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What is Vision?

"Vision is the act of knowing what is where by looking." --Aristotle

Special emphasis: relationship between 3D world and a 2D image. Location and identity of objects.

What is Computer Vision?

It is related to, but not equivalent to:

- Photogrammetry
- Image Processing
- Artificial Intelligence

Why study Computer Vision?

- Images and movies are everywhere
- Fast-growing collection of useful applications
  - building representations of the 3D world from pictures
  - automated surveillance (who's doing what)
  - movie post-processing
  - face finding
- Various deep and attractive scientific mysteries
  - how does object recognition work?
- Greater understanding of human vision

Course Goals and Objectives

- Introduce the fundamental problems of computer vision.
- Introduce the main concepts and techniques used to solve those problems.
- Enable students to implement vision algorithms
- Enable students to make sense of the vision literature

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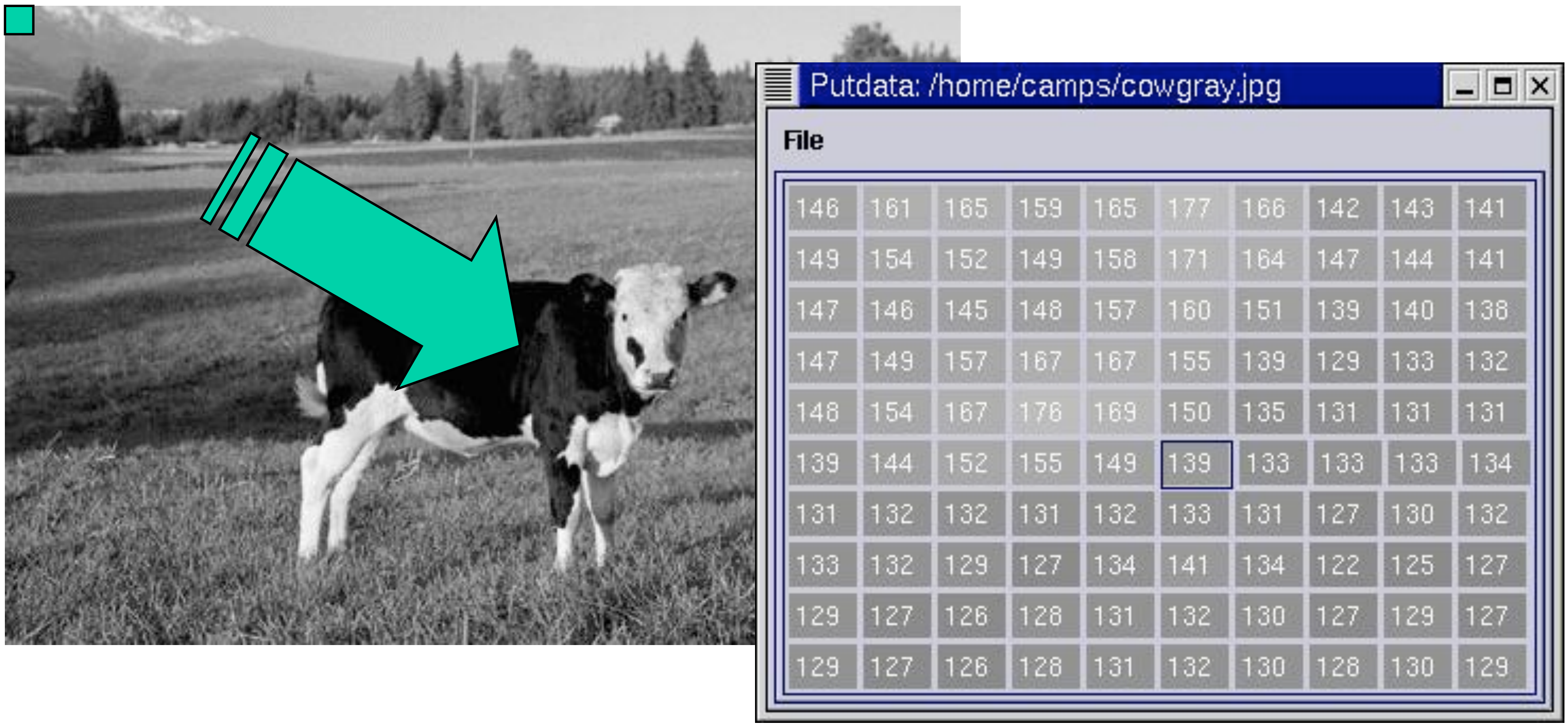
Input: Digital Images

2D arrays (matrices) of numbers:



146	161	165	159	165	177	166	142	143	141
149	154	152	149	158	171	164	147	144	141
147	146	145	148	157	160	151	139	140	138
147	149	157	167	167	155	139	129	133	132
148	154	167	176	169	150	135	131	131	131
139	144	152	155	149	139	133	133	133	134
131	132	132	131	132	133	131	127	130	132
133	132	129	127	134	141	134	122	125	127
129	127	126	128	131	132	130	127	129	127
129	127	126	128	131	132	130	128	130	129

If color image, we have 3 arrays - red, green, blue

Why is Computer Vision Hard?

We are trying to infer things about the world from an array of numbers

Putdata: /home/camps/cowgray.jpg

File

146	161	165	159	165	177	166	142	143	141
149	154	152	149	158	171	164	147	144	141
147	146	145	148	157	160	151	139	140	138
147	149	157	167	167	155	139	129	133	132
148	154	167	176	169	150	135	131	131	131
139	144	152	155	149	139	133	133	133	134
131	132	132	131	132	133	131	127	130	132
133	132	129	127	134	141	134	122	125	127
129	127	126	128	131	132	130	127	129	127
129	127	126	128	131	132	130	128	130	129

Shoulder of a cow…

problems: too local; lack of context; mismatch between levels of abstraction. But wait, it's even worse than that...

Why is Computer Vision Hard?

If we already know the geometry, surface material and lighting conditions, it is well-understood how to generate the value at each pixel. [this is Computer Graphics]

But this confluence of factors contributing to each pixel can not be easily decomposed. The process can not be inverted.

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tell me what you see...

Congratulations! You just did something mathematically impossible.

How?
You used assumptions based on prior knowledge / experience about the way the world works.

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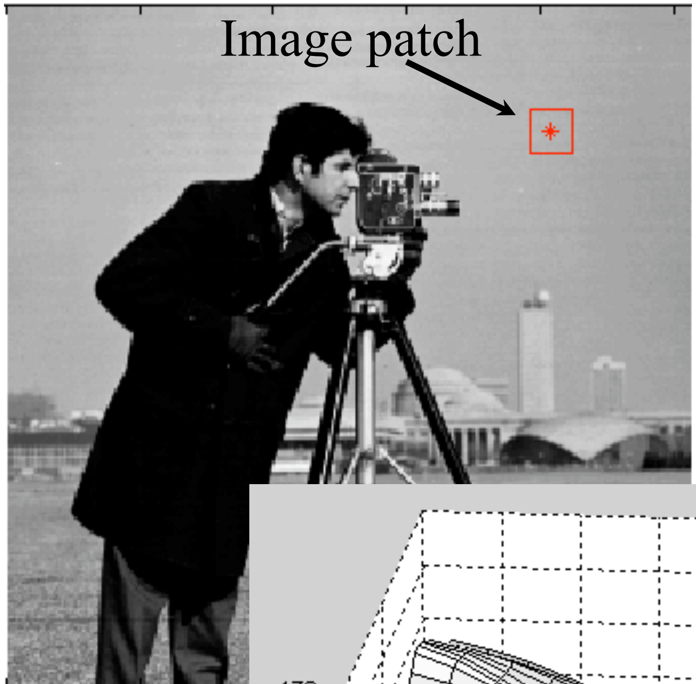
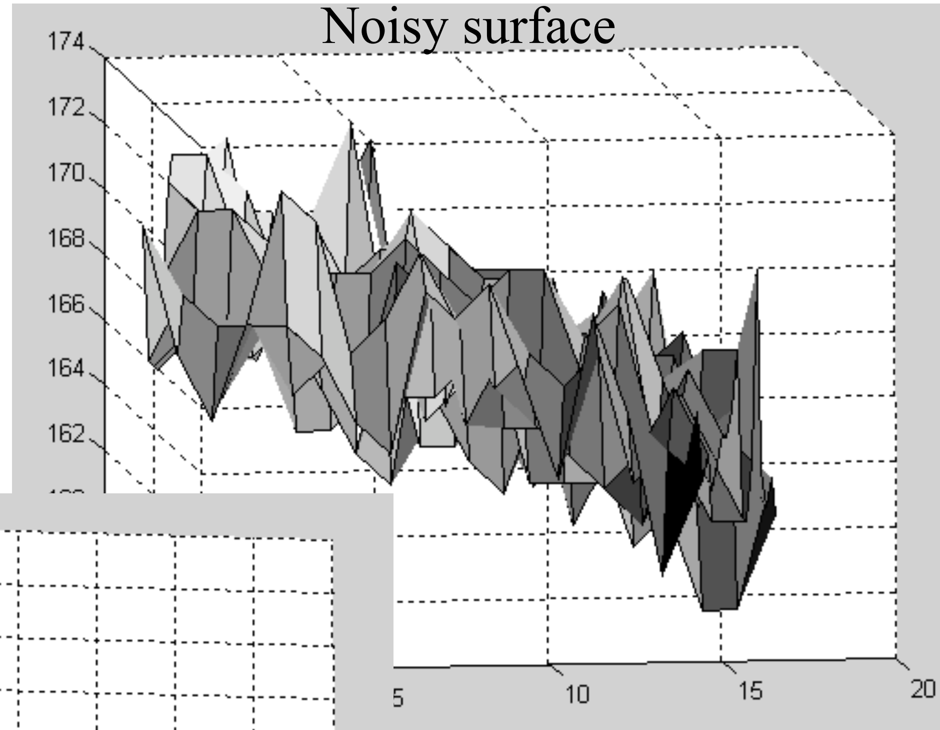
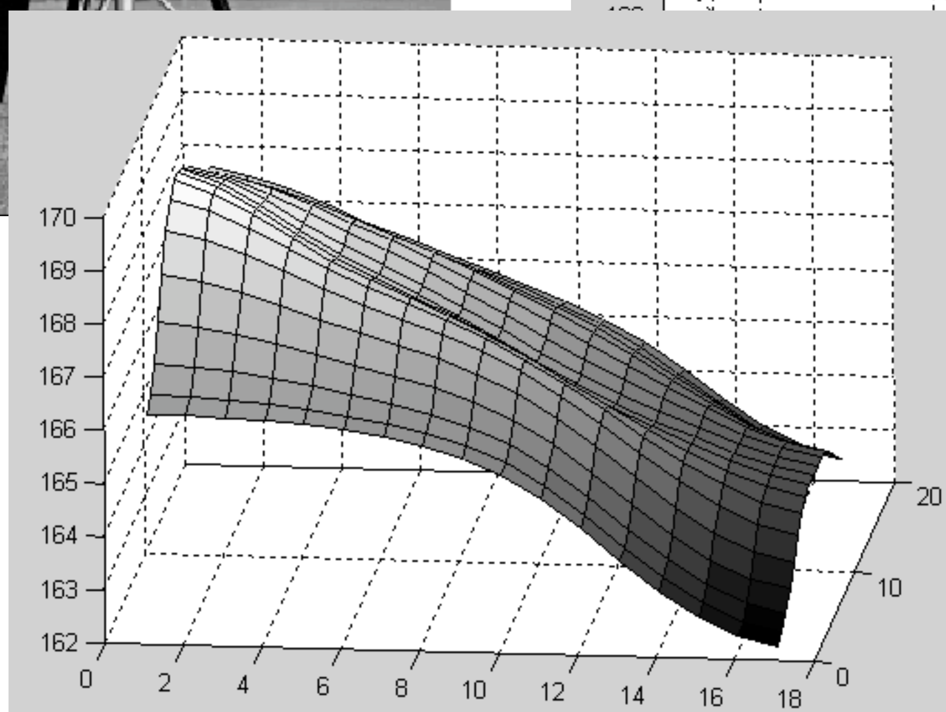
Recall: Smoothing Reduces Noise



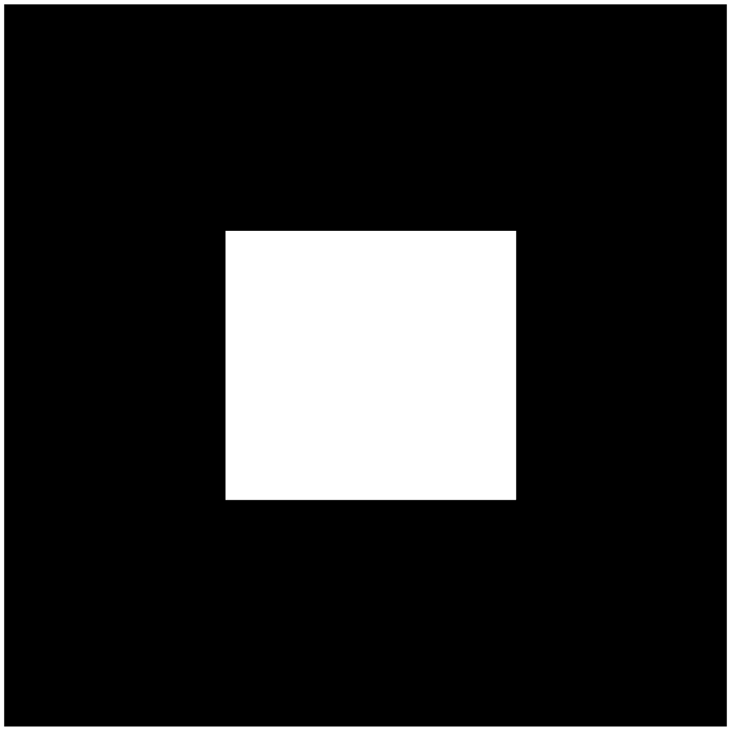




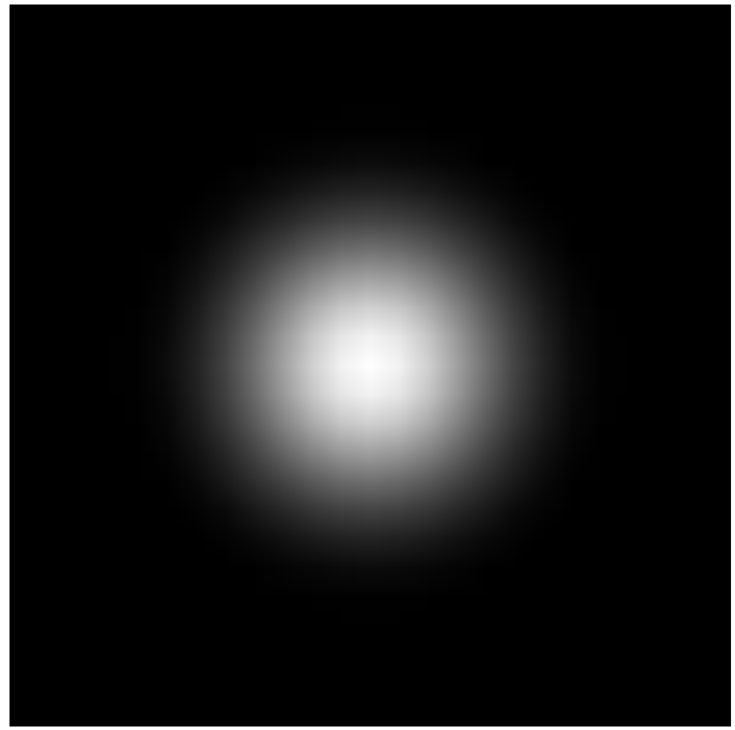
smoothing reduces noise, giving us (perhaps) a more accurate intensity surface.

Smoothing Filters

box filter



(isotropic) Gaussian



What Are Edges?

Simple answer: discontinuities in intensity.

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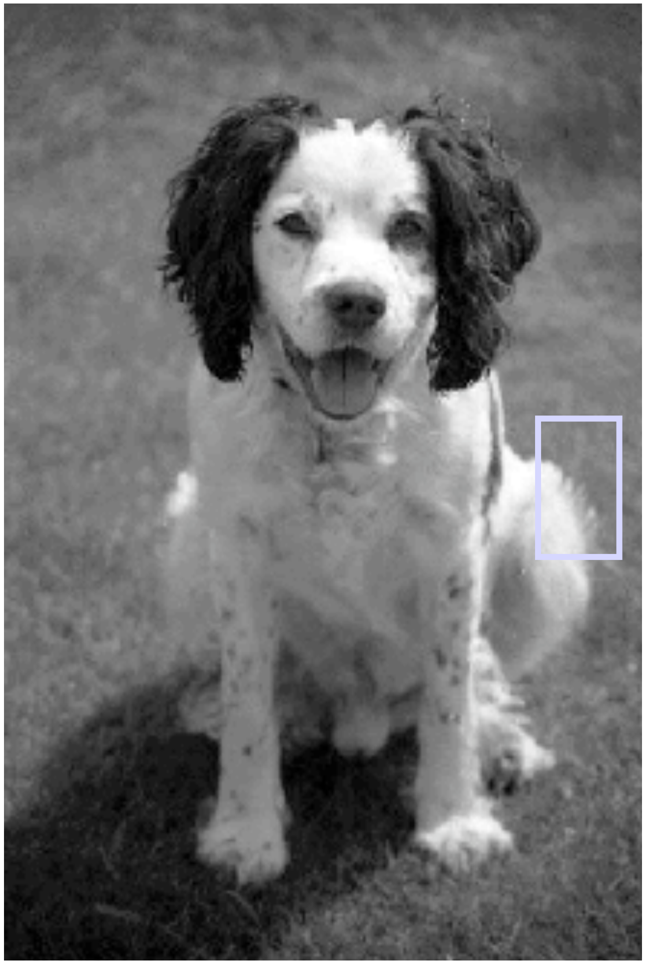
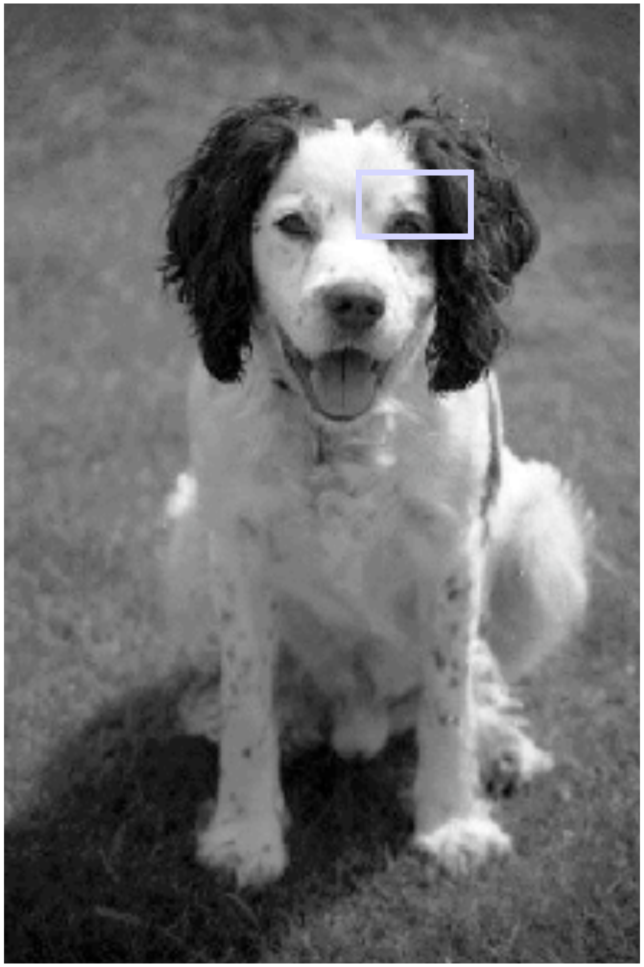
Boundaries of objects



Boundaries of Material Properties



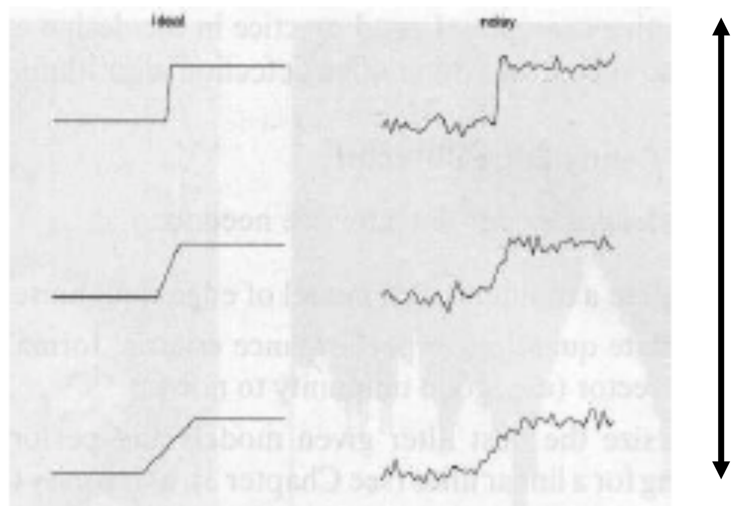
Boundaries of Lighting

Types of Edges (1D Profiles)

- Edges can be modeled according to their intensity profiles:

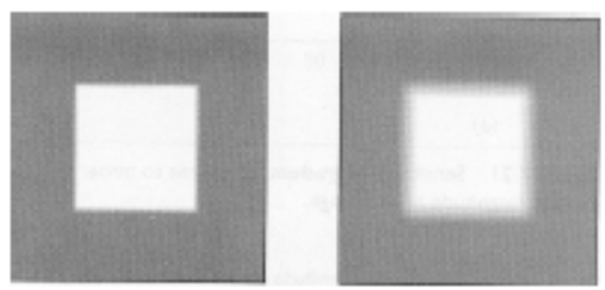
- <u>Step edge</u>:
  - the image intensity abruptly changes from one value to one side of the discontinuity to a different value on the opposite side.

- <u>Ramp edge</u>:
  - a step edge where the intensity change is not instantaneous but occurs over a finite distance.



step

ramp



step ramp

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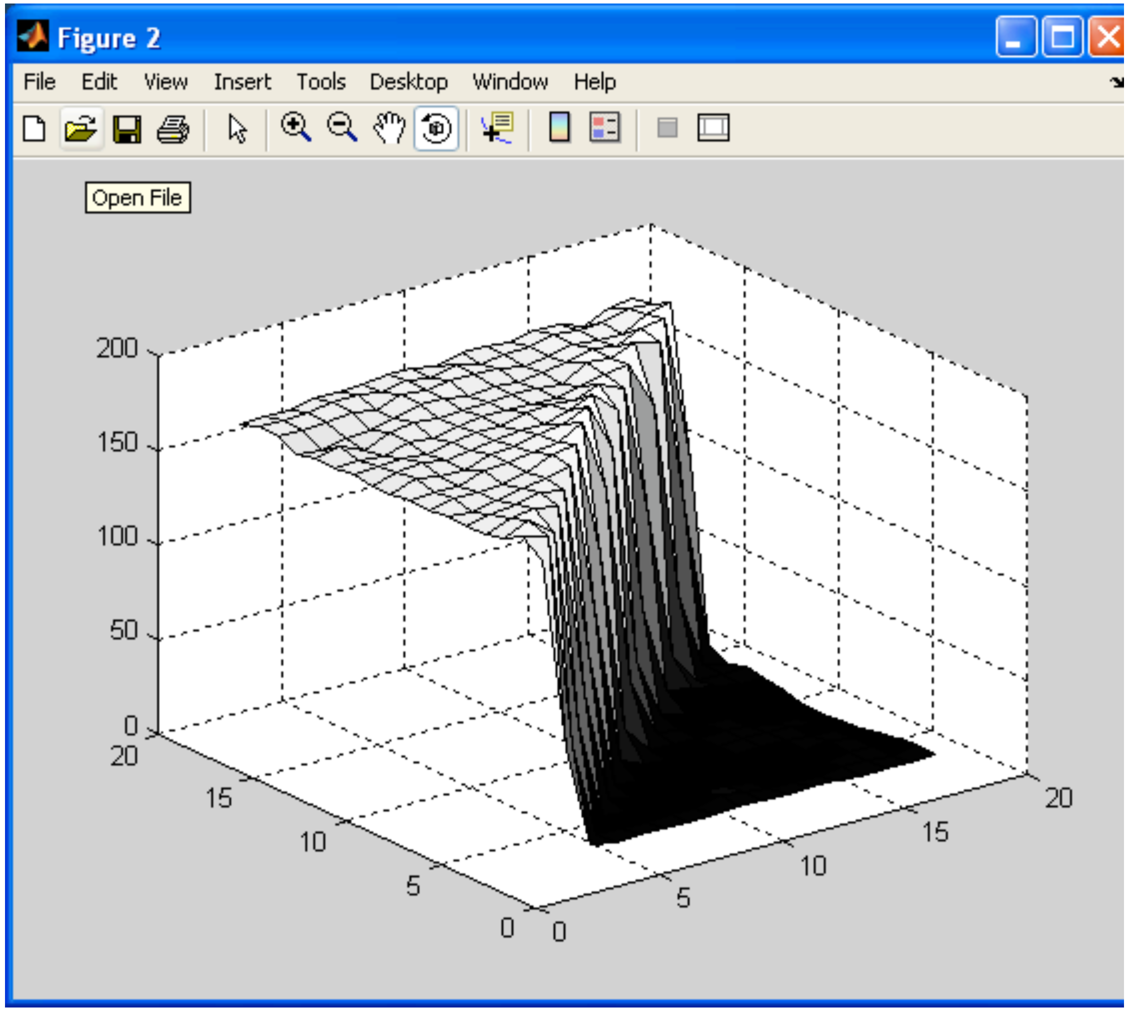
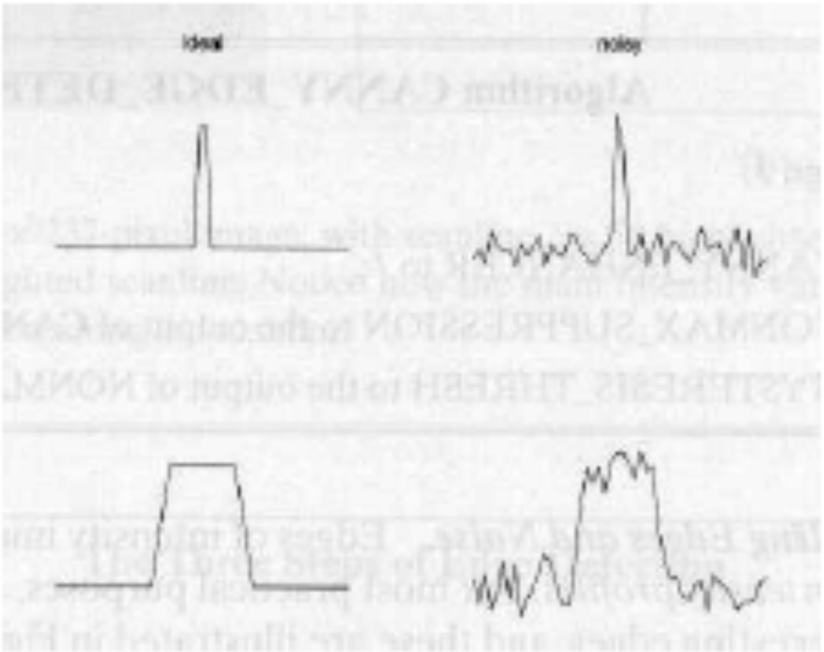
Examples



Types of Edges (1D Profiles)

- Ridge edge:
  - the image intensity abruptly changes value but then returns to the starting value within some short distance
  - generated usually by lines



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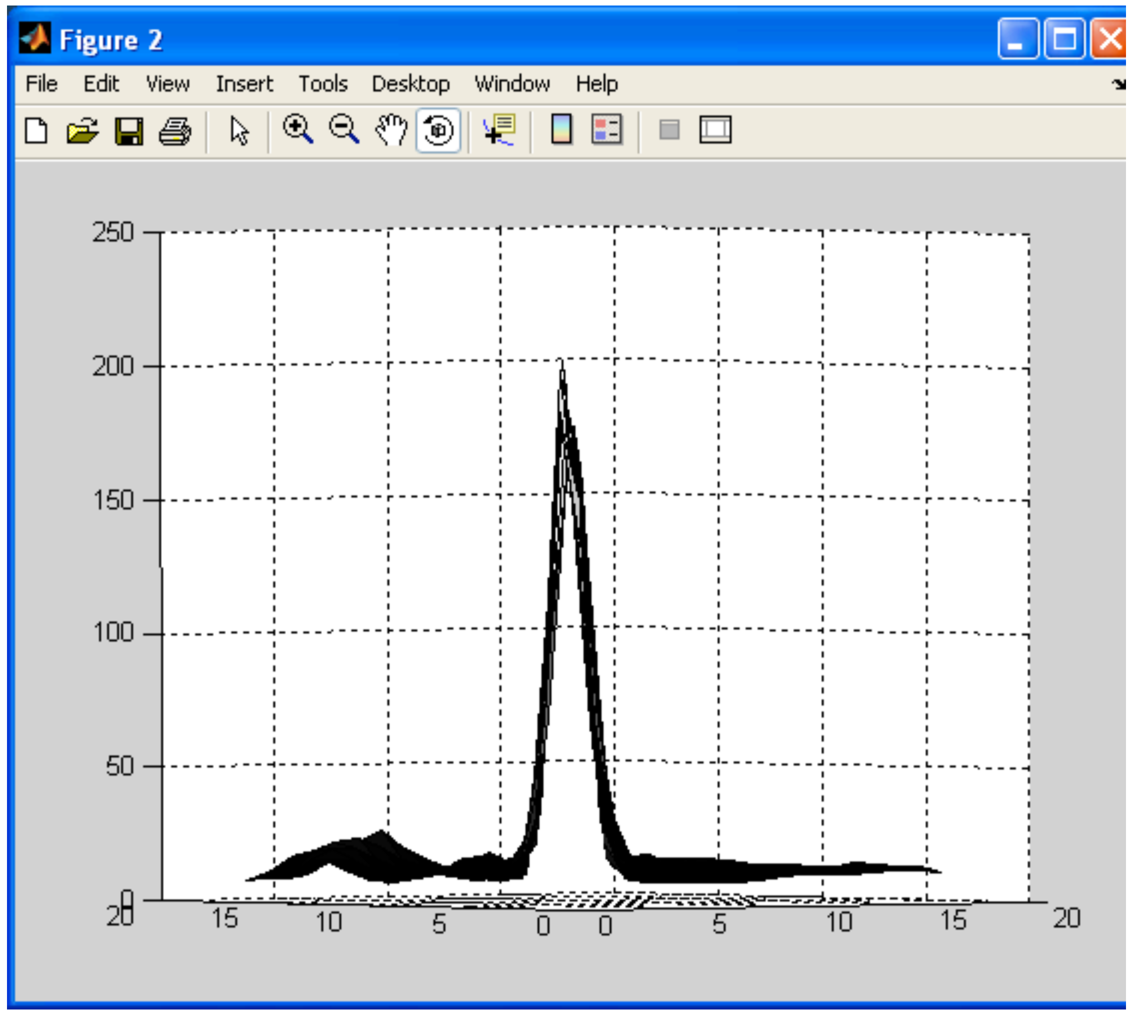
Examples



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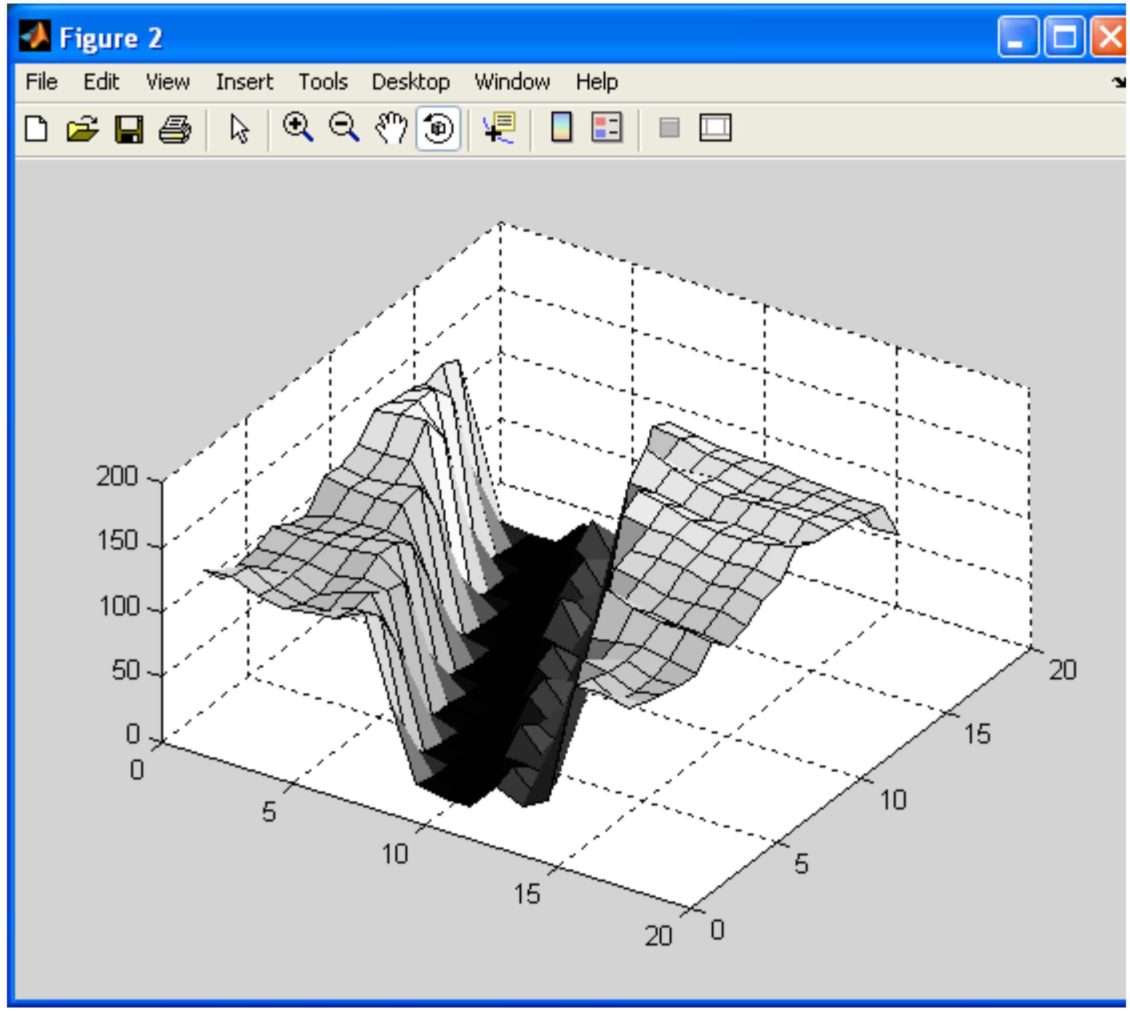
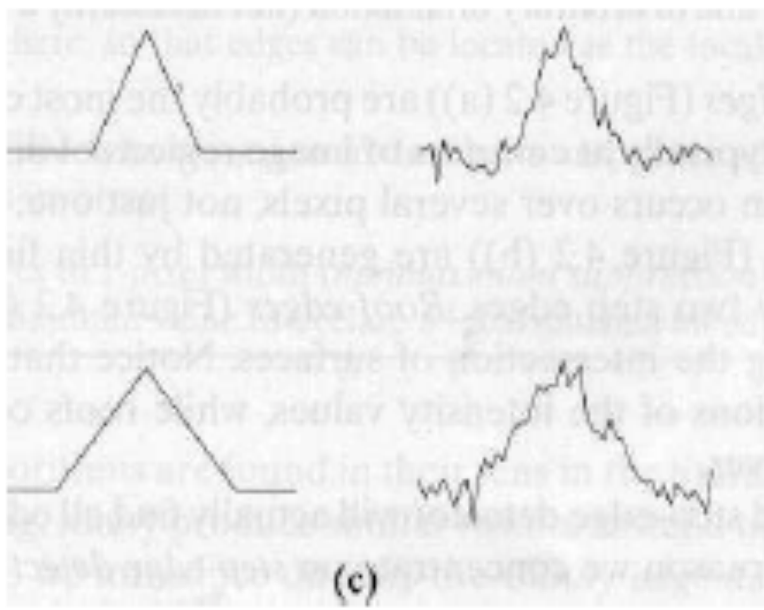
Examples

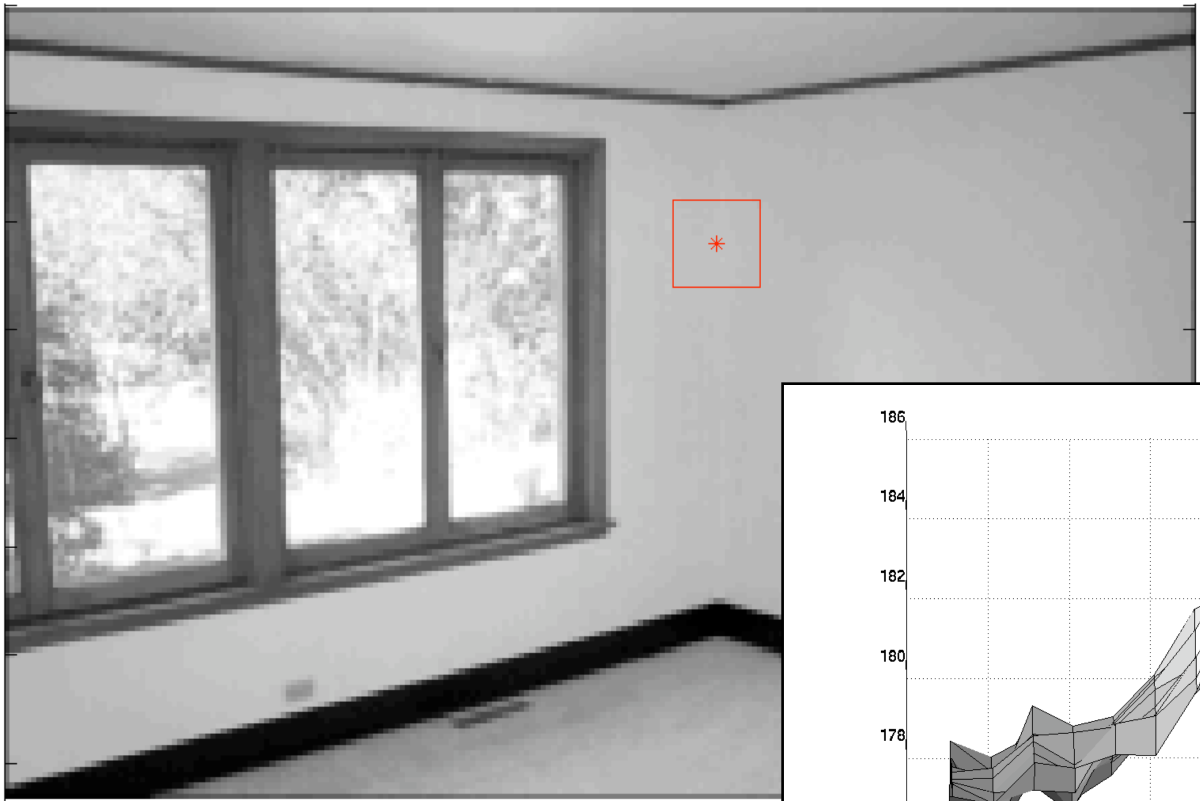


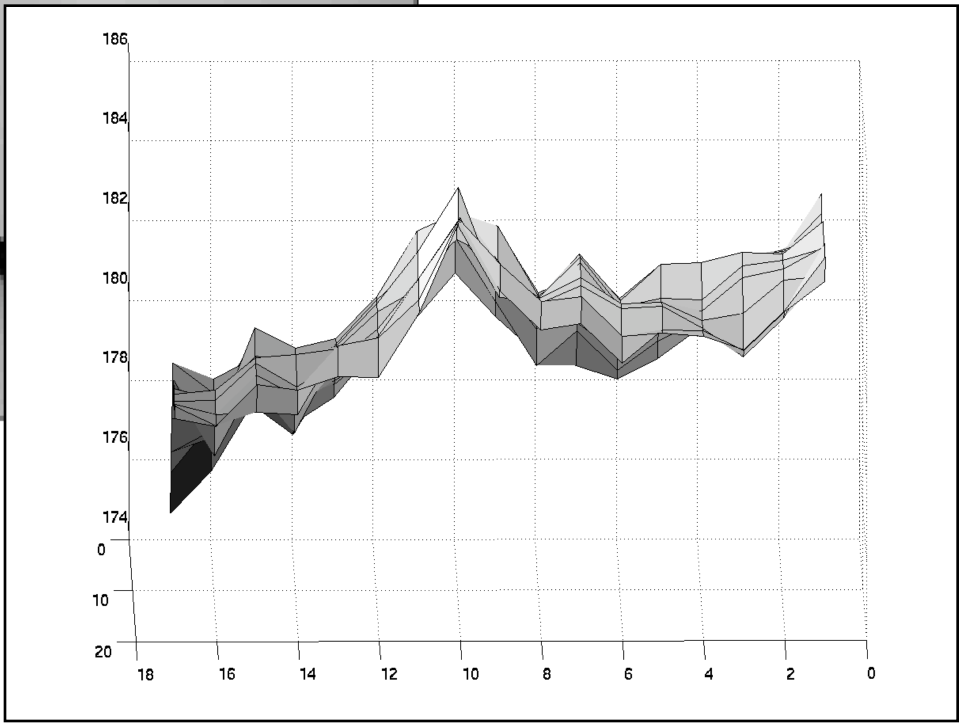
Types of Edges (1D Profiles)

- Roof edge:
  - a ridge edge where the intensity change is not instantaneous but occurs over a finite distance
  - generated usually by the intersection of surfaces



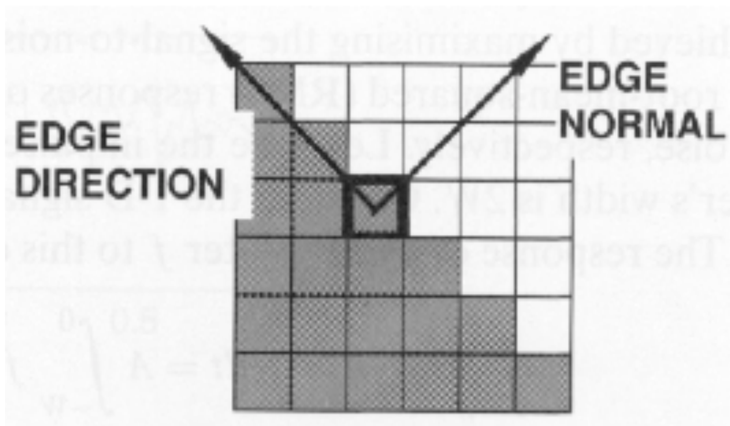
Examples





Step/Ramp Edge Terminology

- Edge descriptors
  – Edge normal: unit vector in the direction of maximum intensity change.
  – Edge direction: unit vector along edge (perpendicular to edge normal).
  – Edge position or center: the image position at which the edge is located.
  – Edge strength or magnitude: local image contrast along the normal.



Important point: All of this information can be computed from the gradient vector field!!

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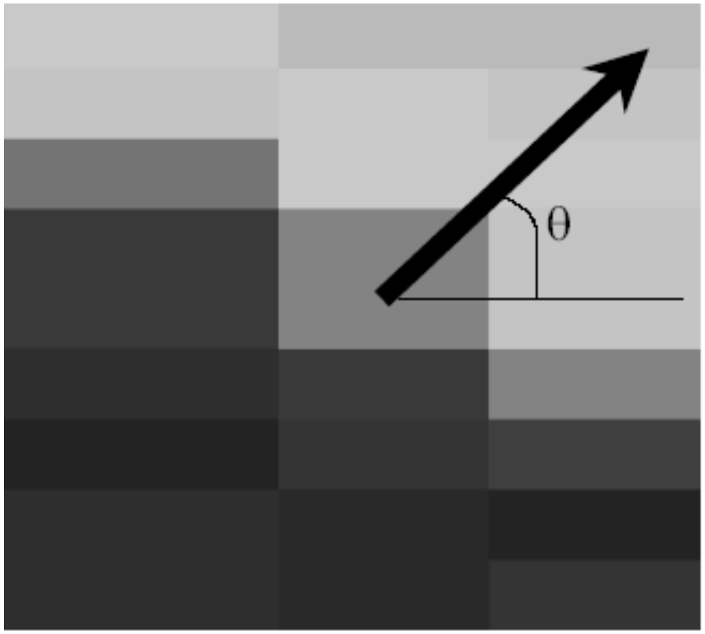
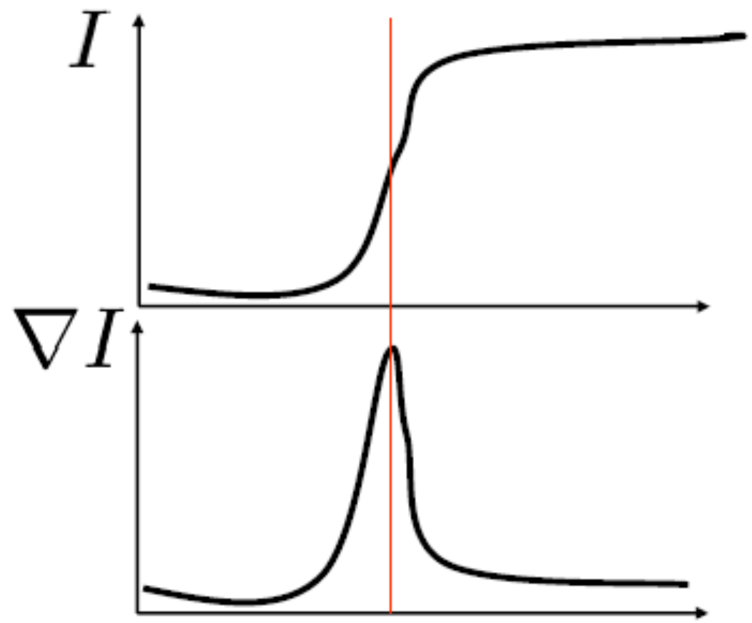
Summary of Gradients





Edge pixels are at local maxima of gradient magnitude
Gradient direction is always perpendicular to edge direction

Gradient Vector: $\nabla I = [\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}]^T$

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

Magnitude:

$$\theta = atan2\left(\frac{\partial I}{\partial y}, \frac{\partial I}{\partial x}\right)$$

Orientation

Simple Edge Detection Using Gradients

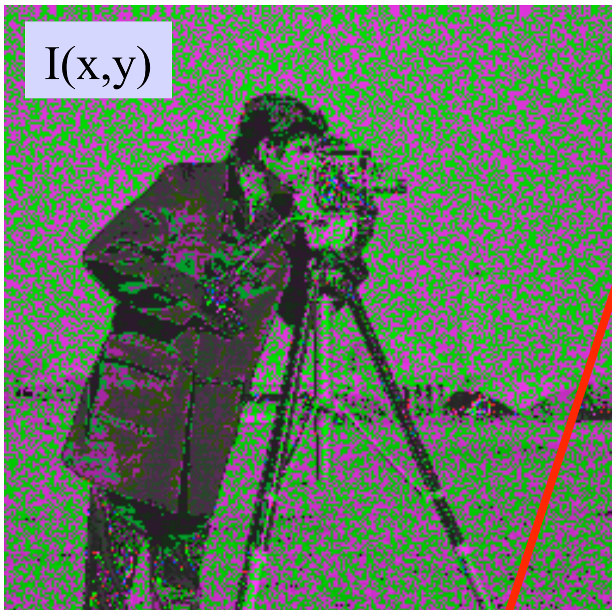
A simple edge detector using gradient magnitude

- Compute gradient vector at each pixel by convolving image with horizontal and vertical derivative filters

- Compute gradient magnitude at each pixel

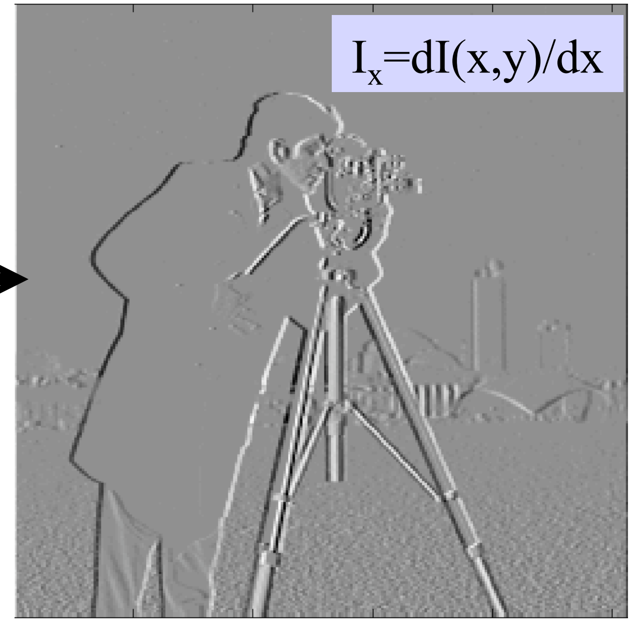
- If magnitude at a pixel exceeds a threshold, report a possible edge point.

Compute Spatial Image Gradients



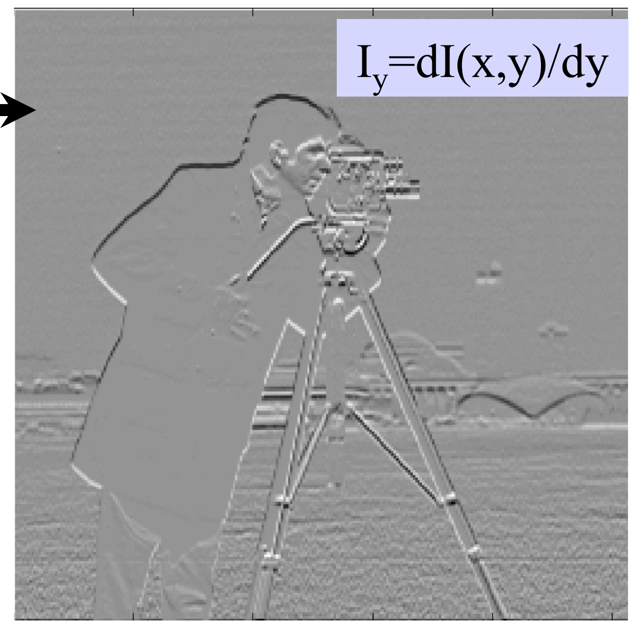
$$\frac{I(x+1,y) - I(x-1,y)}{2}$$

Partial derivative wrt x



$$\frac{I(x,y+1) - I(x,y-1)}{2}$$

Partial derivative wrt y



Replace with your favorite smoothing+derivative operator

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Simple Edge Detection Using Gradients

<u>A simple edge detector using gradient magnitude</u>

- Compute gradient vector at each pixel by convolving image with horizontal and vertical derivative filters

- Compute gradient magnitude at each pixel

- If magnitude at a pixel exceeds a threshold, report a possible edge point.

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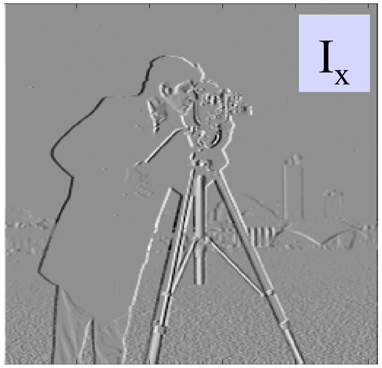
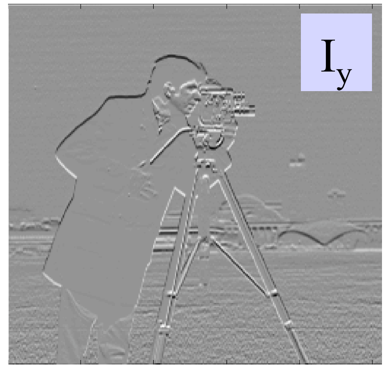
Compute Gradient Magnitude





Magnitude of gradient
sqrt(Ix.^2 + Iy.^2)

Measures steepness of slope at each pixel (= edge contrast)

Simple Edge Detection Using Gradients

<u>A simple edge detector using gradient magnitude</u>

- Compute gradient vector at each pixel by convolving image with horizontal and vertical derivative filters

- Compute gradient magnitude at each pixel

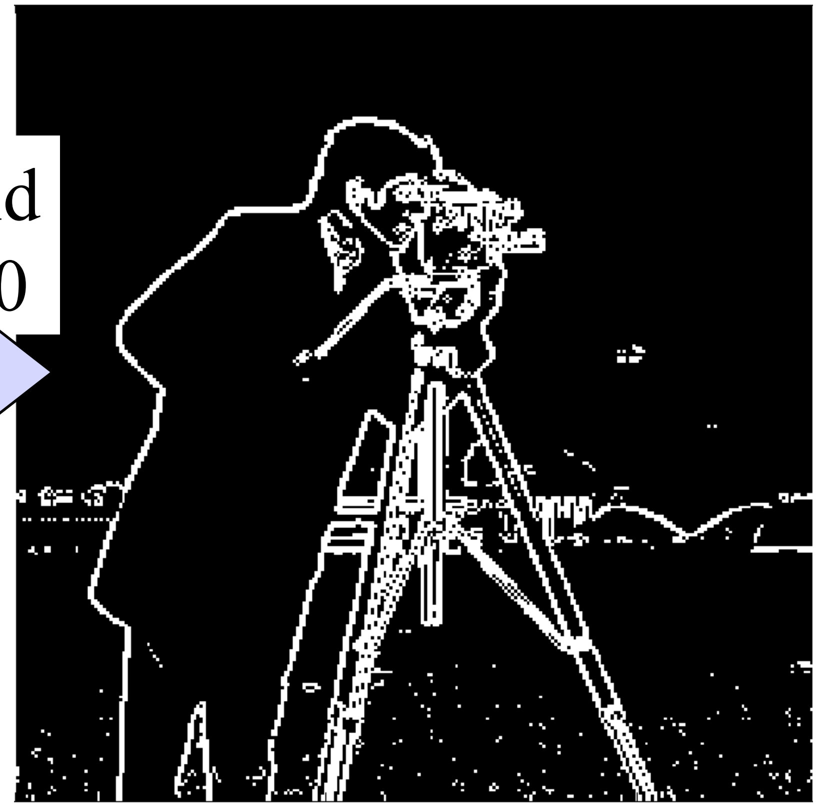
- If magnitude at a pixel exceeds a threshold, report a possible edge point.

Threshold to Find Edge Pixels

- Example – cont.:

Binary edge image

Threshold
Mag > 30



Edge Detection Using Gradient Magnitude

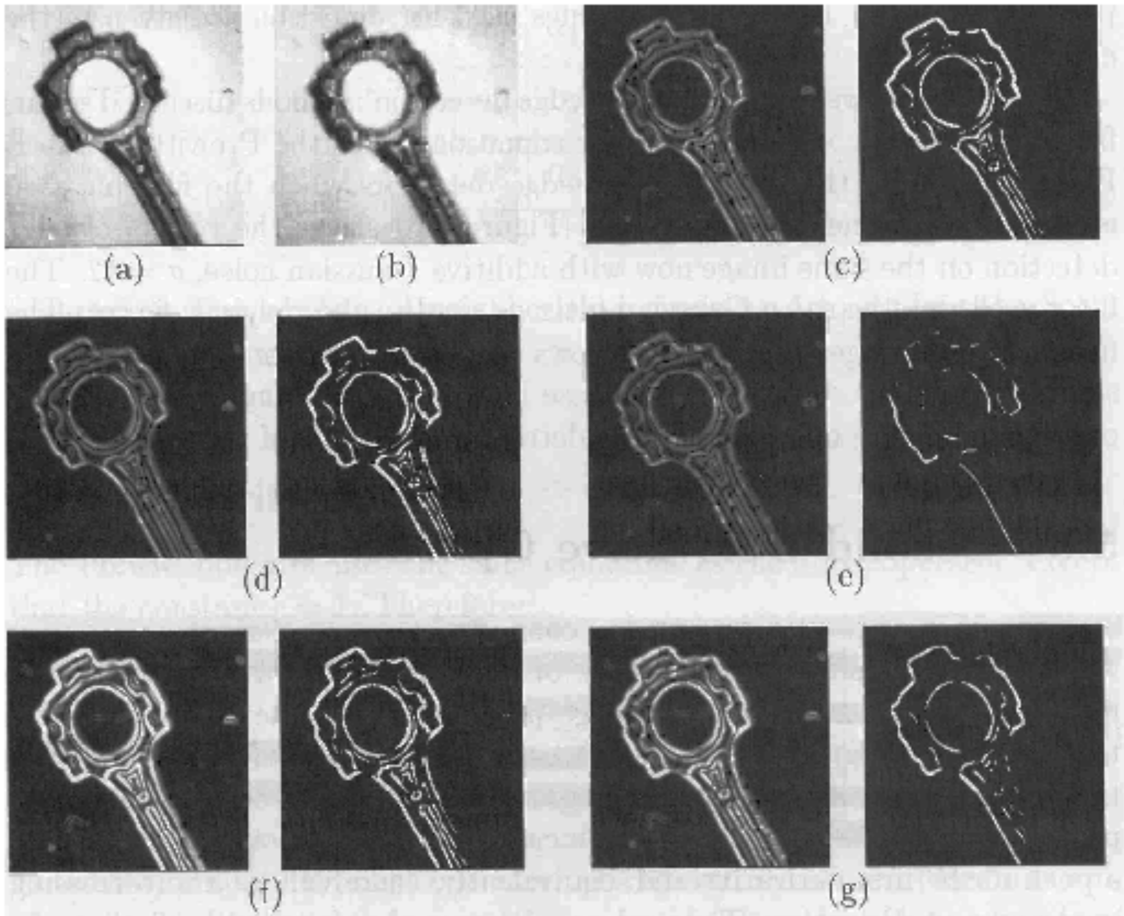
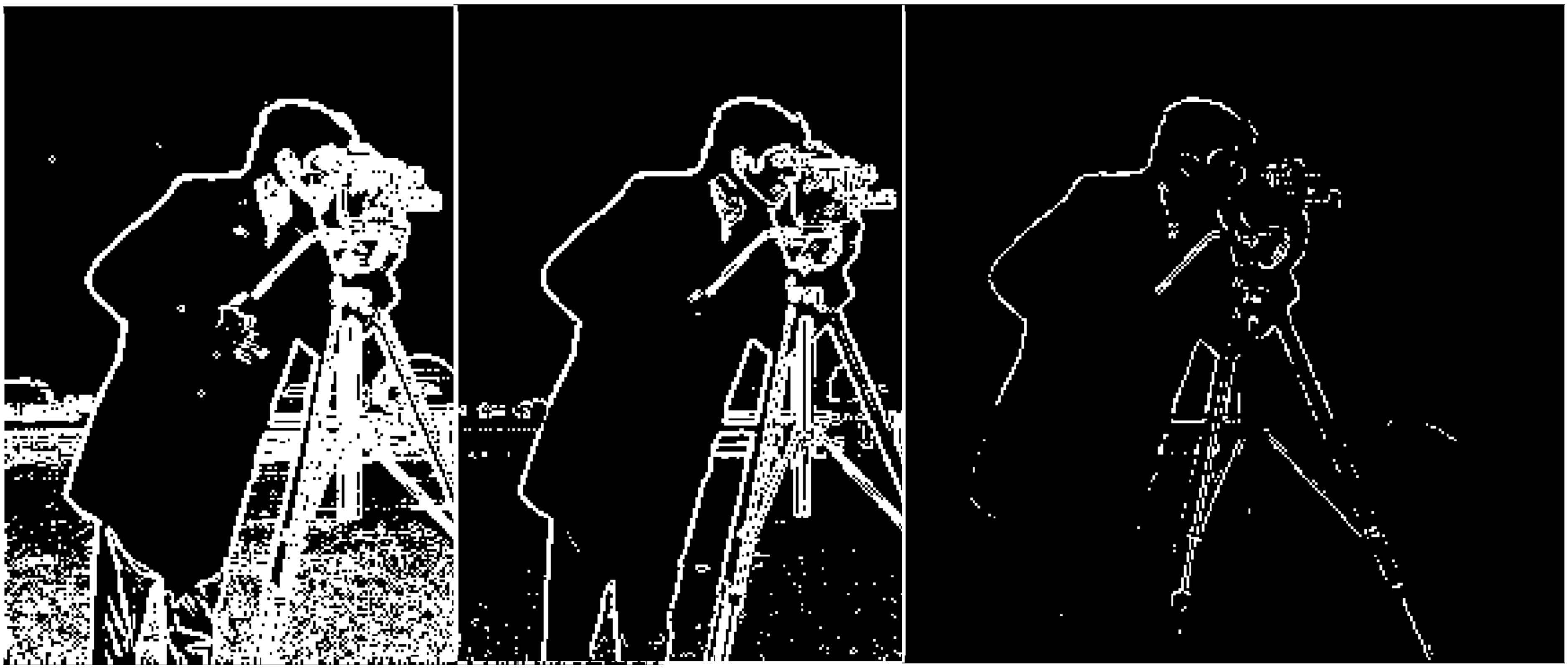


Figure 5.4: A comparison of various edge detectors. (a) Original image. (b) Filtered image. (c) Simple gradient using 1×2 and 2×1 masks, $T = 32$. (d) Gradient using 2×2 masks, $T = 64$. (e) Roberts cross operator, $T = 64$. (f) Sobel operator, $T = 225$. (g) Prewitt operator, $T = 225$.

(with noise filtering)

Issues to Address

How should we choose the threshold?



> 10 > 30 > 80

Trade-off: Smoothing vs Localization

There is ALWAYS a tradeoff between smoothing and good edge localization!

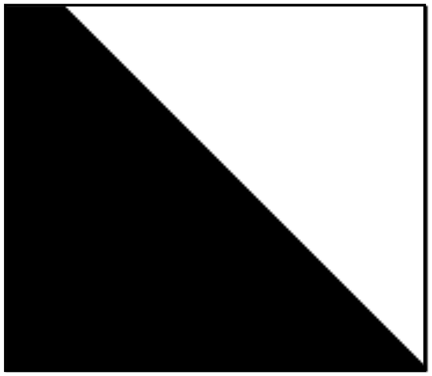
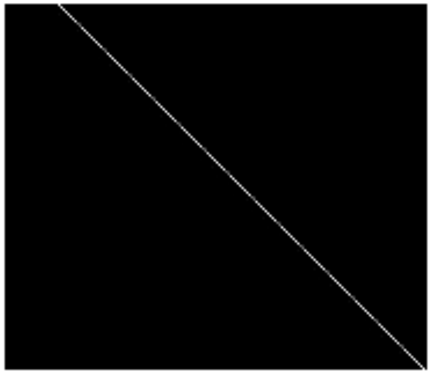


Image with Edge



Edge Location

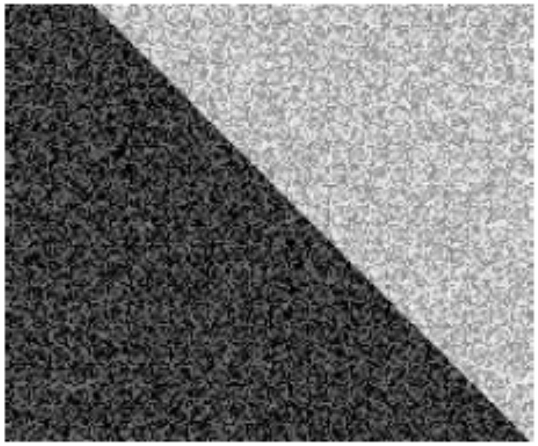
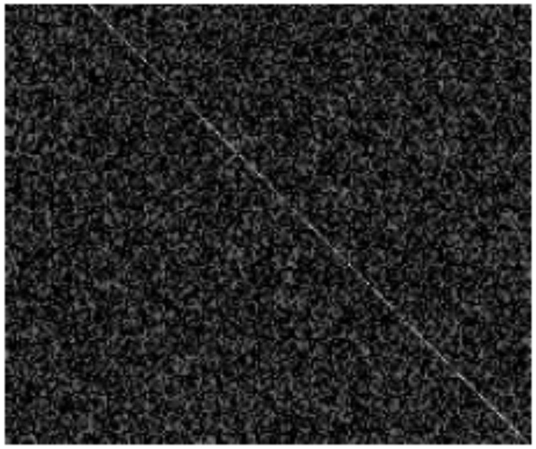


Image + Noise

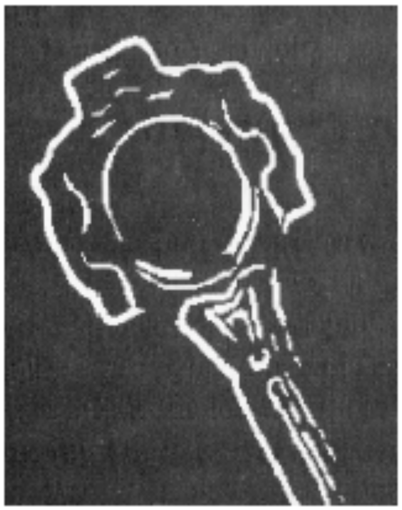


Derivatives detect edge *and* noise

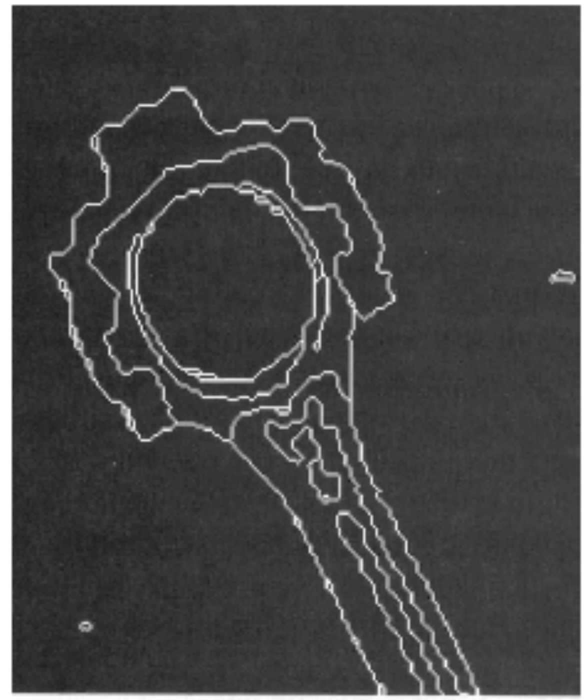
Smoothed derivative removes noise, but blurs edge

Issues to Address

<u>Edge thinning and linking</u>



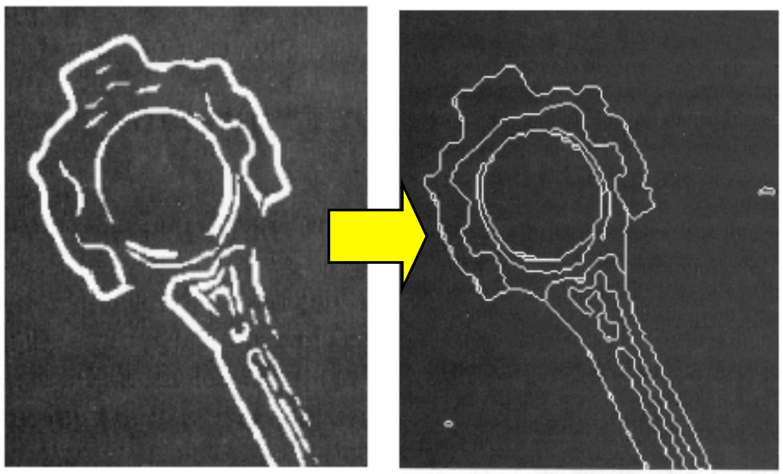
smoothing+thresholding gives us a binary mask with “thick” edges



we want thin, one-pixel wide, connected contours

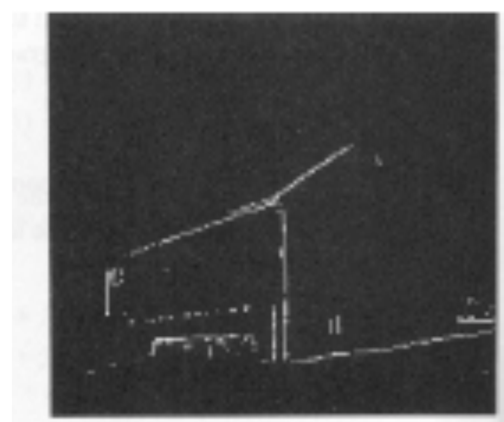
Practical Issues for Edge Detection

Thinning and linking



Choosing a magnitude threshold

OR



Canny has good answers to all!

Canny Edge Detector

An important case study

Probably, the most used edge detection algorithm by C.V. practitioners

Experiments consistently show that it performs very well

J. Canny *A Computational Approach to Edge Detection*, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol 8, No. 6, Nov 1986

In our textbook: T&V Section 4.2