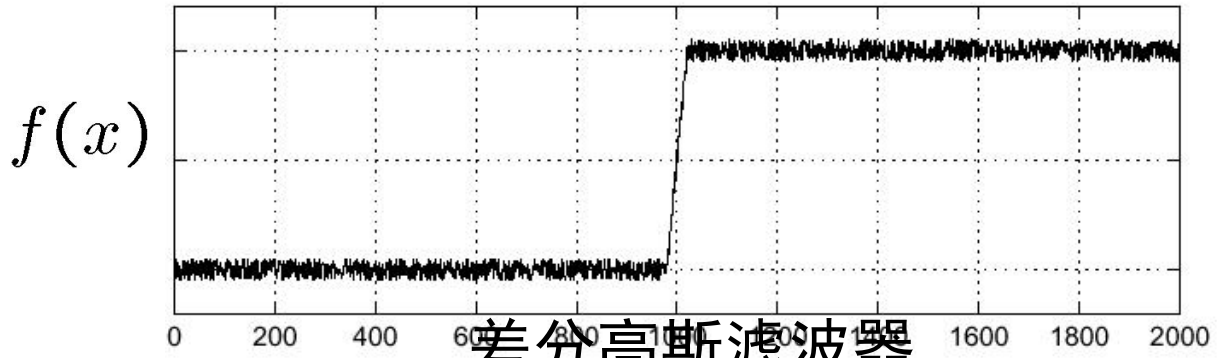
$$g(x,y) = f(x,y) + k * g_{mask}(x,y)$$

  - 权重：$k \geq 0$
  - Unsharp Masking： $k = 1$
  - Highboost Filtering： $k > 1$
  - $k < 1$ de-emphasizes the contribution of unsharp masking.

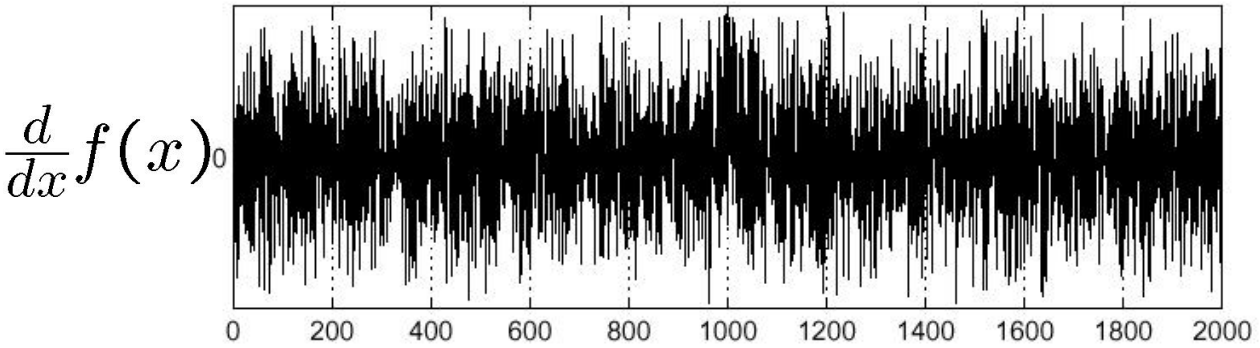


噪声影响 Effects of noise

- **考虑的图像的某一行或列 Consider a single row or column of the image**



差分高斯滤波器



Where is the edge?

Source: S. Seitz

有限差分

- **给定图像$\mathcal{I}$，梯度定义为**

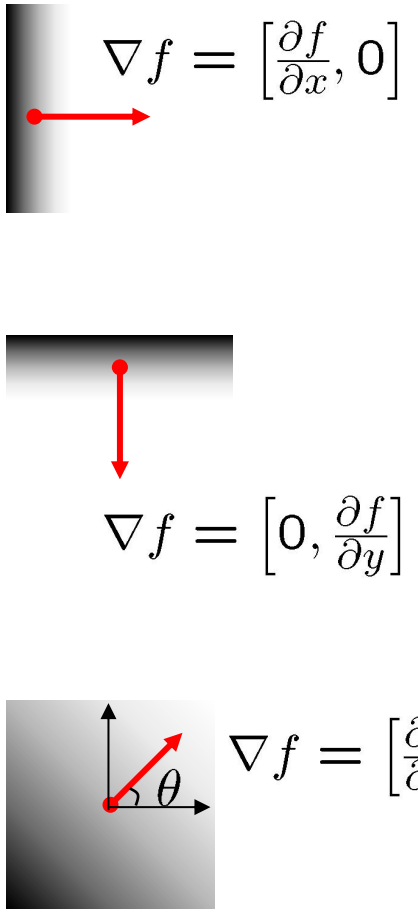
$$(\frac{\partial \mathcal{I}}{\partial x}, \frac{\partial \mathcal{I}}{\partial y})^T$$

  - 可以通过观察得到

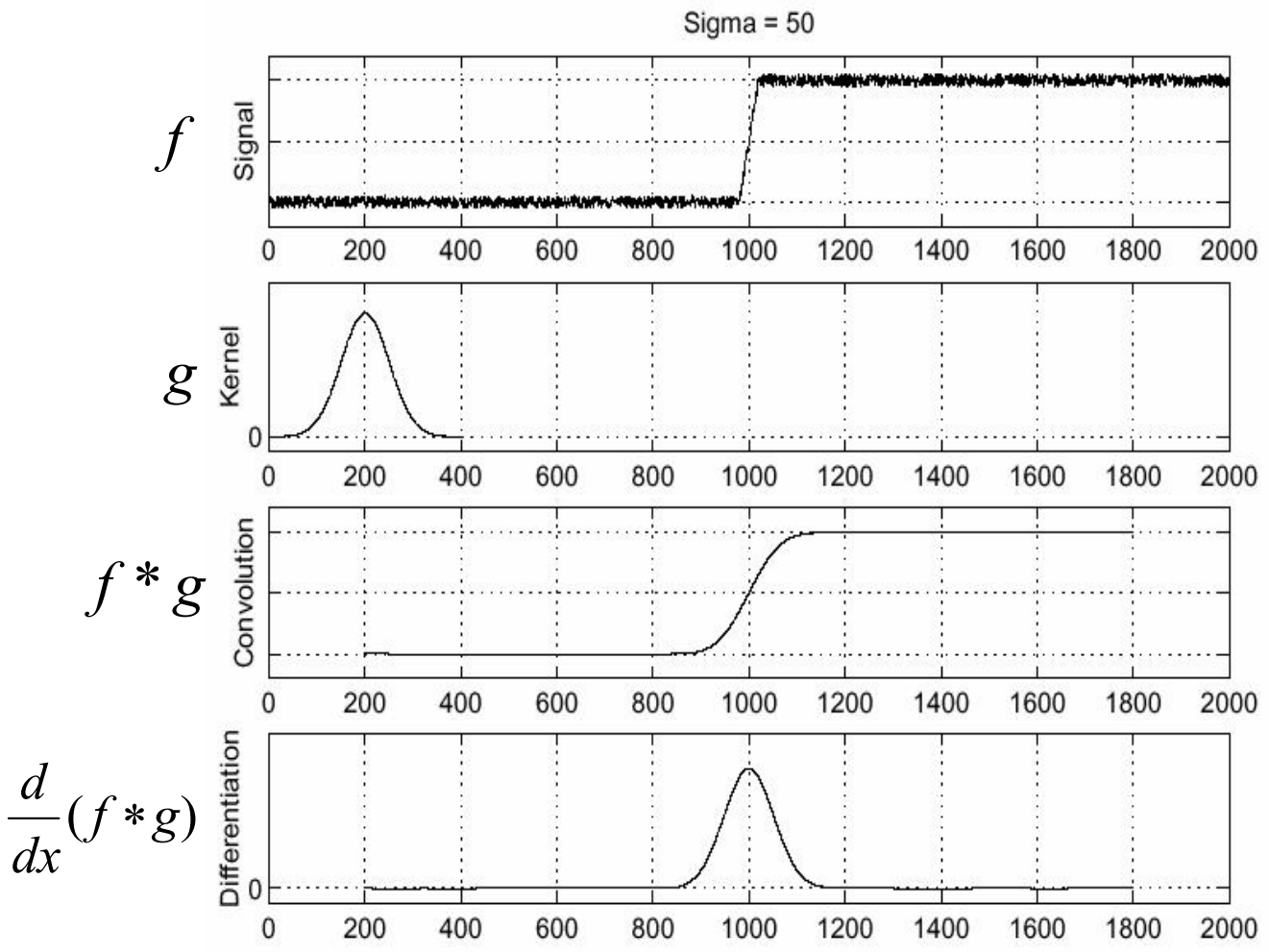
$$\frac{\partial \mathcal{I}}{\partial x} \approx \mathcal{I}_{i+1,j} - \mathcal{I}_{i,j}$$

$$\frac{\partial \mathcal{I}}{\partial y} \approx \mathcal{I}_{i,j+1} - \mathcal{I}_{i,j}$$

  - 这种微分的估计称为“有限差分”（finite difference）
  - 对噪声的反应敏感。



Solution: smooth first 先平滑



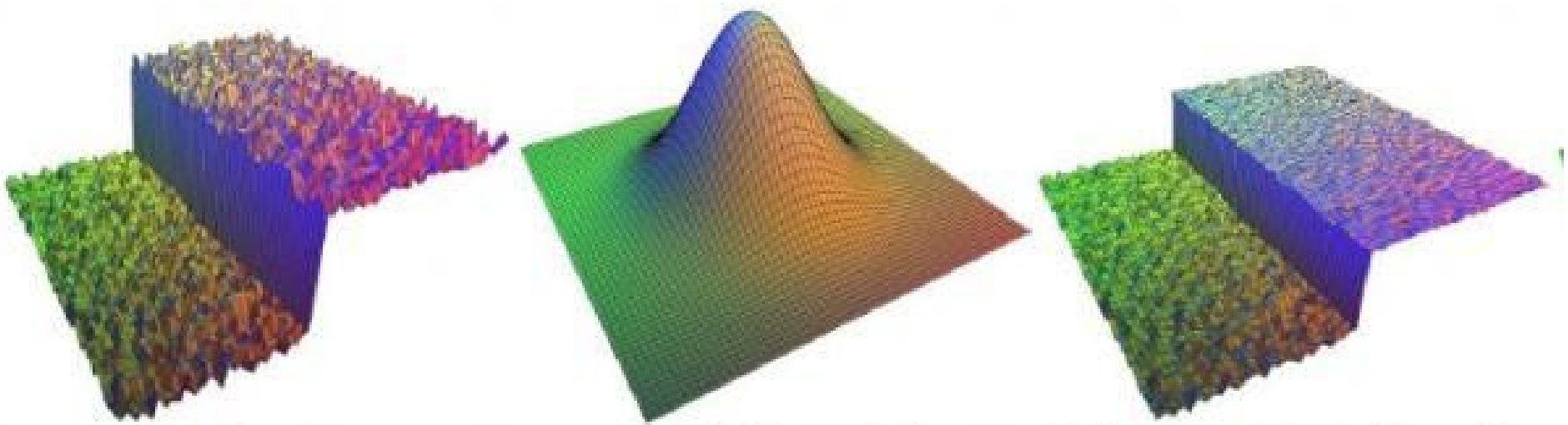
- **To find edges, look for peaks in** $\frac{d}{dx}(f * g)$

Source: S. Seitz

差分高斯滤波器 Derivative of Gaussian filters

- **先进行高斯模糊，然后计算差分**

$$p(x;\mu,\Sigma) = \frac{1}{(2\pi)^{n/2}|\Sigma|^{1/2}} \exp\left(-\frac{1}{2}(x-\mu)^T\Sigma^{-1}(x-\mu)\right).$$



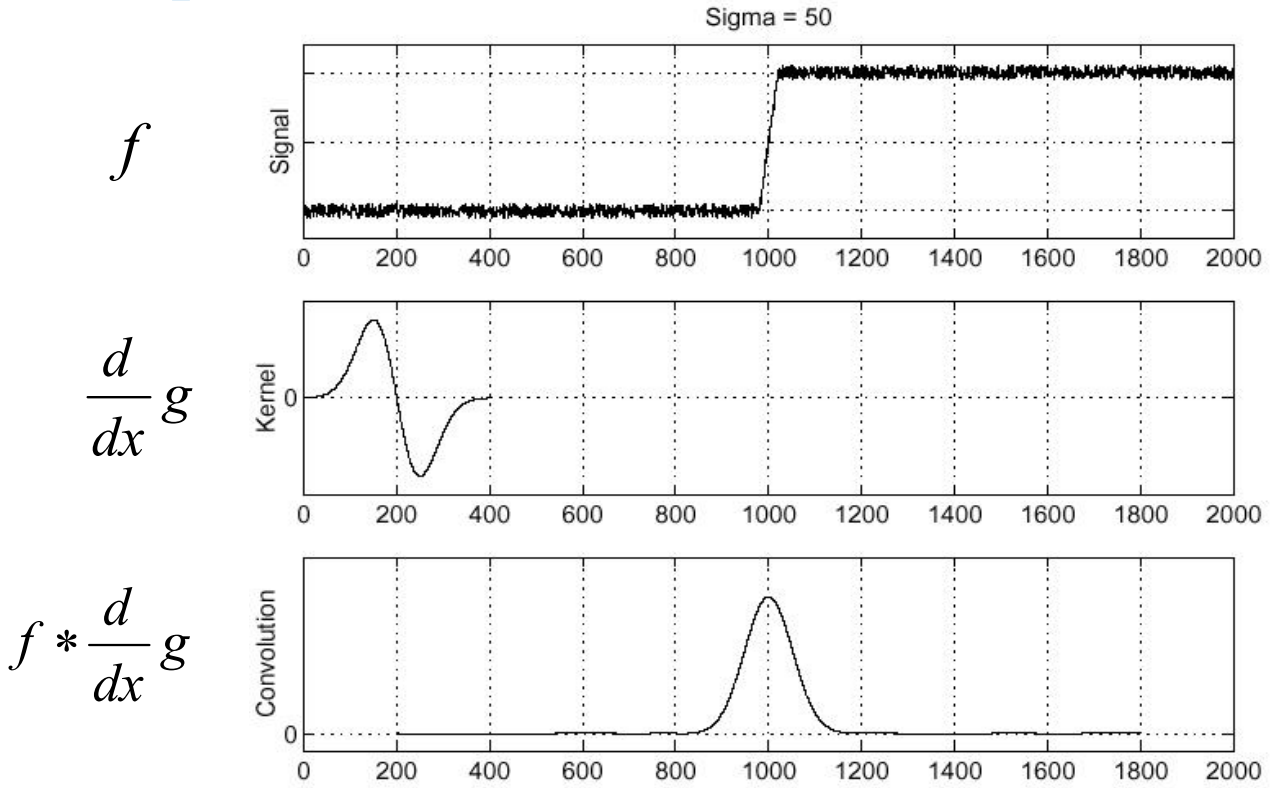
input　　spatial kernel f　　influence g in the intensity domain for the central pixel

卷积的微分定理 Derivative theorem of convolution

- **Differentiation is convolution, and convolution is associative:**
  - 微分是卷积

$$\frac{d}{dx}(f*g)=f*\frac{d}{dx}g$$

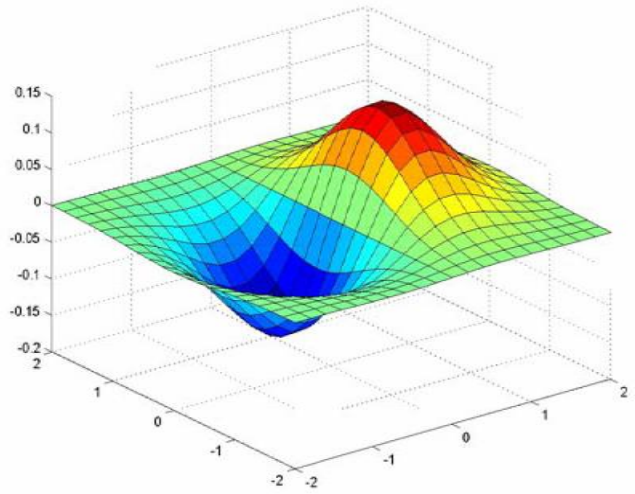
- **This saves us one operation:**



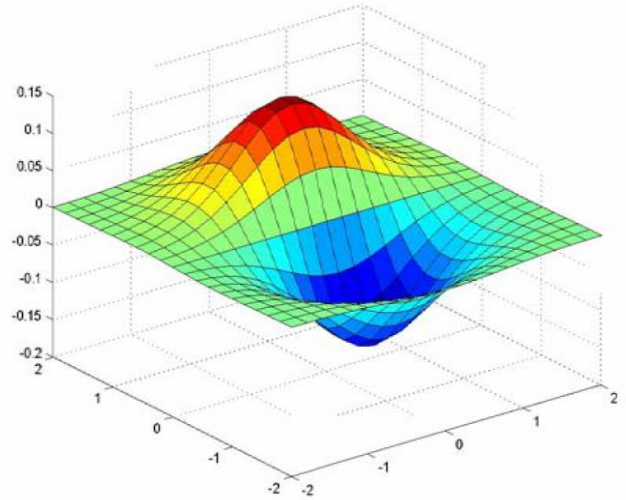
Source: S. Seitz

差分高斯滤波器 Derivative of Gaussian filters

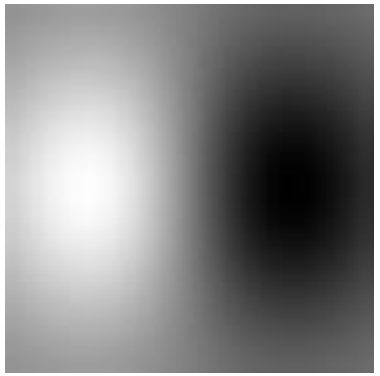
- **哪个提取水平/垂直边缘 Which one finds horizontal/vertical edges?**

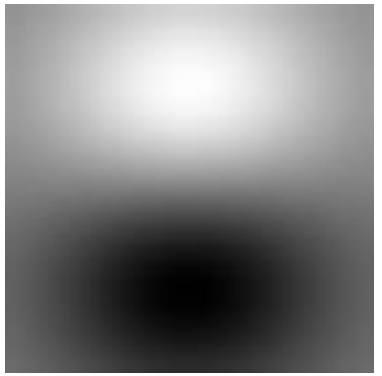


x-direction



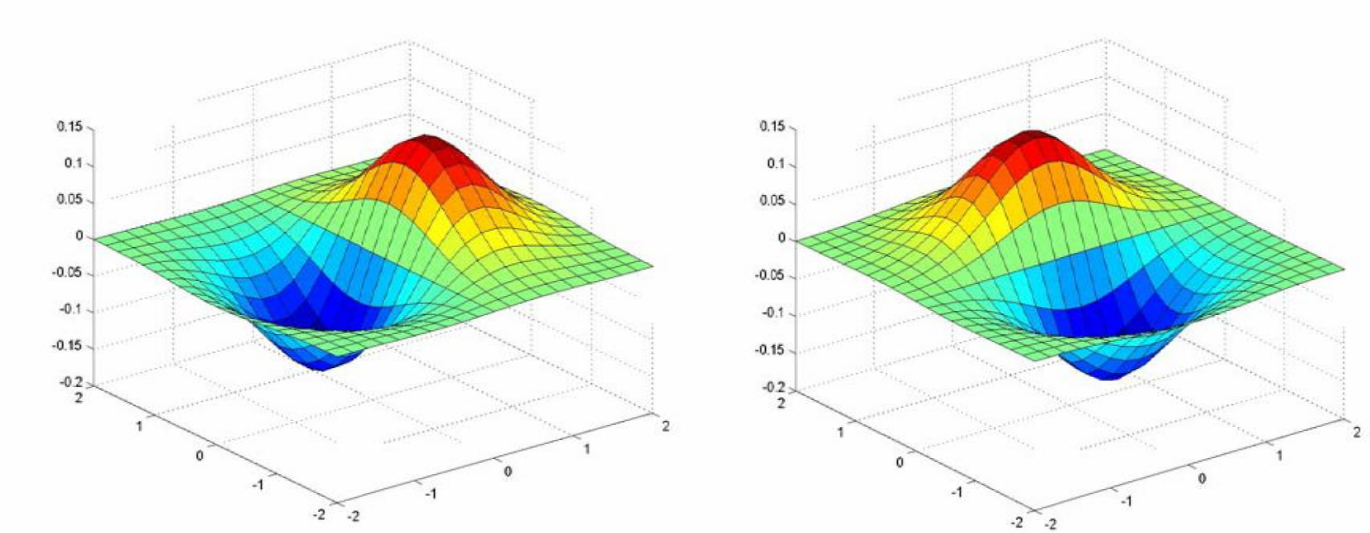
y-direction





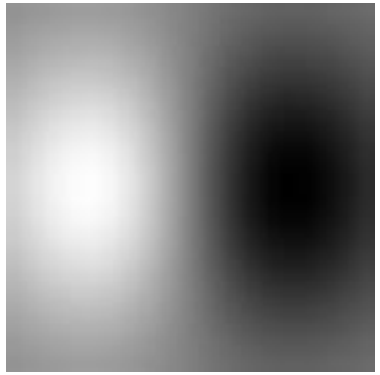
差分高斯滤波器 Derivative of Gaussian filters

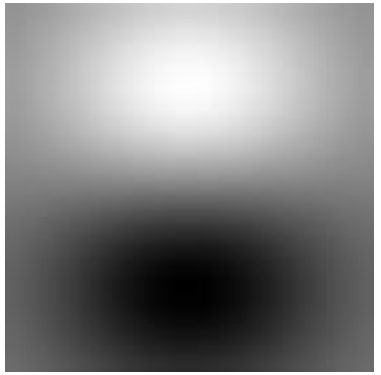
- **是否可分 Are these filters separable?**



x-direction

y-direction





Recall: Separability of the Gaussian filter 可分离性

$$G_\sigma(x,y) = \frac{1}{2\pi\sigma^2}\exp^{-\frac{x^2+y^2}{2\sigma^2}}$$

$$= \left(\frac{1}{\sqrt{2\pi}\sigma}\exp^{-\frac{x^2}{2\sigma^2}}\right)\left(\frac{1}{\sqrt{2\pi}\sigma}\exp^{-\frac{y^2}{2\sigma^2}}\right)$$

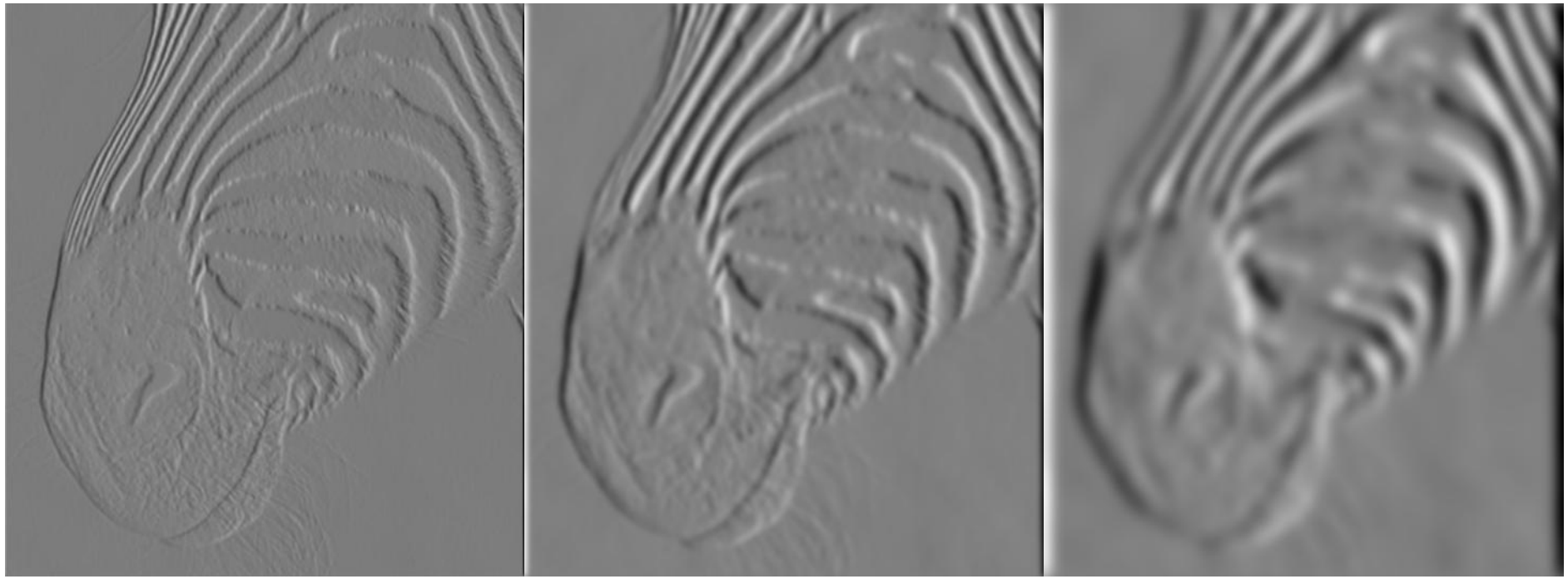
The 2D Gaussian can be expressed as the product of two functions, one a function of x and the other a function of y

In this case, the two functions are the (identical) 1D Gaussian

Source: D. Lowe

差分高斯滤波尺度 Scale of Gaussian derivative filter

- **Smoothed derivative removes noise, but blurs edge. Also finds edges at different "scales"**

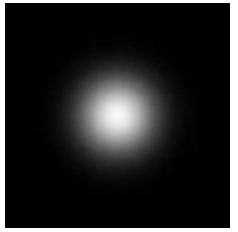


1 pixel　　3 pixels　　7 pixels

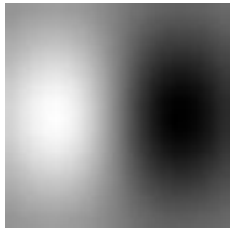
Source: D. Forsyth

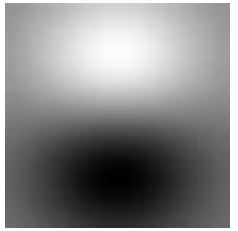
Review: Smoothing vs. derivative filters

- **平滑滤波器 Smoothing filters**
  - 高斯Gaussian: remove “high-frequency” components; “low-pass” filter
  - Can the values of a smoothing filter be negative? 是否可以负数?
  - What should the values sum to? 和是多少?
    - One: constant regions are not affected by the filter



- **差分滤波器 Derivative filters**
  - Derivatives of Gaussian 差分高斯
  - Can the values of a derivative filter be negative? 是否负数?
  - What should the values sum to? 和是多少?
    - Zero: no response in constant regions





构建边缘检测器 Building an edge detector

original image

final output

构建边缘检测器 Building an edge detector

norm of the gradient 梯度标准化

构建边缘检测器 Building an edge detector

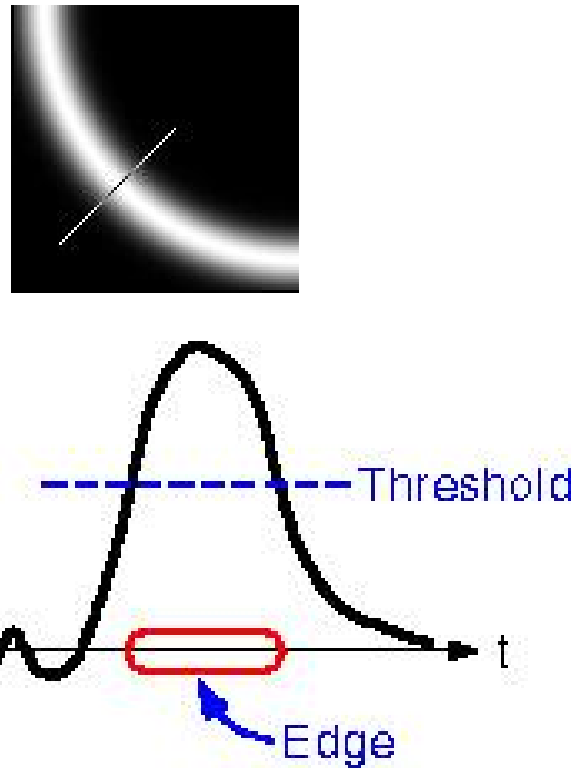
How to turn these thick regions of the gradient into curves?

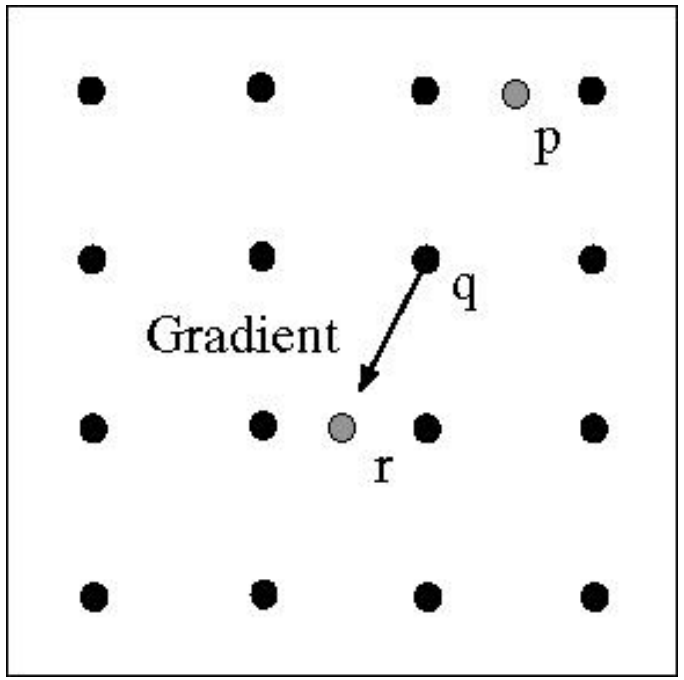
如何将宽的梯度区域转换成曲线？

Thresholded norm of the gradient

阈值过滤后的梯度标准化

非最大抑制 Non-maximum suppression





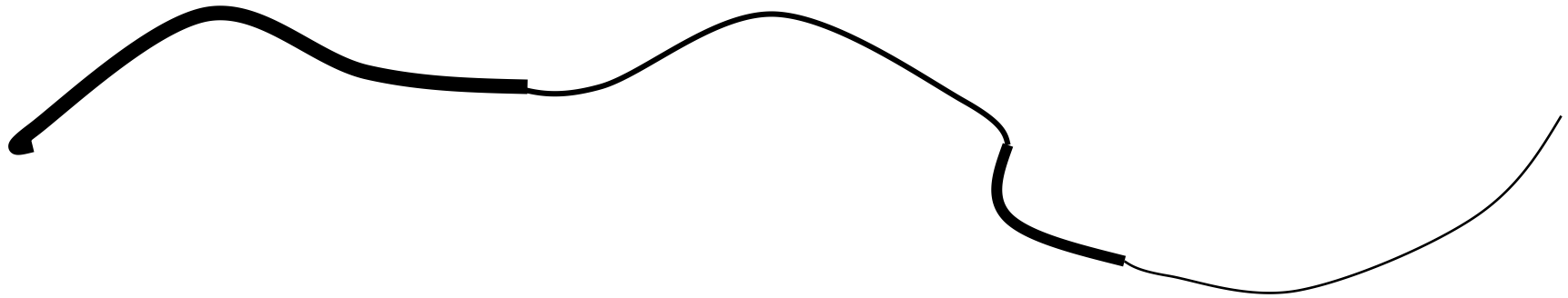
- **For each location q above threshold, check that the gradient magnitude is higher than at neighbors p and r along the direction of the gradient**
  - May need to interpolate to get the magnitudes at p and r

非最大抑制 Non-maximum suppression

Another problem: pixels along this edge didn't survive the thresholding

迟滞阈值化 Hysteresis thresholding

- **Use a high threshold to start edge curves, and a low threshold to continue them.**
  - 使用高阈值检测边缘起点；使用低阈值使边缘连续



Source: Steve Seitz

迟滞阈值化 Hysteresis thresholding

original image

high threshold
(strong edges)

low threshold
(weak edges)

hysteresis threshold

Source: L. Fei-Fei

Recap: Canny edge detector

1. **Compute x and y gradient images 计算两个方向的梯度**
2. **Find magnitude and orientation of gradient 计算梯度幅度和方向**
3. **Non-maximum suppression: 非最大化抑制**
   - Thin wide "ridges" down to single pixel width
4. **Linking and thresholding (hysteresis): 迟滞阈值化**
   - Define two thresholds: low and high
   - Use the high threshold to start edge curves and the low threshold to continue them

J. Canny, A Computational Approach To Edge Detection, IEEE Trans. Pattern Analysis and Machine Intelligence, 8:679-714, 1986.

Recap: Canny edge detector

1. Compute x and y gradient images 计算两个方向的梯度
2. Find magnitude and orientation of gradient 计算梯度幅度和方向
3. Non-maximum suppression: 非最大化抑制
4. Linking and thresholding (hysteresis): 迟滞阈值化

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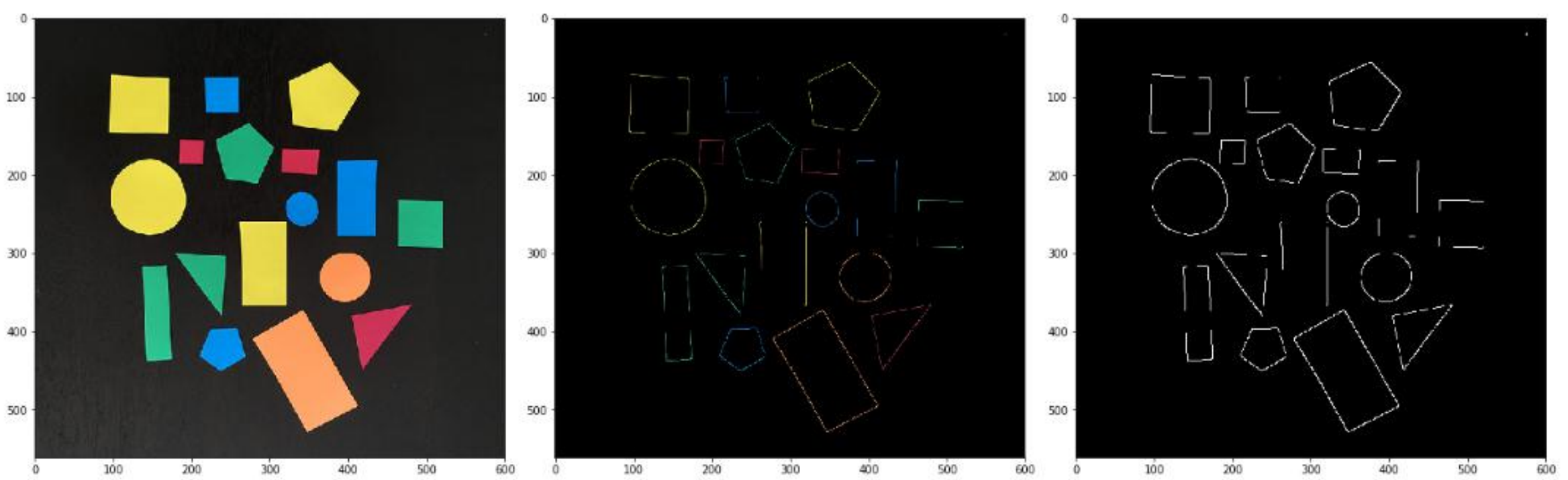
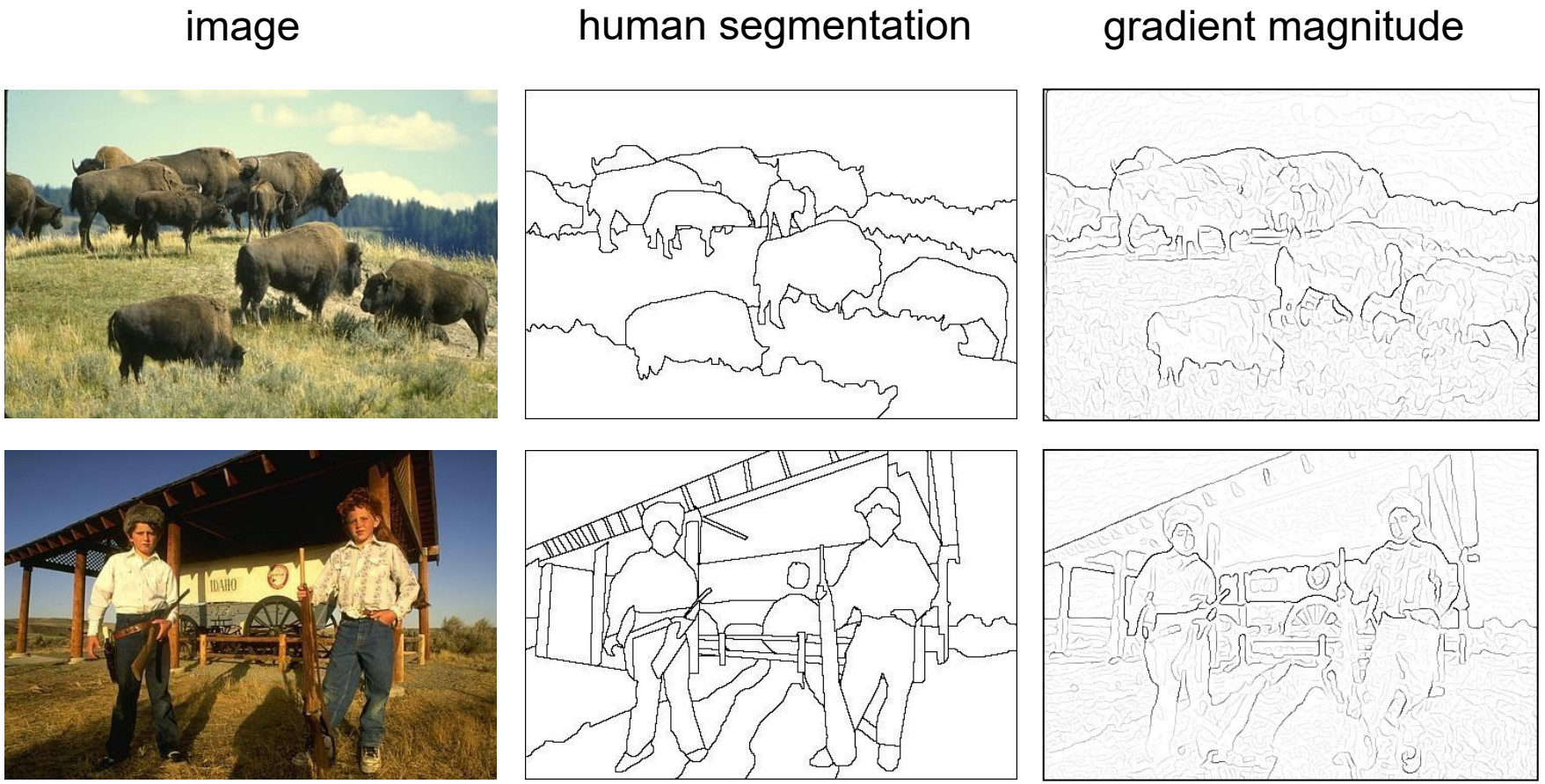
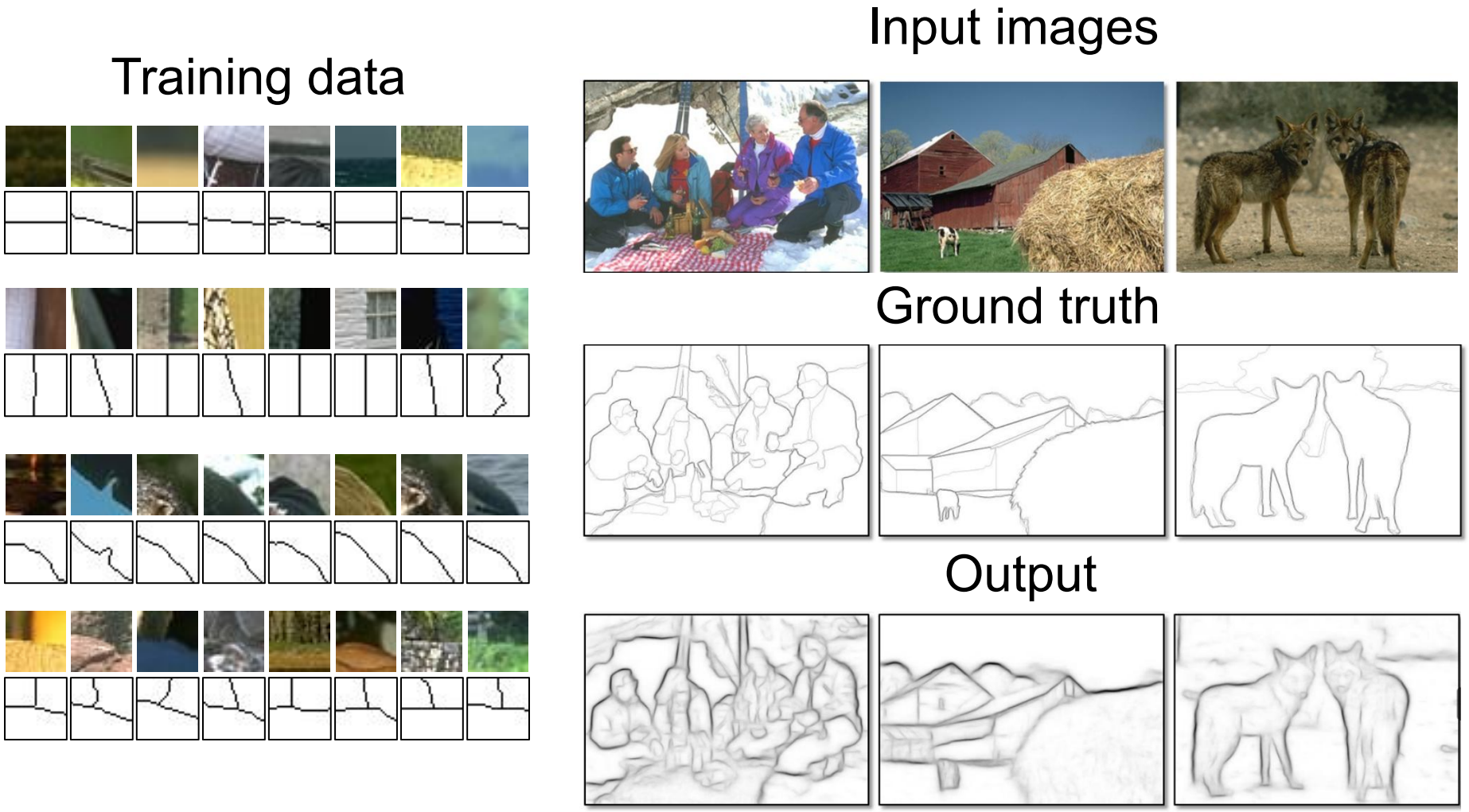


Image gradients vs. meaningful contours

- **Berkeley segmentation database**

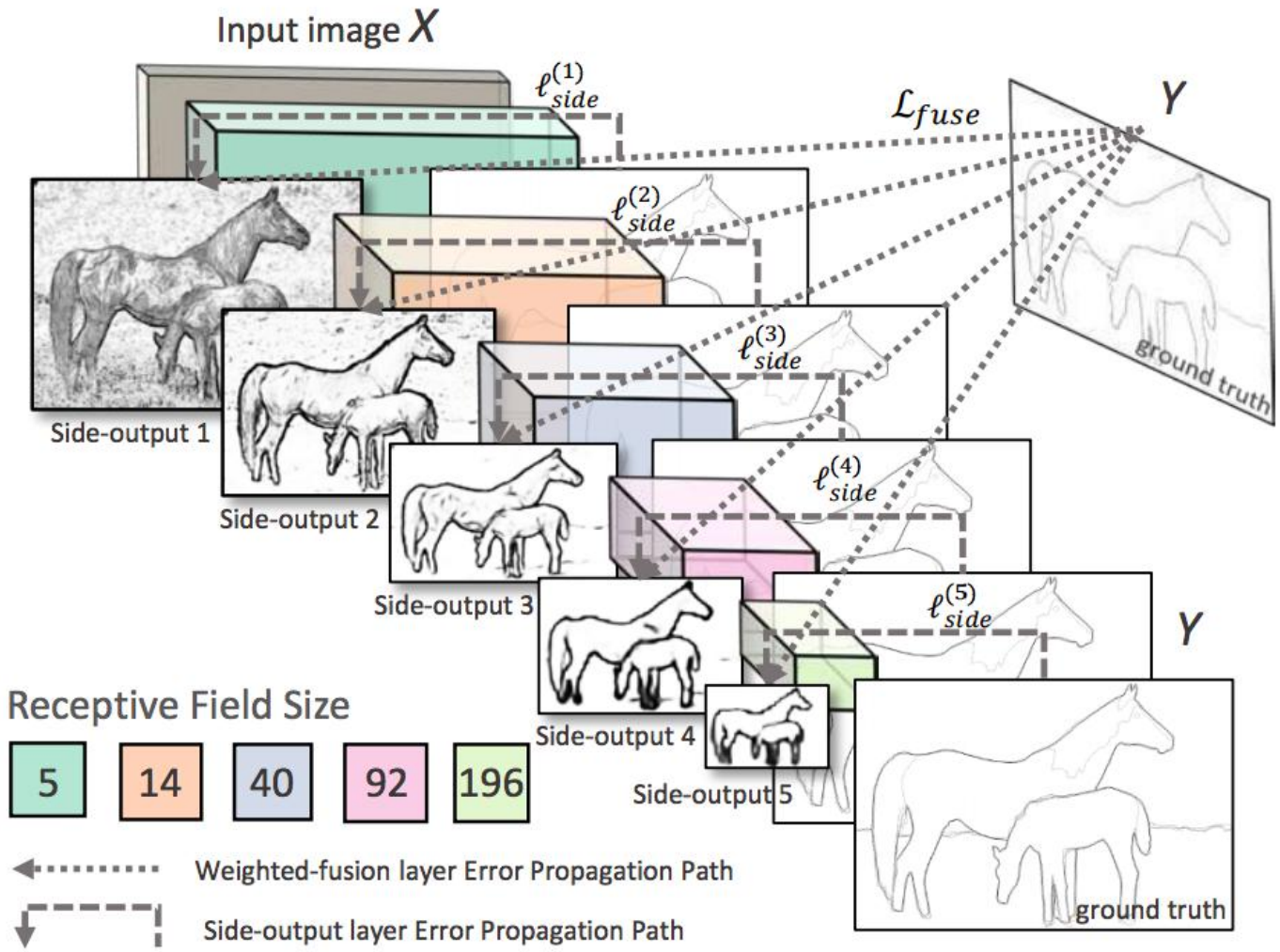


数据驱动的边缘检测 Data-driven edge detection



P. Dollar and L. Zitnick, Structured forests for fast edge detection, ICCV 2013

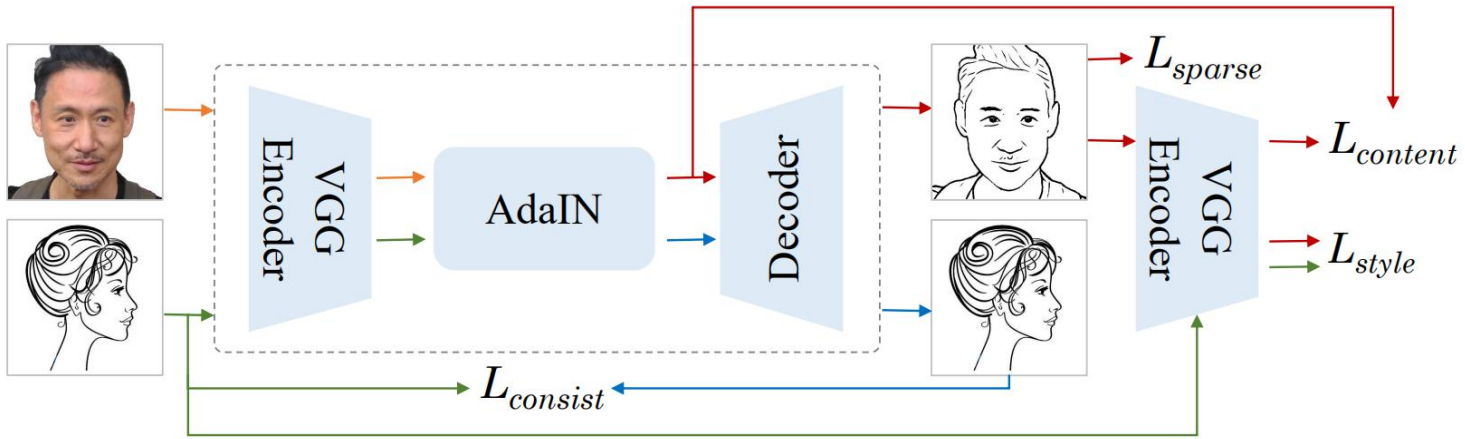
数据驱动的边缘检测 Data-driven edge detection

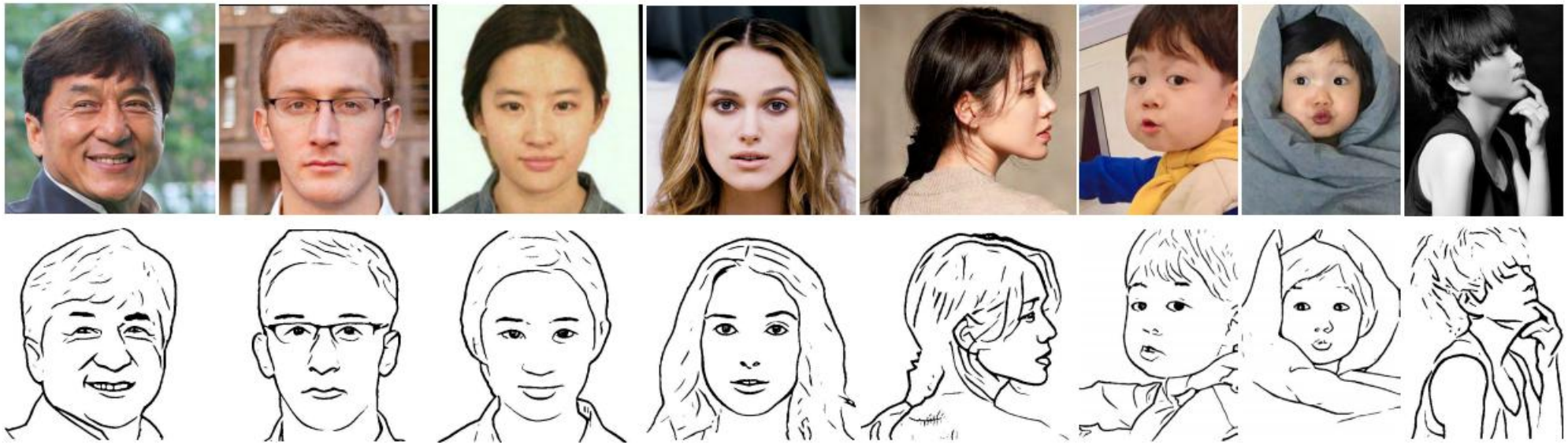


S. Xie and Z. Tu, Holistically-nested edge detection, ICCV 2015

边缘检测作为风格迁移？

Ours





Thank You !

Q & A

Who is she?

- **Lenna**
  - 为什么用这幅图（戴维·C·蒙森）？
    - 1.该图适度的混合了细节、平滑区域、阴影和纹理，从而能很好的测试各种图像处理算法。
    - 2.Lenna是个美女，对于图象处理界的研究者来说，美女图可以有效的吸引他们来做研究。

  - 故事是这样子的
    - 该图原本是刊于1972年11月号花花公子杂志上的一张裸体插图照片的一部分，这期花花公子也是历年来最畅销的一期，销量达7,161,561本。
    - 1973 年6月，美国南加州大学的信号图像处理研究所的一个助理教授和他的一个研究生打算为了一个学术会议找一张数字照片……