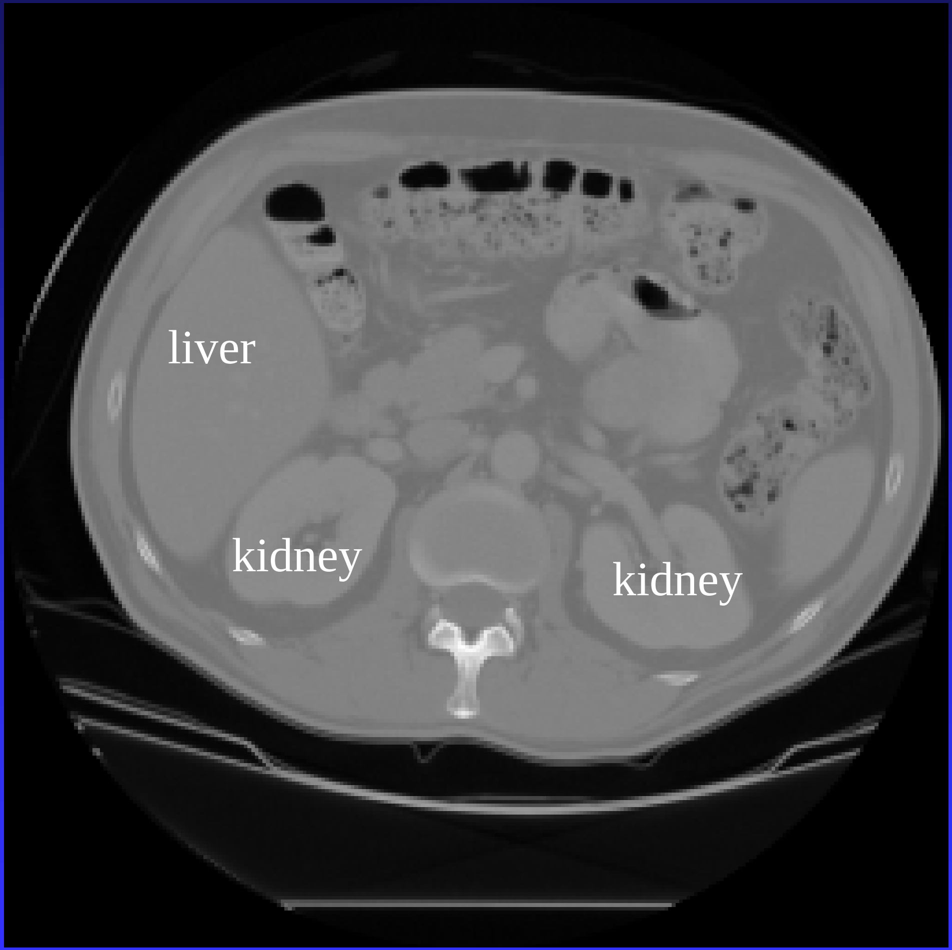
Introduction

Computer vision is the analysis of digital images by a computer for such applications as:

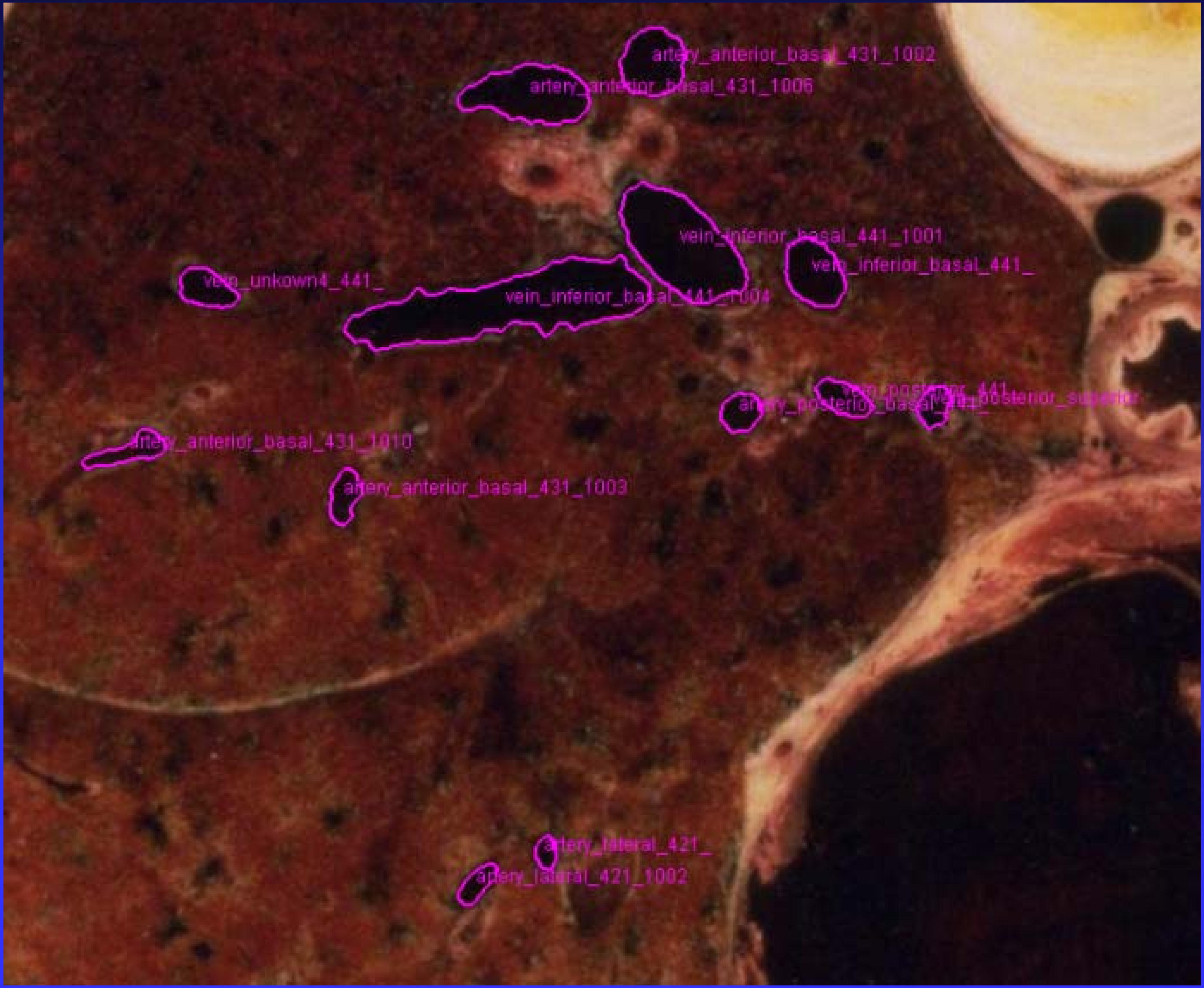
- Industrial: part localization and inspection, robotics
- Medical: disease classification, screening, planning
- Military: autonomous vehicles, tank recognition
- Intelligence Gathering: face recognition, video analysis
- Security: video analysis
- Science: classification, measurement
- Document Processing: text recognition, diagram conversion

Medical Applications

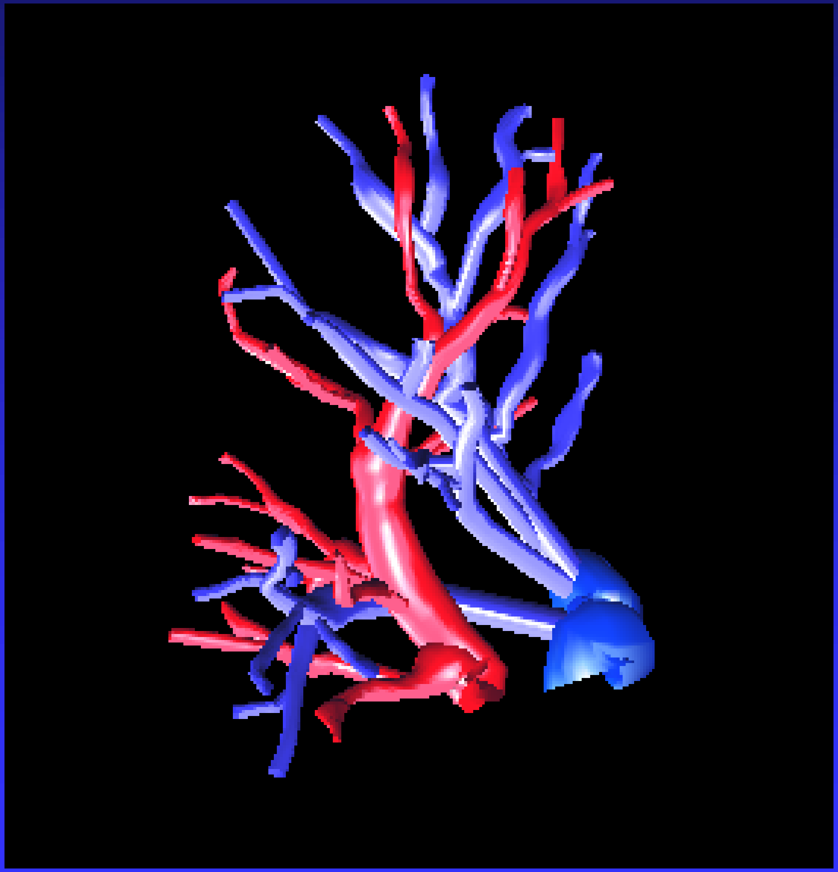
CT image of a patient's abdomen



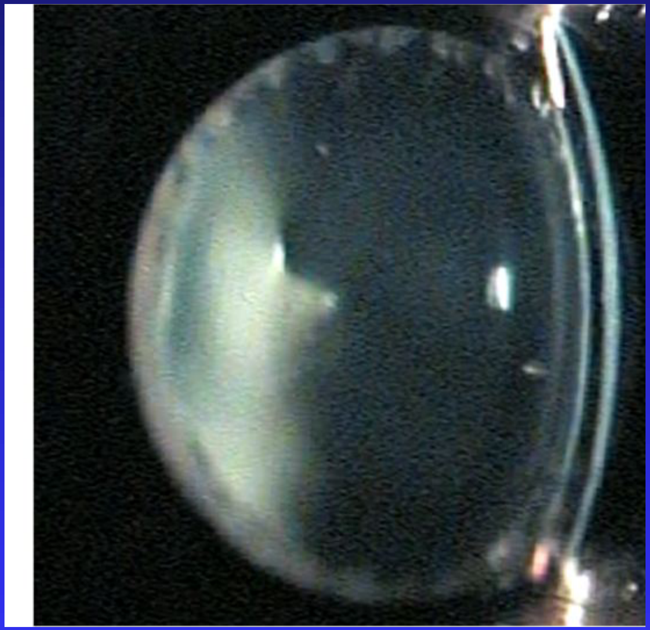
Visible Man Slice Through Lung



3D Reconstruction of the Blood Vessel Tree



CBIR of Mouse Eye Images for Genetic Studies



Robotics

- 2D Gray-tone or Color Images

"Mars" rover

- 3D Range Images

What am I?

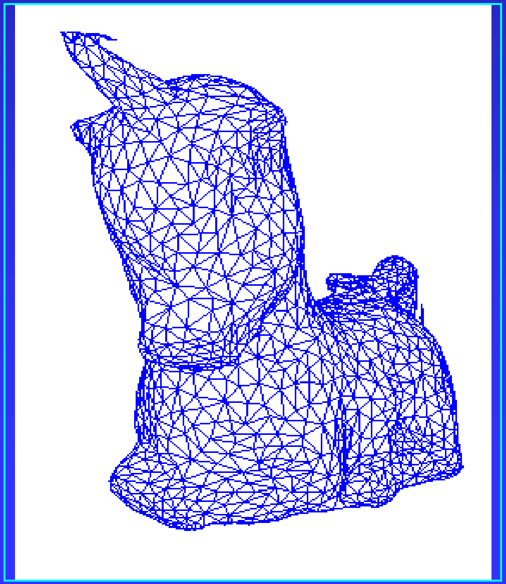
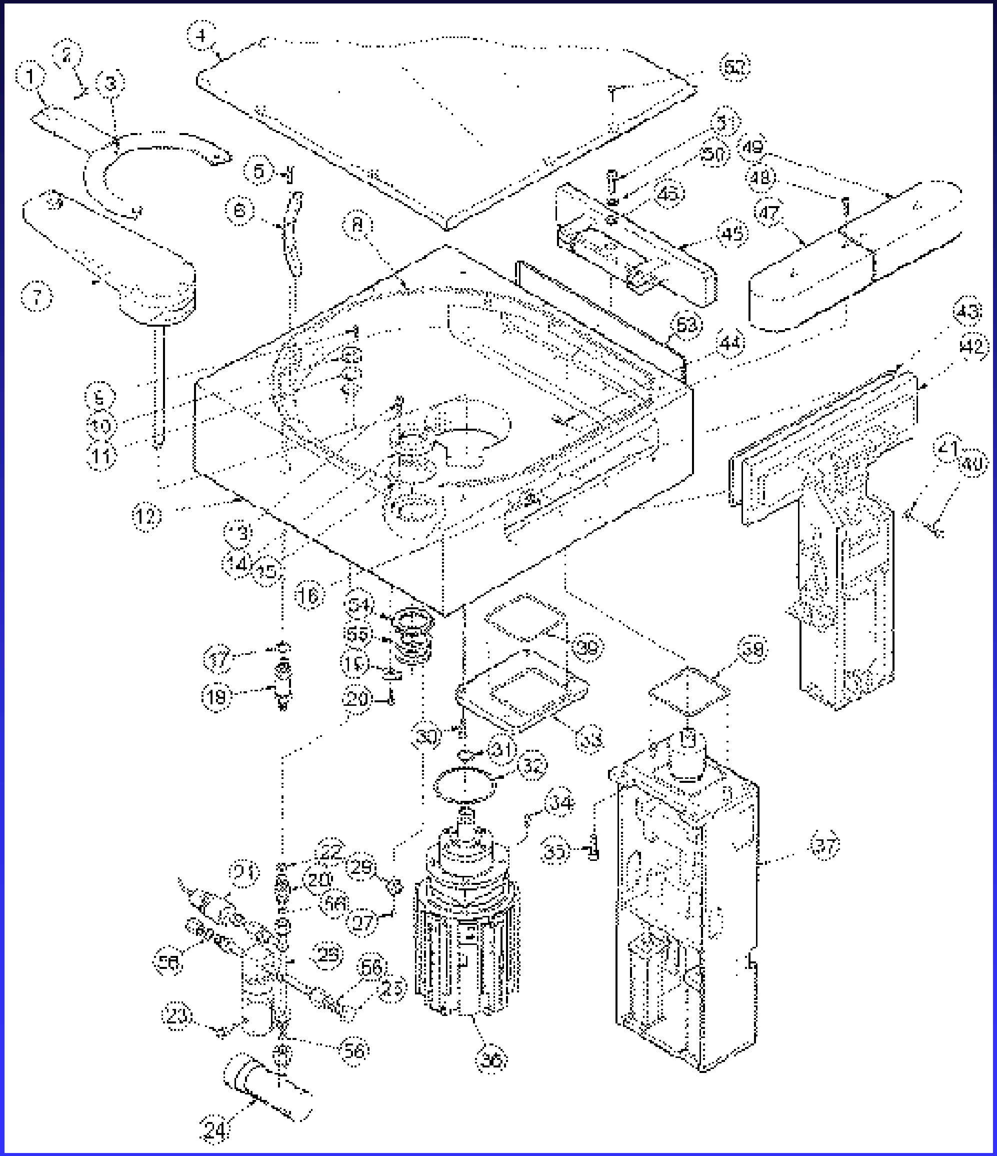


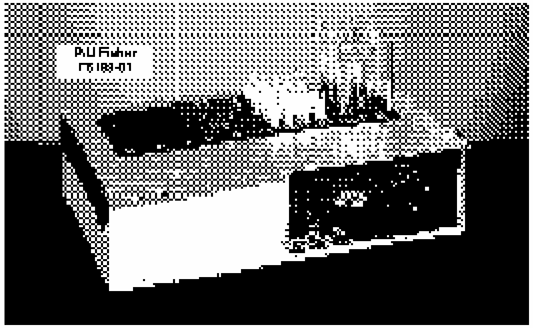
Image Databases:

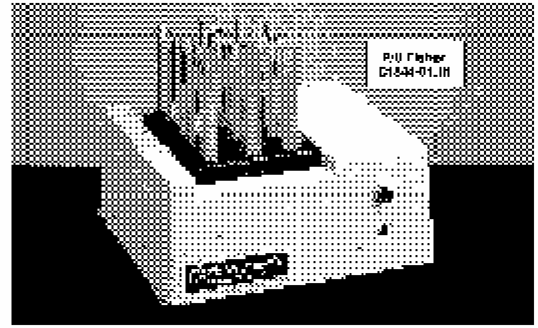
Images from my Ground-Truth collection.

- Retrieve all images that have trees.
- Retrieve all images that have buildings.
- Retrieve all images that have antelope.

Documents:







Model 145 Isotemp* Dry Bath Incubator

- *Holds 1 to 4 heating blocks with choice of 11 well sizes*
- *Maintains every sample to within ±0.1°C of temperature*

Unique sample wells are shaped so that aluminum blocks deliver same amount of heat to all parts of the sample tube. No temperature gradient—neither too hot at the bottom nor too cold at the top—that may invalidate tests in racks with drilled cylindrical wells. Sample tubes rest on insulating plugs to prevent localized heating. A low-watt-density heater is mounted on a thick aluminum heat distribution plate in the floor of the bath. Plate is 3/8" thick (9.5 mm). Dry bath minimizes cleanup problems because tubes stay dry.

Ambient to 125°C (257°F) with ±0.1°C control. Dial temperature control graduated from 25° to 125°C. Ideal for enzyme reactions, inactivation of sera, Rh studies, cross-matching and thrombin determinations. Dimensions: 9 L x 15 W x 4" H (23 x 38 x 10 cm). With line cord and plug. **Heating blocks sold separately** (see lower right).

Electrical Requirements	Cat. No.	Each
120V 50/60 Hz, 300W (CSA approved)	11-715-100	[illegible]
240V 50/60 Hz, 600W	11-715-101	385.25

Average deviation from mean of 37°C
Intermediate Model

Incu-Block* Partial Immersion Thermometers

For all standard heating blocks and water baths. Critical temperatures (25°, 30°, 37°, 56°C) are marked with arrows. Available with shatter-proof, contamination-proof Teflon* coating. Total length: 175 mm. Immersion: 35 mm.

Range, °C	Div., °C	Teflon-Coated	Cat. No.	Each
25-57	0.5	No	14-992	45.24
25-57	0.5	Yes	14-993	45.15

More Thermometers

For more thermometers, including digital types, see page 952

Model 147 Isotemp* Dry Bath

- *Holds single heating block with choice of 11 well sizes*

Similar to Model 145, but with 3/8" thick (9.5 mm) plate. Ideal for labs with smaller volumes of enzyme and coagulation assays, Rh studies, and dry incubations. Screwdriver-adjusted temperature control between ambient and 95°C (203°F). Observe thermometer placed in unused sample tube to set; adjust control through hole in front panel. Maintains set temperature with consistency and uniformity of ±0.5°C.

Supplied with strong nylon case, thermostatically controlled heater, pilot indicator lamp, line cord and plug, and instructions. Dimensions: 6 L x 6¾ W x 3" H (15 x 17 x 8 cm). CSA approved. **Heating blocks sold separately** (see below).

Electrical Requirements	Cat. No.	Each
120V 50/60 Hz, 120W	11-715-102	223.50

Interchangeable Heating Blocks for Isotemp* Dry Baths

For Models 145 and 147 Dry Baths. Composed of black anodized aluminum alloy. Chemical resistant. Dimensions: 4 L x 3 W x 2" H (10 x 7.5 x 5 cm).

The 11-715-123 block provides a safe, dry bath alternative for warming [illegible]. Avoids hazardous use of burners around flammable histological solvents.

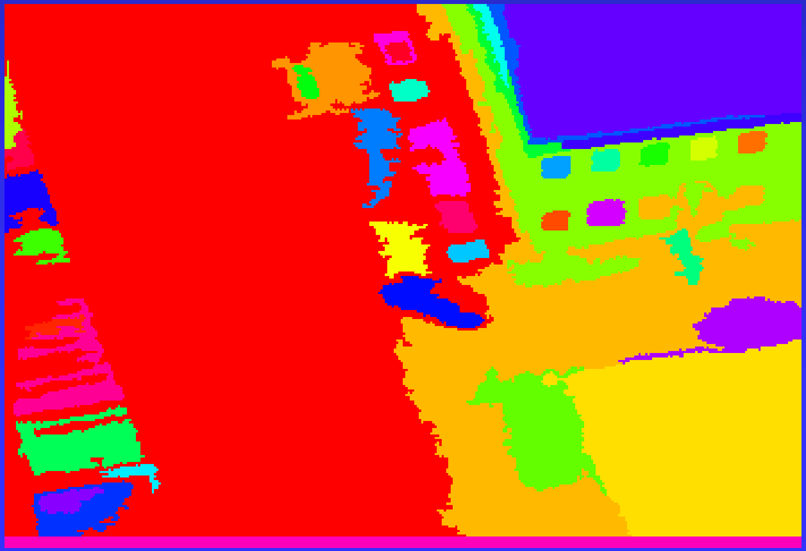
The 11-715-120 block is specifically designed to hold twenty 9.5 mm Roche Diagnostics Placentex* pregnancy test tubes. This special shallow well block is similar to the other blocks with 10 mm holes, but sample wells are only ½" deep (1.3 cm) to meet test requirements. Wells in all other blocks are 1¾" deep (4.4 cm).

Tube Size, mm	Wells/Block	Cat. No.	Each
6	35	11-715-105	[illegible]
10	20	11-715-107	[illegible]
9.5	20 (shallow)	11-715-120	[illegible]
12	12	11-715-109	[illegible]
[illegible]	12	11-715-121	[illegible]
13	12	11-715-111	[illegible]
15	12	11-715-113	[illegible]
16	8	11-715-123	[illegible]
18	12	11-715-115	[illegible]
20	6	11-715-117	[illegible]
25	5	11-715-119	[illegible]

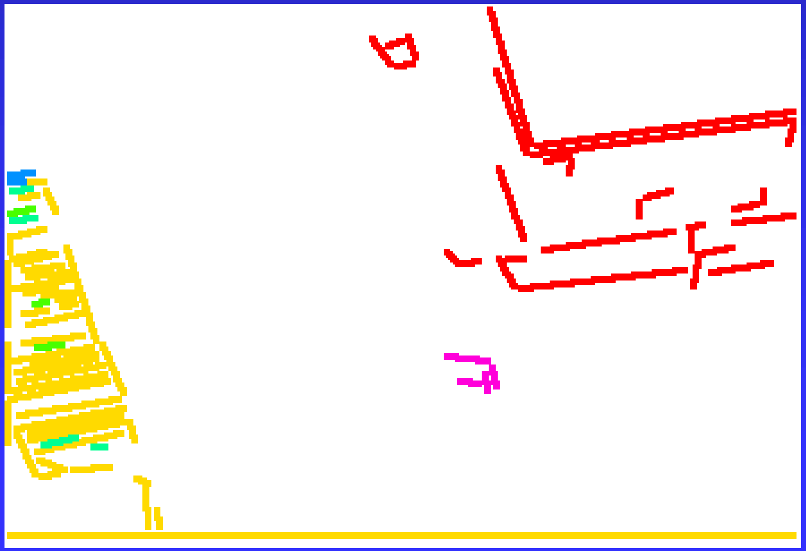
[illegible]
[illegible]

Surveillance: Object and Event Recognition in Aerial Videos

Original Video Frame



Color Regions



Structure Regions

Digital Image Terminology:

0	0	0	0	1	0	0
0	0	1	1	1	0	0
0	1	95	96	94	93	92
0	0	92	93	93	92	92
0	0	93	93	94	92	93
0	1	92	93	93	93	93
0	0	94	95	95	96	95

pixel (with value 94)

its 3x3 neighborhood

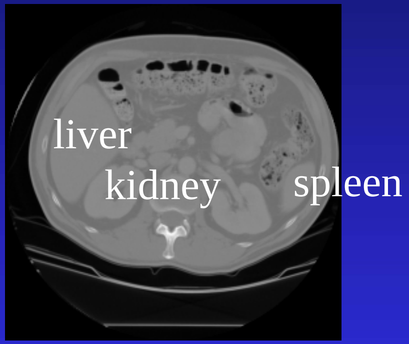
region of medium intensity

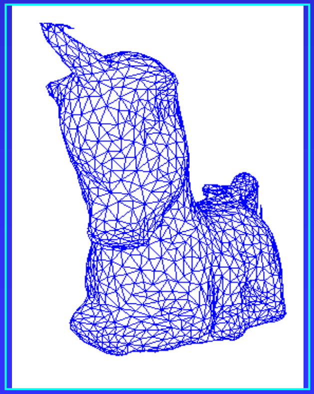
resolution (7x7)

- binary image
- gray-scale (or gray-tone) image
- color image
- multi-spectral image
- range image
- labeled image

Goals of Image and Video Analysis

- Segment an image into useful regions
- Perform measurements on certain areas
- Determine what object(s) are in the scene
- Calculate the precise location(s) of objects
- Visually inspect a manufactured object
- Construct a 3D model of the imaged object
- Find "interesting" events in a video





•The Three Stages of Computer Vision

- low-level

  image → image

- mid-level

  image → features

- high-level

  features → analysis

Low-Level

sharpening

blurring

Low-Level

original image

Canny
edge
operator
→

edge image

Mid-Level (Lines and Curves)

edge image

ORT
line &
circle
extraction
→

data
structure

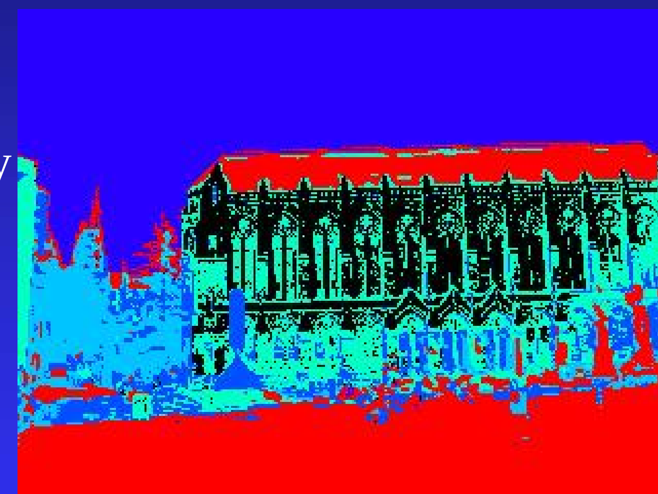
circular arcs and line segments

Mid-level (Regions)

original color image

K-means clustering

(followed by connected component analysis)



regions of homogeneous color

data structure

Low- to High-Level

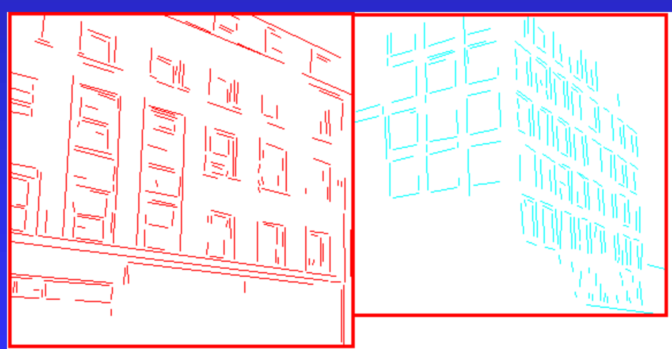
low-level

edge image

mid-level

consistent line clusters

high-level



Building Recognition

Filtering Operations Use Masks

- **Masks operate on a neighborhood of pixels.**
- **A mask of coefficients is centered on a pixel.**
- **The mask coefficients are multiplied by the pixel values in its neighborhood and the products are summed.**
- **The result goes into the corresponding pixel position in the output image.**

36	36	36	36	36
36	36	45	45	45
36	45	45	45	54
36	45	54	54	54
45	45	54	54	54

Input Image

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

3x3 Mask
(mean filter)

**	**	**	**	**
**	39	**	**	**
**	**	**	**	**
**	**	**	**	**
**	**	**	**	**

Output Image

Comparison: salt and pepper noise

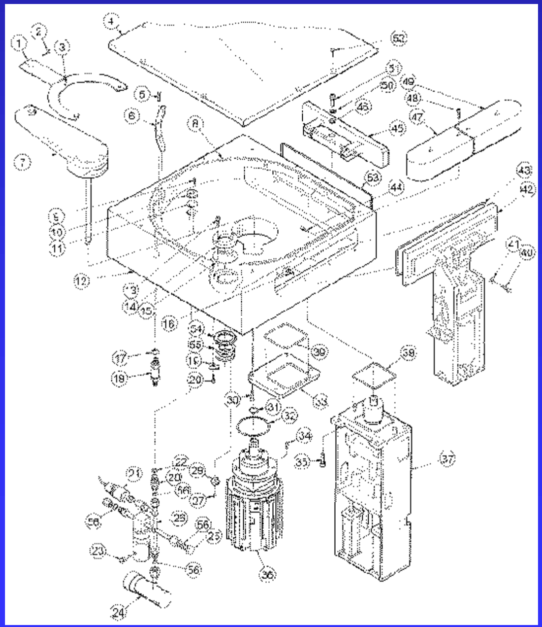
Comparison: Gaussian noise

Lines and Arcs Segmentation

In some image sets, lines, curves, and circular arcs are more useful than regions or helpful in addition to regions.

Lines and arcs are often used in

- object recognition
- stereo matching
- document analysis



Edge Detection

Basic idea: look for a neighborhood with strong signs of change.

Problems:

- neighborhood size
- how to detect change

81	82	26	24
82	33	25	25
81	82	26	24

Differential Operators

Differential operators

- attempt to approximate the gradient at a pixel via masks
- threshold the gradient to select the edge pixels

Example: Sobel Operator

$$Sx = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad Sy = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

On a pixel of the image I

- let gx be the response to Sx
- let gy be the response to Sy

Then the gradient is

$$\nabla I = [gx \;\; gy]^T$$

And $g = (gx^2 + gy^2)^{1/2}$ is the gradient magnitude.

$\theta = \mathrm{atan2}(gy, gx)$ is the gradient direction.

Sobel Operator on the Blocks Image

original image

gradient magnitude

thresholded gradient magnitude

Common Masks for Computing Gradient

- Sobel:

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

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

- Prewitt:

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

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

- Roberts

0	1
-1	0

Sx

1	0
0	-1

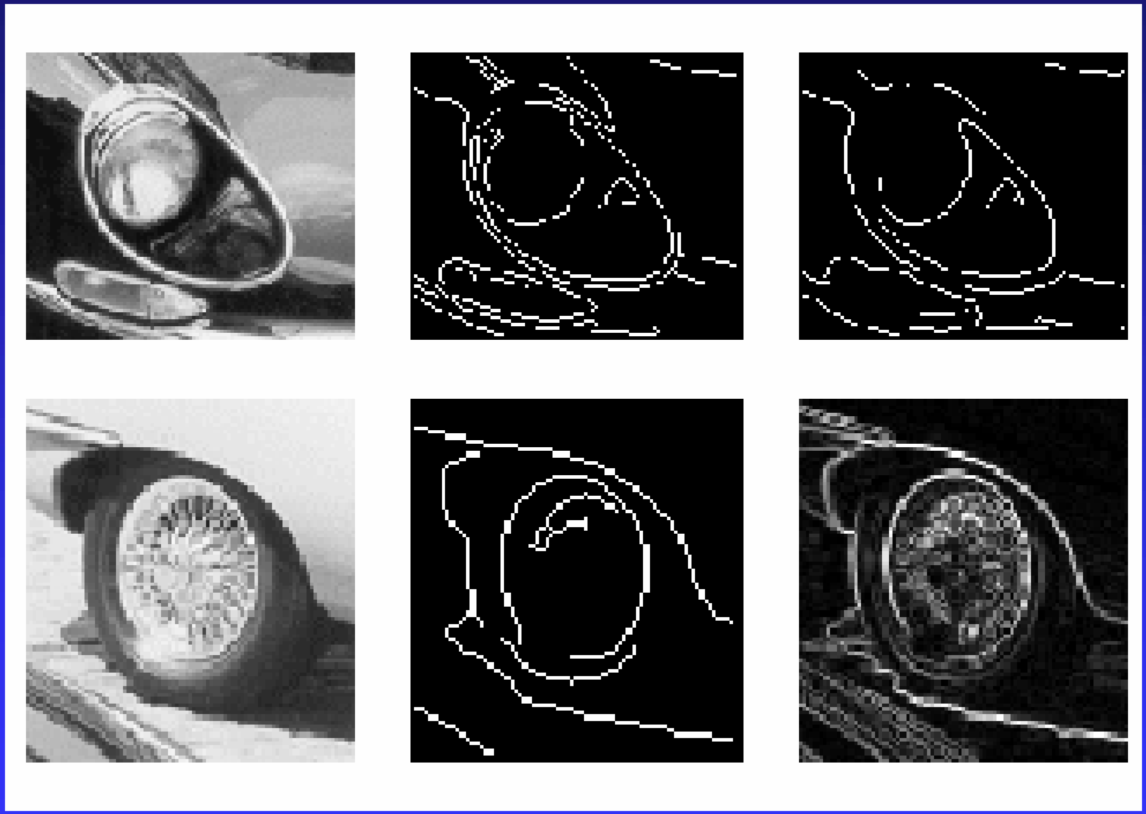
Sy

Canny Edge Detector

- Smooth the image with a Gaussian filter with spread σ.
- Compute gradient magnitude and direction at each pixel of the smoothed image.
- Zero out any pixel response ≤ the two neighboring pixels on either side of it, along the direction of the gradient.
- Track high-magnitude contours.
- Keep only pixels along these contours, so weak little segments go away.

Canny Examples

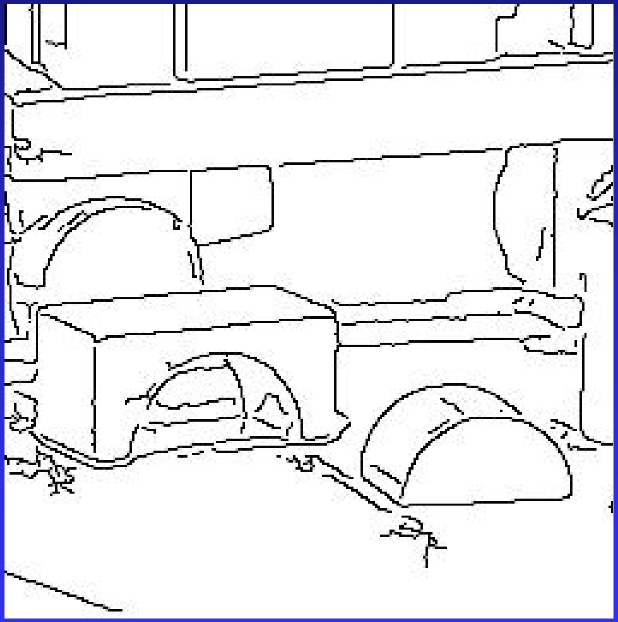
Canny σ=1 Canny σ=4



Canny σ=1 Roberts 2X2

Canny on Kidney Image

Canny on the Blocks image



Canny Characteristics

- The Canny operator gives single-pixel-wide images with good continuation between adjacent pixels
- It is the most widely used edge operator today; no one has done better since it came out in the late 80s. Many implementations are available.
- It is very sensitive to its parameters, which need to be adjusted for different application domains.

Segmentation into Regions

- Instead of looking for 1D features like lines and curves, some processes look for regions.
-
- The regions must be homogeneous in some attribute such as gray-tone, color, texture,...
- Although “region-growing” was popular in the past, clustering the pixels into subsets has become the best methodology for finding regions.

Clustering by K-means Algorithm

Form K-means clusters from a set of n-dimensional feature vectors

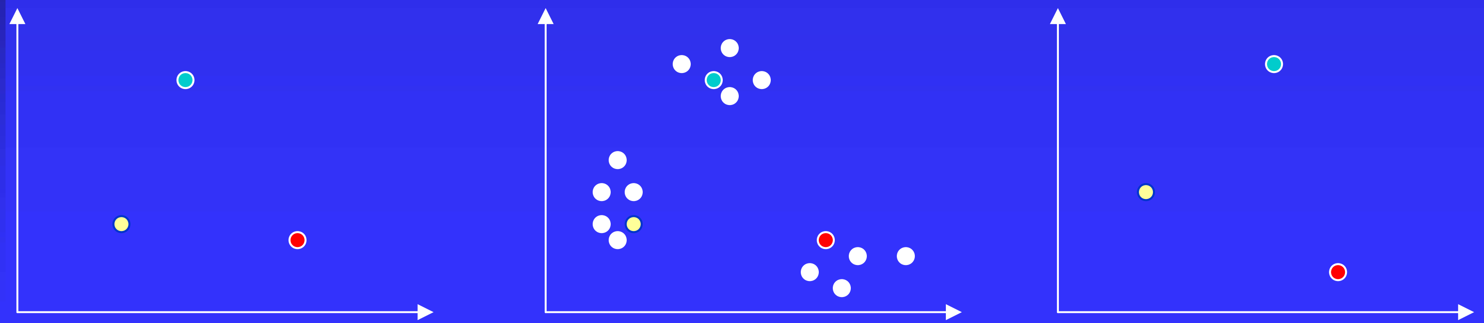
1. Set ic (iteration count) to 1

2. Choose randomly a set of K means $m_1(1), \ldots, m_K(1)$.

3. For each vector x_i, compute $D(x_i, m_k(ic)), k=1,\ldots K$ and assign x_i to the cluster C_j with nearest mean.

4. Increment ic by 1, update the means to get $m_1(ic),\ldots,m_K(ic)$.

5. Repeat steps 3 and 4 until $C_k(ic) = C_k(ic+1)$ for all k.



K-Means Classifier (shown on RGB color data)

$x_1=\{r_1, g_1, b_1\}$

$x_2=\{r_2, g_2, b_2\}$

…

$x_i=\{r_i, g_i, b_i\}$

…

→ Classifier (K-Means) →

Classification Results

$x_1 \rightarrow C(x_1)$

$x_2 \rightarrow C(x_2)$

…

$x_i \rightarrow C(x_i)$

…

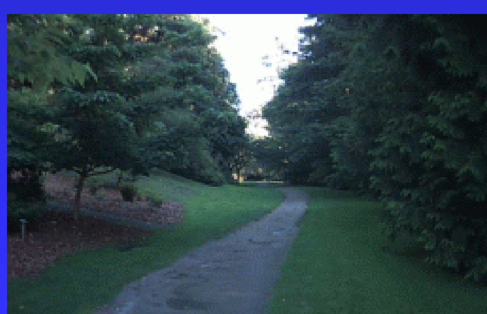
Cluster Parameters

m_1 for C_1

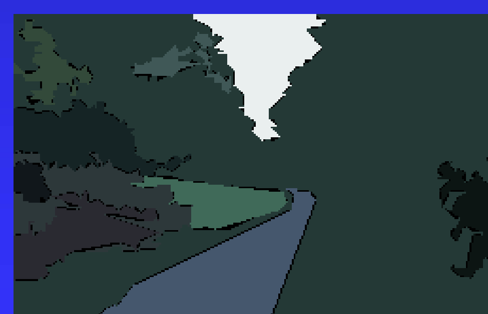
m_2 for C_2

…

m_k for C_k



original data
one RGB per pixel



color clusters

Abstract Regions

Original Images | Color Clusters | Texture Clusters | Line Clusters