Module 3-**Sensors for Robots (4)**

- Tactile sensors –
- Proximity and range sensors –
- Acoustic sensors –
- Vision sensor systems –
- Image processing and analysis –
  – Image data reduction
  – Segmentation
  – Feature extraction
  – Object recognition.

- Tactile sensing is an essential element of autonomous dexterous robot hand manipulation. It provides information about forces of interaction and surface properties at points of contact between the robot fingers and the objects.

- A **tactile sensor** is a device that measures information arising from physical interaction with its

- **What does it sense ?**

Deformation of bodies (strain) or fields (electric or magnetic).

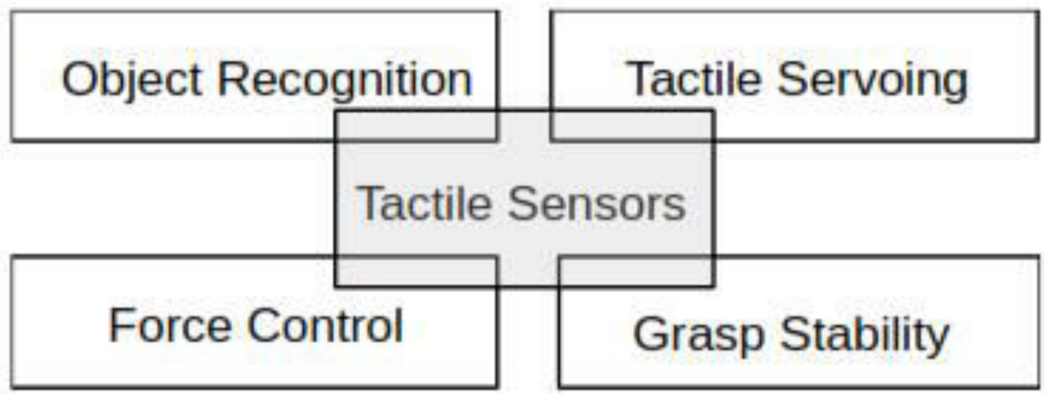


Figure 16: Tactile sensing techniques. Tactile sensing in robot hands is used for object recognition, tactile servoing, force control and for assessing grasp stability.

Types of Human Touch

- Cutaneous Sensations - Cutaneous sense receives sensory inputs from the receptors embedded in the skin.
  - *Senses : temperature, pressure, pain*

- Kinesthetic Sensations - Kinesthetic sense receives sensory inputs from the receptors located within muscles, tendons and joints.
  - *Senses : body position, movement, equilibrium*

- **Tactile Sensor ← Cutaneous Sensory Receptors**

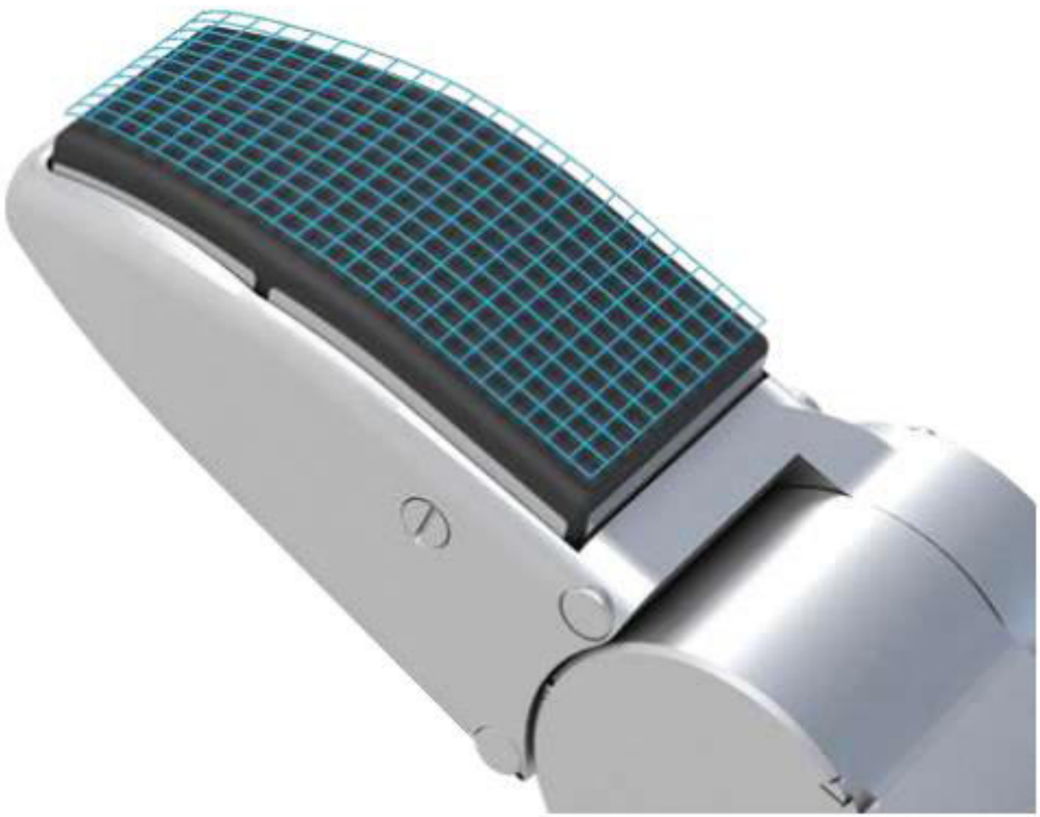
Types of Signal in Human Touch Sensing

Basis of Classification :

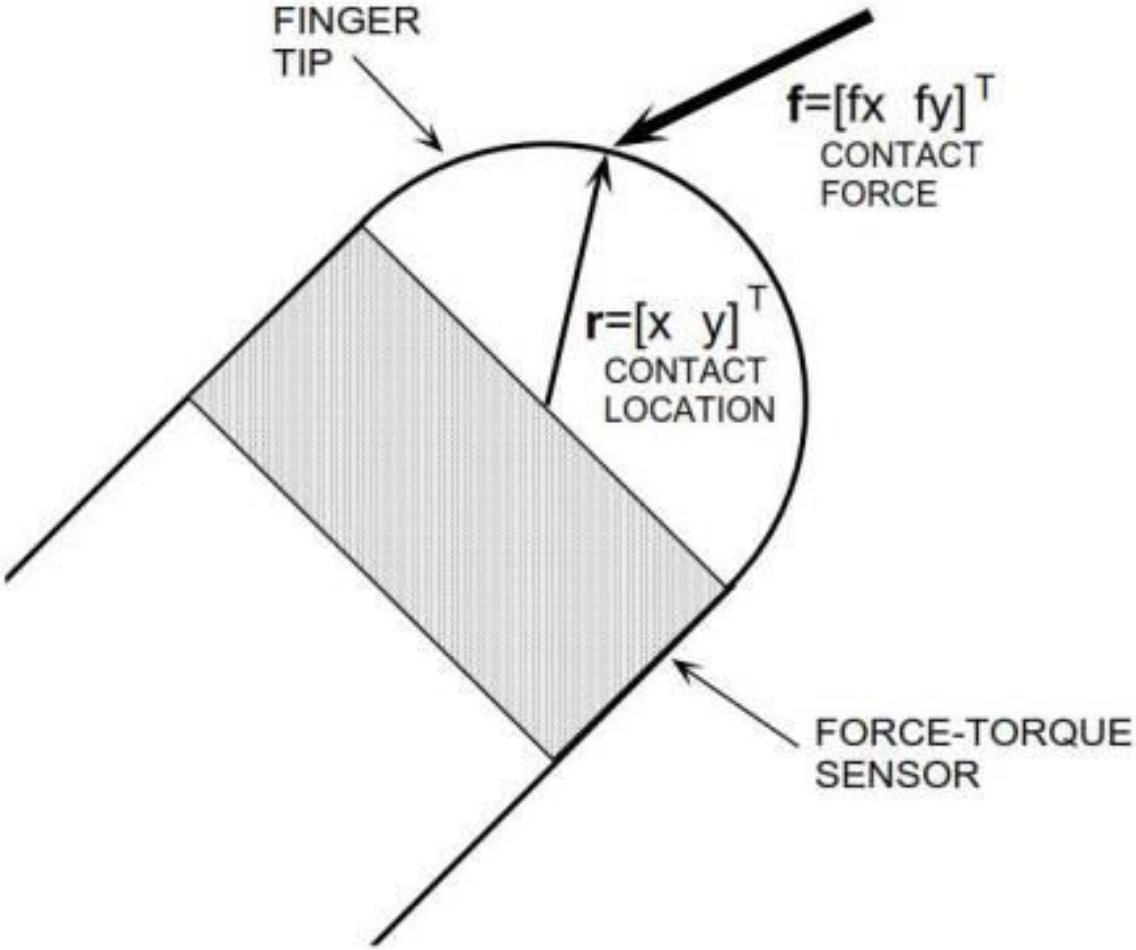
- Type of Signal Frequency of Signal

RECEPTOR TYPE	FIELD DIAMETER	FREQUENCY RANGE	POSTULATED SENSED PARAMETER
FAI	3—4 mm	10—60 Hz	Skin stretch
SAI	3—4 mm	DC—30 Hz	Compressive stress (curvature)
FAII	>20 mm	50—1000 Hz	Vibration
SAII	>10 mm	DC—15 Hz	Directional skin stretch

A grid of Tactels

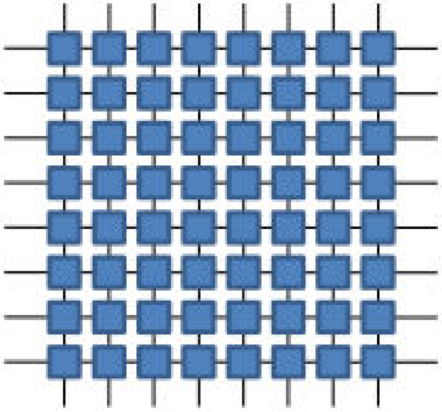
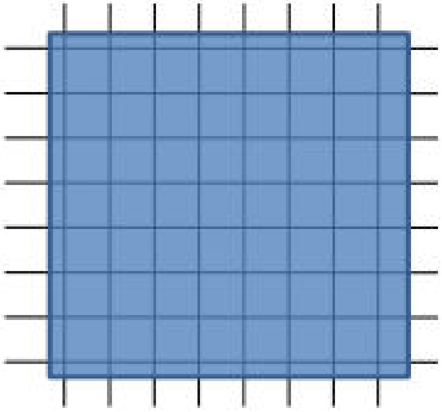


Force-Torque Sensor



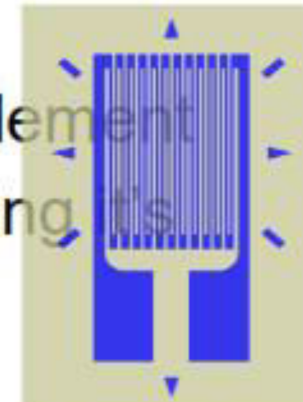
Tactile sensing: Methods of transduction

- Usually an array of discrete sensing elements.
- Sensing elements can be many types:
  - Resistive: strain gauge, piezoresistive.
  - Capacitive
  - Piezoelectric
  - & others like (magnetic, optical, conductive rubber, ultrasonic)

Resistive Sensing Elements :

- Strain gauge: a thin film having a metal pattern that changes resistance when strained.
- Piezoresistive element : Pressure on the element causes the material to compress, changing it's resistance

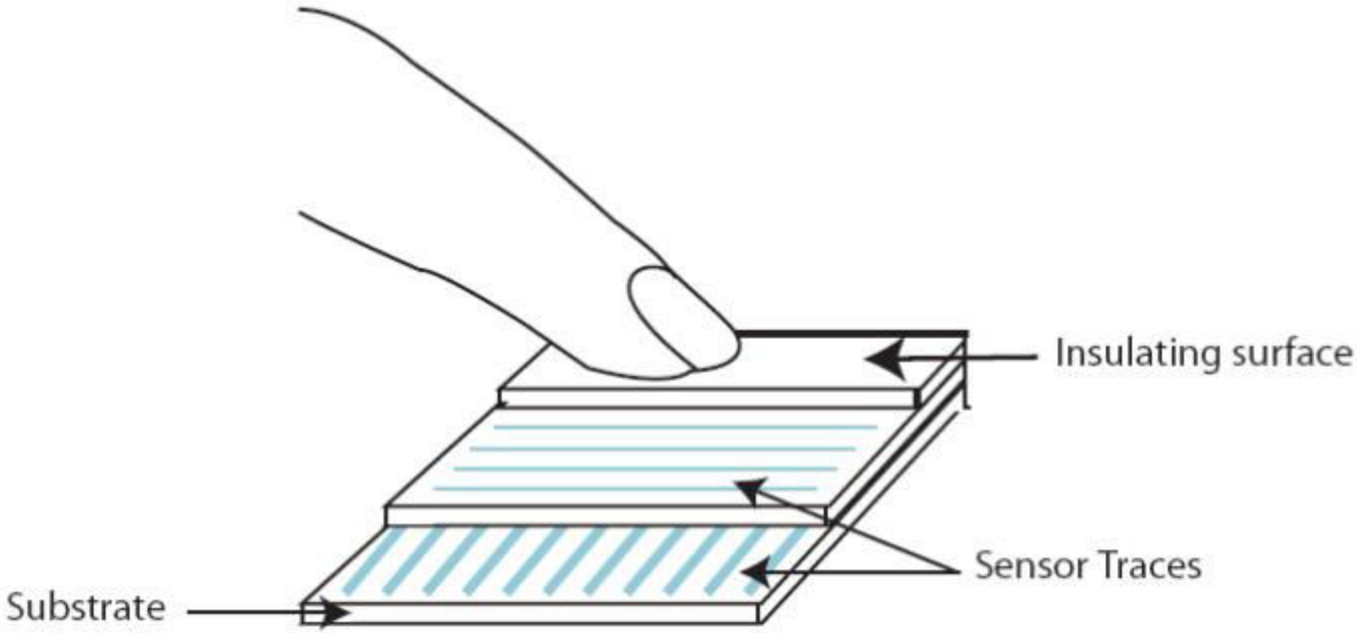


Strain gauge

- Advantages: very simple construction, durable, good dynamic range, easy readout
- Disadvantages: non-linearity, hysteresis, low sensitivity

Capacitive sensing

- Mechanical deformation changes the capacitance of parallel conducting plates



Capacitive Sensing Elements :

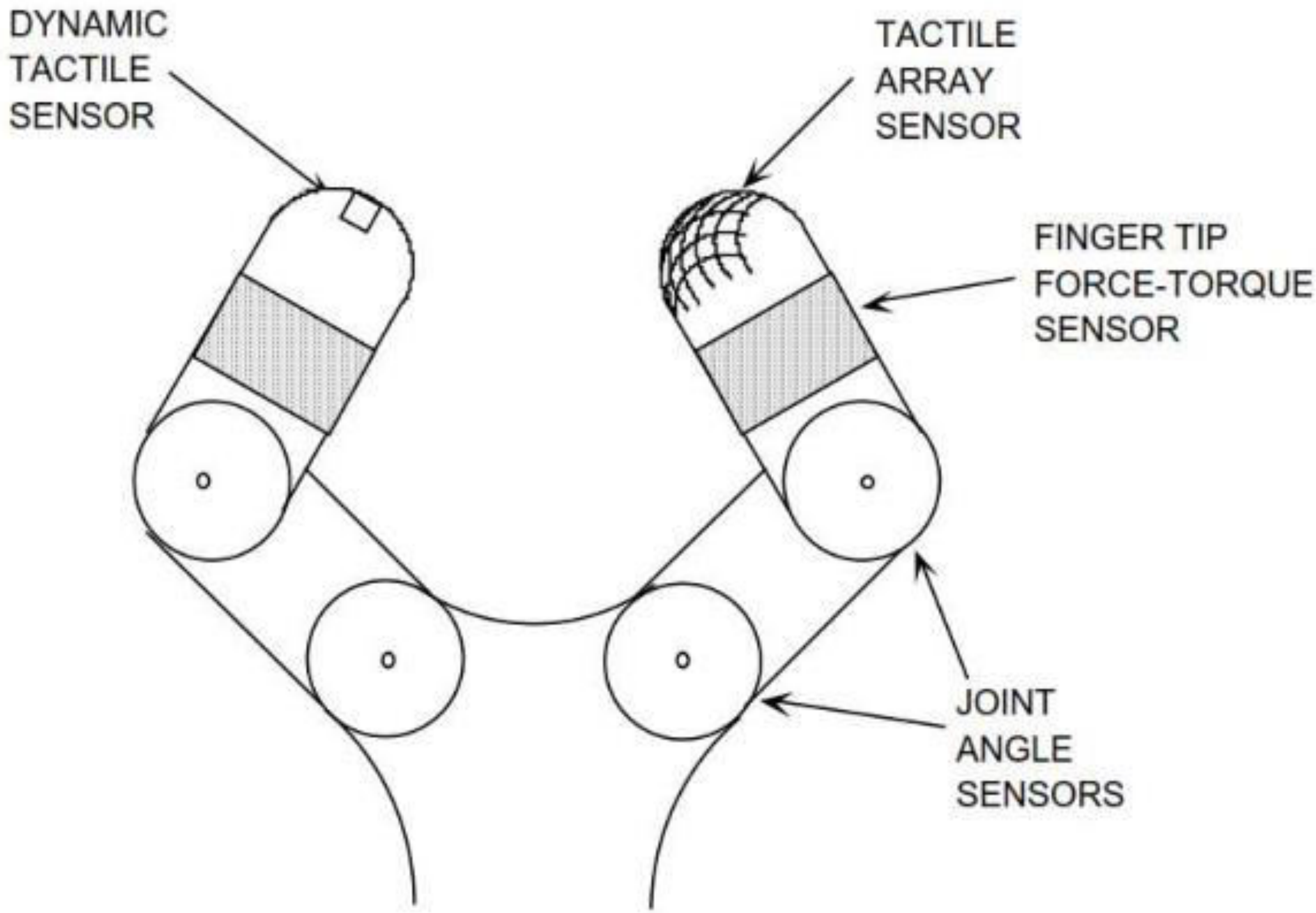
- Main application area: Touchscreens.
- Advantages: good dynamic range, linearity
- Disadvantages: noise, measuring capacitance is hard! (compared to measuring resistance)

Other sensing methods:

- Piezoelectric: measures voltage created due to polarization under stress
- Magnetic: uses Hall effect to measure change in flux density
- List of other methods with their merits & demerits are as follows :

Type	Merits	Demerits
Resistive	• Sensitive • Low Cost	• High Power Consumption • Generally detect single contact point • Lack of Contact force measurement
Piezoresistive	• Low cost • Good sensitivity • Low noise • Simple electronics	• Stiff and frail • Non linear response • Hysteresis • Temperature sensitive • Signal drift
Tunnel Effect	• Sensitive • Physically flexibile	• Non Linear response
Capacitive	• Sensitive • Low cost • Availabilityof commercial A/D chips.	• Cross-talk • Hysteresis • Complex Electronics
Optical	• Immunity to electromagnetic Interference • Physically flexible • Sensitive • Fast • No interconnections.	• Bulky • Loss of light by micro bending • Chirping • Power Consumption • Complex computations.
Ultrasonic	• Fast dynamic response • Good force resolution	• Limited utility at low frequency • Complex electronics • Temperature Sensitive
Magnetic	• High sensitivity • good dynamic range, • no mechanical hysteresis • physical robustness	• Suffer from magnetic interference • Complex computations • Somewhat bulky • Power Consumption
Piezoelectric	• Dynamic Response • High Bandwidth	• Temperature Sensitive • Not so robust electrical connection.
Conductive Rubber	• Physically flexible	• Mechanical hysteresis • Non linear response

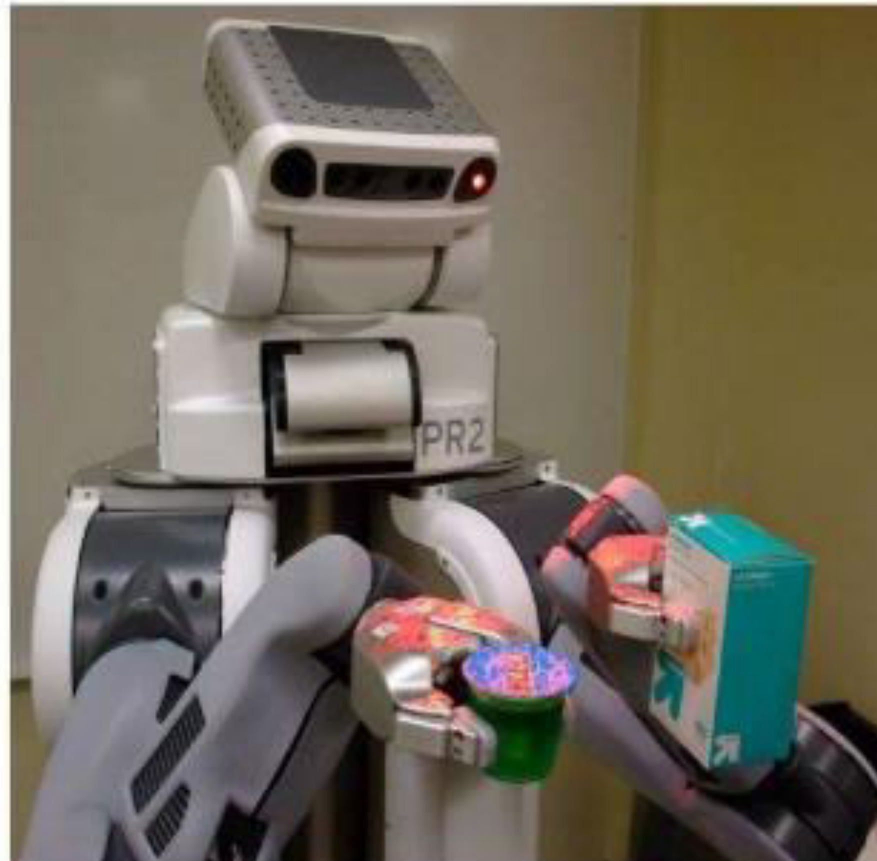
Table 1. Relative merits and demerits of various tactile sensor types.


DYNAMIC
TACTILE
SENSOR
TACTILE
ARRAY
SENSOR
FINGER TIP
FORCE-TORQUE
SENSOR
JOINT
ANGLE
SENSORS

SENSOR	PARAMETER	LOCATION
Tactile array sensor	pressure distribution, local shape	in outer surface of finger tip
Finger tip force-torque sensor	contact force and torque vectors	in structure near finger tip
Finger joint angle sensor	finger tip position, contact location	at finger joints or at motor
Actuator effort sensor	motor torque	at motor or joint
Dynamic tactile sensor	vibration, stress changes, slip, etc.	in outer surface of finger tip

Applications :

- ***Manipulation***: Grasp force control; contact locations and kinematics; stability assessment.
- ***Exploration***: Surface texture, friction and hardness; thermal properties; local features.
- ***Response***: Detection and reaction to contacts from external agents.



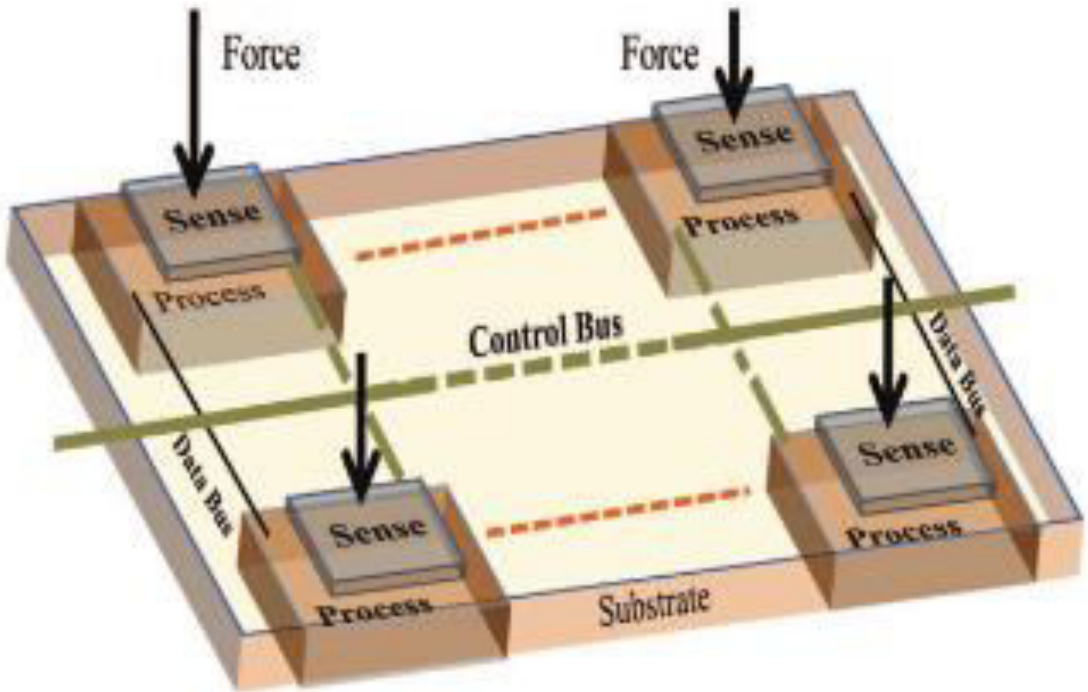
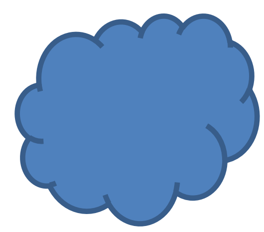
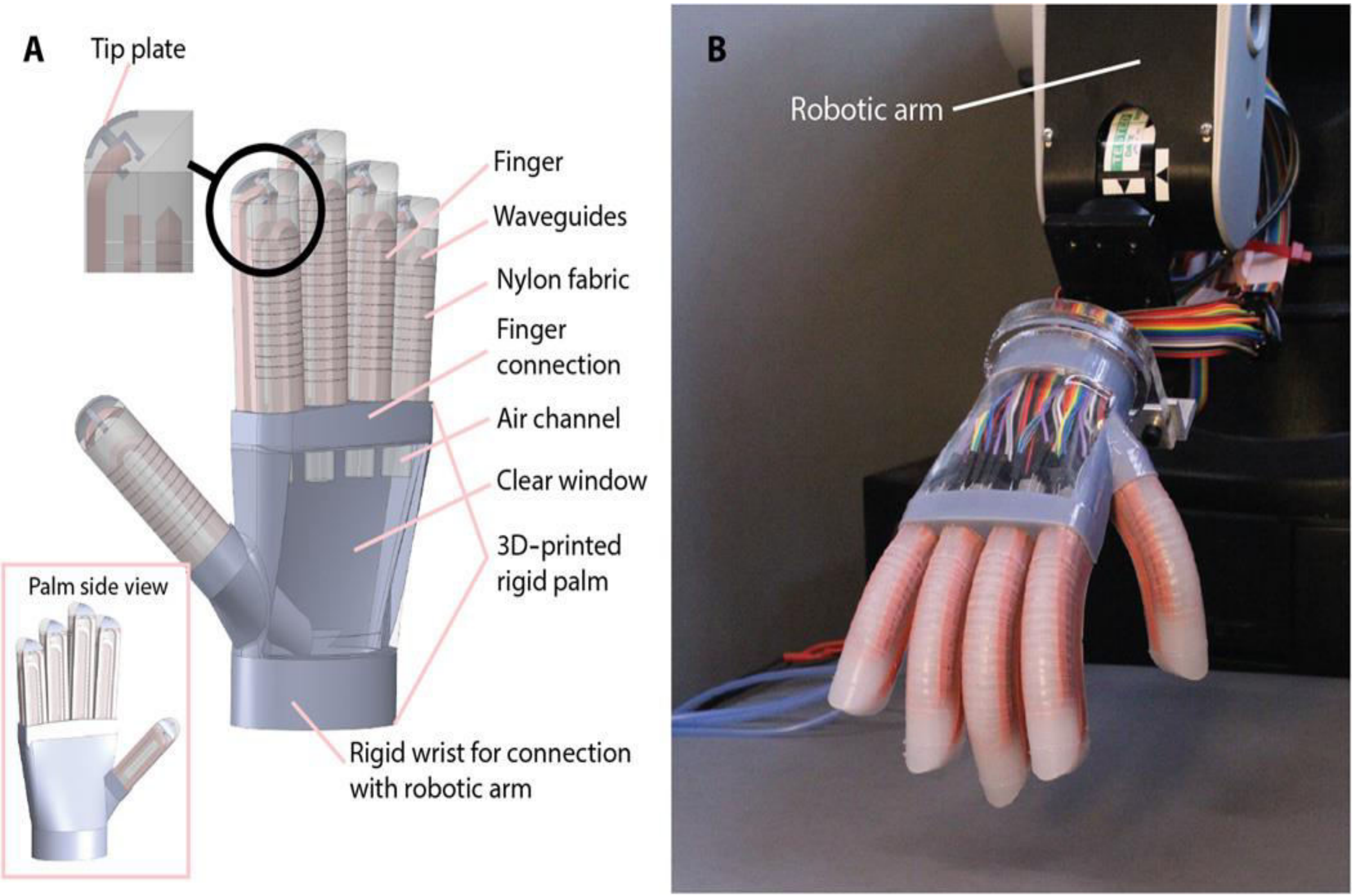
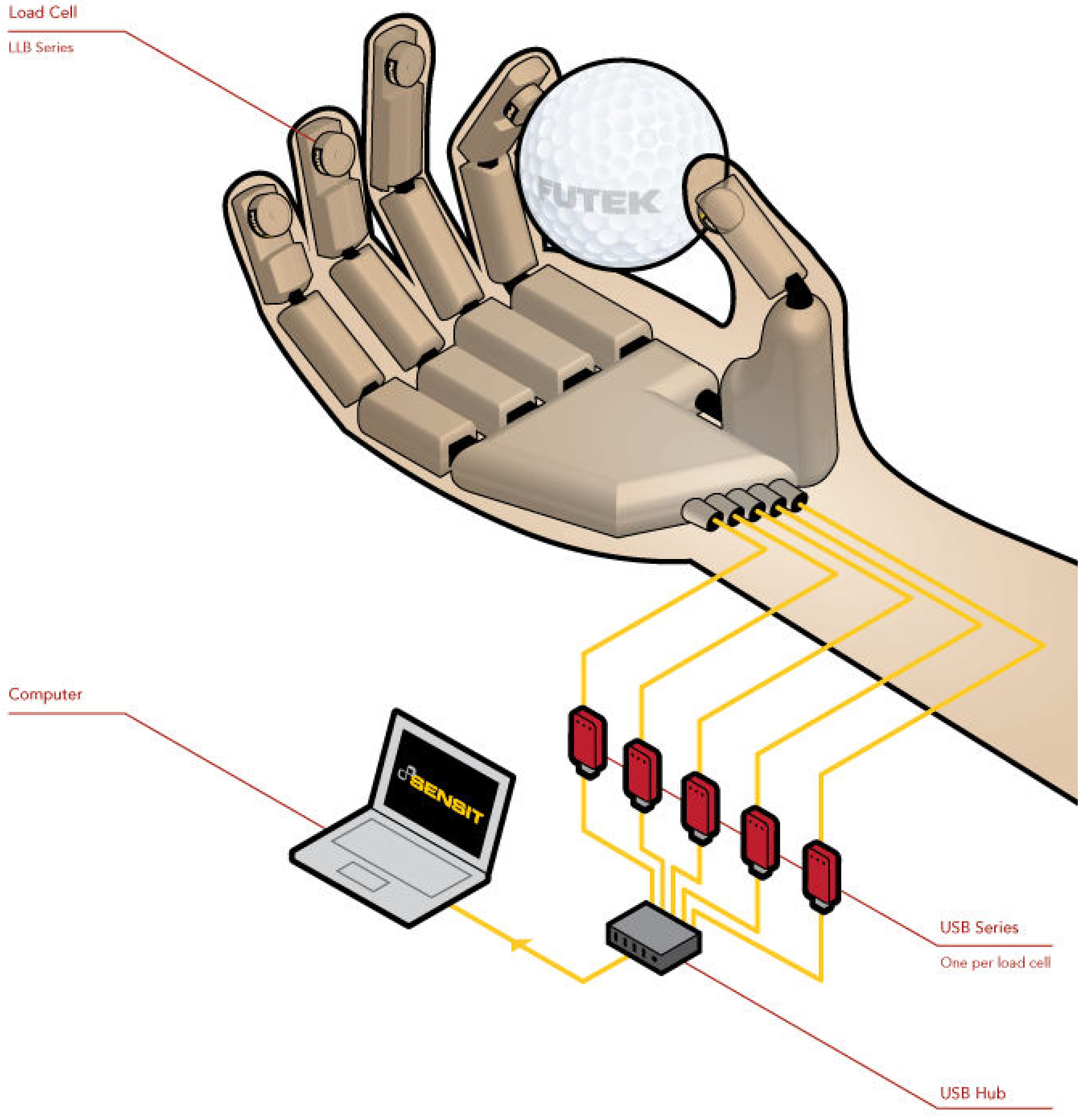


Fig. 1. 'Sense and Process at same place' approach for development of tactile sensign arrays (Dahiya, Valle et al. 2008).




A
Tip plate
Finger
Waveguides
Nylon fabric
Finger connection
Air channel
Clear window
3D-printed rigid palm
Palm side view
Rigid wrist for connection with robotic arm
B
Robotic arm


Load Cell
LLB Series
FUTEK
Computer
SENSIT
USB Series
One per load cell
USB Hub

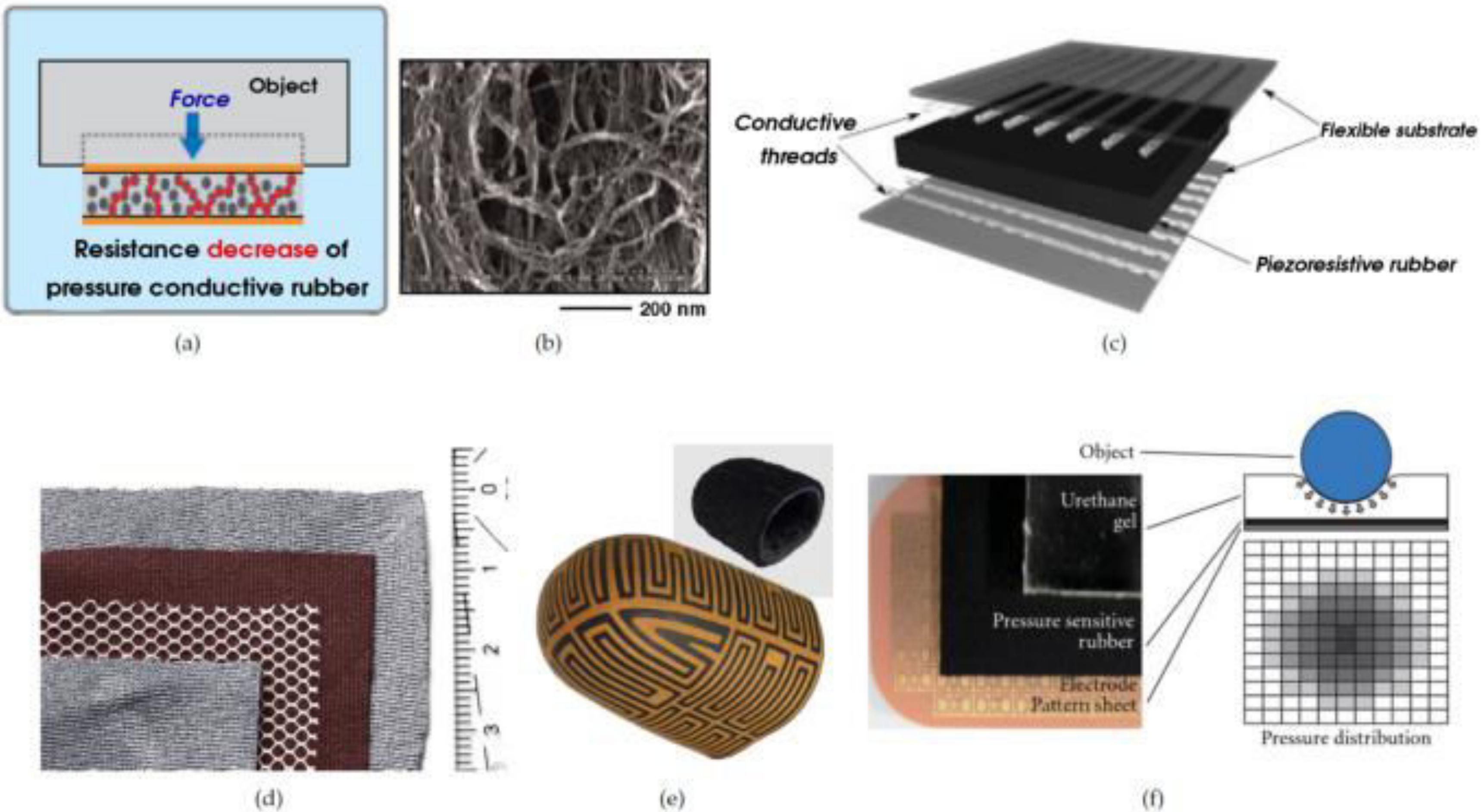


Figure 1: Piezoresistive Tactile Sensor Arrays: (a) illustration of resistance changes in conductive rubber [47],(b) nano-scale image of conductive rubber [48], (c) structure of piezoresistive tactile array [49], (d) piezoresistive fabric tactile sensor [50], (e) schematic of electrode layer of the 3D-shaped tactile sensor [34], (f) tactile image of a piezo-resistive pressure sensor array [35].

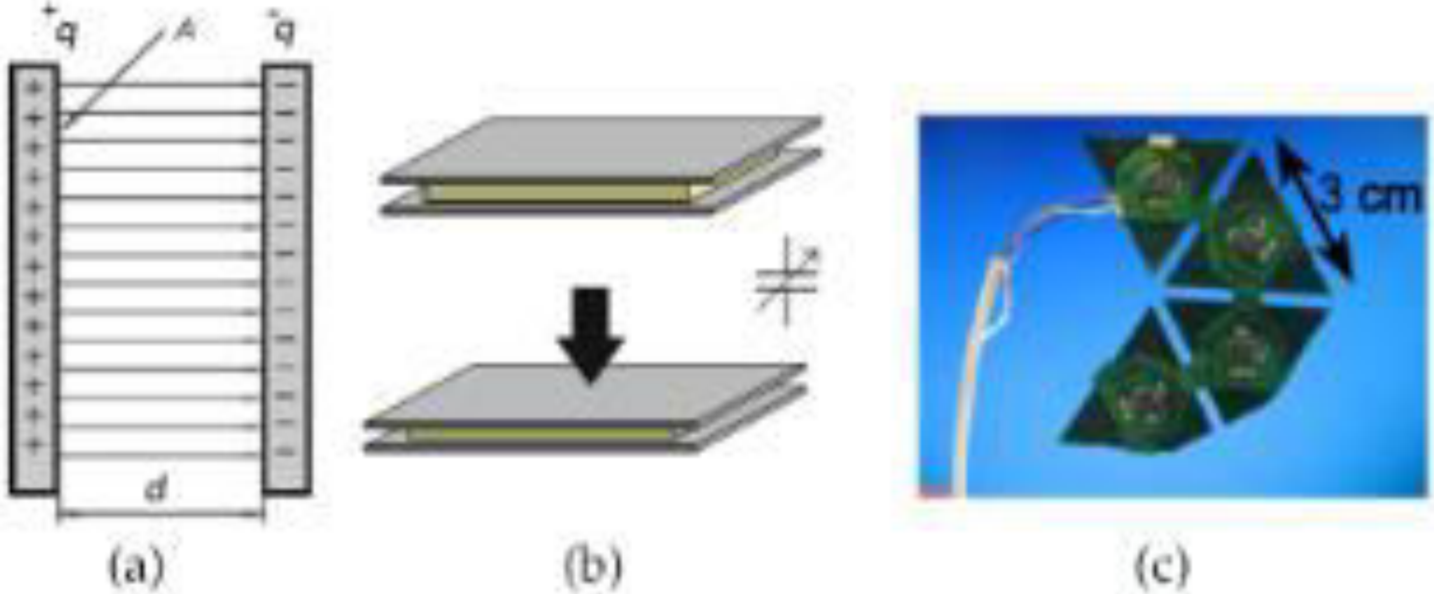


Figure 2: Capacitive Tactile Sensing Technology: (a) capacitance of a parallel plate capacitor depends on distance between plates d and area of the plates A (q is the stored charge) [45]; (b) two conductive plates are separated by an elastic dielectric – as force is applied, the distance between the plates reduces, changing the capacitance [9]; (c) mesh of triangle shape capacitive sensors for the palm of the iCub humanoid robot [44].

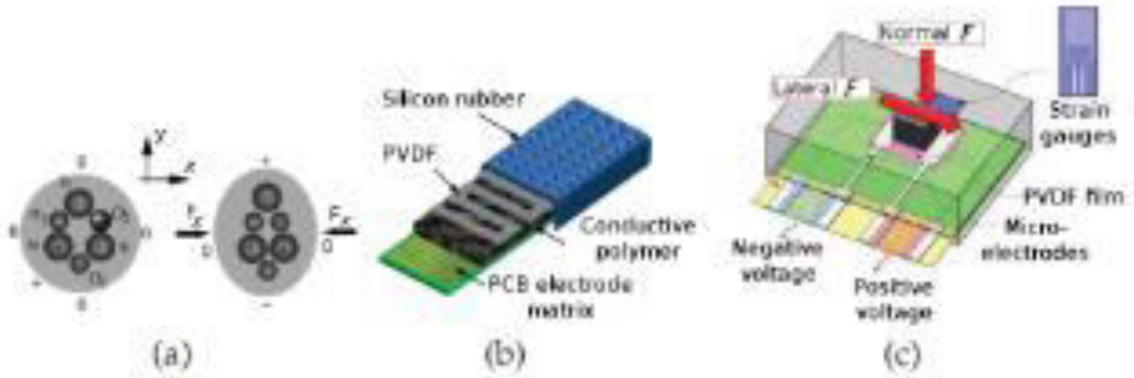


Figure 3: Piezoelectric Tactile Sensing: (a) the piezoelectric effect – an applied force causes rearrangement of positive Si and negative O_2 particles leading to an increase of potential [45]; (b) a tactile sensing array based on the piezoelectric effect with electrodes on the bottom layer, piezolectric material in the middle and rubber on the top [24], (c) schematic model of a piezoelectric sensing tactel [71].

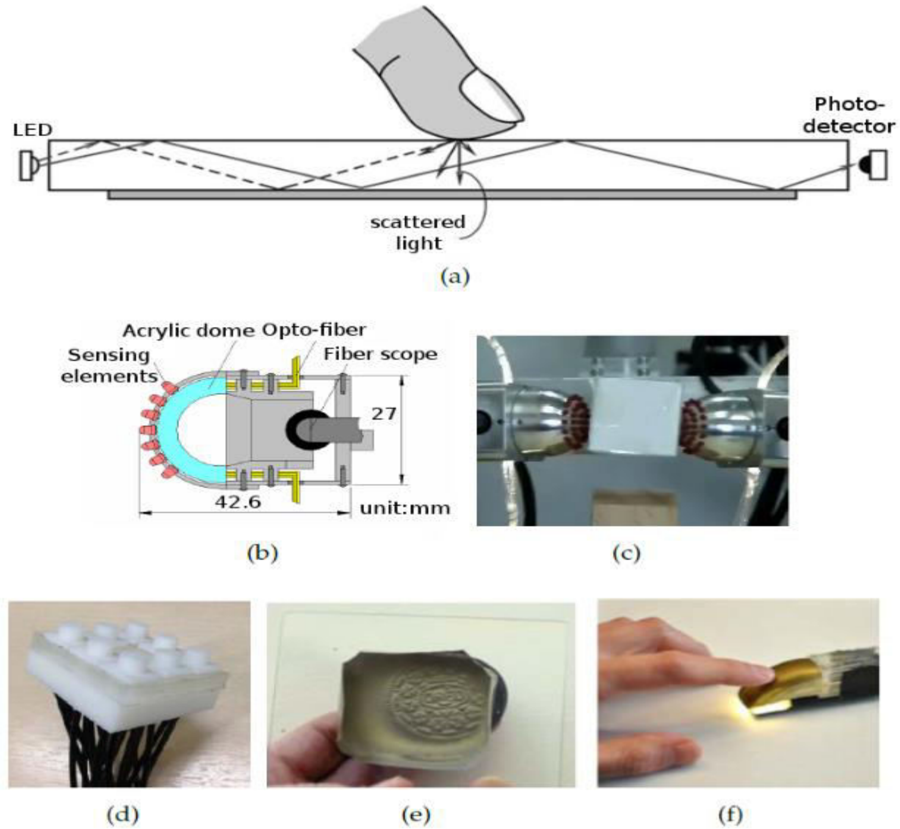


Figure 5: Optical Tactile Sensors: (a) an optical tactile transducer based on the principle of frustrated total internal reflection [45], (b) a structure of optical three-axis tactile sensor: a displacement of a sensing element fixed on flexible finger surface causes changes in light propagation in opto-fibers [37], (c) fingers with the sensitive optical sensors manipulating a light paper box [37], (d) photo of an optical 3 x 3 tactile array with magnetic field compatibility [77], (e) "GelSight" optical sensor consisting of a piece of clear elastomer coated with a reflective membrane senses the shape of the cookie surface [79], (f) finger configurations of the "GelSight" sensor [79].

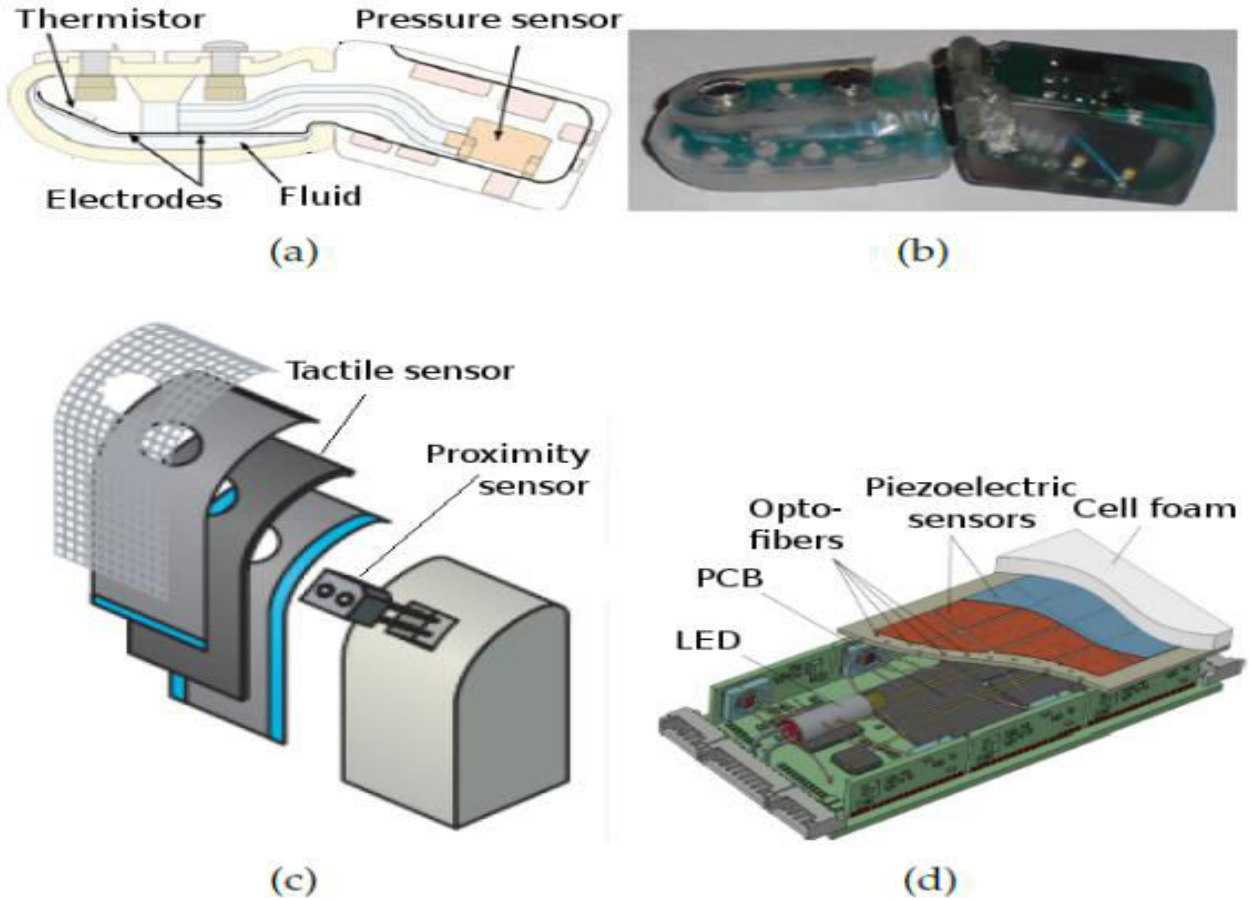


Figure 7: Multimodal Tactile Sensors: (a) schematic of the biomimetic BioTac tactile sensor with 19 electrodes, fluid pressure sensor and thermometer [84], (b) photo of the multimodal BioTac tactile sensor, (c) combined tactile-proximity sensor that can measure both the distance to an object and the contact pressure [90], (d) drawing of a multi-modal tactile sensing module consisting of optical and piezoresistive sensors [76].

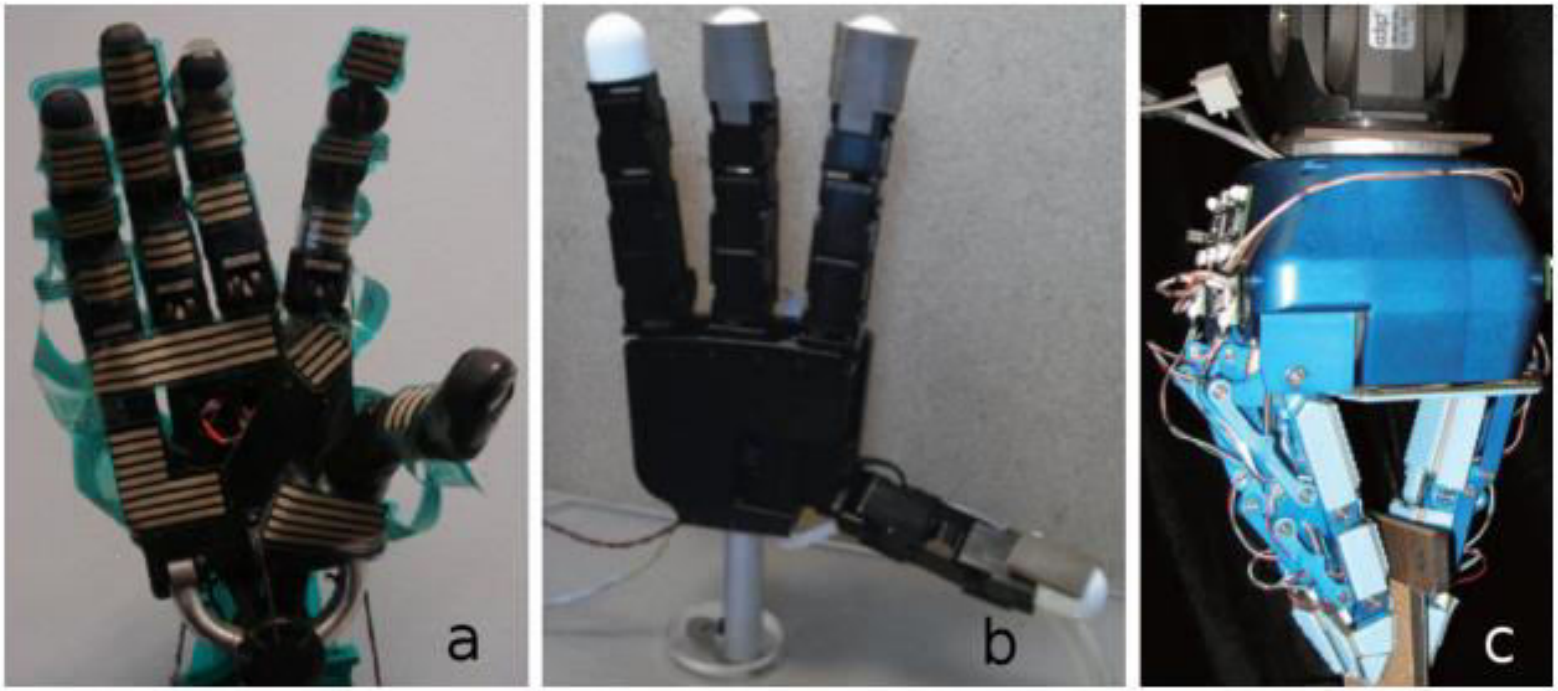


Figure 10: Simple integration of tactile sensing arrays: (a) the Tekscan tactile sensing system consisting of 349 taxels with the Shadow robot hand [94], (b) the Allegro robot hand with PPS RoboTouch capacitive arrays [64], (c) the Robotiq adaptive gripper with sensor suite installed on the contact surface [65]

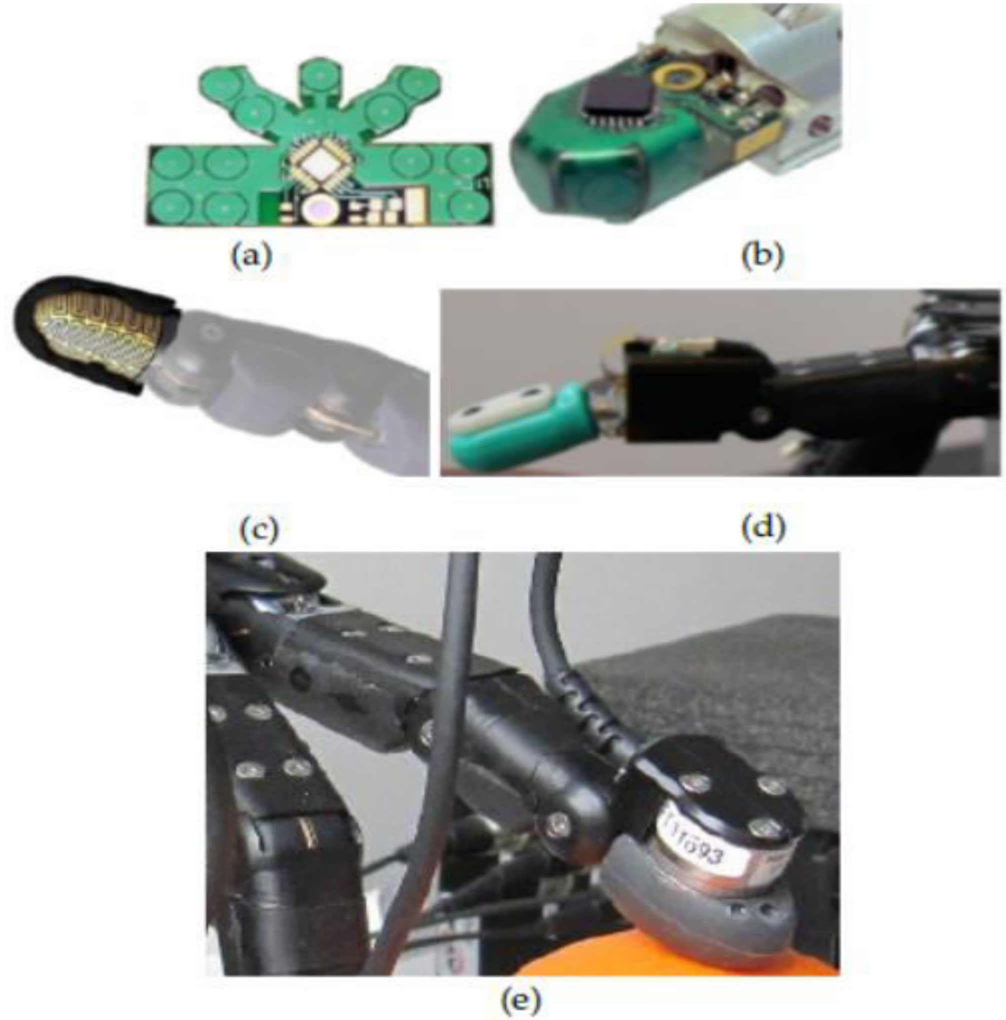


Figure 11: Advanced integration of tactile sensors on the robot fingertips: (a) a flexible PCB for a capacitive tactile sensing array with 12 taxels designed for the iCub humanoid robot [103],(b) the iCub flexible PCB wrapped around the inner support of the fingertip [103], (c) a 3D-shaped rigid tactile sensing array with 12 sensing elements attached to the fingertip of the Shadow robot hand [34], (d) the BioTac multimodal tactile sensor installed on the Shadow robot hand by replacing two last links of the finger [43], (e) ATi nano 17 force/torque sensor on the fingertip of the Shadow robot hand [30].

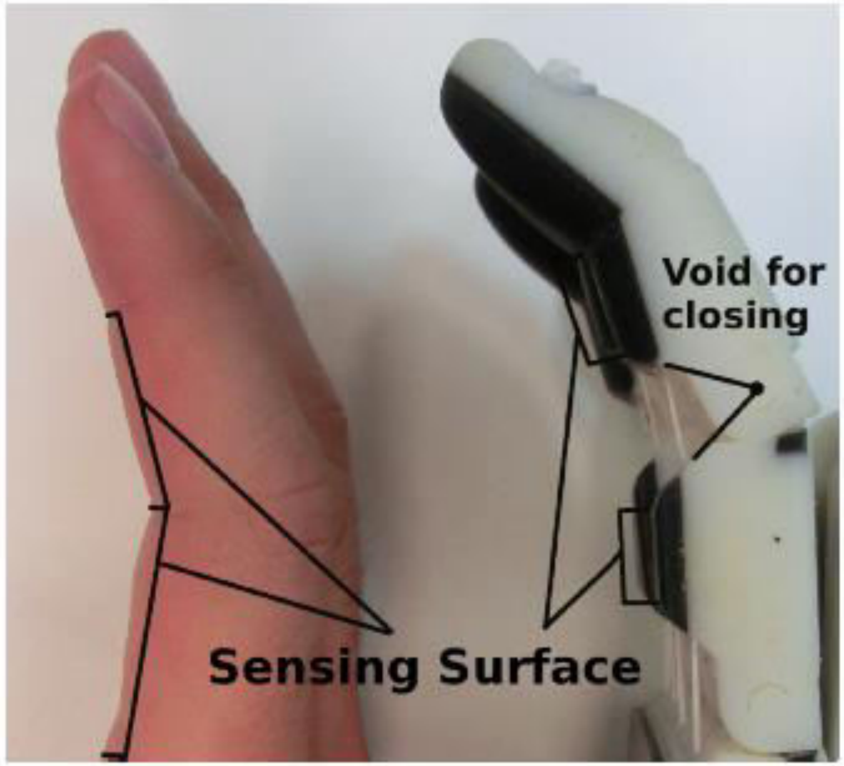


Figure 12: Difference in contact surfaces between a human finger and a robot finger [105].

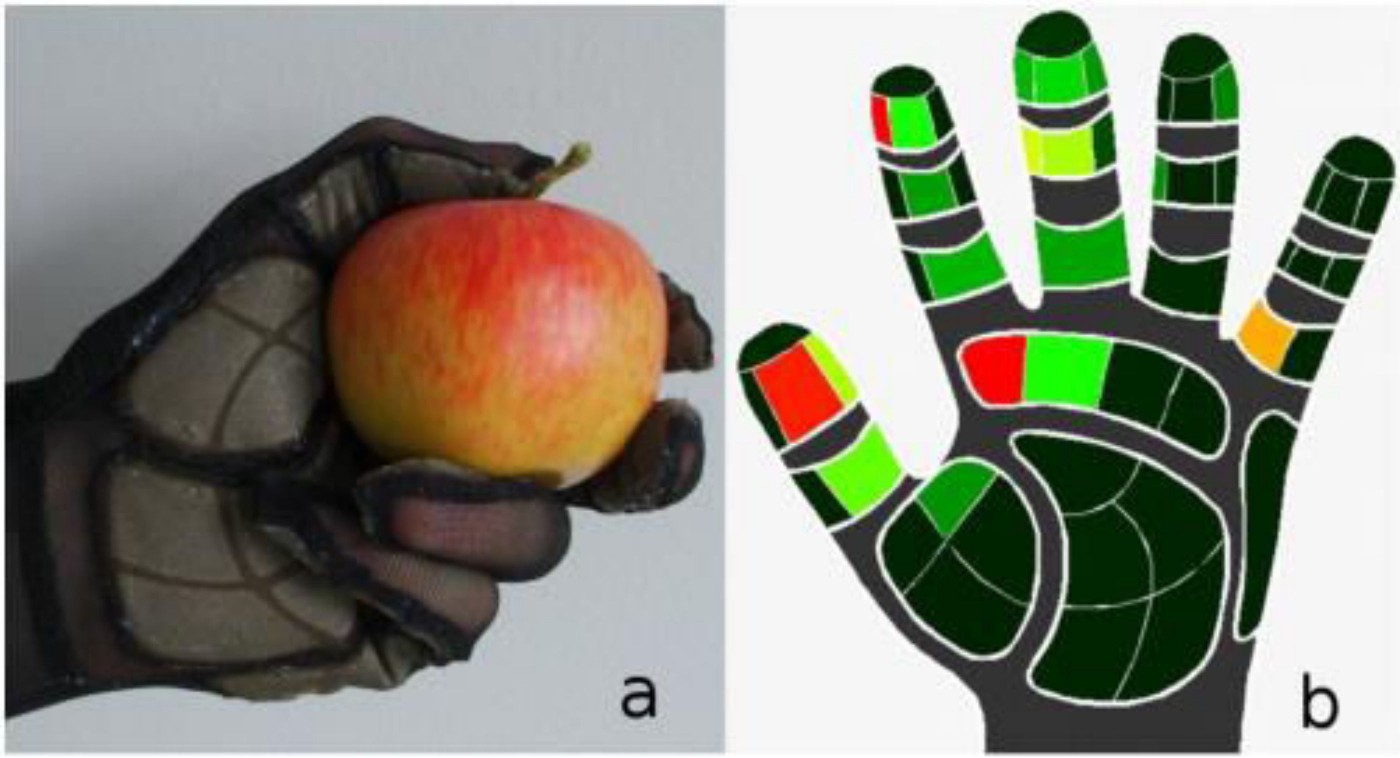
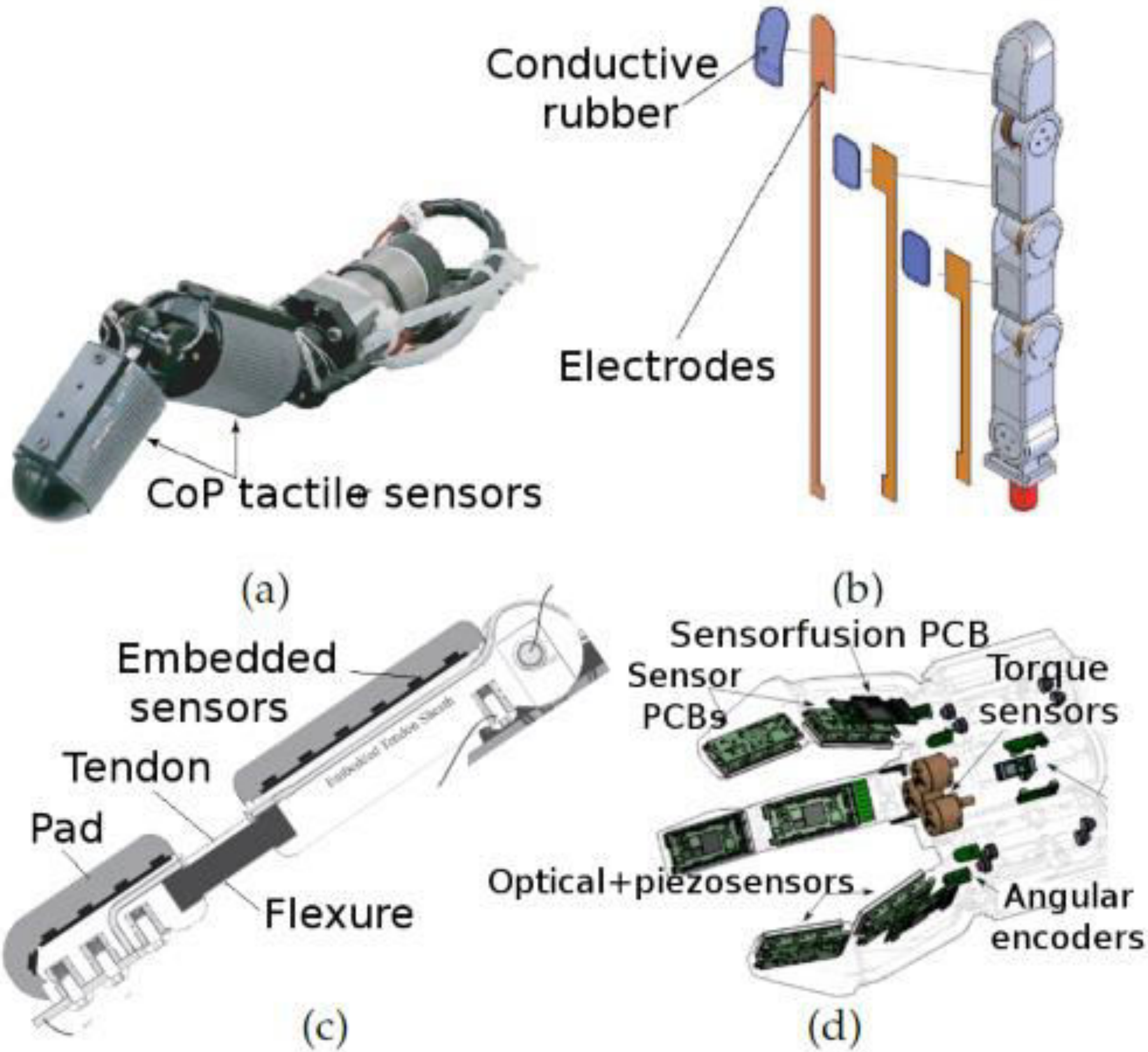


Figure 13: Tactile data glove based on conductive rubber (a) and the tactile information from the data glove during a grasp (b) [54].

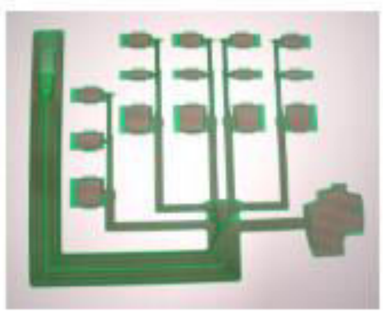


Conductive rubber
Electrodes
CoP tactile sensors
(a)
(b)
Embedded sensors
Tendon
Pad
Flexure
(c)
Sensorfusion PCB
Sensor PCBs
Torque sensors
Optical+piezosensors
Angular encoders
(d)

Figure 14: Three-fingered robot hands with tactile sensors: (a) a finger with tactile sensor of the 3-fingered high-speed robot hand [101], (b) assembly of tactile sensing arrays with a robot finger of the Universal robot hand with 3 movable and 2 immovable fingers [35], (c) schematic illustration of a finger of the iHY robot hand with embedded array of pressure sensors based on digital barometers placed inside the soft paddings of the fingers [42]; (d) schematic illustration of the integration of a multimodal sensing system with a three-fingered robot hand [76]

(a)

(b)



(c)

(d)

Figure 15: Five-fingered robot hands with tactile sensors: (a) the fluidic robot hand with combined piezoelectric and piezoresistive tactile sensors that can sense high-frequency vibrations due to the absence of electric motors [24], (b) the robot hand of the iCub humanoid robot with tactile sensors on the fingertips and the palm [44], (c) flexible tactile sensing arrays of the SKKU robot hand [88], (d) the SKKU robot hand [88]

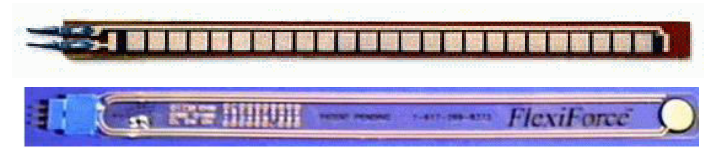
PROXIMITY AND RANGE SENSORS

- It is a technique of detecting the presence or absence of an object with electronic noncontact sensors.
- Typical application of proximity sensors includes:
  - ש Object detection
  - ש Collision avoidance
  - ש Object verification & counting

- Commonly available proximity sensors are:
  1. Photoelectric/optical sensors
  2. Inductive proximity sensors
  3. Capacitive proximity sensors
  4. Ultrasonic proximity sensors

Resistive Sensors

Bend Sensors
• Resistance = 10k to 35k
• As the strip is bent, resistance increases



Resistive Bend Sensor

Potentiometers
• Can be used as position sensors for sliding mechanisms or rotating shafts
• Easy to find, easy to mount

Potentiometer

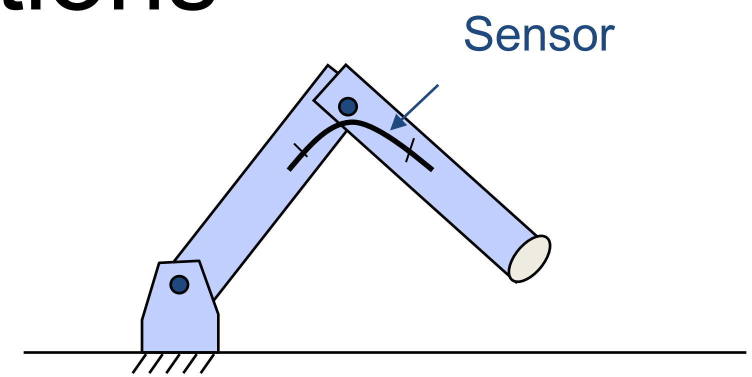
Light Sensor (Photocell)
• Good for detecting direction/presence of light
• Non-linear resistance
• Slow response to light changes

Photocell

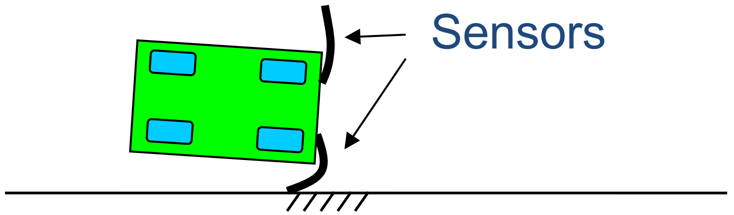
R is small when brightly illuminated

Applications

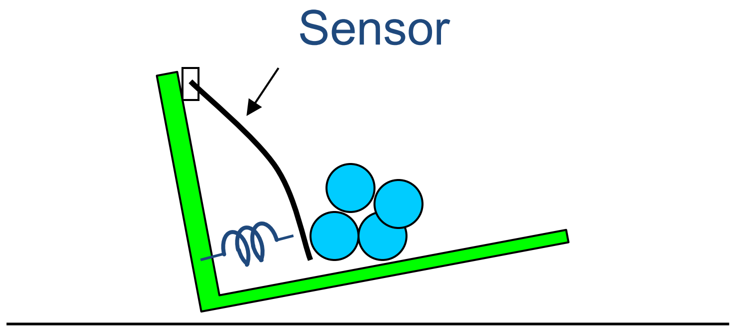
- Measure bend of a joint



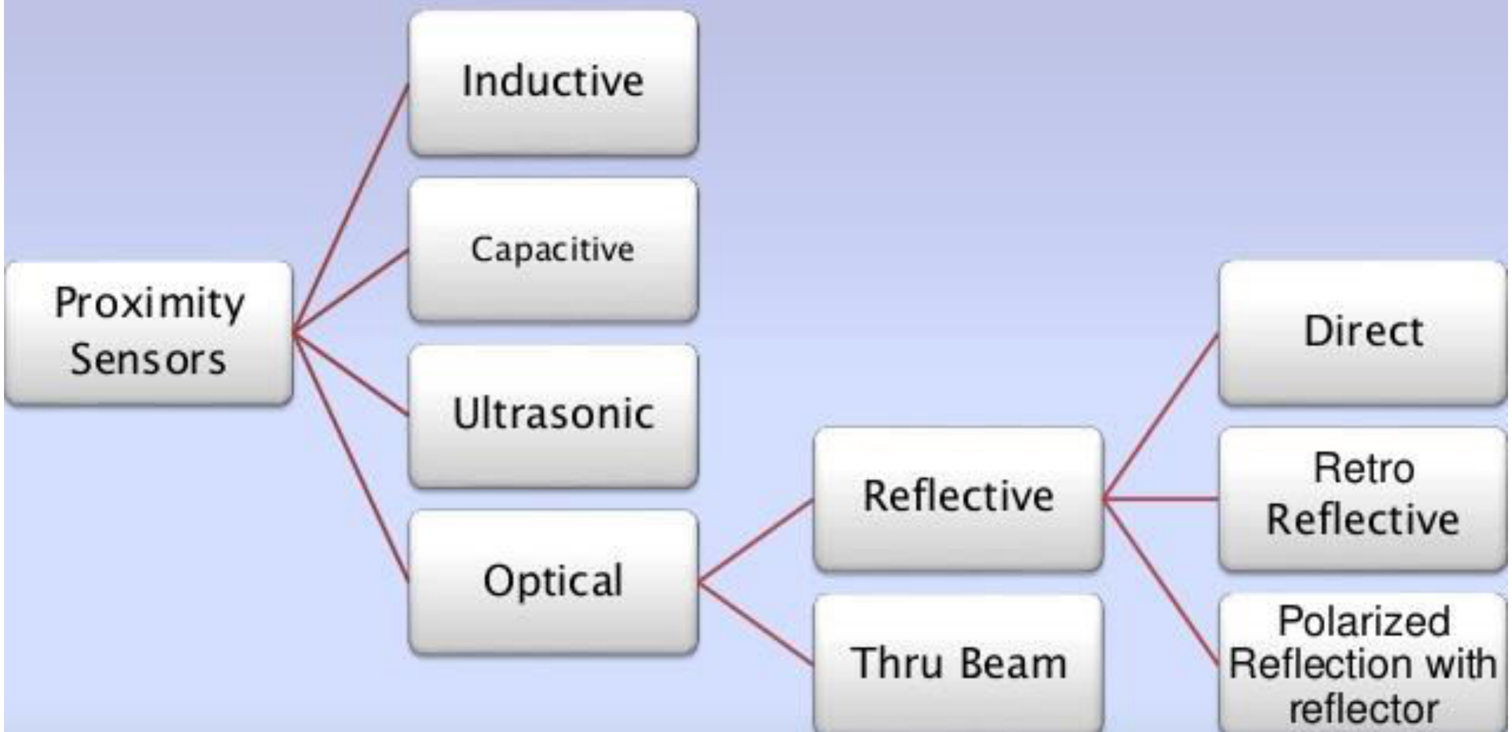
- Wall Following/Collision Detection

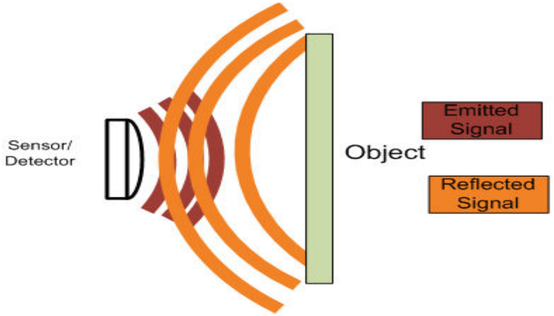


- Weight Sensor



Types of Proximity Sensors



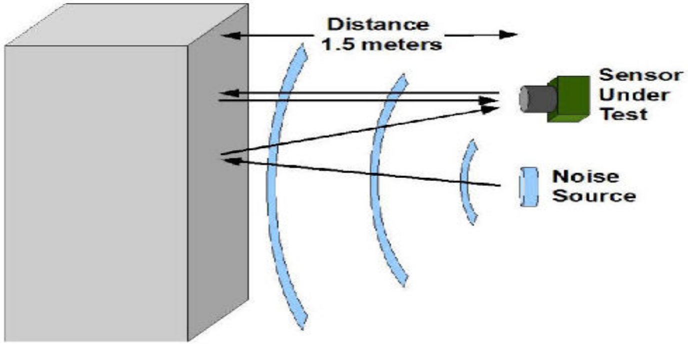


ACOUSTIC PROXIMITY SENSOR

An acoustic proximity sensor can be used by a robot to detect the presence of, and determine the distance to, an object or barrier at close range. It works based on acoustic wave interference.

The principle is similar to that of sonar; but rather than measuring the time delay between the transmission of a pulse and its echo, the system analyzes the phase relationship between the transmitted wave and the reflected wave.

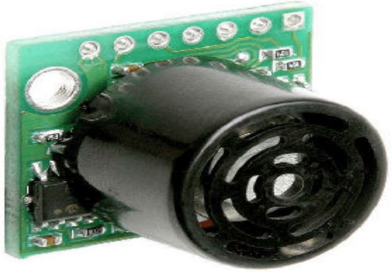
How Does It Work

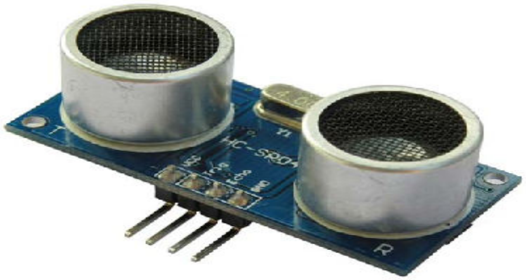


When an acoustic signal having a single, well-defined, constant frequency(and therefore a single,well-defined, constant wavelength) reflects from a nearby object, the reflected wave combines with the incident wave to form alternating zones at which the acoustic energy adds and cancels in phase.

If the robot and the object are both stationary, these zones remain fixed. Because of this, the zones are called standing waves. If the robot moves with respect to the object, the standing waves change position.

Even a tiny shift in the relative position of the robot and the sensed object can produce a considerable change in the pattern of standing waves. This effect becomes more pronounced as the acoustic wave frequency increases, because the wavelength is inversely proportional to the frequency.





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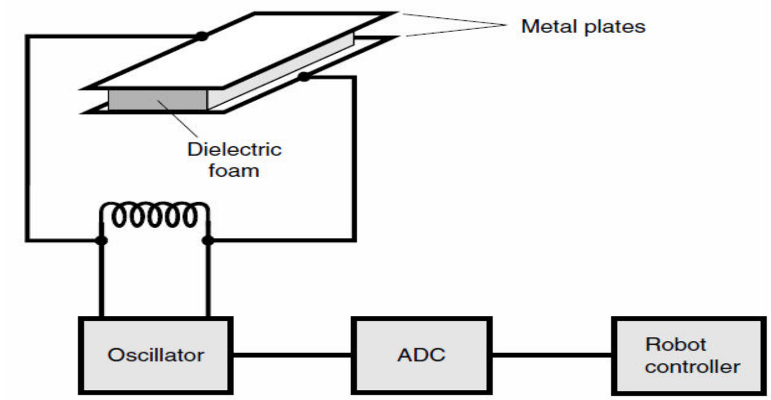
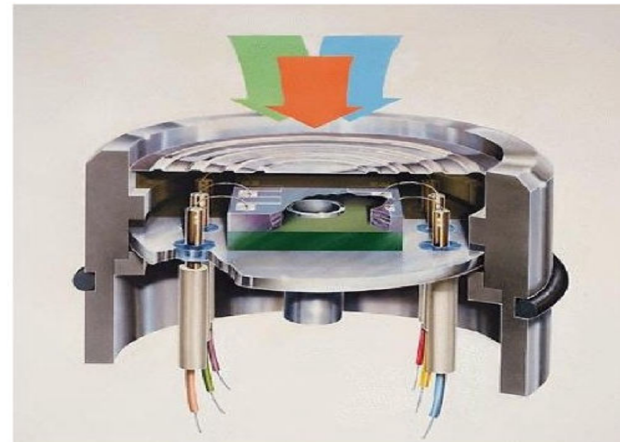
Encyclopedia of Robotics - CAPACITIVE PRESSURE SENSOR

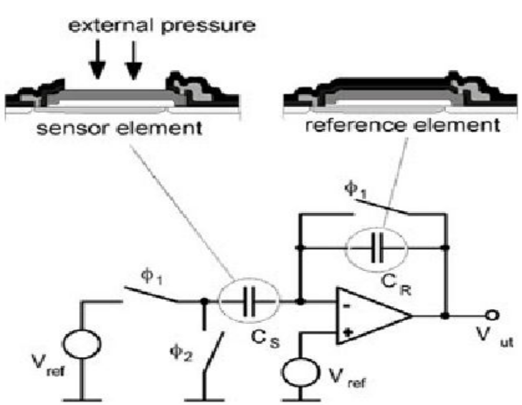
A capacitive pressure sensor consists of two metal plates separated by a layer of nonconductive (dielectric) foam. The resulting variable capacitor is connected in parallel with an inductor; the inductance/capacitance (LC) circuit determines the frequency of an oscillator.

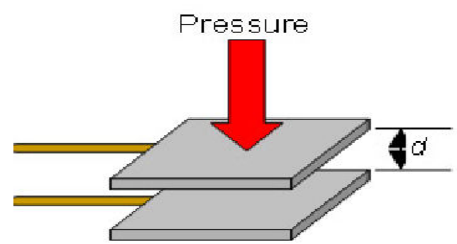


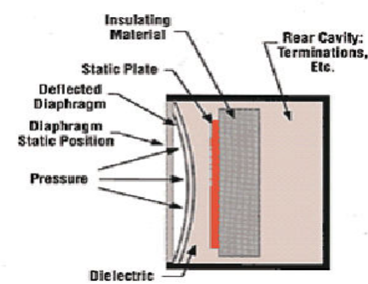
Capacitive pressure sensor



If an object strikes the sensor, the plate spacing momentarily decreases. This increases the capacitance, causing a drop in the oscillator frequency. When the object moves away from the transducer, the foam springs back, the plates return to their original spacing, and the oscillator frequency returns to normal. The illustration is a functional block diagram of a capacitive pressure sensor.







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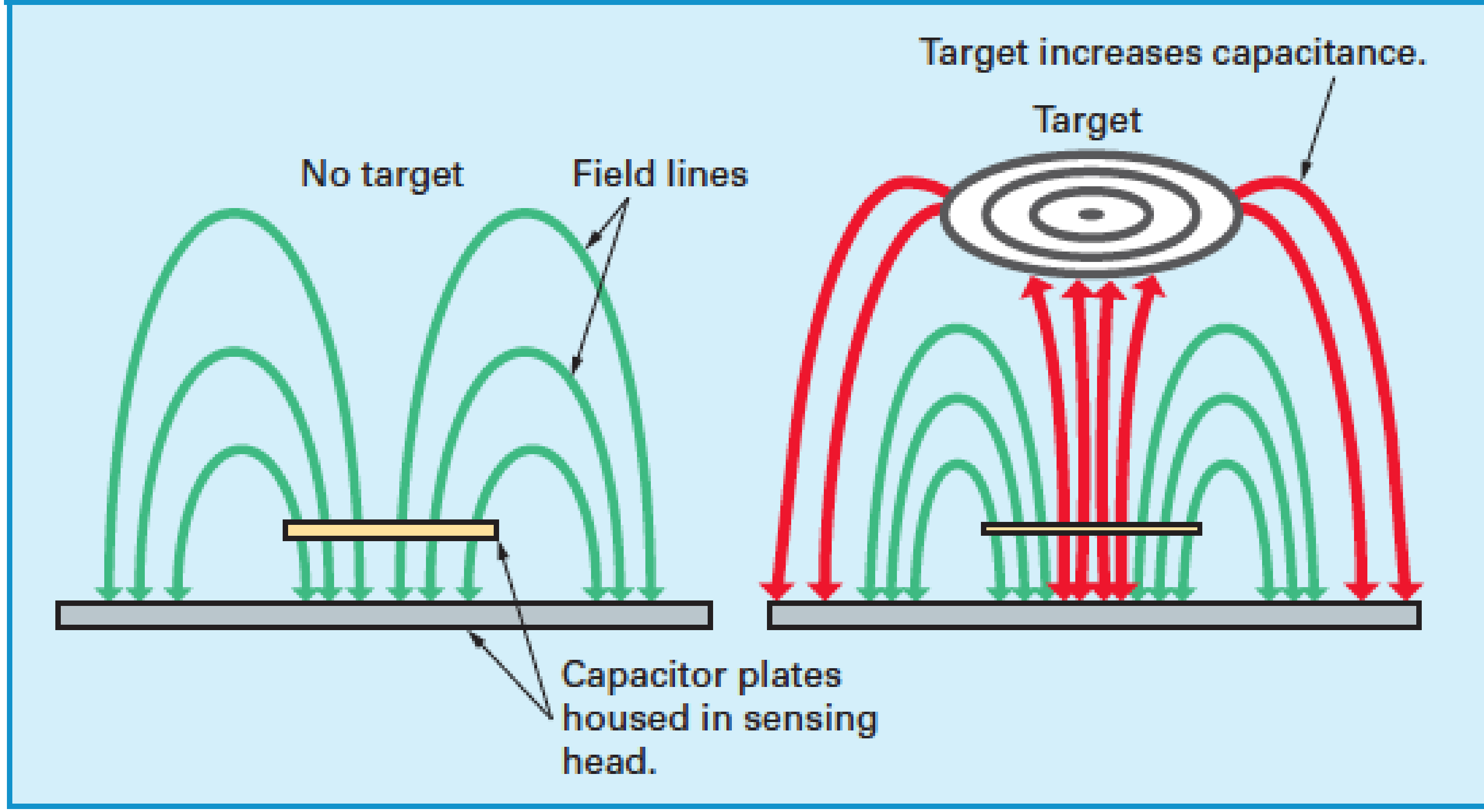
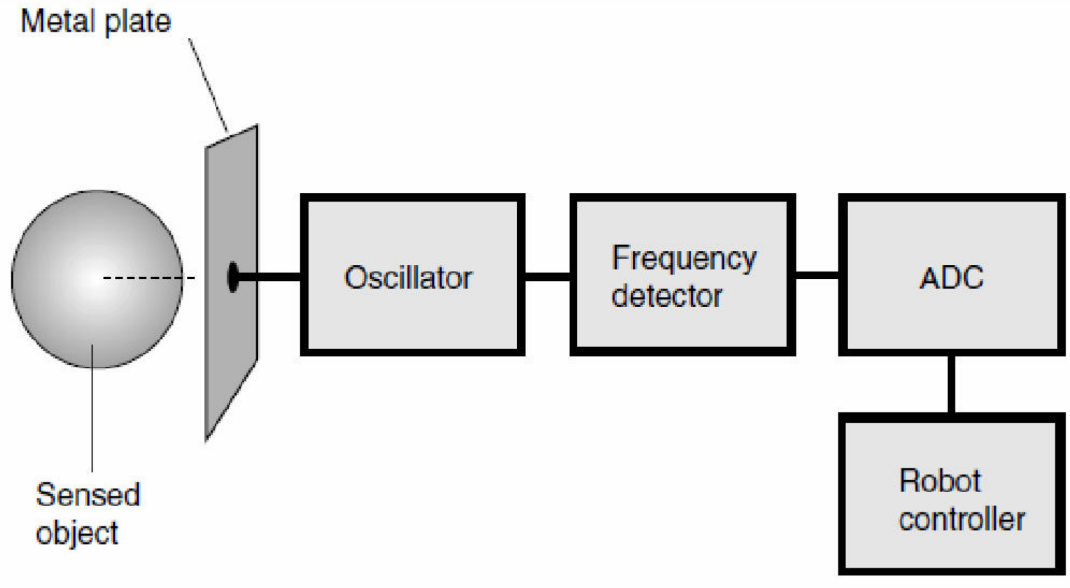
Capacitive sensing



As a ferrous or nonferrous target enters the sensing zone, capacitance increases; circuit natural frequency shifts towards the oscillation frequency, causing amplitude gain.

A capacitive proximity sensor takes advantage of the mutual capacitance that occurs between or among objects near each other.



Capacitive proximity sensor

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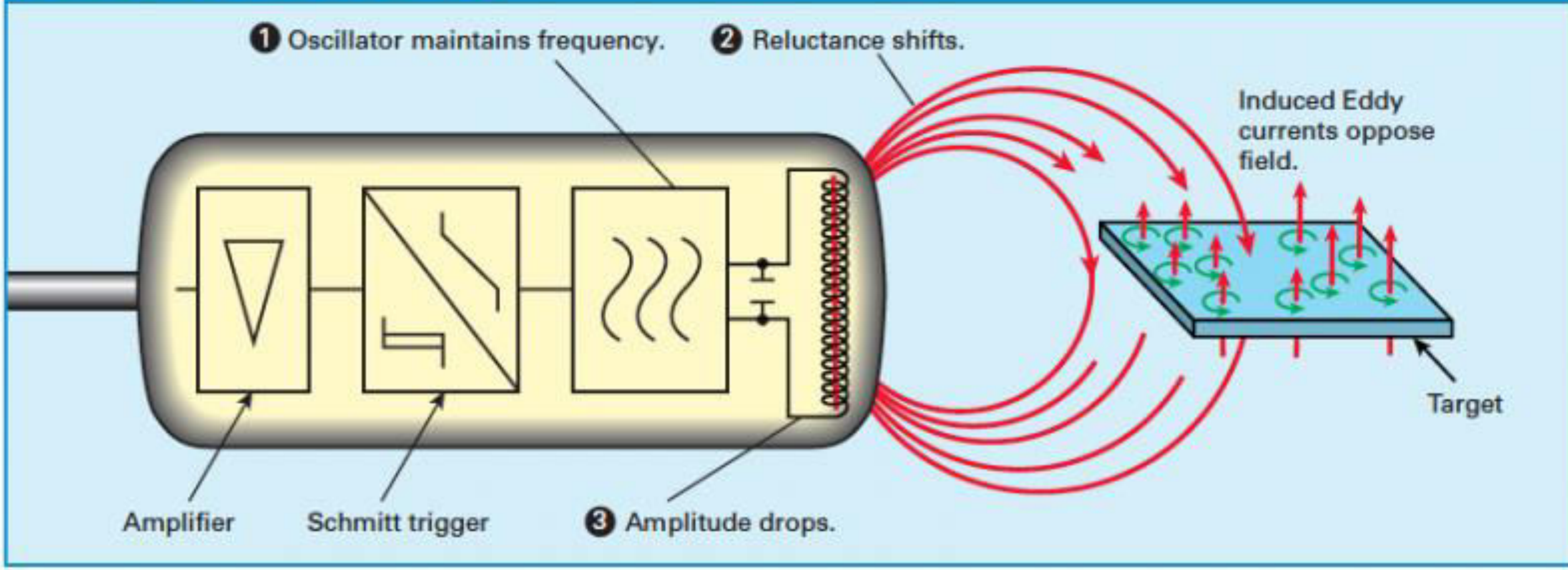
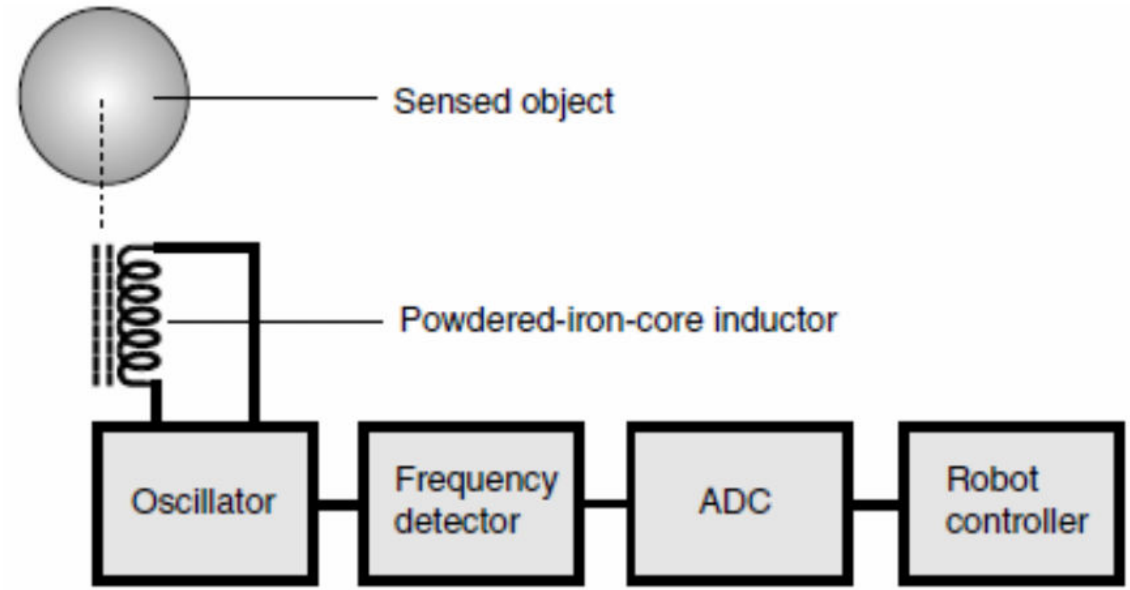
Inductive sensing



Ferrous targets change the reluctance of the magnetic circuit; system oscillation frequency, which gets left behind when the natural frequency shifts, then loses amplitude.

Encyclopedia of Robotics - INDUCTIVE PROXIMITY SENSOR

An inductive proximity sensor takes advantage of electromagnetic interaction that occurs between or among metallic objects when they are near each other.



Inductive proximity sensor

An inductive proximity sensor uses a radio-frequency (RF) oscillator, a frequency detector, and a powdered-iron-core inductor connected into the oscillator circuit, as shown in the diagram. The oscillator is designed so a change in the magnetic flux field in the inductor core causes the frequency to change.

Proximity sensor comparison

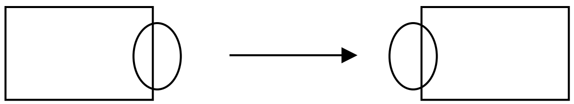
Technology	Sensing range	Applications	Target materials
Inductive 	*<4-40 mm*	*Any close-range detection of ferrous material*	*Iron Steel Aluminum Copper etc.* 
Capacitative 	*<3-60 mm*	*Close-range detection of non-ferrous material*	*Liquids Wood Granulates Plastic Glass etc.* 
Photoelectric 	*<1mm- 60 mm*	*Long-range, smalll or large target detection*	*Silicon Plastic Paper Metal etc.* 
Ultrasonic 	*<30 mm- 3 mm*	*Long-range detection of targets with difficult surface properites. Color/reflectivity insensitive.*	*Cellophane Foam Glass Liquid Powder etc.* 

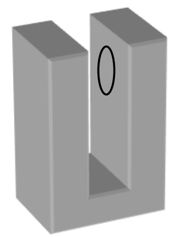

Inductive Proximity
Sensor

Infrared Sensors

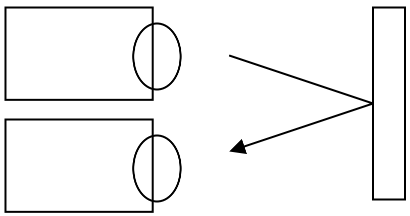
- Intensity based infrared
  - Reflective sensors
  - Easy to implement
  - susceptible to ambient light
- Modulated Infrared
  - Proximity sensors
  - Requires modulated IR signal
  - Insensitive to ambient light
- Infrared Ranging
  - Distance sensors
  - Short range distance measurement
  - Impervious to ambient light, color and reflectivity of object

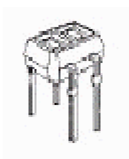
Intensity Based Infrared



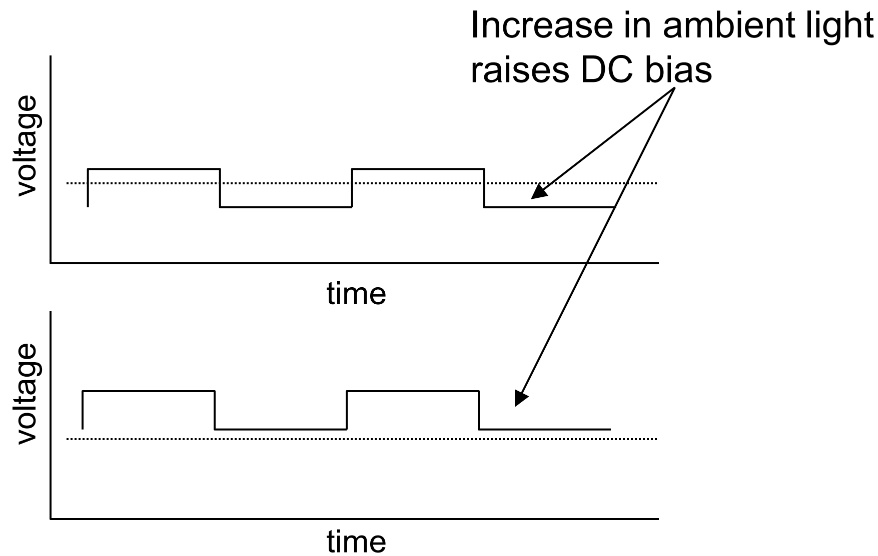


Break-Beam sensor





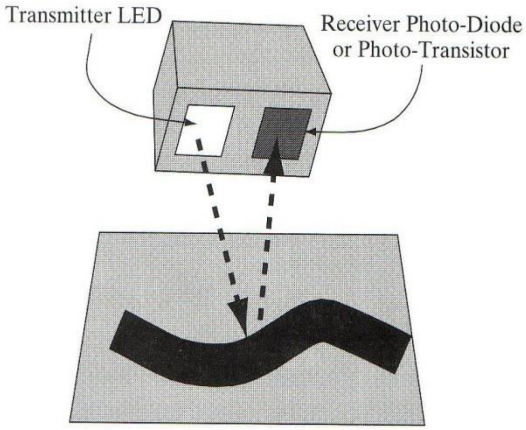
Reflective Sensor



- Easy to implement (few components)
- Works very well in controlled environments
- Sensitive to ambient light

IR Reflective Sensors

- Reflective Sensor:
  - Emitter IR LED + detector photodiode/phototransistor
  - Phototransistor: the more light reaching the phototransistor, the more current passes through it
  - A beam of light is reflected off a surface and into a detector
  - Light usually in infrared spectrum, IR light is invisible

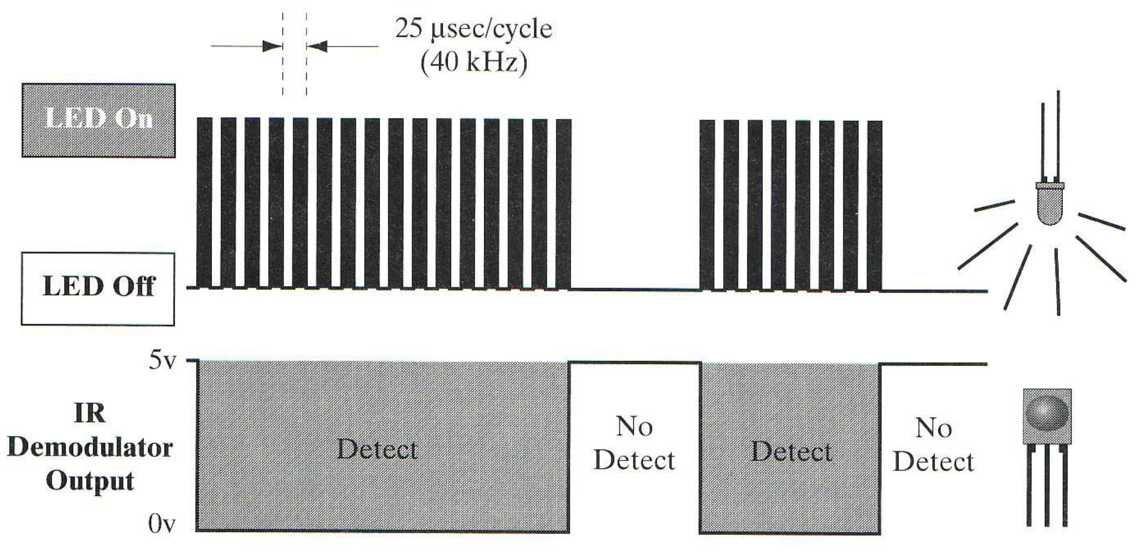


- Applications:
  - Object detection,
  - Line following, Wall tracking
  - Optical encoder (Break-Beam sensor)

- Drawbacks:
  - Susceptible to ambient lighting
    - Provide sheath to insulate the device from outside lighting
  - Susceptible to reflectivity of objects
  - Susceptible to the distance between sensor and the object

Modulated Infrared

- Modulation and Demodulation
  - Flashing a light source at a particular frequency
  - Demodulator is tuned to the specific frequency of light flashes. (32kHz~45kHz)
  - Flashes of light can be detected even if they are very week
  - Less susceptible to ambient lighting and reflectivity of objects
  - Used in most IR remote control units, proximity sensors

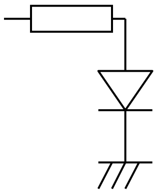


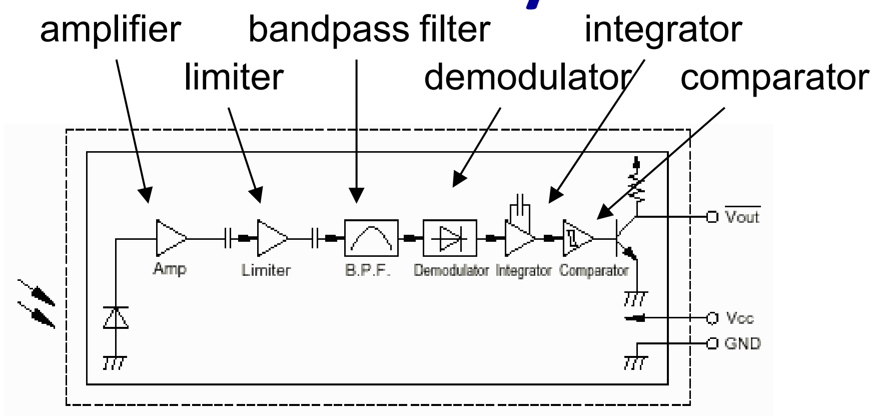
Negative true logic:

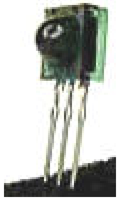
Detect = 0v

No detect = 5v

IR Proximity Sensors



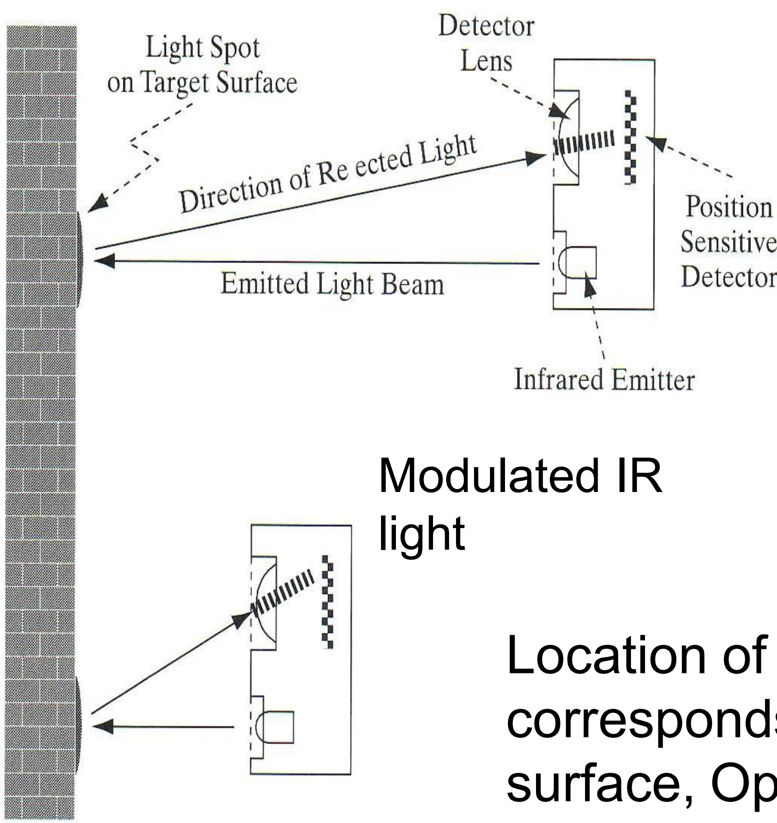




- Proximity Sensors:
  - Requires a modulated IR LED, a detector module with built-in modulation decoder
  - Current through the IR LED should be limited: adding a series resistor in LED driver circuit
  - Detection range: varies with different objects (shiny white card vs. dull black object)
  - Insensitive to ambient light
- Applications:
  - Rough distance measurement
  - Obstacle avoidance
  - Wall following, line following

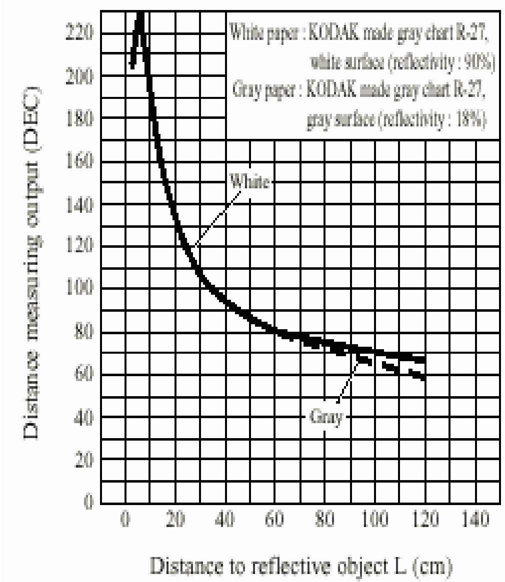
IR Distance Sensors

- Basic principle of operation:
  - IR emitter + focusing lens + position-sensitive detector



Modulated IR light

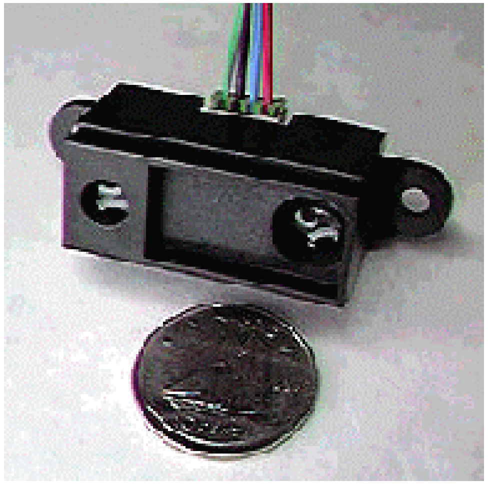
Fig. 1 Distance Measuring Output vs. Distance to Reflective Object



Location of the spot on the detector corresponds to the distance to the target surface, Optics to covert horizontal distance to vertical distance

IR Distance Sensors

- Sharp GP2D02 IR Ranger
  - Distance range: 10cm (4") ~ 80cm (30").
  - Moderately reliable for distance measurement
  - Immune to ambient light
  - Impervious to color and reflectivity of object
  - Applications: distance measurement, wall following, …



Range Finder

(Ultrasonic, Laser)

Range Finder

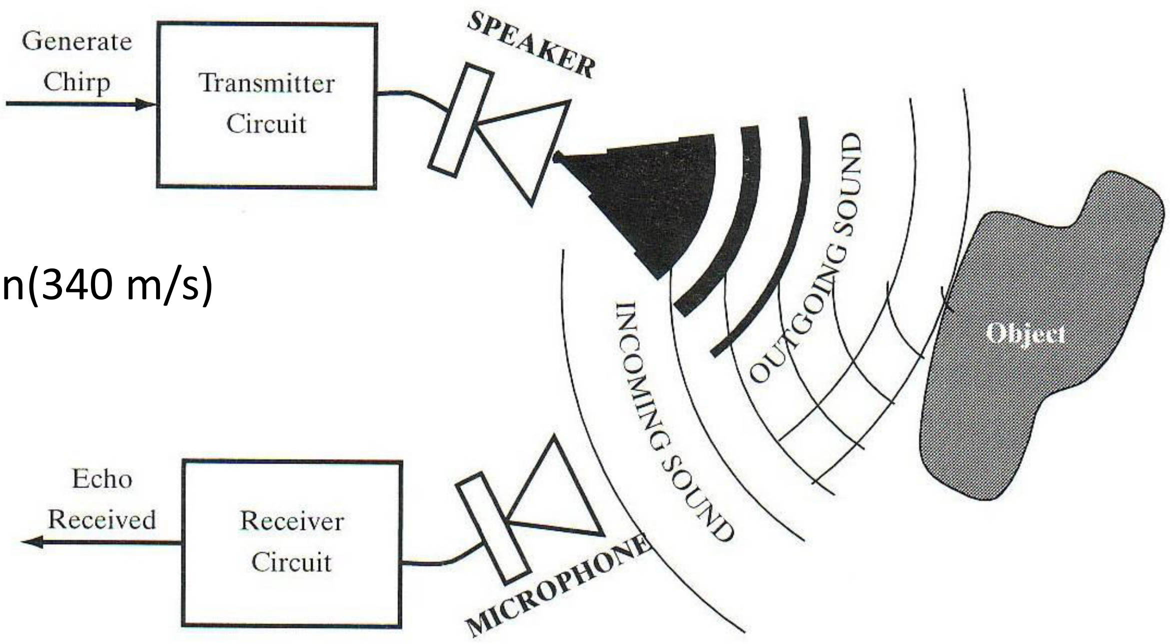
- Time of Flight
- The measured pulses typically come form ultrasonic, RF and optical energy sources.
  - **D = v * t**
  - D = round-trip distance
  - v = speed of wave propagation
  - t = elapsed time
- Sound = 0.3 meters/msec
- RF/light = 0.3 meters / ns (Very difficult to measure short distances 1-100 meters)

Ultrasonic Sensors

- Basic principle of operation:
  - Emit a quick burst of ultrasound (50kHz), (human hearing: 20Hz to 20kHz)
  - Measure the elapsed time until the receiver indicates that an echo is detected.
  - Determine how far away the nearest object is from the sensor

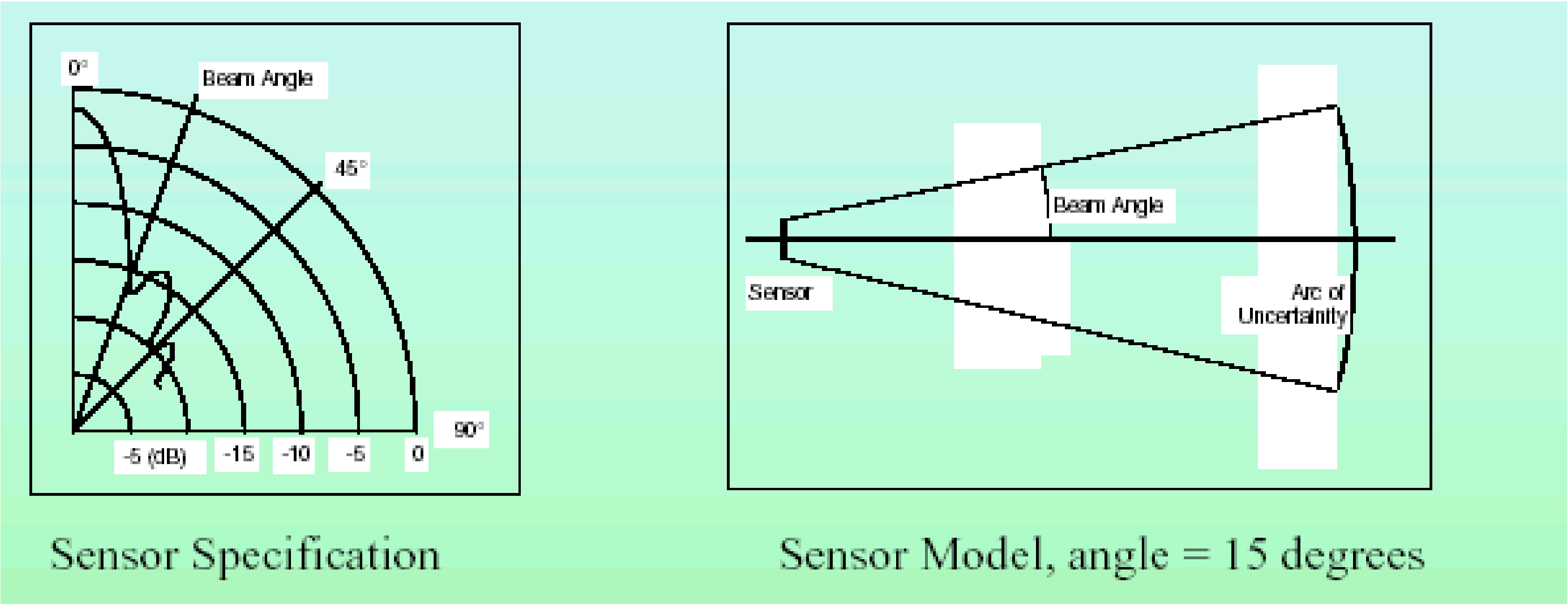
- **$D = v * t$**

  D = round-trip distance
  v = speed of propagation(340 m/s)
  t = elapsed time



Bat, dolphin, …

Ultrasonic Sensors



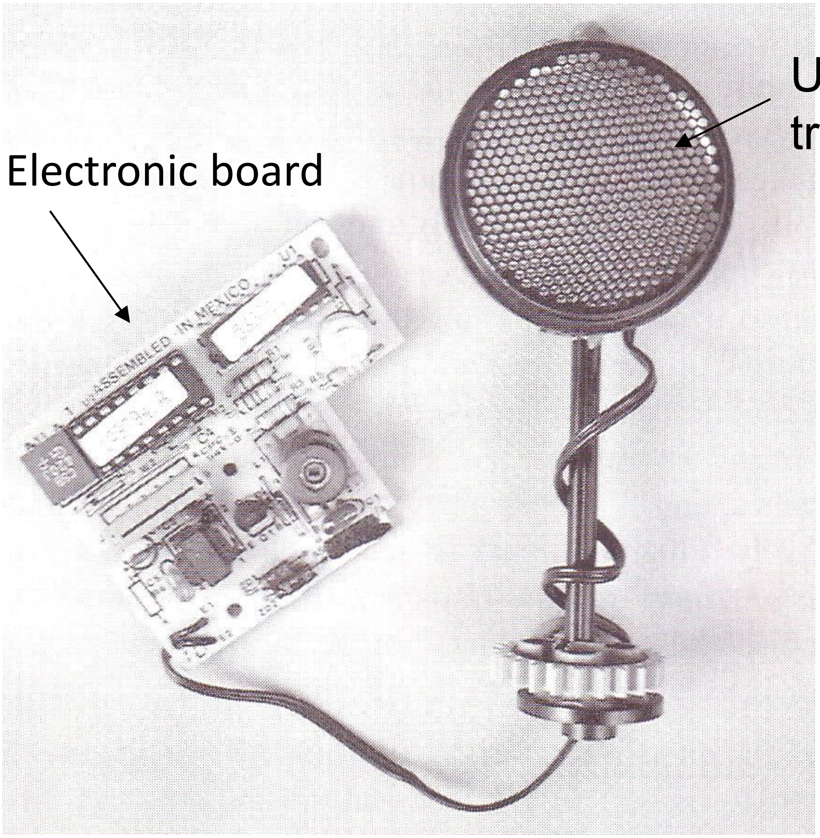
- Ranging is accurate but bearing has a 30 degree uncertainty. The object can be located anywhere in the arc.
- Typical ranges are of the order of several centimeters to 30 meters.
- Another problem is the propagation time. The ultrasonic signal will take 200 msec to travel 60 meters. (30 meters roundtrip @ 340 m/s)

Ultrasonic Sensors

- Polaroid ultrasonic ranging system
  - It was developed for auto-focus of cameras.
  - Range: 6 inches to 35 feet

Transducer Ringing:

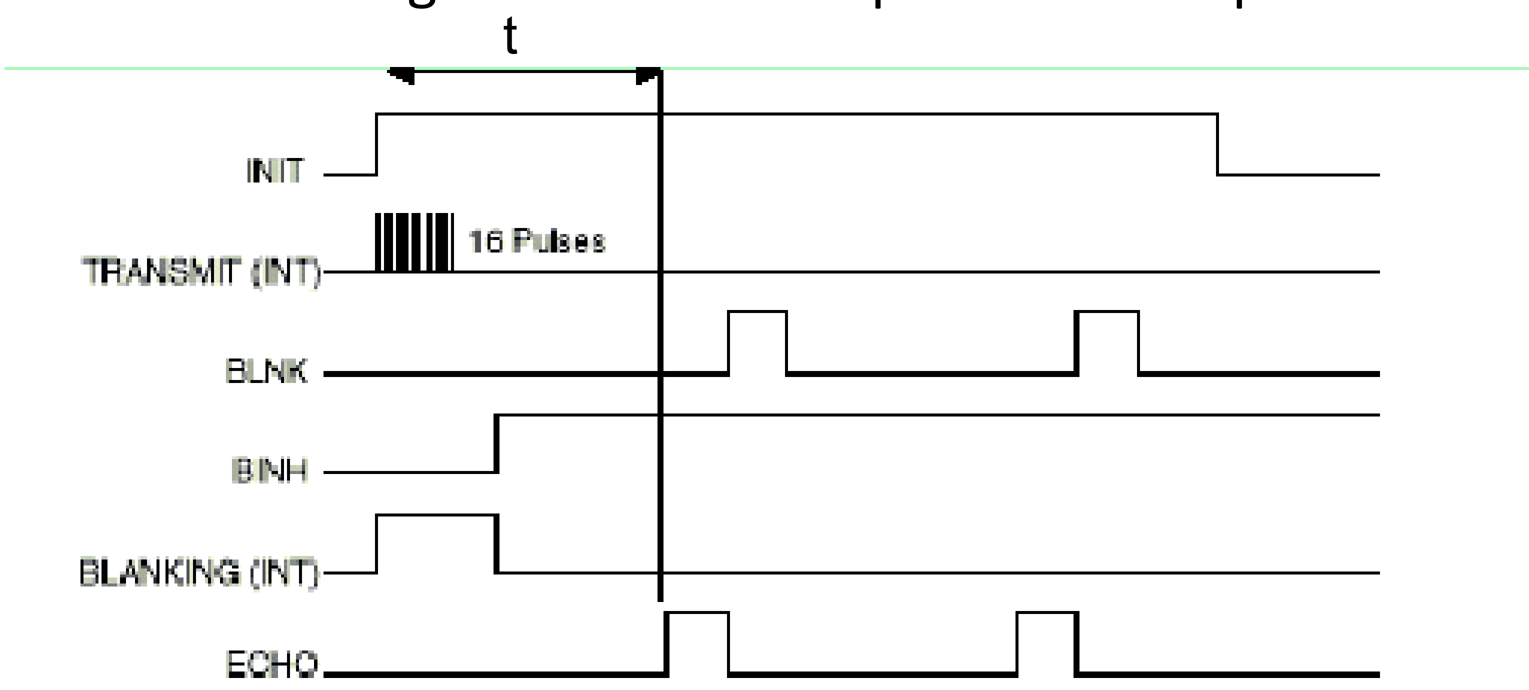
- transmitter + receiver @ 50 KHz
- Residual vibrations or ringing may be interpreted as the echo signal
- Blanking signal to block any return signals for the first 2.38ms after transmission



http://www.acroname.com/robotics/info/articles/sonar/sonar.html

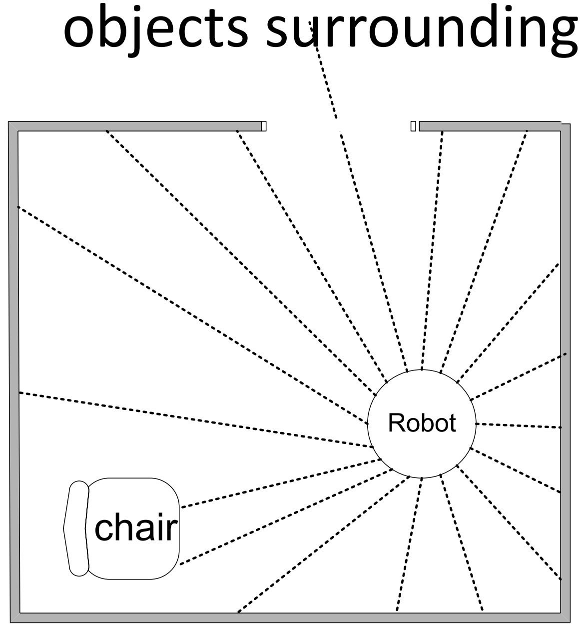
Operation with Polaroid Ultrasonic

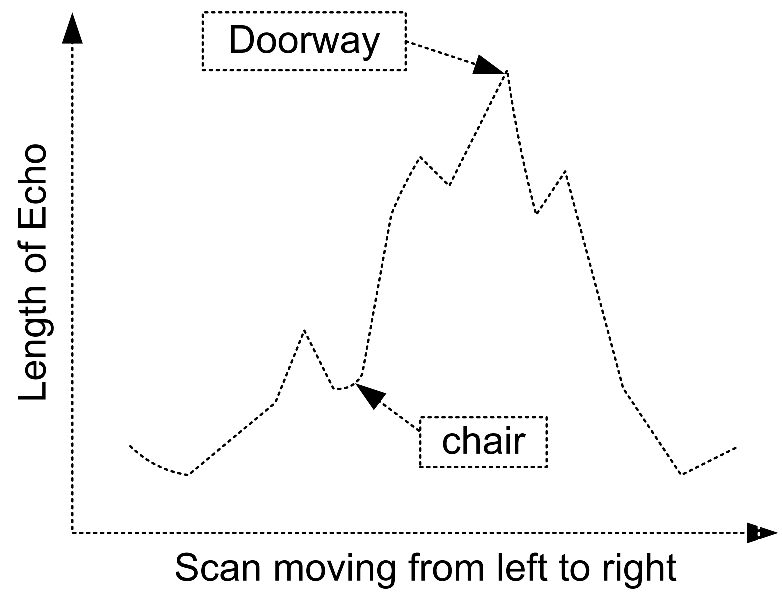
- The Electronic board supplied has the following I/0
  - **INIT** : trigger the sensor, (16 pulses are transmitted)
  - **BLANKING** : goes high to avoid detection of own signal
  - **ECHO** : echo was detected.
  - **BINH** : goes high to end the blanking (reduce blanking time < 2.38 ms)
  - **BLNK** : to be generated if multiple echo is required



Ultrasonic Sensors

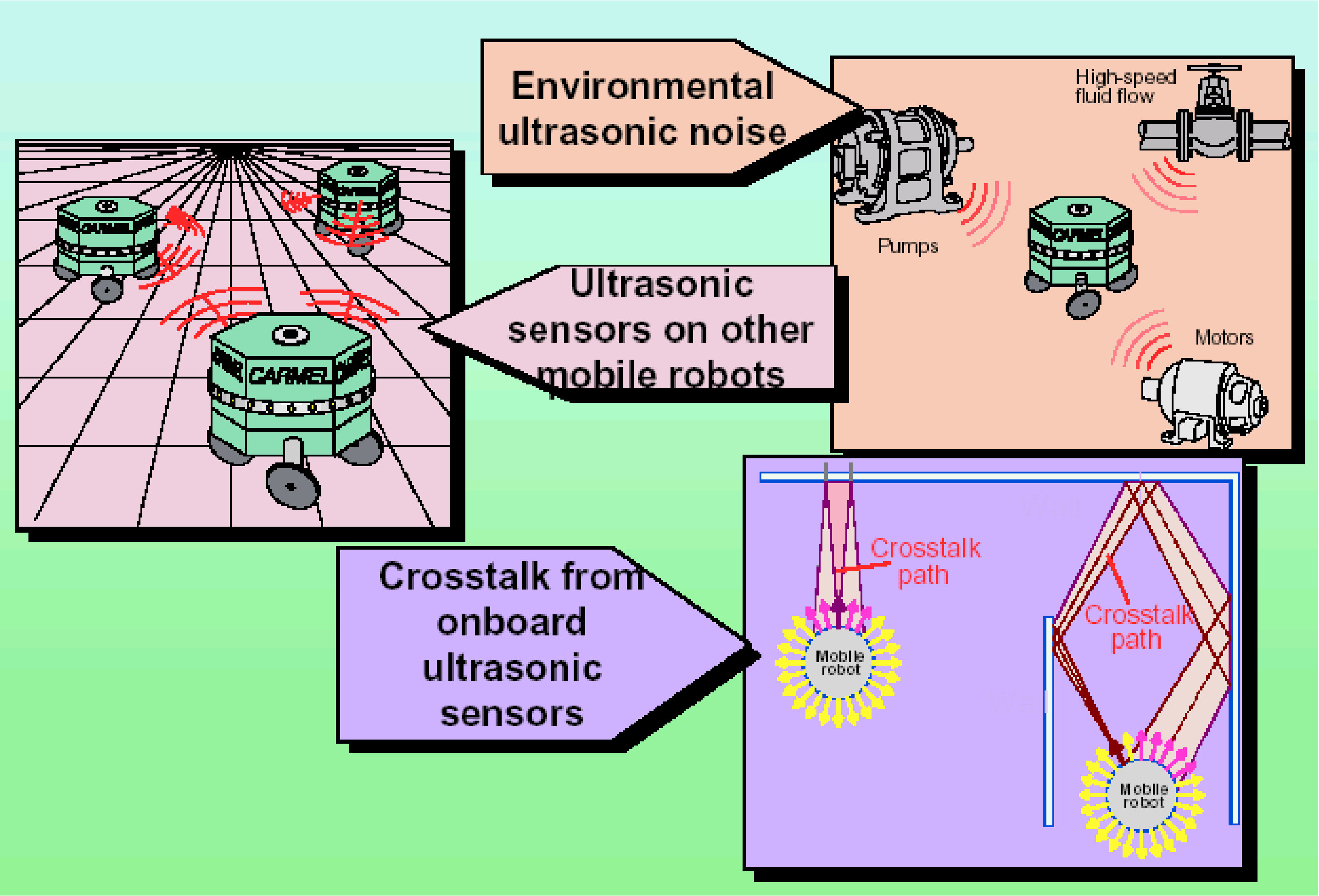
- Applications:
  - Distance Measurement
  - Mapping: Rotating proximity scans (maps the proximity of objects surrounding the robot)





Scanning at an angle of 15º apart can achieve best results

Noise Issues



Laser Ranger Finder

- Range 2-500 meters
- Resolution : 10 mm
- Field of view : 100 - 180 degrees
- Angular resolution : 0.25 degrees
- Scan time : 13 - 40 msec.
- These lasers are more immune to Dust and Fog

Acoustic Sensing (Hearing)

Acoustic sensors can detect and sometimes discriminate between different sounds. They can be employed in **speech recognition for giving verbal commands** or for recognizing abnormal sounds such as explosions. The most common acoustic sensor is the microphone . The obvious problem with acoustic sensors in an industrial environment is the large amount of background noise. Acoustic sensors can fairly easily be tuned to respond only to certain frequencies thus enabling them to discriminate between different noises.

Capacitive

A range of proximity detectors with built in amplifiers and solid state output stages making them extremely versatile electronic switches

These sense the presence of non-conducting materials such as wood, PVC, glass etc. as well as ferrous and non-ferrous metals. All types have built in potentiometers for sensitivity adjustment and LED indicators. Applications include batch counting alarm systems limit switching etc.

Inductive

A miniature inductive proximity detector housed in a threaded anodised aluminium cylindrical case with integral 3-core PVC sheathed cable. Environmental protection to IP 67. The device incorporates electrical protection against reverse polarity, supply line and load transients and has a current limiting PTC resistor in the load output.

When an acoustic signal having a single, well-defined, constant frequency(and therefore a single,well-defined, constant wavelength) reflects from a nearby object, the reflected wave combines with the incident wave to form alternating zones at which the acoustic energy adds and cancels in phase.

If the robot and the object are both stationary, these zones remain fixed. Because of this, the zones are called standing waves. If the robot moves with respect to the object, the standing waves change position. Even a tiny shift in the relative position of the robot and the sensed object can produce a considerable change in the pattern of standing waves. This effect becomes more pronounced as the acoustic wave frequency increases, because the wavelength is inversely proportional to the frequency.

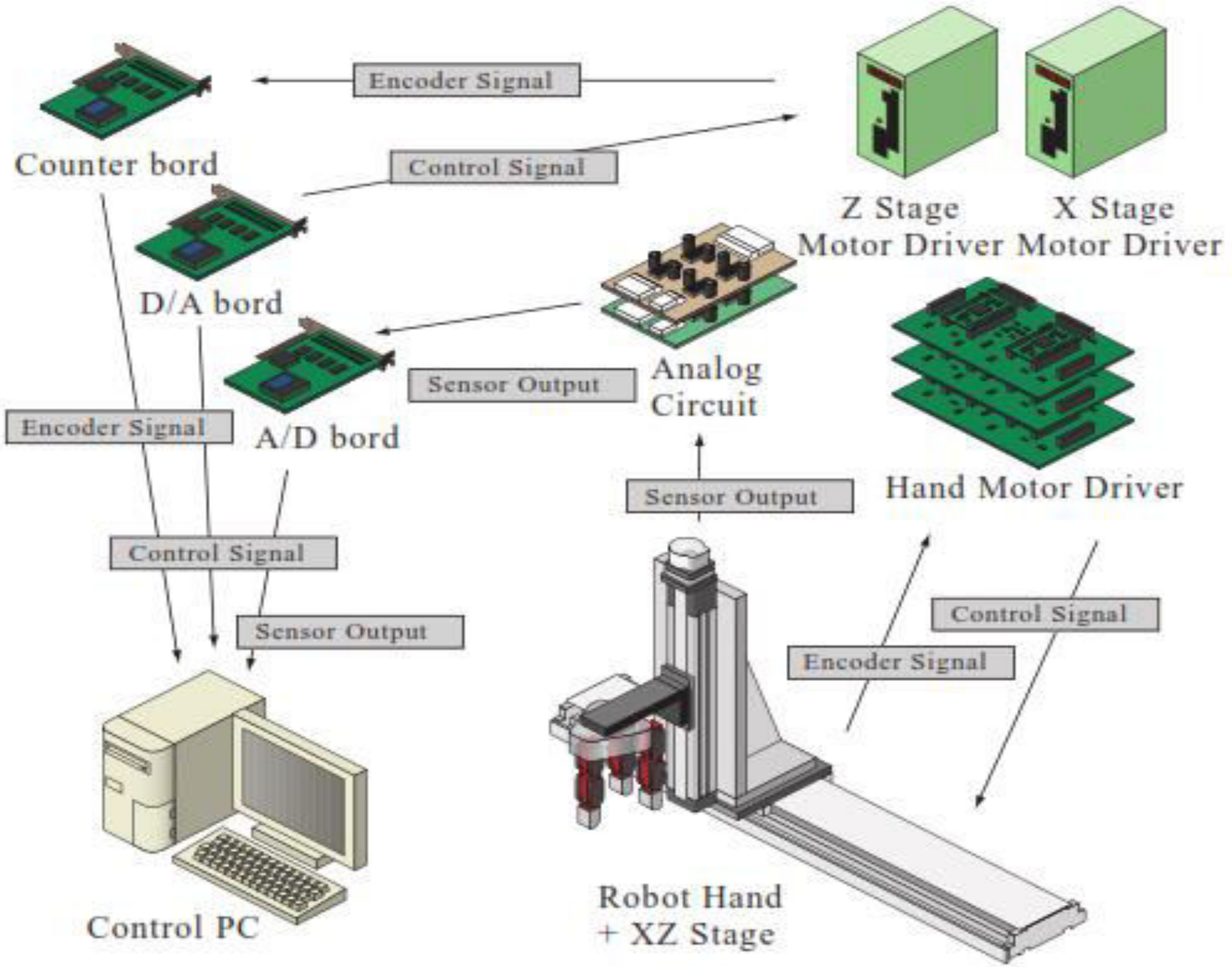
The characteristics and effectiveness of an acoustic proximity sensor depend on how well the object or barrier reflects acoustic waves. A solid concrete wall is more easily detected than a sofa upholstered with cloth. The distance between the robot and the obstacle is a factor; in general, an acoustic proximity sensor works better as the distance decreases, and less well as the distance increases. The amount of acoustic noise in the robot's work environment is also important. The higher the noise level, the more limited is the range over which the sensor functions, and the more likely are errors or false positives. Ultrasound waves provide exceptional accuracy at close range, in some cases less than 1 cm. Audible sound can allow the system to function at distances on the order of several meters. However, audible signals can annoy people who must work around the machine.

PHOTOELECTRIC PROXIMITY SENSOR **Reflected light can provide a way for a robot to tell if it is approaching something.** A photoelectric proximity sensor uses a modulated light-beam generator, a photodetector, a frequency-sensitive amplifier, and a microcomputer.

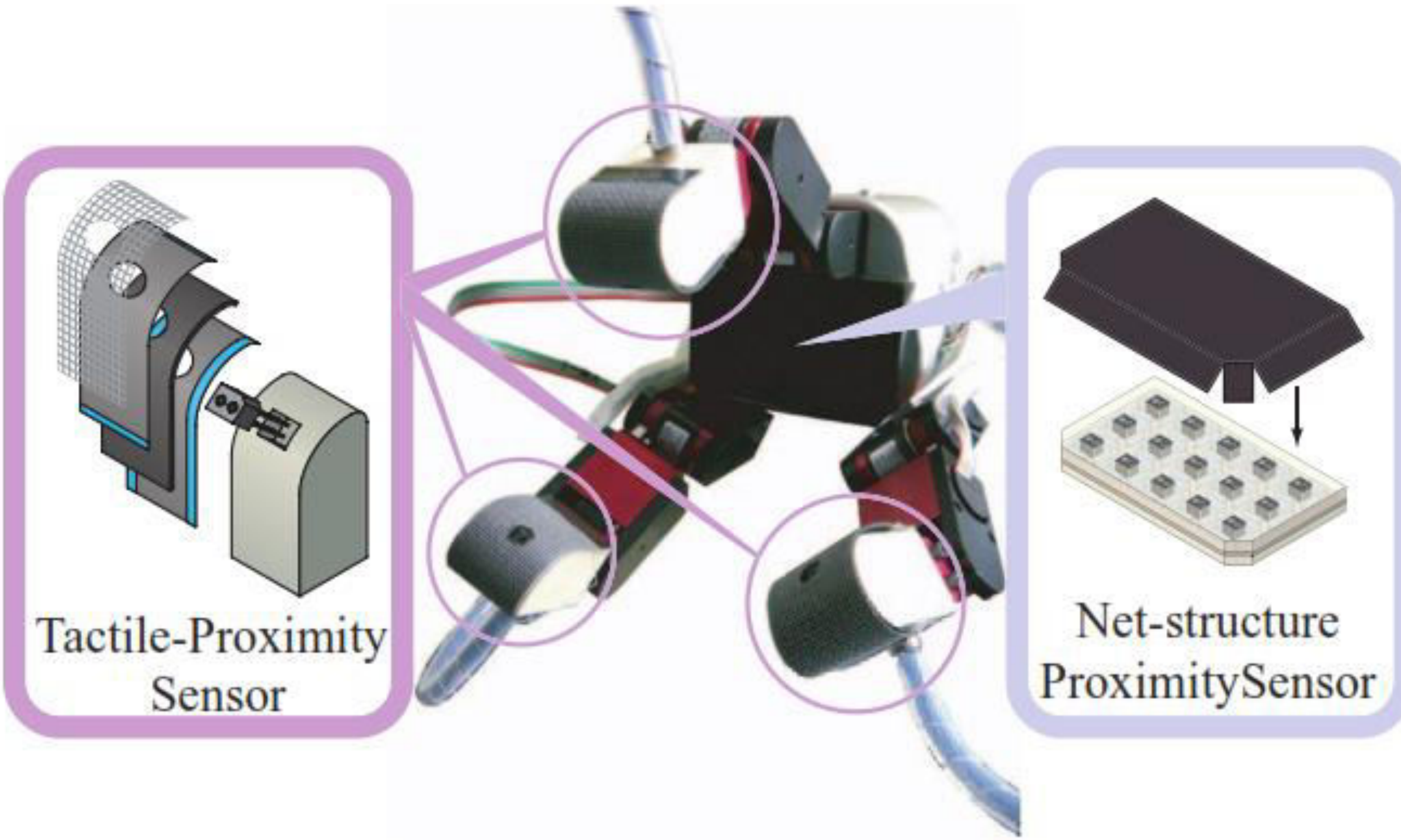
The light beam reflects from the object and is picked up by the photodetector.The light beam is modulated at a certain frequency, say 1000 Hz (hertz), and the detector has an amplifier that responds only to light modulated at that frequency. This prevents false imaging that might otherwise be caused by stray illumination such as lamps or sunlight. If the robot is approaching an object, the microcomputer senses that the reflected beam is getting stronger. The robot can then steer clear of the object.

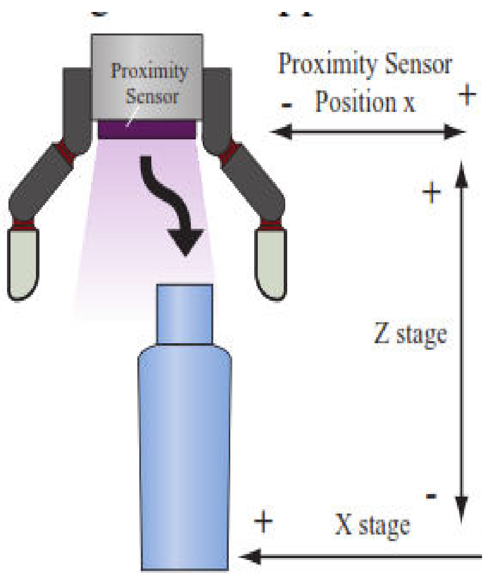
This method of proximity sensing does not work for black or very dark objects, or for flat windows or mirrors approached at a sharp angle. These sorts of objects fool this system, because the light beam is not reflected back toward the photodetector.

Outline of the intelligent hand system

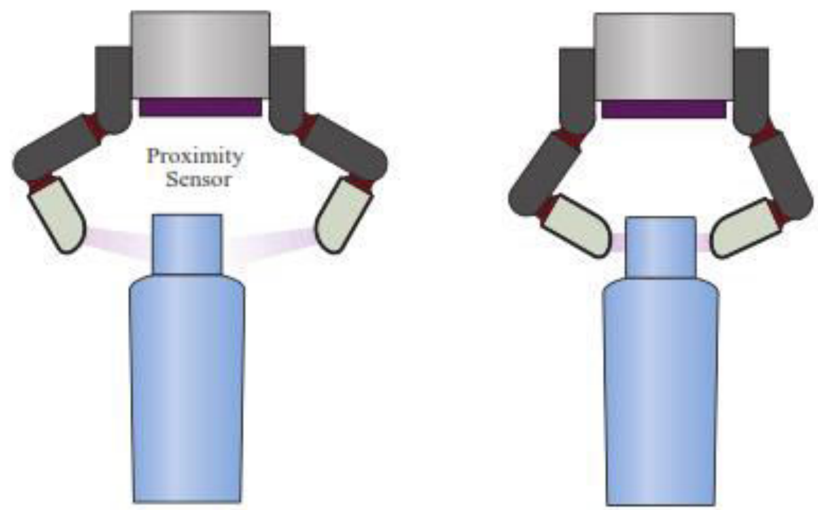


Intelligent hand with proximity and tactile sensors





Response to the initial position error usin

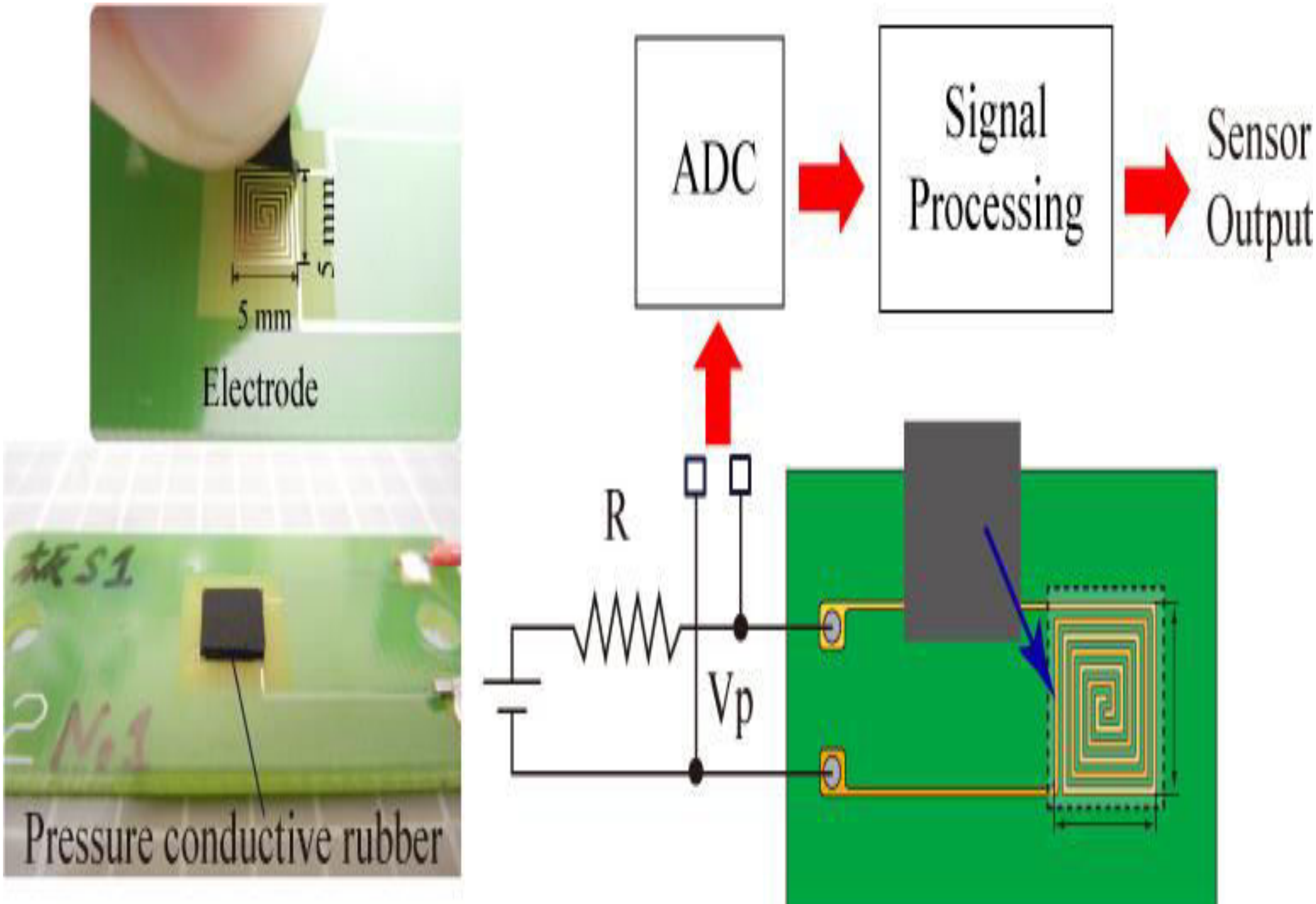


Contact timing control by the finger's proximity sensor

Slip sensing

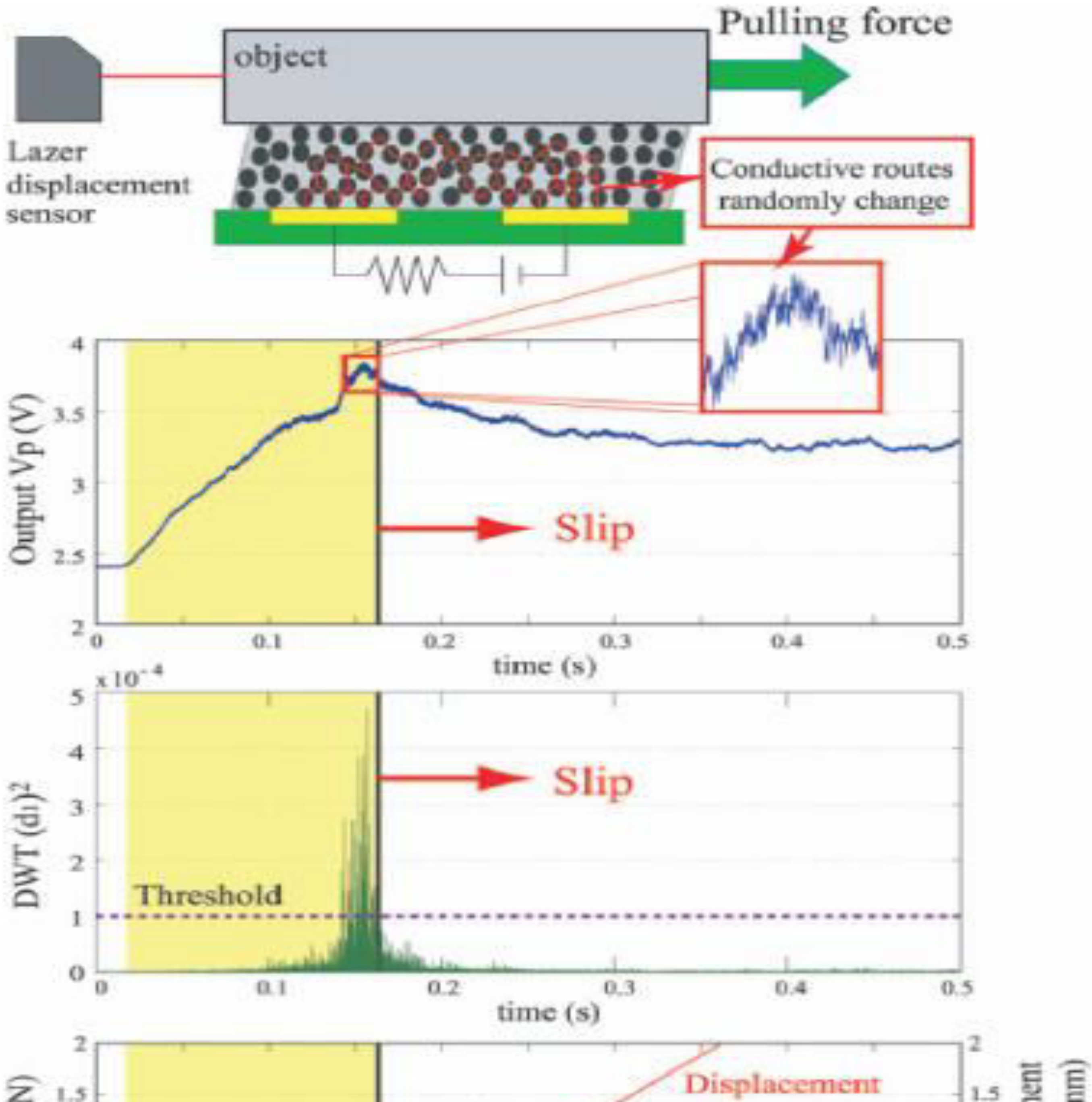
- Humans can grasp an object without information such as a coefficient of friction or weight. To implement this grasping motion with the robot hand, sensors have been proposed that detect an incipient slip within the contact surface or stick-slip.
- **Slip may be regarded as the relative movement of one object surface over an other when in contact**. The relative movement ranges from simple translational motion to a combination of translational and rotational motions.

- When handling an object, the detection of slip becomes necessary so as to prevent the object being dropped due to the application of a low grip force.
- In an assembly operation, it is possible to test the occurrence of slip to indicate some predetermined contact forces between the object and the assembled part.
- For the majority of applications some qualitative information on object slip may be sufficient, and can be detected using a number of different approaches.

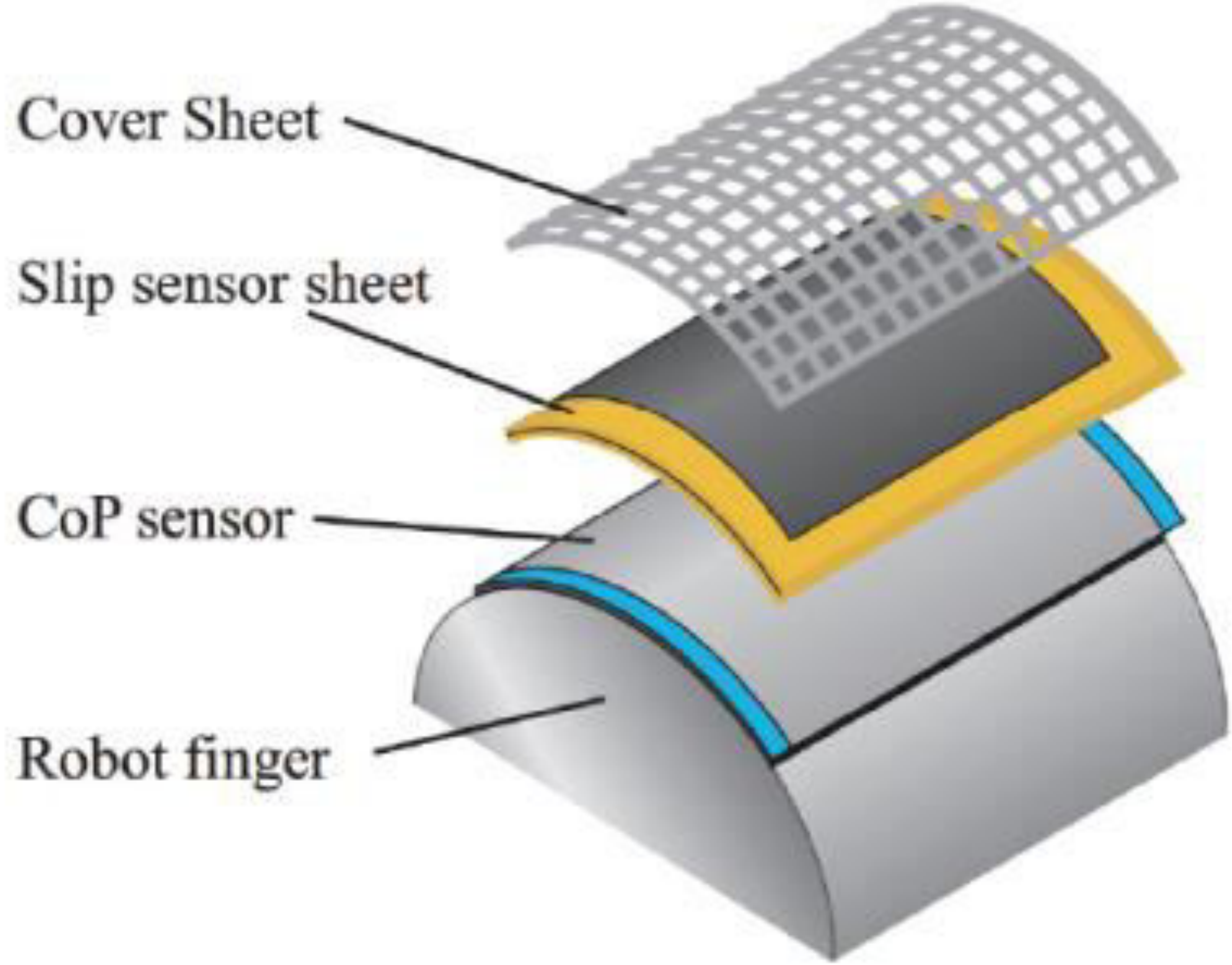


5 mm
5 mm
Electrode
Pressure conductive rubber
ADC
Signal Processing
Sensor Output
R
Vp

- The sensor is constructed of electrode and pressure conductive rubber as shown in figure
- The voltage difference Vp is measured and the signal processing is performed.
- Then the initial slip can be detected. The pressure conductive rubber was a high polymer material primarily composed of silicone rubber with carbon particles uniformly distributed within
- In an unloaded condition, the electrical resistance is infinity.
- However, the electrical resistance changes when the normal force was added, because the mutual contact between carbon particles increases.
- Moreover, when added a tangential force, the electrical resistance randomly changes by changing the mutual contact between carbon particles.



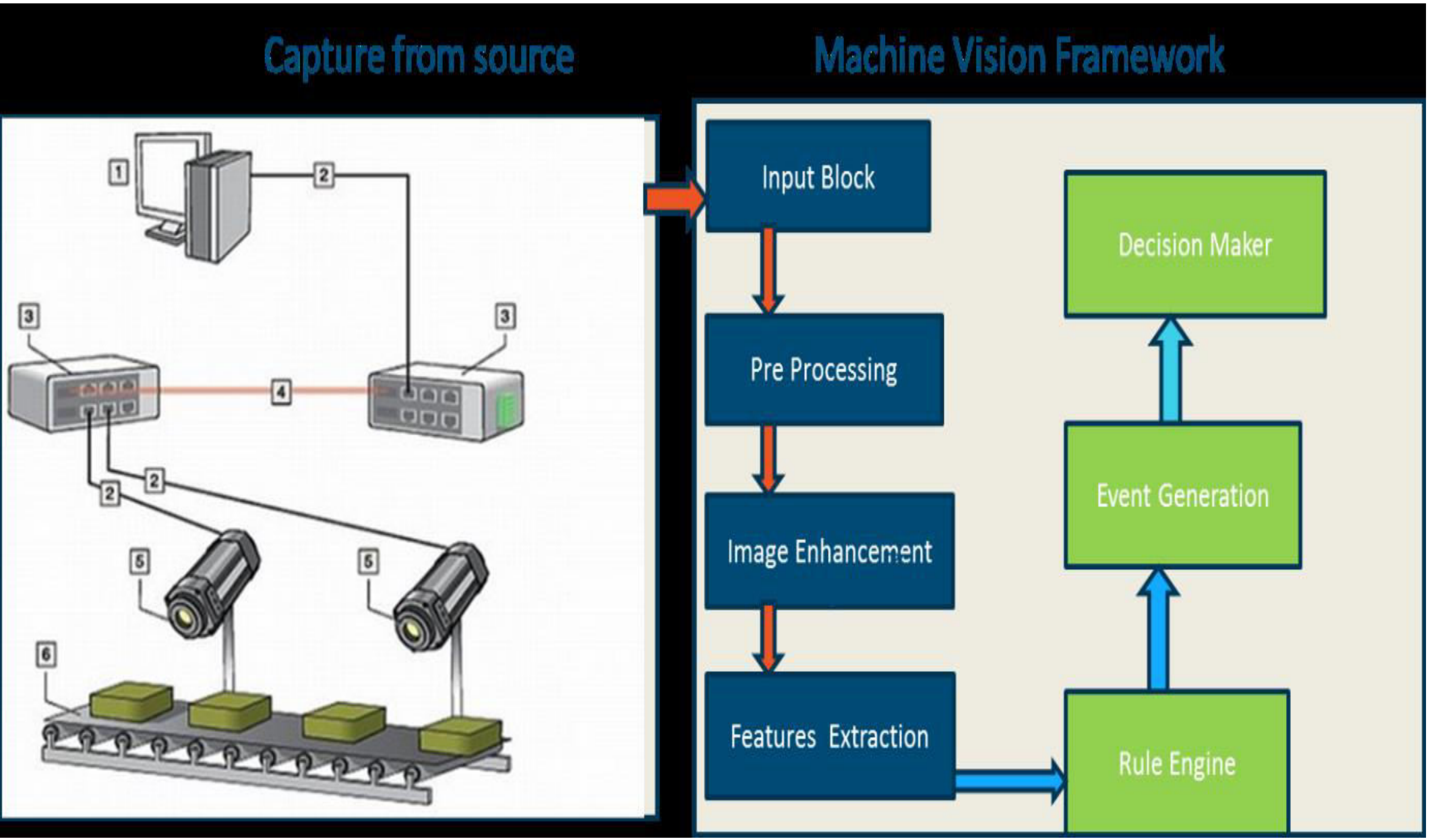
Pulling force
object
Lazer displacement sensor
Conductive routes randomly change
Output Vp (V)
Slip
time (s)
x 10^-4
DWT (d1)^2
Threshold
Slip
time (s)
Displacement



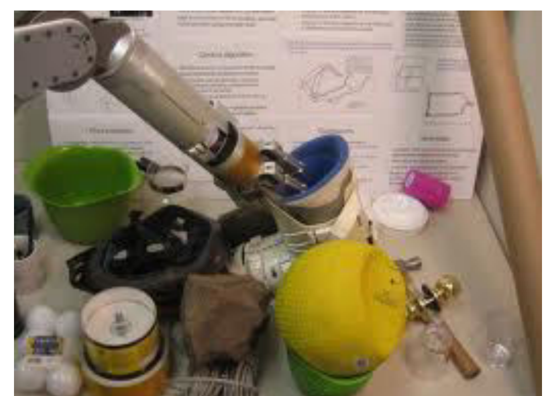
First, we equipped the CoP sensor on the fingers to detect contact position and force. Next, the slip sensor was covered over the CoP sensor.

COP stands for Coil-On-Plug electronic ignition

Robotic Vision


Capture from source
Machine Vision Framework
1
2
3
3
4
2
2
5
5
6
Input Block
Pre Processing
Image Enhancement
Features Extraction
Decision Maker
Event Generation
Rule Engine

Robot vision



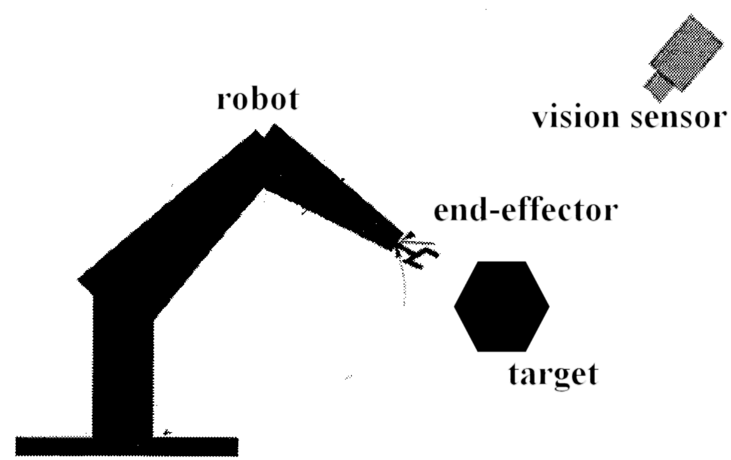
Sight

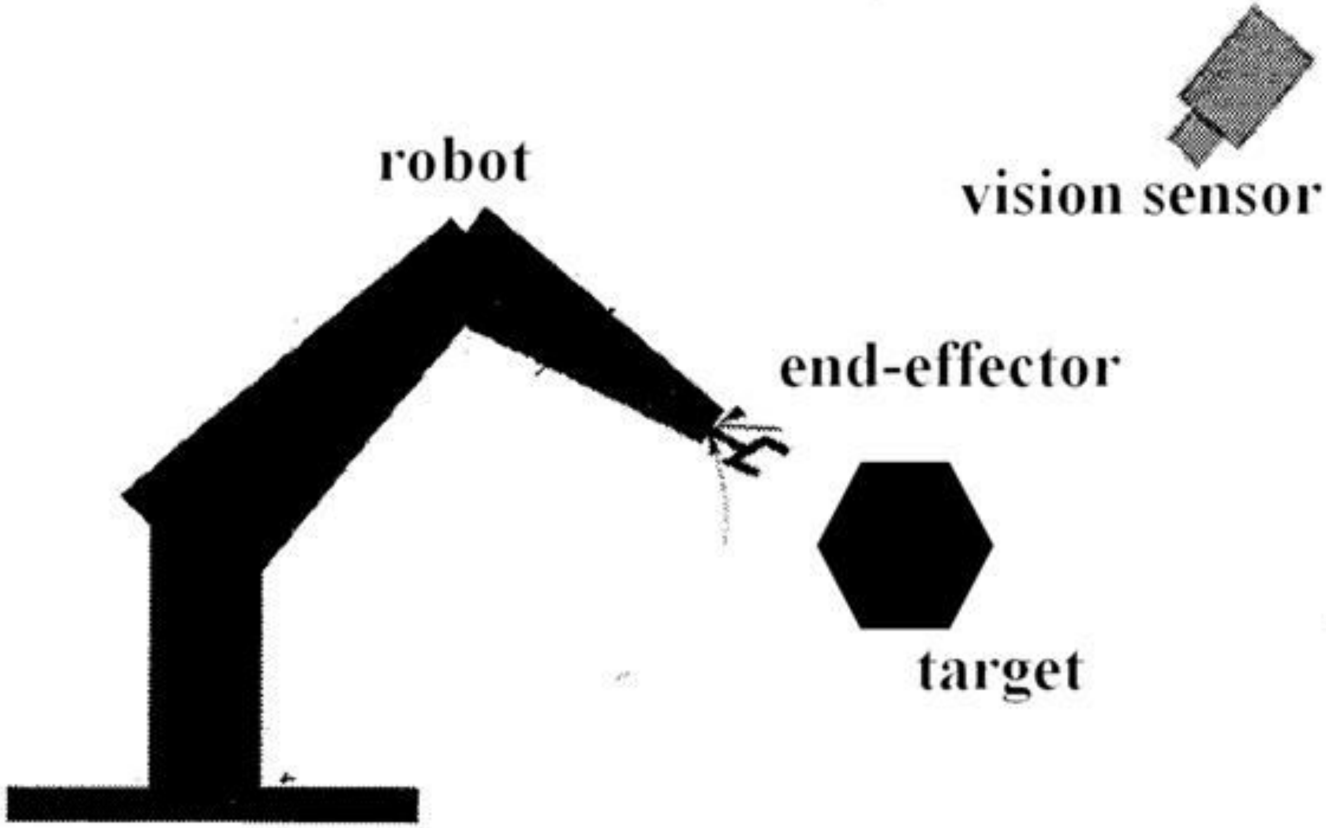
Robots detect vision in ways that are both like and unlike human vision. Some robots have cameras that create images similar to what we see with our eyes. Robots process these images very differently than humans; human brains give context to the images we see, while robot computers process information as objects in space. **Context** is the interrelated information about something that gives it *meaning*. A robot wouldn't know that a chair is a chair; it knows that there are rectangles and squares next to each other in space. Robots can see using sensors that detect waves in the **electromagnetic (EM) spectrum**, the electromagnetic waves that travel through space. Humans can see the part of the EM spectrum known as visible light, i.e. the colors of the rainbow. Robots can detect radio waves, ultraviolet (UV) waves, infrared (IR) waves and more—all of which are outside the range of what humans can see.

What can Computer Vision do for Robotics?

Visual Servoing

- Accurate Robot-Object Positioning
- Keeping Relative Position under Movement
- Visualization / Teaching / Telerobotics
- Performing measurements
- Object Recognition
- Registration



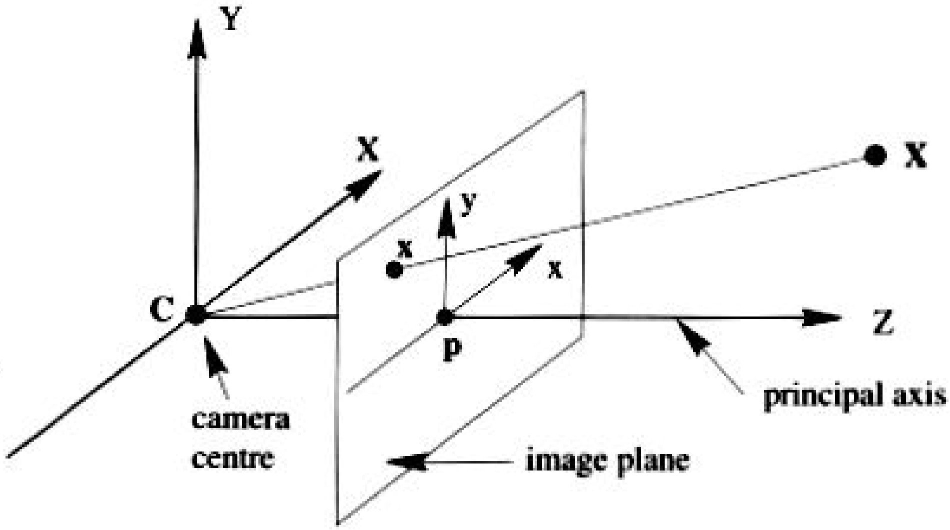

robot
vision sensor
end-effector
target

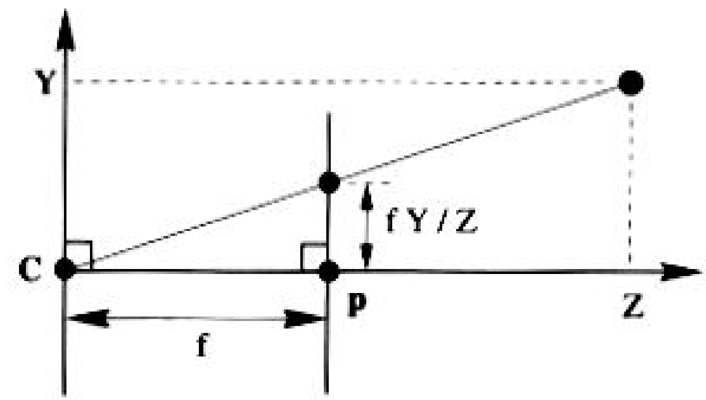
Vision Sensors

- Single Perspective Camera
- Multiple Perspective Cameras (e.g. Stereo Camera Pair)
- Laser Scanner
- Omnidirectional Camera
- Structured Light Sensor

Vision Sensors

- Single Perspective Camera

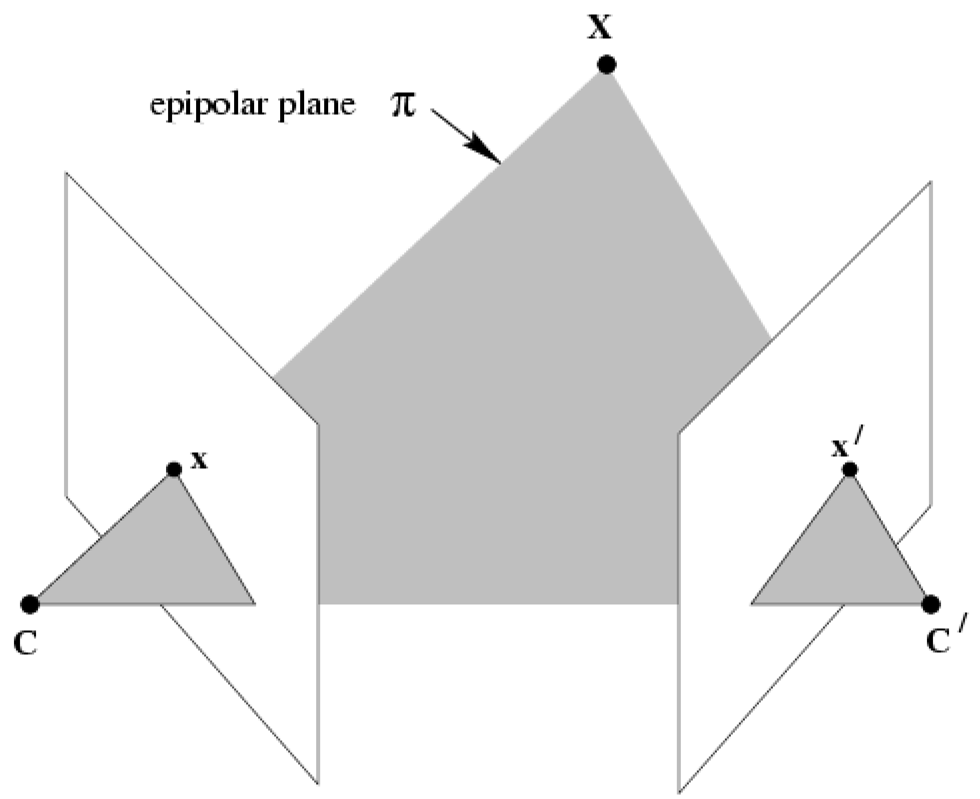




$$x = P_{3x4} X$$

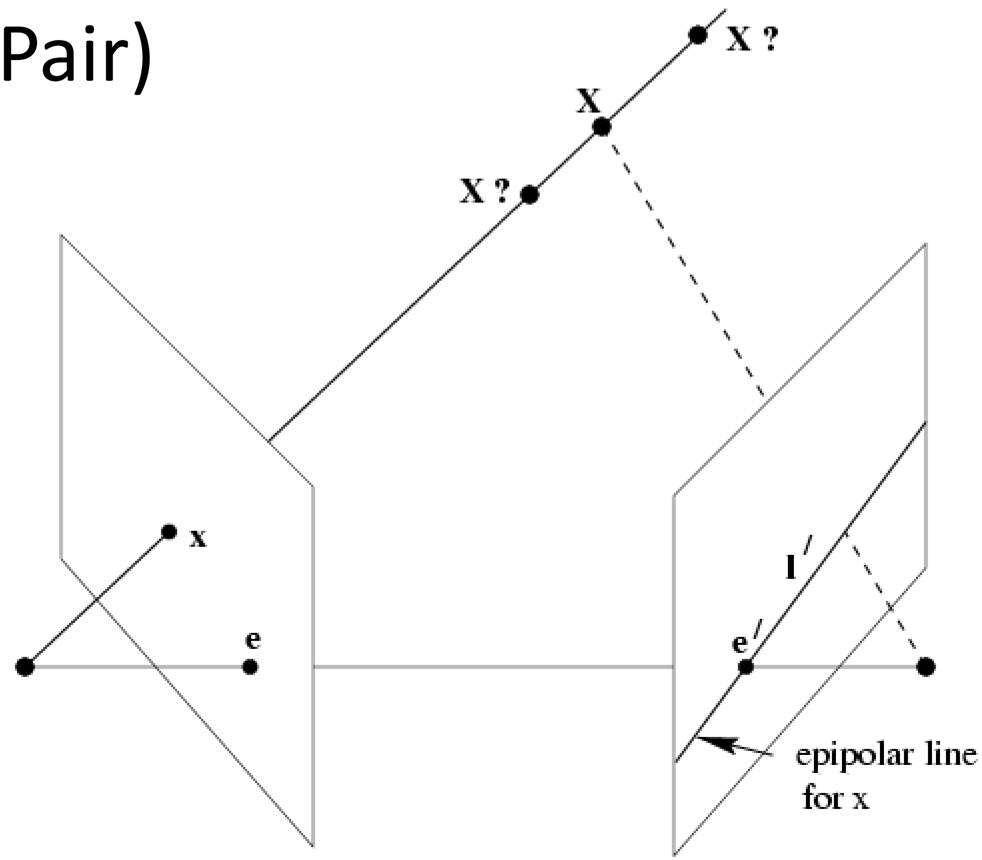
Vision Sensors

- Multiple Perspective Cameras (e.g. Stereo Camera Pair)



Vision Sensors

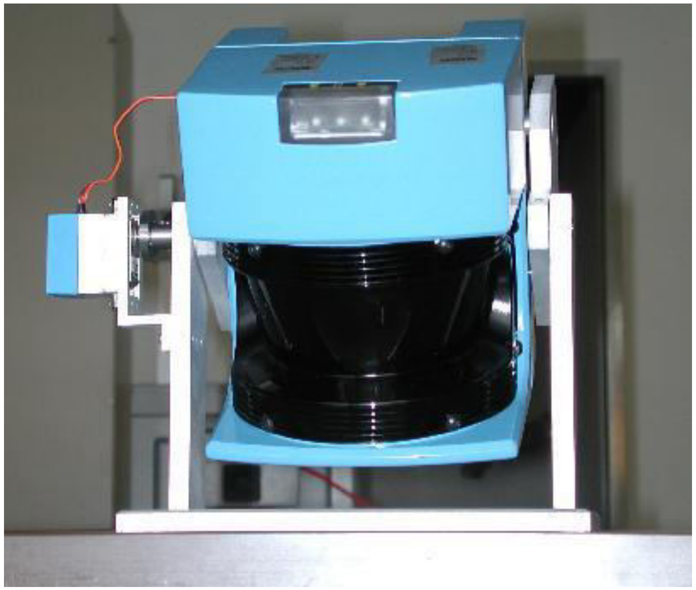
- Multiple Perspective Cameras (e.g. Stereo Camera Pair)

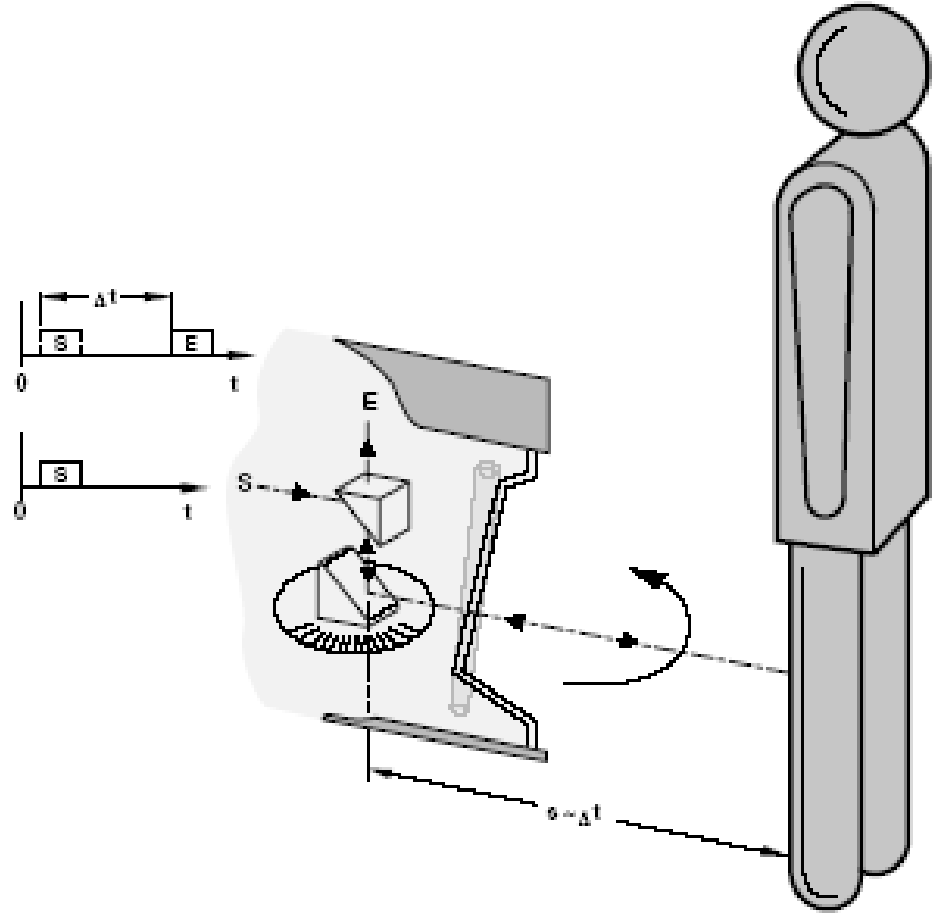


$$x'^T F x = 0 \qquad\qquad l' = Fx$$

Vision Sensors

- Laser Scanner



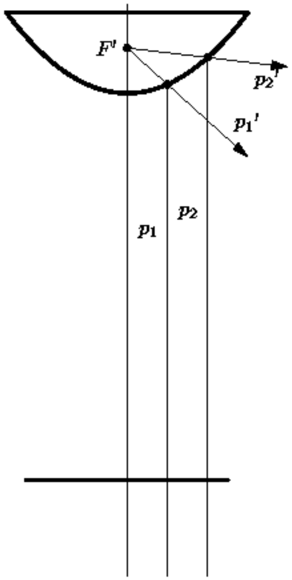


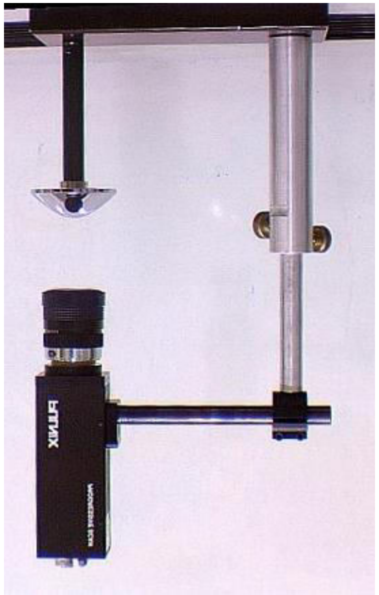
Vision Sensors

- Laser Scanner

Vision Sensors

- Omnidirectional Camera



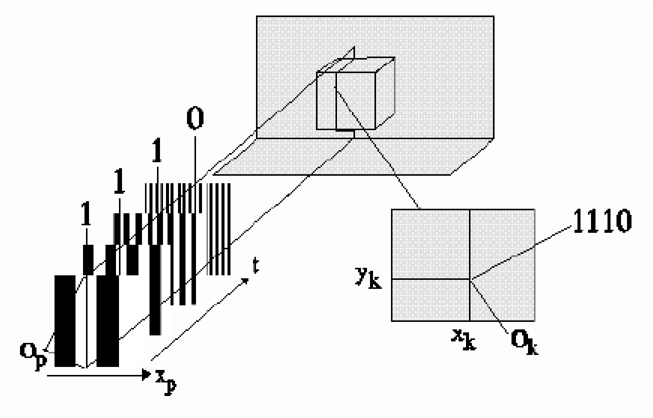


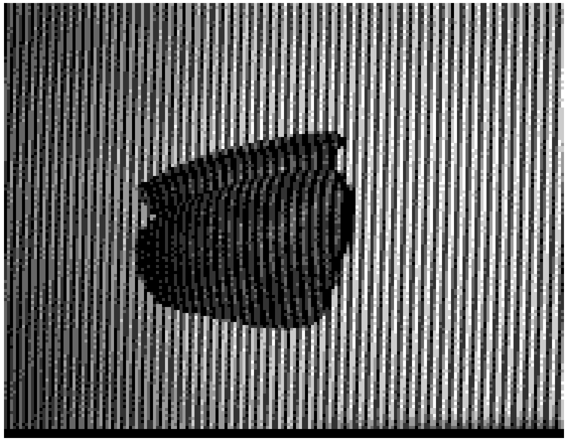
Vision Sensors

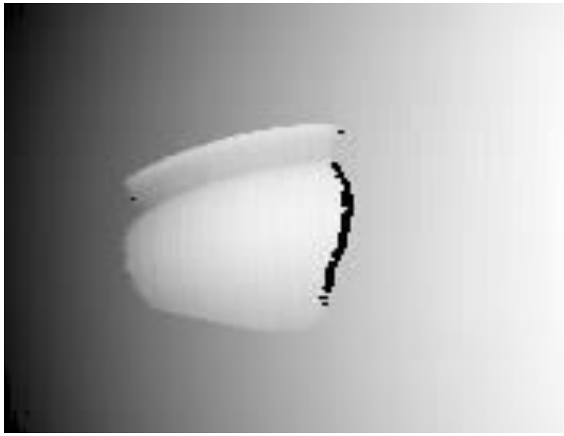
- Omnidirectional Camera

Vision Sensors

- Structured Light Sensor







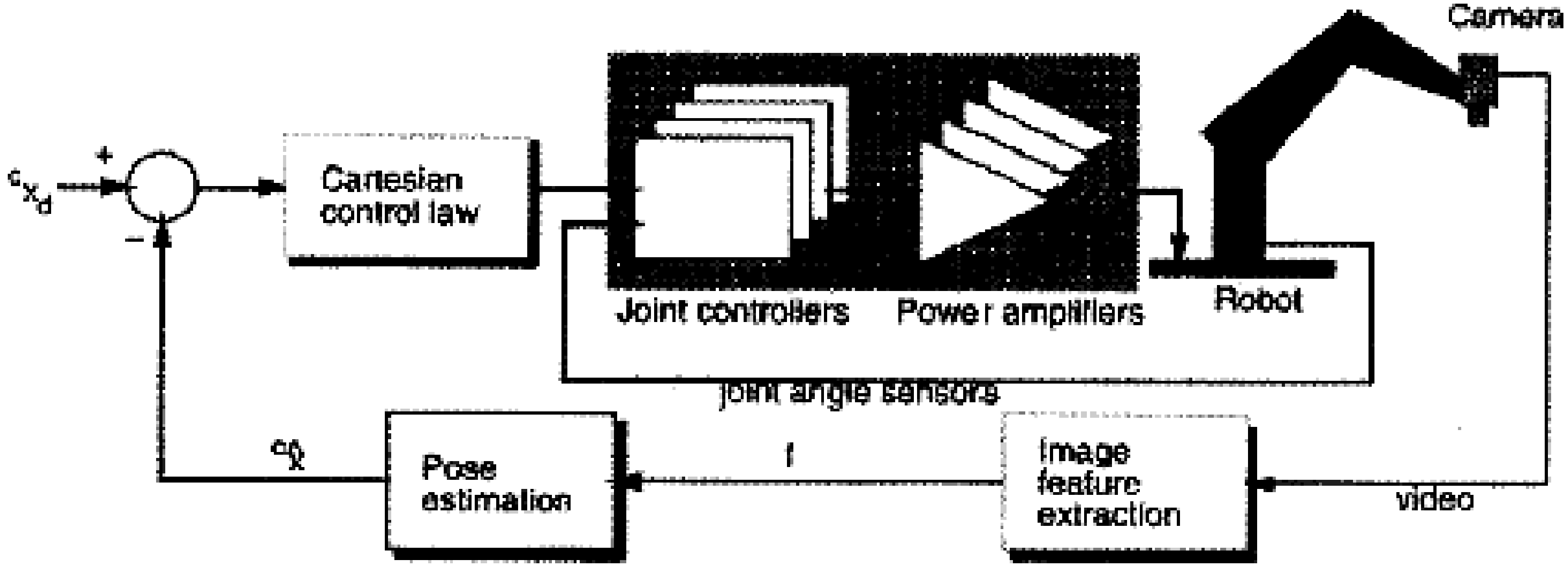
Figures from PRIP, TU Vienna

Issues/Problems of Vision Guided Robotics

- Measurement Frequency
- Measurement Uncertainty
- Occlusion, Camera Positioning
- Sensor dimensions

Visual Servoing

- Vision System operates in a closed control loop.
- Better Accuracy than „Look and Move“ systems



Figures from S.Hutchinson: A Tutorial on Visual Servo Control

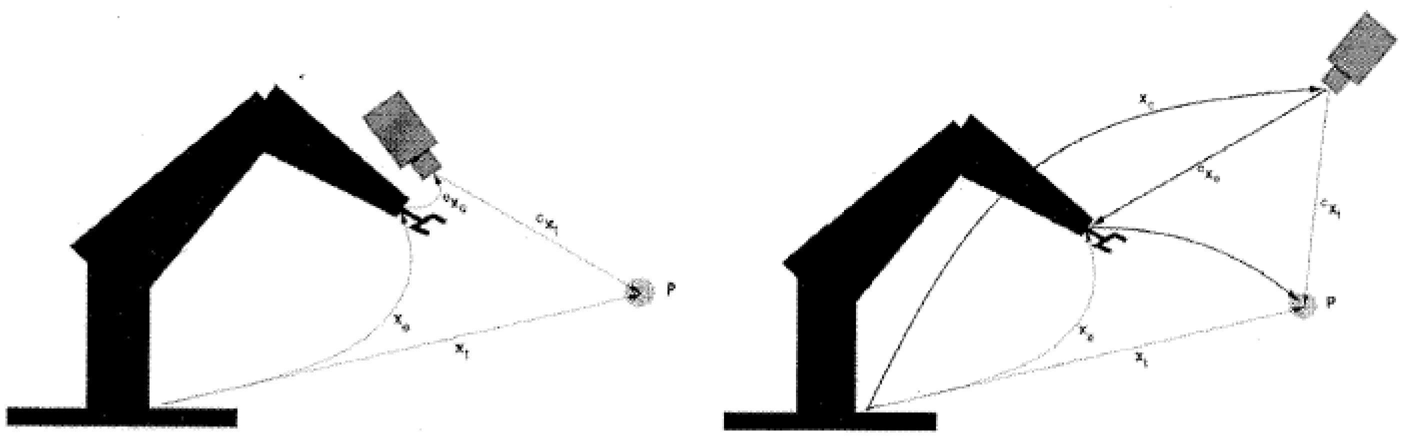
Visual Servoing

- Example: Maintaining relative Object Position

Figures from P. Wunsch and G. Hirzinger. *Real-Time Visual Tracking of 3-D Objects with Dynamic Handling of Occlusion*

Visual Servoing

- Camera Configurations:



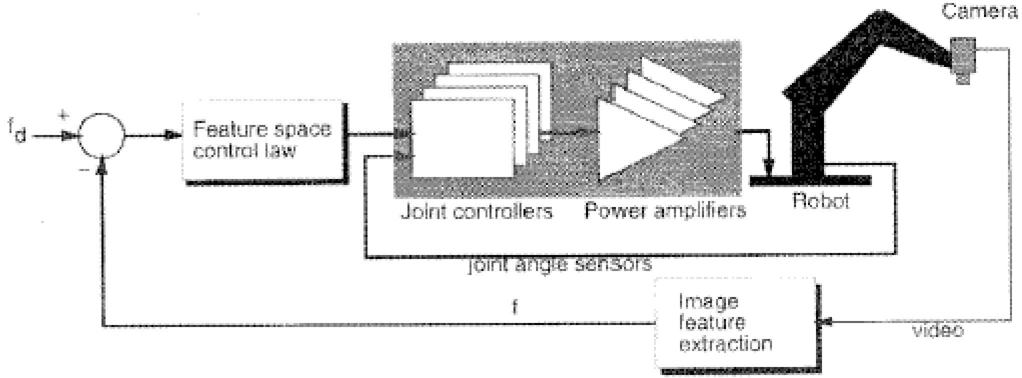
End-Effector Mounted

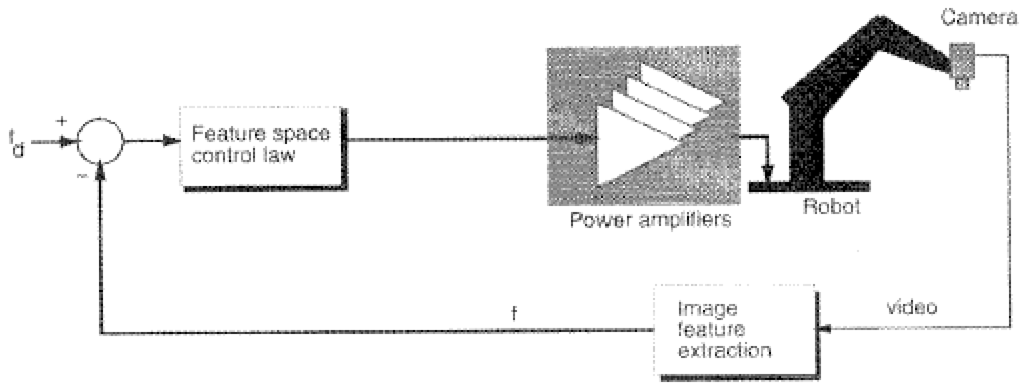
Fixed

Figures from S.Hutchinson: A Tutorial on Visual Servo Control

Visual Servoing

- Servoing Architectures

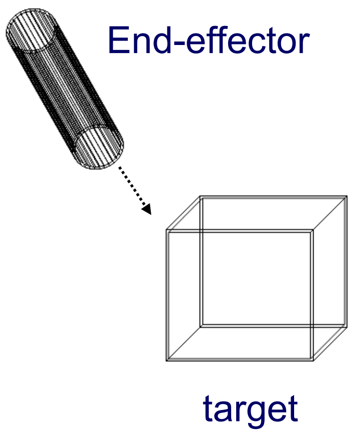




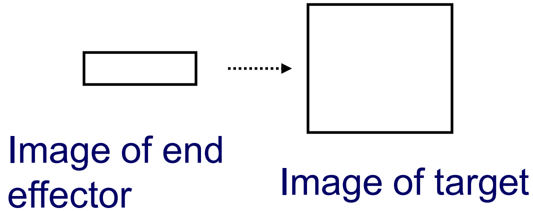
Figures from S.Hutchinson: A Tutorial on Visual Servo Control

Visual Servoing

- Position-based and Image Based control
  - Position based:
    - Alignment in target coordinate system
    - The 3D structure of the target is rconstructed
    - The end-effector is tracked
    - Sensitive to calibration errors
    - Sensitive to reconstruction errors

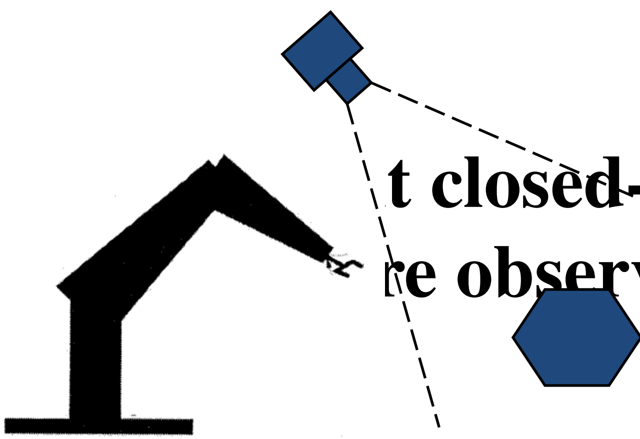


  - Image based:
    - Alignment in image coordinates
    - No explicit reconstruction necessary
    - Insensitive to calibration errors
    - Only special problems solvable
    - Depends on initial pose
    - Depends on selected features

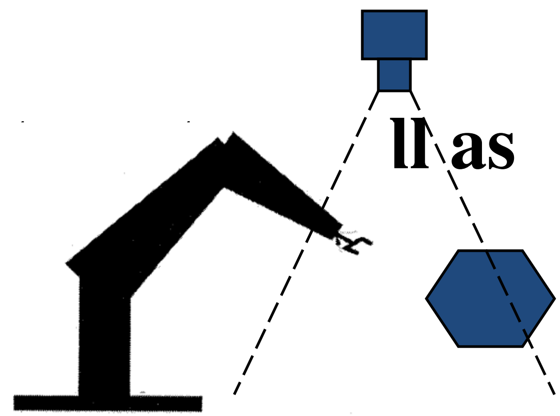


Visual Servoing

- EOL and ECL control
  - **EOL: endpoint open-loop; only the target is observed by the camera**
  - **E… t closed-loop; … ll as en… re observed by…**



EOL

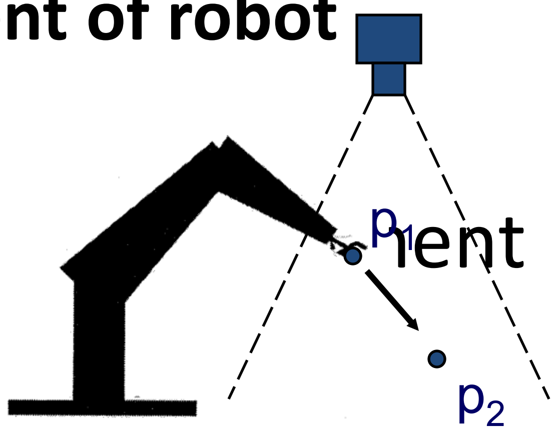


ECL

Visual Servoing

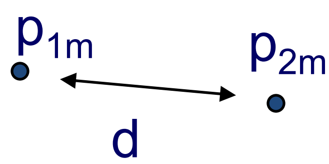
- Position Based Algorithm:
  1. **Estimation of relative pose**
  2. **Computation of error between current pose and target pose**
  3. **Movement of robot**

- Example: ┃ ent



Visual Servoing

- Position based point alignment



- Goal: bring e to 0 by moving p_1

  $\mathbf{e = |p_{2m} - p_{1m}|}$

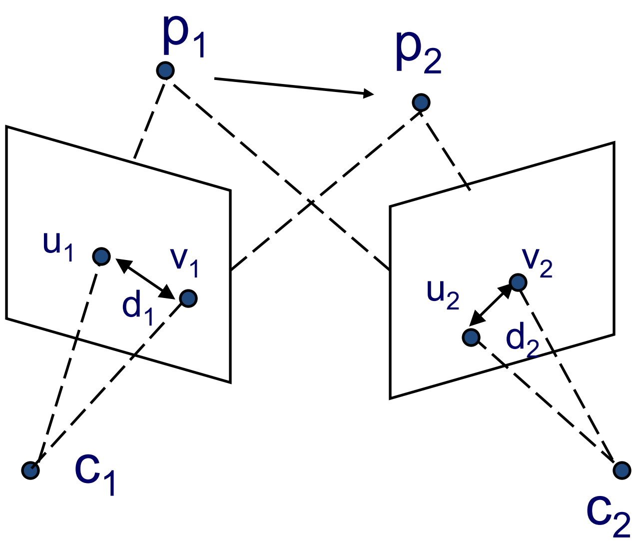
  $\mathbf{u = k^*(p_{2m} - p_{1m})}$

- p_{xm} is subject to the following measurement errors: sensor position, sensor calibration, sensor measurement error

- p_{xm} is independent of the following errors: end effector position, target position

Visual Servoing

- Image based point alignment



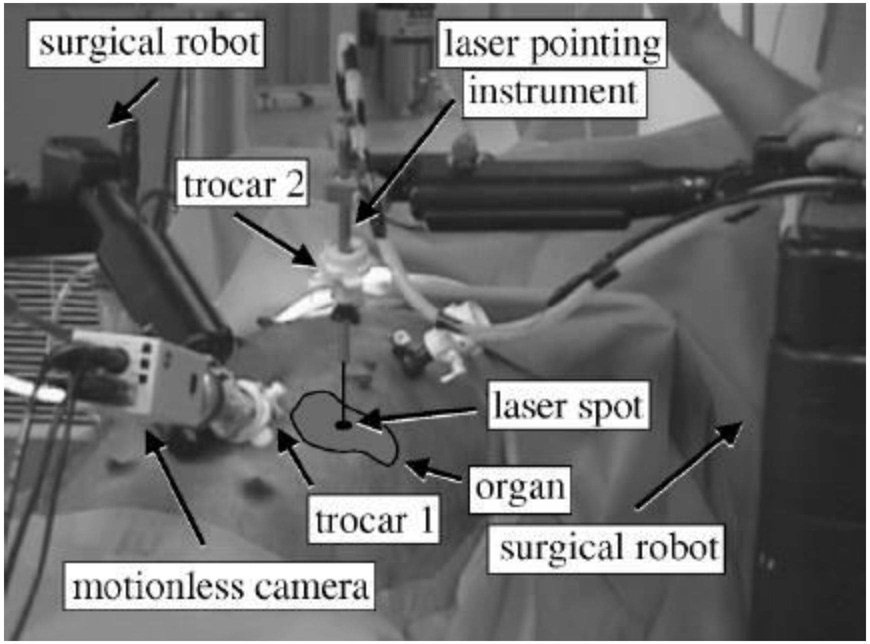
- Goal: bring e to 0 by moving p_1
  $\mathbf{e = |u_{1m} - v_{1m}| + |u_{2m} - v_{2m}|}$

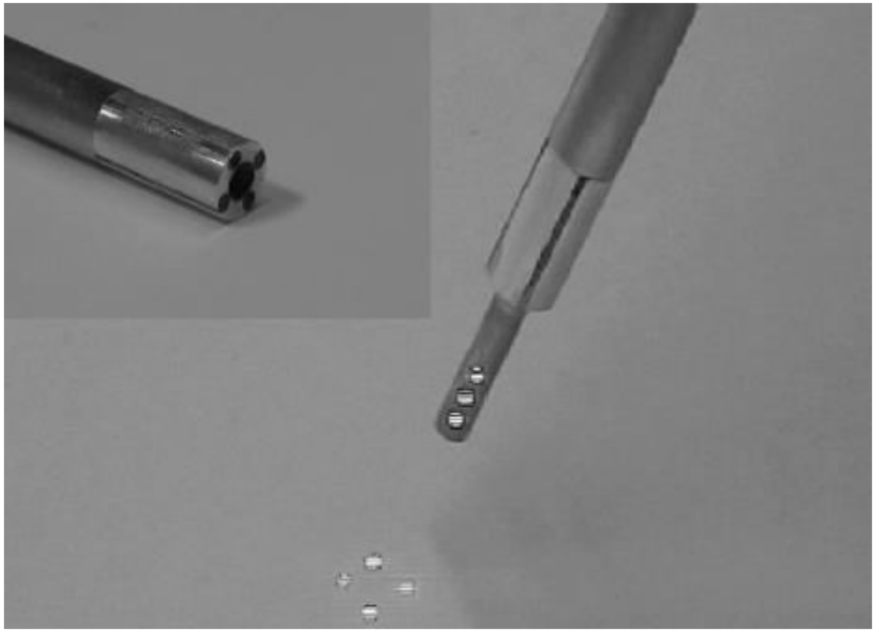
- u_{xm}, v_{xm} is subject only to <u>sensor measurement error</u>

- u_{xm}, v_{xm} is independent of the following measurement errors: <u>sensor position, end effector position, sensor calibration, target position</u>

Visual Servoing

- Example Laparoscopy

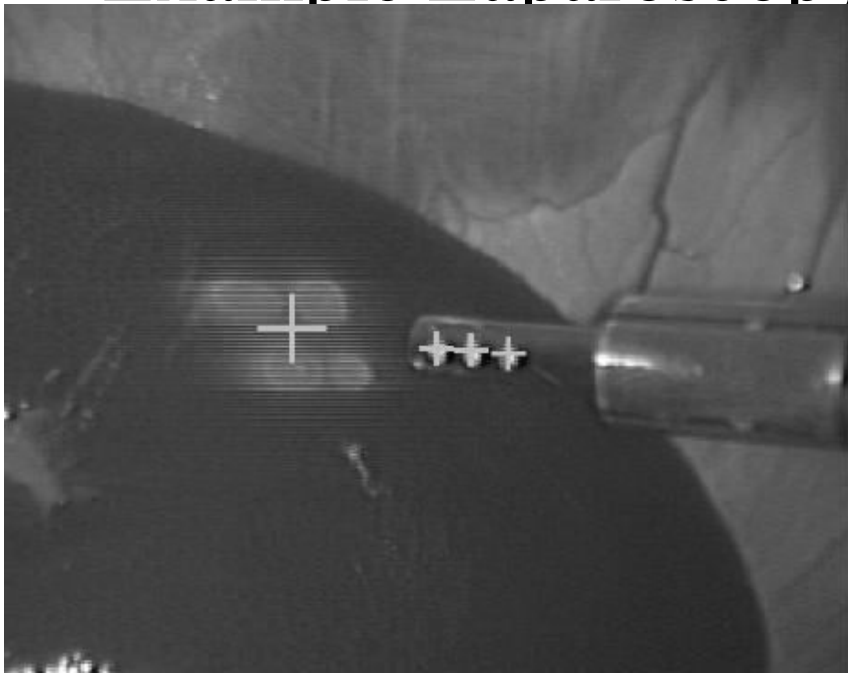


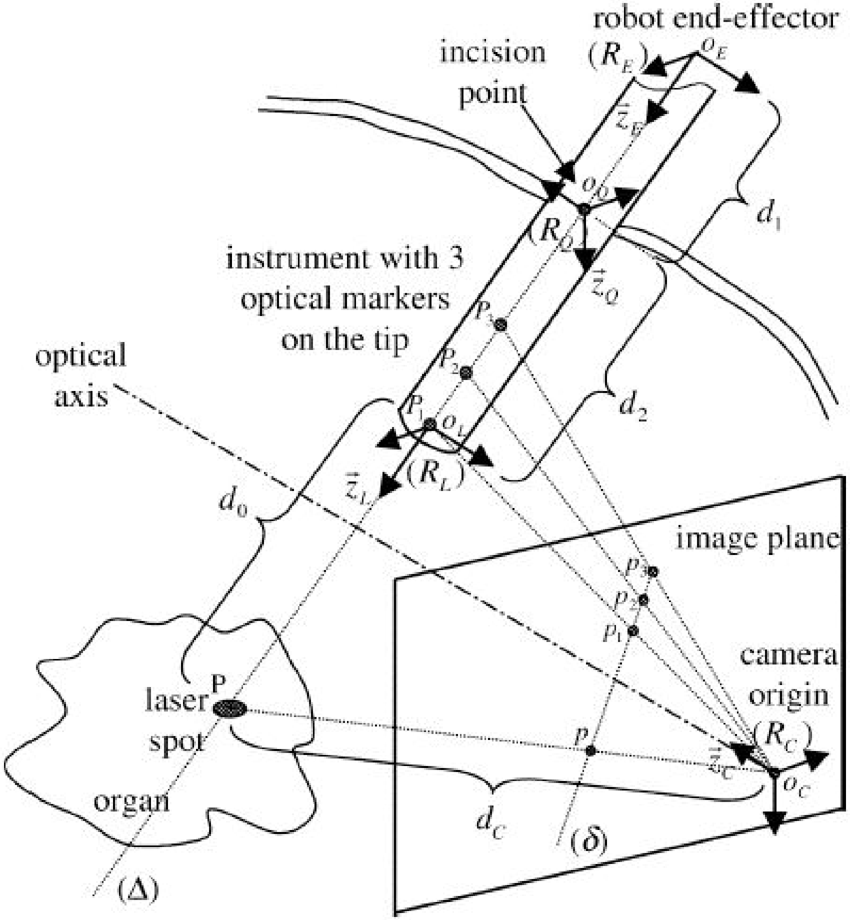


Figures from A.Krupa: Autonomous 3-D Positioning of Surgical Instruments in Robotized Laparoscopic Surgery Using Visual Servoing

Visual Servoing

- Example Laparoscopy

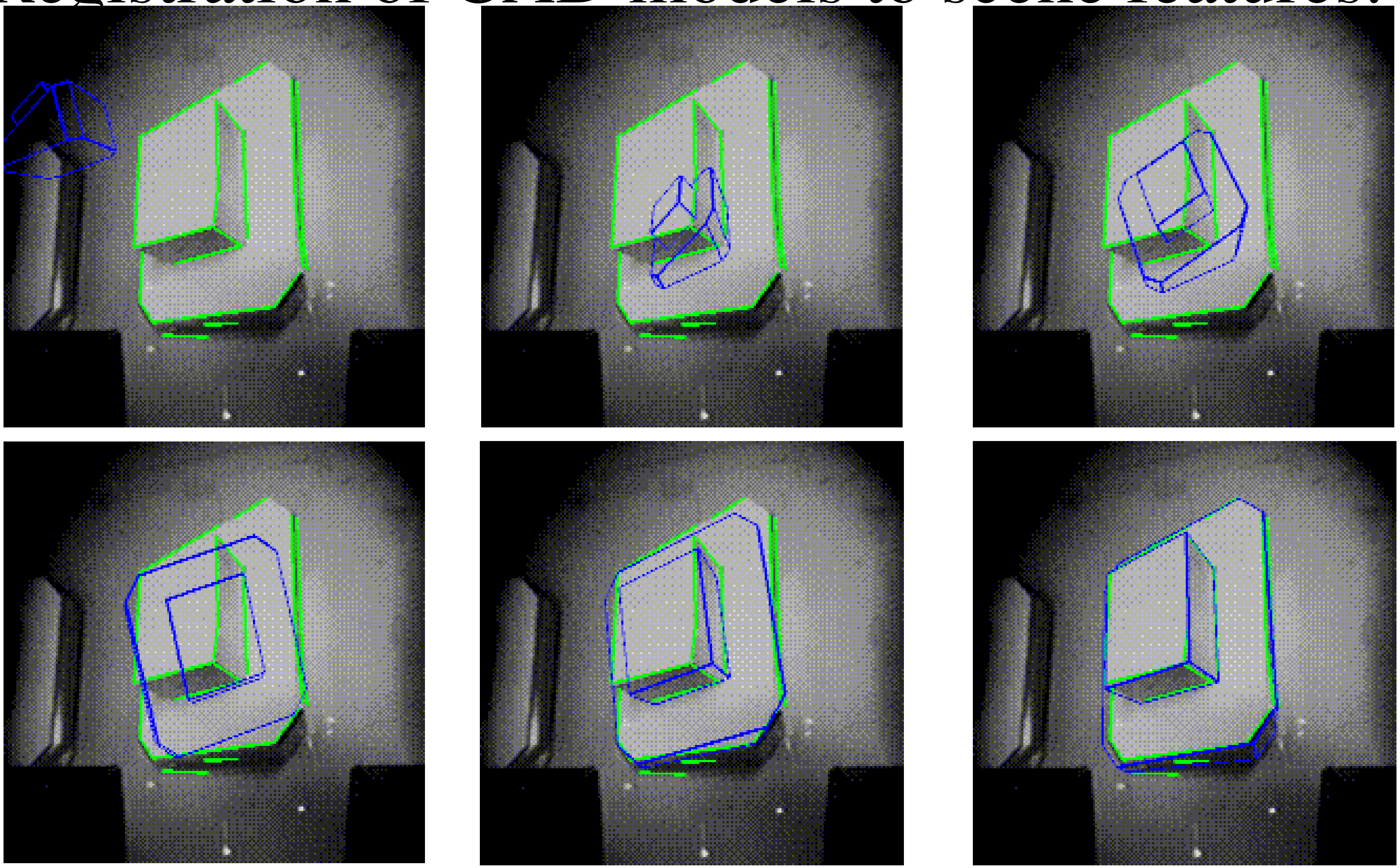




Figures from A.Krupa: Autonomous 3-D Positioning of Surgical Instruments in Robotized Laparoscopic Surgery Using Visual Servoing

Registration

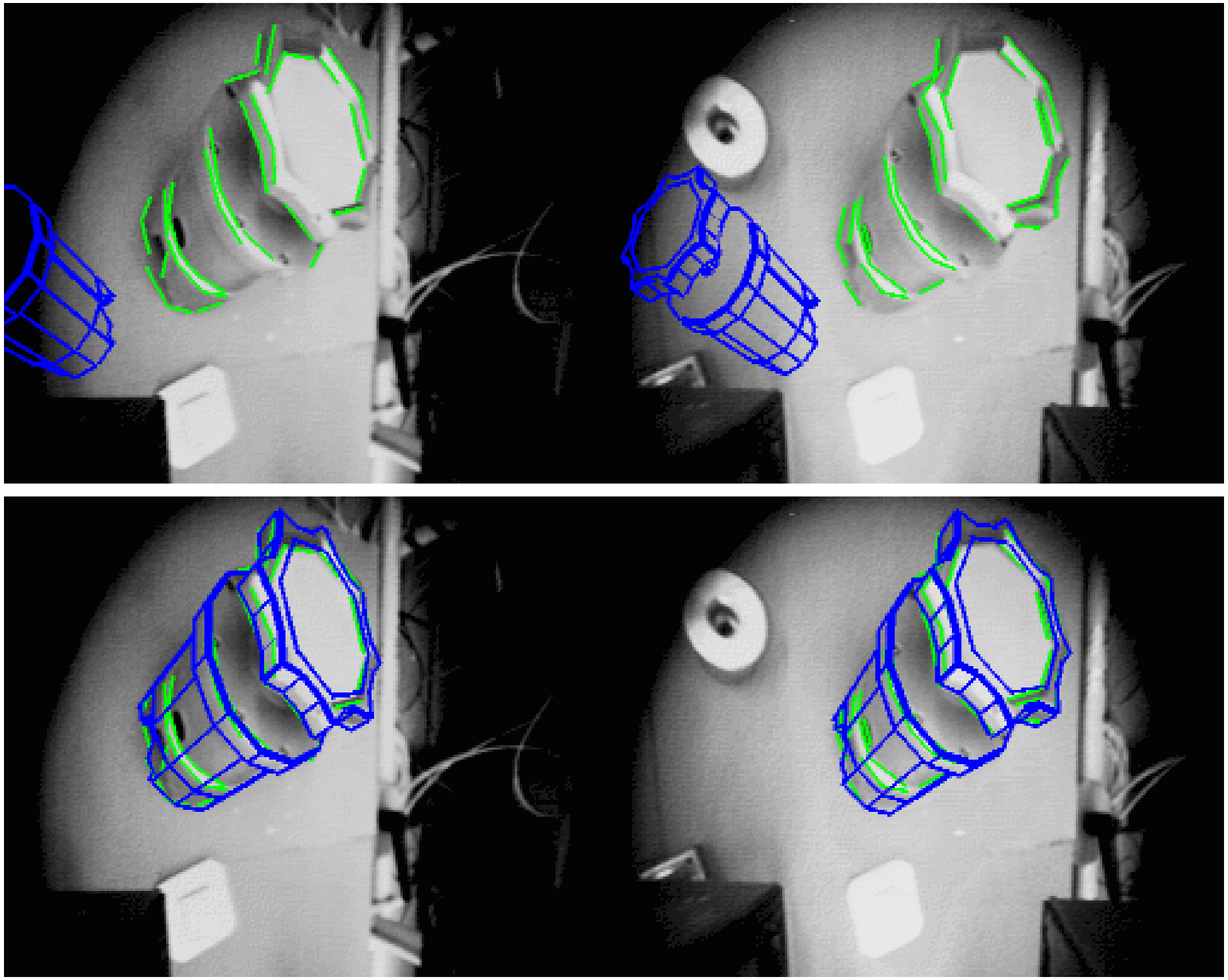
- Registration of CAD models to scene features:



Figures from P.Wunsch: Registration of CAD-Models to Images by Iterative Inverse Perspective Matching

Registration

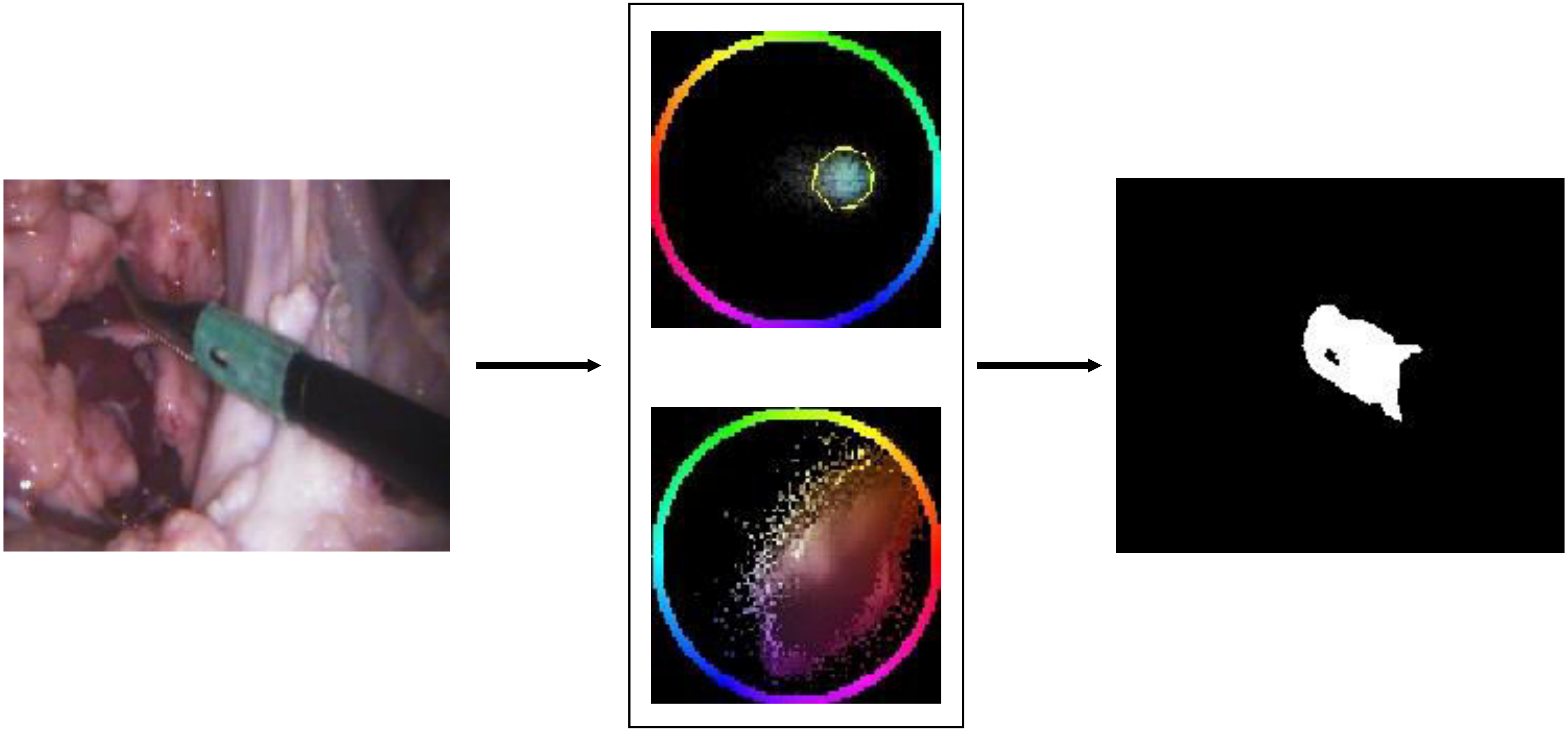
- Registration of CAD models to scene features:



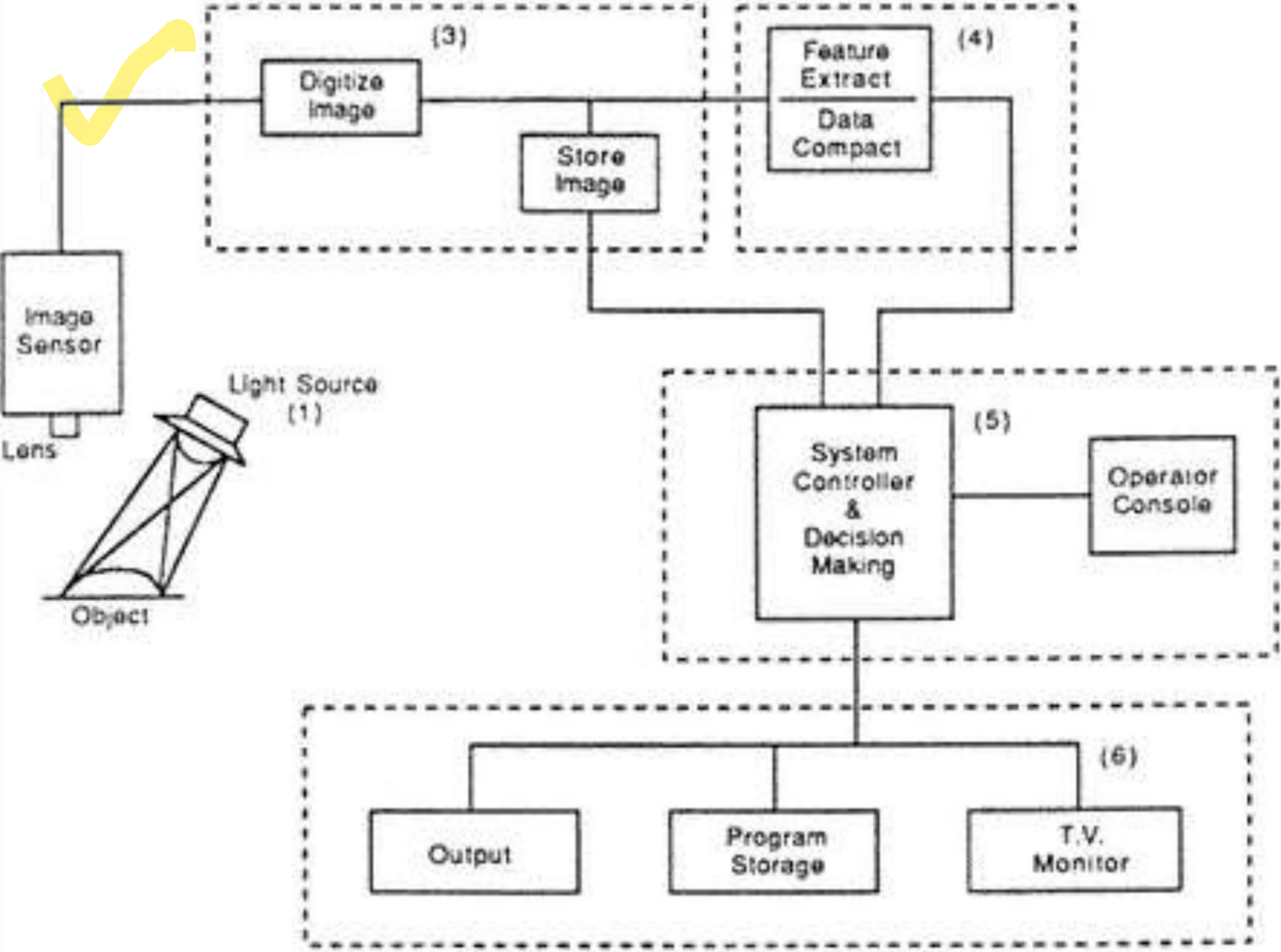
Figures from P.Wunsch: Registration of CAD-Models to Images by Iterative Inverse Perspective Matching

Tracking

- Instrument tracking in laparoscopy

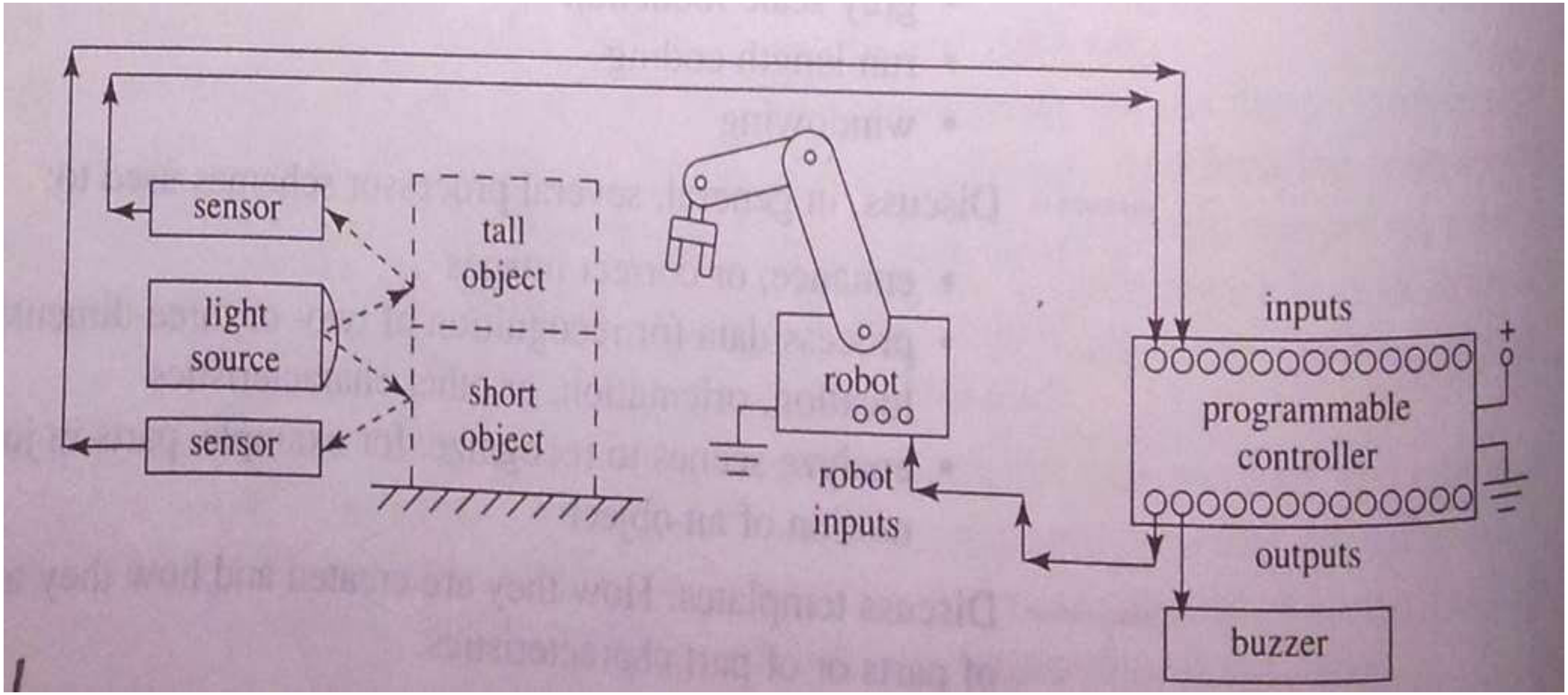


Figures from Wei: A Real-time Visual Servoing System for Laparoscopic Surgery

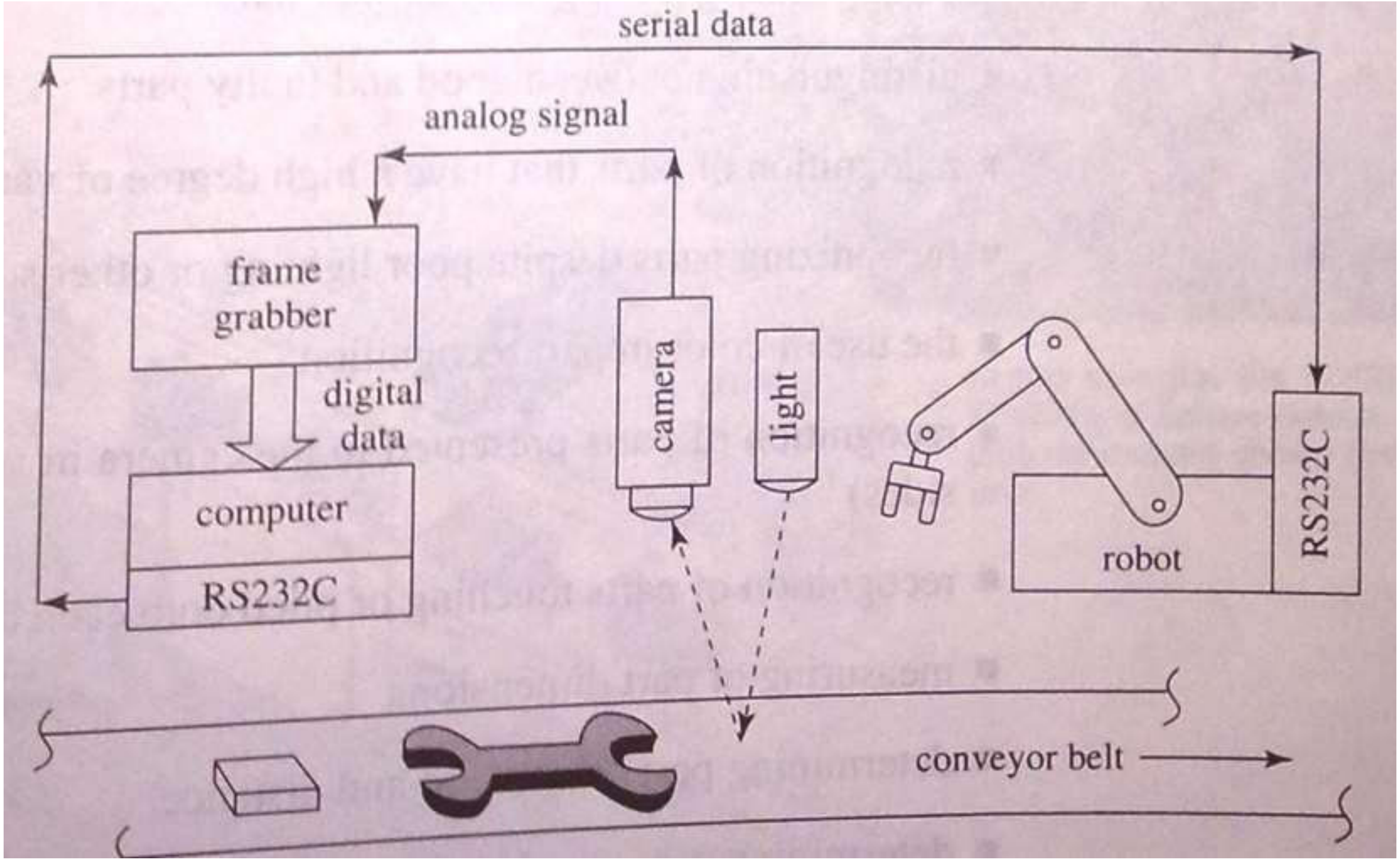


(3)
Digitize Image
Store Image
(4)
Feature Extract
Data Compact
Image Sensor
Lens
Light Source
(1)
Object
System Controller & Decision Making
(5)
Operator Console
(6)
Output
Program Storage
T.V. Monitor

Simple machine vision system

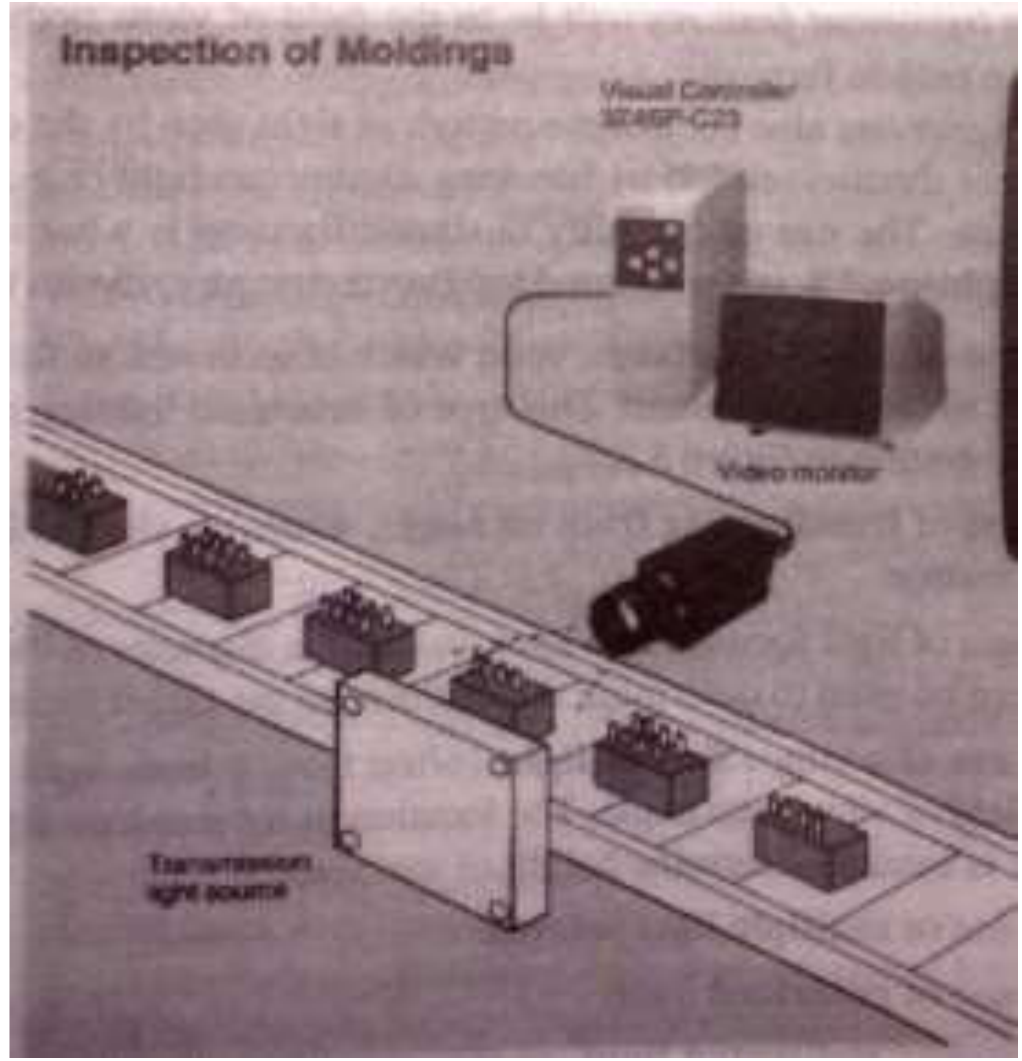


1.Camera 2.light source
3.frame grabber 4.circuitry and programming
5.computer 6.output interface

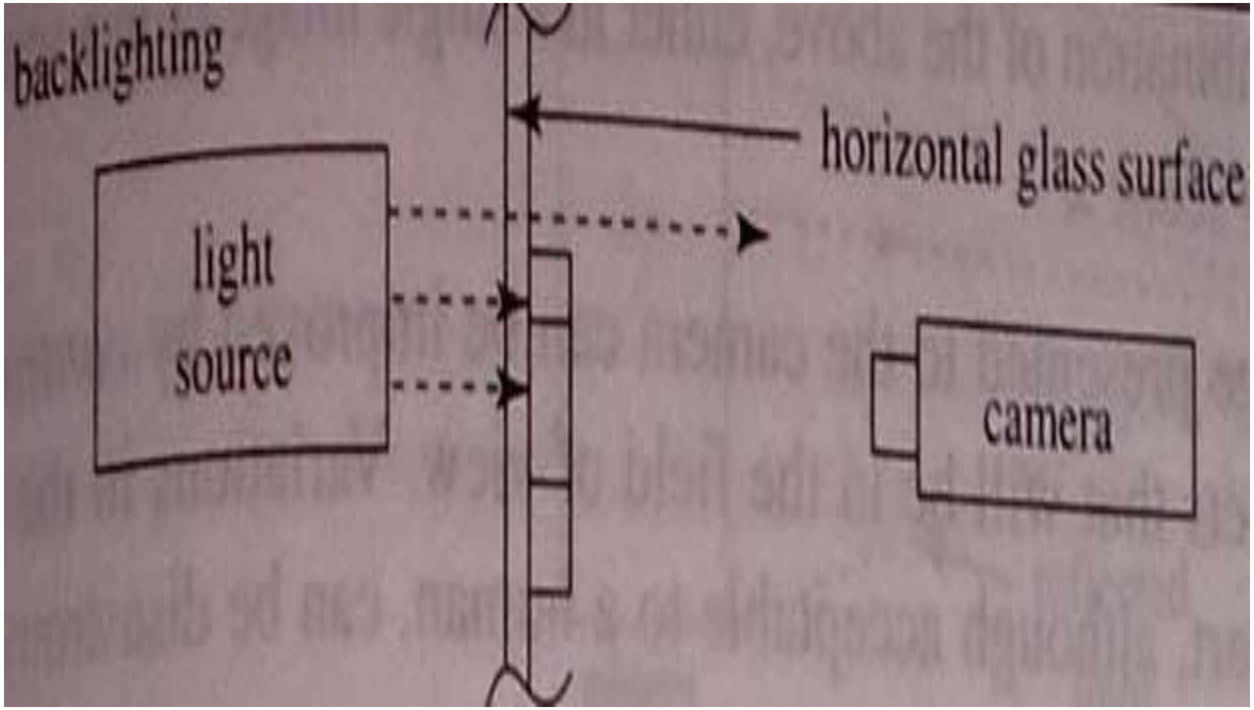


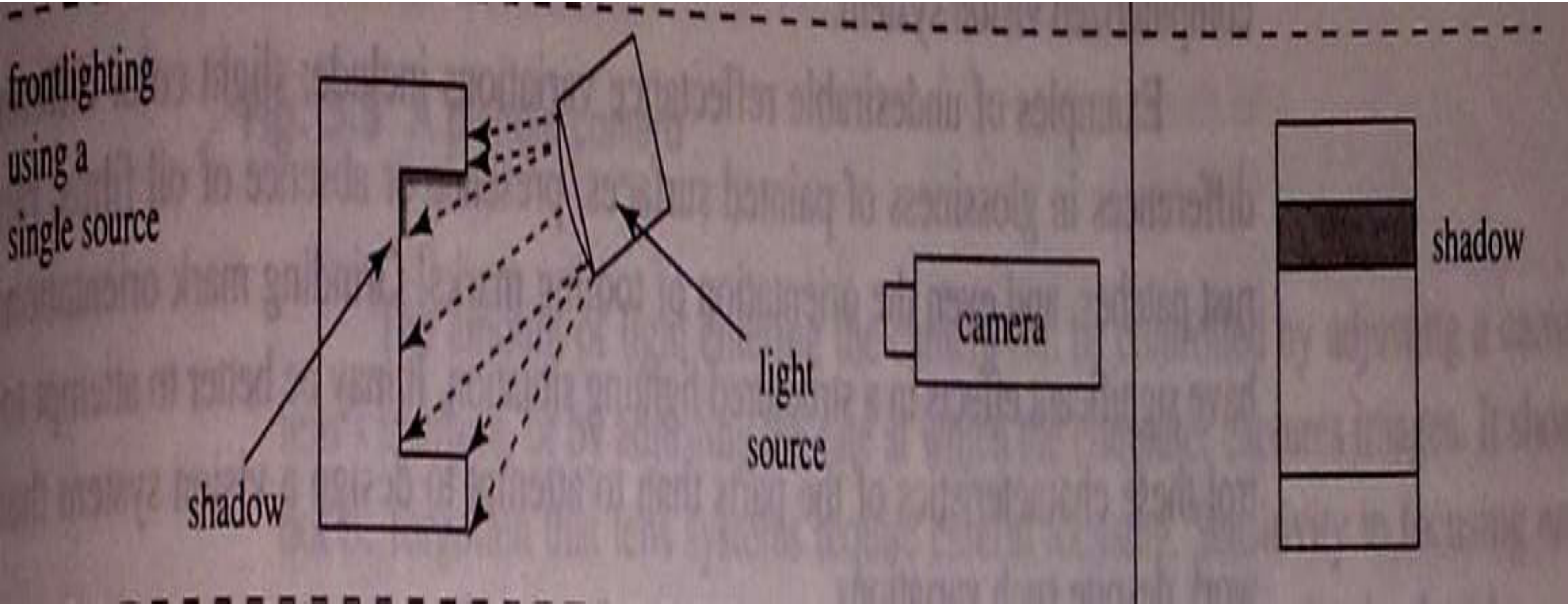
COMPONENTS OF MACHINE VISION SYSTEM

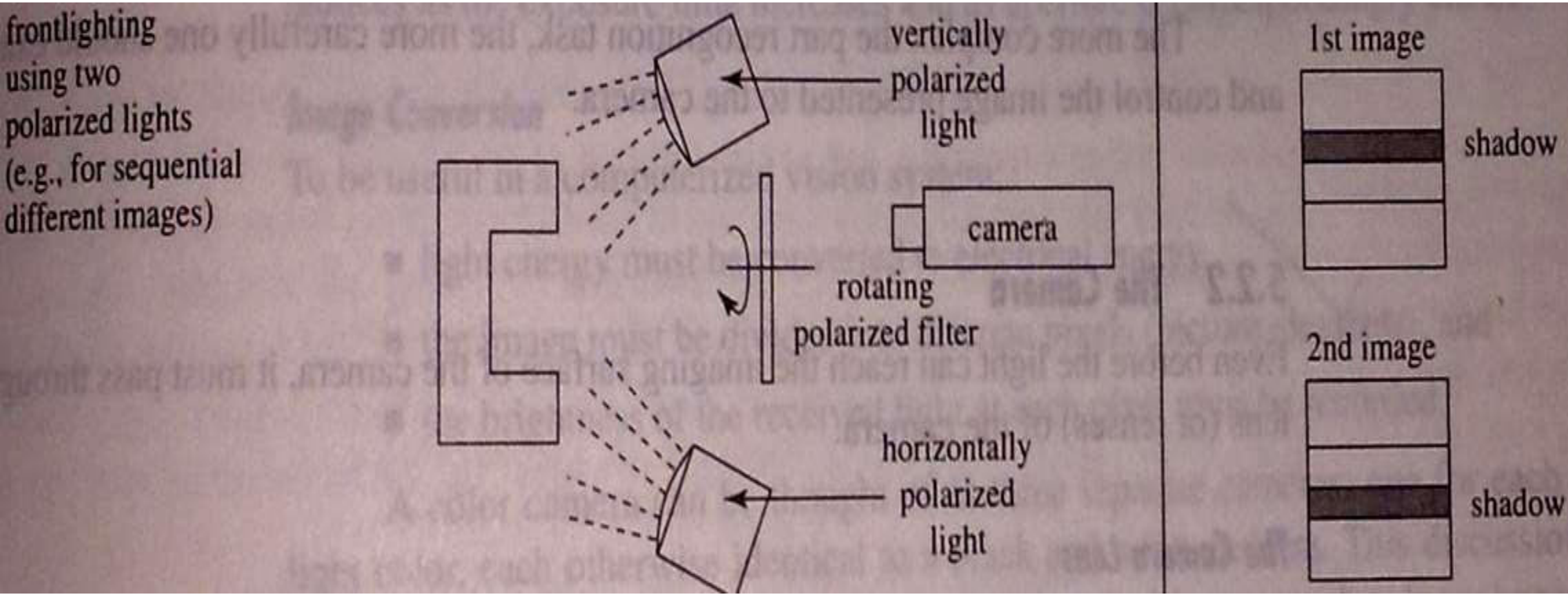
- ➢Image
- ➢Camera
- ➢Image capturing system or framegrabber
- ➢The pre processor
- ➢The memory
- ➢The processor
- ➢The output interface

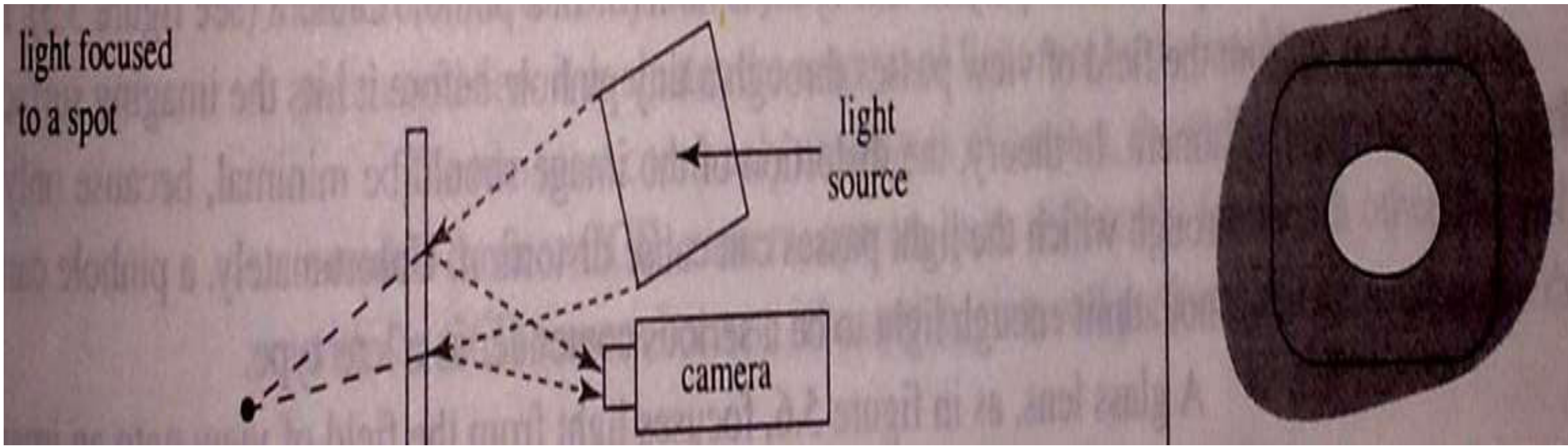


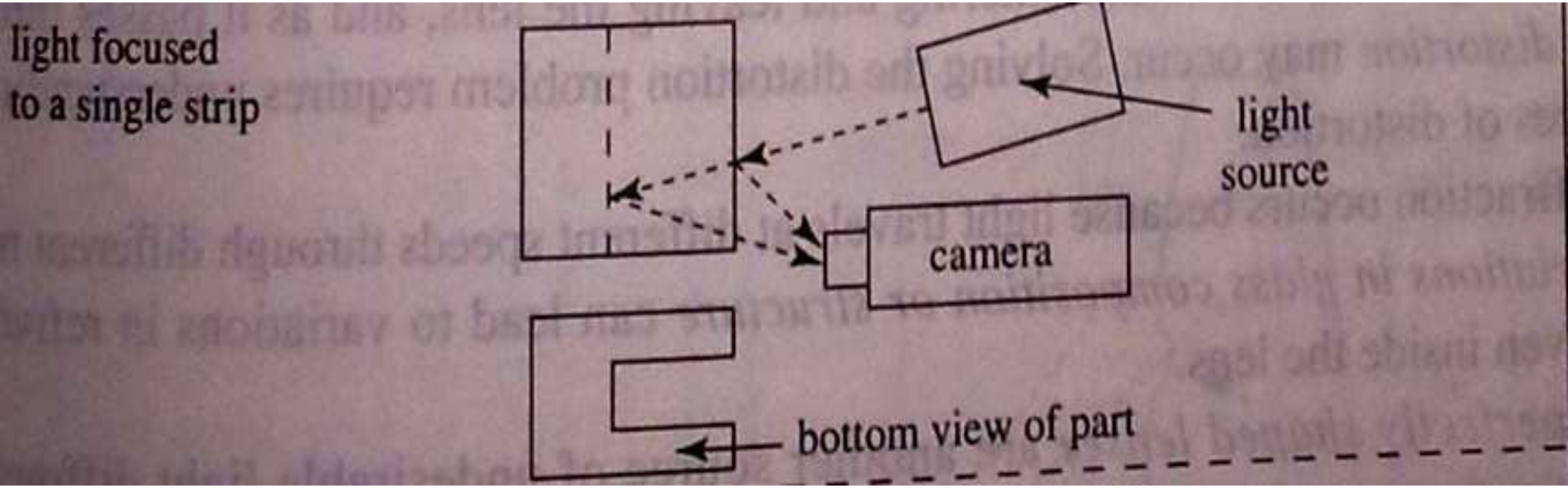
Structured light technique




frontlighting
using a
single source
shadow
light
source
camera
shadow

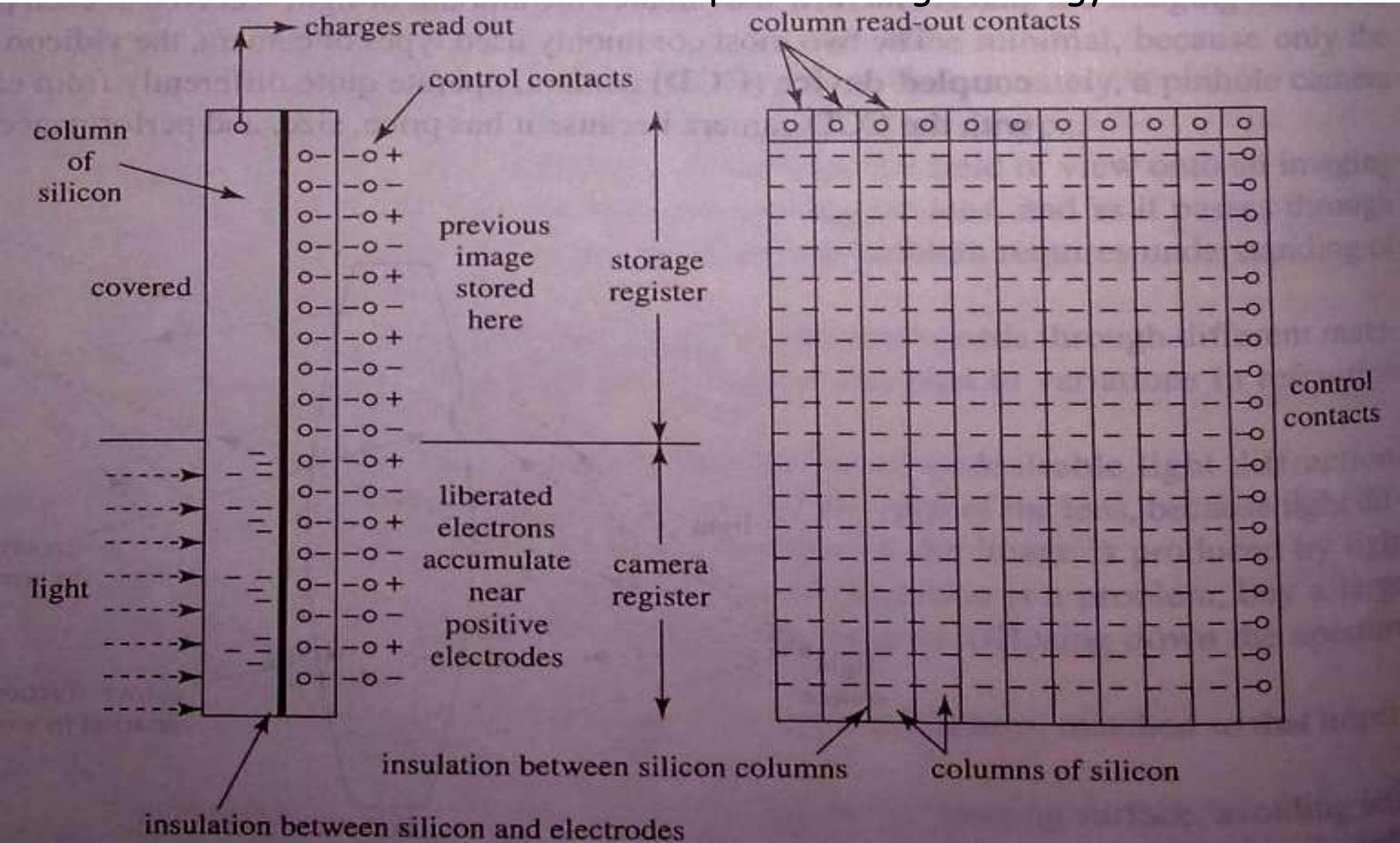

frontlighting
using two
polarized lights
(e.g., for sequential
different images)
vertically
polarized
light
camera
rotating
polarized filter
horizontally
polarized
light
1st image
shadow
2nd image
shadow


light focused
to a spot
light
source
camera


light focused
to a single strip
light
source
camera
bottom view of part

CCD (CHARGE COUPLED DEVICE)

- It is a silicon based integrated circuit.
- Image gets focused on chip.
- Charge at each electrode is proportional to exposure to light energy



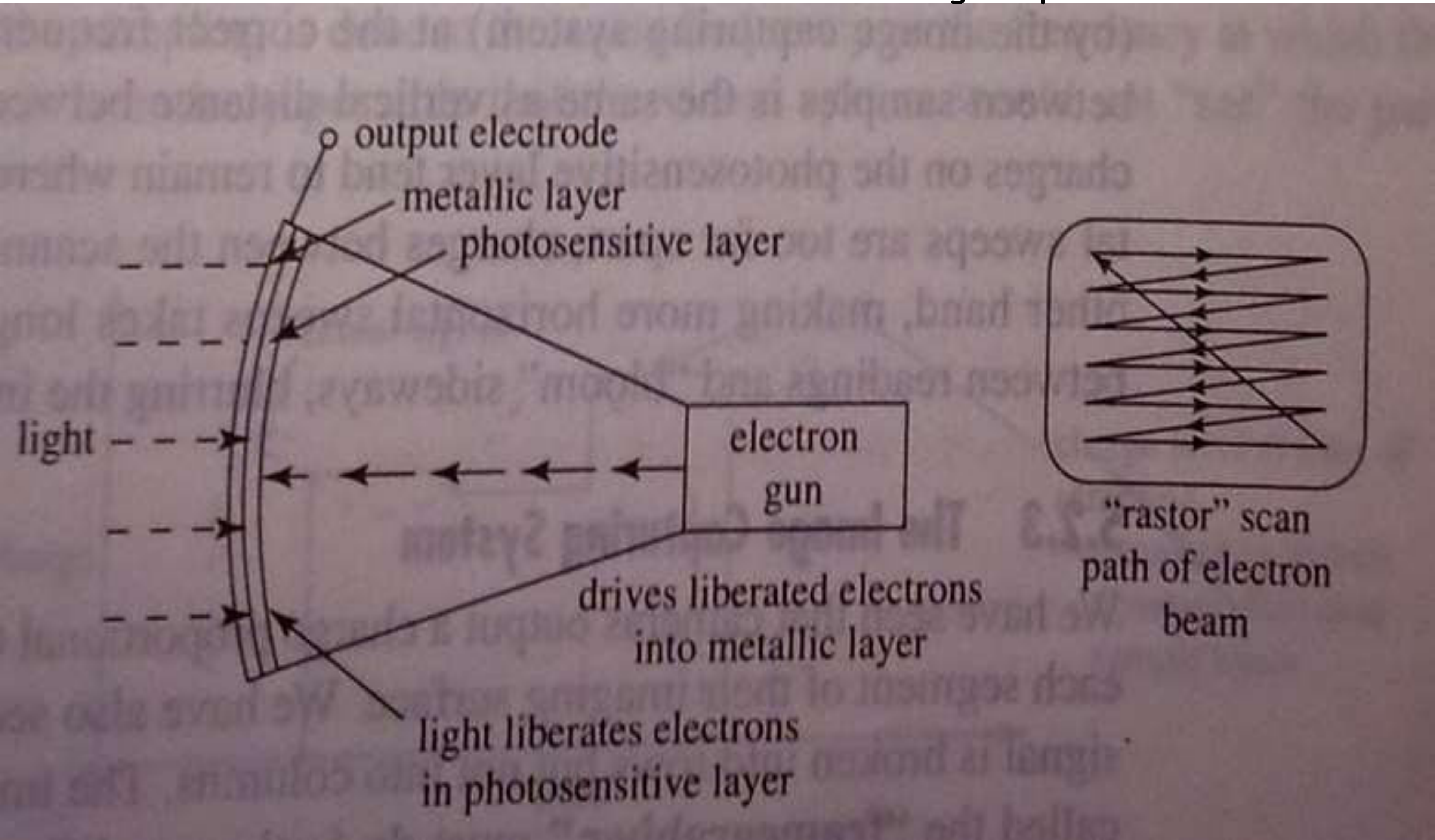
CCD CAMERA

ADVANTAGES

- More sensitive at low light.
- Produces better image even in extreme variation in brightness

Vidicon camera

- Technique used is same as in television.
- The charge in electrode is proportional to amount of light received.
- Does not break image in pixel as CCD camera.



Vidicon camera

advantages

- Is more reliable.
- Low cost.
- Number and arrangement of pixel is in the hand of programmer.
- More flexible.
- Grid and pixel shape can be varied.

disadvantages

- Doesn't break the image in pixel as ccd camera.
- Analog output.
- Imposes constraints on system designer.

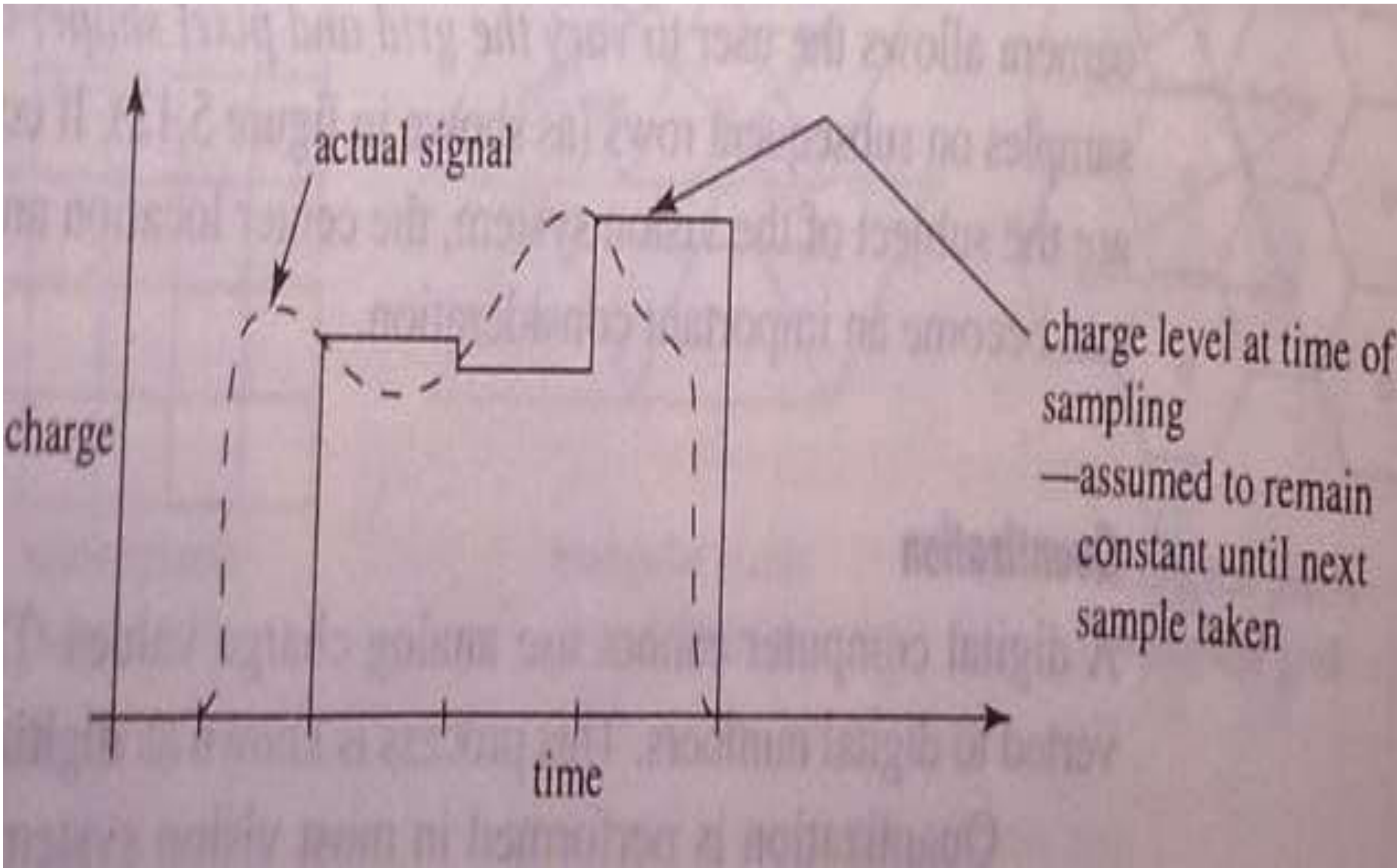
Function of Framegrabber.

- Sampling

- Quantization
- Note : image from videocon camera must be sampled and quantized, images from ccd camera need only quantization.

Sampling.

- Breaks each row of continuous charge reading to column of discrete charge reading.

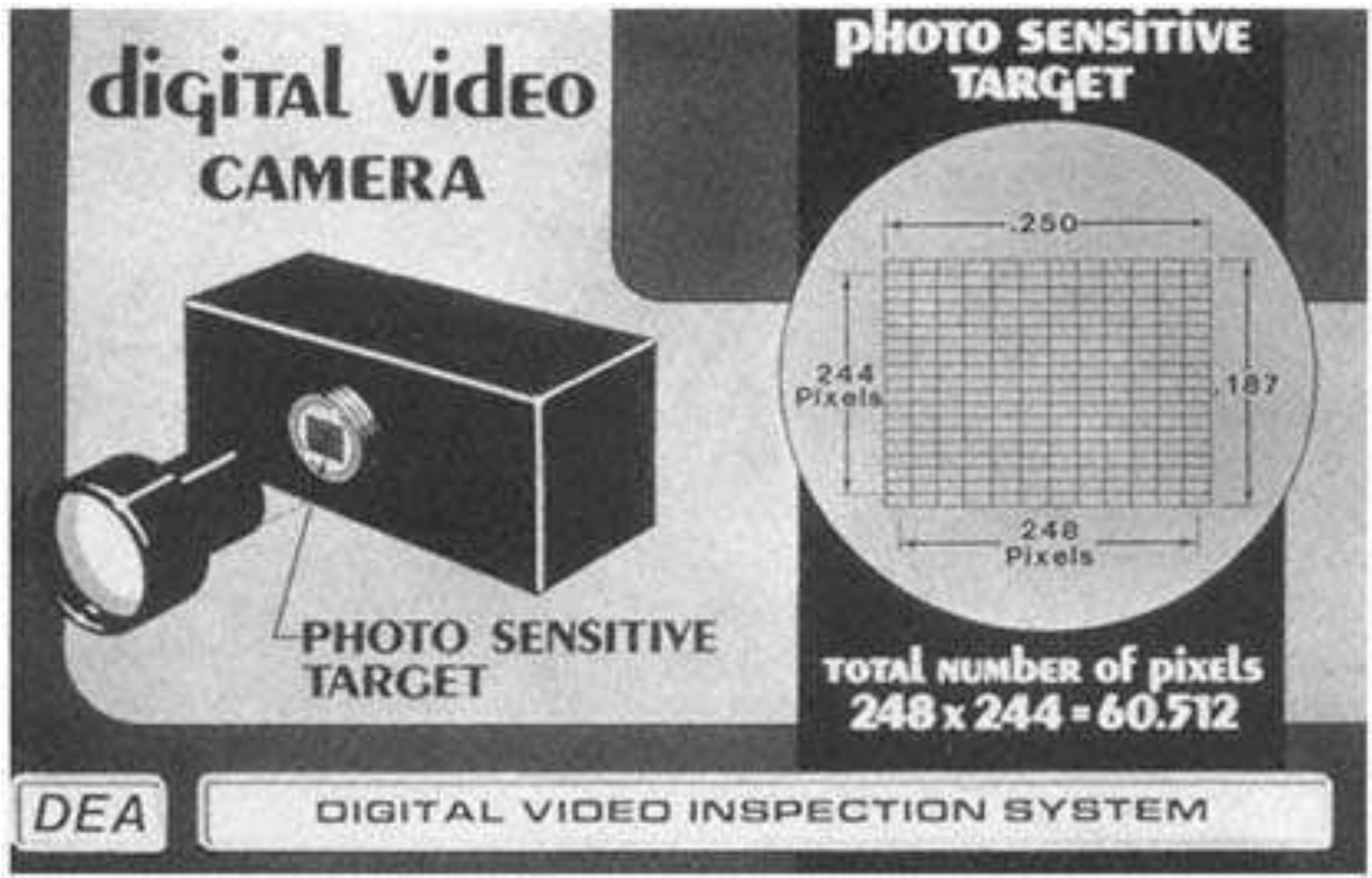


Quantization.

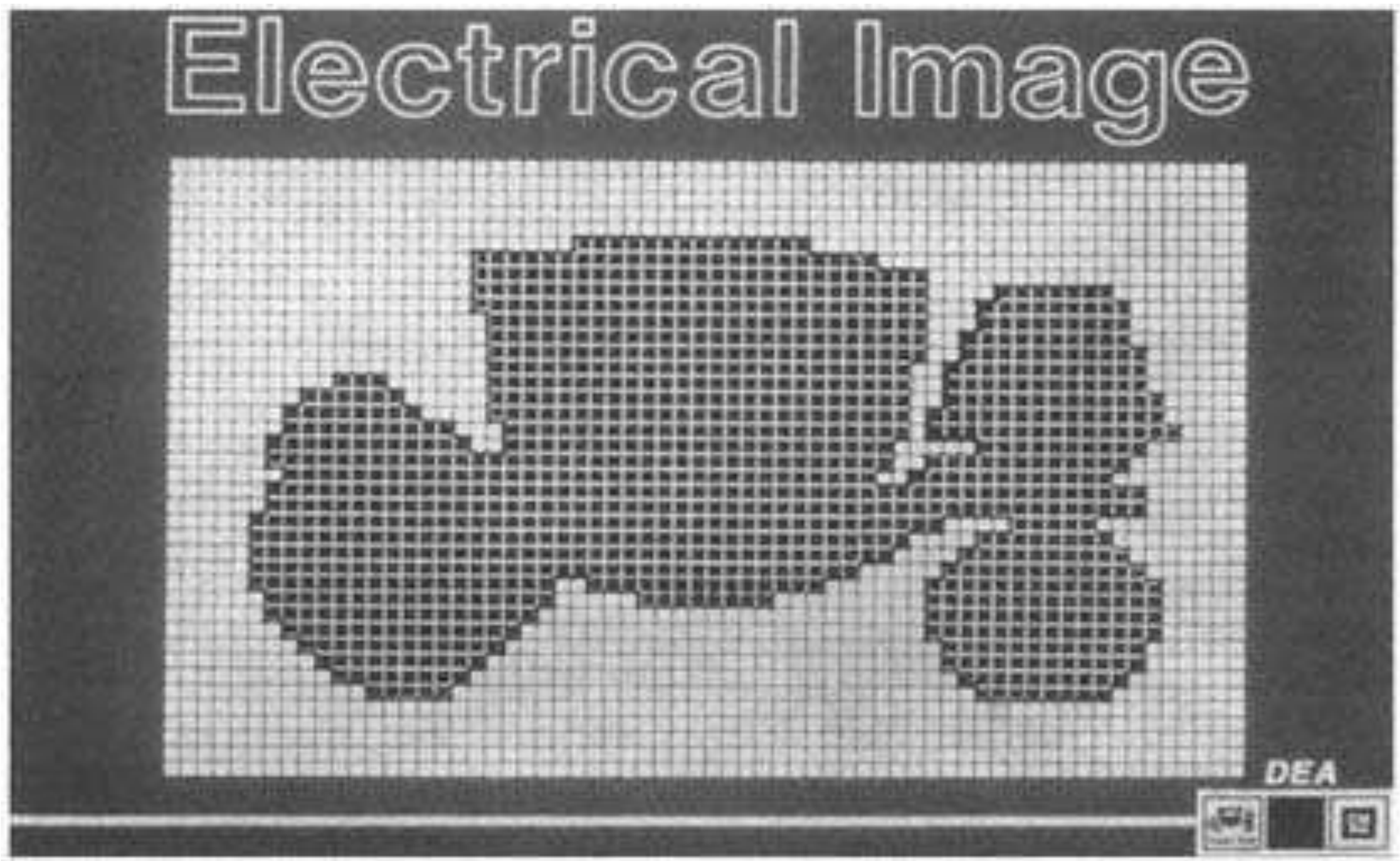
- Analog to digital converter.
- Binary codes are assigned on the level of light.

14	17	14	19	14	17	14	21
8	17	8	17	8	17	21	30
24	19	8	14	17	21	29	28
30	17	19	19	21	27	32	29
29	26	25	27	29	30	28	27
24	27	24	24	28	24	26	24
19	24	21	24	24	24	27	21
22	24	19	24	24	21	24	24

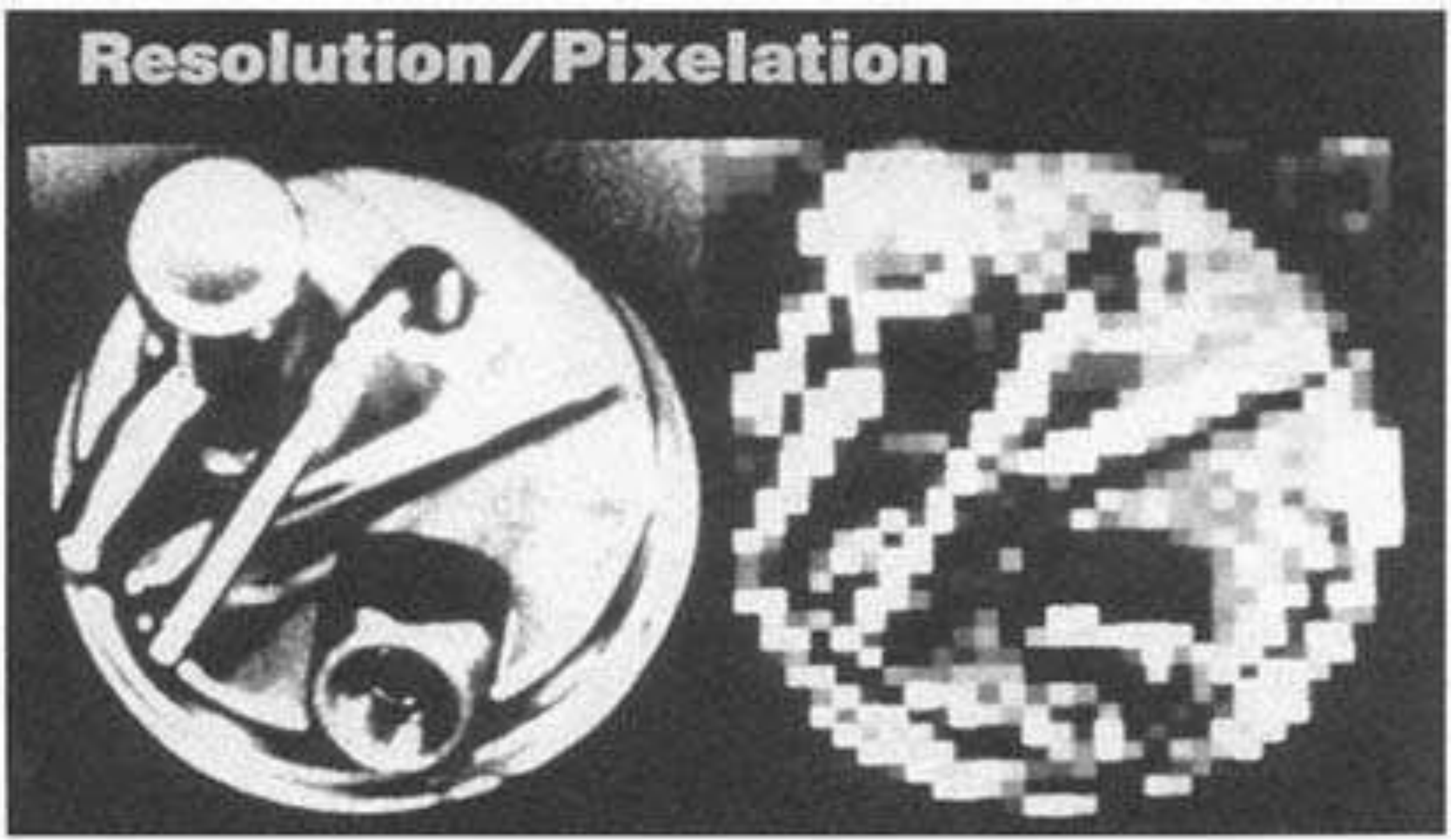
Camera with analog-to-digital converter results in digital representation of image



Mapping of three-dimensional scene into two-dimensional plane



Depiction of resolution/pixelation; digitally encoded values of shades of grey



Object Properties in Pixel Grey Value

- Color

a. Hue

b. Saturation

c. Brightness

- Specular properties

I. Reflectance

II. Texture

III. Shading

IV. Shadows

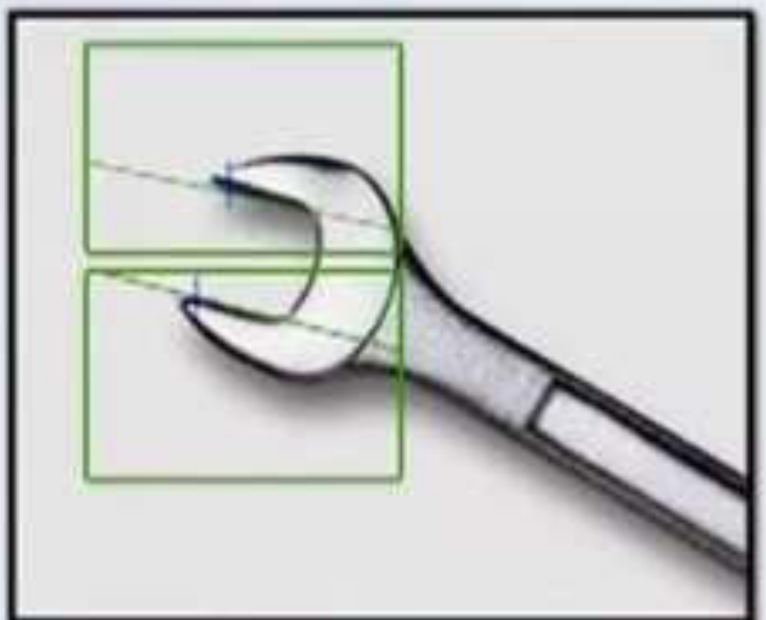
- Non-uniformities
- Lighting

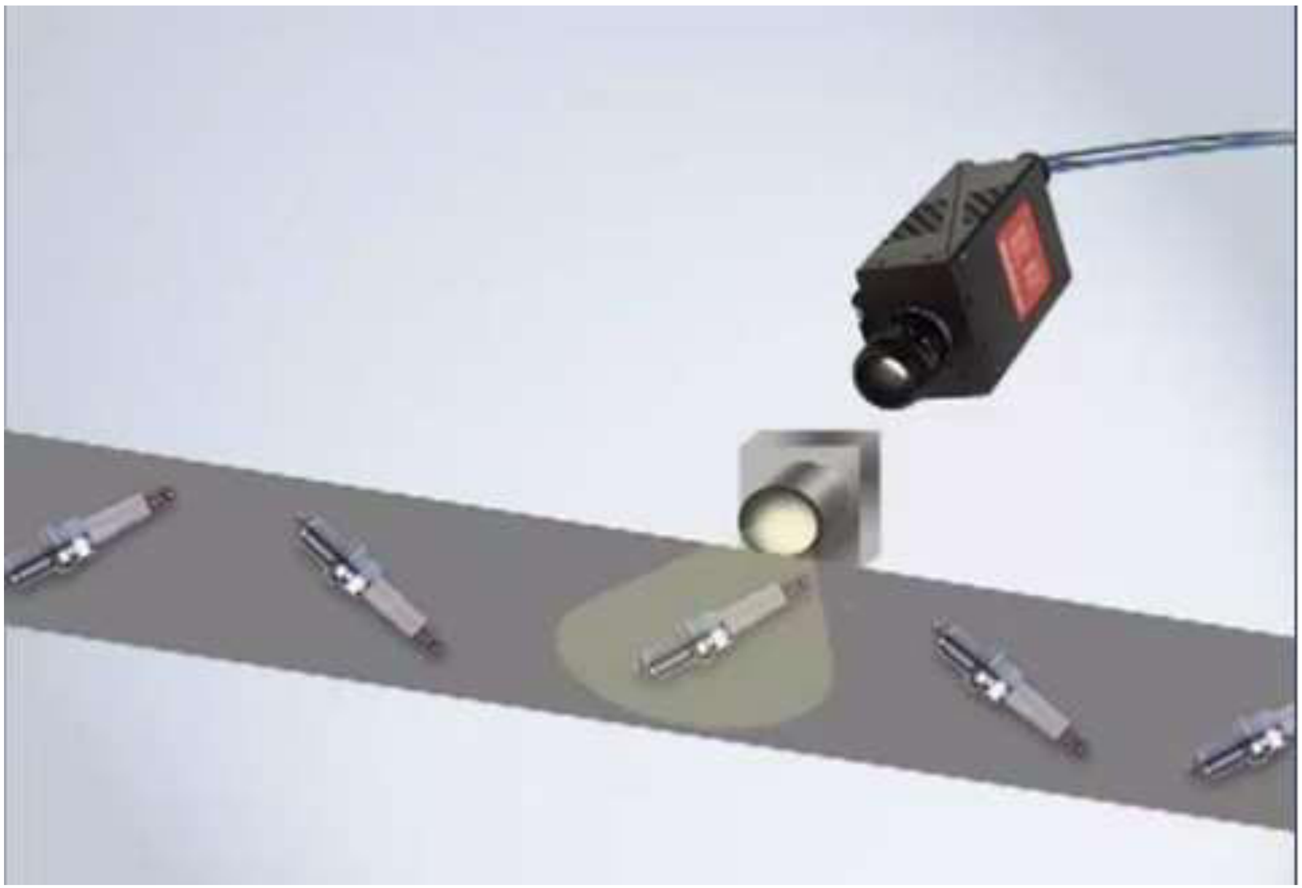
Advantages

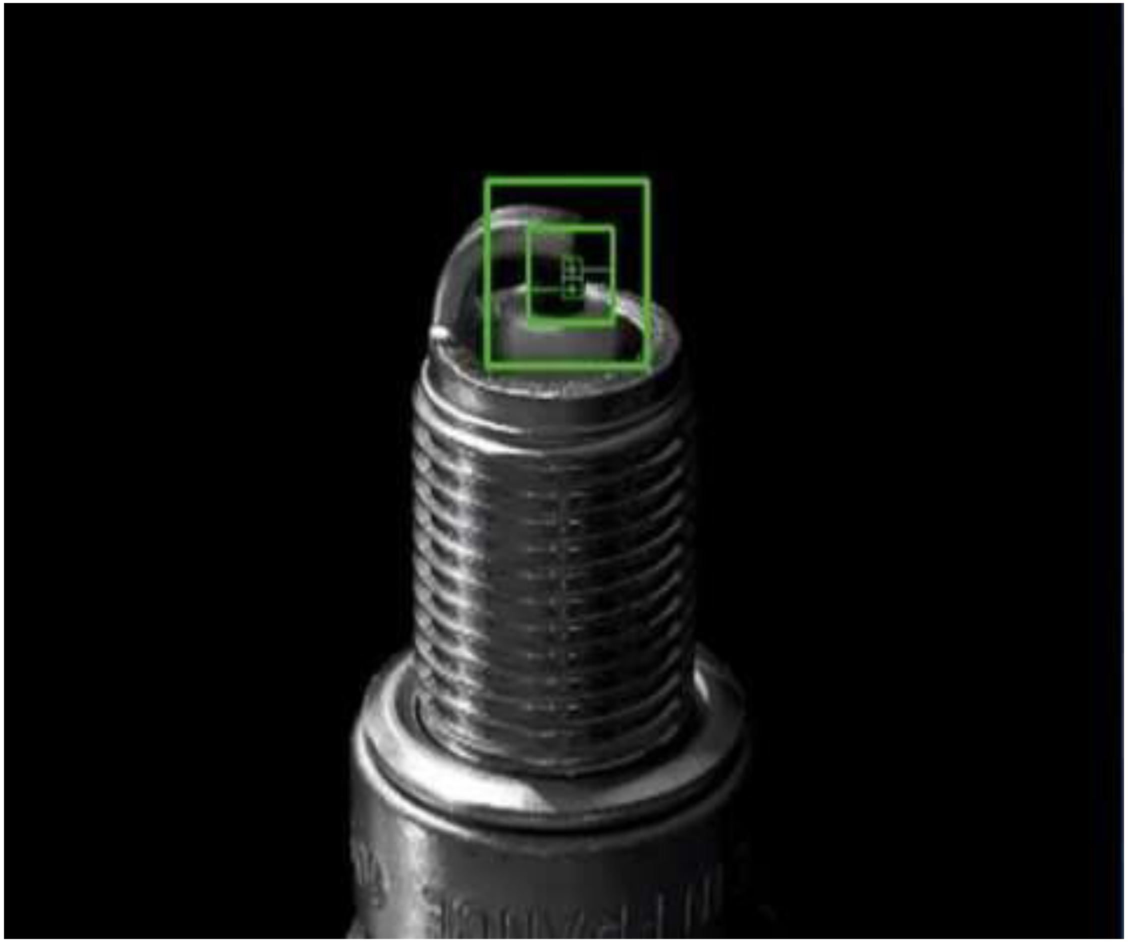
- Faster
- More consistent
- Longer

APPLICATION

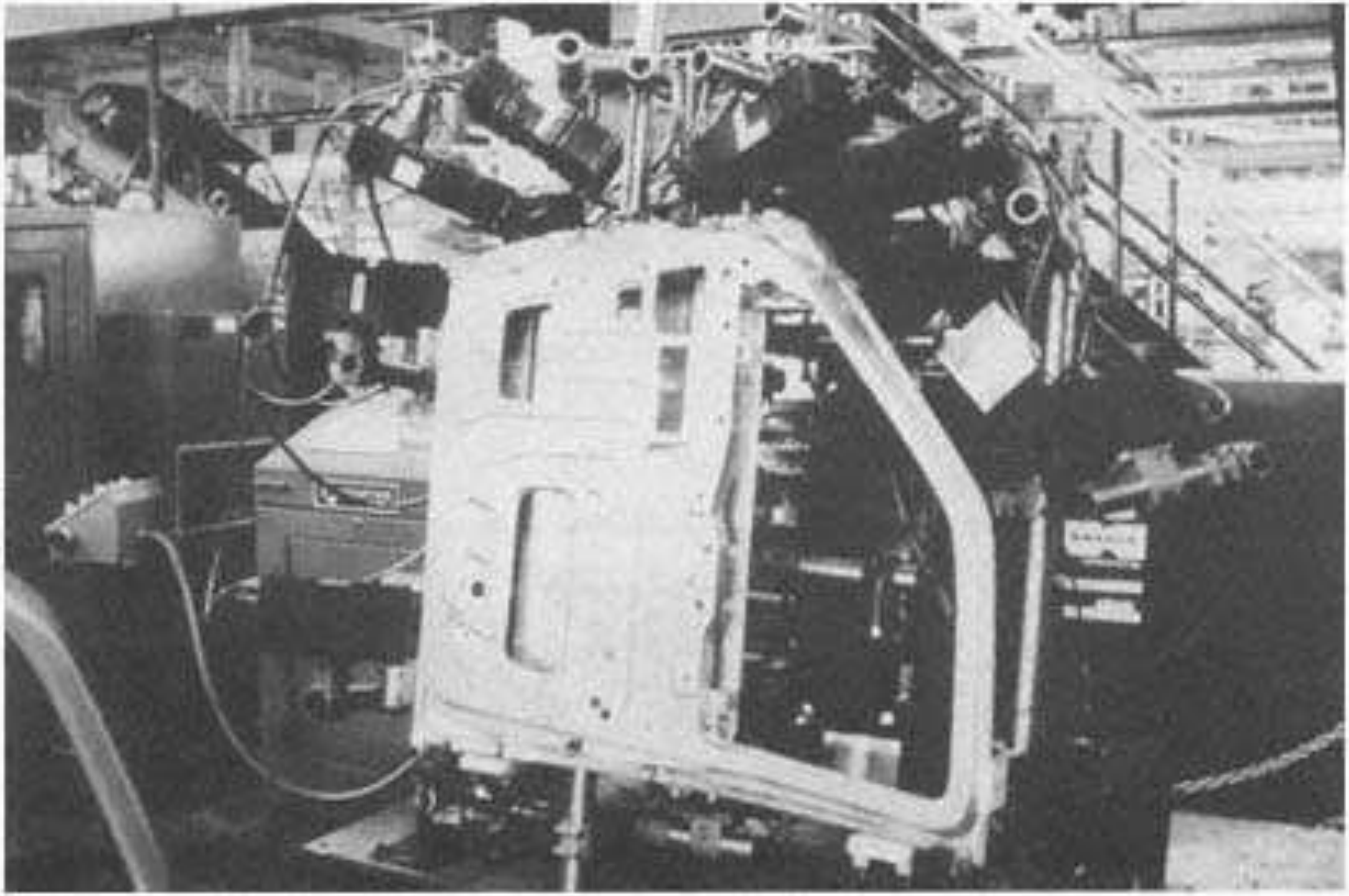
MEASURE: Check to specified tolerances



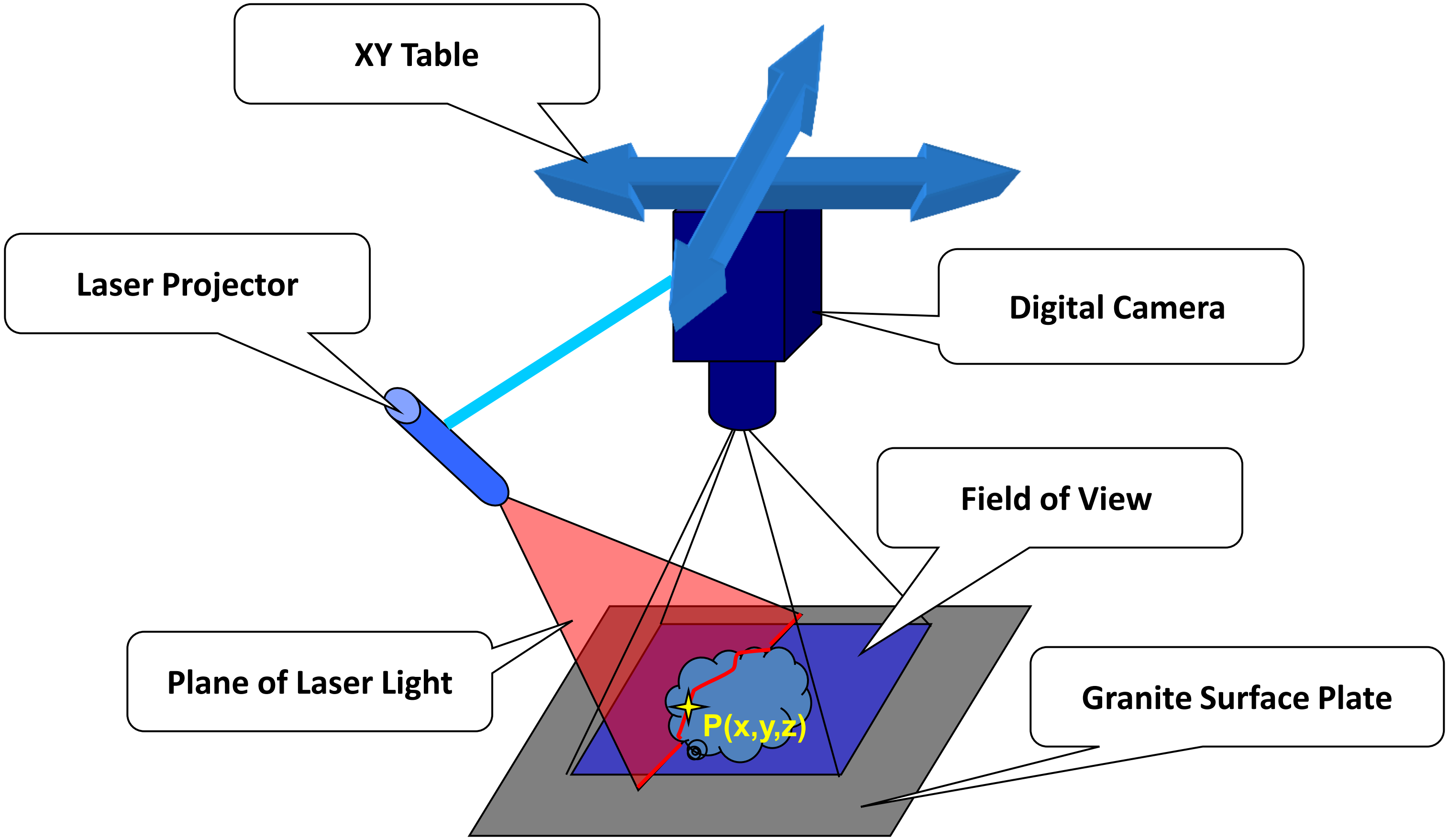




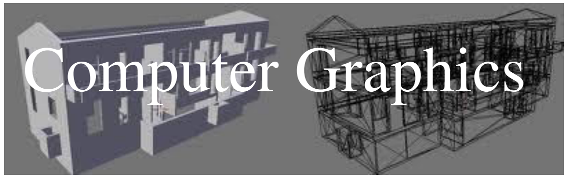

MICROSCAN

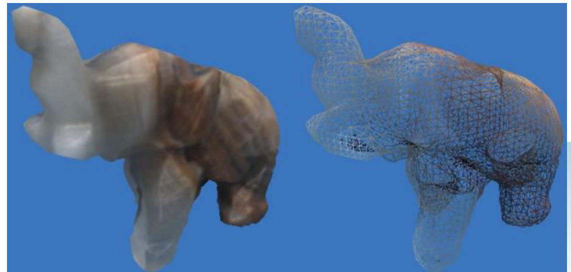


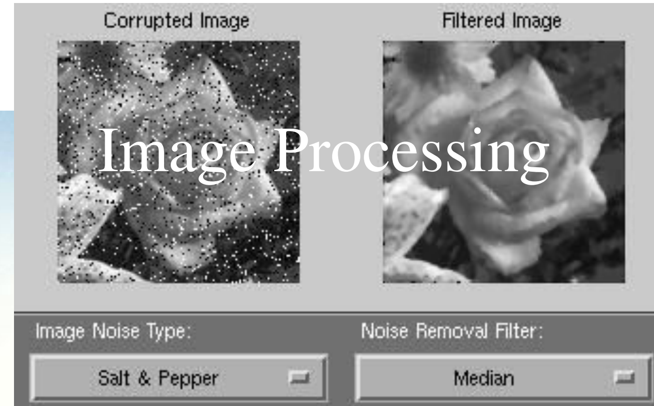
3D MACHINE VISION SYSTEM



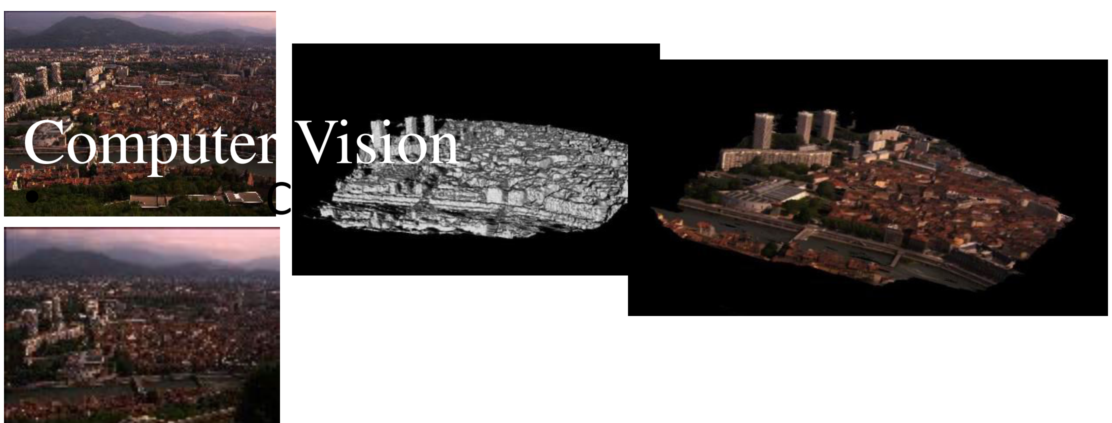
What is Computer Vision?

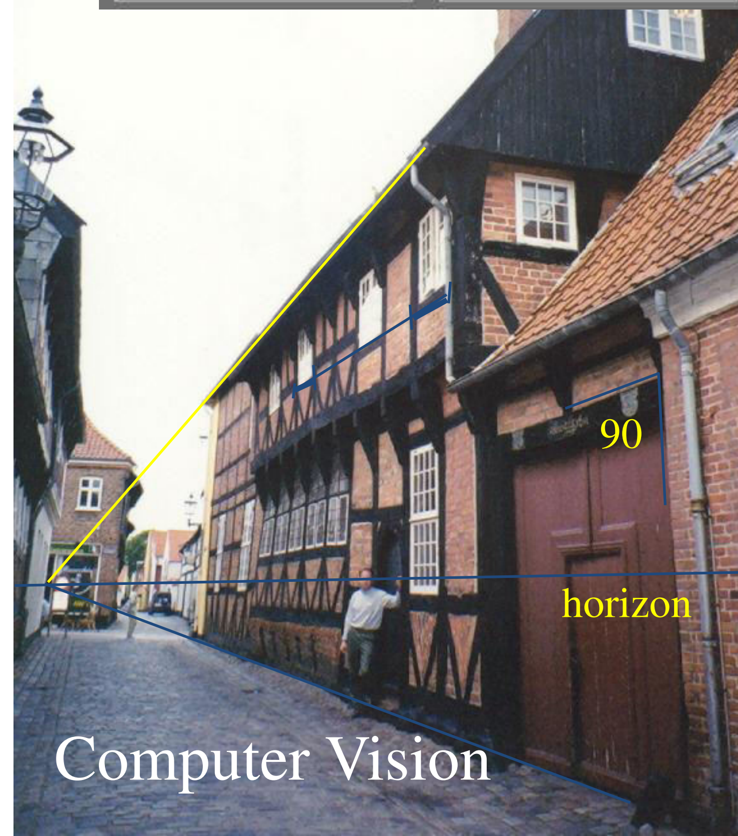






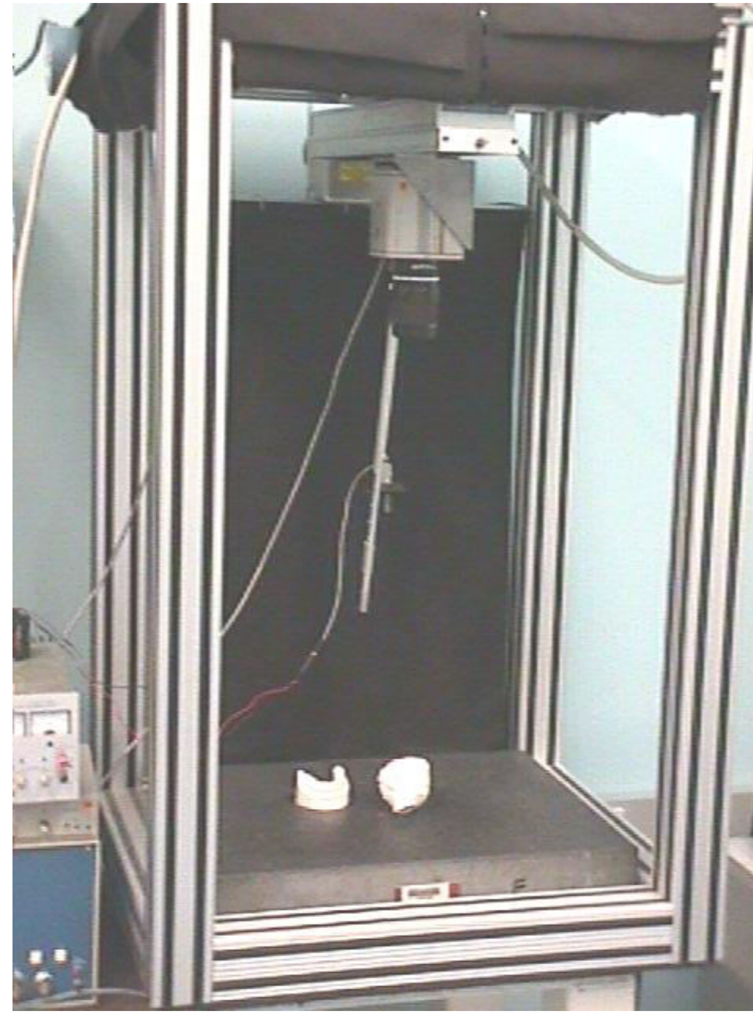
- Three Related fields
  - Image Processing: Changes 2D images into other 2D images
  - Computer Graphics: Takes 3D models, renders 2D images
  - Computer vision: Extracts scene information from 2D images and video
    - e.g. Geometry, “Where” something is in 3D,
    - Objects “What” something is”
- What information is in a 2D image?
- What information do we need for 3D analysis?



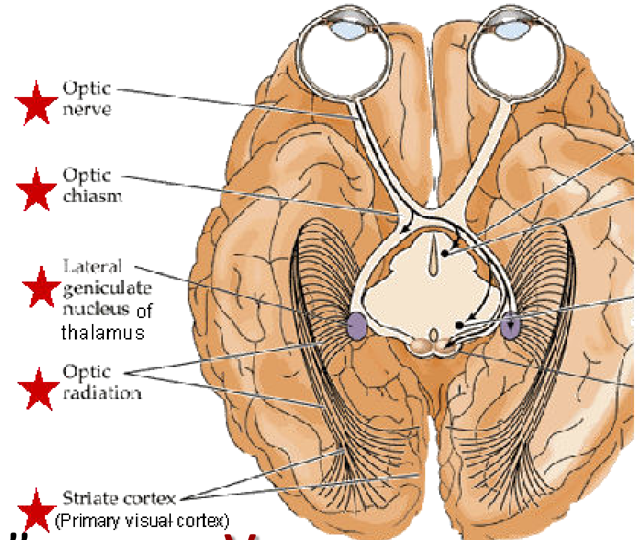


Machine Vision

- 3D Camera vision in general environments hard
- Machine vision:
  - Use engineered environment
  - Use 2D when possible
  - Special markers/LED
  - Can buy working system!
- Photogrammetry:
  - Outdoors
  - 3D surveying using cameras



Vision



- Full: Human vision
  - We don’t know how it works in detail
- Limited vision: Machines, Robots, “AI”

What is the most basic useful information we can get from a camera?

1. Location of a dot (LED/Marker) [u,v] = f(I)
2. Segmentation of object pixels

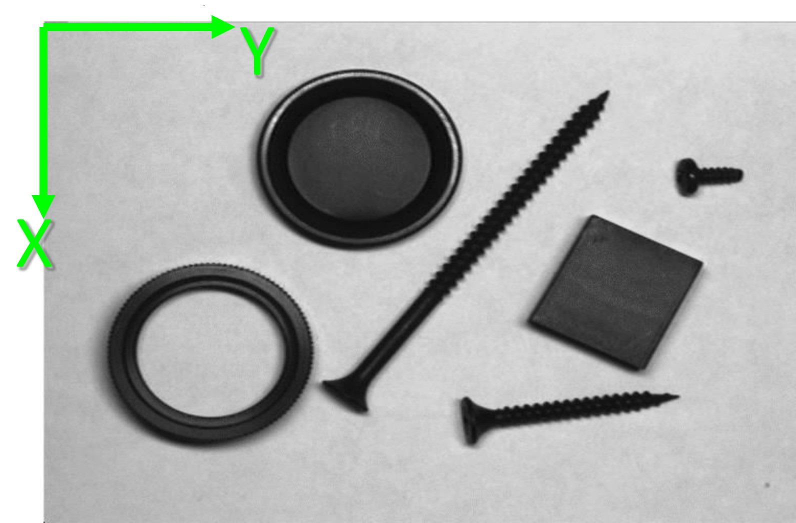
All of these are 2D image plane measurements!

What is the best camera location?

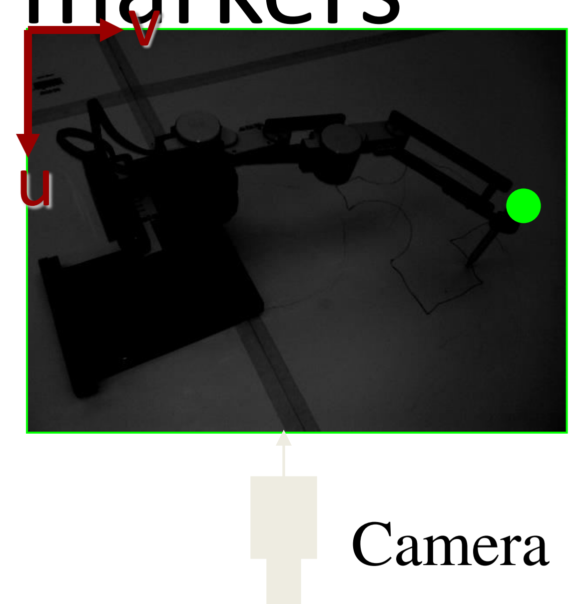
Usually overhead pointing straight down

Adjust cam position so pixel [u,v] = s[X,Y].

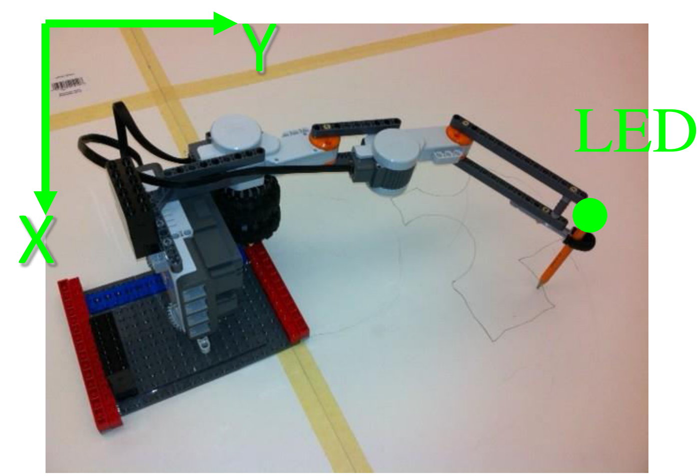
Pixel coordinates are scaled world coord



Tracking LED special markers

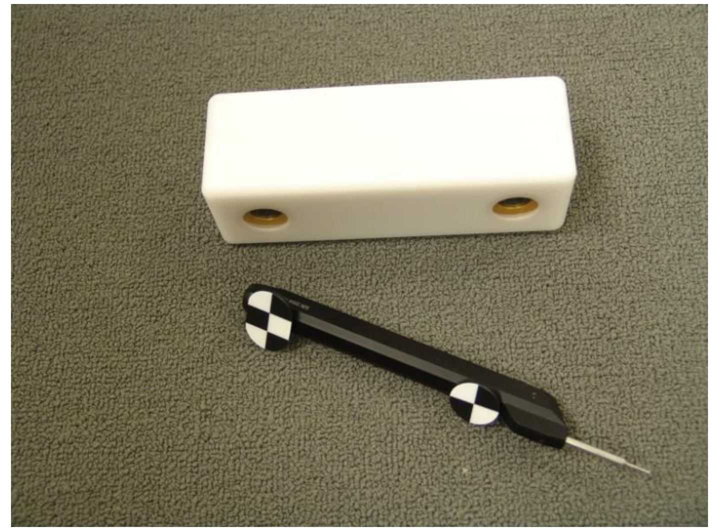


- Put camera overhead pointing straight down on worktable.
  - Adjust cam position so pixel [u,v] = s[X,Y]. Pixel coordinates are scaled world coord
  - Lower brightness so LED brighterest
- Put LED on robot end-effector
- Detection algorithm:
  - Threshold brightest pixels I(u,v)>200
  - Find centroid [u,v] of max pixels
- Variations:
  - Blinking LED can enhance detection in ambient light.
  - Different color LED's can be detected separately from R,G,B color video.



Commercial tracking systems

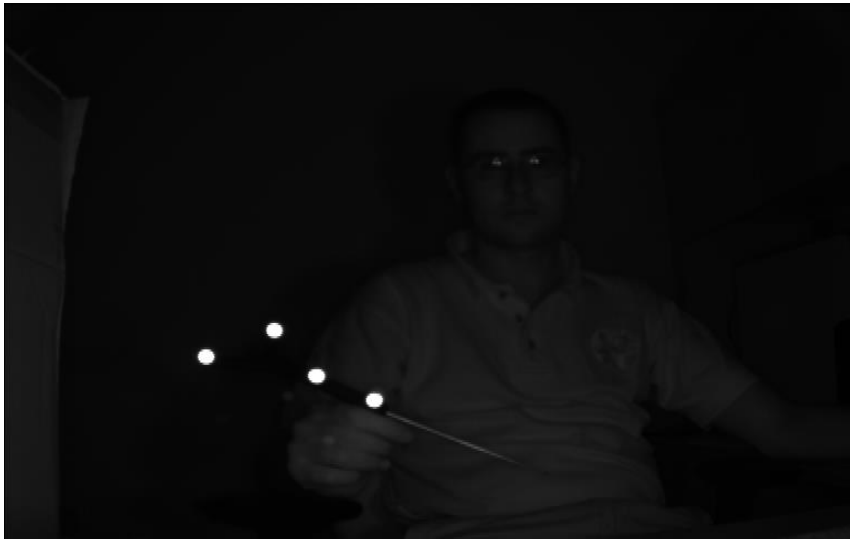
Polaris Vicra infra-red system
(Northern Digitial Inc.)



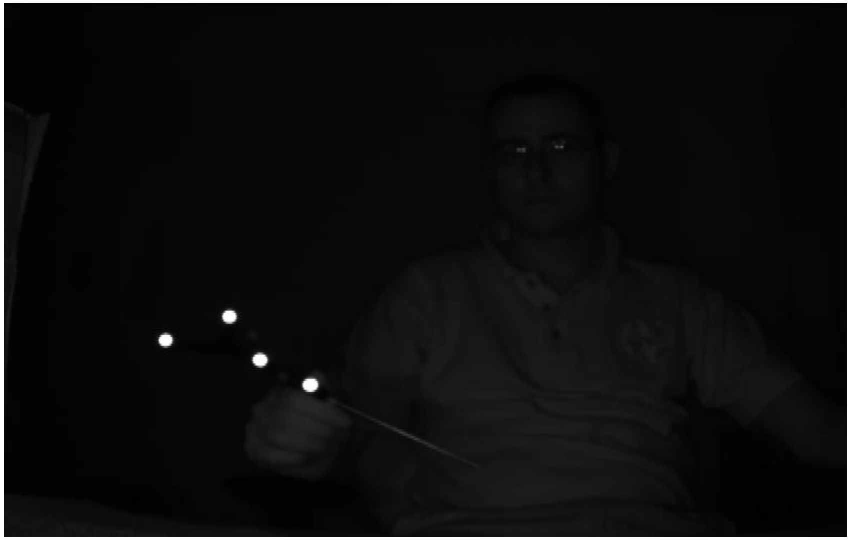
MicronTracker visible light system
(Claron Technology Inc.)

Commercial tracking system

Images acquired by the Polaris Vicra infra-red stereo system:



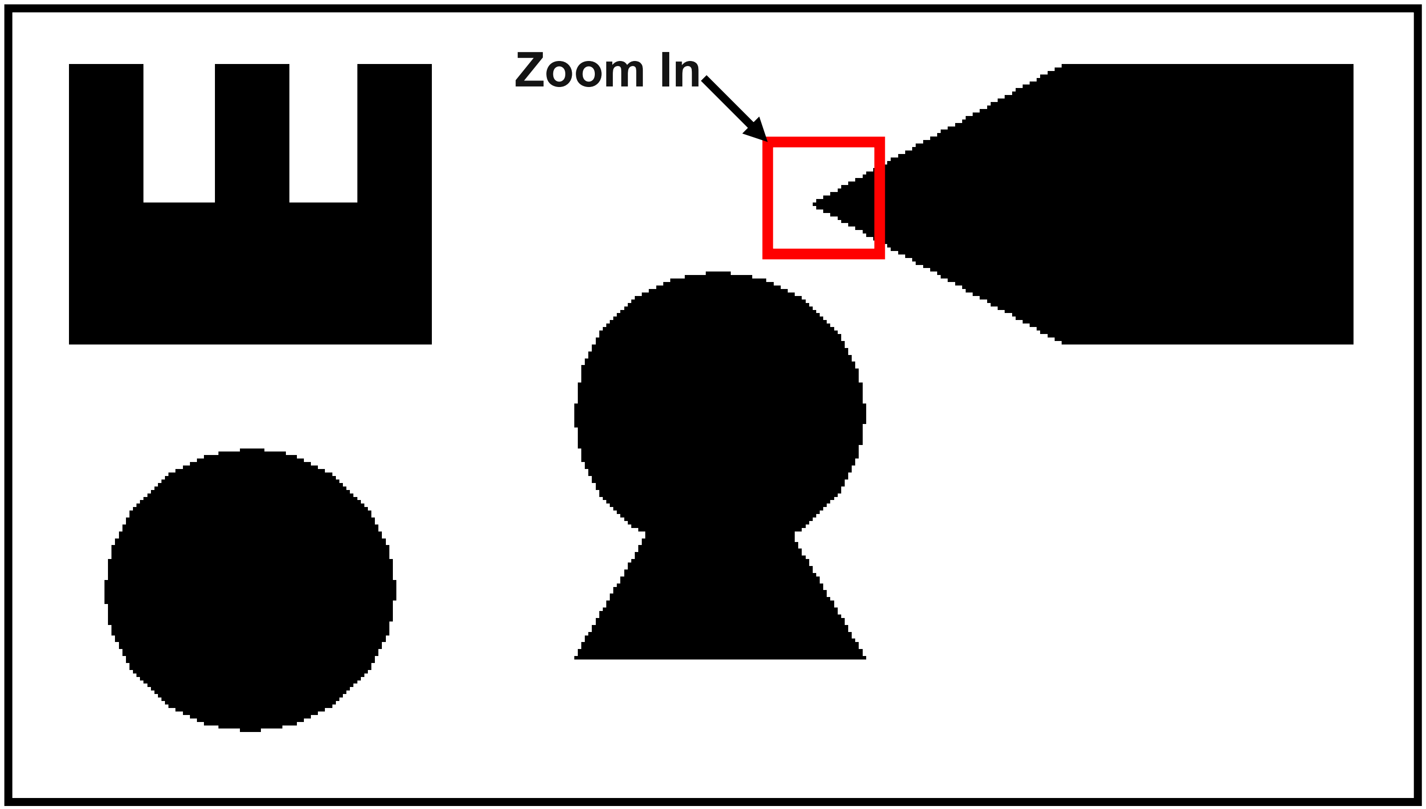
left image



right image

IMAGE SEGMENTATION

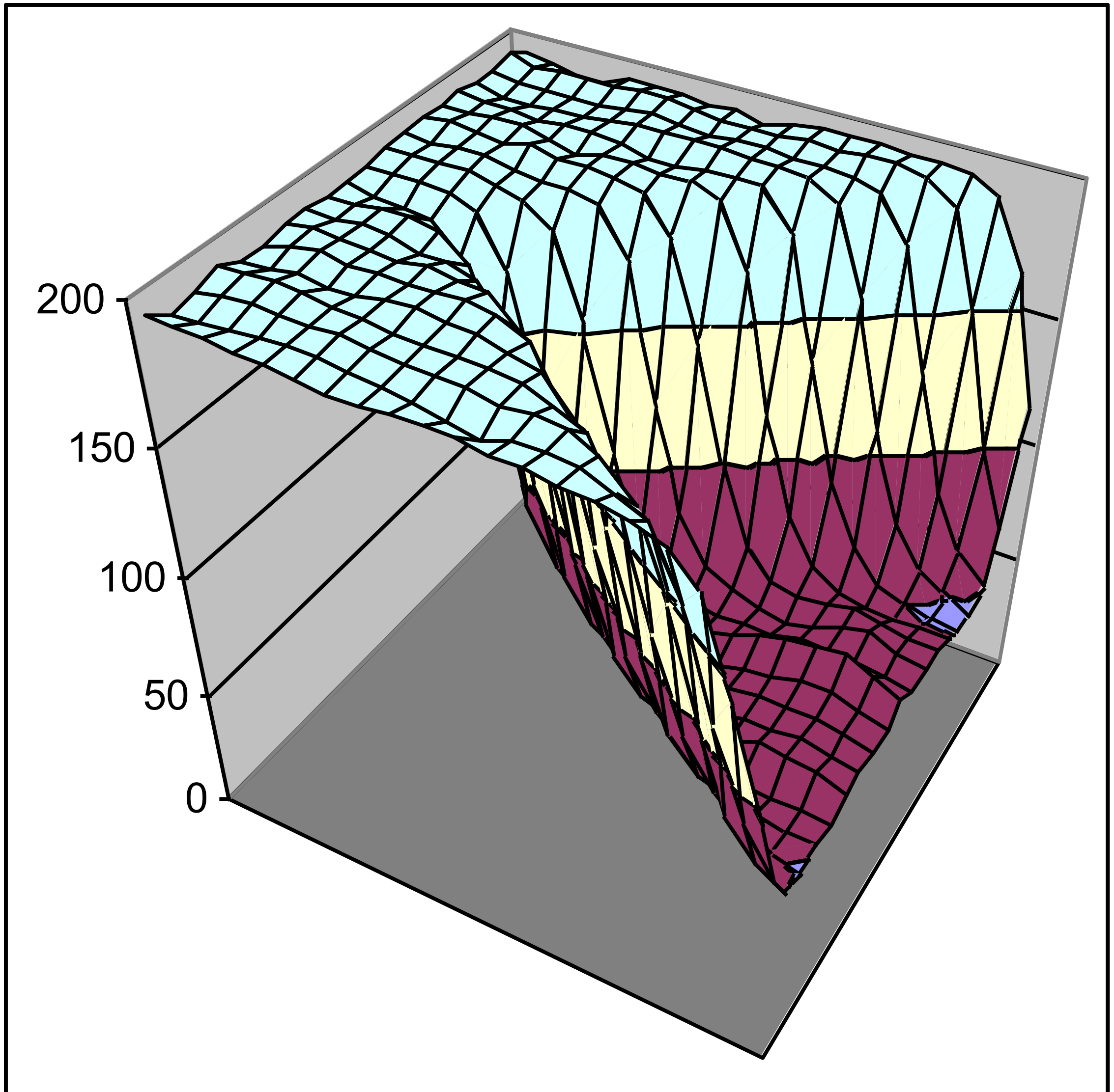
- How many *"objects"* are there in the image below?
- Assuming the answer is "4", what exactly defines an object?



8 BIT GRAYSCALE IMAGE

197	197	197	195	195	194	193	193	194	194	194	193	193	191	190	188	185	174	142	101
191	192	193	194	195	195	194	193	191	189	187	190	191	190	186	181	158	119	86	66
193	195	196	196	195	196	195	194	194	193	191	192	191	187	175	145	105	73	58	51
196	197	197	197	196	195	194	193	193	193	192	188	183	161	121	86	67	59	52	48
192	193	194	193	194	195	196	195	195	192	189	176	144	102	72	59	56	53	51	52
192	194	196	195	195	195	195	196	195	189	167	124	87	68	57	53	52	51	51	50
194	195	195	194	194	195	194	193	184	155	107	73	60	55	53	55	60	60	58	54
194	193	194	194	191	191	188	172	134	94	68	56	51	51	53	57	57	58	56	54
193	193	194	195	193	184	156	112	77	60	53	52	51	53	56	58	58	58	56	53
192	190	189	188	178	140	92	68	57	52	50	50	52	53	56	57	60	60	58	54
193	193	194	193	189	170	125	85	63	55	54	54	55	58	63	66	67	68	64	59
194	195	195	195	193	191	183	153	107	76	60	55	54	54	55	57	57	56	55	53
195	194	195	196	193	192	192	190	173	123	83	63	57	53	51	54	59	62	57	54
196	197	196	195	197	195	195	194	192	179	143	99	69	58	56	56	59	58	55	54
195	195	196	196	194	192	194	194	194	194	190	168	117	78	61	54	51	51	52	52
196	195	195	193	194	195	194	191	191	192	193	193	179	134	90	66	53	50	47	46
194	192	192	193	193	194	195	195	195	195	195	195	194	187	156	110	74	57	51	46
194	193	192	192	192	194	194	193	192	193	193	192	192	192	189	173	129	84	62	52
196	194	194	195	195	196	195	194	193	193	193	194	193	195	194	192	185	150	99	69
192	190	189	189	192	192	192	191	192	190	192	194	194	194	193	192	192	187	163	114

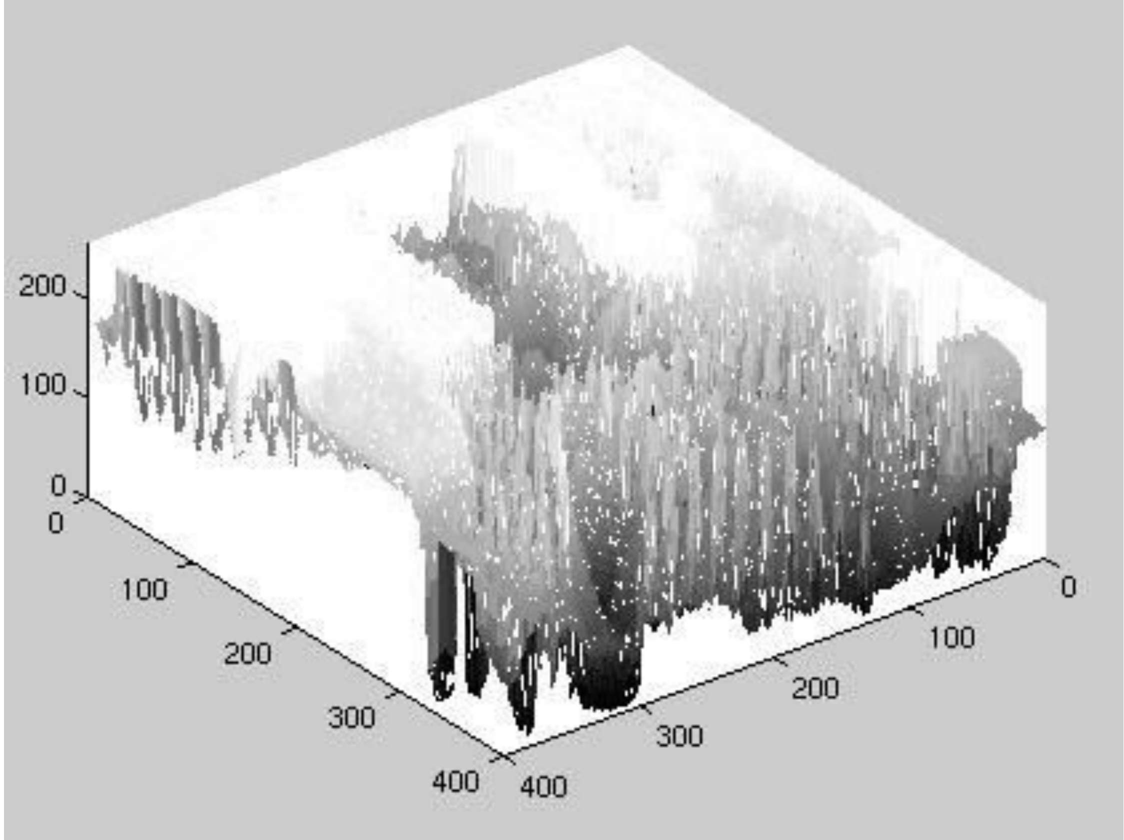
8 BIT GRAYSCALE IMAGE



Compare: Natural image

What is this?

207	200	194	194	203	130	105	095	107	153	192	196	190	186	175
242	194	222	254	255	124	074	082	072	076	208	206	202	194	185
254	170	204	255	248	122	153	135	111	081	252	253	233	232	250
255	172	201	255	249	123	092	040	094	106	255	253	239	150	254
255	197	192	255	248	133	024	027	076	032	250	255	255	181	255
253	210	190	239	250	089	092	149	128	013	254	254	253	229	255
252	238	180	218	251	106	116	181	140	024	250	255	255	255	200
248	248	169	227	252	111	066	118	061	021	252	251	255	255	142
253	255	171	254	253	142	037	132	006	017	253	253	255	254	201
253	250	170	255	253	139	134	127	156	078	255	253	253	254	237
254	228	169	213	235	146	123	096	090	130	230	250	253	254	254
252	244	140	215	245	125	055	043	081	077	252	234	253	253	253
254	250	169	211	235	117	108	093	119	078	246	249	235	225	255
254	234	167	212	217	110	070	049	098	074	244	246	239	207	254
255	219	170	238	253	113	130	109	063	075	243	235	233	252	252
255	221	179	248	227	111	083	041	061	083	240	249	243	232	253
221	217	180	213	243	109	079	048	100	045	246	249	244	221	210
236	216	178	208	230	156	077	062	110	088	244	249	230	220	221
229	224	183	211	132	052	087	062	124	085	135	246	236	220	214
230	223	185	185	112	079	008	124	158	125	119	119	232	225	232
221	215	194	100	154	071	008	031	097	010	093	098	148	229	216
223	217	132	046	072	076	056	048	013	182	073	076	083	215	219
224	216	041	102	090	162	079	111	118	164	083	170	065	221	219
215	222	046	111	077	075	060	046	069	032	179	068	157	224	226
219	216	092	045	074	143	013	171	159	072	087	065	143	217	222
222	224	070	041	074	131	085	150	112	140	139	154	055	231	218
226	232	118	109	041	165	130	105	097	175	078	081	067	064	174
253	254	079	072	116	089	020	068	103	074	031	130	106	052	161
047	034	090	045	145	027	135	109	082	082	048	113	087	061	157
193	192	057	038	051	092	018	062	110	052	060	084	066	071	154
191	192	043	153	052	030	078	061	062	054	046	049	054	078	158
184	181	066	019	043	038	046	083	057	050	145	048	035	087	158
138	074	030	082	030	038	076	041	141	046	045	040	009	063	149
135	016	057	071	035	025	040	062	030	084	130	043	059	113	151



Compare: Natural image

020	067	073	058	055	076	069	050	074	064	065	066	066	059	023
047	109	107	118	107	115	110	120	120	124	120	128	124	132	131
047	125	130	130	122	121	117	142	131	133	134	141	149	144	135
051	139	143	139	147	134	149	069	127	144	139	144	150	161	149
054	136	161	148	147	158	055	052	034	030	158	156	165	163	156
043	144	165	159	154	171	224	191	047	030	171	165	175	164	163
025	161	174	172	167	049	200	193	112	028	120	169	173	177	173
011	091	101	105	177	039	078	060	041	026	073	102	167	208	121
011	091	094	066	094	033	199	184	139	024	060	094	125	152	134
009	068	072	072	065	031	151	171	075	028	035	072	083	109	063
013	068	074	059	057	037	161	129	062	028	035	071	072	078	056
012	042	063	055	072	033	020	067	031	022	027	082	070	073	060
011	037	064	094	091	026	025	080	066	026	023	071	070	080	060
011	060	077	082	037	023	024	147	140	038	023	037	043	076	037
013	049	076	059	032	028	174	197	182	060	021	021	121	101	062
013	059	111	072	020	078	200	211	182	061	069	059	043	086	106
007	053	057	092	023	105	189	230	210	084	034	021	017	033	091
011	061	072	018	027	054	069	068	062	023	045	011	016	042	044
014	041	047	025	018	040	065	039	024	021	036	041	013	030	022
013	093	106	017	019	027	030	042	012	021	043	013	014	020	027
019	040	029	023	016	024	015	026	011	010	026	017	012	013	014
022	042	030	040	019	015	016	011	012	009	008	012	009	017	019
022	026	018	030	020	012	017	010	008	011	007	015	008	016	034
019	018	048	029	012	054	012	008	008	009	008	012	007	016	005
022	015	057	043	126	135	122	006	005	008	007	019	010	011	008
018	008	009	019	023	093	109	128	063	052	031	010	012	009	006
017	010	010	007	067	054	106	116	067	056	011	028	005	009	006
015	010	012	014	062	076	057	055	019	024	020	006	005	013	004
016	010	008	011	039	025	020	016	011	007	008	007	006	010	003
015	009	010	010	012	011	014	009	008	007	007	005	005	008	002
014	007	008	011	007	012	010	009	007	008	007	005	005	007	003
020	011	015	019	013	017	017	013	019	013	012	013	011	009	005
020	067	073	058	055	076	069	050	074	064	065	066	066	059	023
025	161	174	172	167	049	200	193	112	028	120	169	173	177	173

GRAY LEVEL THRESHOLDING

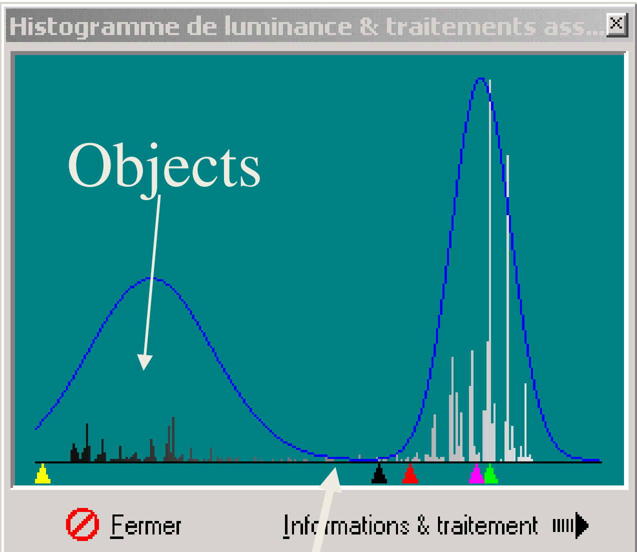
•Many images consist of two regions that occupy different gray level ranges.

•Such images are characterized by a *bimodal image histogram.*

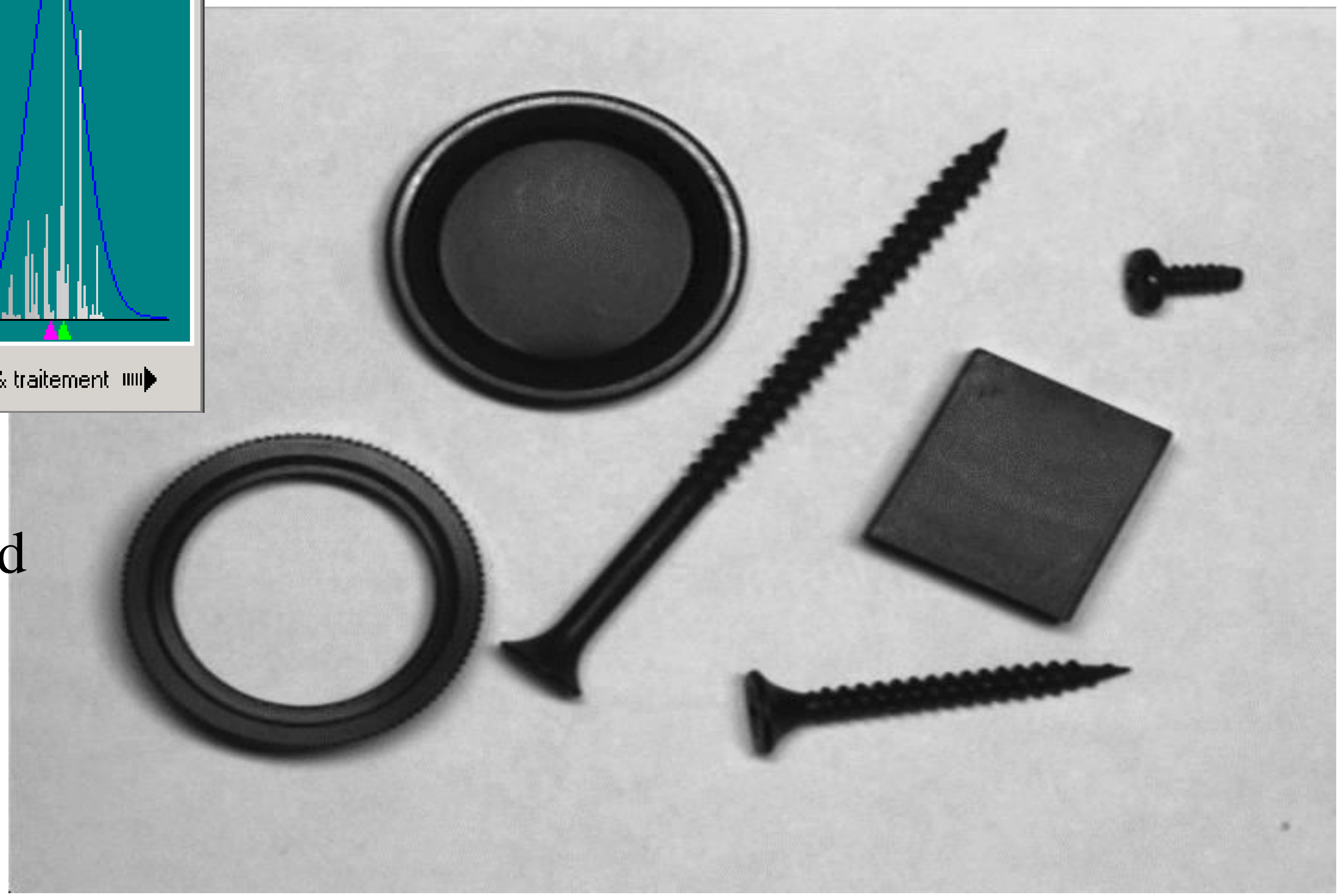
•An *image histogram* is a function **h** defined on the set of gray levels in a given image.

•The value **h(k)** is given by the number of pixels in the image having image intensity **k**.

GRAY LEVEL THRESHOLDING



Set threshold here



BINARY IMAGE

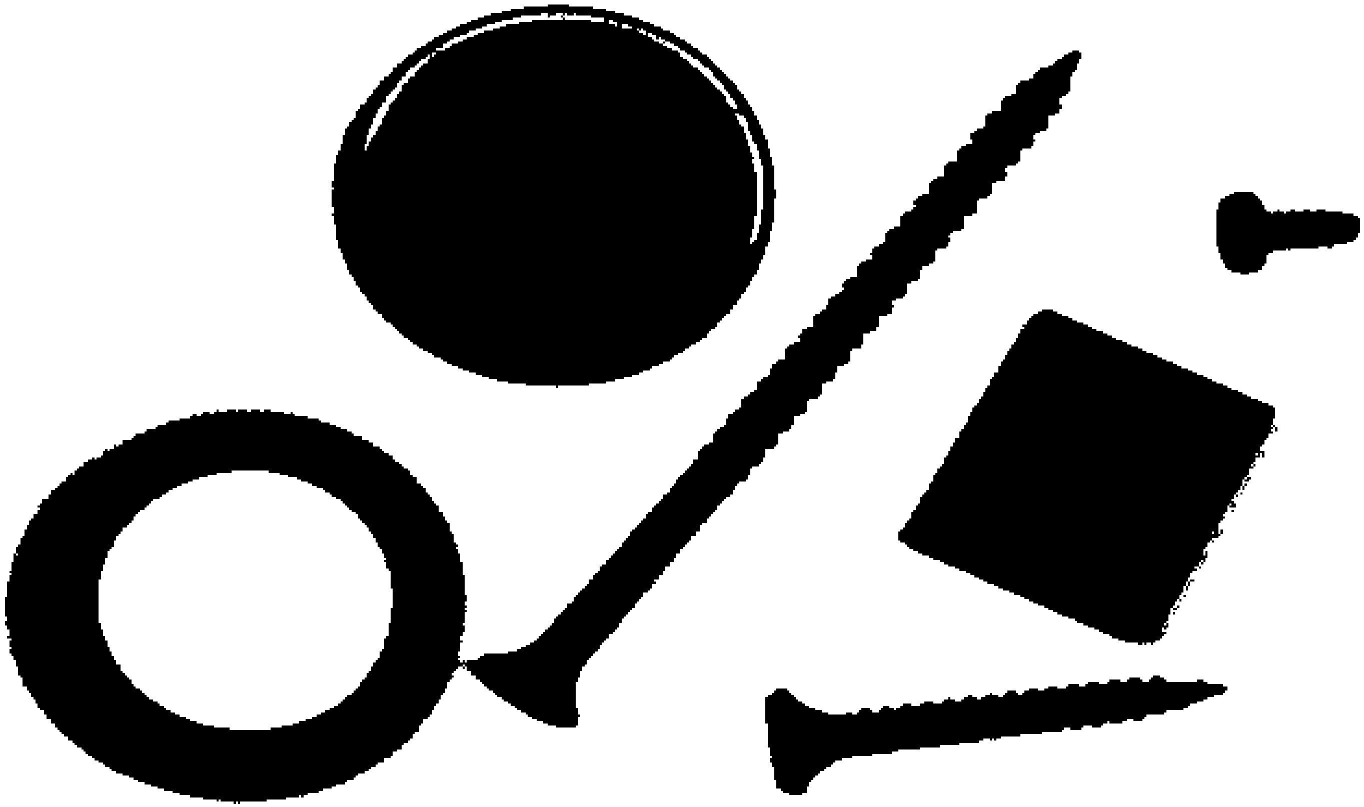


IMAGE SEGMENTATION – CONNECTED COMPONENT LABELING

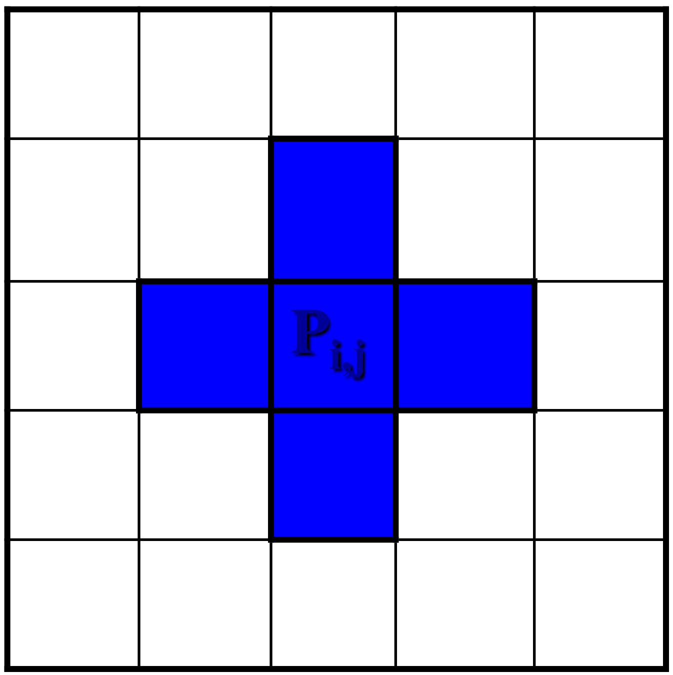
•Segmentation can be viewed as a process of *pixel classification*; the image is segmented into *objects* or *regions* by assigning individual pixels to classes.

•*Connected Component Labeling* assigns pixels to specific classes by verifying if an adjoining pixel (i.e., *neighboring pixel*) already belongs to that class.

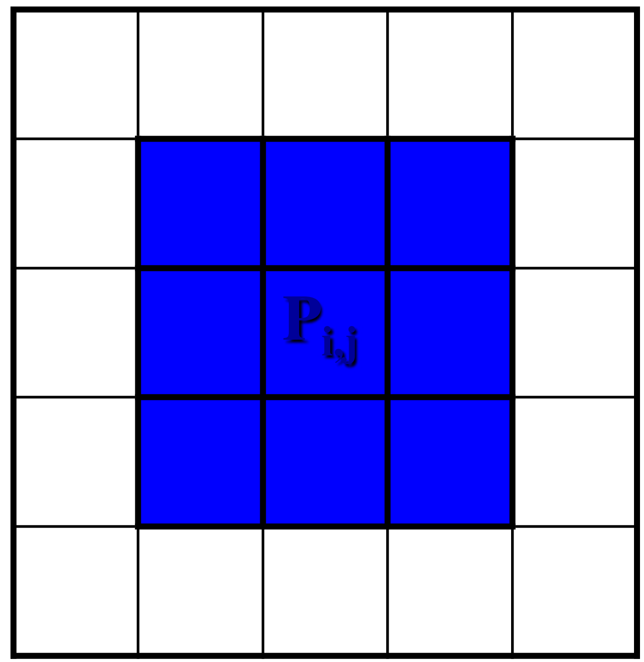
•There are two “standard” definitions of pixel connectivity: 4 neighbor connectivity and 8 neighbor connectivity.

IMAGE SEGMENTATION – CONNECTED COMPONENT LABELING

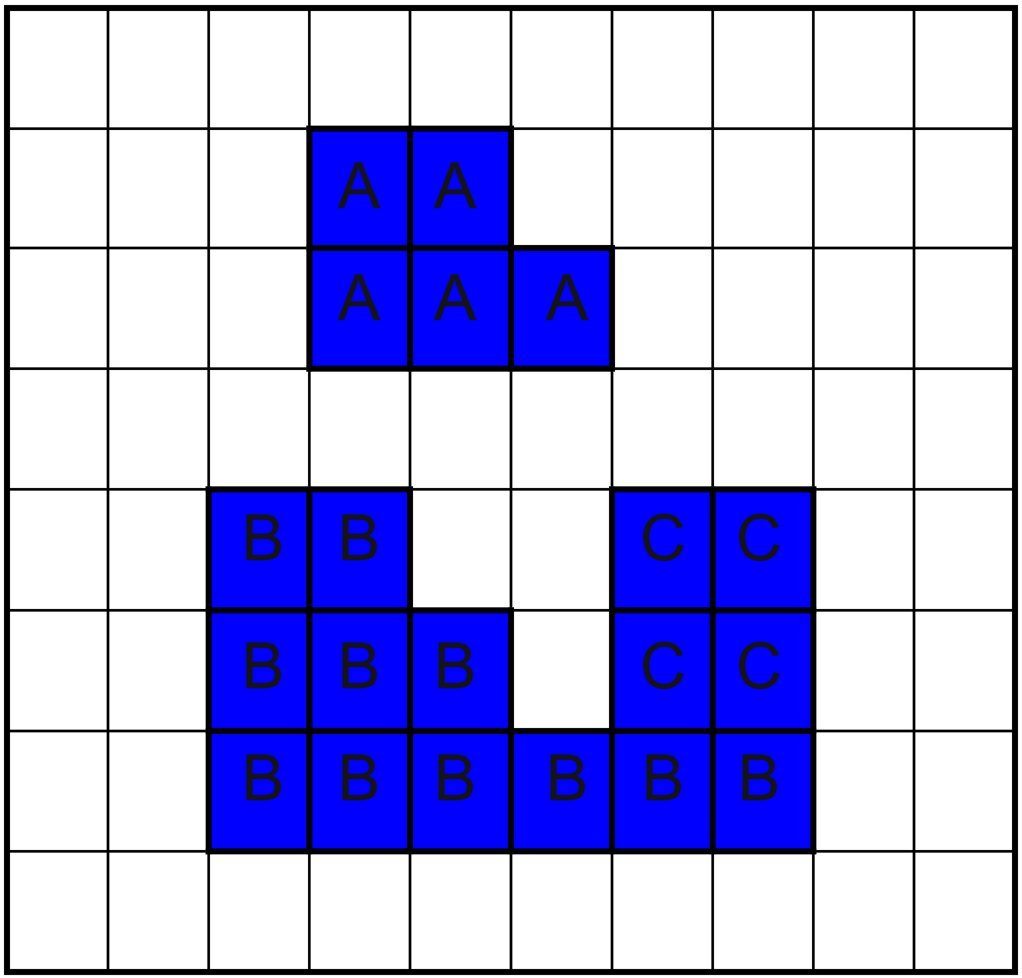
4 Neighbor Connectivity



8 Neighbor Connectivity



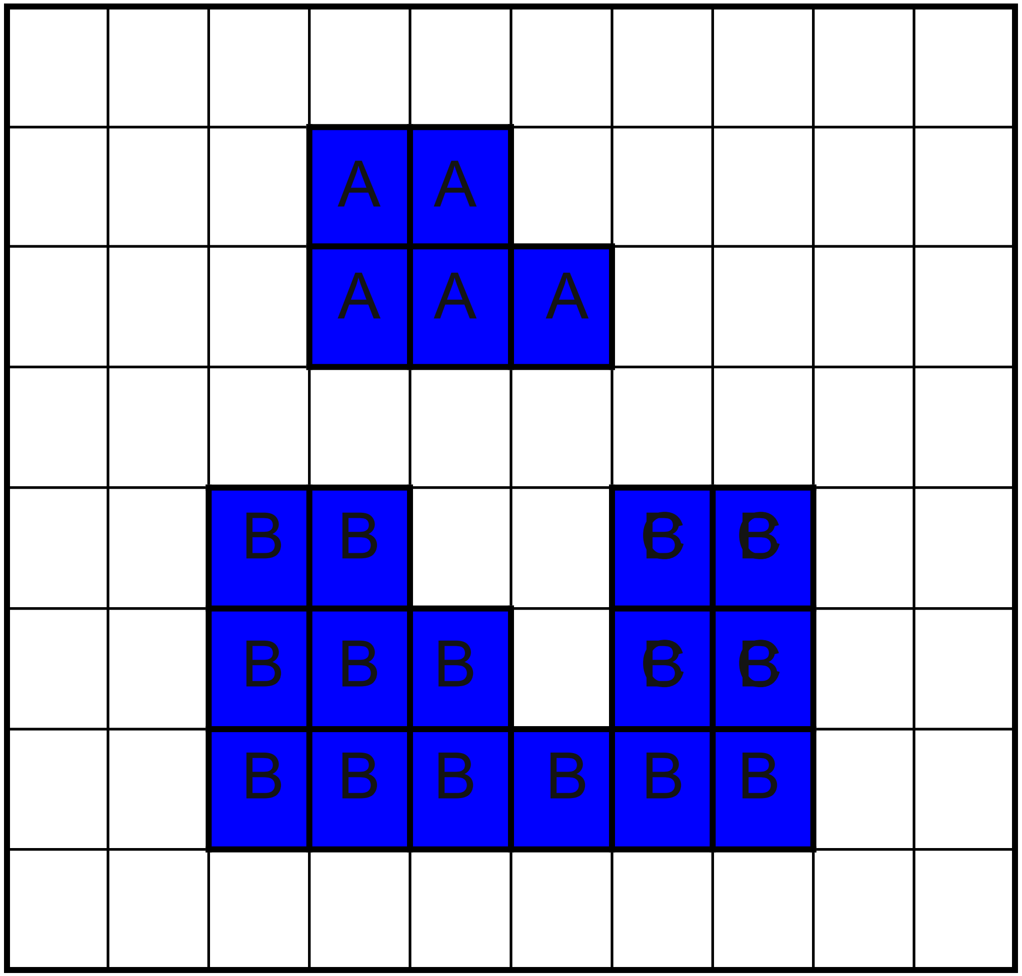
CONNECTED COMPONENT LABELING: FIRST PASS



EQUIVALENCE:

B=C

CONNECTED COMPONENT LABELING: SECOND PASS



TWO OBJECTS!

CONNECTED COMPONENT LABELING: TABLE OF EQUIVALENCES

2	=	5	16	=	27	16	=	50	50	=	81	112	=	127
5	=	9	5	=	28	5	=	39	50	=	86	112	=	134
2	=	5	27	=	34	34	=	51	50	=	86	112	=	137
5	=	10	16	=	37	5	=	39	5	=	87	112	=	138
5	=	10	5	=	39	34	=	46	111	=	112			
5	=	10	5	=	39	5	=	66	112	=	113			
5	=	12	40	=	41	34	=	72	112	=	119			
5	=	16	5	=	39	34	=	72	112	=	120			
5	=	18	34	=	46	50	=	76	112	=	120			
16	=	23	34	=	46	50	=	81	112	=	122			

CONNECTED COMPONENT LABELING: TABLE OF EQUIVALENCES

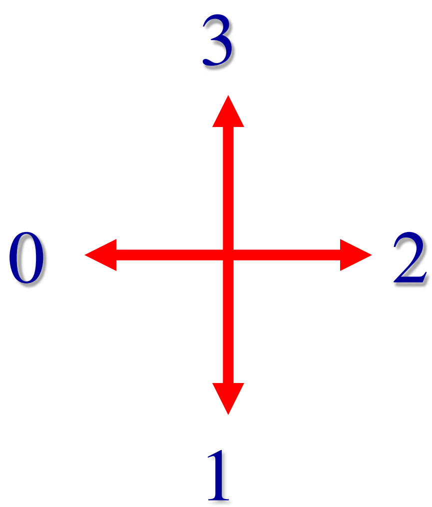
2	=	5		2	=	37		2	=	86		111	=	138
2	=	9		2	=	39		2	=	87				
2	=	10		40	=	41		111	=	112				
2	=	12		2	=	46		111	=	113				
2	=	16		2	=	50		111	=	119				
2	=	18		2	=	51		111	=	120				
2	=	23		2	=	66		111	=	122				
2	=	27		2	=	72		111	=	127				
2	=	28		2	=	76		111	=	134				
2	=	34		2	=	81		111	=	137				

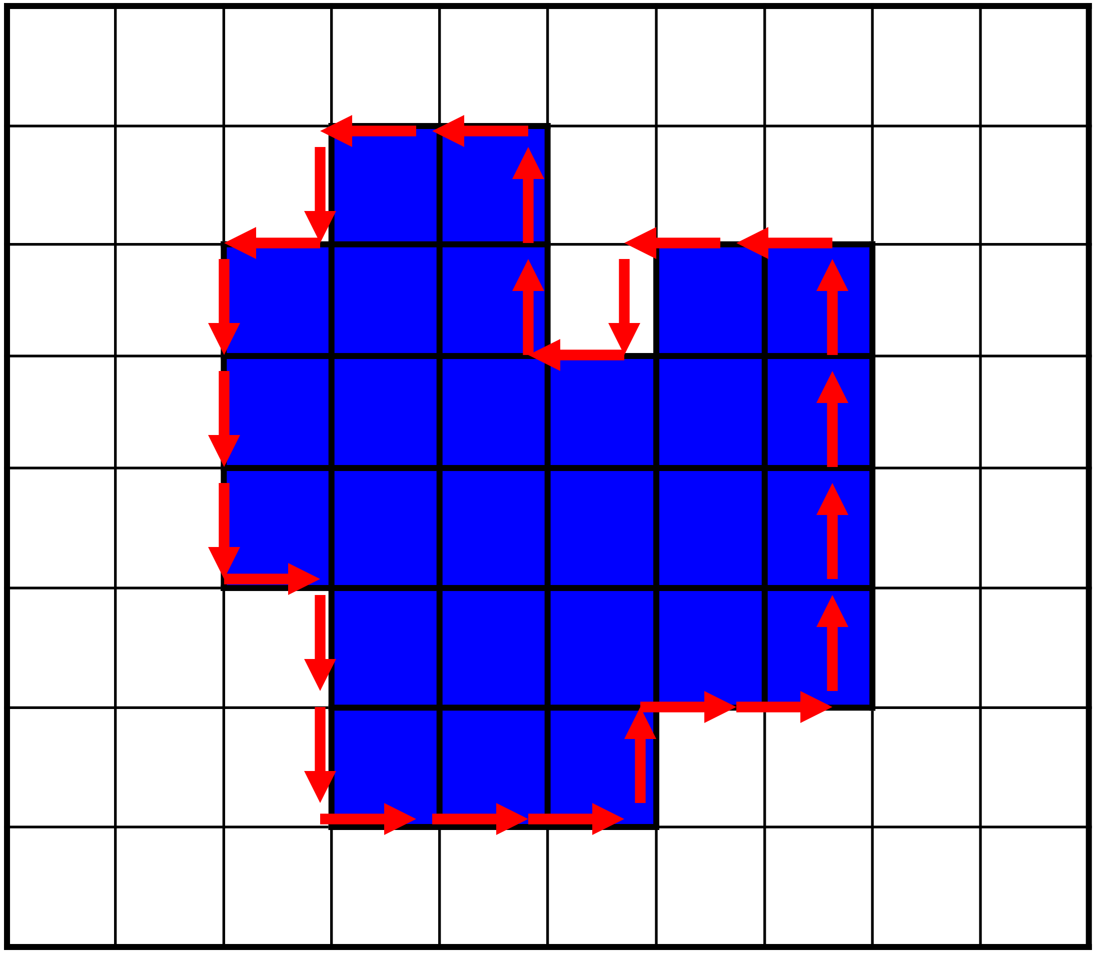
IS THERE A MORE COMPUTATIONALLY EFFICIENT TECHNIQUE FOR SEGMENTING THE OBJECTS IN THE IMAGE?

•Contour tracking/border following identify the pixels that fall on the boundaries of the objects, i.e., pixels that have a neighbor that belongs to the *background class or region*.

•There are two “standard” code definitions used to represent boundaries: code definitions based on 4-connectivity (*crack* code) and code definitions based on 8-connectivity *(chain code)*.

BOUNDARY REPRESENTATIONS: 4-CONNECTIVITY (*CRACK CODE*)

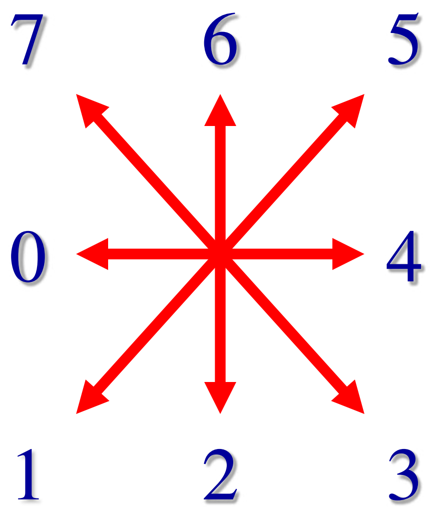


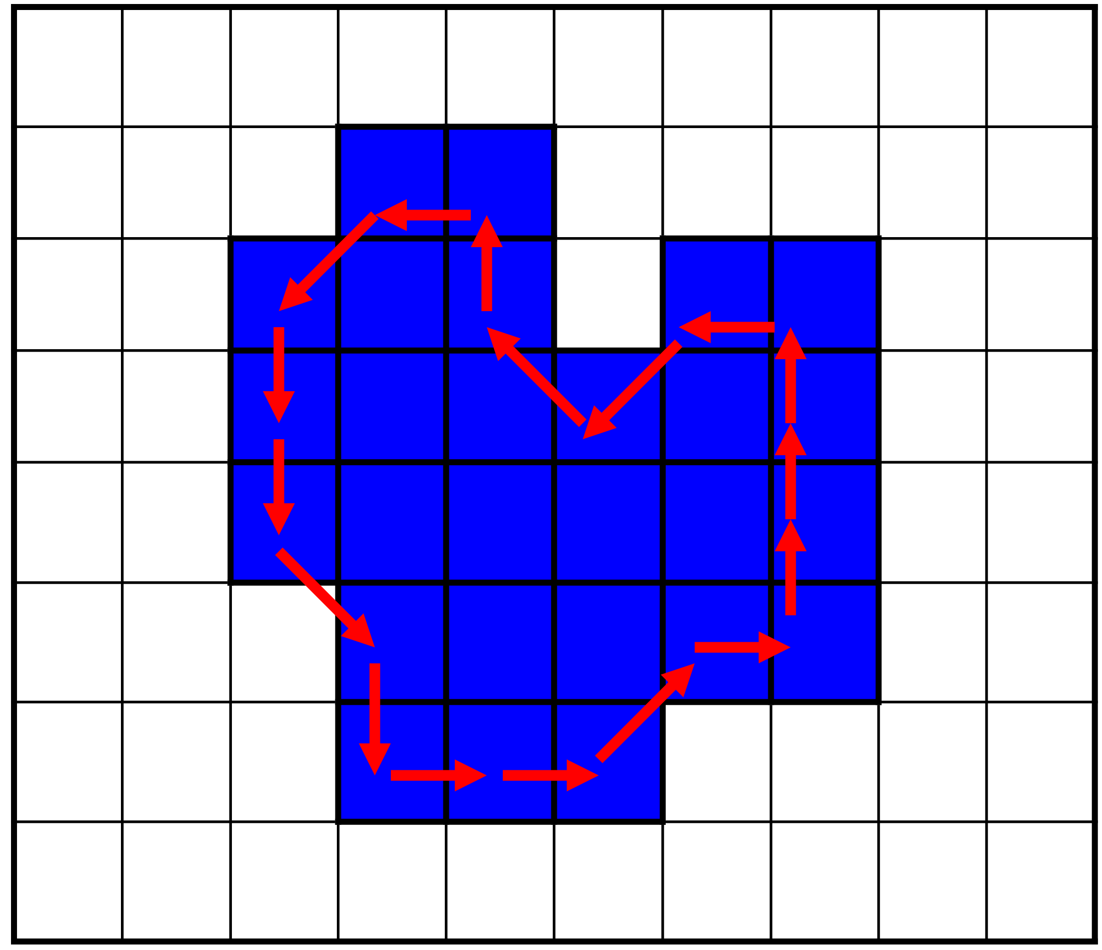


CRACK CODE:

10111211222322333300
103300

BOUNDARY REPRESENTATIONS: 8-CONNECTIVITY (*CHAIN CODE*)





CHAIN CODE:

12232445466601760

CONTOUR TRACKING ALGORITHM FOR GENERATING CRACK CODE

- Identify a pixel **P** that belongs to the class “objects” and a neighboring pixel (4 neighbor connectivity) **Q** that belongs to the class “background”.
- Depending on the relative position of **Q** relative to **P**, identify pixels **U** and **V** as follows:

CODE 0

V	Q
U	P

CODE 1

Q	P
V	U

CODE 2

P	U
Q	V

CODE 3

U	V
P	Q

CONTOUR TRACKING ALGORITHM

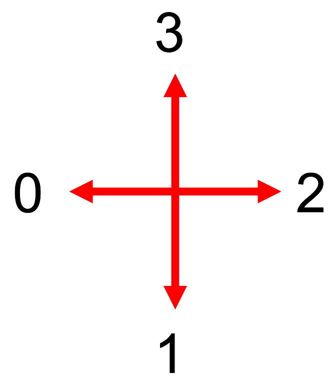
•Assume that a pixel has a value of “1” if it belongs to the class “object” and “0” if it belongs to the class “background”.

•Pixels **U** and **V** are used to determine the next “move” (i.e., the next element of crack code) as summarized in the following truth table:

U	V	P’	Q’	TURN	CODE*
X	1	V	Q	RIGHT	CODE-1
1	0	U	V	NONE	CODE
0	0	P	U	LEFT	CODE+1

*Implement as a modulo 4 counter

CONTOUR TRACKING ALGORITHM



CODE 0

V	Q
U	P

CODE 1

Q	P
V	U

CODE 2

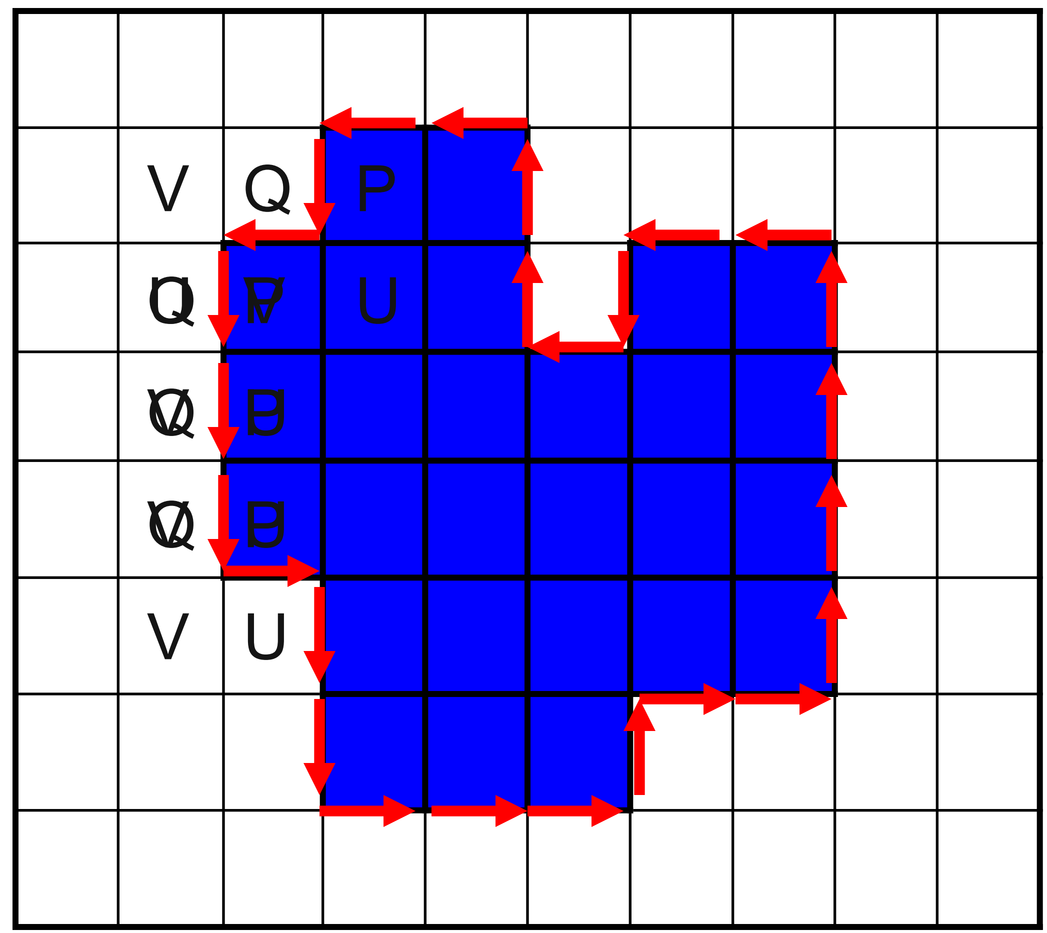
P	U
Q	V

CODE 3

U	V
P	Q

U	**V**	**P'**	**Q'**	**TURN**	**CODE***
X	1	V	Q	RIGHT	CODE-1
1	0	U	V	NONE	CODE
0	0	P	U	LEFT	CODE+1

*Implement as a modulo 4 counter



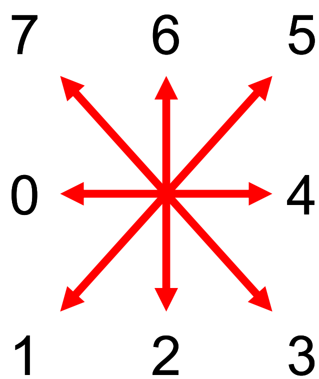
CONTOUR TRACKING ALGORITHM FOR GENERATING CHAIN CODE

- Identify a pixel **P** that belongs to the class “objects” and a neighboring pixel (4 neighbor connectivity) $\mathbf{R_0}$ that belongs to the class “background”. Assume that a pixel has a value of “1” if it belongs to the class “object” and “0” if it belongs to the class “background”.

- Assign the 8-connectivity neighbors of **P** to $\mathbf{R_0}$, $\mathbf{R_1}$, …, **R7** as follows:

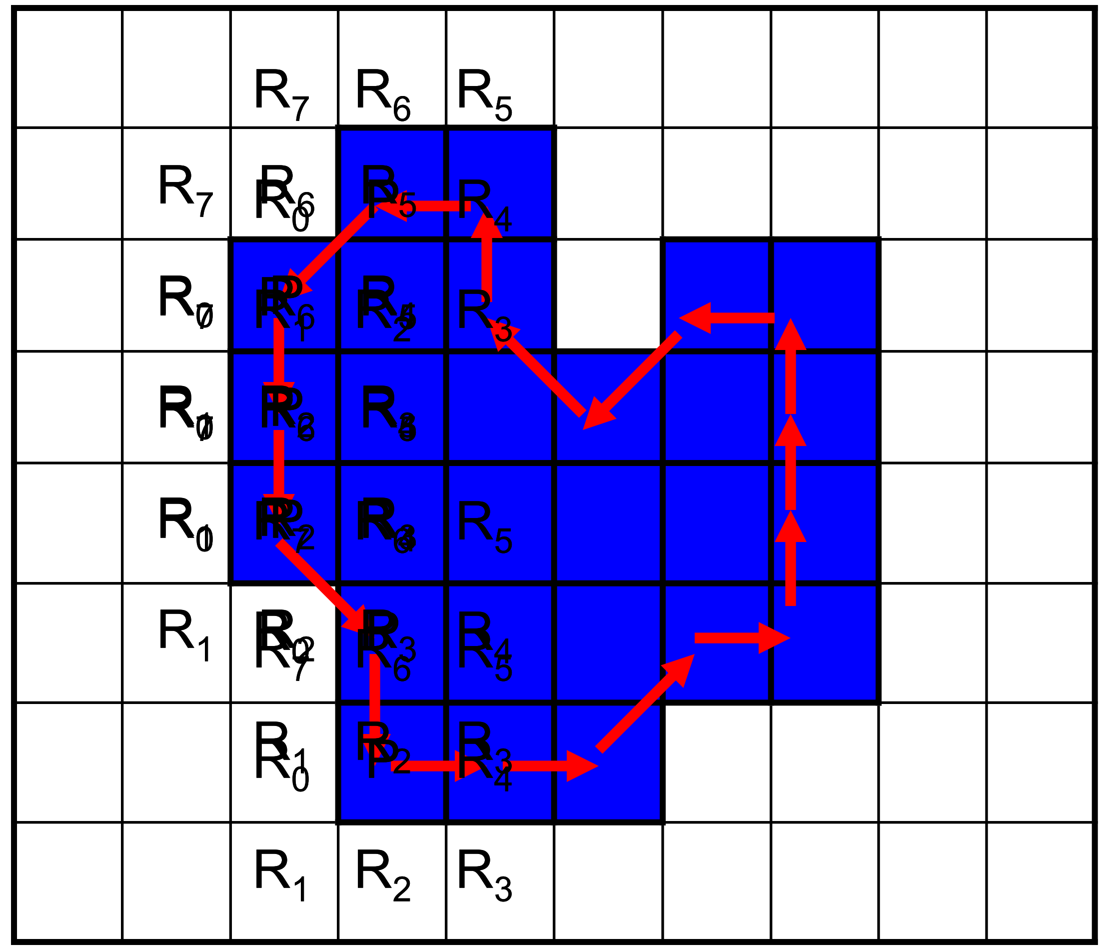
R_7	R_6	R_5
R_0	P	R_4
R_1	R_2	R_3

CONTOUR TRACKING ALGORITHM FOR GENERATING CHAIN CODE



ALGORITHM:

i=0
WHILE (R_i==0) { i++ }
•Move P to R_i
•Set i=6 for next search



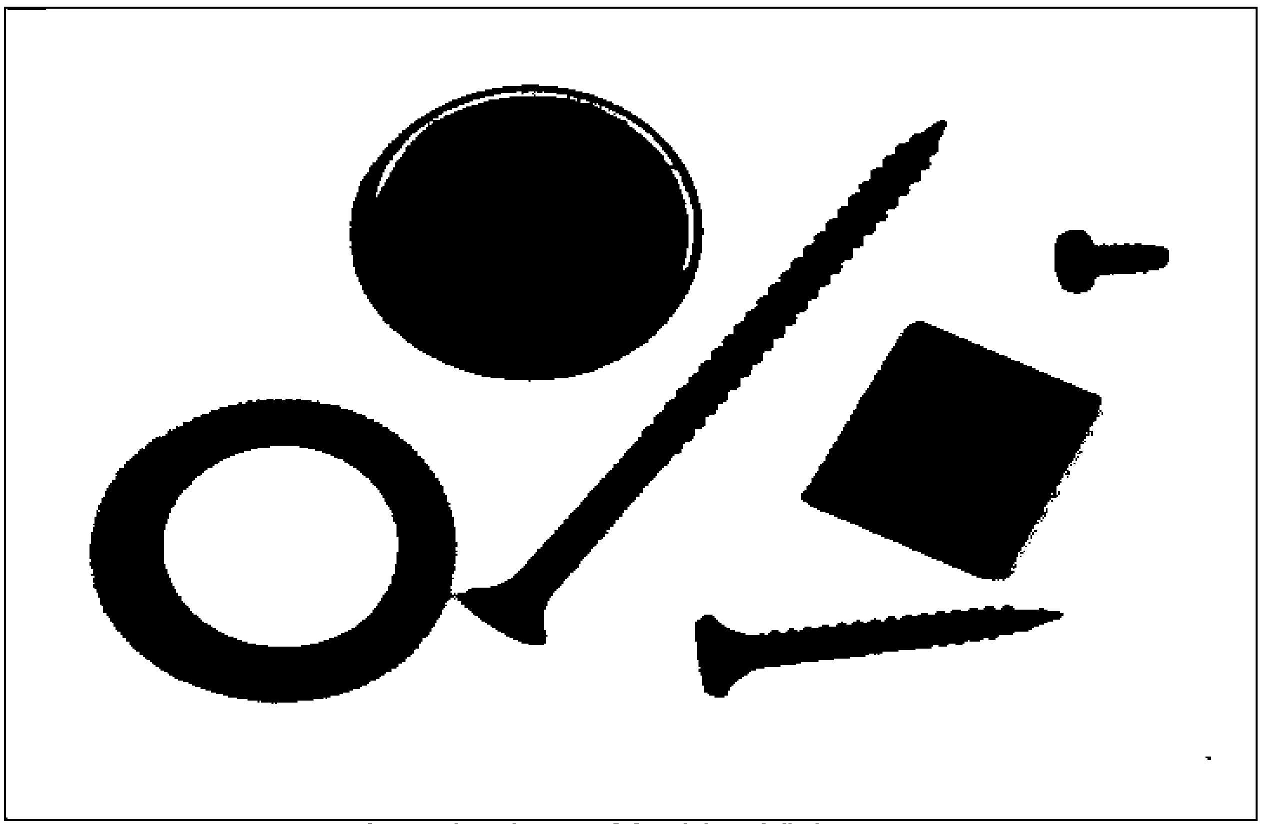
OBJECT RECOGNITION – BLOB ANALYSIS

•Once the image has been segmented into classes representing the objects in the image, the next step is to generate a high level *description* of the various objects.

•A comprehensive set of form parameters describing each object or region in an image is useful for object recognition.

•Ideally the form parameters should be independent of the object's position and orientation as well as the distance between the camera and the object (i.e., scale factor).

What are some examples of form parameters that would be useful in identifying the objects in the image below?



OBJECT RECOGNITION – BLOB ANALYSIS

- Examples of form parameters that are invariant with respect to position, orientation, and scale:
  - Number of holes in the object
  - Compactness or Complexity: $(\text{Perimeter})^2/\text{Area}$
  - Moment invariants
- All of these parameters can be evaluated during contour following.

GENERALIZED MOMENTS

- Shape features or form parameters provide a high level description of objects or regions in an image
- Many shape features can be conveniently represented in terms of moments. The **(p,q)th** moment of a region **R** defined by the function **f(x,y)** is given by:

$$m_{pq} = \iint_R x^p y^q f(x, y) dx dy$$

GENERALIZED MOMENTS

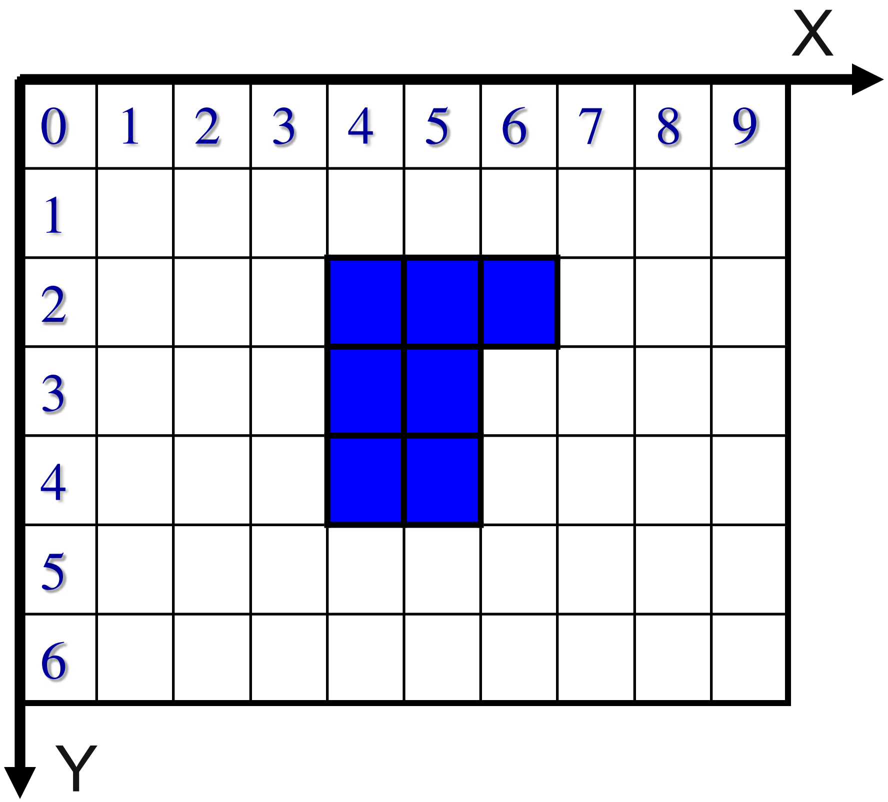
•In the case of a digital image of size **n** by **m** pixels, this equation simplifies to:

$$M_{ij} = \sum_{x=1}^{n} \sum_{y=1}^{m} x^i y^j f(x, y)$$

•For binary images the function f(x,y) takes a value of 1 for pixels belonging to class “object” and “0” for class “background”.

GENERALIZED MOMENTS

$$M_{ij} = \sum_{x=1}^{n} \sum_{y=1}^{m} x^i y^j f(x, y)$$



i	j	M_{ij}
0	0	7
1	0	33
0	1	20
2	0	159
0	2	64
1	1	93

Area

Moment of Inertia

SOME USEFUL MOMENTS

•The center of mass of a region can be defined in terms of generalized moments as follows:

$$\boxed{\overline{X} = \frac{M_{10}}{M_{00}}} \qquad \boxed{\overline{Y} = \frac{M_{01}}{M_{00}}}$$

SOME USEFUL MOMENTS

•The moments of inertia relative to the center of mass can be determined by applying the general form of the parallel axis theorem:

$$\boxed{\overline{M}_{02} = M_{02} - \frac{M_{01}^2}{M_{00}}}$$

$$\boxed{\overline{M}_{20} = M_{20} - \frac{M_{10}^2}{M_{00}}}$$

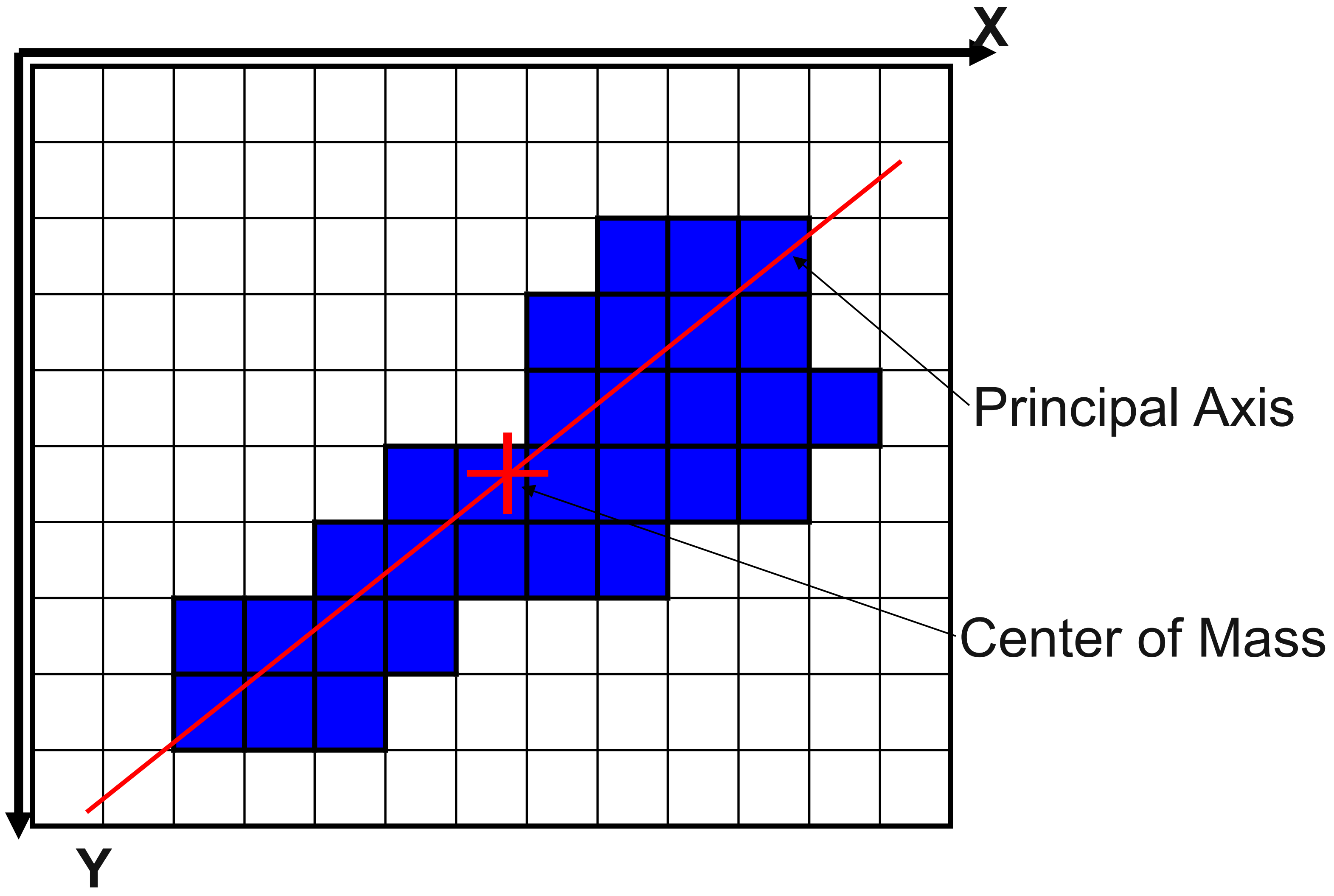
$$\boxed{\overline{M}_{11} = M_{11} - \frac{M_{10}M_{01}}{M_{00}}}$$

SOME USEFUL MOMENTS

- The principal axis of an object is the axis passing through the center of mass which yields the minimum moment of inertia.
- This axis forms an angle θ with respect to the X axis.
- The principal axis is useful in robotics for determining the orientation of randomly placed objects.

$$\boxed{TAN2\theta = \frac{2\overline{M}_{11}}{\overline{M}_{20} - \overline{M}_{02}}}$$

Example



SOME (MORE) USEFUL MOMENTS

- The minimum/maximum moment of inertia about an axis passing through the center of mass are given by:

$$\boxed{\bar{I}_{MIN} = \frac{\bar{M}_{02} + \bar{M}_{20}}{2} - \frac{\sqrt{(\bar{M}_{02} - \bar{M}_{20})^2 + 4\bar{M}_{11}^2}}{2}}$$

$$\boxed{\bar{I}_{MAX} = \frac{\bar{M}_{02} + \bar{M}_{20}}{2} + \frac{\sqrt{(\bar{M}_{02} - \bar{M}_{20})^2 + 4\bar{M}_{11}^2}}{2}}$$

SOME (MORE) USEFUL MOMENTS

•The following moments are independent of position, orientation, and reflection. They can be used to identify the object in the image.

$$\boxed{\phi_1 = \overline{M}_{20} + \overline{M}_{02}}$$

$$\boxed{\phi_2 = (\overline{M}_{20} + \overline{M}_{02})^2 + 4\overline{M}_{11}^2}$$

SOME (MORE) USEFUL MOMENTS

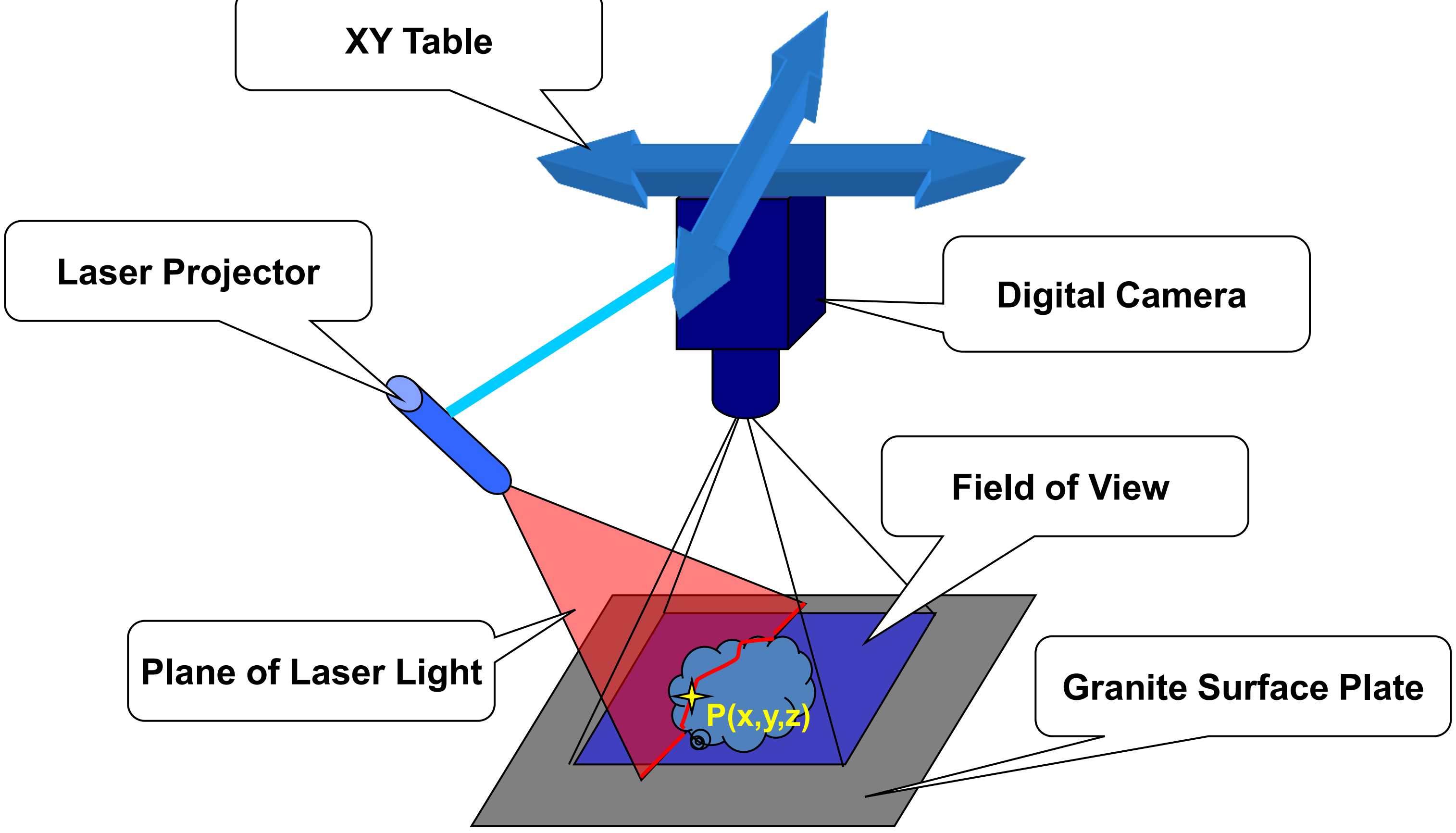
- The following moments are normalized with respect to area. They are independent of position, orientation, reflection, and scale.

$$\boxed{\psi_1 = \frac{\phi_1}{M_{00}^2}} \quad \boxed{\psi_2 = \frac{\phi_2}{M_{00}^4}}$$

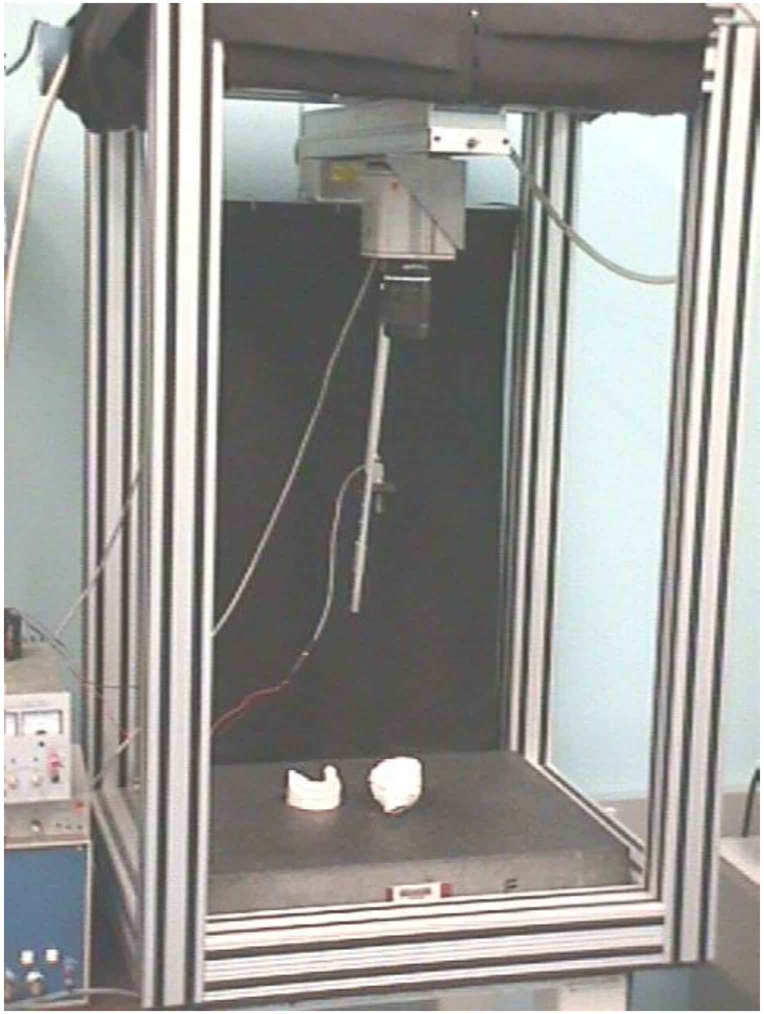
EVALUATING MOMENTS DURING CONTOUR TRACKING

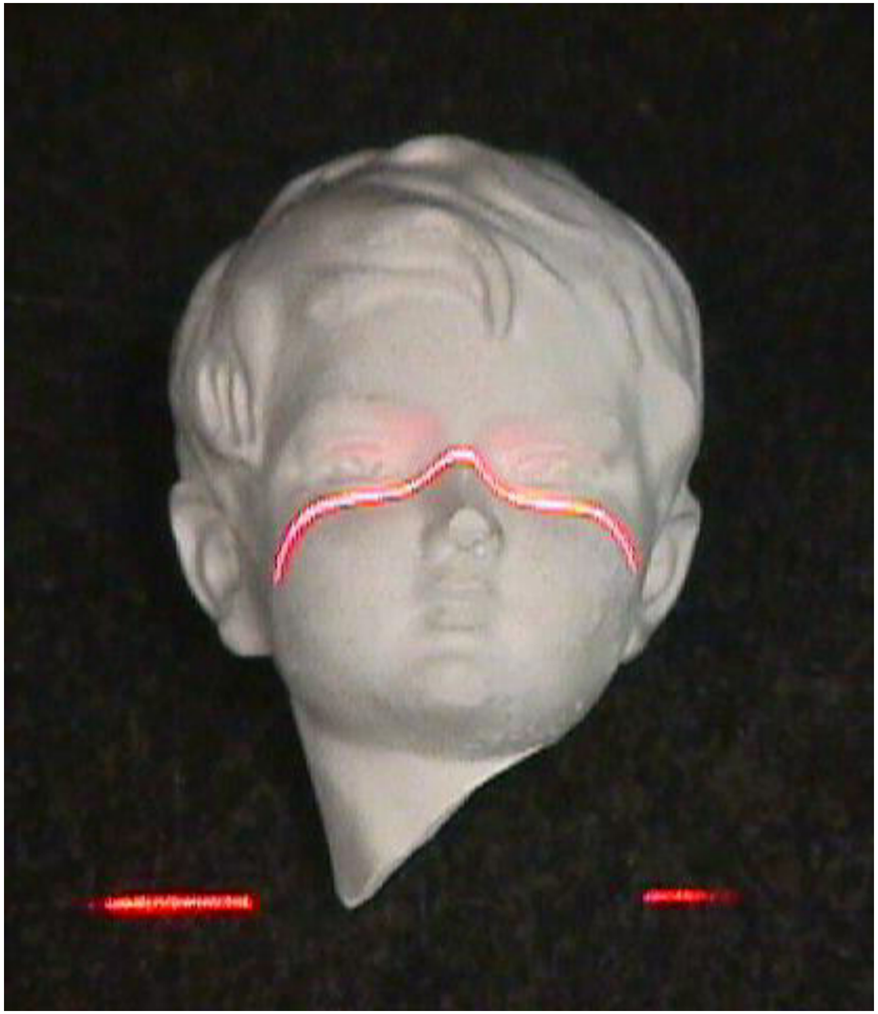
- Generalized moments are computed by evaluating a double (i.e., surface) integral over a region of the image.
- The surface integral can be transformed into a line integral around the boundary of the region by applying Green’s Theorem.
- The line integral can be easily evaluated during contour tracking.
- The process is analogous to using a planimeter to graphically evaluate the area of a geometric figure.

3D MACHINE VISION SYSTEM

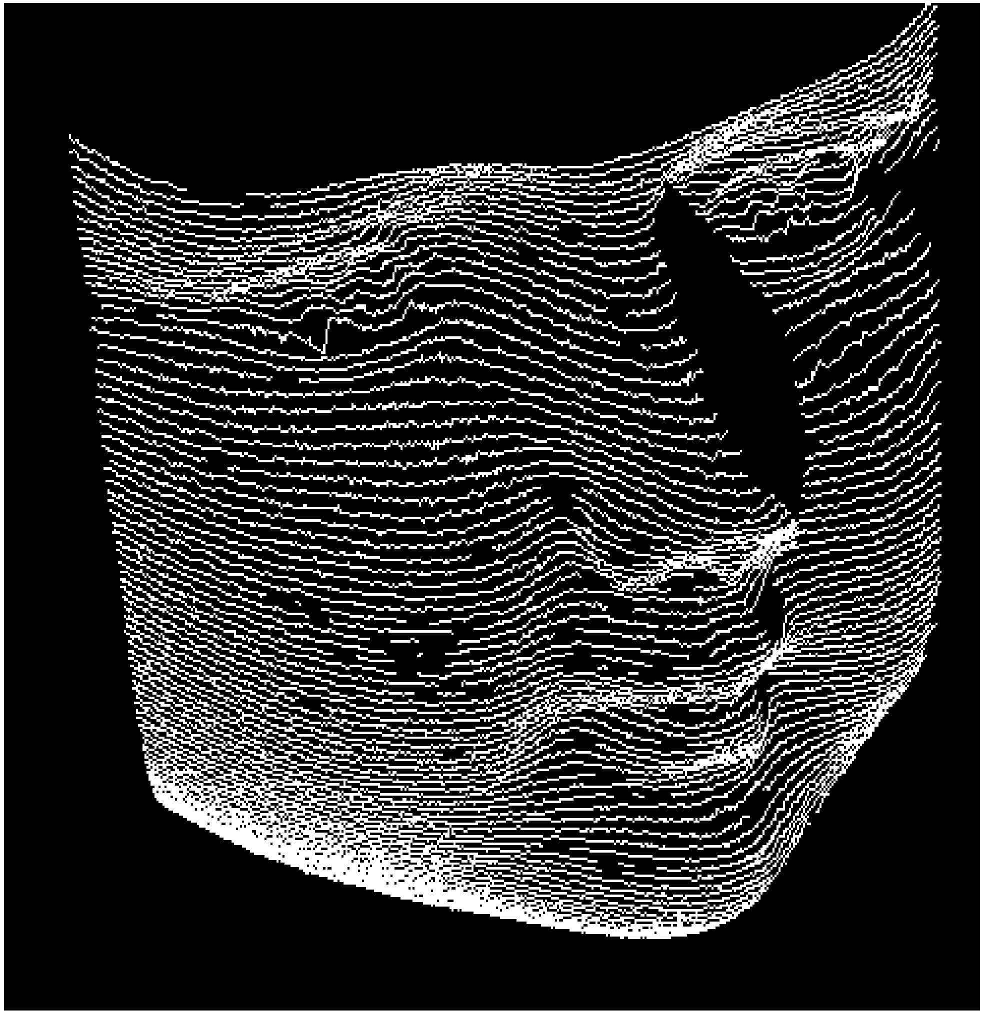


3D MACHINE VISION SYSTEM

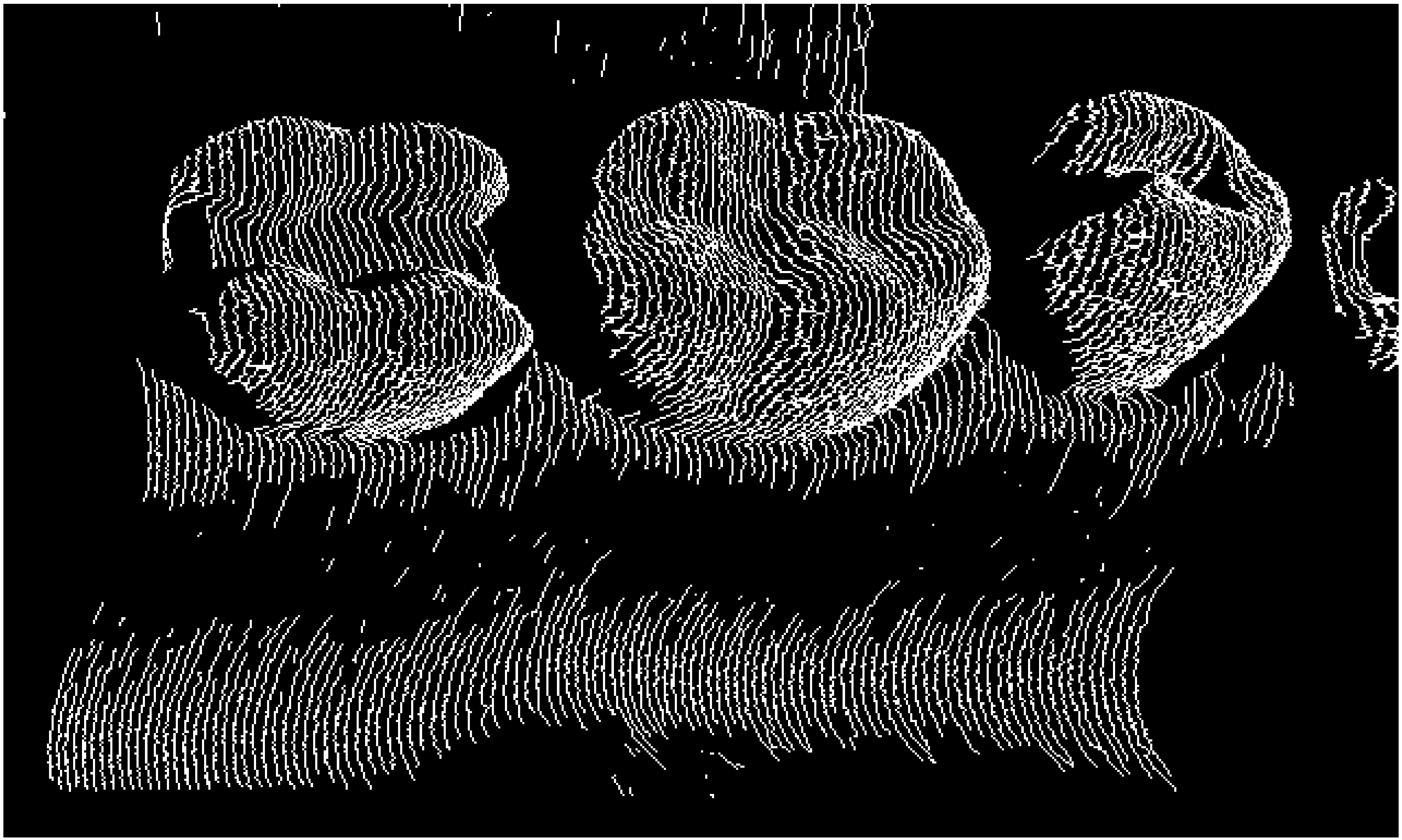




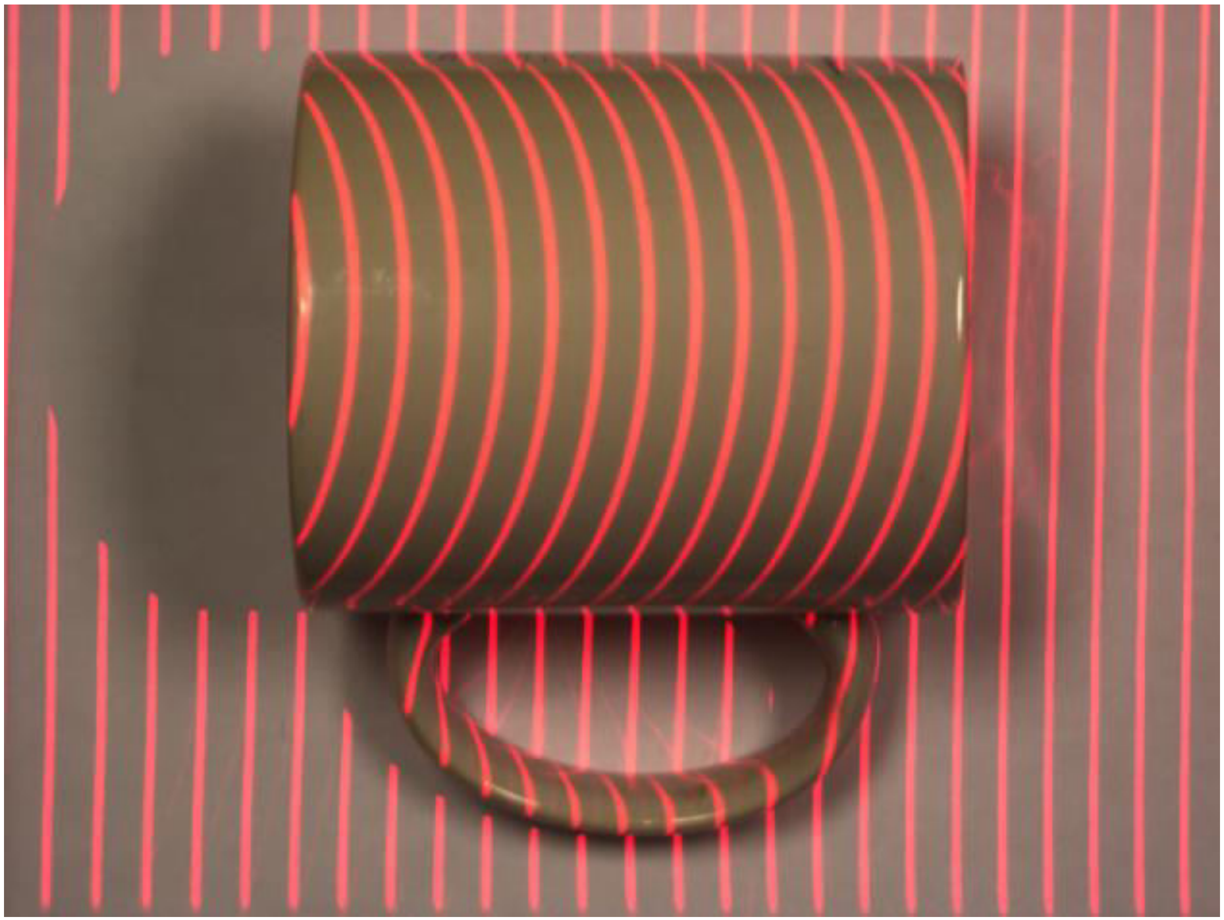
3D MACHINE VISION SYSTEM



3D MACHINE VISION SYSTEM



3D MACHINE VISION SYSTEM

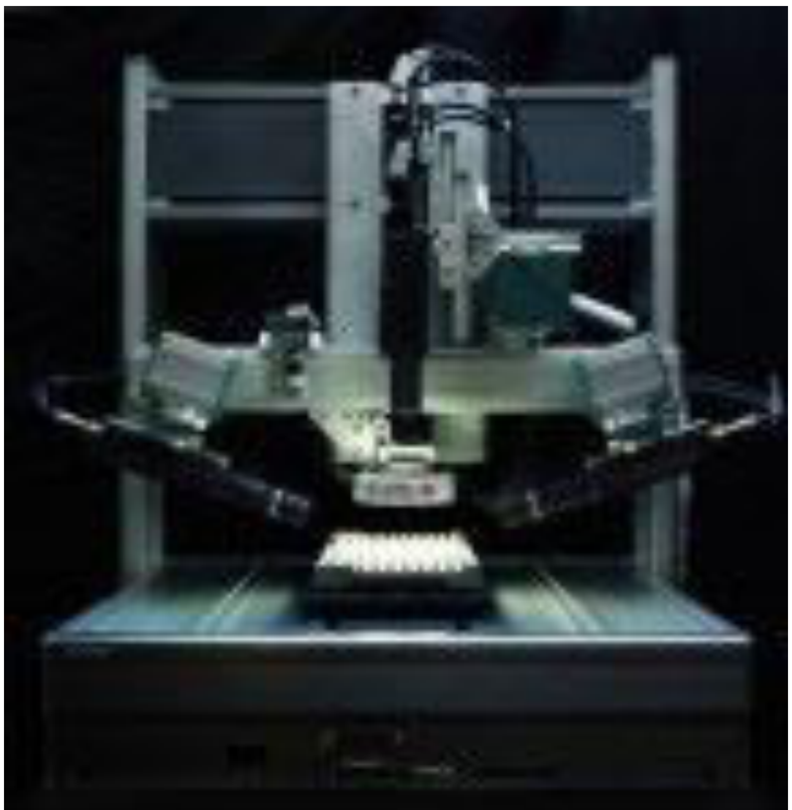


Commercial Machine Vision Definition

"Machine vision is the capturing of an image (a snapshot in time), the conversion of the image to digital information, and the application of processing algorithms to extract useful information about the image for the purposes of pattern recognition, part inspection, or part positioning and orientation"….Ed Red

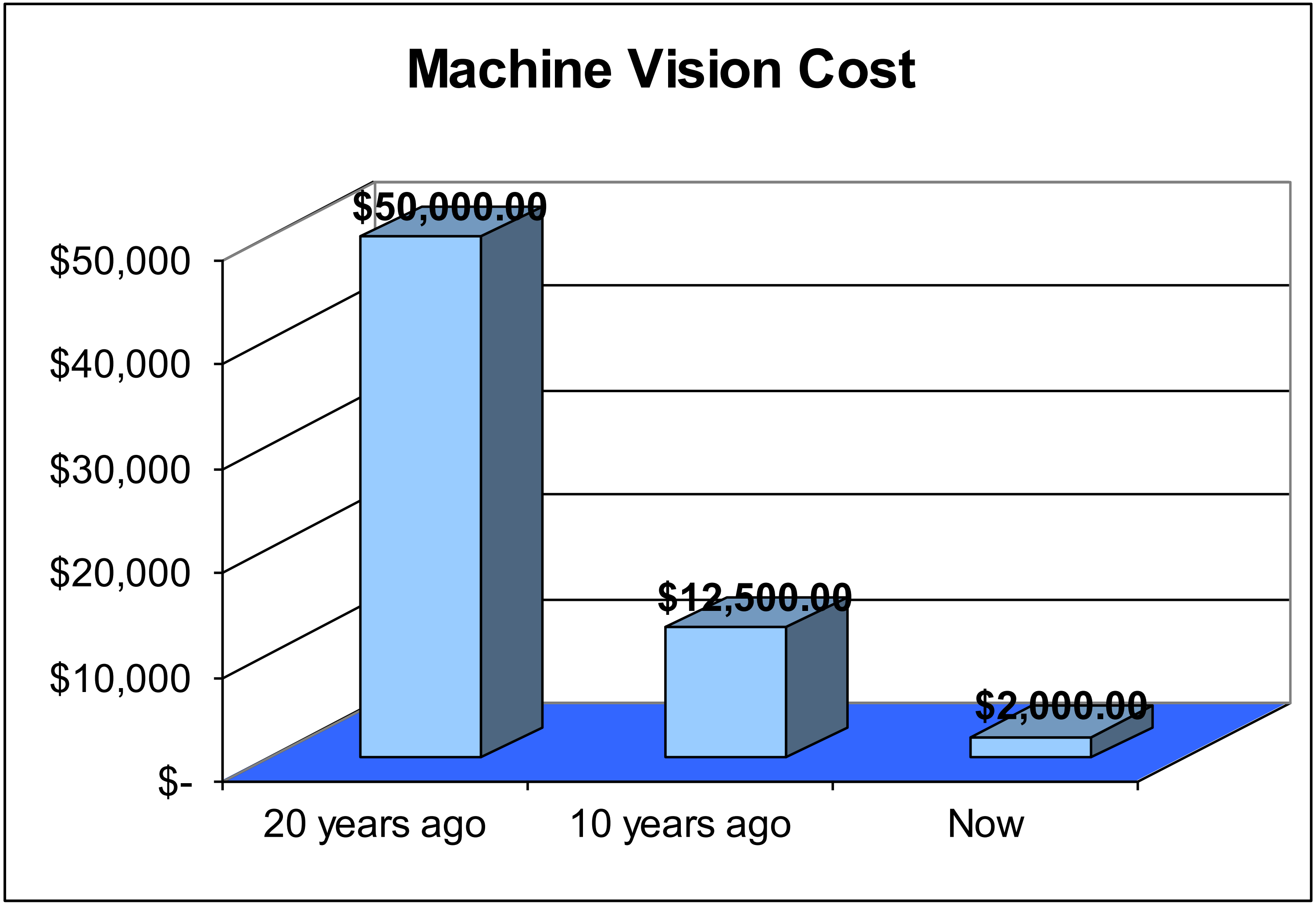
Current State

Cheap and **Easy** to Use



- The ***Sony approved Scorpion Robot Inspection Starter Kit*** contains everything you need for bringing your Scorpion Robot Inspection project to life.
- The kit includes a Scorpion Enterprise software license
- new high quality Sony XCD-710 (CR) camera (XGA resolution)
- Sony Desktop Robot
- 2 days training course
- A standard and configurable user interface paired with innovative, easy-to-use and robust imaging tools
- **$1995.00**

Costs



Data Source: http://www.qualitydigest.com/oct97/html/machvis.html

Costs

Savings from using machine vision

- Cost of recruiting and training
- Scrap/rework created while learning a new job
- Average workers' compensation paid for injuries
- Average educational grant per employee
- Personnel/payroll department costs per employee

Where, What, Whom

Machine vision now has a wide range of installations in high-production industries including:

- Semiconductor
- Electronic
- Automotive
- Container
- Pharmaceutical
- medical device
- Plastic

- Chemicals
- Food
- Footwear
- Textiles
- Printing
- Wood/forest products
- Fabricated metal

Machine vision can be found wherever parts are formed and packaged.

Where, What, Whom

- Automotive
  - fuse box inspection,
  - tire tread recognition,
  - power train inspection and
  - sheet metal inspection.
- Electronics
  - bare-board manufacturer
    - (inspect artwork, inner/outer layer circuit patterns, drill-hole patterns),
  - board assembler
    - (inspect solder paste/epoxy for presence and volume, check co-planarity of component leads, verify presence and position of components pre-solder, verify presence and position of components post-solder, and solder presence/absence and properties),
  - assembly
    - (alignment to assure position of screen-printed patterns, epoxy, component placement, and board pattern position.)

Where, What, Whom

- Food
  - fruit and vegetable sorting and grading,
  - automatic portioning,
  - inspection for foreign objects, and
  - general package-line applications
- Beverage
  - quality inspection of containers,
  - fill level inspection, and
  - closure inspection are among the leading applications

Where, What, Whom

- Aerospace
  - Design of a new sensor system with improved performance for accurately locating and measuring the parameters of holes in aerospace components
  - The specification for the sensor system included the ability to locate and measure both conventional and countersunk holes, in a range of surfaces including aluminum and the latest graphite-based materials
- Work Zone Monitoring uses:
  - 1300 x 1030 All Digital Camera
  - Image Capture and License Plate Reader
  - Fiber Optic Transmission
  - Software Plate Reader
  - PCIbus Wintel Architecture

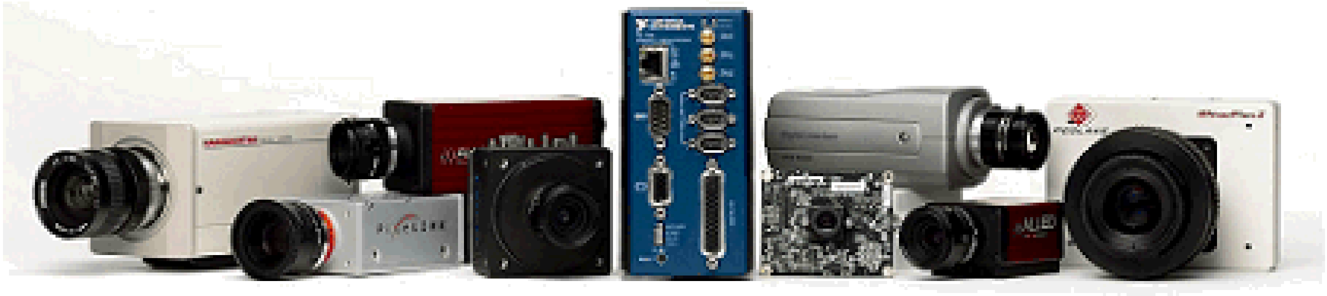
Industry Example

Supporting Technology

SOFTWARE: 7 Things to Consider When Choosing Vision Software

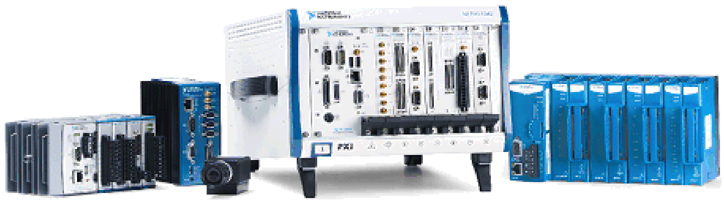
Camera Choice

- The first consideration when picking vision software is to determine if it works with the camera that is best suited for your application.



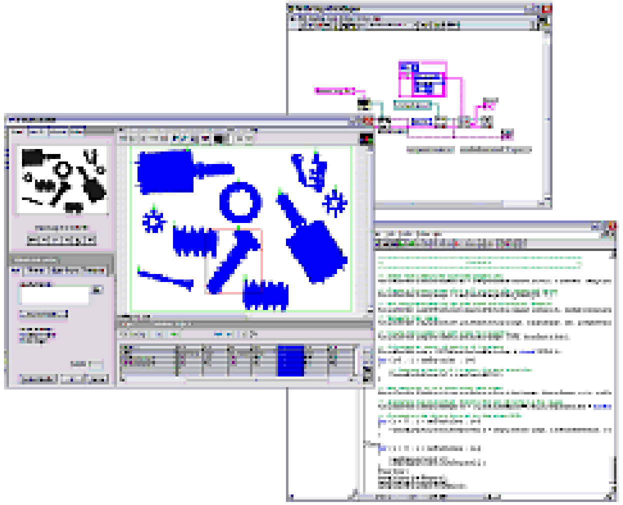
Hardware Scalability

- Because camera technologies are advancing rapidly, someday you may want to upgrade your cameras to improve image quality or measure additional features.



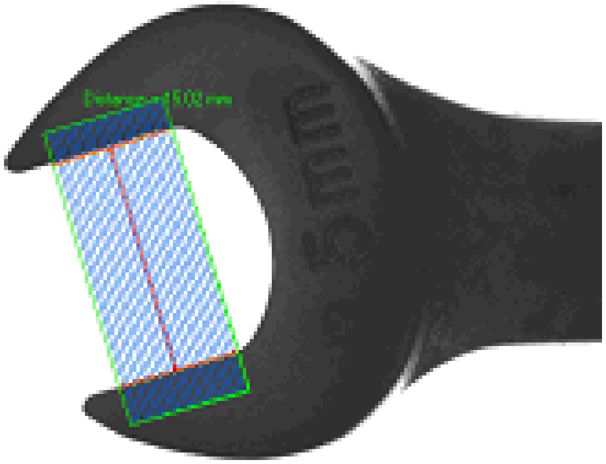
Supporting Technology

SOFTWARE: 7 Things to Consider When Choosing Vision Software



Software Ease of Use

- Once you acquire an image, the next step is to process it.



Algorithm Breadth and Accuracy

- whether the software tools can correctly and accurately measure important part or object features down to the subpixel. If the software is not accurate and reliable, then it does not matter how fast your computer is or how many pixels your camera has.

Supporting Technology

SOFTWARE: 7 Things to Consider When Choosing Vision Software

Algorithm Performance

- No matter how many hundreds of algorithms you have to choose from or how quickly you can build an application with them, if the inspection tools are inefficient and take too long to run, then much of your work goes to waste.

Integration with Other Devices

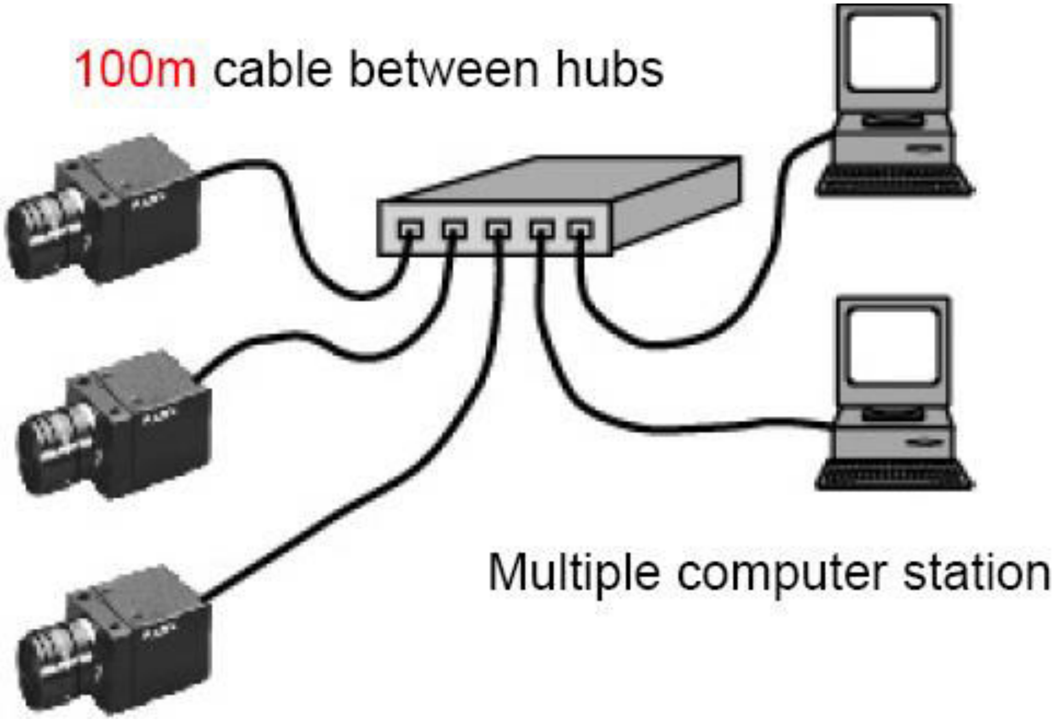
- In industrial automation, your vision application may need to control actuators to sort products; communicate inspection results to a robot controller, PLC, or programmable automation controller; save images and data to network servers; or communicate inspection parameters and results to a local or remote user interface.

Price

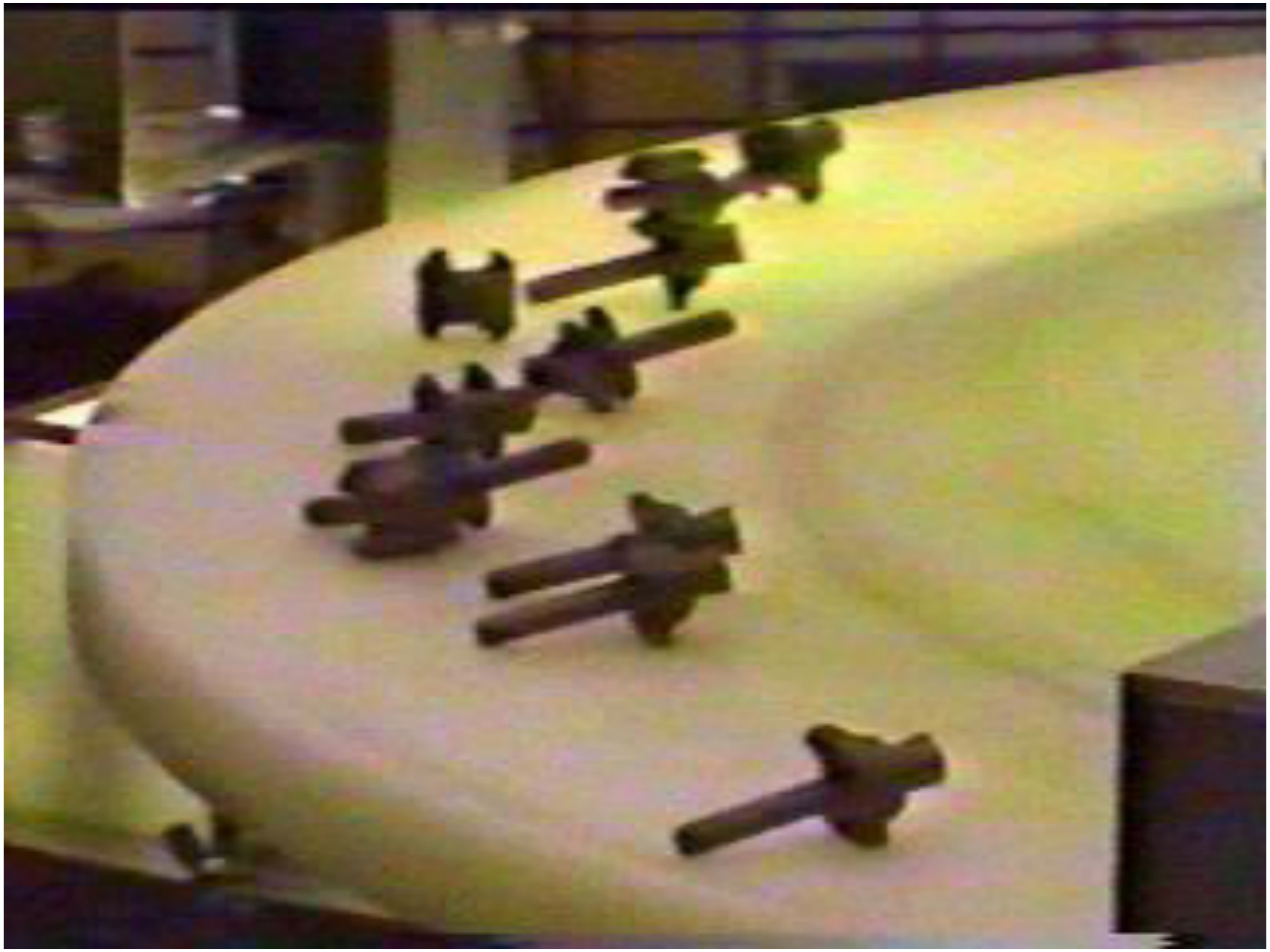
- Vision software packages come in many variations. Many cater to OEM customers by splitting up their development libraries and selling algorithms a la carte. While each individual algorithm bundle seems lower in cost, the total vision development package cost is often quite high. Add to that the cost of a license for each component, and application deployment becomes complicated as well as costly.

Standardization

- GigE Vision is the newest effort at communications interoperability. Work is on-going to develop and release a standard for the connection of vision components using a standard Gigabit **Ethernet cable and connector**.



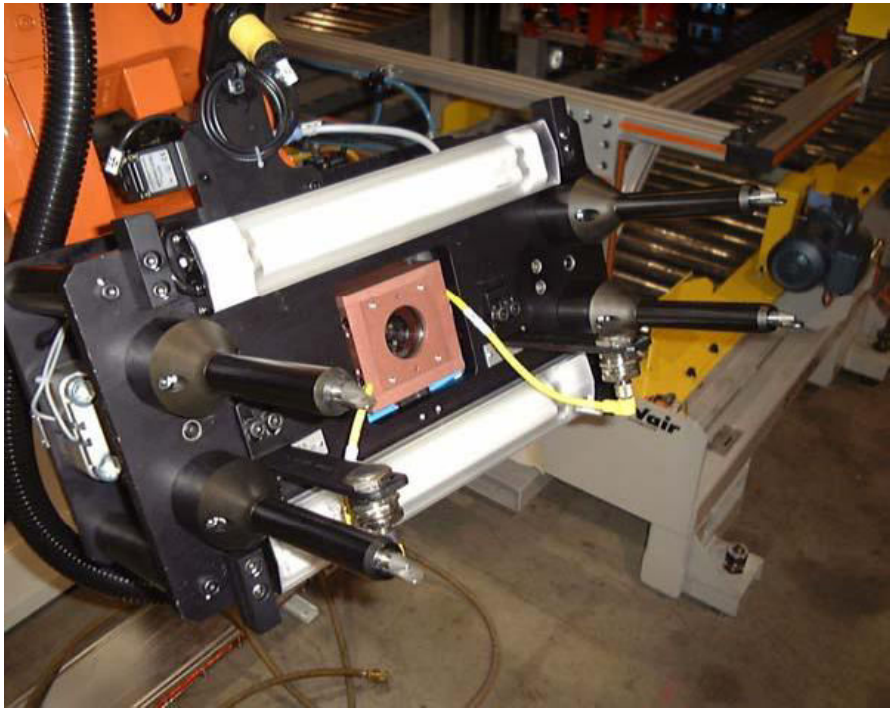
Industry Example



Single Camera 3DTM (SC3DTM)

A novel technology for guidance of industrial robots in three-dimensional space

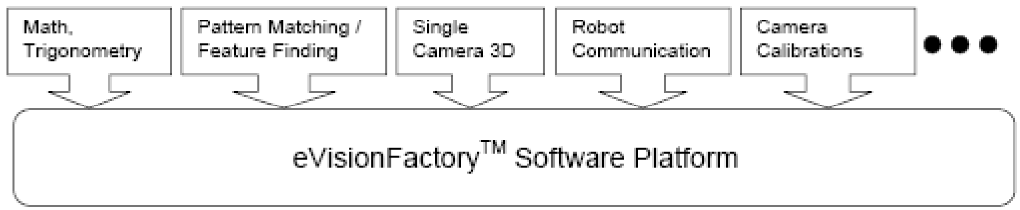
- Provides accurate 3D pose (6 d.o.f) information to industrial robots
- Machines able to ‘see’ the part while at the same time addressing the issues of reliability, usability and global supply.



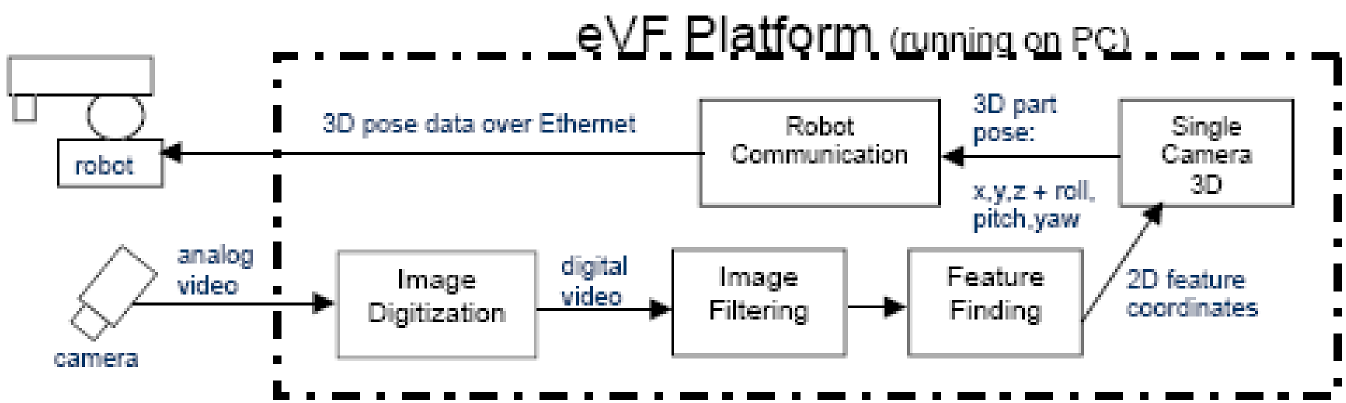
Single Camera 3DTM (SC3DTM)

A novel technology for guidance of industrial robots in three-dimensional space

- Software



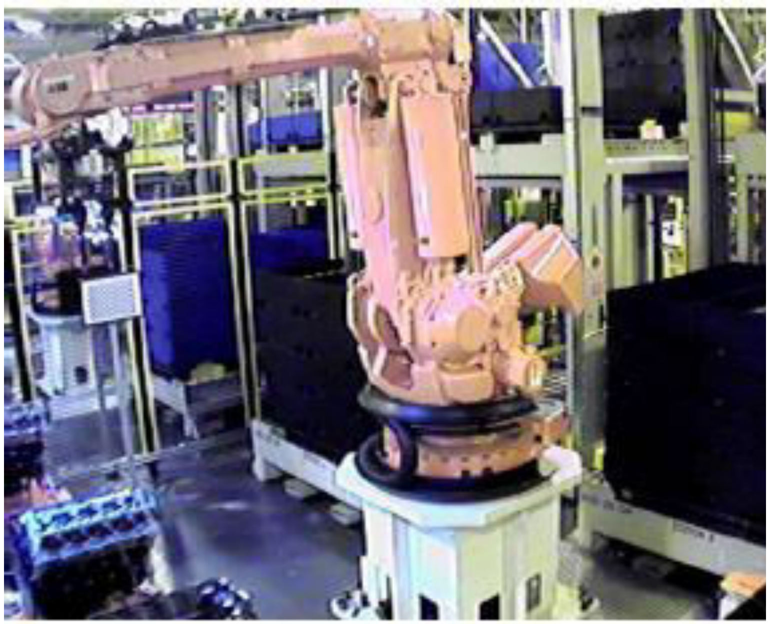
- Data Flow



Single Camera 3DTM (SC3DTM)

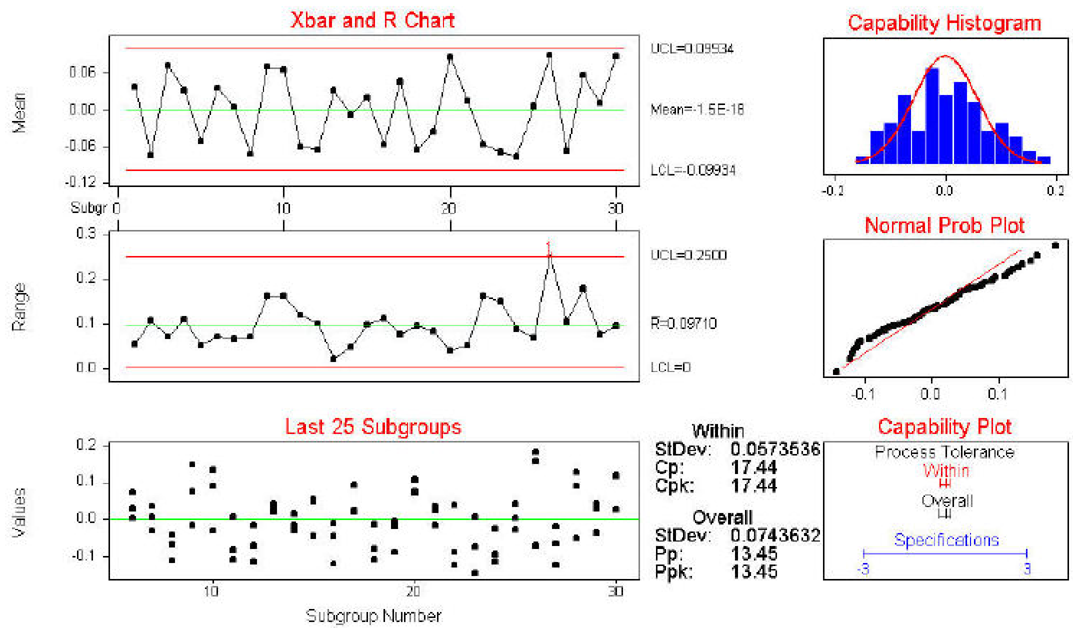
A novel technology for guidance of industrial robots in three-dimensional space

Machine



Repeatability

Cell CA010 Test at Essex Z Repeatability

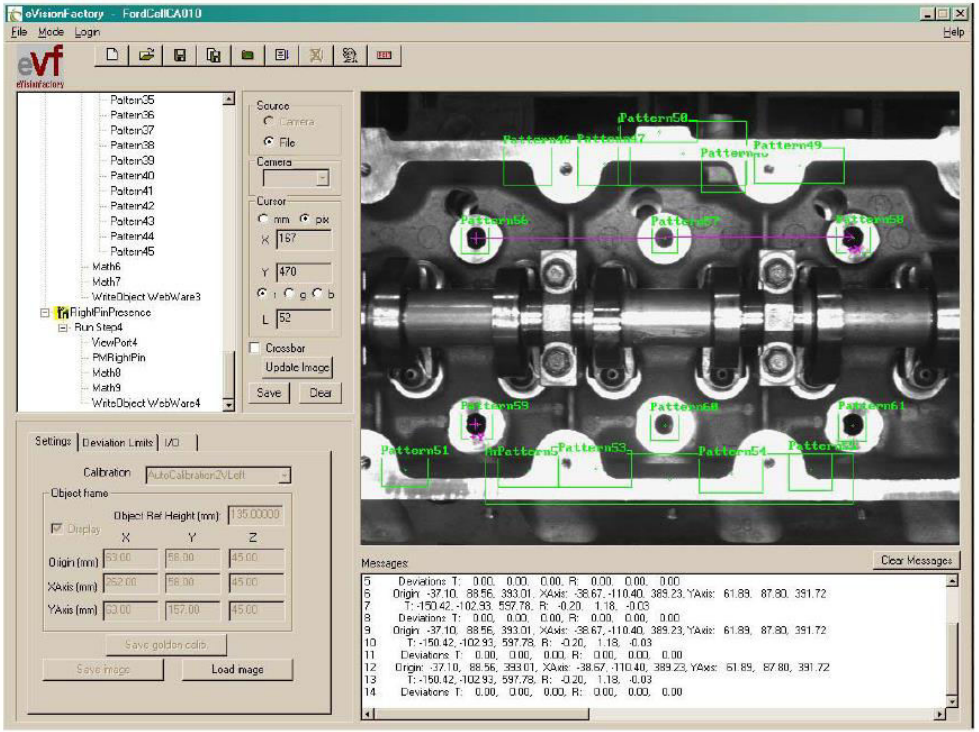


Single Camera 3DTM (SC3DTM)

A novel technology for guidance of industrial robots in three-dimensional space

Requirements

- Parts must be stationary
- No part overlap
- 10 unique features visible to the camera
- Part to part variation in the position of features must be minimal
- Field of view must contain all features
- Camera resolution must be less than 10% of the accuracy/repeatability required by the application



Summary

Machine Vision is:

- ✓ Affordable
- ✓ Used in many applications
- ✓ Convenient
- ✓ Easy-to-use
- ✓ Saves time
- ✓ Safe

Primary Vendors of Technology

3D Systems

- Cohu, Inc., Electronics Division
- LMI Technologies Inc
- SICK IVP AB
- StockerYale Canada
- VITRONIC Machine Vision Ltd.

Cameras

- Adimec
- Basler Vision Technologies
- Daitron
- JAI A/S
- Sony Electronics Inc.

Complete Vision Systems

- Cognex Corporation
- ISRA Vision Systems
- Tordivel AS
- Vitronic Machine Vision

References

- Beattie, RJ, Cheng, SK and Logue, PS, "The Use of Vision Sensors in Multipass Welding Applications", pp 28-33, The Welding Journal 67(11), November 1988.
- www.machinevisiononline.org
- http://www.qualitydigest.com/oct97/html/machvis.html
- http://zone.ni.com/devzone/conceptd.nsf/webmain/9F5D44BDD177005886256FDC007B2C78?opendocument&node=1286_US
- http://www.machinevisiononline.org/public/articles/Babak_Habibi_July03.pdf

Image Processing and Sampling

Introduction to image

- An **natural image** captured with a camera, telescope, microscope or other type of optical instrument displays a **continuously varying array of shades and color tones**. This is known as continuous tone image or analog image.

- An image provides **information**.

Overview

- Image representation
  - What is an image?
- Halftoning and dithering
  - Trade spatial resolution for intensity resolution
  - Reduce visual artifacts due to quantization

What is an Image?

- An image is a 2D rectilinear array of pixels

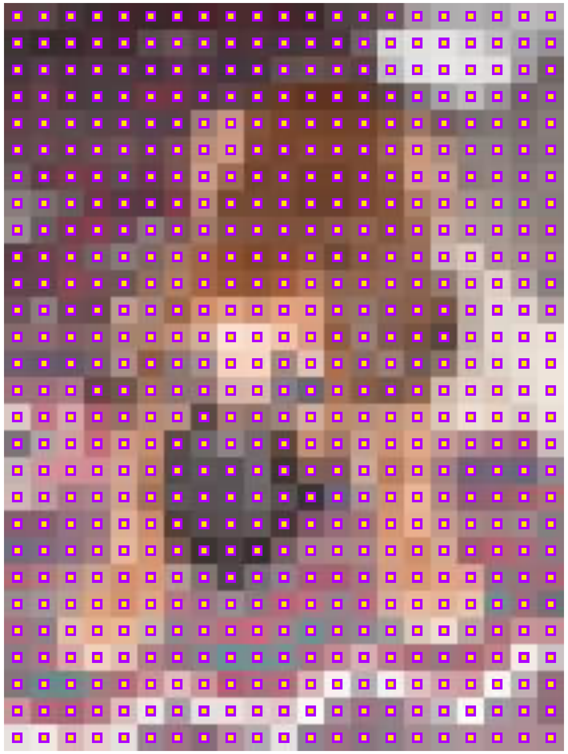
Continuous image

Digital image

What is an Image?

- An image is a 2D rectilinear array of pixels

Continuous image



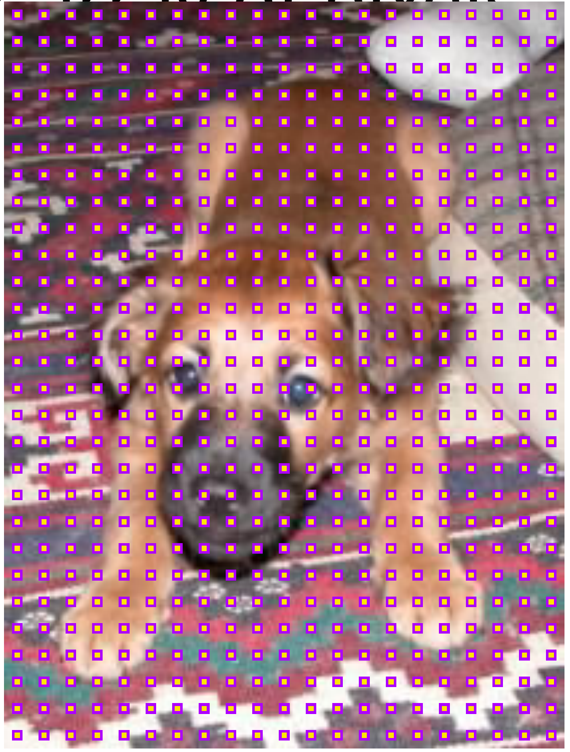
Digital image

A pixel is a sample, not a little square!

What is an Image?

- An image is a 2D rectilinear array of pixels

Continuous image



Digital image

A pixel is a sample, not a little square!

Image Representation

Data Representation

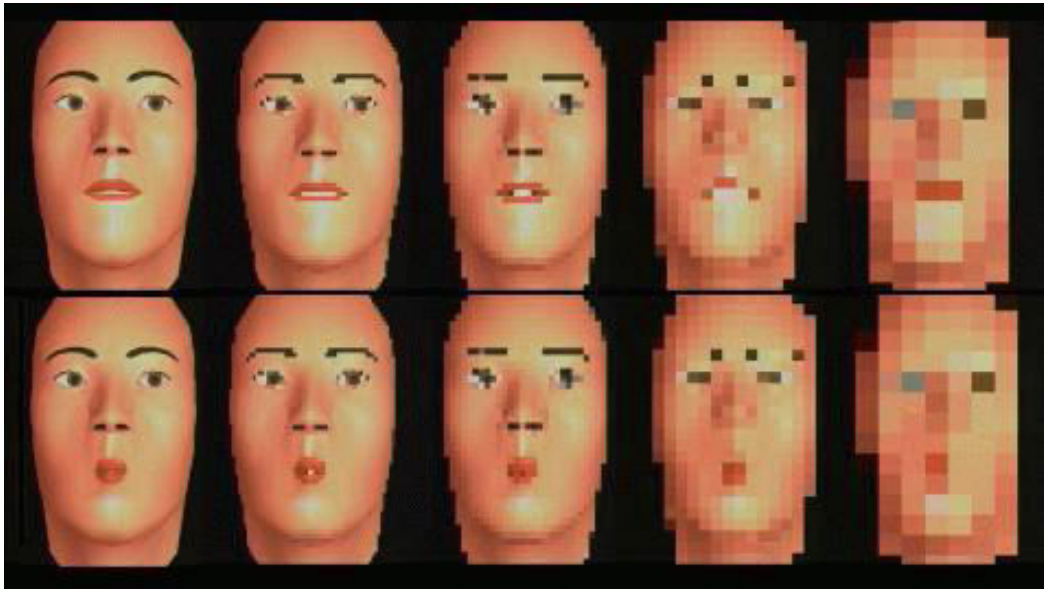
- Text representation
  - ASCII character set
  - Unicode
  - Data compression
- Images!

What is an image?

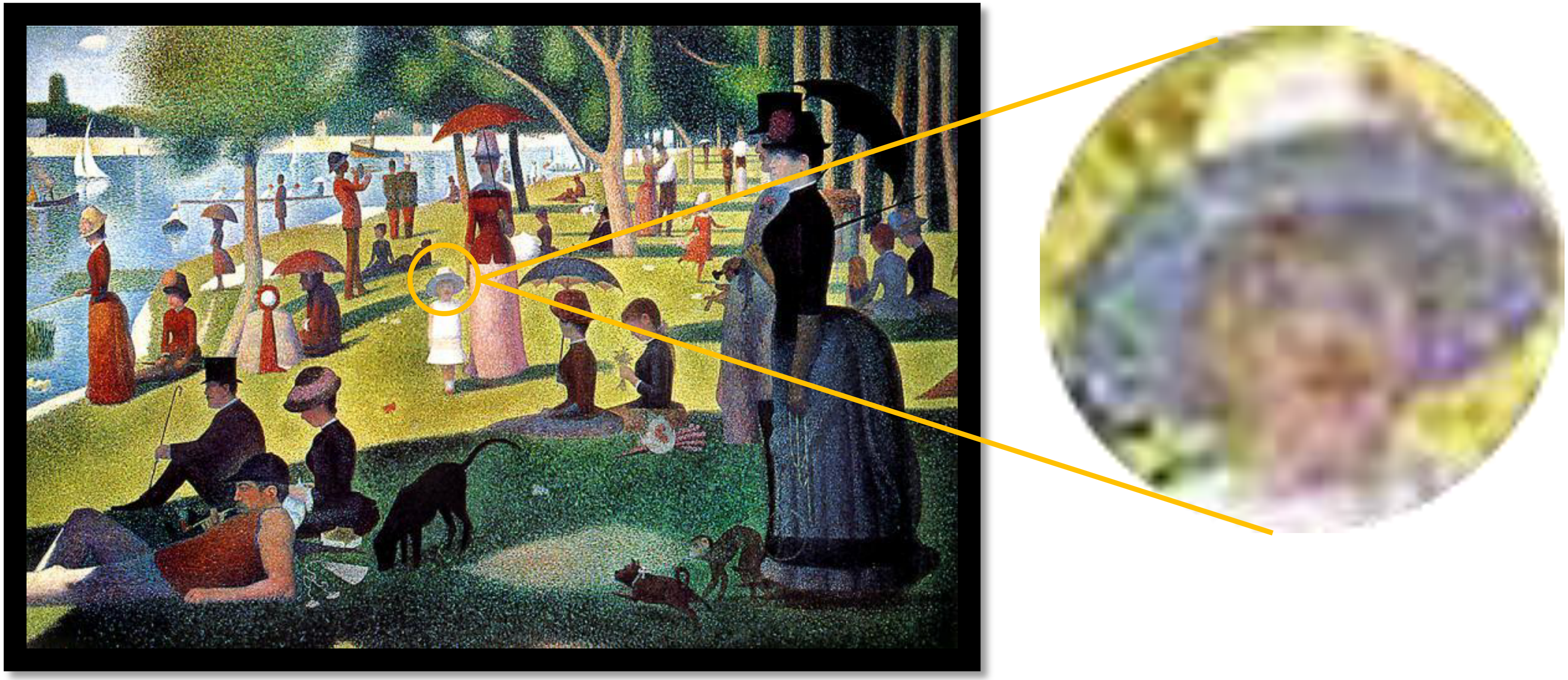
- Rectangular grid of pixels- 5x5 grid
  - If we are using 1 bit per cell, *how many bits are needed to present the picture*?
- What is a pixel?
  - Point/Cell in the image that contains color data
  - Each pixel is made up of *bits*
- Resolution: Details contained in an image
  - Defined by the number of pixels

5 x5 grid

[0,0]	[0,1]	[0,2]	[0,3]	[0,4]
[1,0]	[1,1]	[1,2]	[1,3]	[1,4]
[2,0]	[2,1]	[2,2]	[2,3]	[2,4]
[3,0]	[3,1]	[3,2]	[3,3]	[3,4]
[4,0]	[4,1]	[4,2]	[4,3]	[4,4]



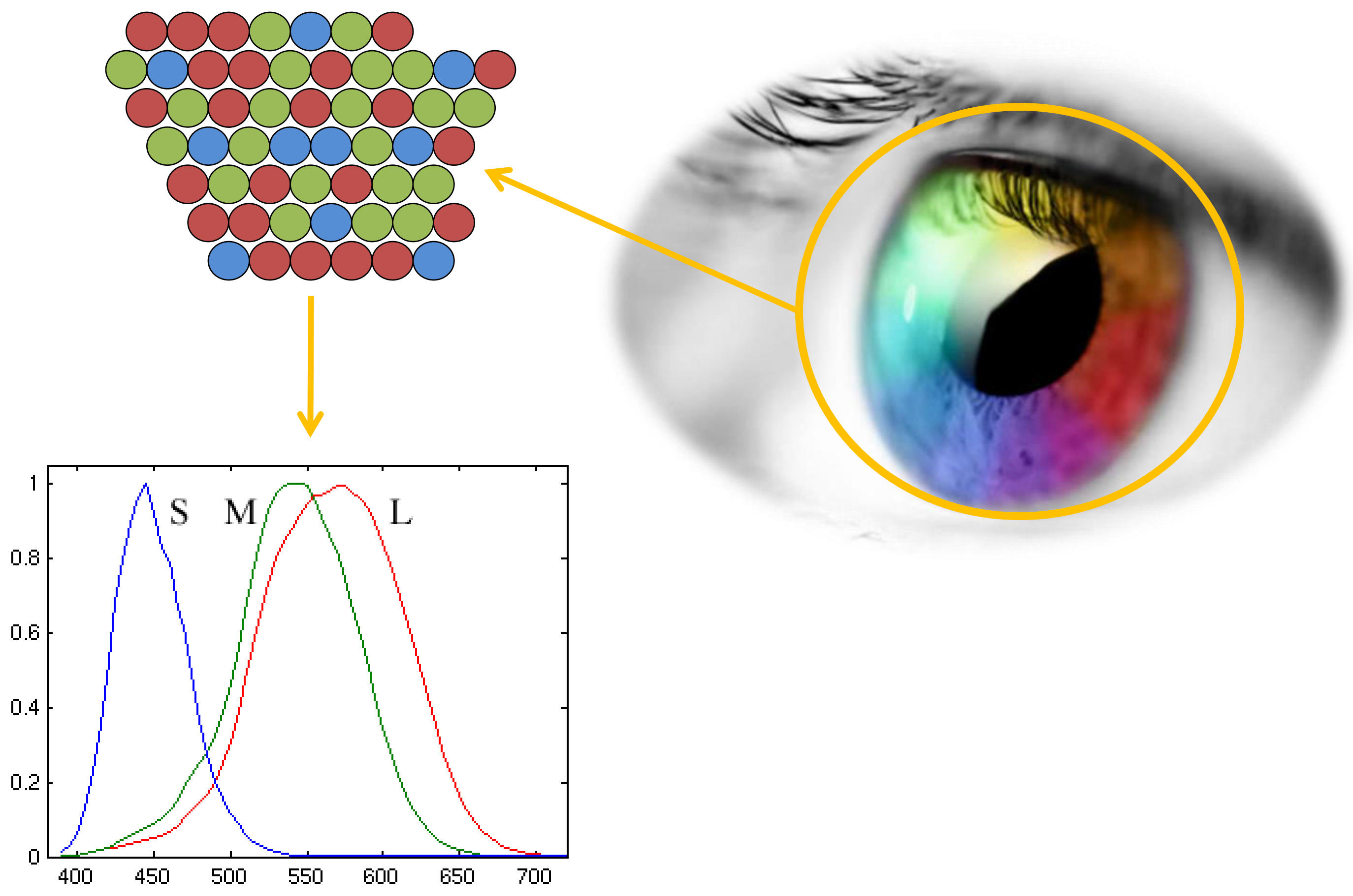
Digital images



George Seurat: *Sunday afternoon on the island of La Grande Jatte (1884-1886)*

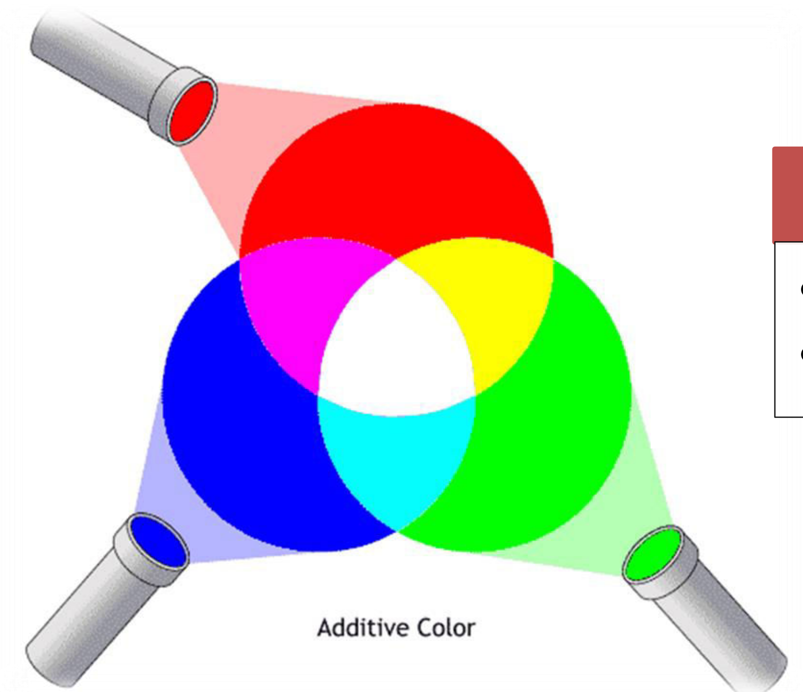
Representing Color

Red Green Blue



Representing Color

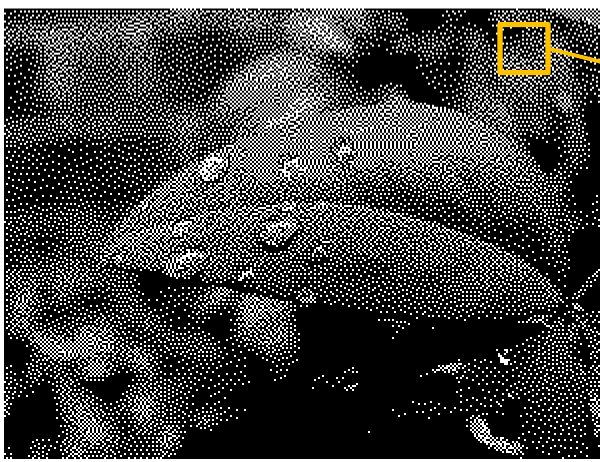
- Computer graphics/Images: RGB
- R: 0 to 255, G: 0 to 255, B: 0 to 255



Red	Green	Blue	Color
• 255 • 255	• 255 • 255	• 255 • 0	• White • Yellow

Binary Images

- Remember, everything on a computer is stored as 0s and 1s.
- Thus, we must *interpret* these numbers as different forms of data.
- One bit (binary digit) can be either a 0 or a 1.
  - Therefore, it can only represent two possibilities: hot or cold, black or white, on or off, etc…



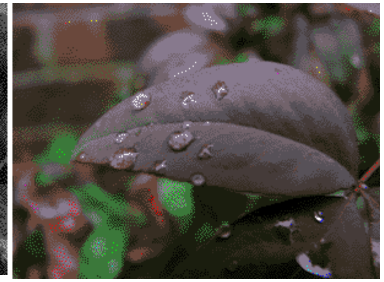
1 bit per pixel

```
000000110011100111001
100001100111010000111
000111000110001111000
011100011110000111000
110111001110011011000
101001100010101000110
001010111011101000110
100101010100001110000
101010100000000001110
```

Bit Color Depth

1 bit

2 bits



4 bits

8 bits

24 bits

1= ON   0 =OFF

00   01   10   11
Different shades of gray

24 bit *TrueColor* can represent more than 16.7 million unique colors. More colors than the human eye can distinguish!

Raster vs Vector Graphics

- Raster graphics: made up of pixels
  - Resolution dependent
  - Cannot be scaled without losing quality
  - Can represent photo realistic elements better than vector graphics

- Vector graphics: geometric primitives, composed of paths
  - Mathematical equations
  - Resolution independent
  - Can be scaled to any size without losing quality
  - Best for cartoon-like images
  - 3D modeling

Raster vs Vector Graphics

- Raster graphics - Image formats:
  - BMP
  - GIF
  - JPEG
  - PNG
- Vector graphics - Image formats:
  - Flash
  - Scalable vector graphics (SVG)
  - CDR (corelDraw)
  - AI (Adobe Illustrator)

Raster Graphics

- BMP (bitmaps)
  - Simple structure
  - Pixel color values *left to right, top to bottom*
  - Can be compressed using run-length encoding

- GIF (graphics interchange format)
  - 8-bit palette (any 256 colors)
  - Small size
  - Simple images: line art, shapes, logos
  - Lossless compression: covering areas with single color

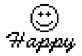
- JPEG (joint photographic experts group)
  - Is a *compression method* stored in JFIF (JPEG file interchange format)
  - Lossy compression: Averages color hues over short distances
    - Taking advantage of limitations of our visual system, discarding invisible information
  - Compression ratio is usually 0.1
  - Structure: sequence of segments. Marker followed by a definition of the marker

Images

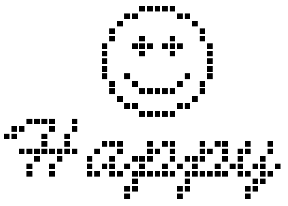
- The Science of Images
  - 2D array of pixels
- The Psychology of Images
- The Technology of Images
  - Image Formats
  - Images in Director

The Science of Images:

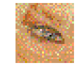
B&W Image Representation

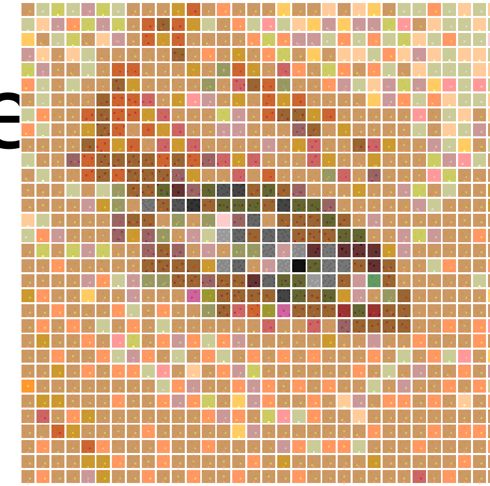


- An image is simply a 2D array of pixels
  - Its dimensions: say, **w** pixels wide by **h** pixels high
- Each **pixel** is a small square on the screen



- Each pixel has a **color** associated with it
- If the color can be either **black or white**, then one needs only 1 bit per pixel
- **Size** of a BW image: w * h * 1 bits = (w * h)/8 B
  - A 640 x 480 BW image takes 38,400 B = 37.5 KB (1KB = 1024 B)





The Science of Images

Color Image Representation

- We can represent every visible color by its **RGB** percentage composition
  - (R, G, B) = (100%, 0%, 0%) is a fully saturated **red**
  - (R, G, B) = (0%, 50%, 0%) is a half-saturated **green**
  - (R, G, B) = (50%, 50%, 50%) is a medium **gray**
- We can also represent it by its 3 actual RGB ***values***
  - The value **scale** has 256 different values
- Each value is a number between 0 and 255
  and one needs 8 bits to represent such a number
  therefore 8+8+8=24 bits to fully represent an RGB color
- **Size** of a color image: w * h * 24 bits = (w * h*24)/8 B
  - A 640 x 480 color image takes 921,600 B = **900** KB!

The Technology of Images:

Compression Formats

- **24 bits** (bit-depth) are enough to represent
 up to **16 million** different colors

- A particular photograph, even though it may be very colorful,
it may not need all 24 bits to be represented
because it will likely not use all of them

- **JPG** is a **compression** format that allows the image
to be stored using far fewer than 24 bits/pixel

- When we save an image "as jpg" we actually compress it.

- As a result, the **quality** of the image will **degrade**
so that the compression image may lose some of its quality

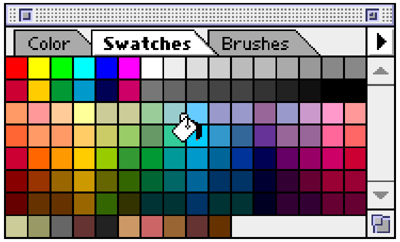
- There are several **levels** of jpg compression
and most people may not be able to tell the difference
(see http://www.wellesley.edu/Chemistry/Flick/jpgquality.html)

The Technology of Images:

Limited Palette Image Representation

- If we use fireworks or director to create a drawing,
  we likely are going to use far fewer than 16 million colors

- **GIF** is a image format that
  uses only 256 colors
  (it determines the best 256 colors for the image)



- A gif image uses only 1byte/pixel,
  plus the table to remember which particular 256 colors it uses
  (its "**palette**")

- When **importing** a gif image in Director,
  we are also importing its palette -
  which goes into the palette channel

Digital Images

Representing Digital Images

Digital images are composed of PIXELS (or picture elements)

- a natural image is typically represented by a continuous or analog signal (such as a photograph, video frame, etc.)

Representing Digital Images

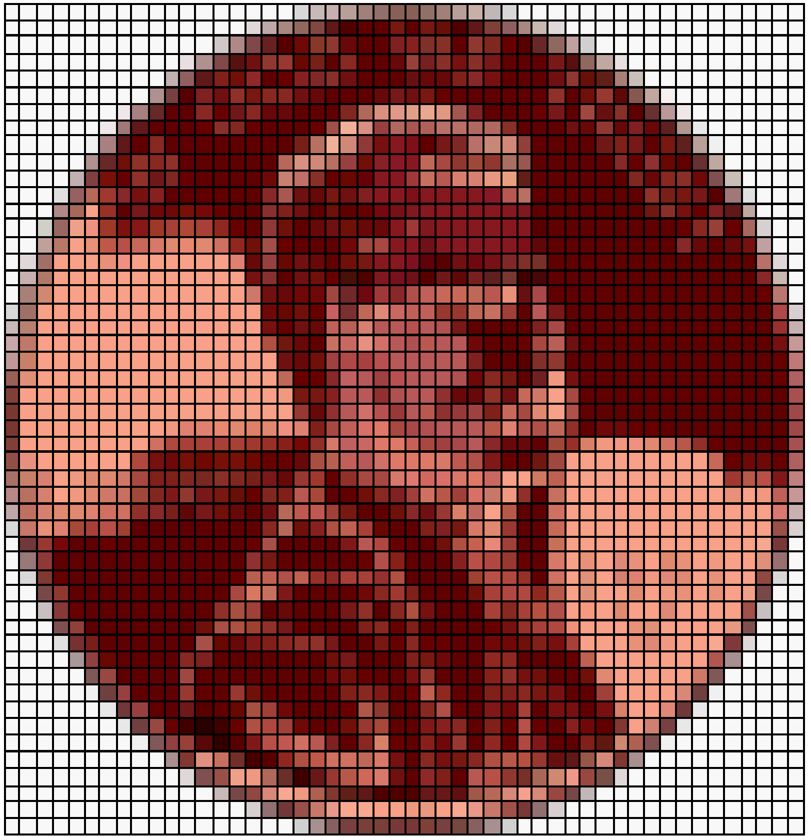
Digital images are composed of PIXELS (or picture elements)

- digitizing samples the natural image into discrete components

Representing Digital Images

Digital images are composed of PIXELS (or picture elements)

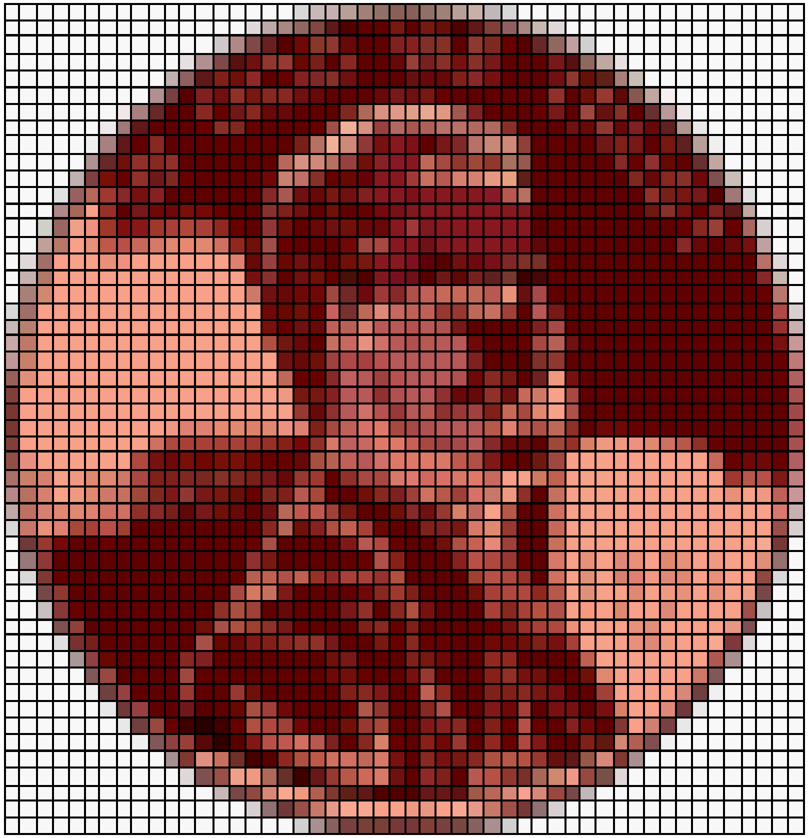
- each discrete sample is averaged to represent a uniform value for that area in the image



Representing Digital Images

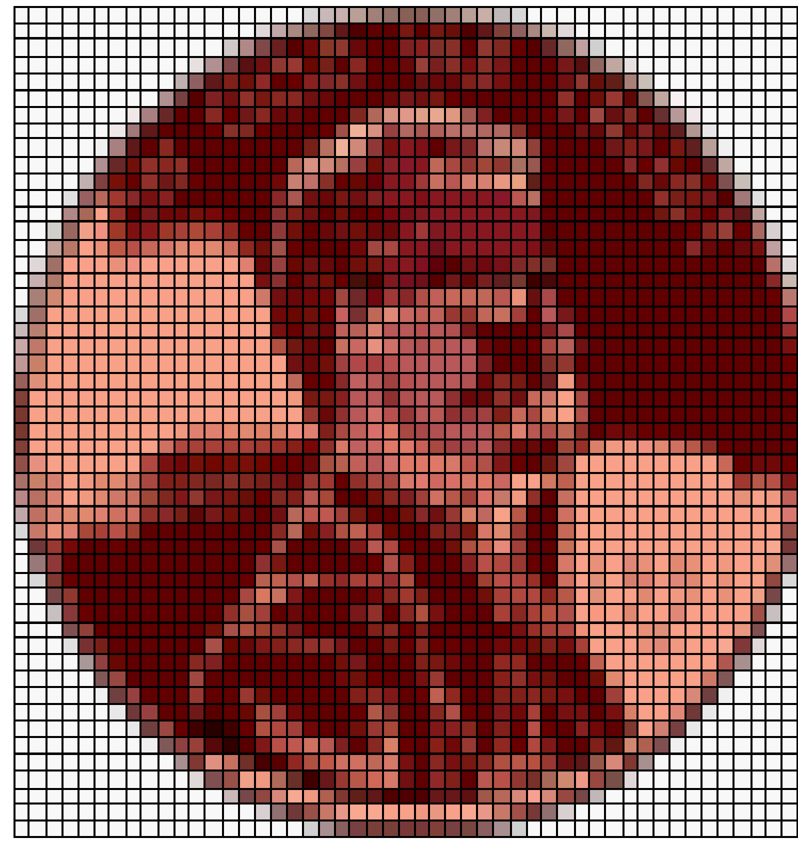
Digital images are composed of PIXELS (or picture elements)

- PICTURE RESOLUTION is the number of pixels or samples used to represent the image



Representing Digital Images

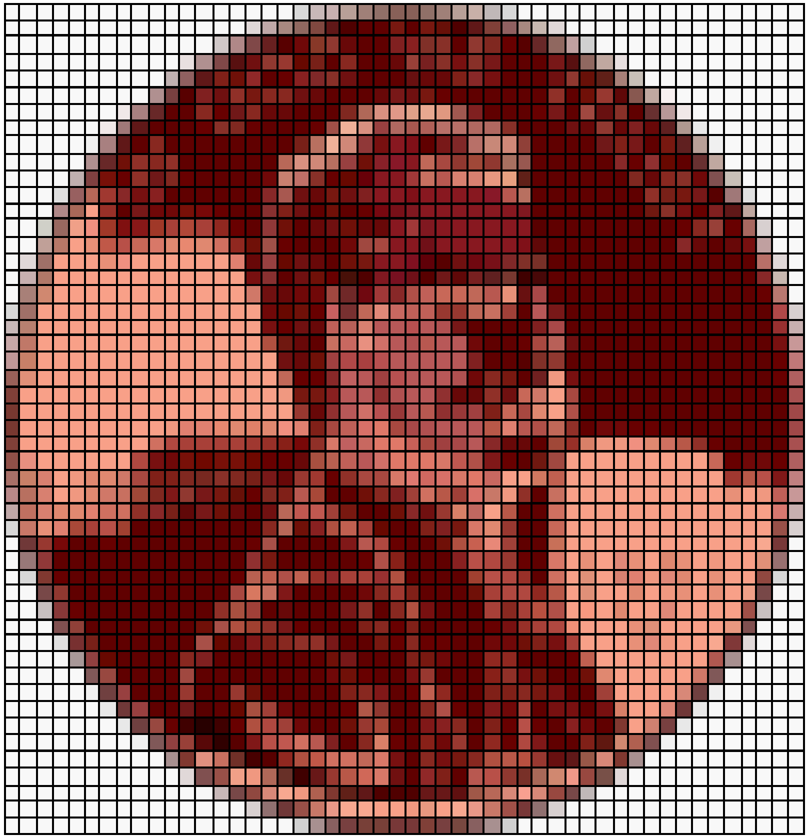
Digital images are composed of PIXELS (or picture elements)



- ASPECT RATIO expresses this resolution as the product of the no. of horizontal pixels by the no. of vertical pixels

Representing Digital Images

Digital images are composed of PIXELS (or picture elements)



- this image is square, 50 X 50
- sample ratios are 320 X 200 or 1.6:1, 640 X 480, 800 X 600, and 1024 X 768--all of which are 1.33:1

Representing Digital Images

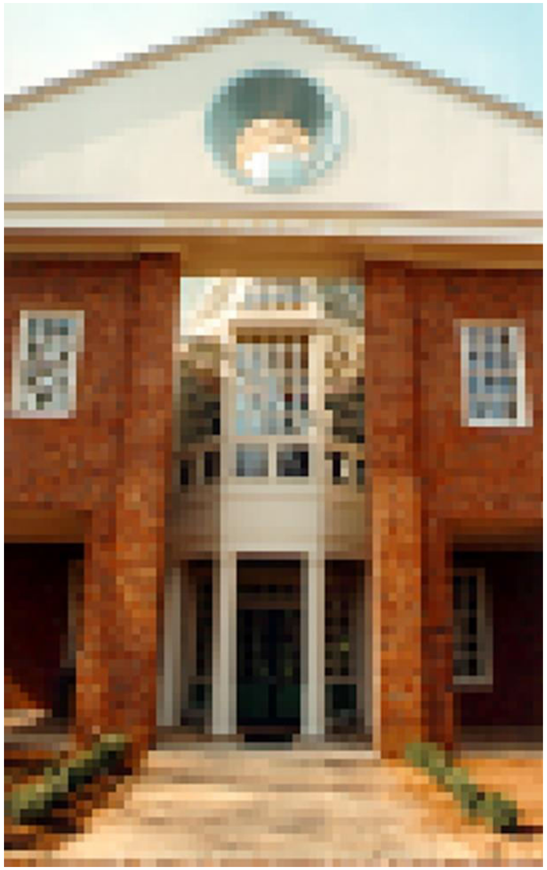
Picture resolution determines both the amount of detail as well as its storage requirements

- here is a (edited) digitized image with a resolution of 272 X 416

Representing Digital Images

Picture resolution determines both the amount of detail as well as its storage requirements

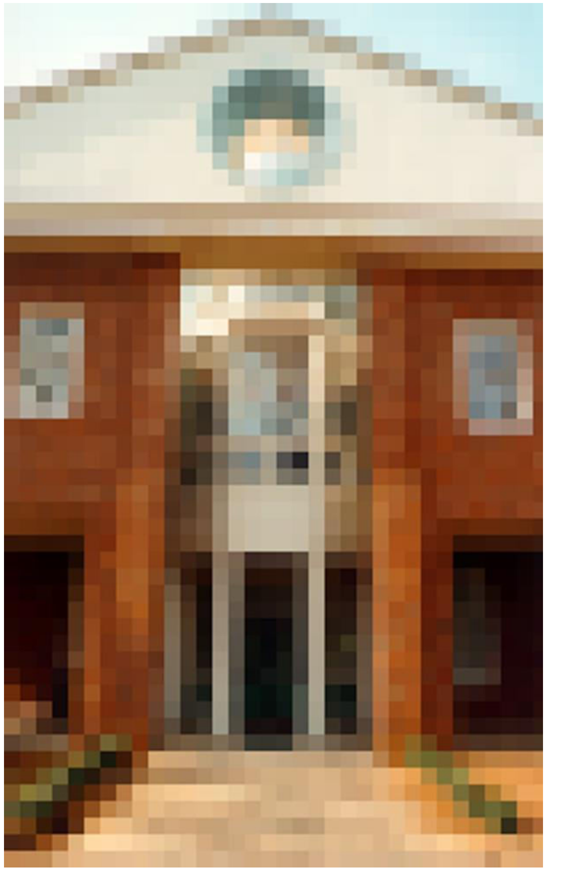
- notice the changes when the resolution is reduced (136 X 208)



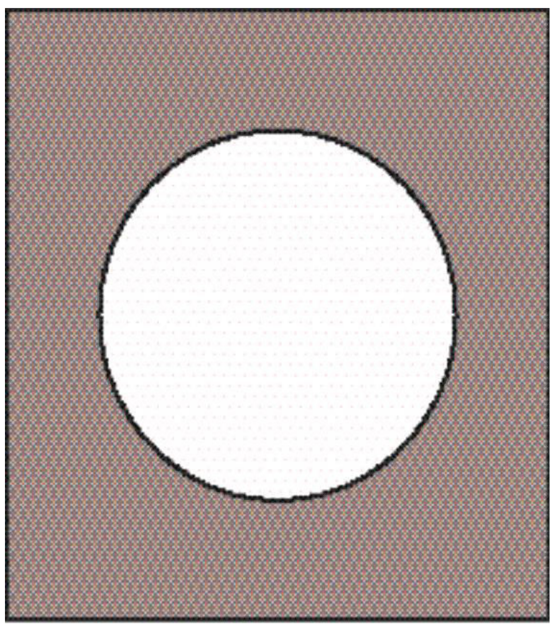
Representing Digital Images

Picture resolution determines both the amount of detail as well as its storage requirements

- notice more changes when the resolution is reduced (68 X 104)



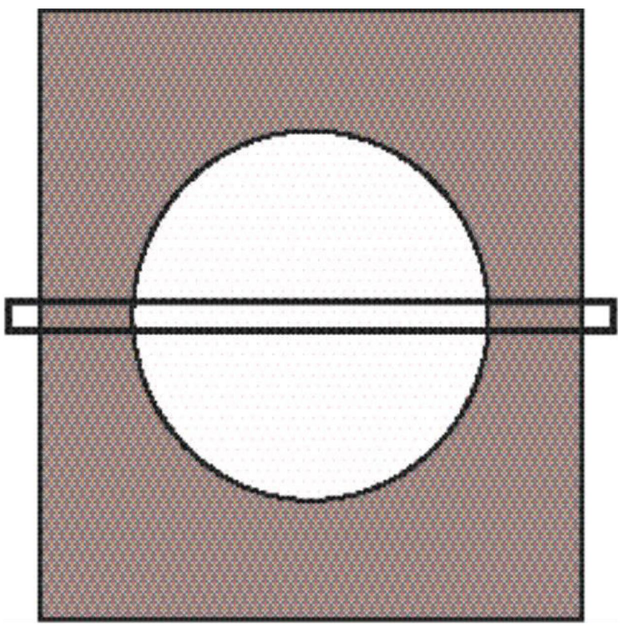
Representing Digital Images



QUANTIZING a sampled image refers to representing each discrete sample by a set of numbers chosen from a given scale

- imagine a simple image with a bright object in the foreground surrounded by a dark background

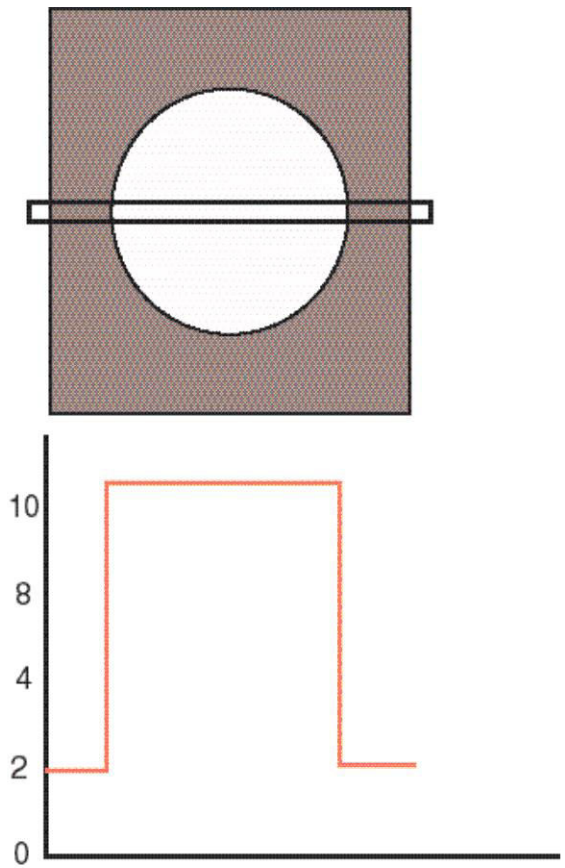
Representing Digital Images



QUANTIZING a sampled image refers to representing each discrete sample by a set of numbers chosen from a given scale

- suppose that we sampled the signal horizontally across the middle of the image

Representing Digital Images



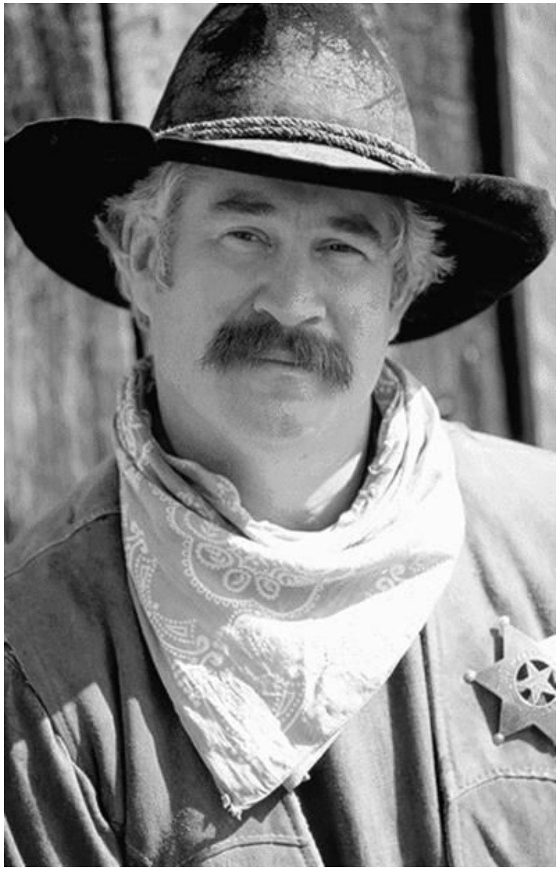
QUANTIZING a sampled image refers to representing each discrete sample by a set of numbers chosen from a given scale

- if we assigned a numeric scale for the signal it might look like this

Representing Digital Images

DYNAMIC RANGE refers the number of values for the measuring scale used in quantizing

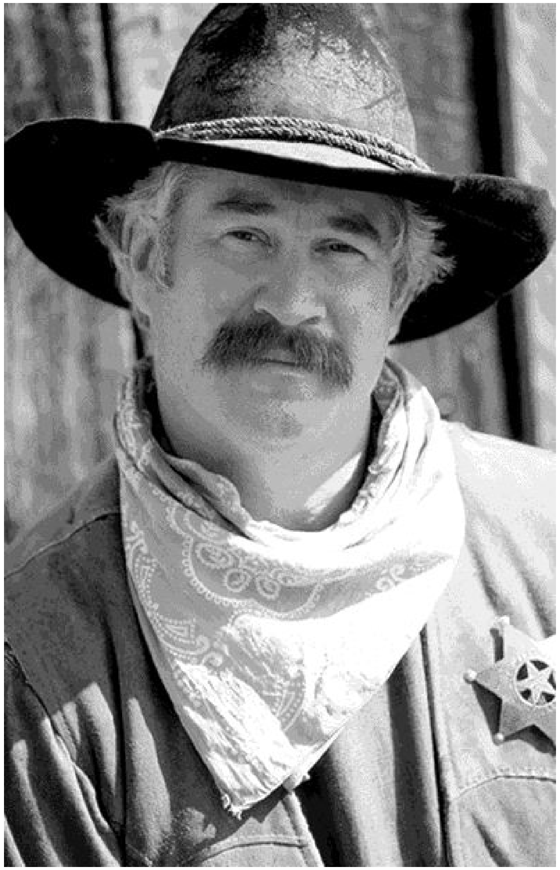
- Here is an intensity or graylevel image with 256 levels (i.e., 0 to 255 scale)



Representing Digital Images

DYNAMIC RANGE refers the number of values for the measuring scale used in quantizing

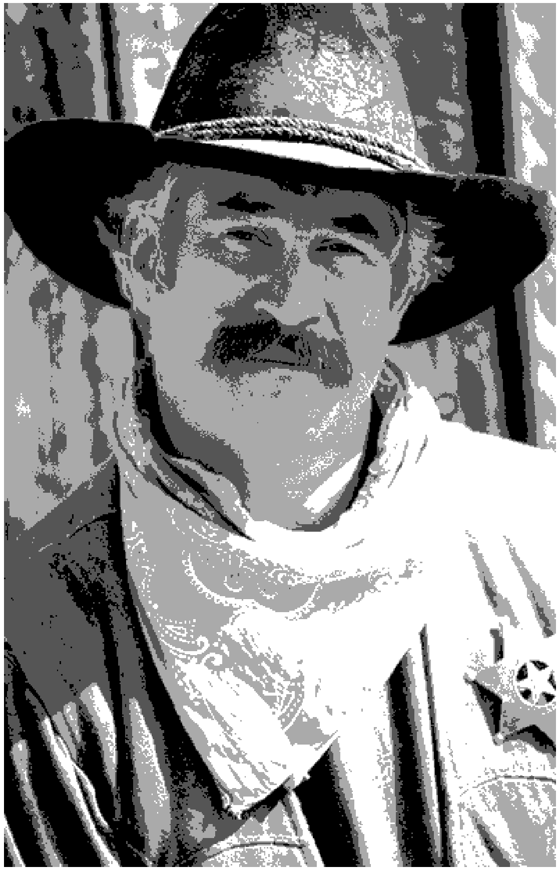
- Here is an intensity or graylevel image with 16 levels (i.e., 0 to 15 scale)



Representing Digital Images

DYNAMIC RANGE refers the number of values for the measuring scale used in quantizing

- Here is an intensity or graylevel image with 4 levels (i.e., 0 to 3 scale)



Representing Digital Images

DYNAMIC RANGE refers the number of values for the measuring scale used in quantizing

- Here is an intensity or graylevel image with 2 levels (i.e., 0 to 1 scale or a binary image)

Image Size

- "image size" refers to both
  - picture resolution
  - physical dimensions of the image
- the physical dimensions of the image are determined by
  - the number of pixels in the image (resolution) and
  - the characteristics of the output device

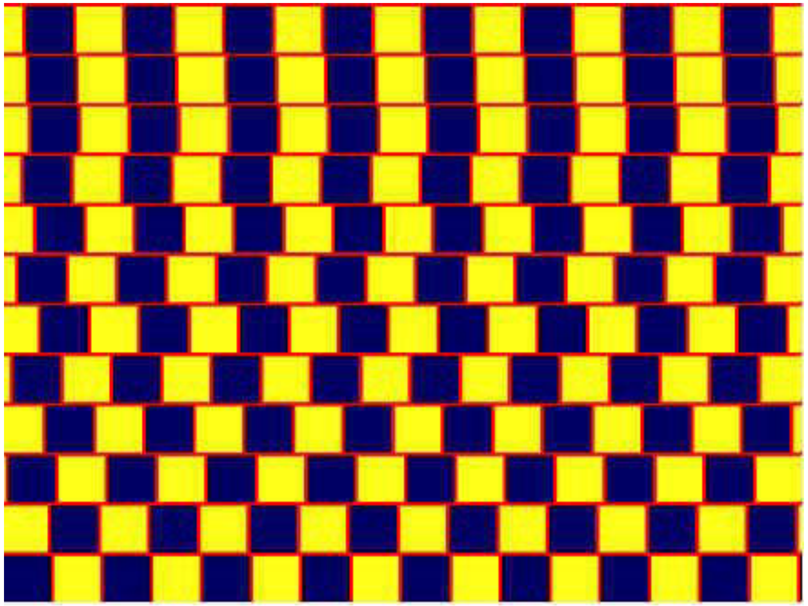
Image Size: Example

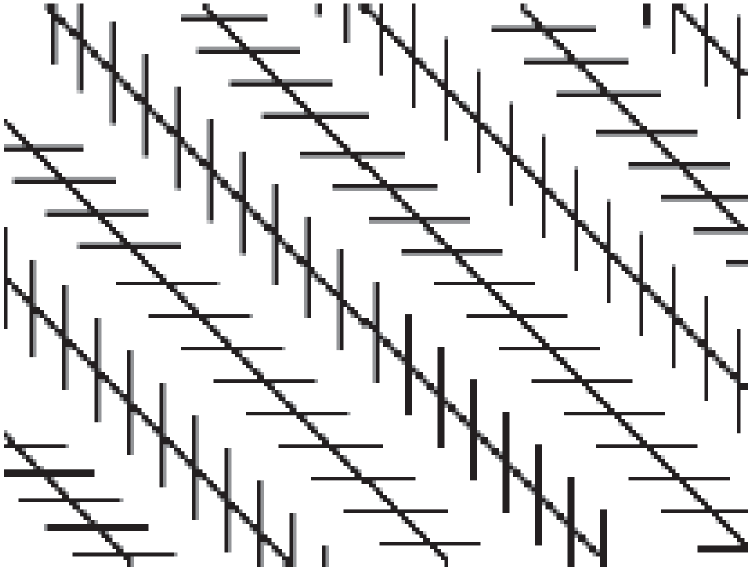
Here is an image with a resolution of 300 X 300 at 72 dpi.

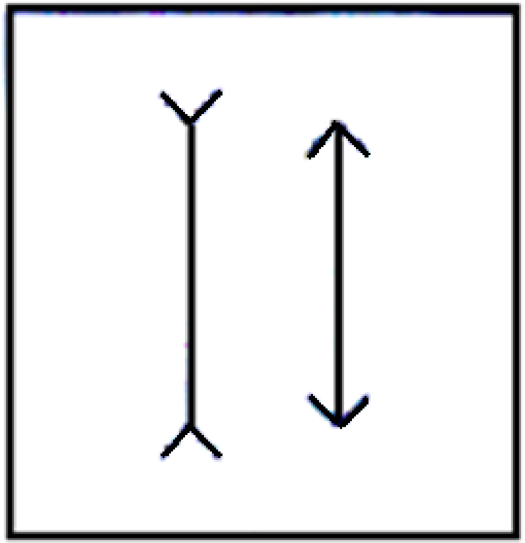
(v) Optical Illusion and Visual Phenomena

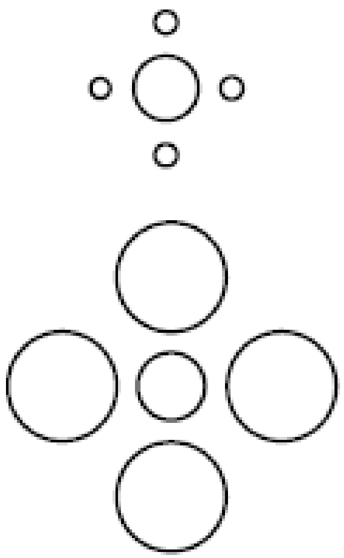
The human brain tricks us whenever it can!

Are the lines parallel or not?

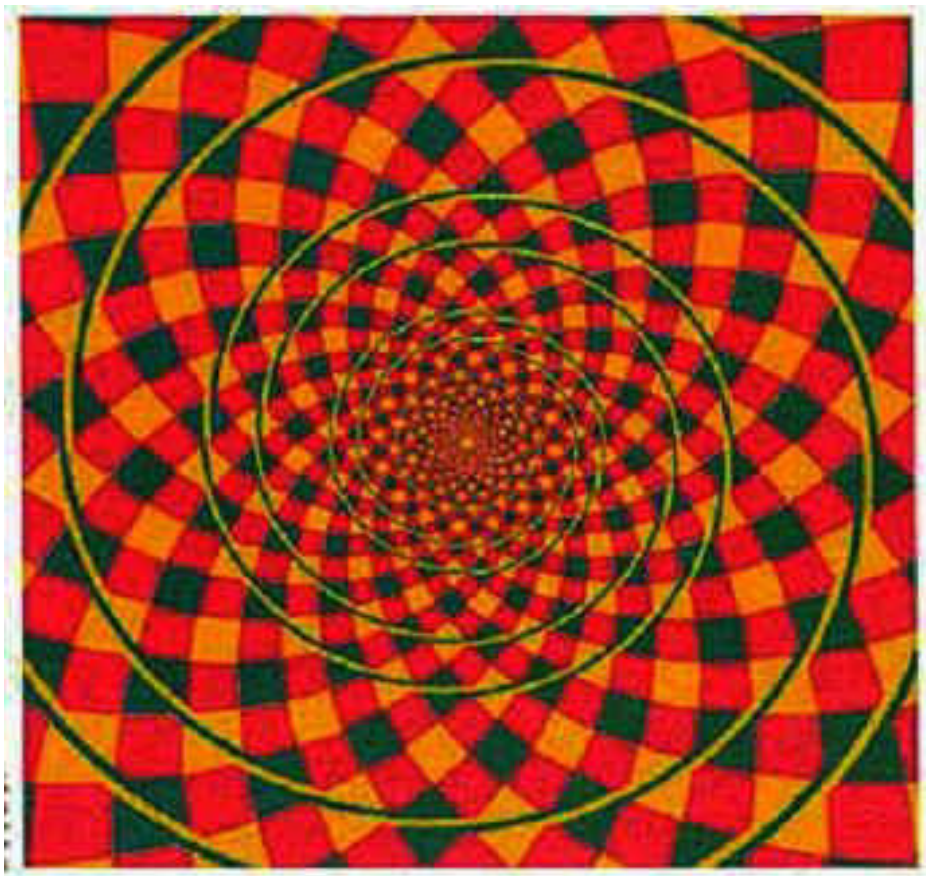




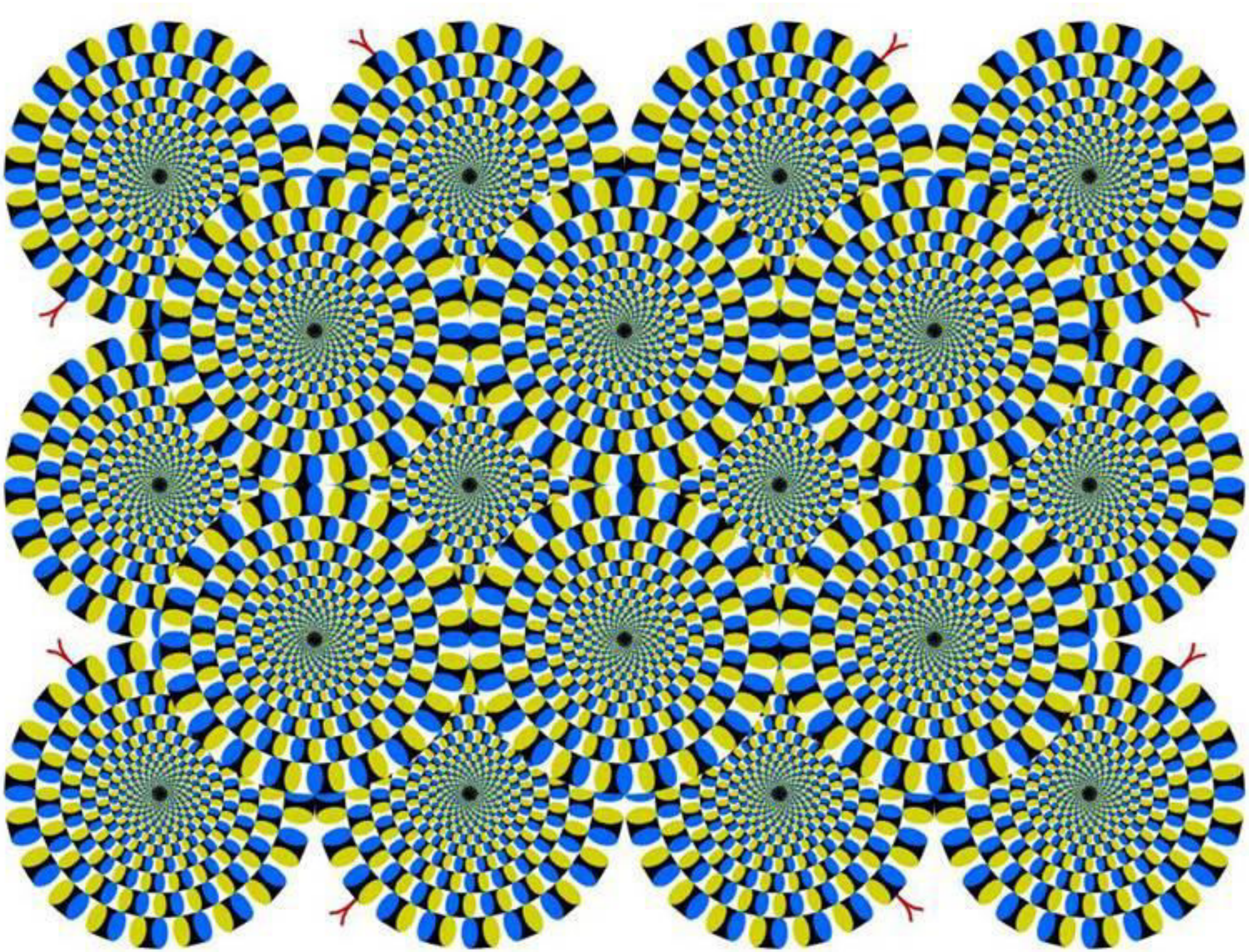




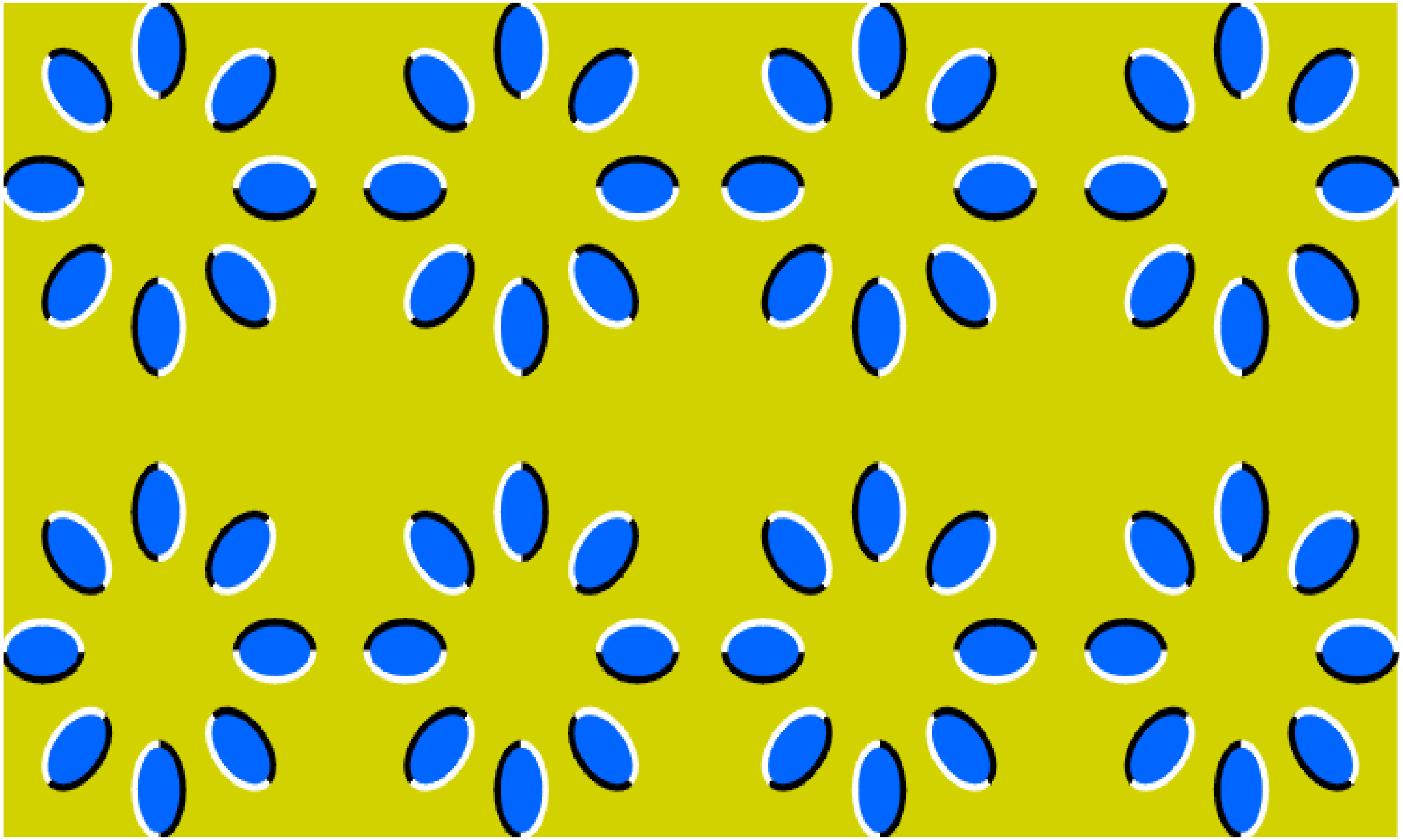
Coil or circle?



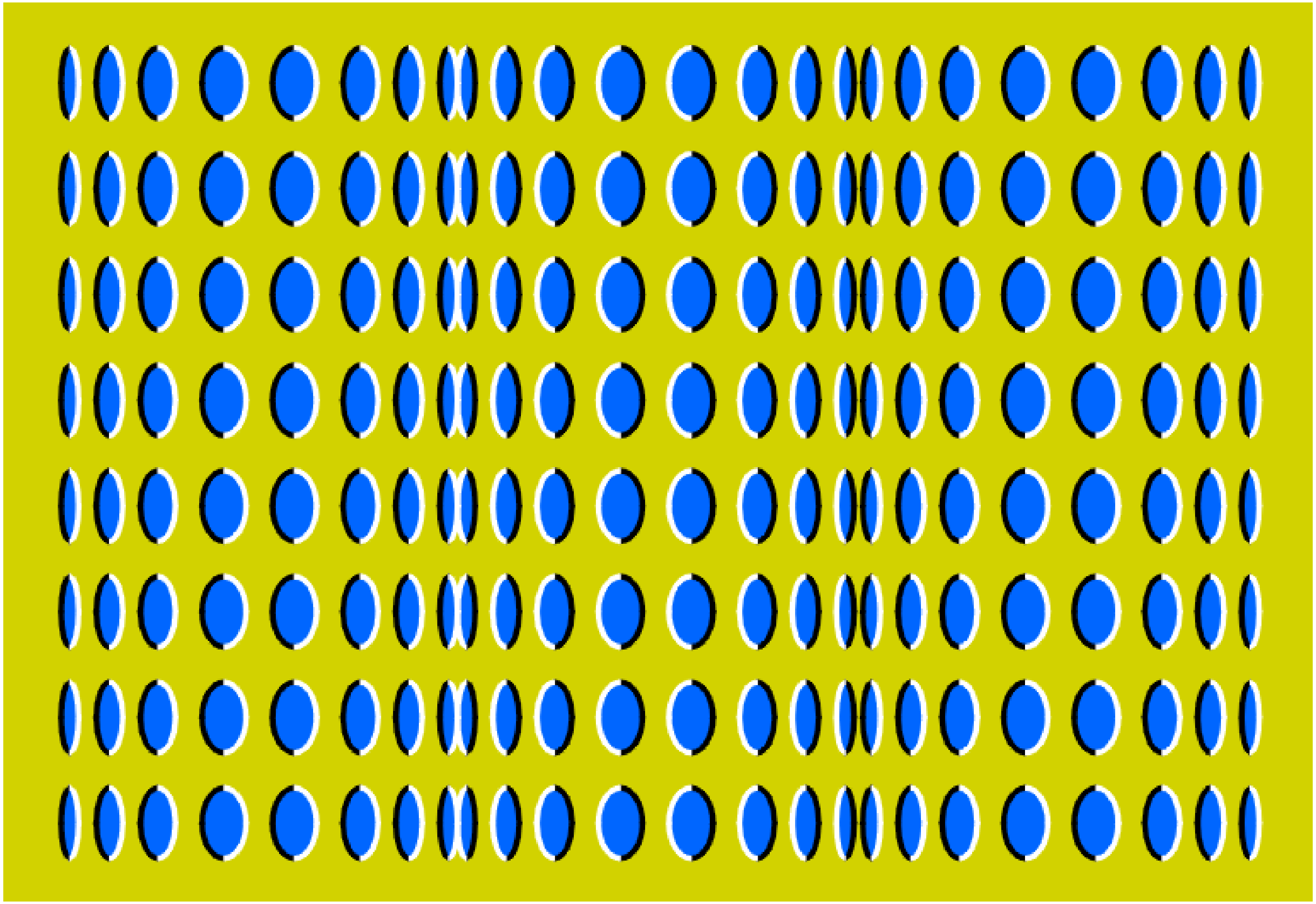
If something‘s rotating – you need a break!



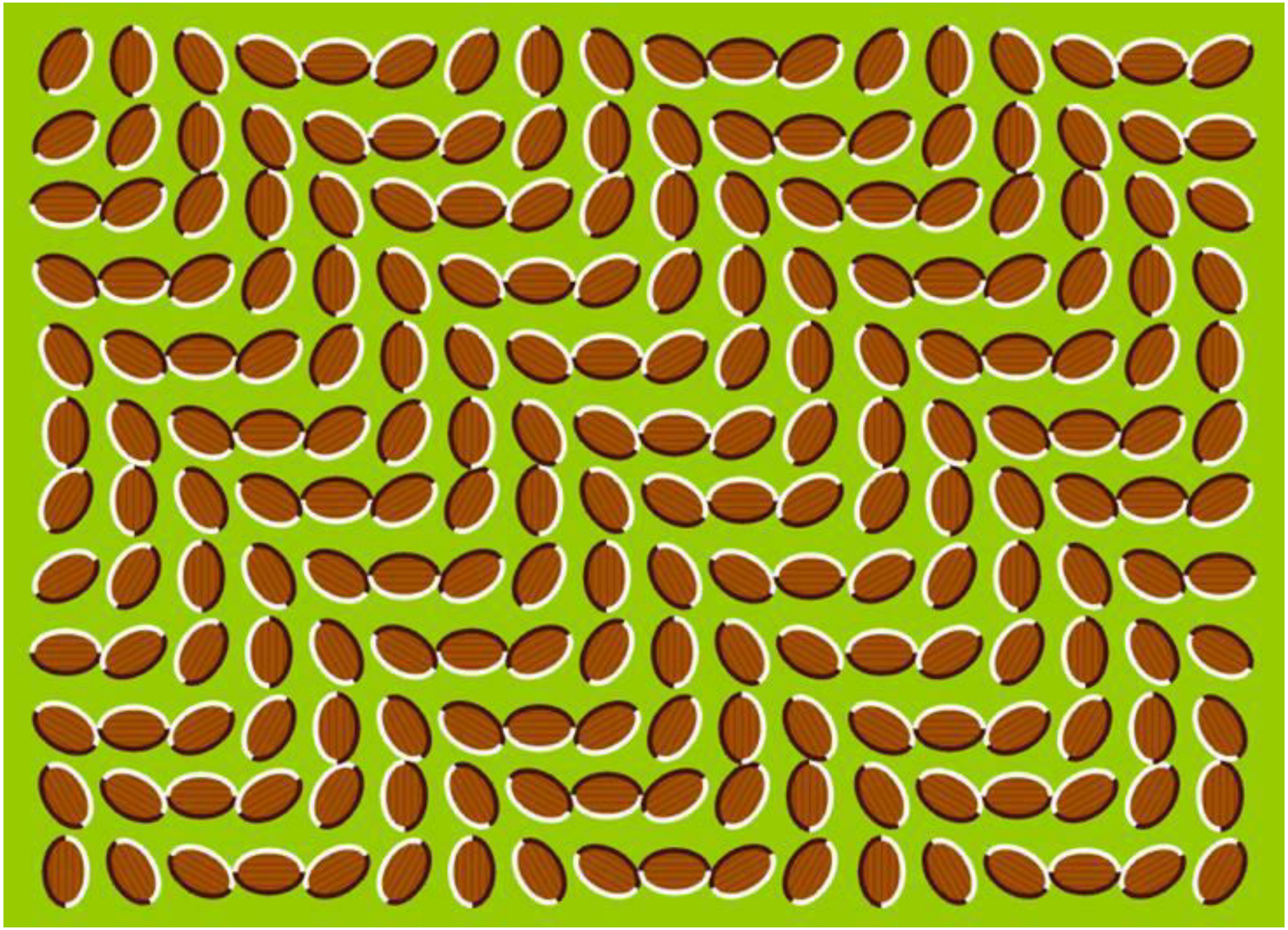
It doesn‘t move!



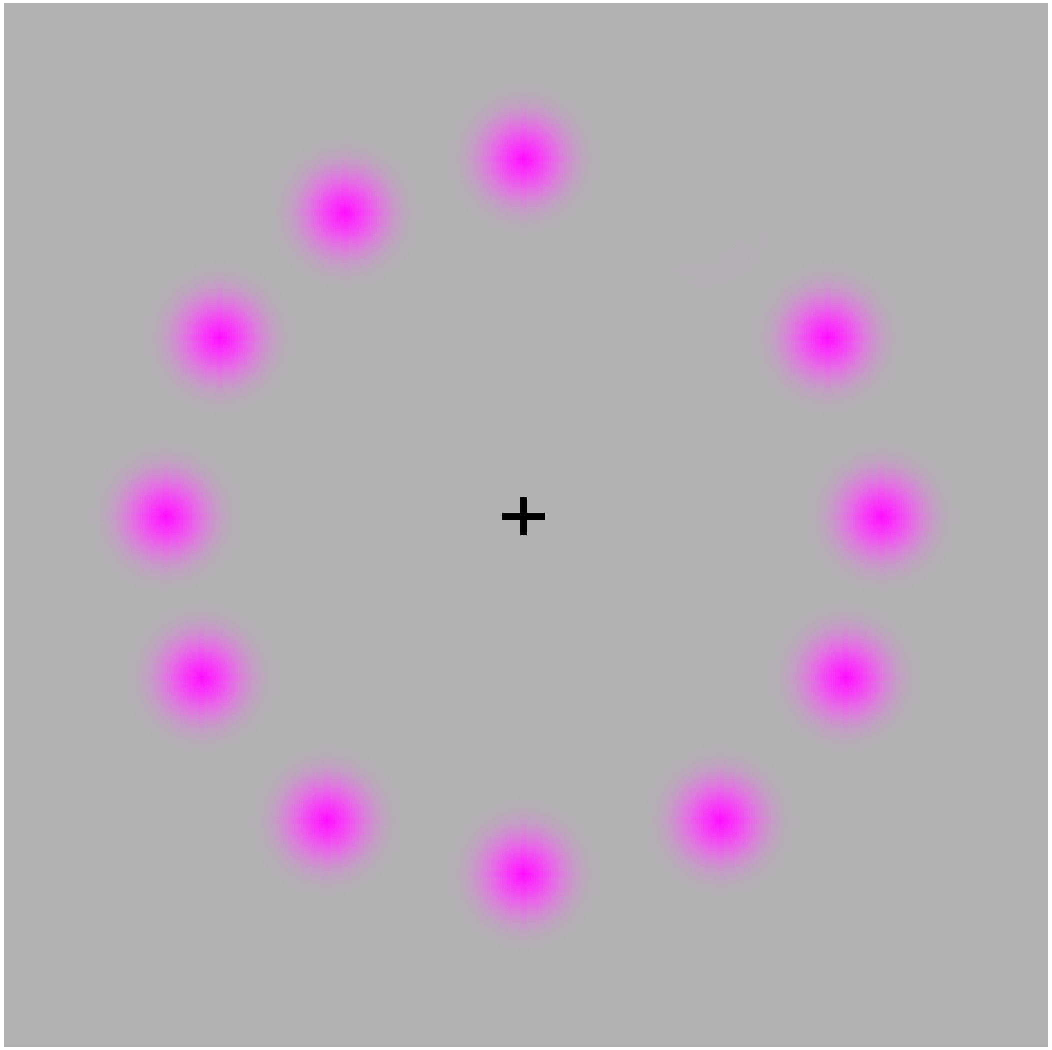
It doesn‘t move too!



It doesn‘t move too!



Concentrate on the cross in the middle, after a while you will notice that this moving purple dot will turn green!



Look at the cross a bit longer and you'll notice that all dots except the green one will disappear.

Image Size: Example

Here is an image with a resolution of 300 X 300 at 300 dpi.

Image Acquisition

- Pixels are samples from continuous function
  - Photoreceptors in eye
  - CCD cells in digital camera
  - Rays

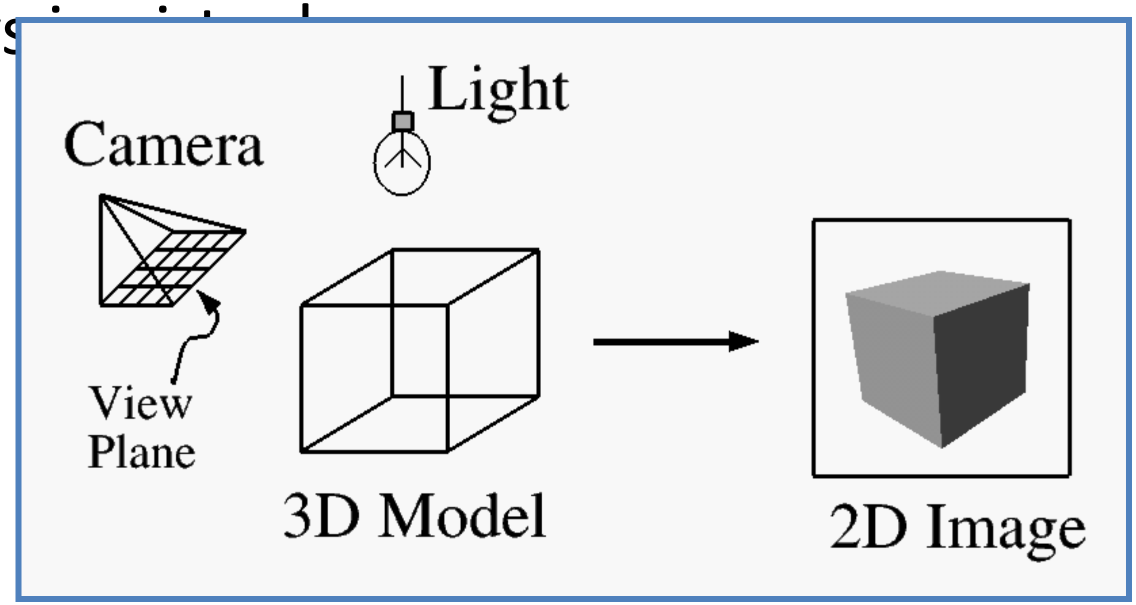
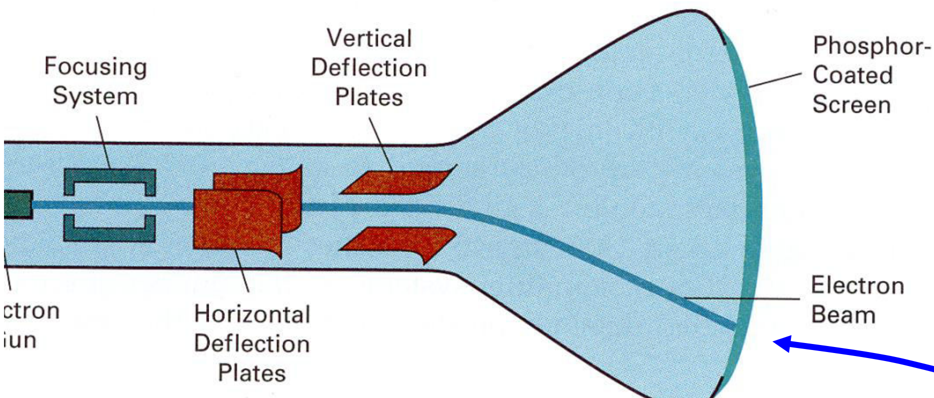


Image Display

- Re-create continuous function from samples



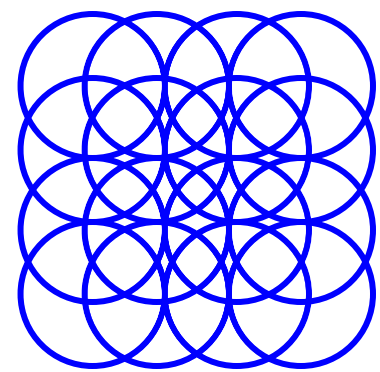


Image is reconstructed by displaying pixels with finite area (Gaussian)

Image Resolution

- Intensity resolution
  - Each pixel has only "Depth" bits for colors/intensities
- Spatial resolution
  - Image has only "Width" x "Height" pixels
- Temporal resolution
  - Monitor r

Typical Resolutions

	Width x Height	Depth	Rate
NTSC	640 x 480	8	30
Workstation	1280 x 1024	24	75
Film	3000 x 2000	12	24
Laser Printer	6600 x 5100	1	-

Sources of Error

- Intensity quantization
  - Not enough intensity resolution
- Spatial aliasing
  - Not enough spatial resolution
- Temporal aliasing
  - Not enough temporal resolution

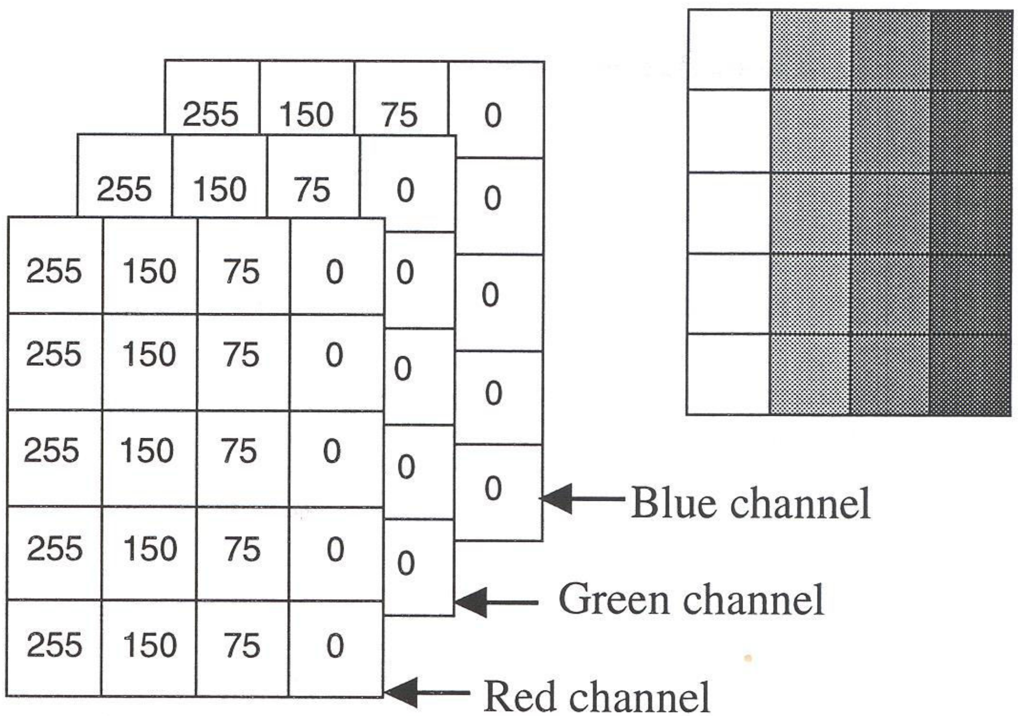
$$E^2 = \sum_{(x,y)} \big(I(x,y) - P(x,y) \big)^2$$

Overview

- Image representation
  - What is an image?
- Halftoning and dithering
  - Reduce visual artifacts due to quantization

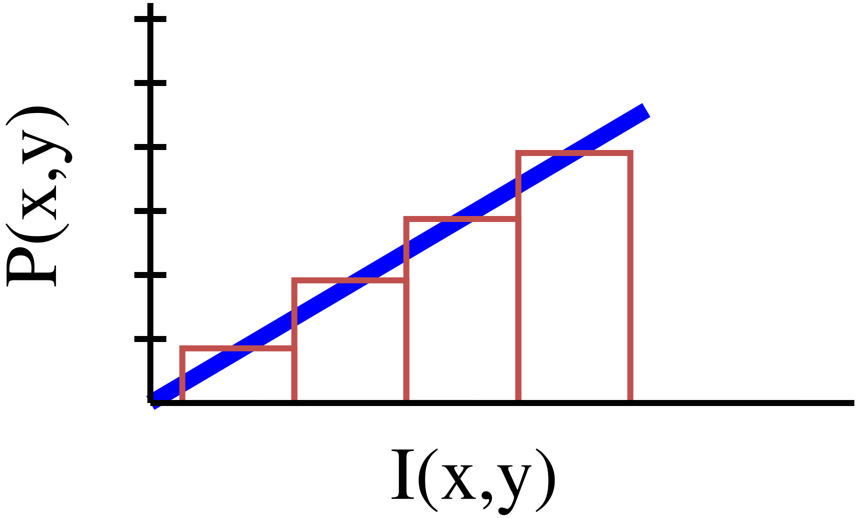
Quantization

- Artifacts due to limited intensity resolution
  - Frame buffers have limited number of bits per pix
  - Ph range

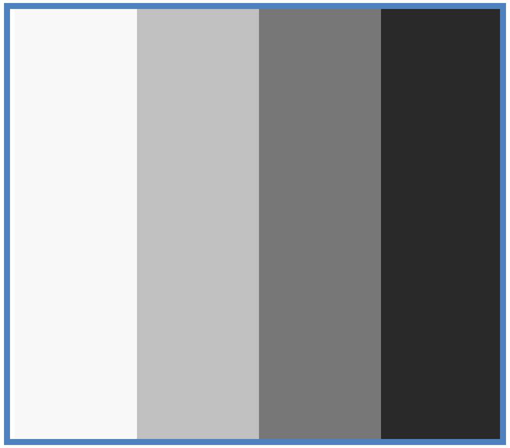


Uniform Quantization

$$P(x, y) = \mathrm{trunc}(I(x, y) + 0.5)$$



I(x,y)



P(x,y)
(2 bits per pixel)

Uniform Quantization

- Images with decreasing bits per pixel:

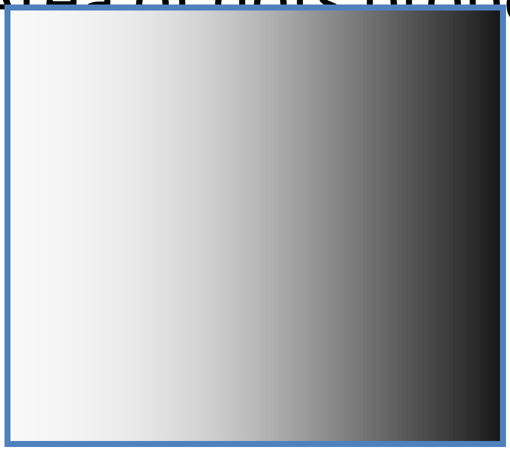
256 bpp 32 bpp 8 bpp 2
bpp

Reducing Effects of Quantization

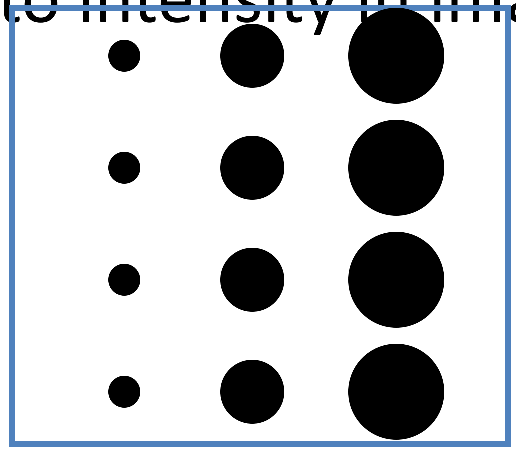
- Halftoning
  - Classical halftoning
- Dithering
  - Error diffusion dither
  - Random dither
  - Ordered dither

Classical Halftoning

- Use dots of varying size to represent intensities
  - Area of dots proportional to intensity in image

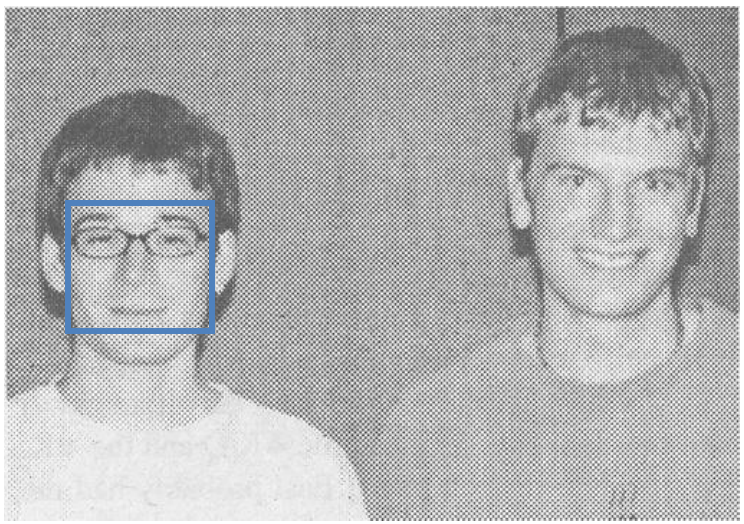


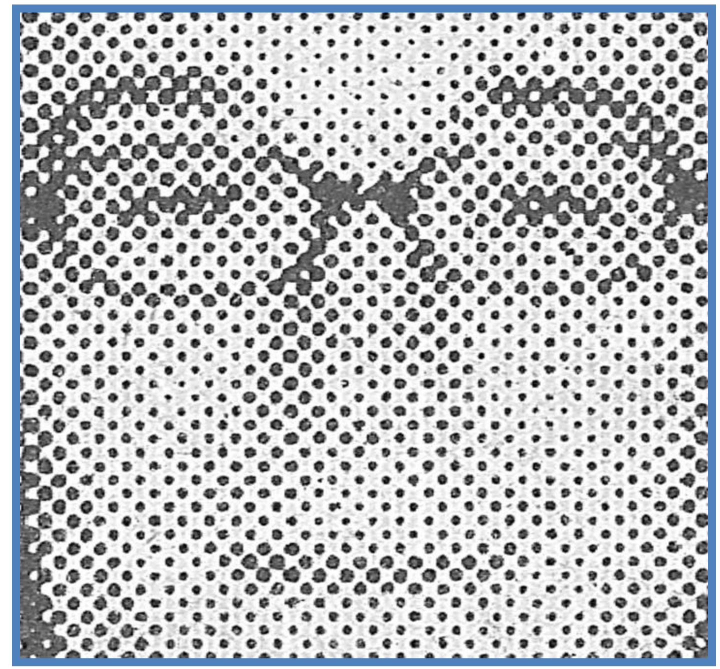
I(x,y)



P(x,y)

Classical Halftoning





Newspaper image from *North American Bridge Championships Bulletin*, Summer 2003

Halftone patterns

- Use cluster of pixels to represent intensity
  - Trade spatial resolution for intensity resolution

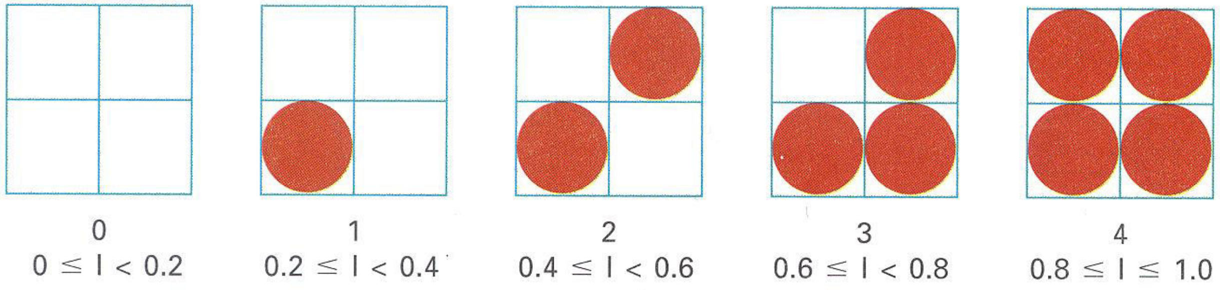


Figure 14.37 from H&B

Dithering

- Distribute errors among pixels
  - Exploit spatial integration in our eye
  - Display greater range of perceptible intensities
- Uniform quantization discards all errors
  - i.e. all "rounding" errors
- Dithering is also used in audio, by the way

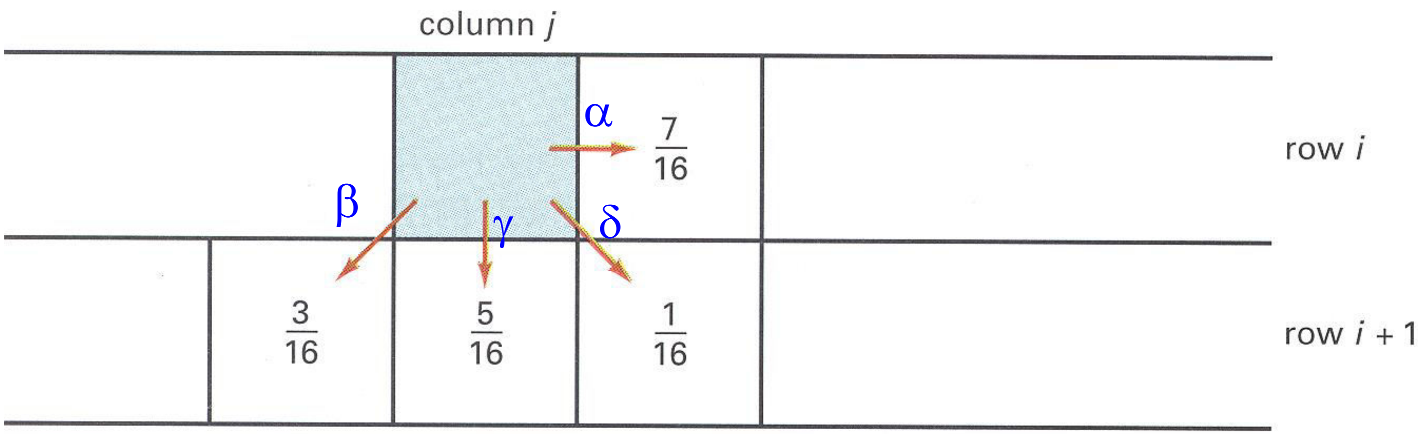
Floyd-Steinberg dithering

- Any “rounding” errors are distributed to other pixels
  - Specifically to the pixels below and to the right
    - 7/16 of the error to the pixel to the right
    - 3/16 of the error to the pixel to the lower left
    - 5/16 of the error to the pixel below
    - 1/16 of the error to the pixel to the lower right
- Assume the 1 in the middle gets “rounded” to 0

$$\begin{bmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 1.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \end{bmatrix} \longrightarrow \begin{bmatrix} 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.44 \\ 0.19 & 0.31 & 0.06 \end{bmatrix}$$

Error Diffusion Dither

- Spread quantization error over neighbor pixels
  - Error dispersed to pixels right and below



$$\alpha + \beta + \gamma + \delta = 1.0$$

Figure 14.42 from H&B

Floyd-Steinberg dithering

- Floyd-Steinberg dithering is a specific error dithering algorithm

Original
(8 bits)

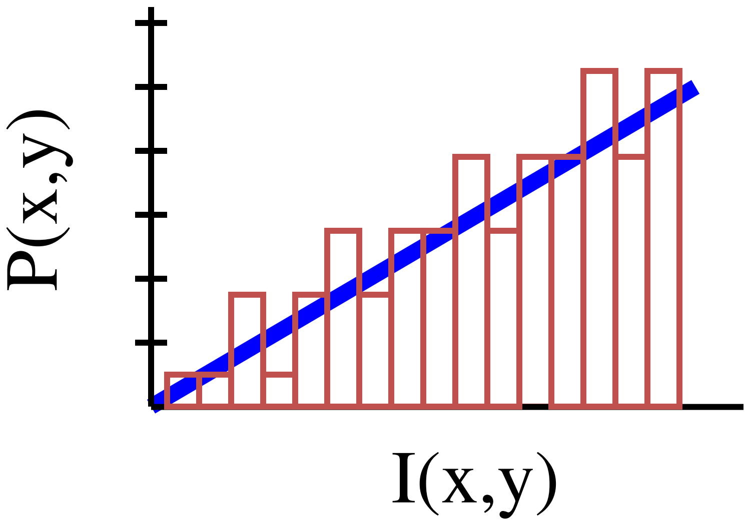
Uniform
Quantization
(1 bit)

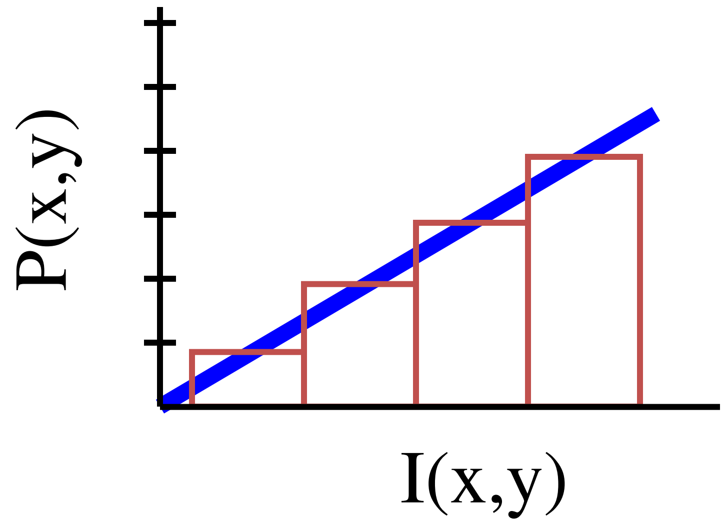
Floyd-Steinberg
Dither (1 bit)

Floyd-Steinberg
Dither (1 bit)
(pure B&W)

Random Dither

- Randomize quantization errors
  - Errors appear as noise





$$P(x, y) = \mathrm{trunc}(I(x, y) + \mathrm{noise}(x,y) + 0.5)$$

Random Dither

Original
(8 bits)

Uniform
Quantization
(1 bit)

Random
Dither
(1 bit)

Ordered Dither

- Pseudo-random quantization errors
  - Matrix stores pattern of thresholds

$$D_2 = \begin{bmatrix} 3 & 1 \\ 0 & 2 \end{bmatrix}$$

```
i = x mod n
j = y mod n
e = I(x,y) - trunc(I(x,y))
if (e > D(i,j))
        P(x,y) = ceil(I(x, y))
else
        P(x,y) = floor(I(x,y))
```

Ordered Dither

- Bayer's ordered dither matrices
  - Reflections and rotations of these are used as well

$$D_n = \begin{bmatrix} 4D_{n/2} + D_2(1,1)U_{n/2} & 4D_{n/2} + D_2(1,2)U_{n/2} \\ 4D_{n/2} + D_2(2,1)U_{n/2} & 4D_{n/2} + D_2(2,2)U_{n/2} \end{bmatrix}$$

$$D_2 = \begin{bmatrix} 3 & 1 \\ 0 & 2 \end{bmatrix} \qquad D_4 = \begin{bmatrix} 15 & 7 & 13 & 5 \\ 3 & 11 & 1 & 9 \\ 12 & 4 & 14 & 6 \\ 0 & 8 & 2 & 10 \end{bmatrix}$$

Ordered Dither

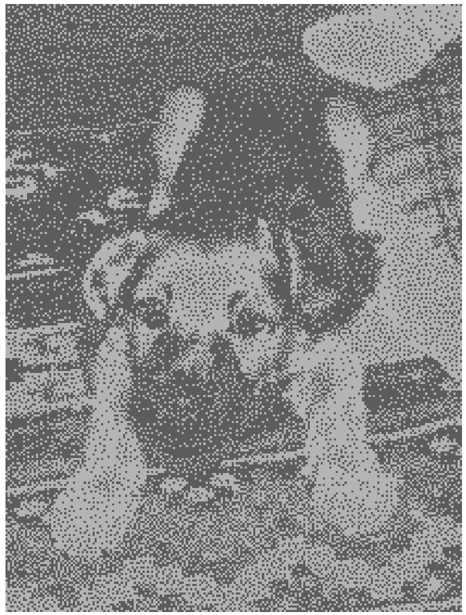
Original
(8 bits)

Uniform
Quantization
(1 bit)

4x4 Ordered
Dither
(1 bit)

Dither Comparison

Original
(8 bits)

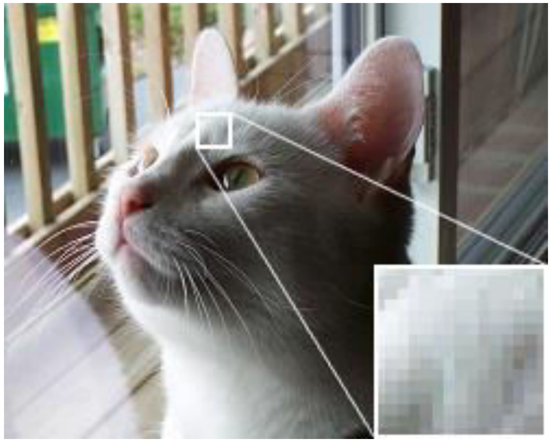


Random
Dither
(1 bit)

Ordered
Dither
(1 bit)

Floyd-Steinberg
Dither
(1 bit)

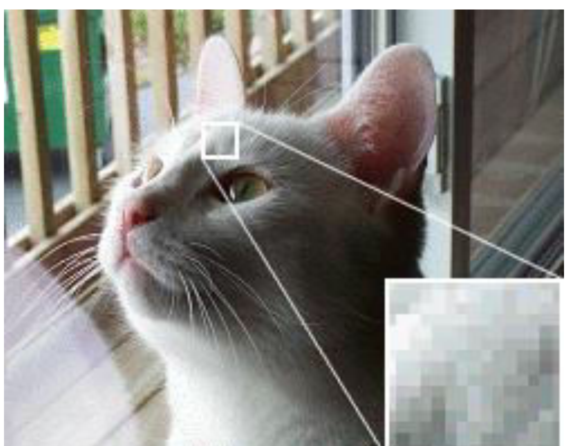
Color dithering comparison



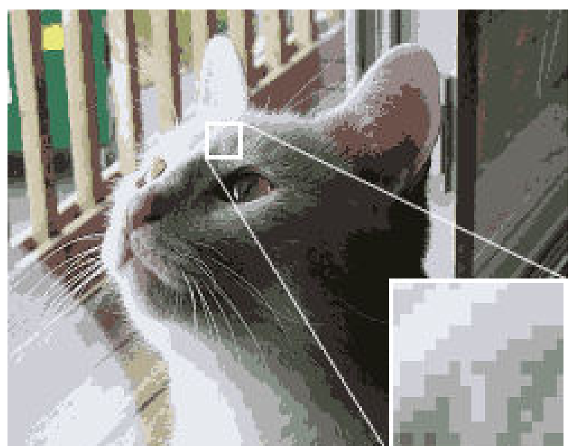
Original image

Web-safe palette, no dithering

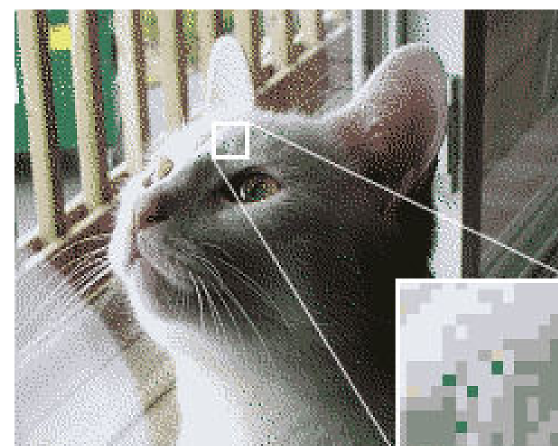
Web-safe palette, FS dithering



Optimized 256 color palette
FS dithering



Optimized 16 color palette
No dithering



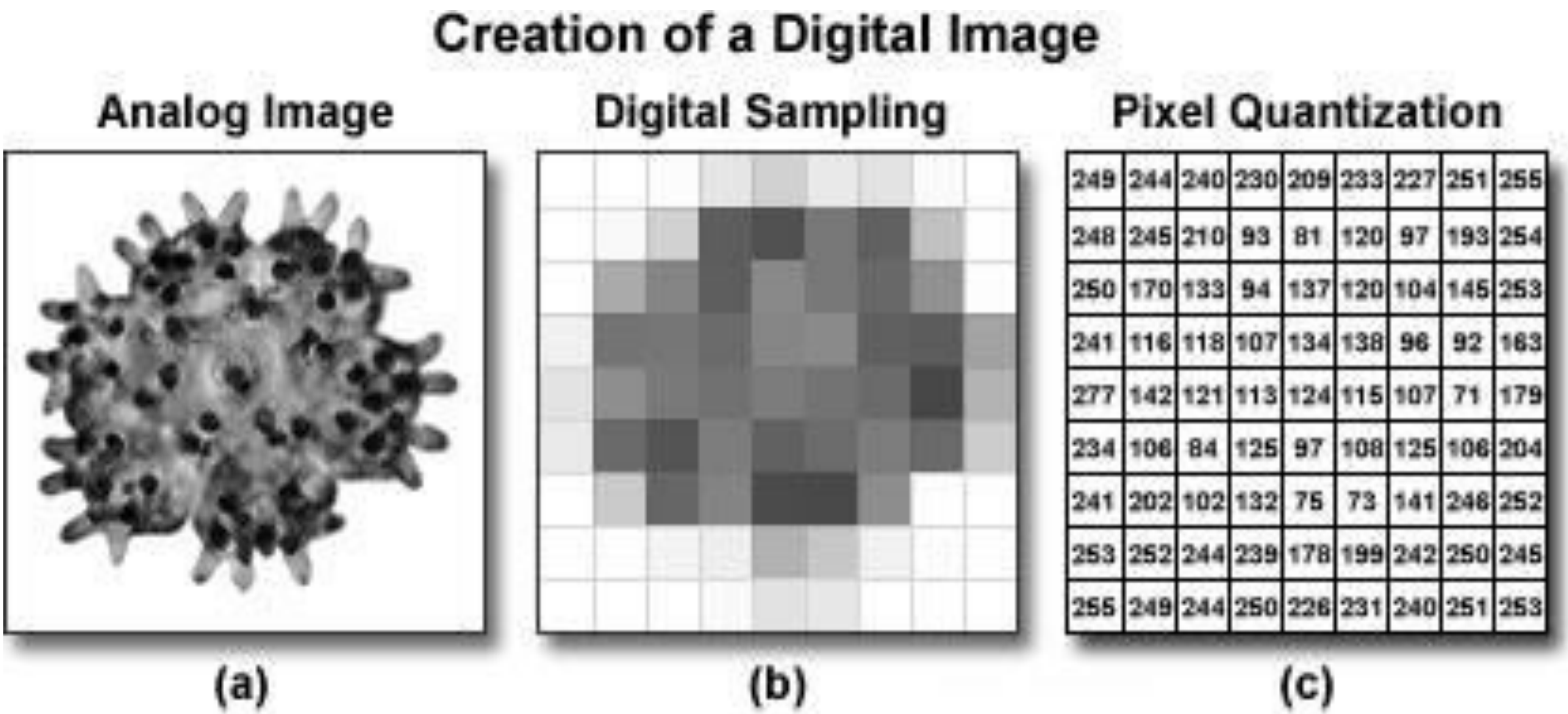
Optimized 16 color palette
FS dithering

Why DIGITAL IMAGE??

- Storage of an analog image !!!
- Processing an analog image !!!

Answer is impossible to store and difficult to Process the image.

What is Digital image??



A **digital image** differs from an photo in that x,y and f(x,y) values are **discrete**.

What is Digital Image Processing??

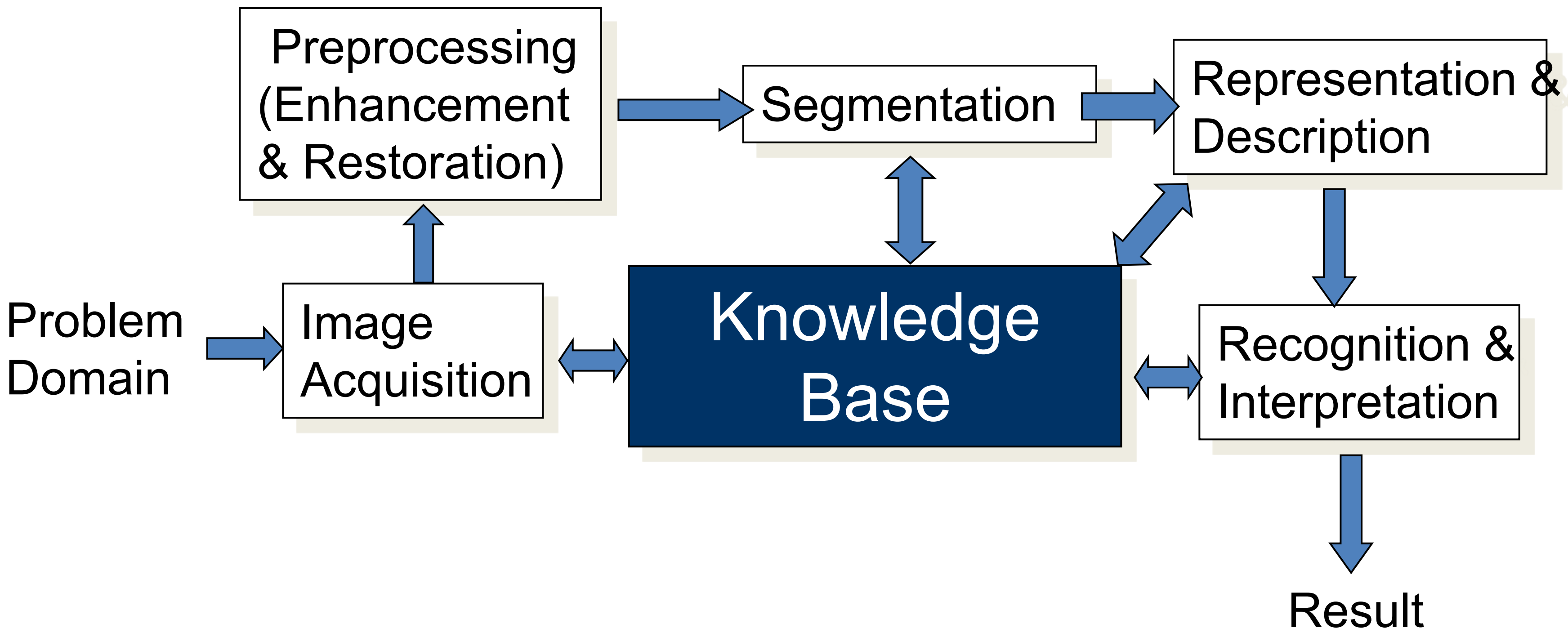
- Image processing involves changing the nature of an image in order to either

  1) improve pictorial information for human interpretations, or

  2) render it more suitable for autonomous machine perception

  3) reducing image size on disk

An Image Processing Task



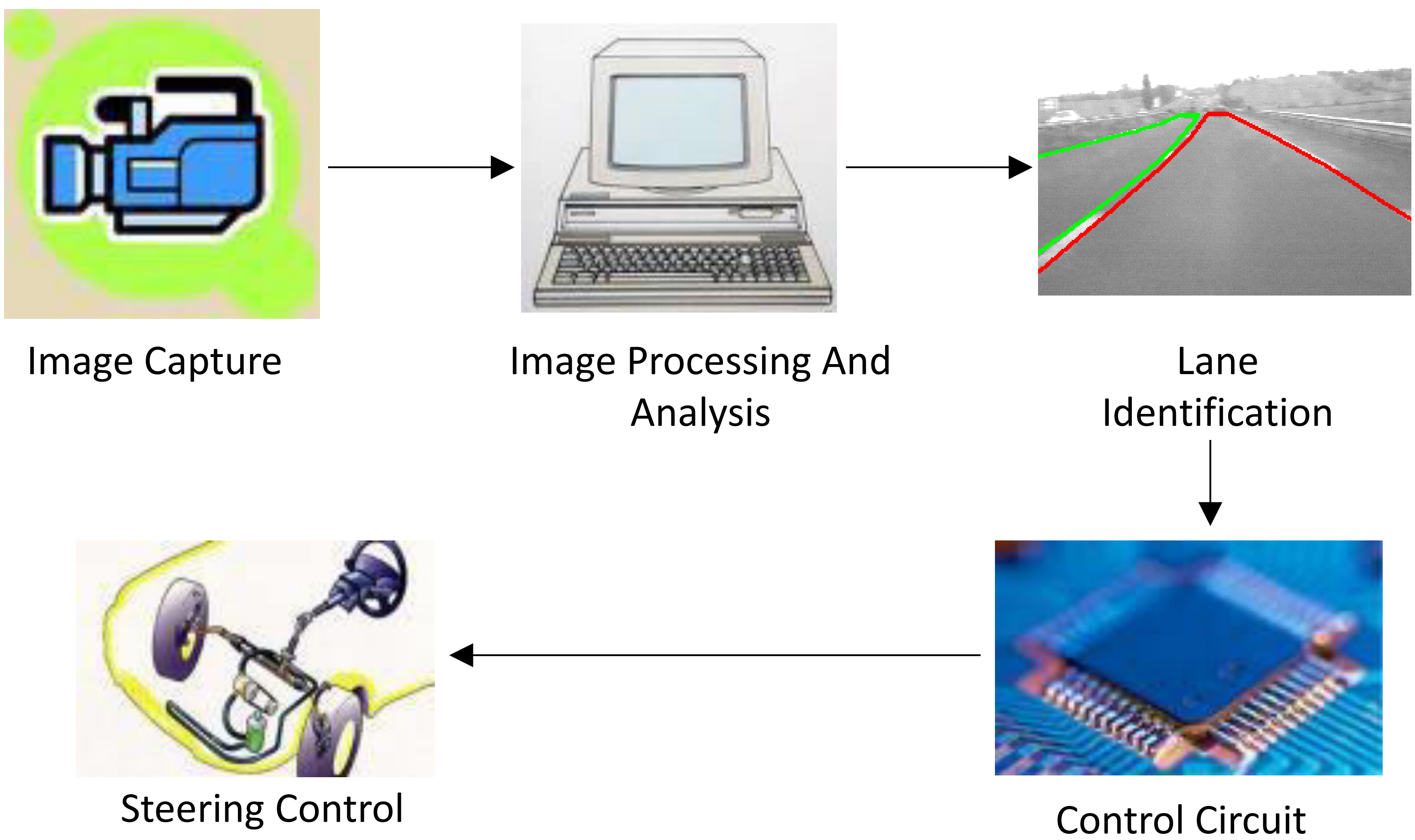
*Rafael C. Gonzalez and Richard E. Woods, *Digital Image Processing*, Addison-Wesley, 1992

Applications

- Lane tracking & Guidance of an autonomous vehicle:-

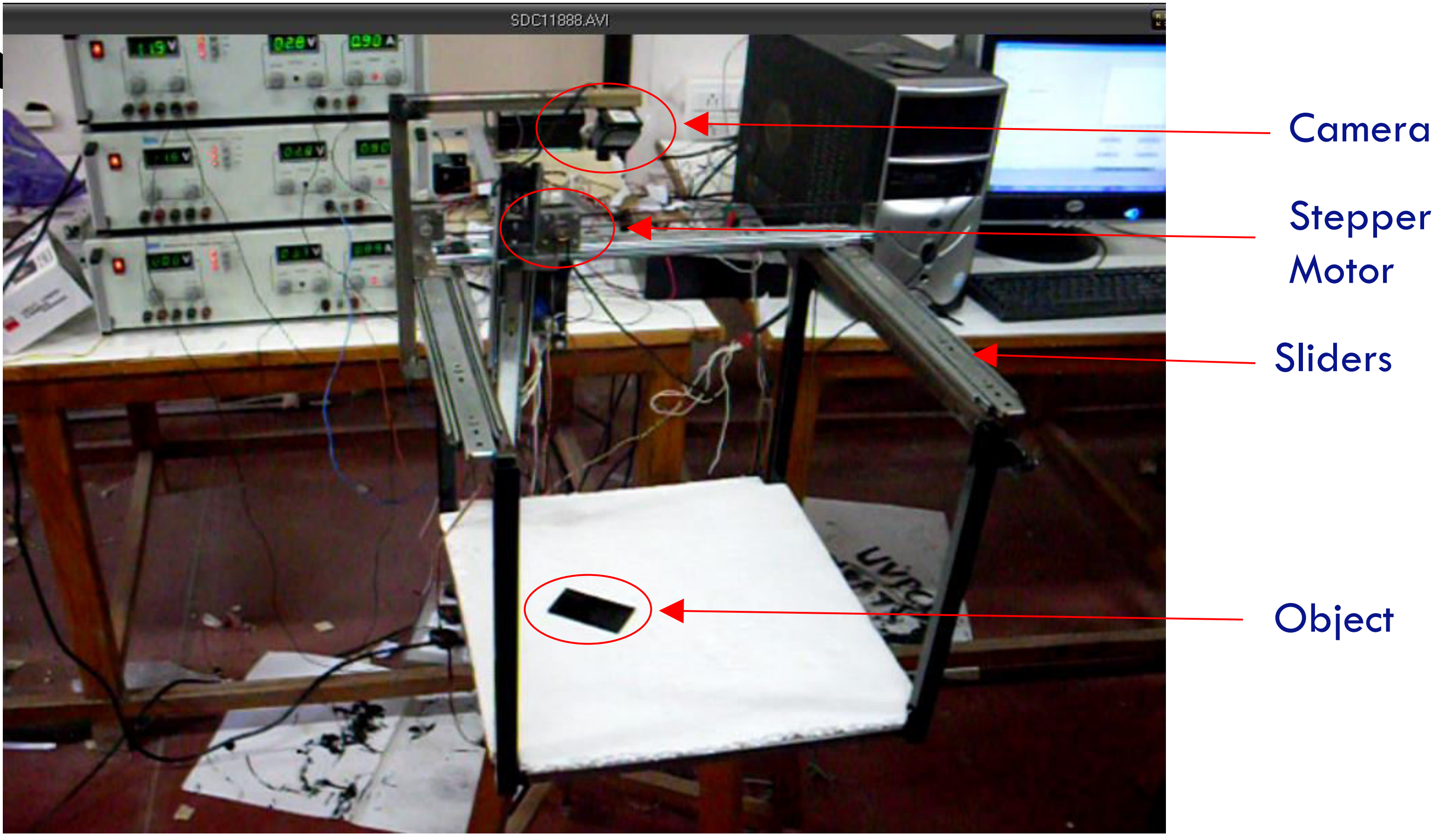
Applications – block diagram

Lane tracking & Guidance of an autonomous vehicle



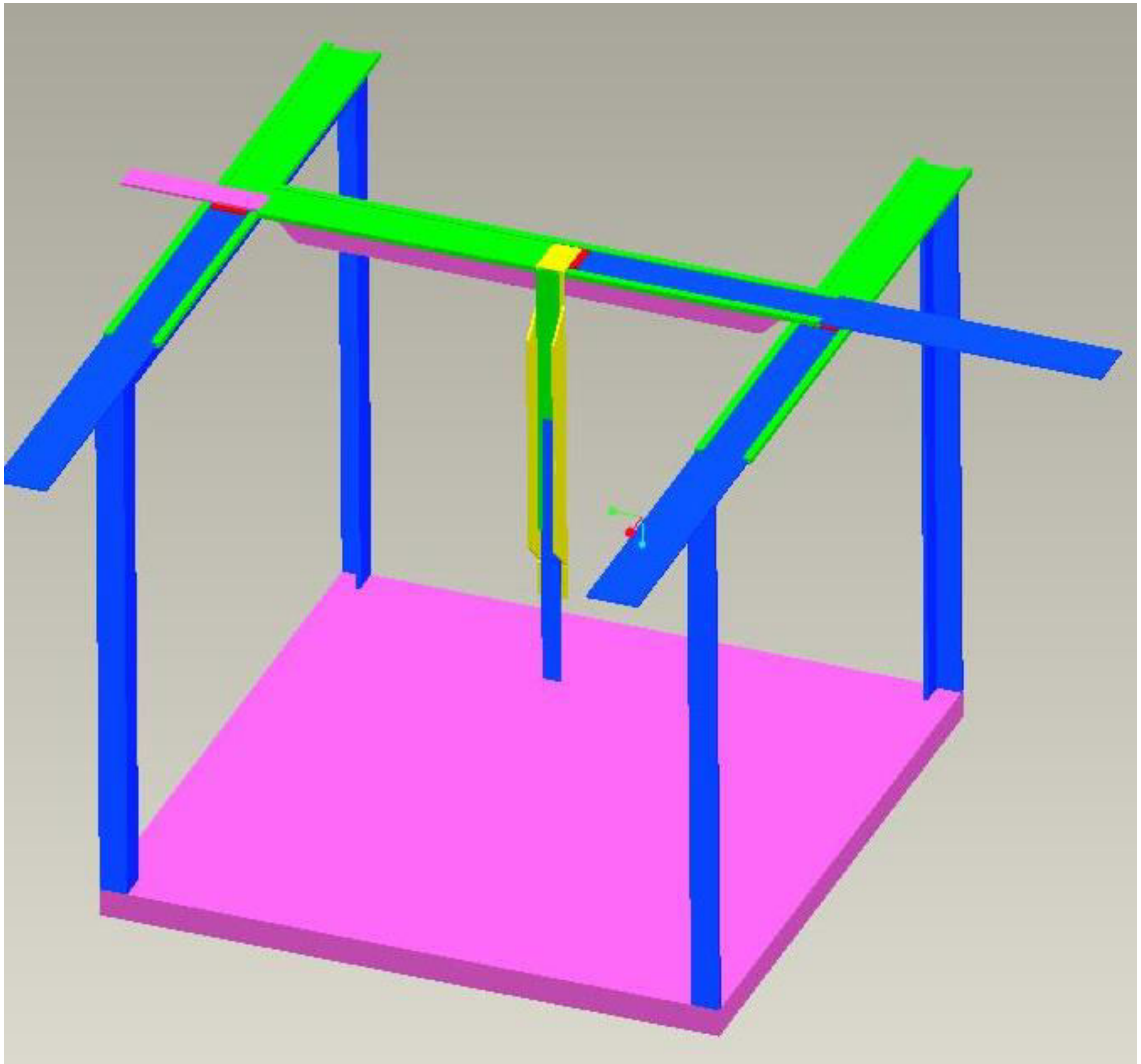
Applications
Real model of Manipulator

- Object detection in Pick & Place Robotic
  Man



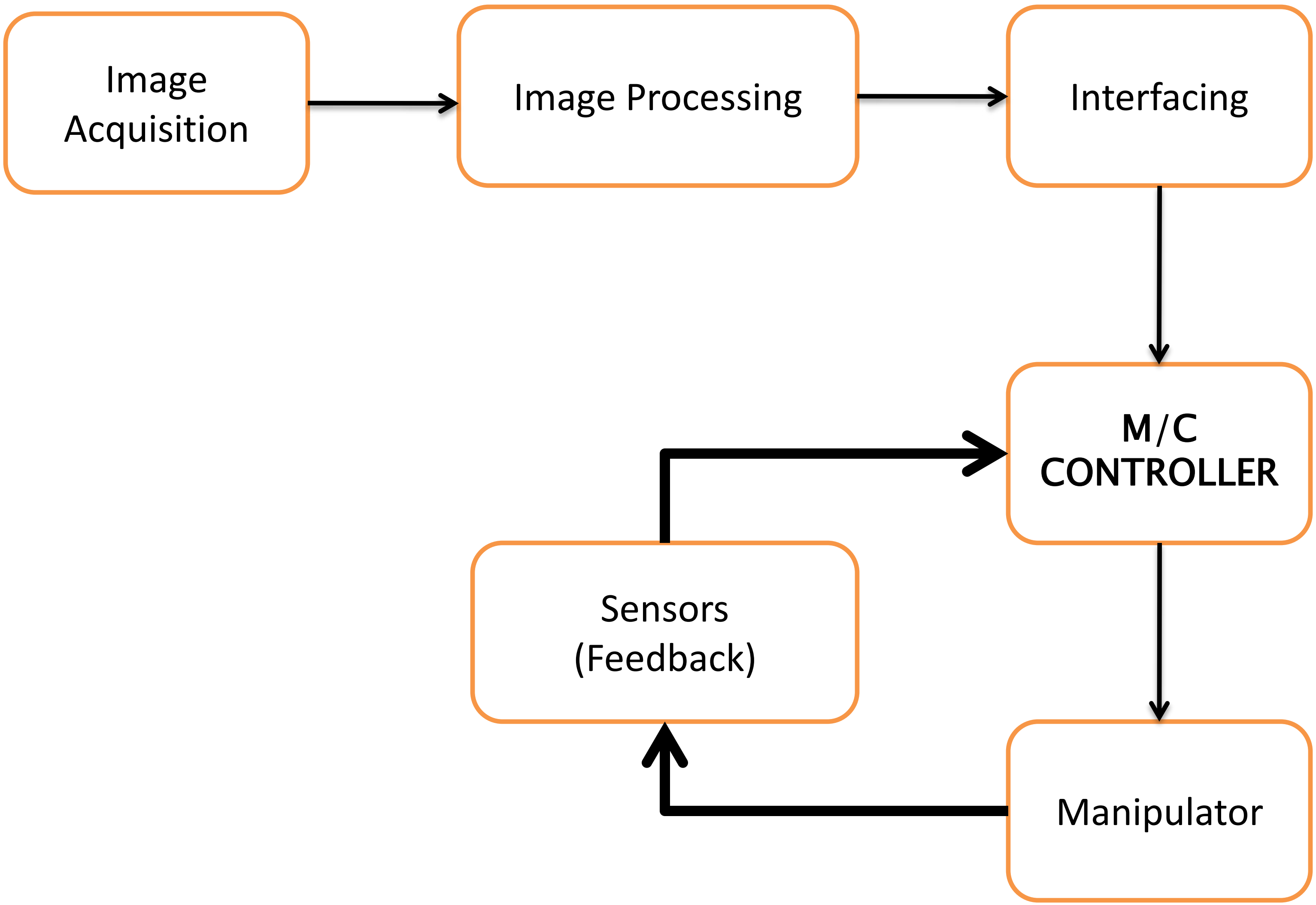
Applications- CAD model

Object detection in Pick & Place Robotic Manipulator



Application

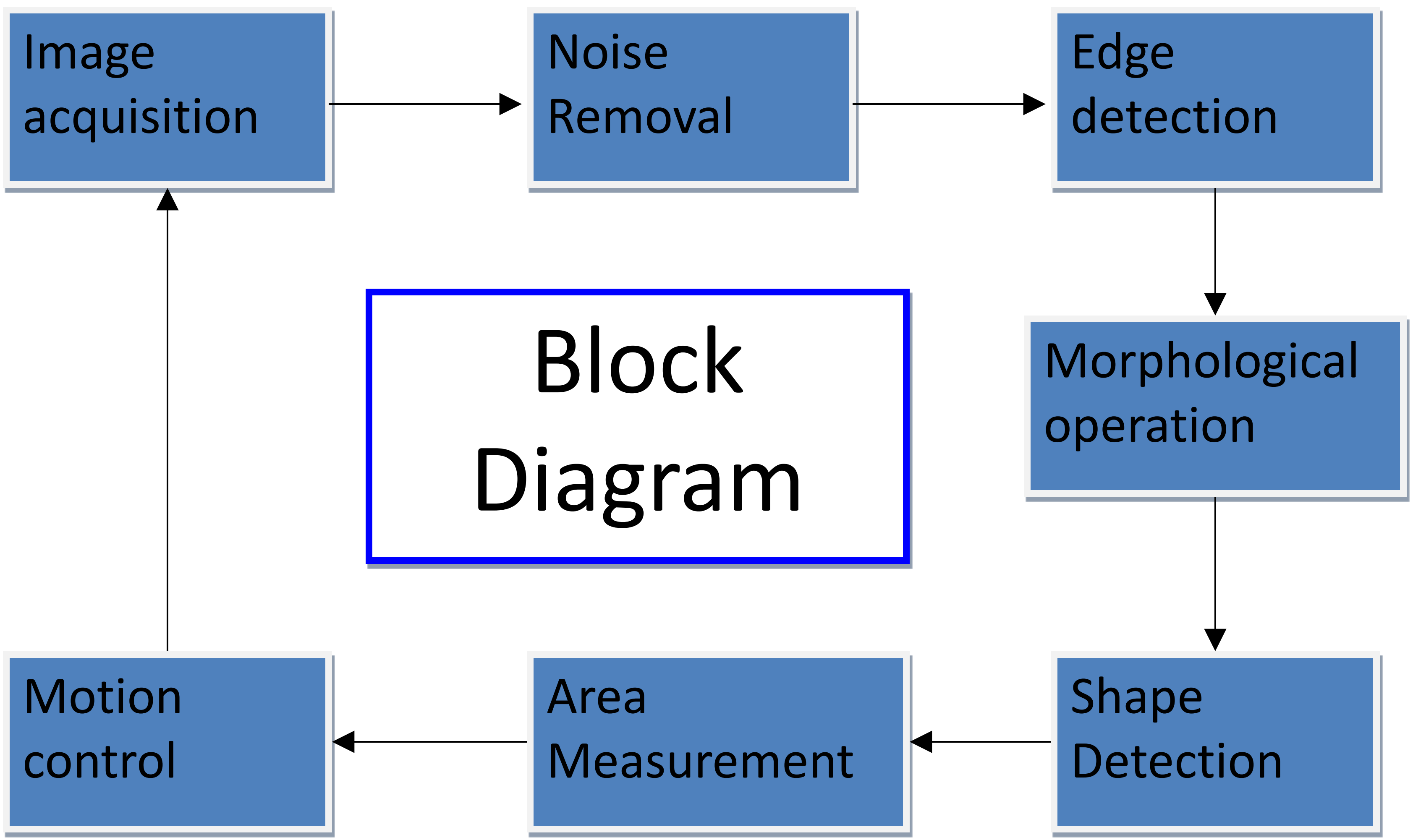
Object detection in Pick & Place Robotic Manipulator – block diagram



Applications

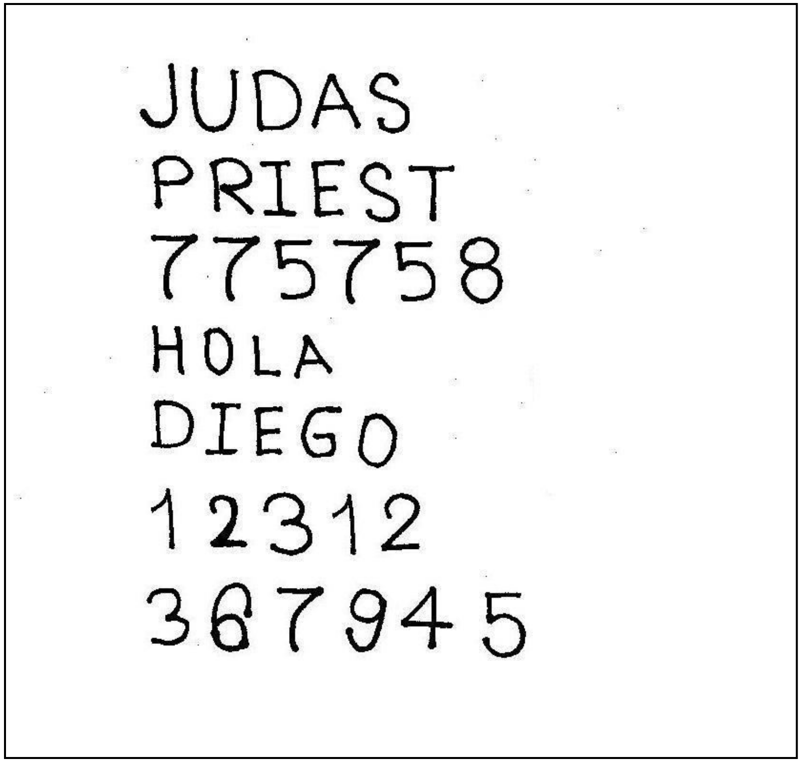
- Object Follower : -

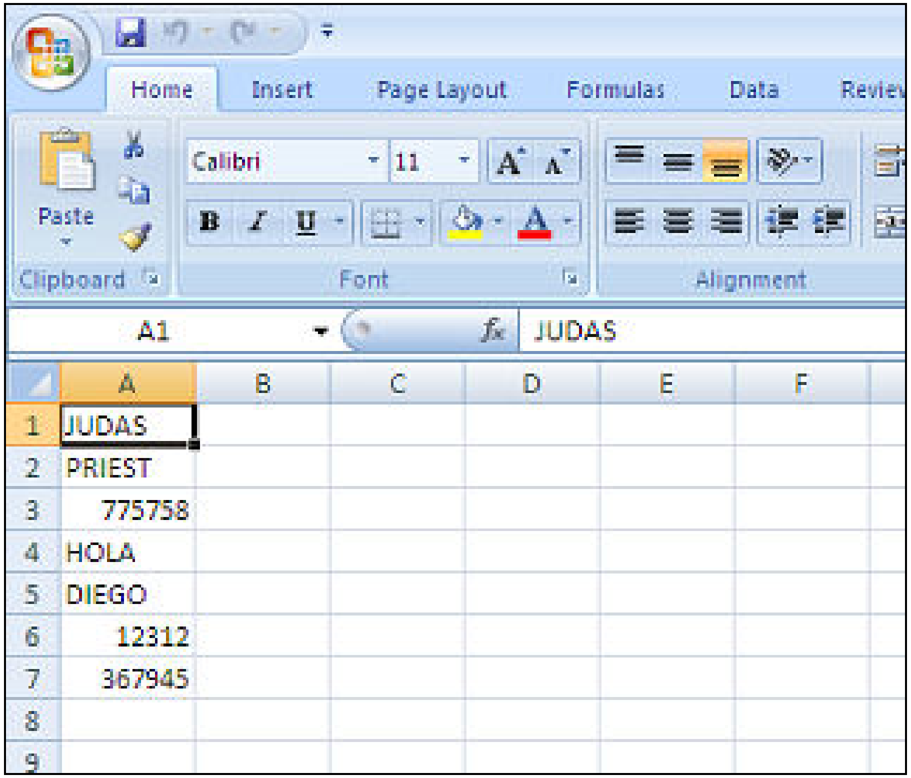
Object Follower



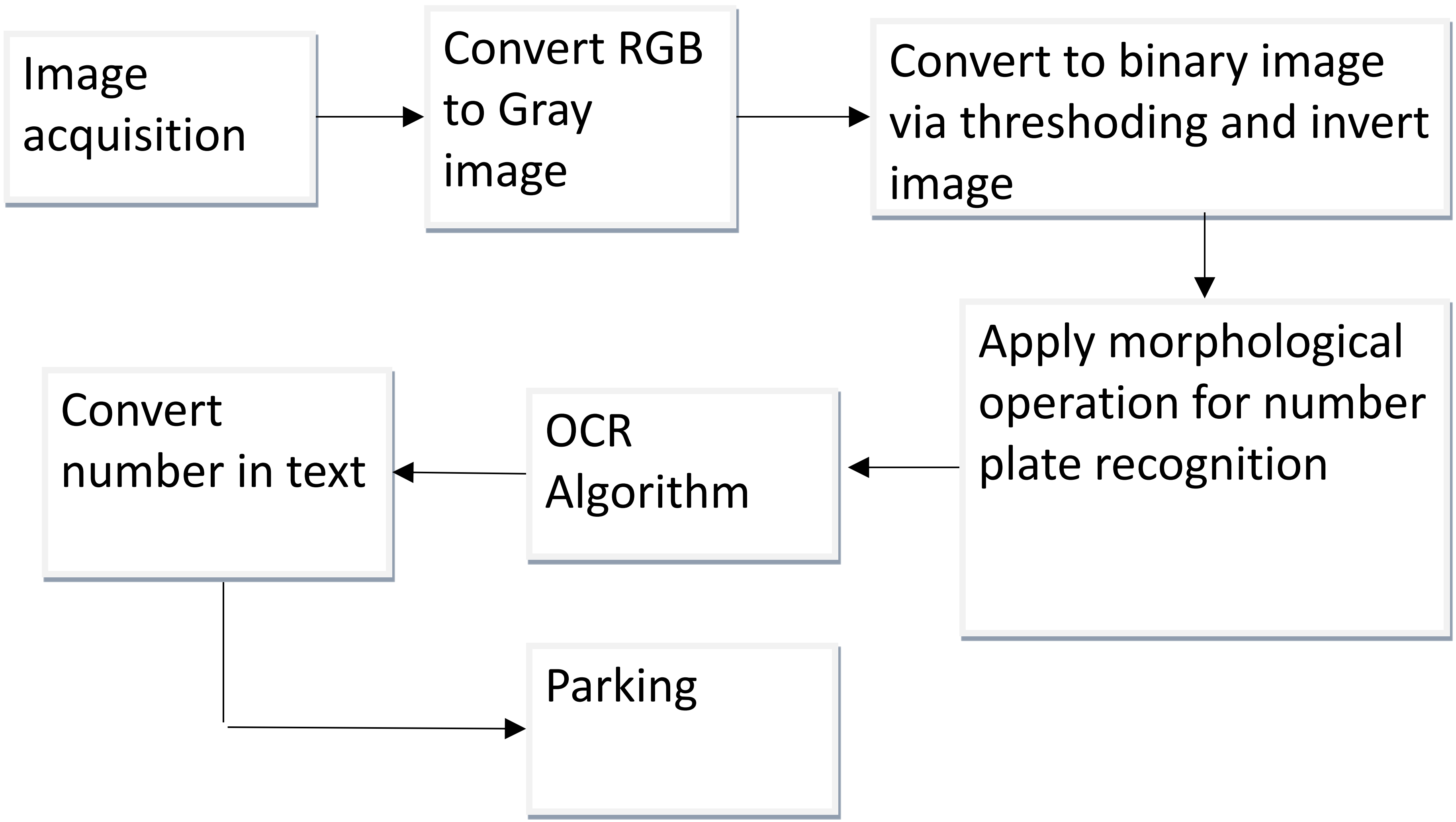
Applications

- Automatic Character Recognition :-



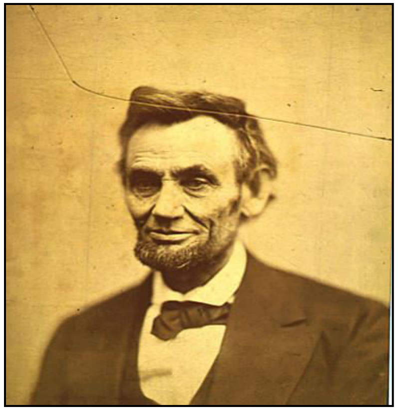


Block diagram for OCR

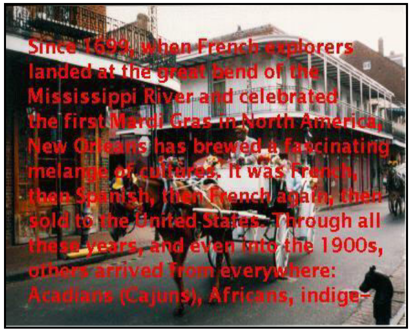


Applications

- Image Inpainting: -







Types of digital Images

- Binary image
- Gray scale image,
- True color image or RGB image,
- Indexed image.

Difficulty in digital image processing

- Image size
- Gray scale image of 512 X 512 requires

  = 512 X 512 X 8

  = 2097152 bits.

  = 2MB
- 3D image perception

Image Acquisition

- Image Characteristics
- Image Digitization

  Spatial domain

  Intensity domain

What is an Image ?

- An image is a projection of a 3D scene into a 2D *projection plane*.
- An image can be defined as a 2 variable function f(x,y): $R^2 \rightarrow R$, where for each position (x,y) in the projection plane, f(x,y) defines the light intensity at this point.

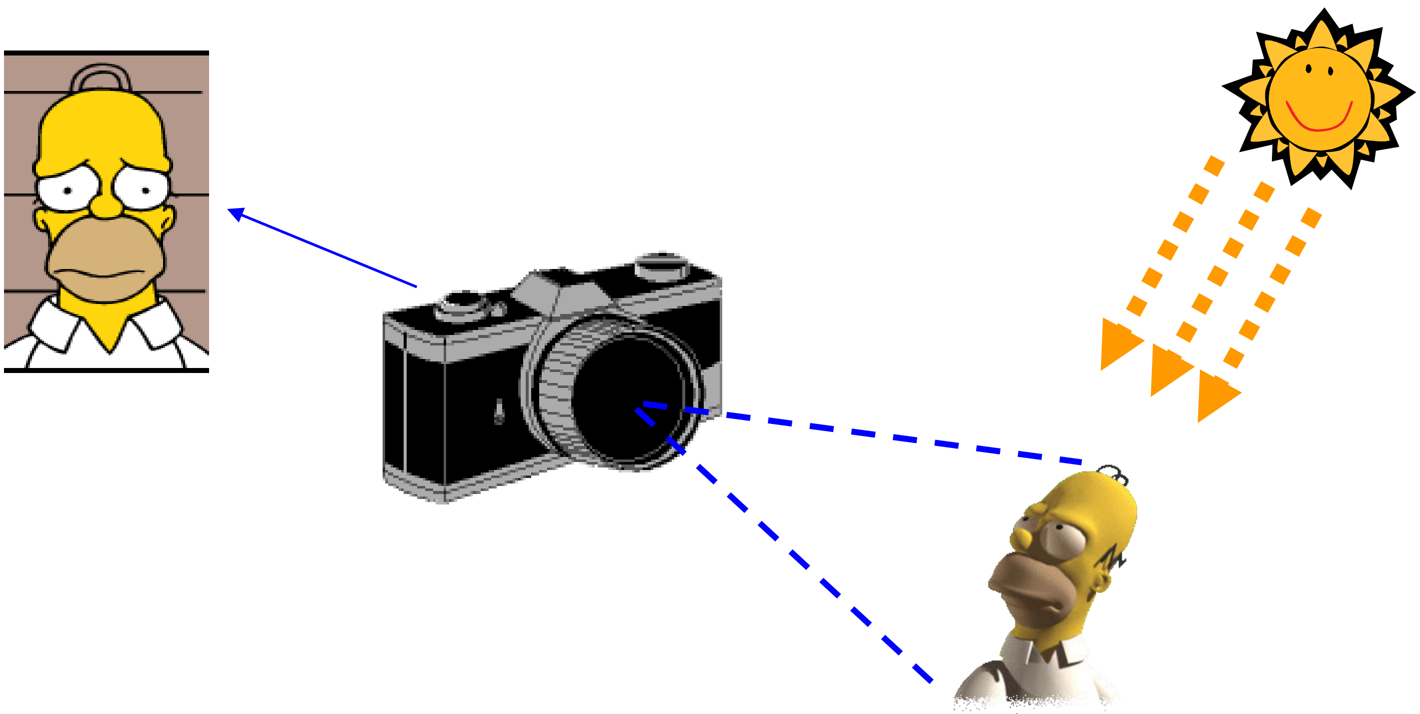


Image as a function

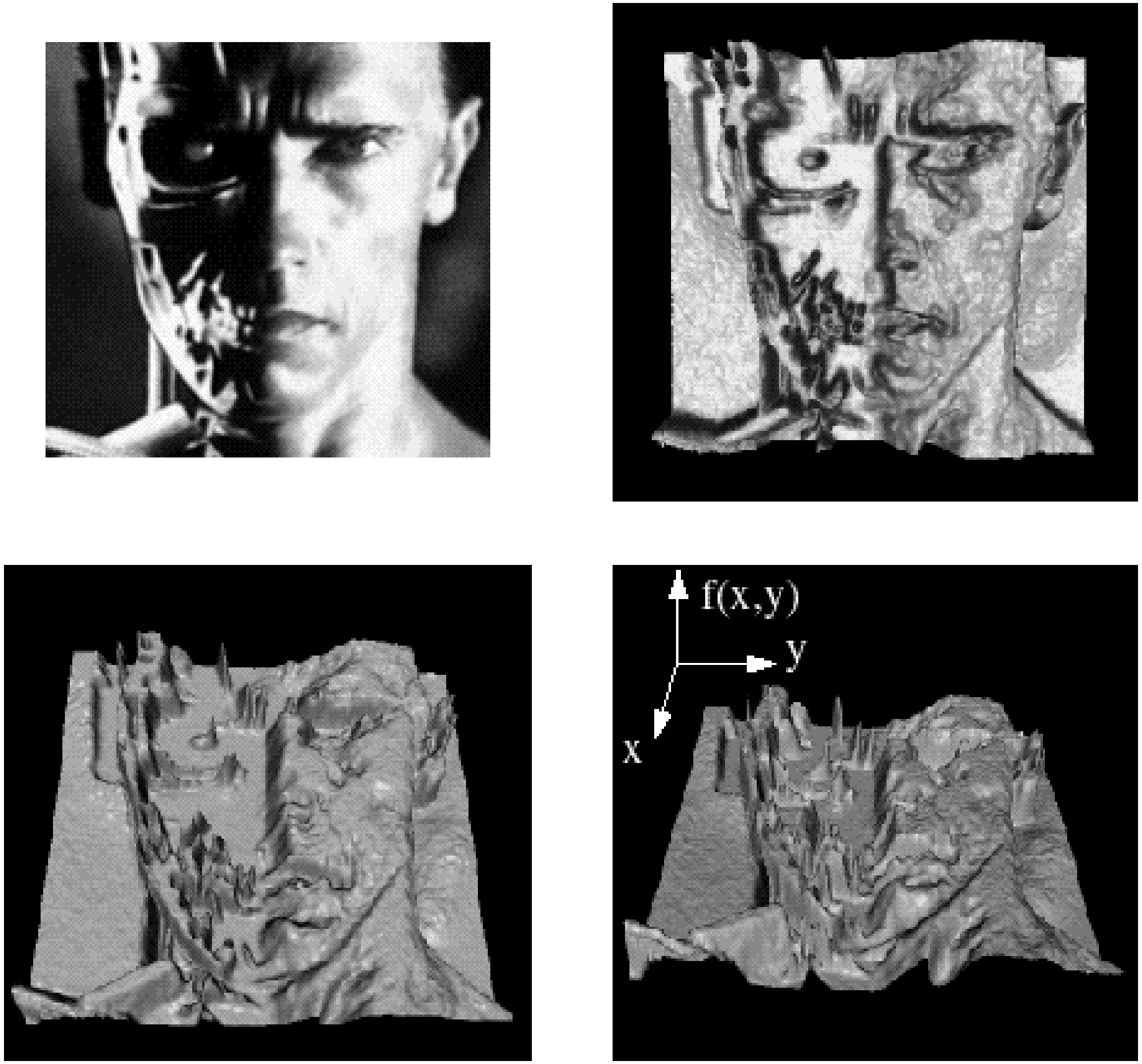
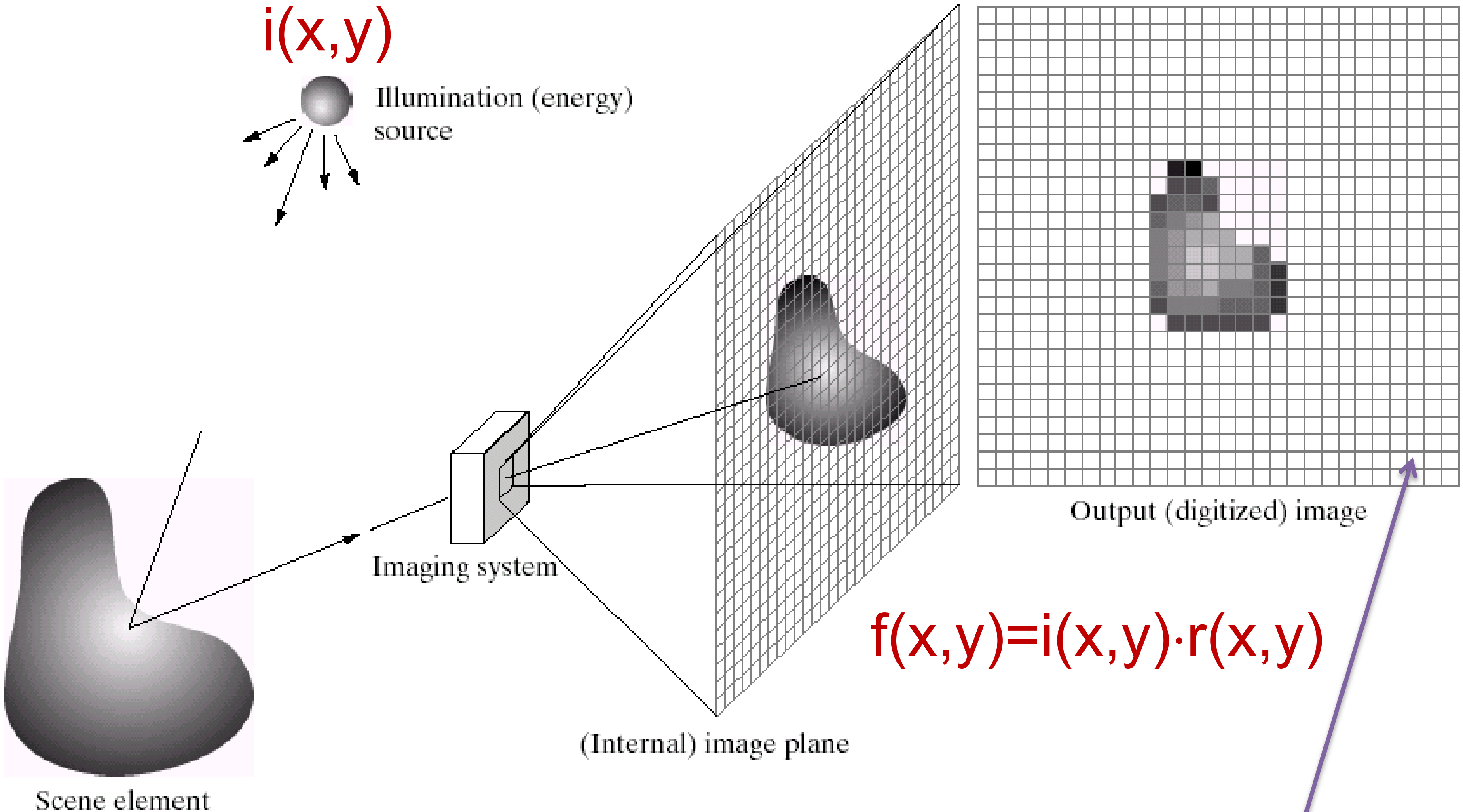


Image Acquisition

g(i,j)

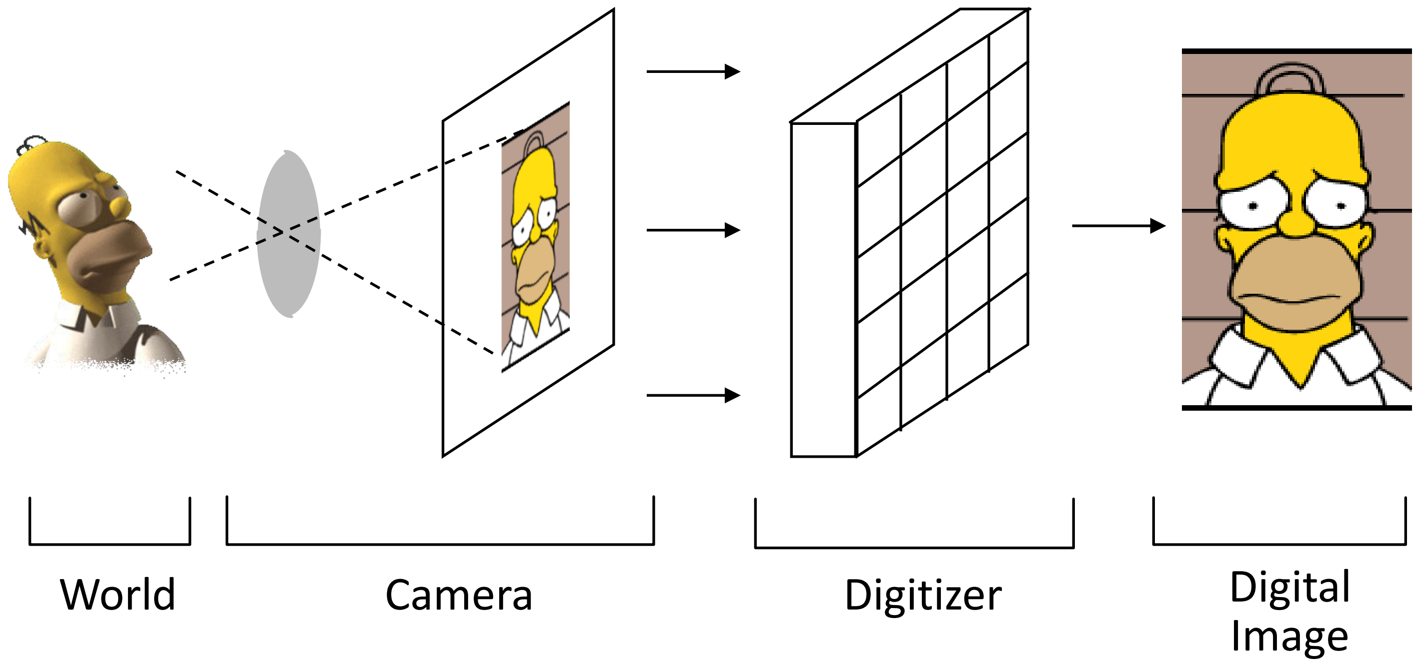
i(x,y)

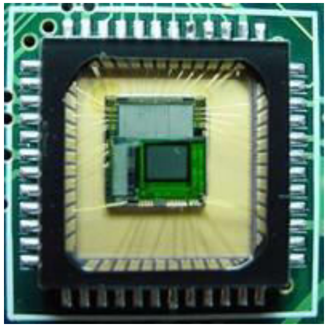


r(x,y)

pixel=picture element

Acquisition System





CMOS sensor

Image Types

Three types of images:

– Binary images

$g(x,y) \in \{0 , 1\}$

– Gray-scale images

$g(x,y) \in C$

typically $c=\{0,\ldots,255\}$

– Color Images

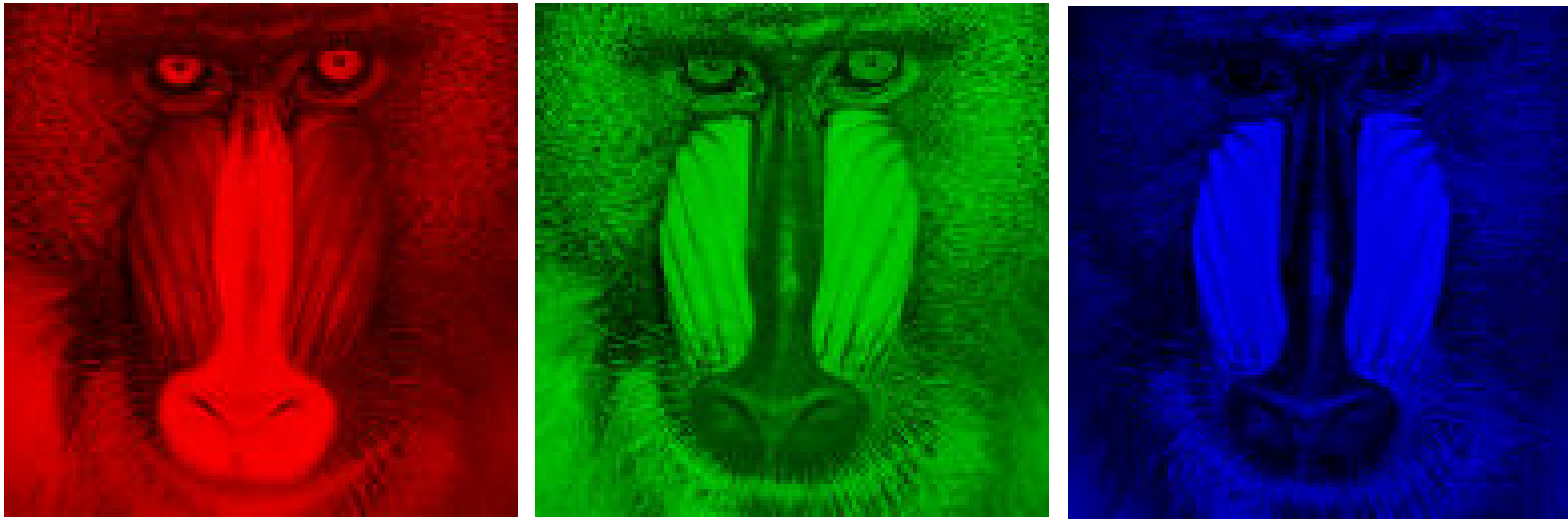
three channels:

$g_R(x,y)\in C$ $g_G(x,y)\in C$ $g_B(x,y)\in C$

Gray Scale Image

y =	x = 58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
41	210	209	204	202	197	247	143	71	64	80	84	54	54	57	58
42	206	196	203	197	195	210	207	56	63	58	53	53	61	62	51
43	201	207	192	201	198	213	156	69	65	57	55	52	53	60	50
44	216	206	211	193	202	207	208	57	69	60	55	77	49	62	61
45	221	206	211	194	196	197	220	56	63	60	55	46	97	58	106
46	209	214	224	199	194	193	204	173	64	60	59	51	62	56	48
47	204	212	213	208	191	190	191	214	60	62	66	76	51	49	55
48	214	215	215	207	208	180	172	188	69	72	55	49	56	52	56
49	209	205	214	205	204	196	187	196	86	62	66	87	57	60	48
50	[illegible]	[illegible]	205	203	202	186	174	185	149	71	63	55	55	45	56
			211	199	217	194	183	177	209	90	62	64	52	93	52
			209	209	197	194	183	187	187	239	58	68	61	51	56
			203	209	195	203	188	185	183	221	75	61	58	60	60
			199	236	188	197	183	190	183	196	122	63	58	64	66
			202	203	199	197	196	181	173	186	105	62	57	64	63

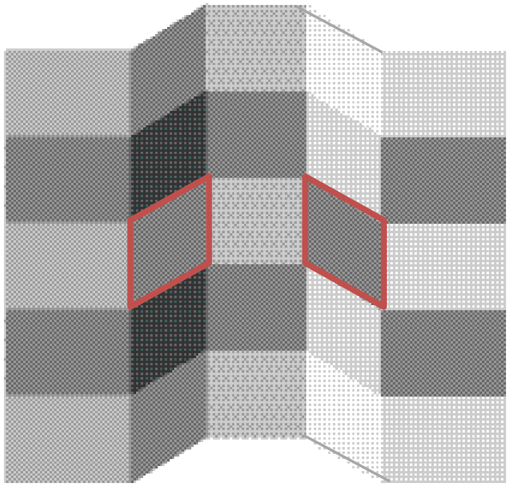
Color Image

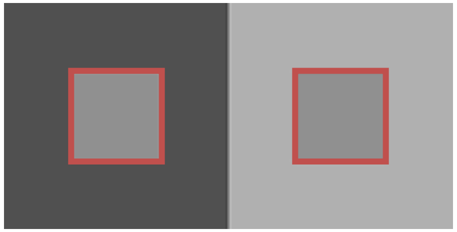


Notations

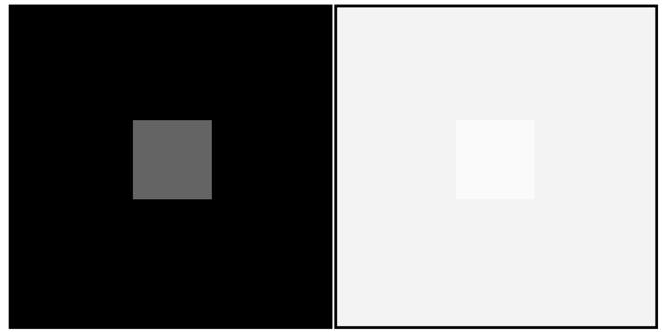
- Image Intensity -
  - Light energy emitted from a unit area in the image
  - Device dependence
- Image Brightness -
  - The subjective appearance of a unit area in the image
  - Context dependence
  - Subjective
- Image Gray-Level -
  - The relative intensity at each unit area
  - Between the lowest intensity (Black value) and the highest intensity (White value)
  - Device independent

Intensity vs. Brightness

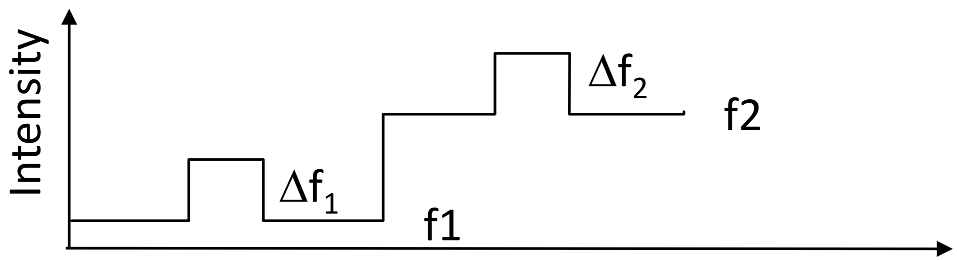




Intensity vs. Brightness



$f_1 < f_2,\ \Delta f_1 = \Delta f_2$



Equal intensity steps:

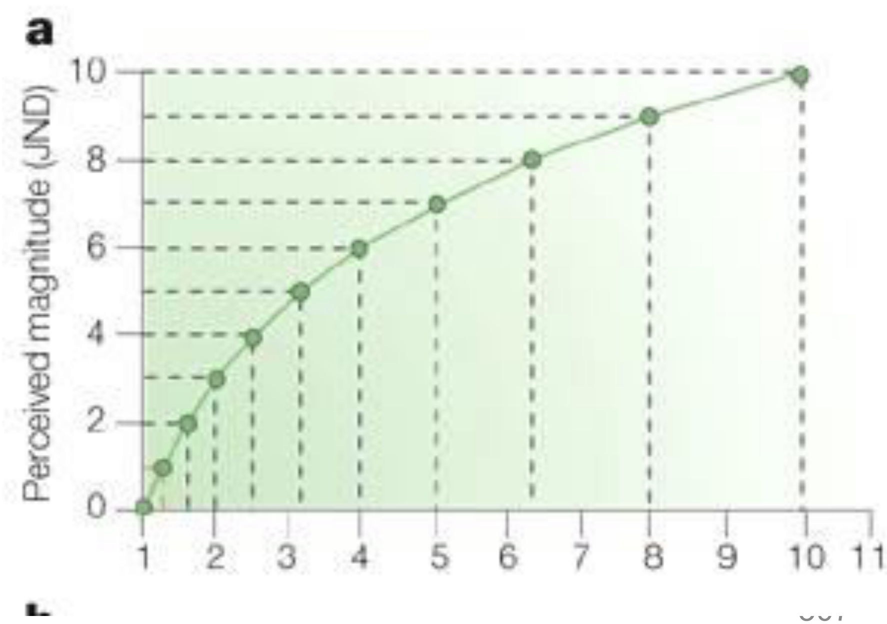
Equal brightness steps:

Weber Law

- Describe the relationship between the physical magnitudes of stimuli and the perceived intensity of the stimuli.
- In general, **Δf** needed for just noticeable difference (JND) over background **f** was found to satisfy:

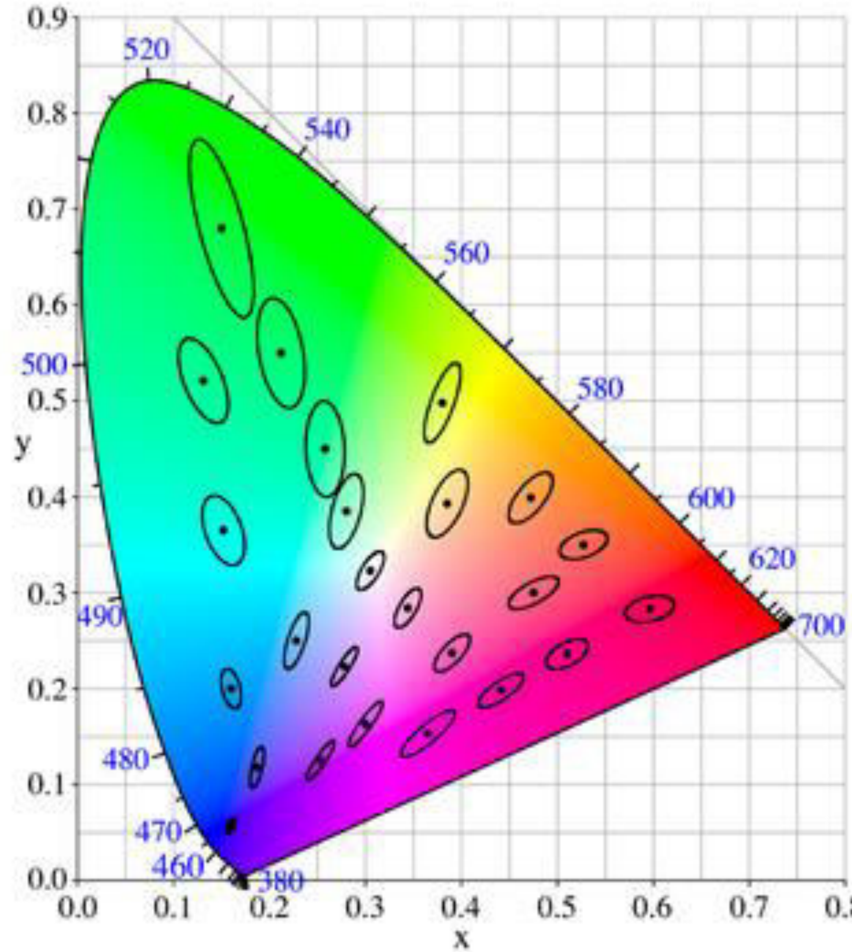
$$\frac{\Delta f}{f} = const$$

Brightness $\propto$ log(**f**)



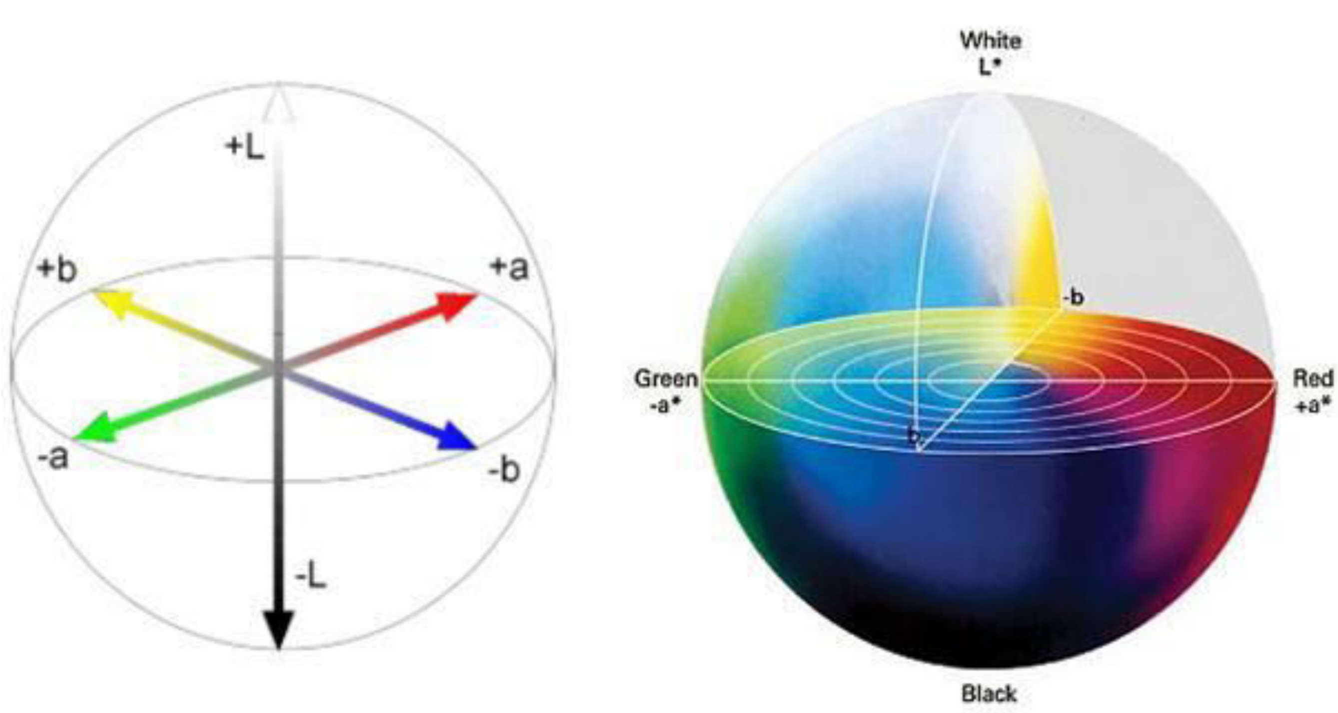
What about Color Space?

- JND in XYZ color space was measured by Wright and Pitt, and MacAdam in the thirties
- MacAdam ellipses: JND plotted at the CIE-xy diagram
- Conclusion: measuring perceptual distances in the cie-XYZ space is not a good idea



Perceptually Uniform Color Space

- Most common: CIE-L*a*b* (CIELAB) color space.
- L* represents luminance.
- a* represents the difference between green and red, and b* represents the difference between yellow and blue.



Perceptually Uniform Color Space

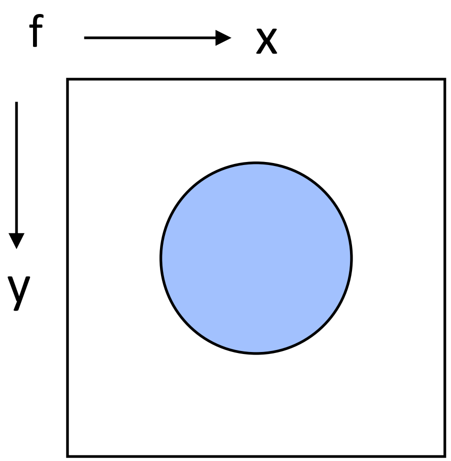
- XYZ to CIELAB conversion:

$$a^* = 500\left[(X/X_0)^{1/3} - (Y/Y_0)^{1/3}\right]$$
$$b^* = 200\left[(X/X_0)^{1/3} - (Z/Z_0)^{1/3}\right]$$
$$L^* = \begin{cases} 116(Y/Y_0)^{1/3} - 16 & for\, Y/Y_0 > 0.01 \\ 903(Y/Y_0) & otherwise \end{cases}$$

- where (X_0, Y_0, Z_0) are the XYZ values of a reference white point

Digitization

- Two stages in the digitization process:
  - **Spatial sampling**: Spatial domain
  - **Quantization**: Gray level



Continuous Image

i \ j	1	2	3	4	5
1	100	100	100	100	100
2	100	0	0	0	100
3	100	0	0	0	100
4	100	0	0	0	100
5	100	100	100	100	100

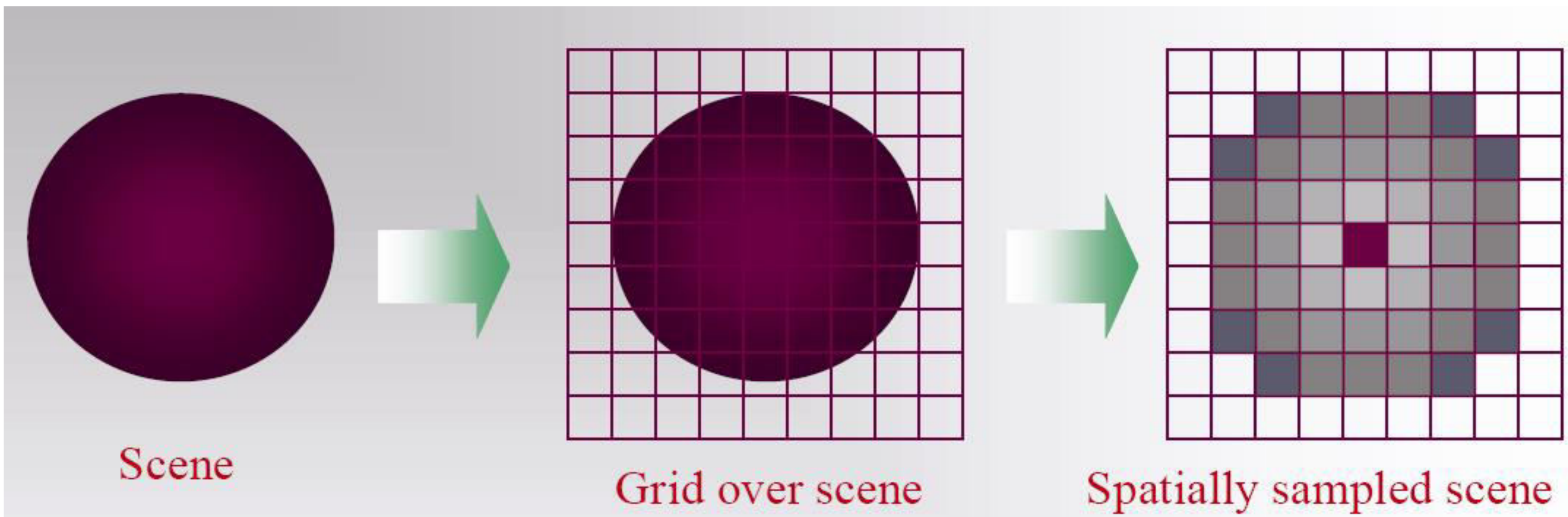
Digital Image

$f(x,y)$

$g(i,j) \in C$

Spatial Sampling

- When a continuous scene is imaged on the sensor, the continuous image is divided into discrete elements - picture elements (pixels)



Spatial Sampling

Original

2 points

4 points

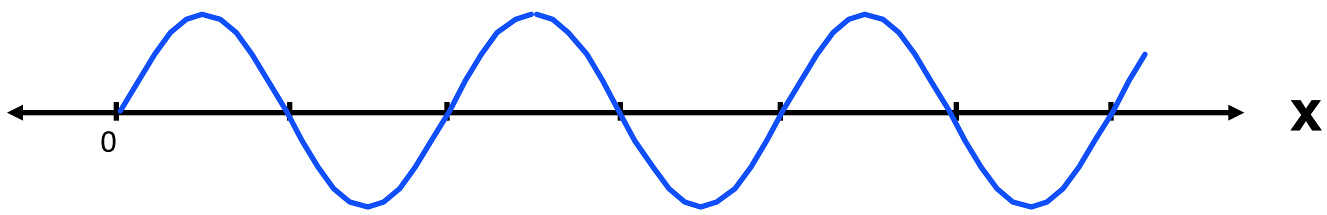
8 points

Sampling

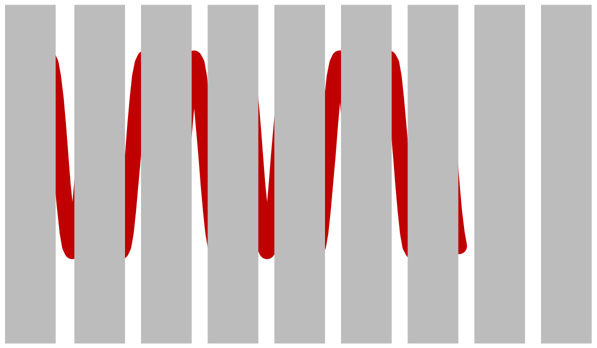
- The density of the sampling denotes the separation capability of the resulting image
- **Image resolution** defines the finest details that are still visible by the image
- We use a cyclic pattern to test the separation capability of an image

$$\text{Frequency} = \frac{\text{number of cycles}}{\text{unit length}}$$

$$\text{Wavelength} = \frac{1}{\text{frequency}}$$



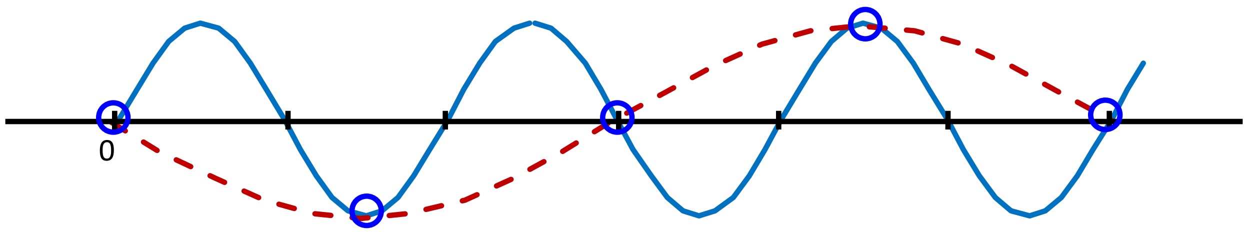
Sampling Rate



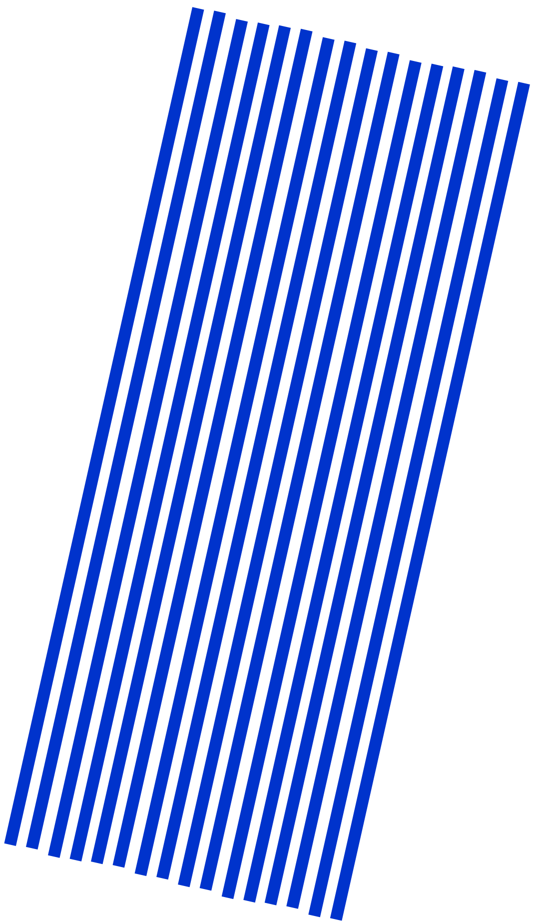
Nyquist Frequency

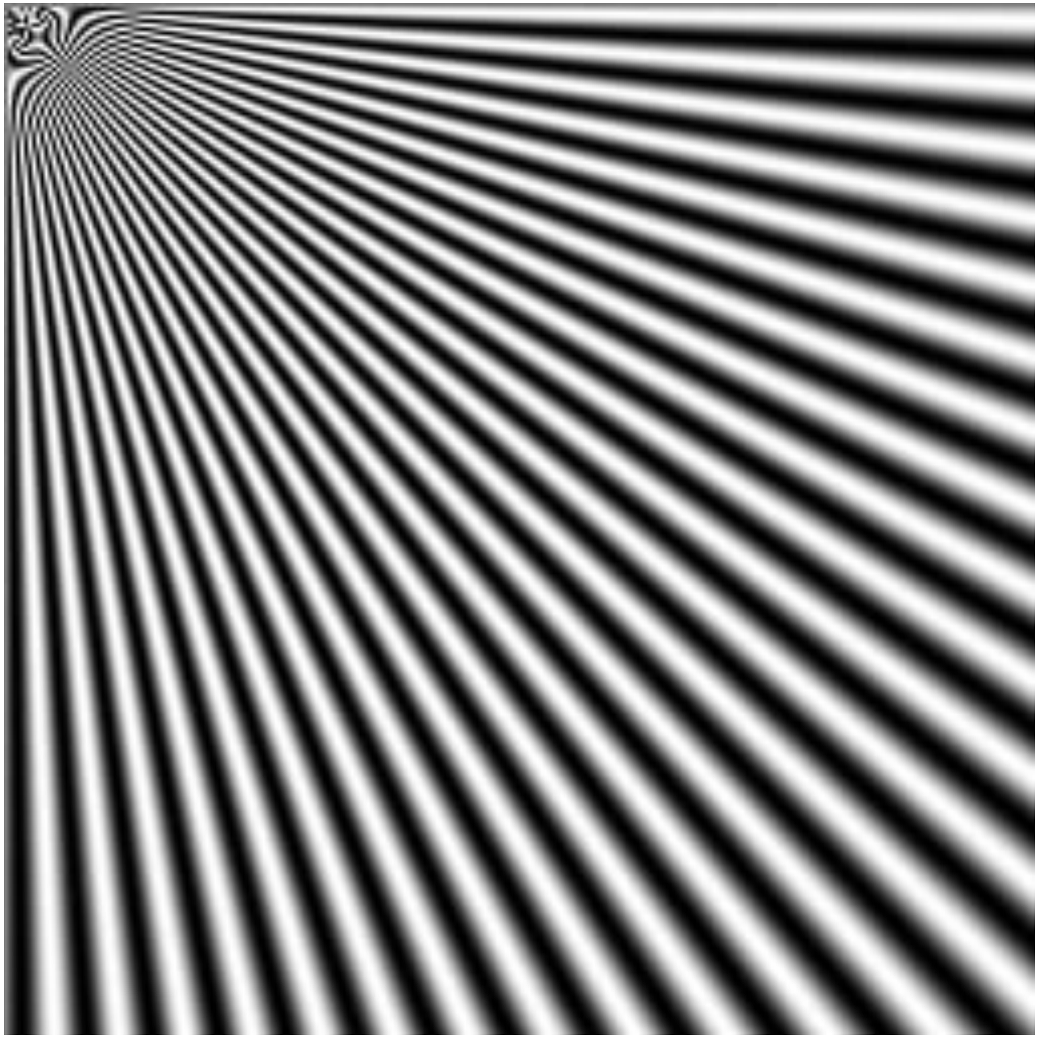
- **Nyquist Rule**: To observe details at frequency f (wavelength d) one must sample at frequency > 2f (sampling intervals < d/2)
- The Frequency 2f is the **Nyquist Frequency**.
- **Aliasing**: If the pattern wavelength is less than 2d erroneous patterns may be produced.

1D Example:

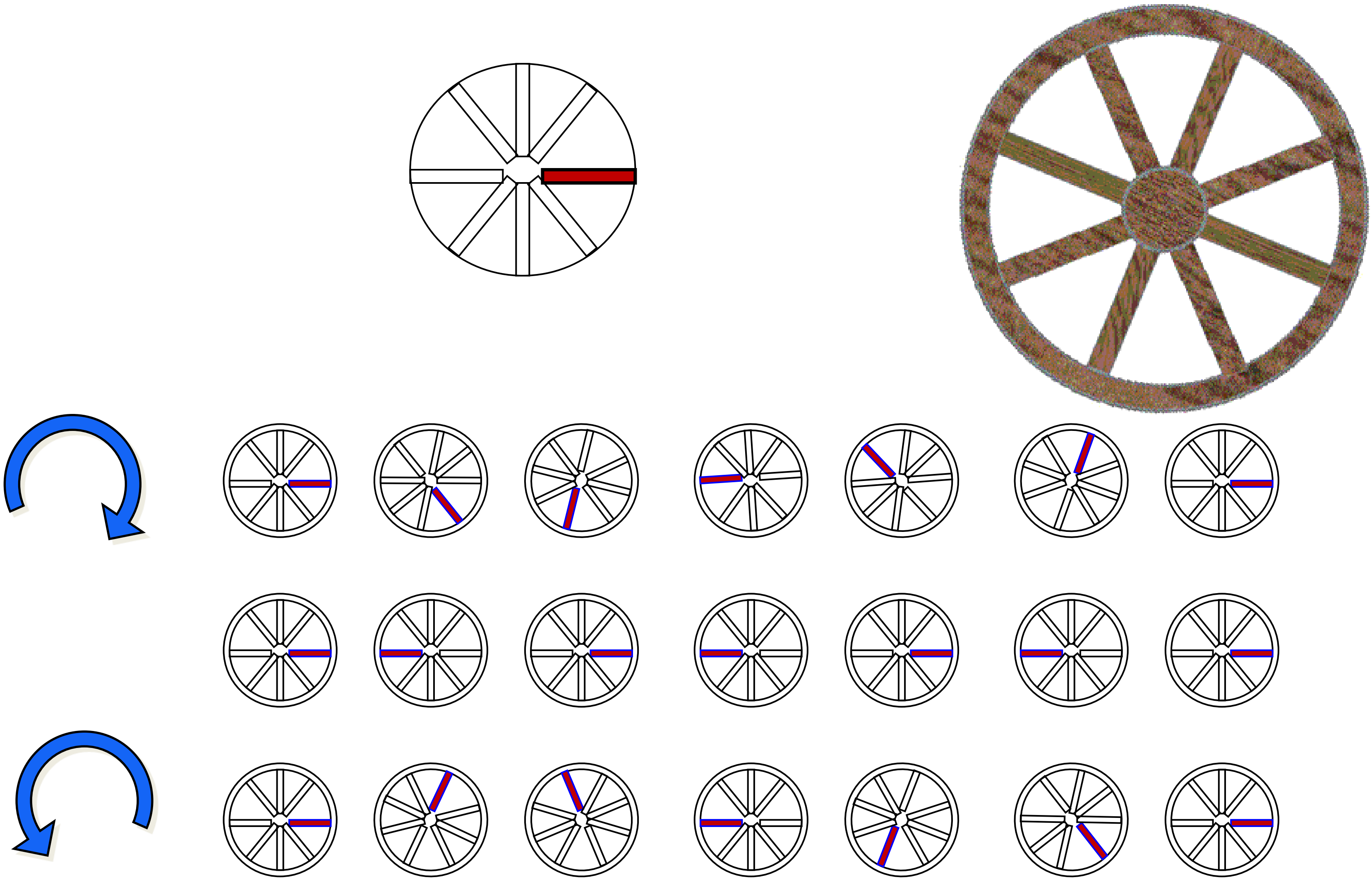


Aliasing - Moiré Patterns





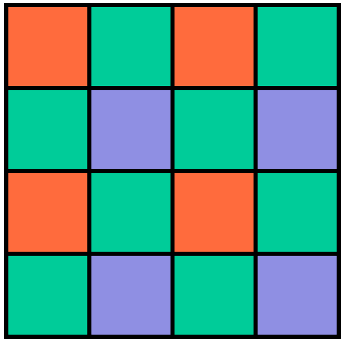
Temporal Aliasing



Temporal Aliasing Example

Image De-mosaicing

- Can we do better than Nyquist?



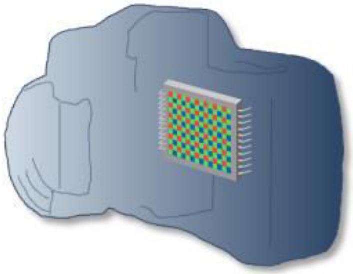
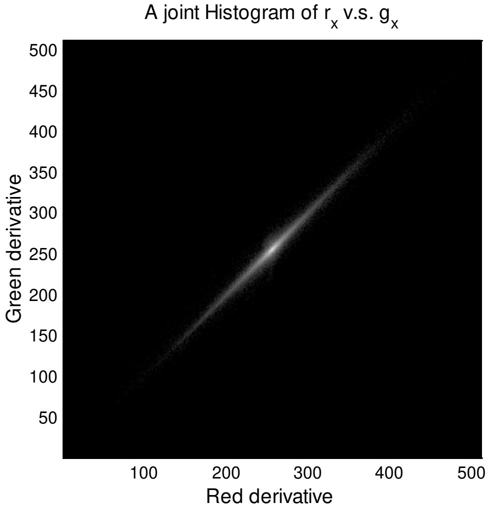


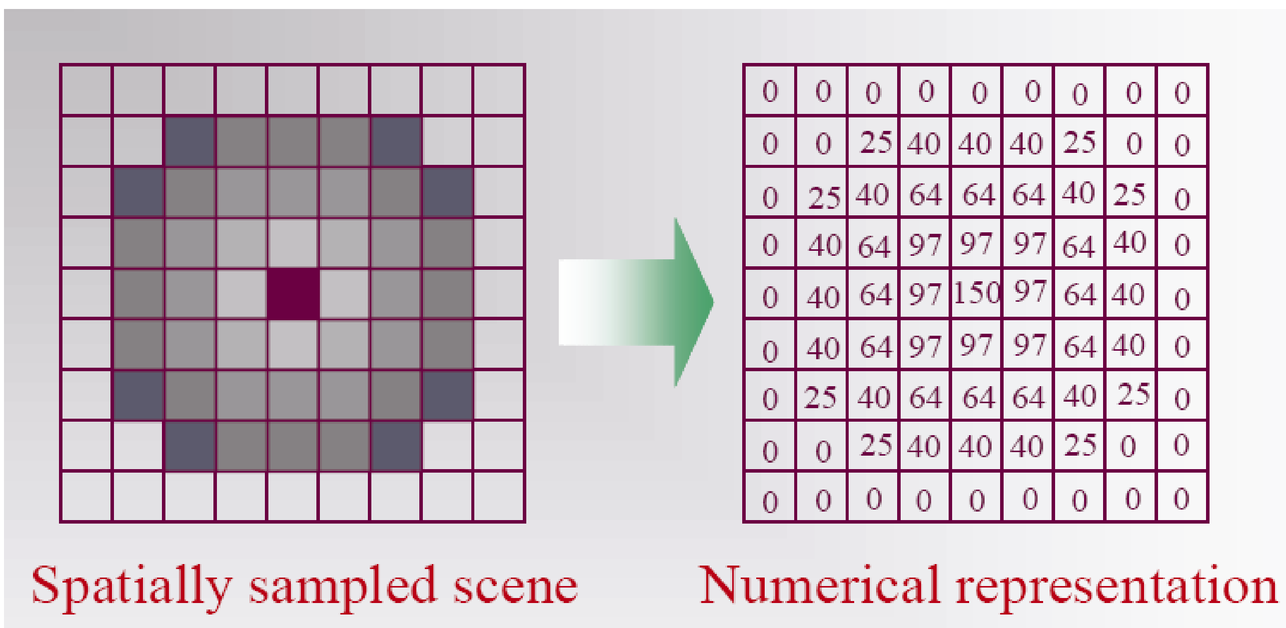
Image De-mosaicing

- Basic idea: use correlations between color bands

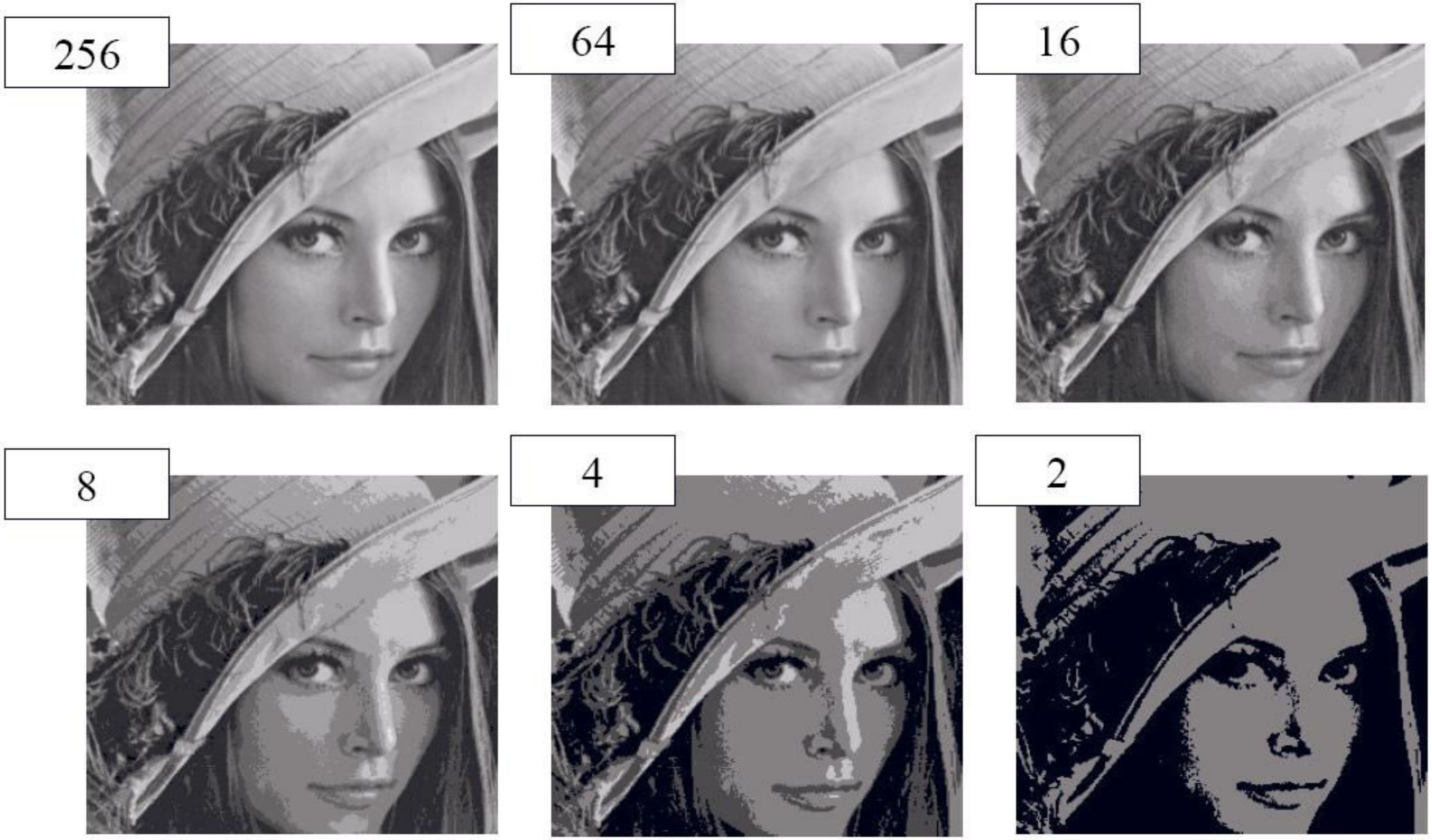


Quantization

- Choose number of gray levels (according to number of assigned bits)
- Divide continuous range of intensity values



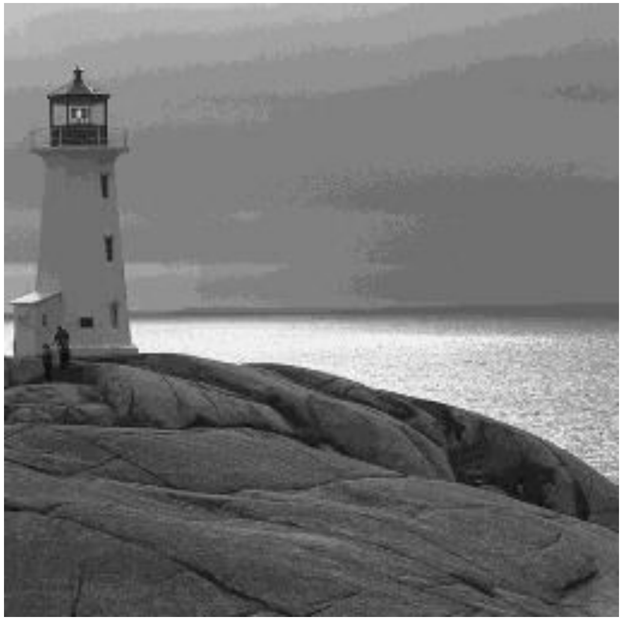
Quantization



Quantization

- Low freq. areas are more sensitive to quantization

8 bits image



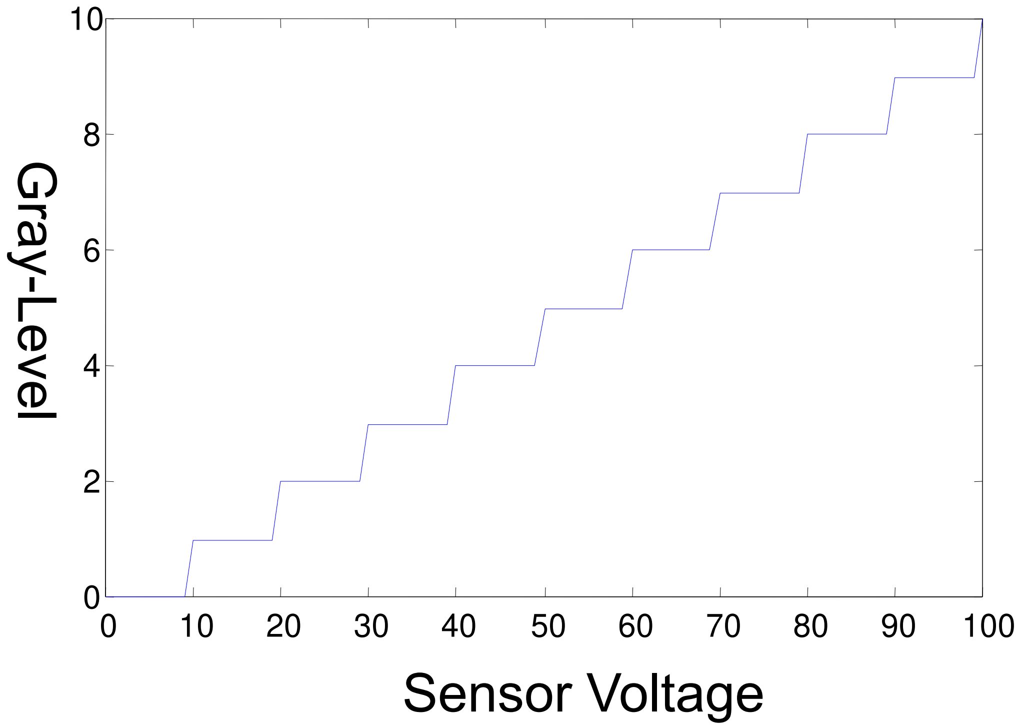
4 bits image

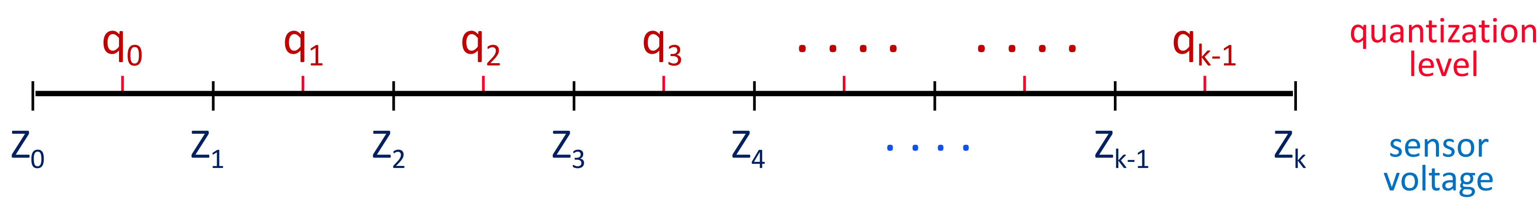
How should we quantize an image?

- Simplest approach: **uniform quantization**

$$Z_{i+1} - Z_i = \frac{Z_k - Z_0}{K}$$

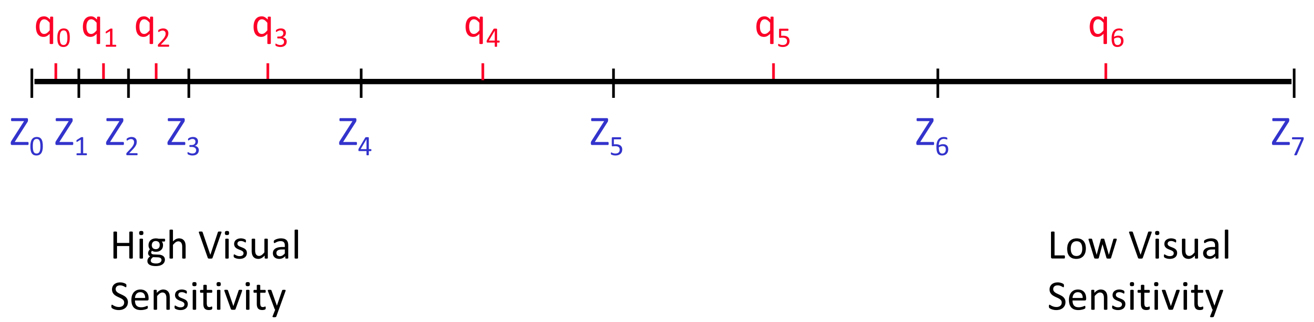
$$q_i = \frac{Z_{i+1} + Z_i}{2}$$





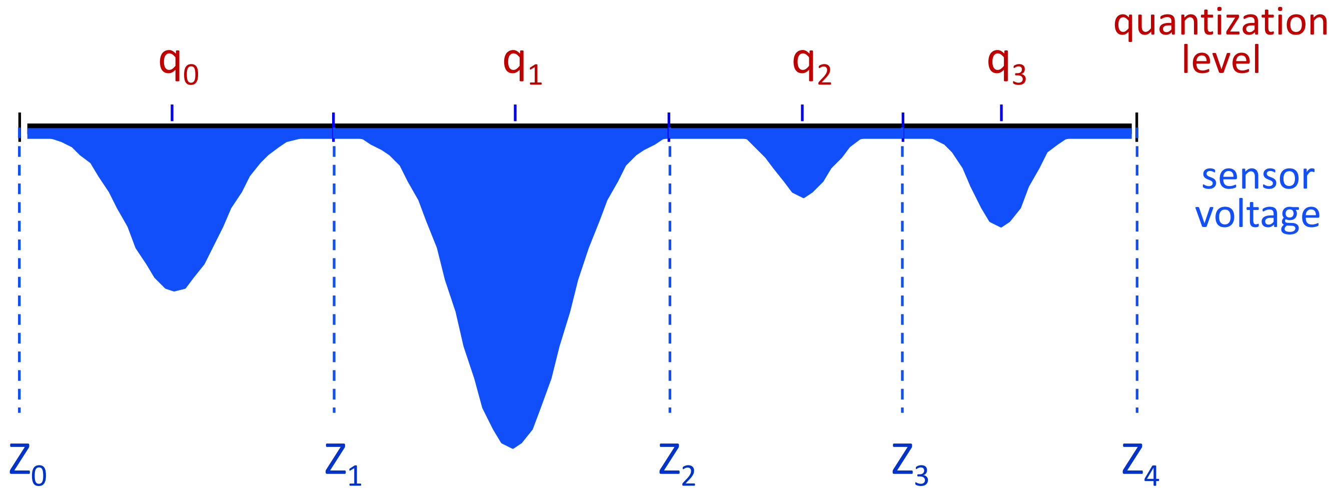
Non-uniform Quantization

- Quantize according to visual sensitivity (Weber's Law)
- Non uniform sensor voltage distribution



Optimal Quantization (Lloyd-Max)

- Content dependant
- Minimize quantization error



Optimal Quantization (Lloyd-Max)

- Also known as Loyd-Max quantizer
- Denote P(z) the probability of sensor voltage
- The quantization error is :

$$E = \sum_{i=0}^{k-1} \int_{z_i}^{z_{i+1}} P(z)(z - q_i)^2 dz$$

- Solution:

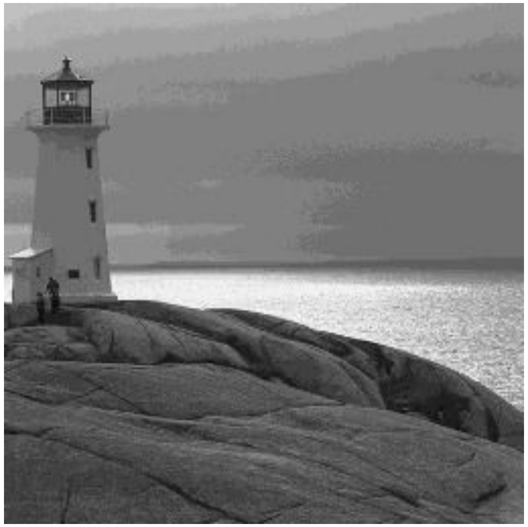
$$q_i = \frac{\int_{z_i}^{z_{i+1}} zP(z)dz}{\int_{z_i}^{z_{i+1}} P(z)dz} \qquad z_i = \frac{q_{i-1} + q_i}{2}$$

- Iterate until convergence (but optimal minimum is not guaranteed).

Example

8 bits image

4 bits image
Uniform quantization

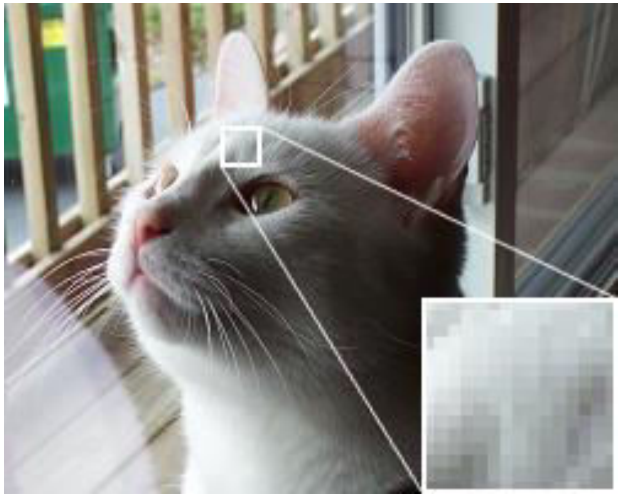


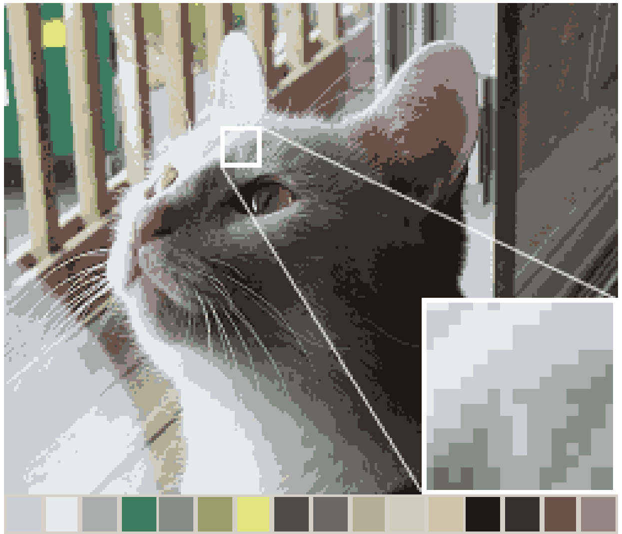
4 bits image
Optimal quantization

Color Quantization

- Common color resolution for high quality images is 256 levels for each Red, Greed, Blue channels, or $256^3 = 16777216$ colors.
- How can an image be displayed with fewer colors than it contains?
- Select a subset of colors (the colormap or pallet) and map the rest of the colors to them.

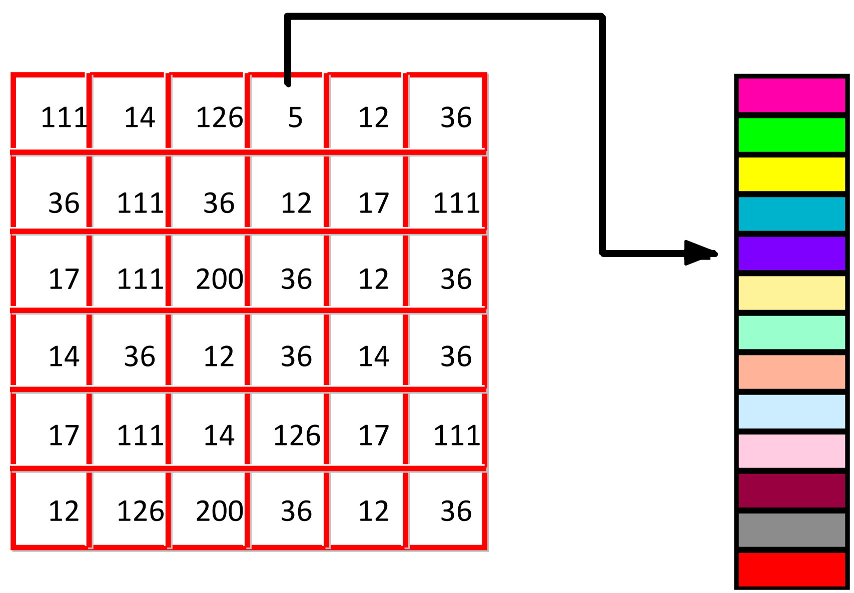
from: Daniel Cohen-Or





Color Quantization

- With 8 bits per pixel and color look up table we can display at most 256 distinct colors at a time.
- To do that we need to choose an appropriate set of representative colors and map the image into these colors



from: Daniel Cohen-Or

Color Quantization

2
colors

4
colors

16
colors

256
colors

from: Daniel Cohen-Or

Color Quantization

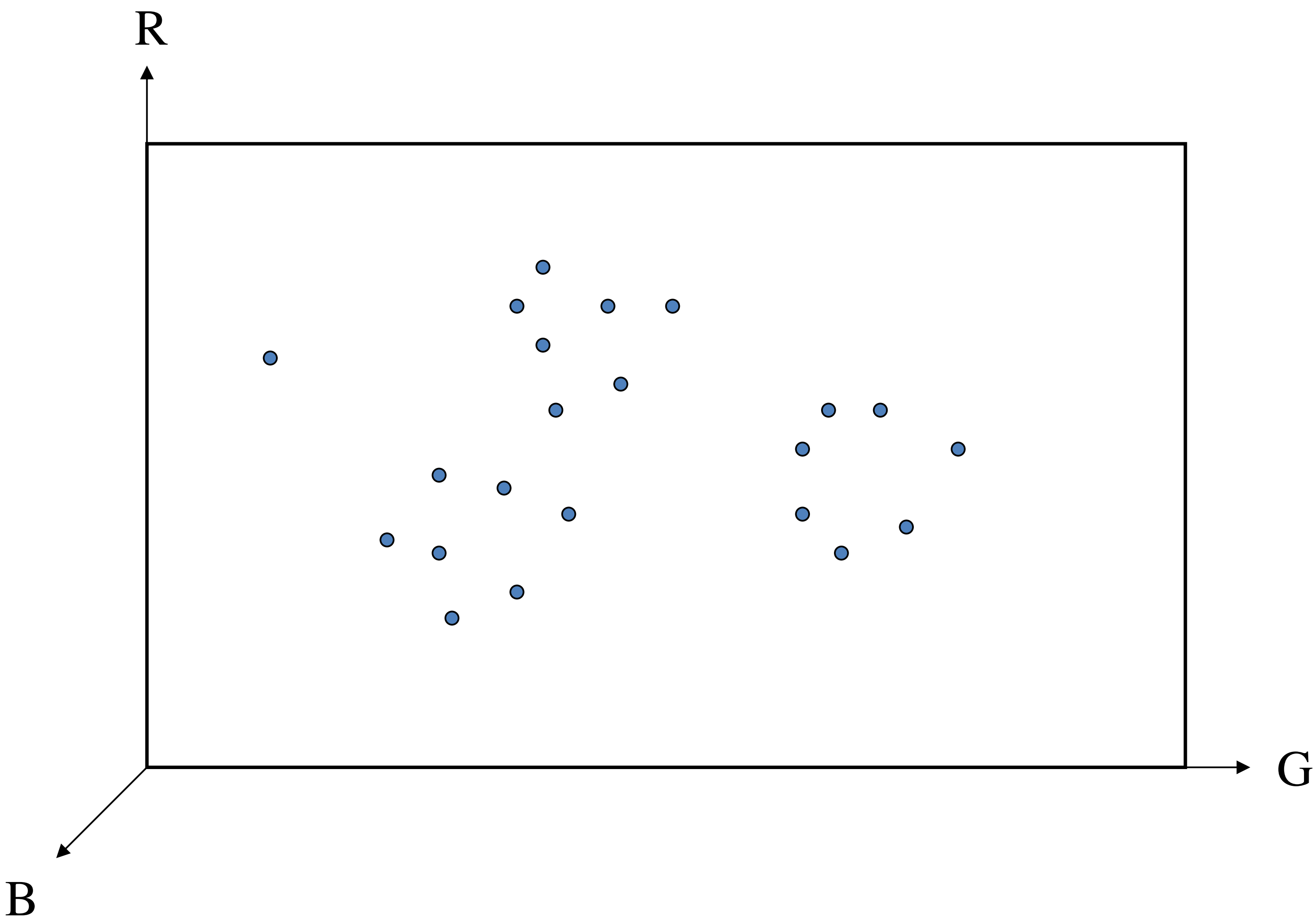
Naïve (uniform) Color Quantization 24 bit to 8 bit:

Retaining 3-3-2 most significant bits of the R,G and B components.

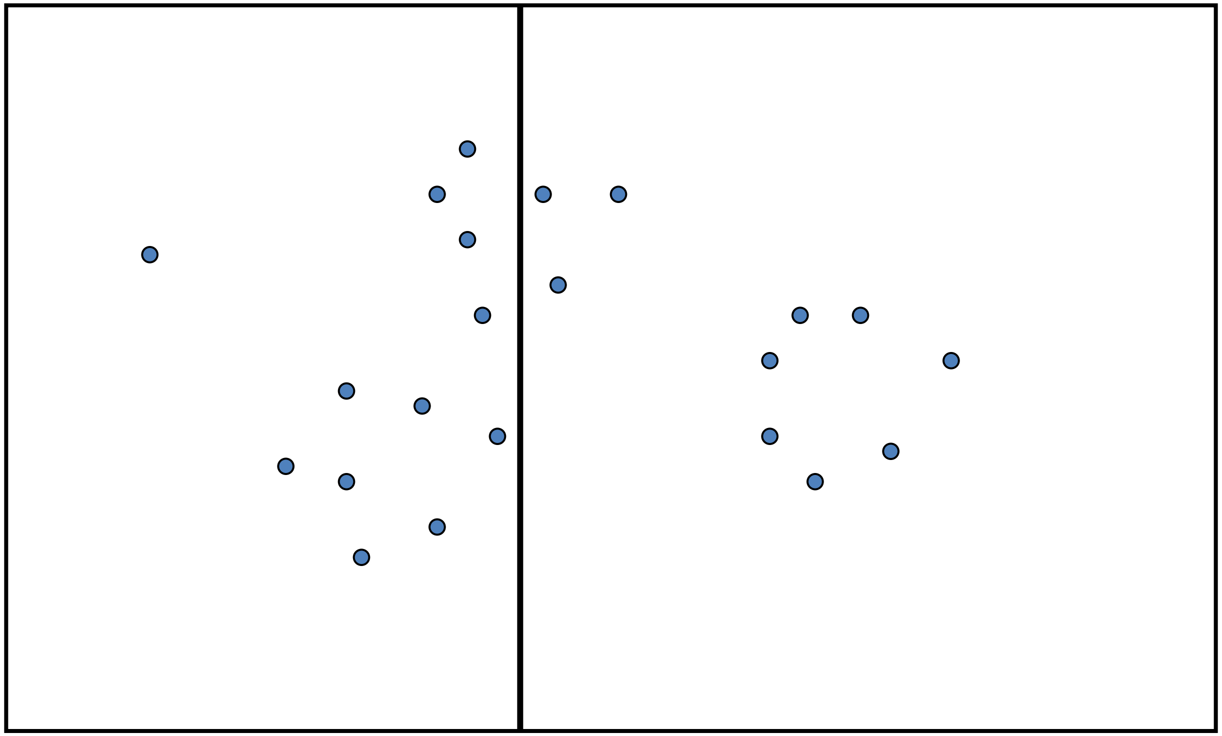
false contours

from: Daniel Cohen-Or

Median Cut

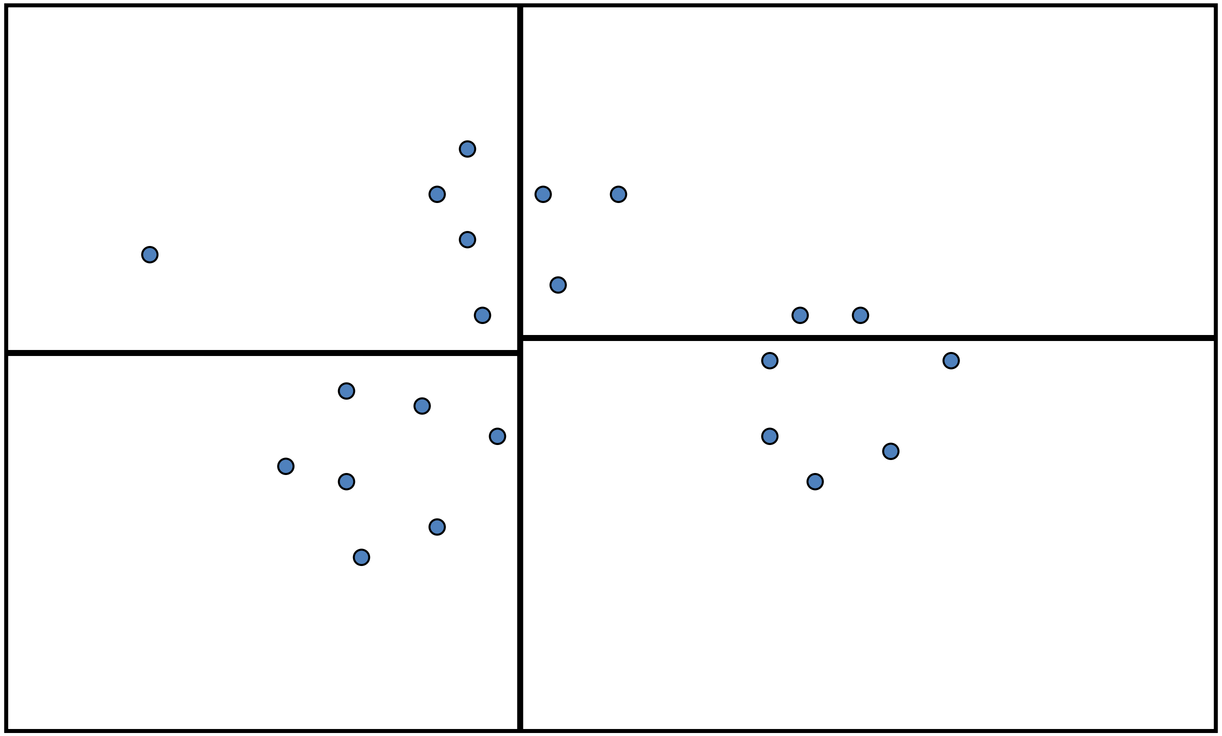


Median Cut



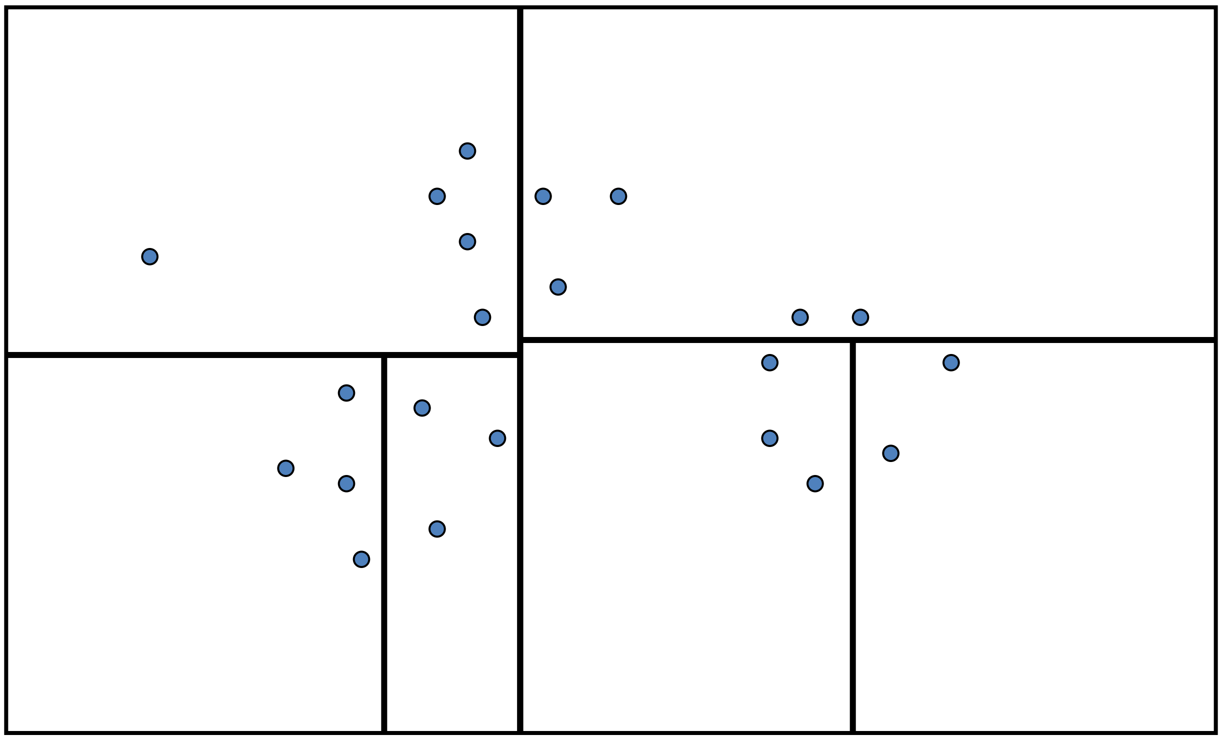
from: Daniel Cohen-Or

Median Cut



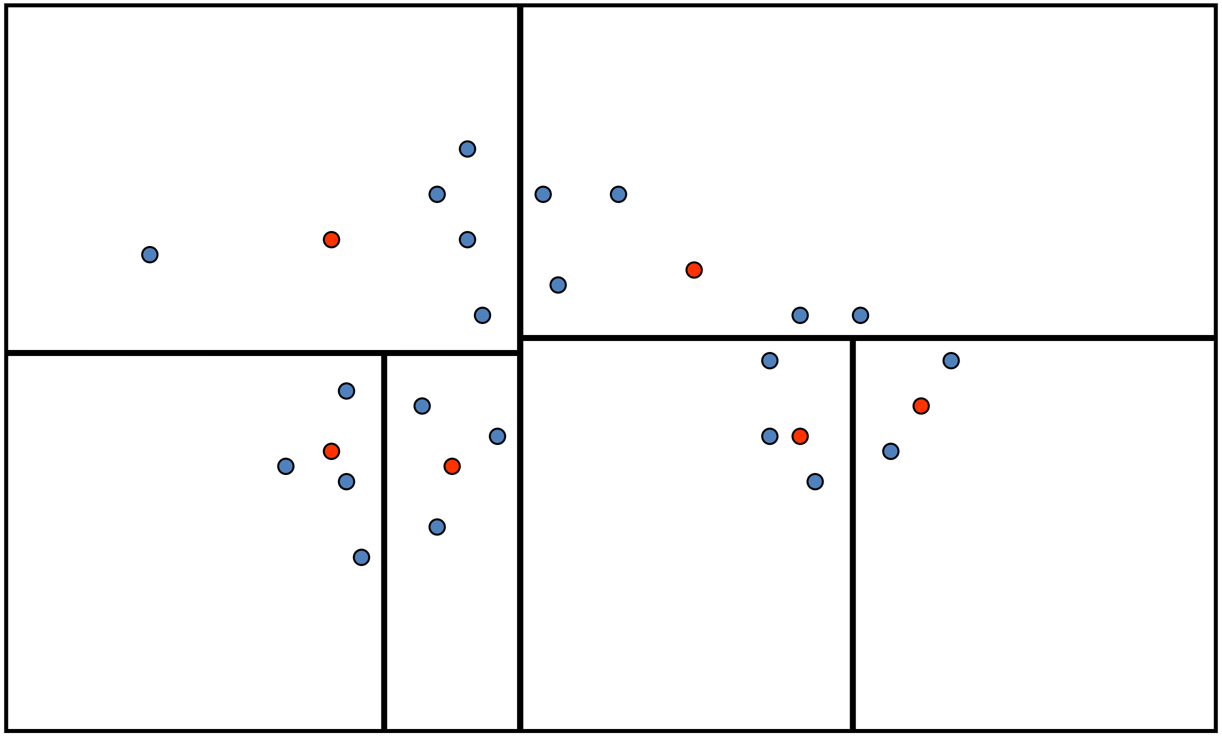
from: Daniel Cohen-Or

Median Cut



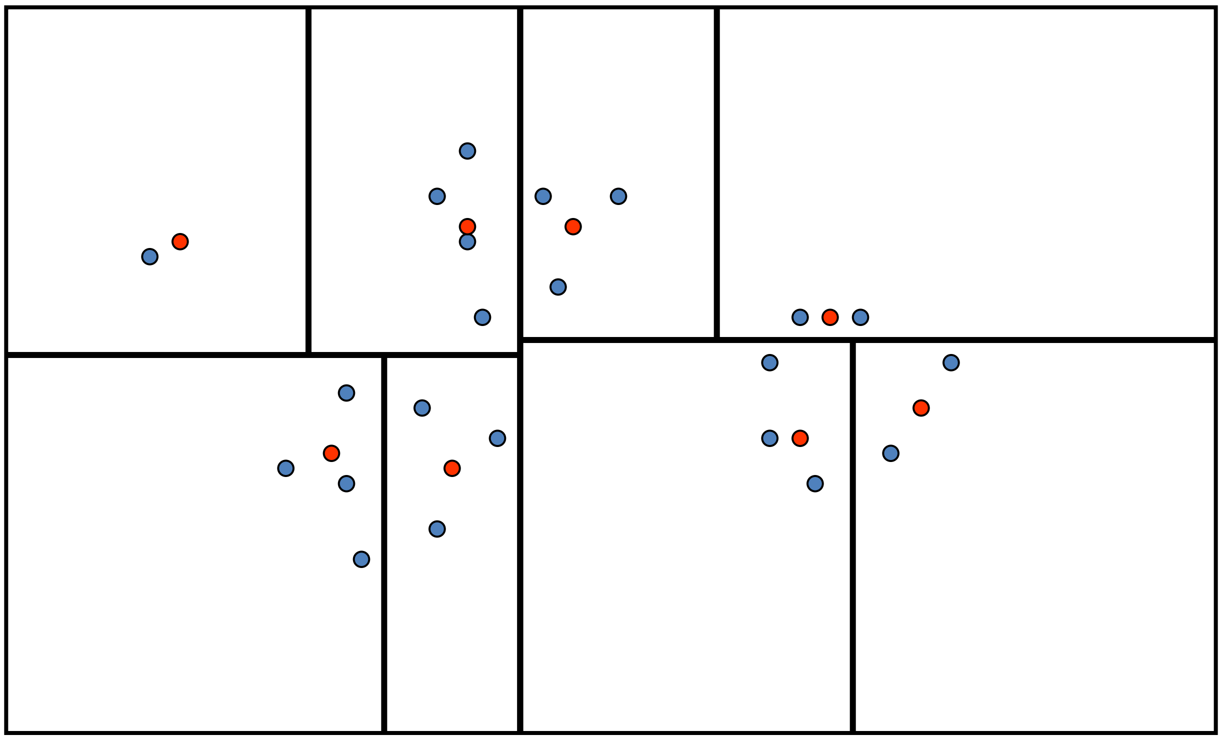
from: Daniel Cohen-Or

Median Cut



from: Daniel Cohen-Or

Median Cut



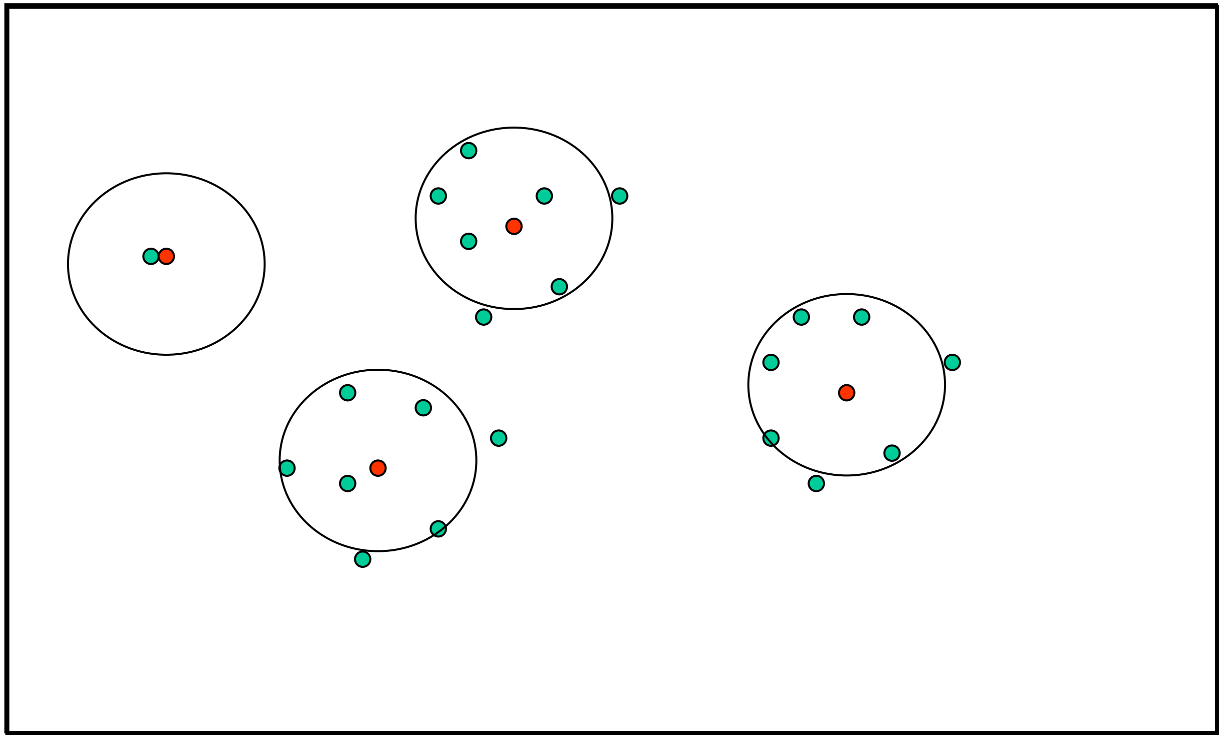
from: Daniel Cohen-Or

The median cut algorithm

```
Color_MedCut (Image, n){

        For each pixel in Image with color C, map C in RGB space;

        B = {RGB space};
        While (n-- > 0) {
                L = Heaviest (B);
                Split L into L1 and L2;
                Remove L from B, and add L1 and L2 instead;
                }

        For all boxes in B do
                assign a representative (color centroid);

        For each pixel in Image do
                map to one of the representatives;
}
```

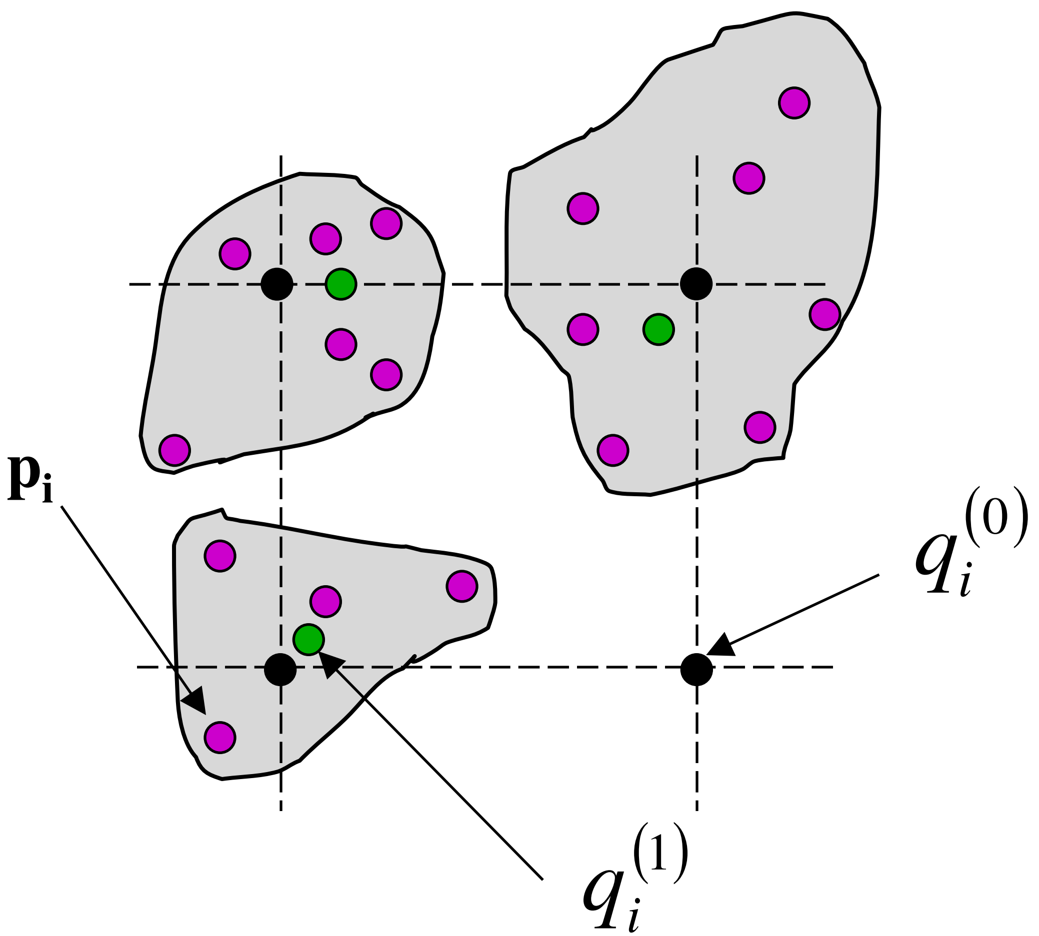
from: Daniel Cohen-Or

Better Solution



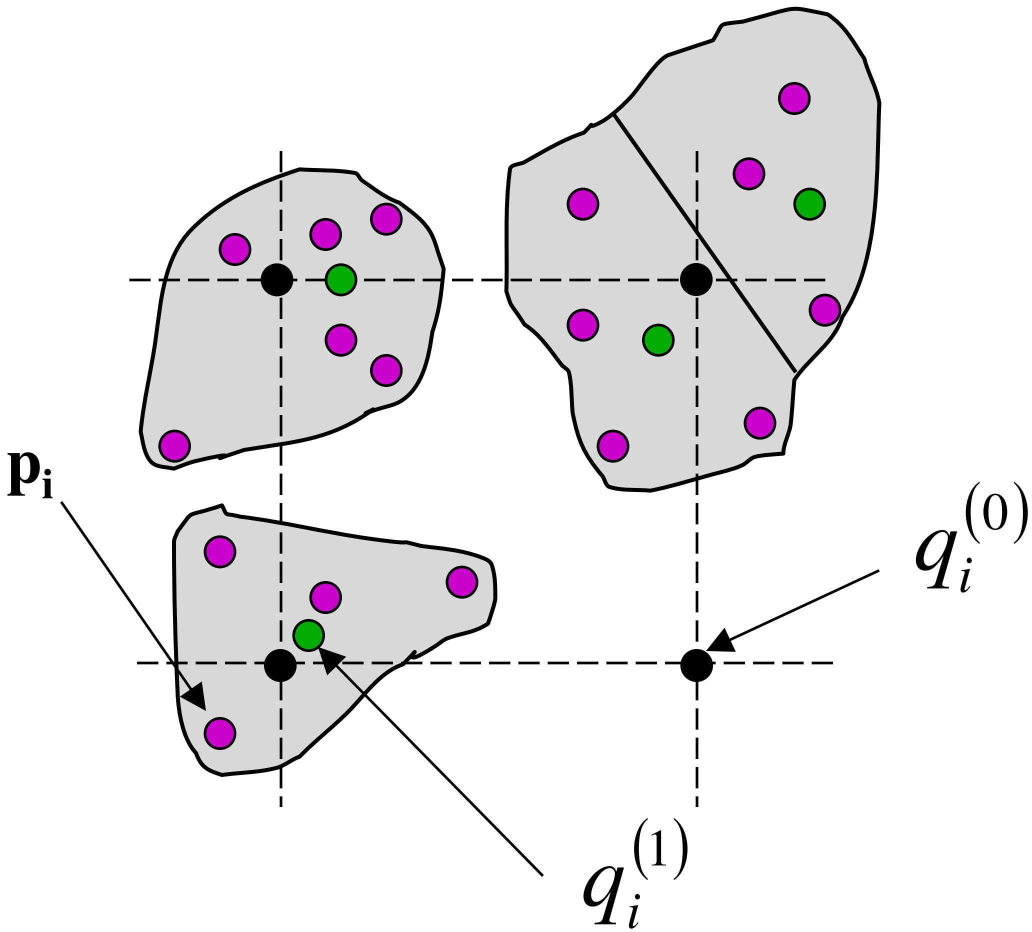
from: Daniel Cohen-Or

Generalized Lloyed Algorithm (GLA)



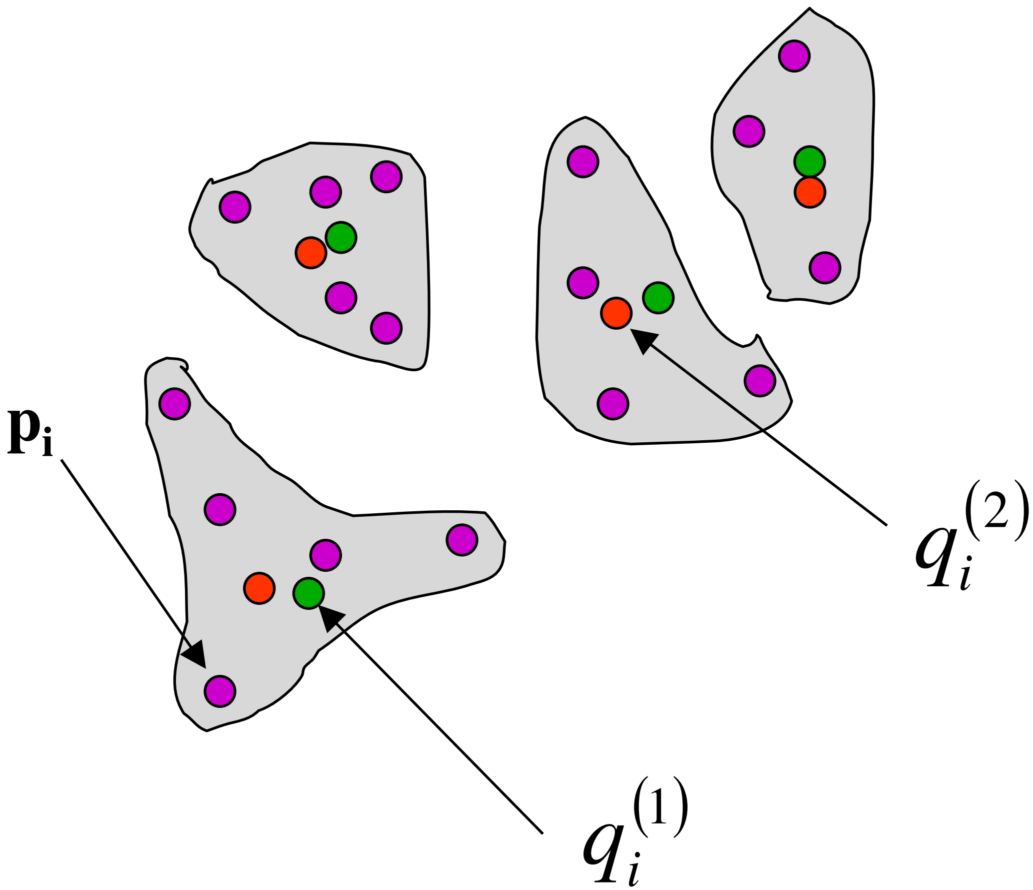
from: Daniel Cohen-Or

Generalized Lloyed Algorithm (GLA)



from: Daniel Cohen-Or

Generalized Lloyed Algorithm (GLA)



from: Daniel Cohen-Or

- The GLA algorithms aims at minimizing the quantization error:

$$E = \sum_{i=1}^{K} \sum_{j \in C_i} \left(p_j - q_i \right)^2$$

```
Color_GLloyd(Image, K)  {
   - Guess K  cluster centre locations
   - Repeat until convergence {
            - For each data point finds out which centre it's closest to
            - For each centre finds the centroid of the points it owns
            - Set a new set of cluster centre locations
            - optional: split clusters with  high variance
     }
}
```

24 bit

from: Daniel Cohen-Or

More on Color Quantization

- **Observation 1**: Distances and quantization errors measured in RGB space, do not relate to human perception.
- **Solution**: Apply quantization in perceptually uniform color space (such as CIELAB).

More on Color Quantization

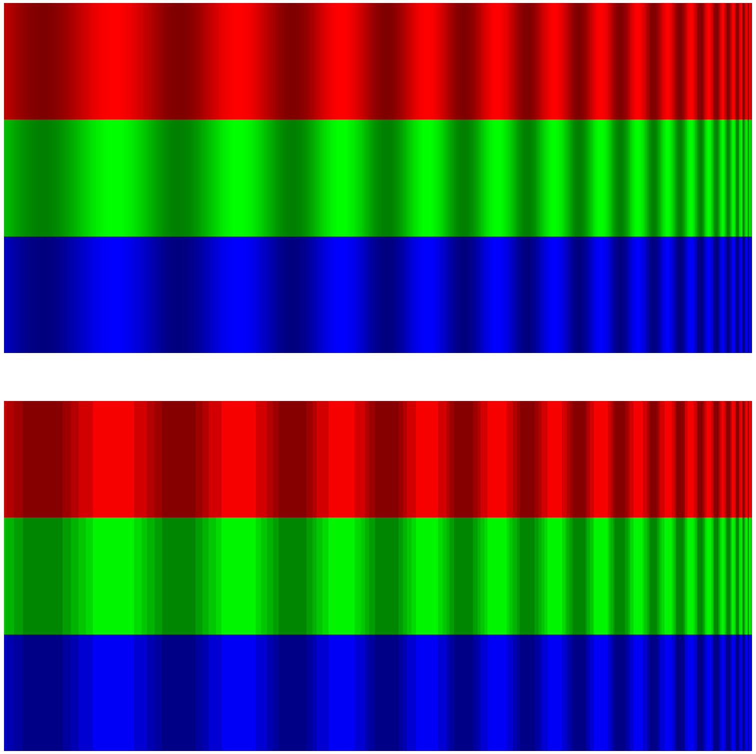
Original

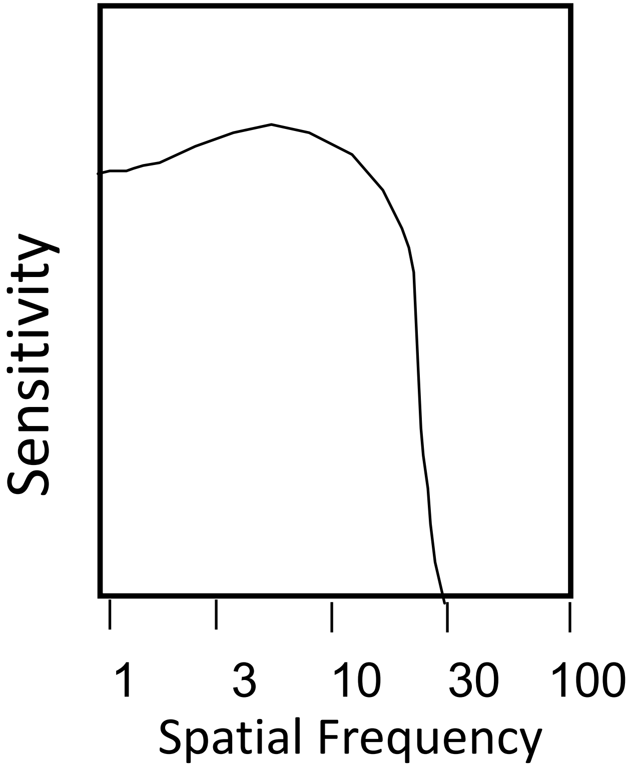
RGB Quantization

Lab Quantization

More on Color Quantization

- **Observation 2**: Quantization errors are spatially dependent: we are more sensitive to errors at lower spatial frequencies.

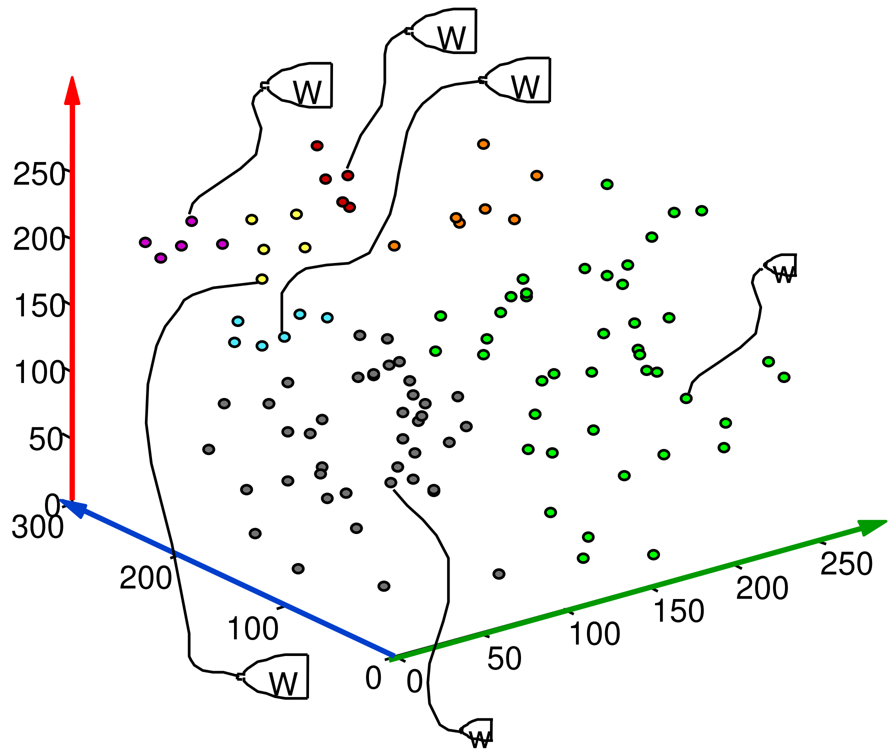




More on Color Quantization

- **Solution**: Assign weight for each pixel color
- Using this scheme we minimize:

$$E = \sum_{i=0}^{k-1} \sum_{j \in C_i} w_j \left(p_j - q_i\right)^2$$



Original

Standard quantization

Weighted quantization

Image segmentation

edge-based: point, line, edge detection

edge-based segmentation(1)

- There are three basic types of gray-level discontinuities in a digital image: points, lines, and edges
- The most common way to look for discontinuities is to run a mask through the image.
- We say that a point, line, and edge has been detected at the location on which the mask is centered if ,where

$$|R| \geq T \qquad\qquad R = w_1 z_1 + w_2 z_2 + \ldots\ldots + w_9 z_9$$

w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

edge-based segmentation(2)

- Point detection

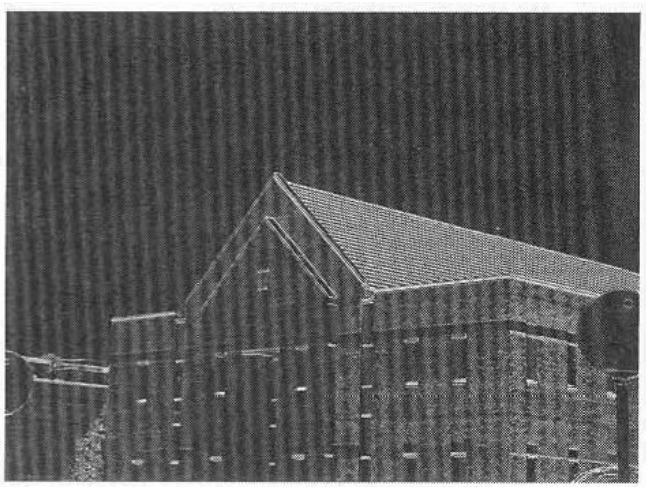
-1	-1	-1
-1	8	-1
-1	-1	-1

a point detection mask

- Line detection

-1	-1	-1
2	2	2
-1	-1	-1

a line detection mask



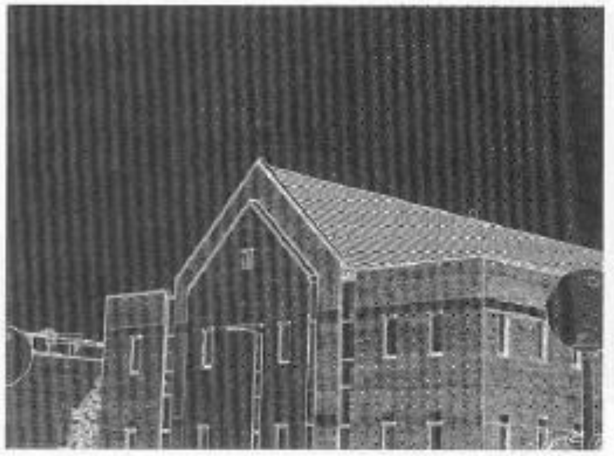
edge-based segmentation(3)

- Edge detection: Gradient operation

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

$$\nabla f = mag(\nabla f) = \left[G_x{}^2 + G_y{}^2 \right]^{1/2}$$

$$\alpha(x, y) = \tan^{-1}\left(\frac{G_y}{G_x}\right)$$

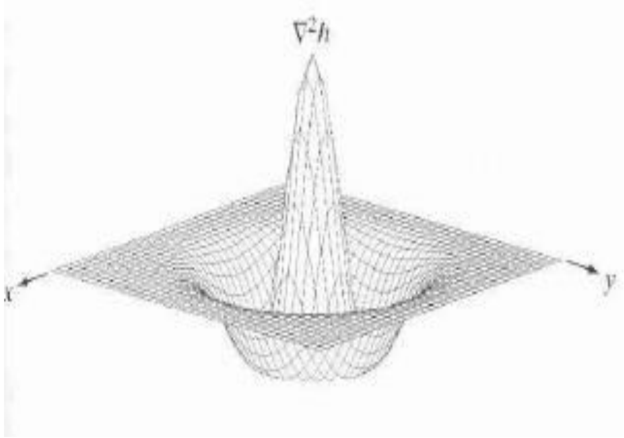


edge-based segmentation(4)

- Edge detection: Laplacian operation

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

$$\nabla^2 h(r) = -\left[\frac{r^2 - \sigma^2}{\sigma^4}\right] e^{-\frac{r^2}{2\sigma^2}}$$



0	0	−1	0	0
0	−1	−2	−1	0
−1	−2	16	−2	−1
0	−1	−2	−1	0
0	0	−1	0	0

Image segmentation

Region-base: SRG, USRG, Fast scanning

region-based segmentation
SRG(1)

- Region growing: Groups pixels or sub-region into larger regions.
  - step1:
    - Start with a set of “seed” points and from these grow regions by appending to each seed those neighboring pixels that have properties similar to the seed.
  - step2:
    - Region splitting and merging

region-based segmentation
SRG(2)

- Advantage:
  - With good connectivity
- Disadvantage:
  - Initial seed-points:
    - different sets of initial seed-point cause different segmented result
  - Time-consuming problem

region-based segmentation
USRG(1)

- Unseeded region growing:
  - no explicit seed selection is necessary, the seeds can be generated by the segmentation procedure automatically.
  - It is similar to SRG except the choice of seed point

region-based segmentation
USRG(2)

- Advantage:
  - easy to use
  - can readily incorporate high level knowledge of the image composition through region threshold

- Disadvantage:
  - slow speed

region-based segmentation
fast scanning(1)

- Fast scanning Algorithm:
  - The fast scanning algorithm somewhat resembles unseeded region growing
  - the number of clusters of both two algorithm would not be decided before image passing through them.

255	250	254	80	150	149	152	150
250	82	81	85	88	149	151	149
84	85	82	84	89	188	193	152
79	81	83	80	79	195	191	155
81	83	123	121	123	120	122	124
40	85	120	125	120	230	235	229

255	250	254	80	150	149	152	150
250	82	81	85	88	149	151	149
84	85	82	84	89	188	193	152
79	81	83	80	79	195	191	155
81	83	123	121	123	120	122	124
40	85	120	125	120	230	235	229

region-based segmentation
fast scanning(2)

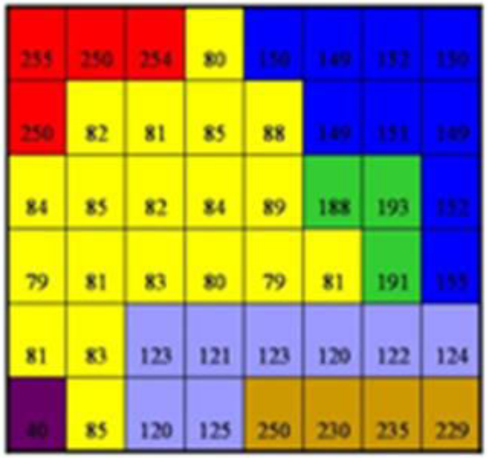
255	250	254	80	150	149	152	150
250	82	81	85	88	149	151	149
84	85	82	84	89	188	193	152
79	81	83	80	79	195	191	155
81	83	123	121	123	120	122	124
40	85	120	125	120	230	235	229

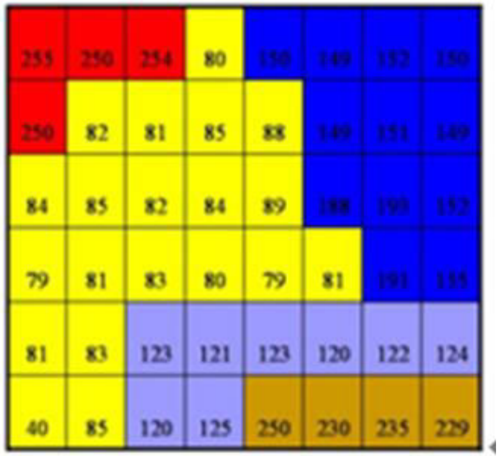
255	250	254	80	150	149	152	150
250	82	81	85	88	149	151	149
84	85	82	84	89	188	193	152
79	81	83	80	79	195	191	155
81	83	123	121	123	120	122	124
40	85	120	125	120	230	235	229

255	250	254	80	150	149	152	150
250	82	81	85	88	149	151	149
84	85	82	84	89	188	193	152
79	81	83	80	79	195	191	155
81	83	123	121	123	120	122	124
40	85	120	125	120	230	235	229

255	250	254	80	150	149	152	150
250	82	81	85	88	149	151	149
84	85	82	84	89	188	193	152
79	81	83	80	79	195	191	155
81	83	123	121	123	120	122	124
40	85	120	125	120	230	235	229

region-based segmentation
fast scanning(3)





- Last step:
  - merge small region to big region

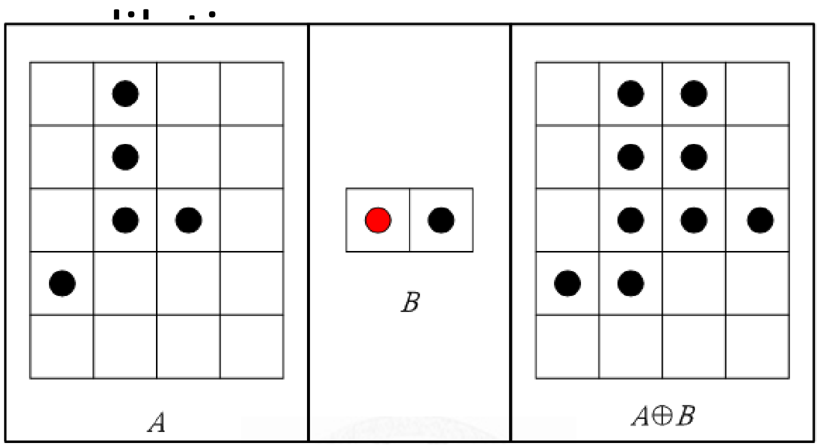
region-based segmentation
fast scanning(4)

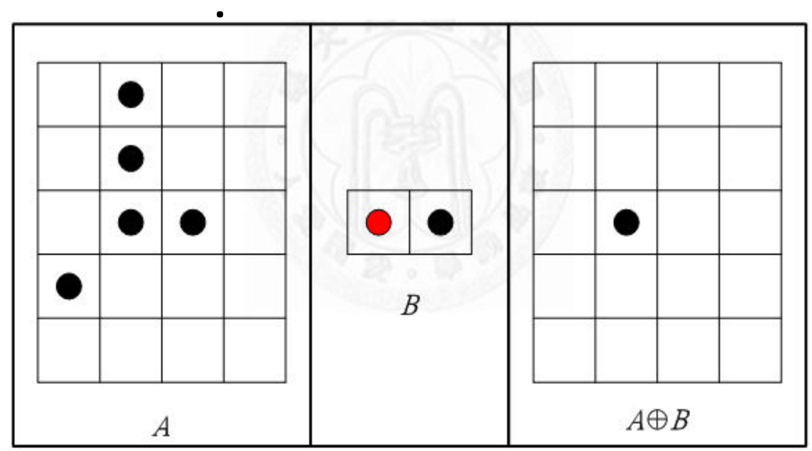
- Advantage:
  - The speed is very fast
  - The result of segmentation will be intact with good connectivity

- Disadvantage:
  - The matching of physical object is not good
    - It can be improved by morphology and geometric mathematic

region-based segmentation

fast scanning-improved by morphology





$$A \oplus B = \{c \in E^N \mid c = a + b \text{ for some } a \in A \text{ and } b \in B\}$$

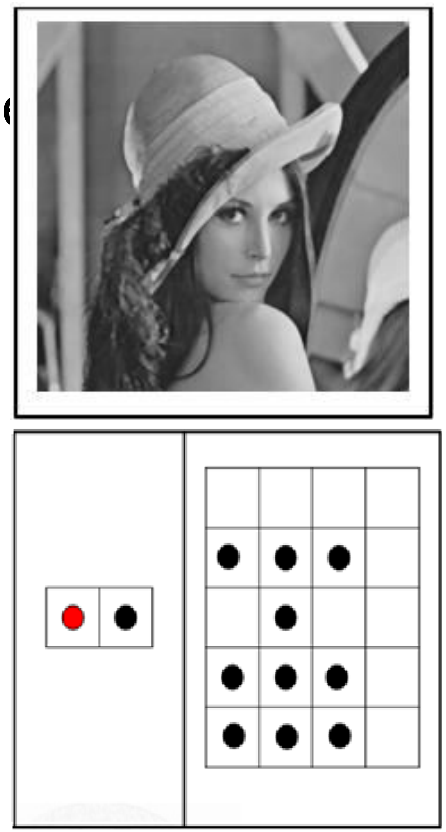
$$A\,!\;\; B = \{x \in E^N \mid x + b \in A \text{ for every } b \in B\}$$

region-based segmentation
fast scanning-improved by morphology

- 
- 

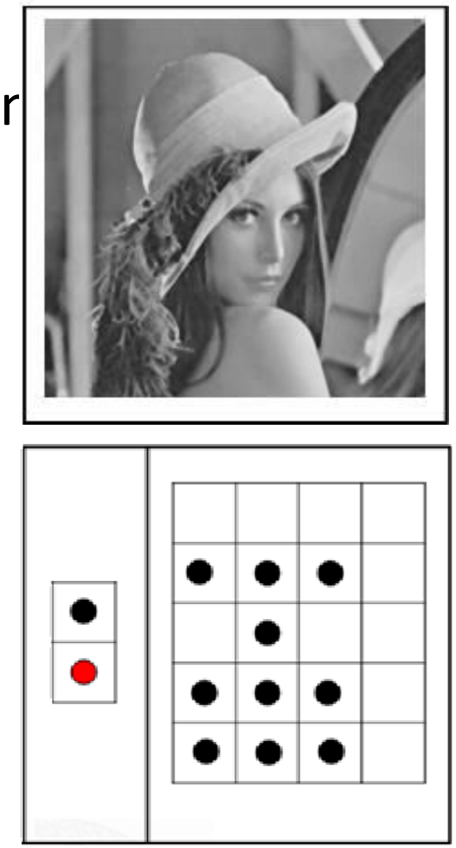
region-based segmentation
fast scanning-improved by morphology

- ope



Erosion=>Dilation

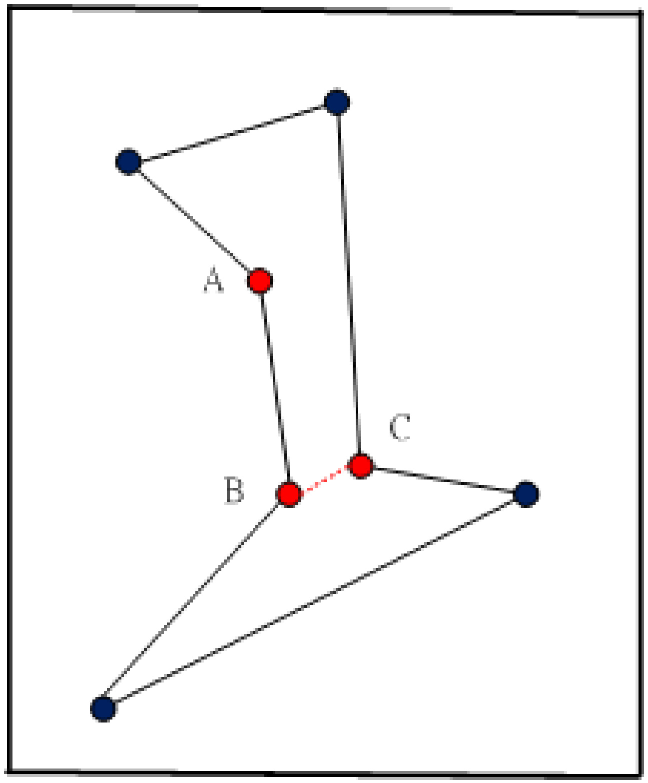
- closir

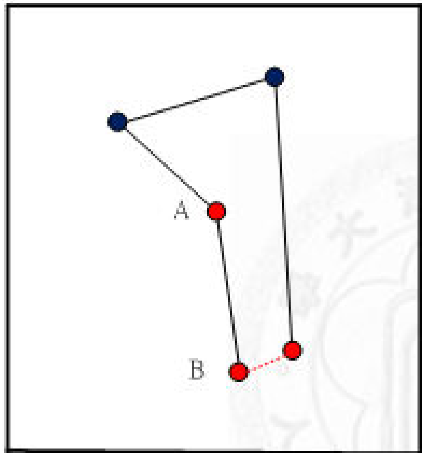


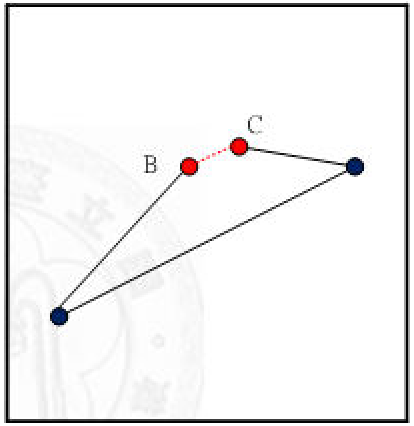
Dilation=>Erosion

region-based segmentation

fast scanning-improved by Geometric Mathematic

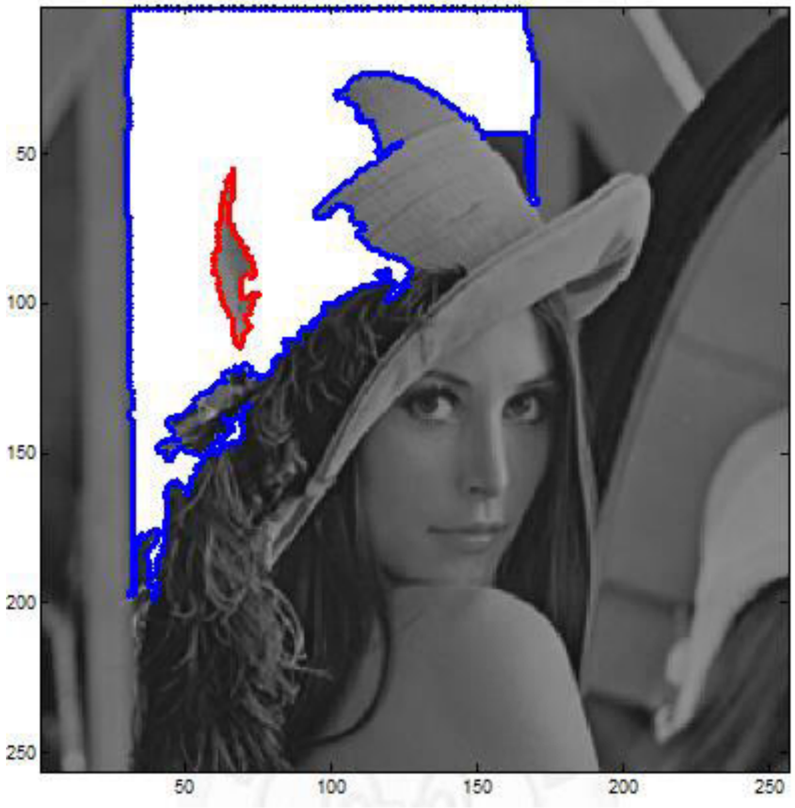






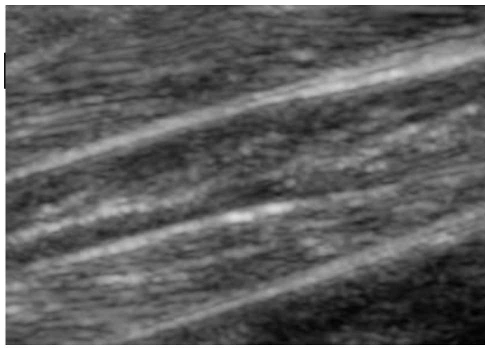
region-based segmentation

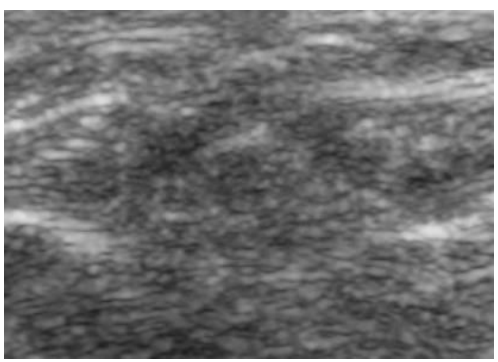
fast scanning-improved by Geometric Mathematic



region-based segmentation
application

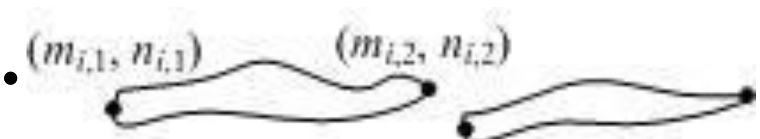
- Musc n



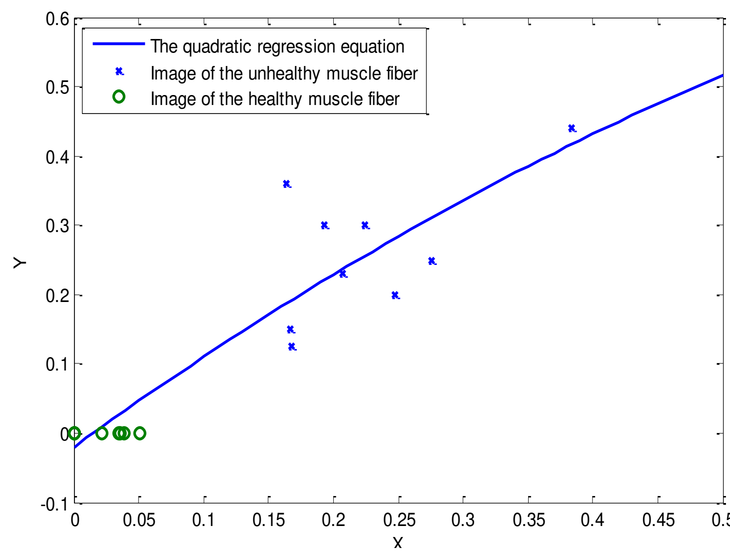


- How to judge for using image segmentation?

-



segment it.

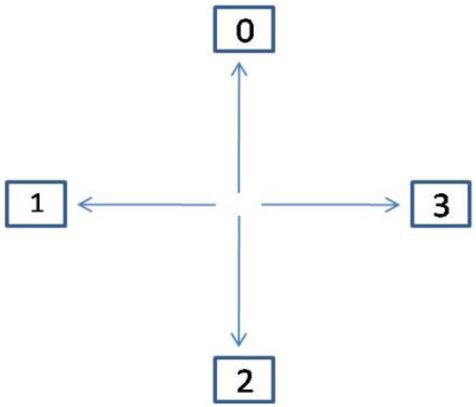


Representation

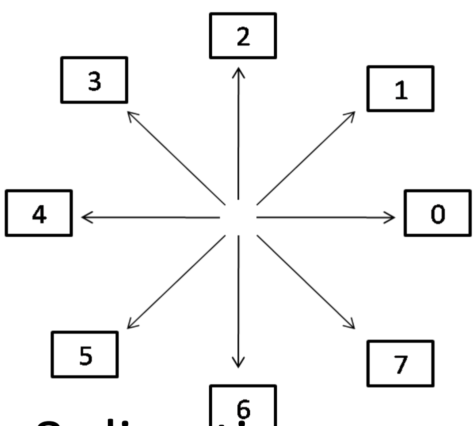
chain code, polynomial approximation, signature, skeletons

Representation

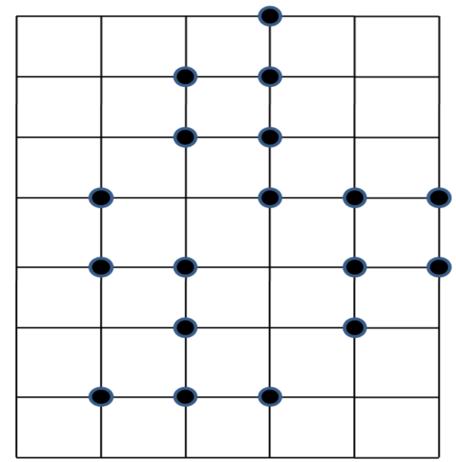
chain code

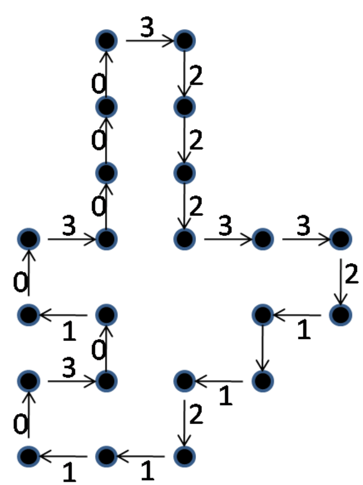


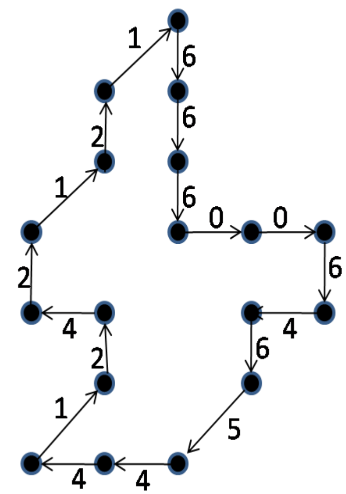
4-direction



8-direction



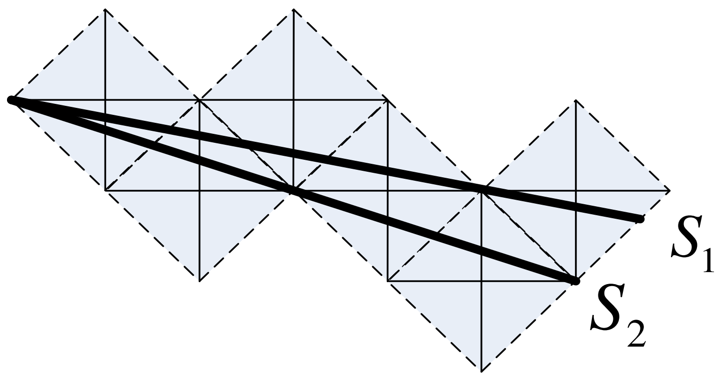




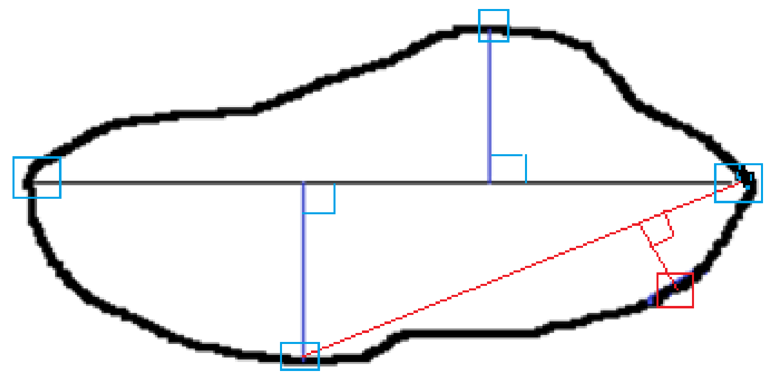
Representation

polynomial approximations

- Merging Techniques



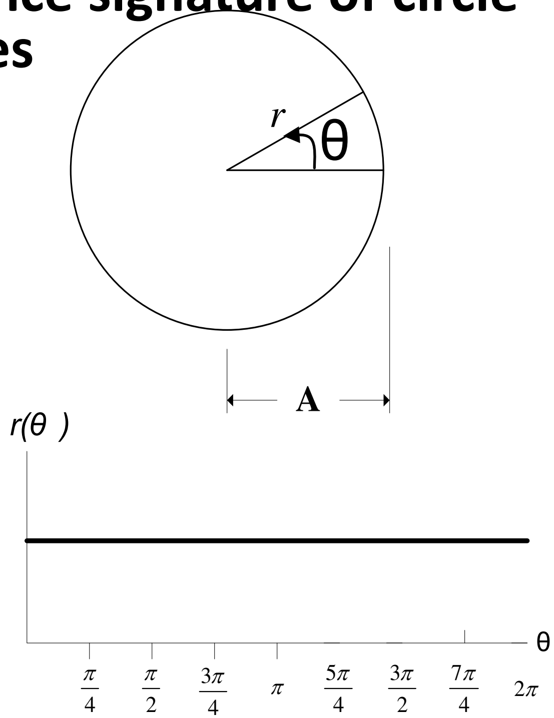
- Splitting Techniques



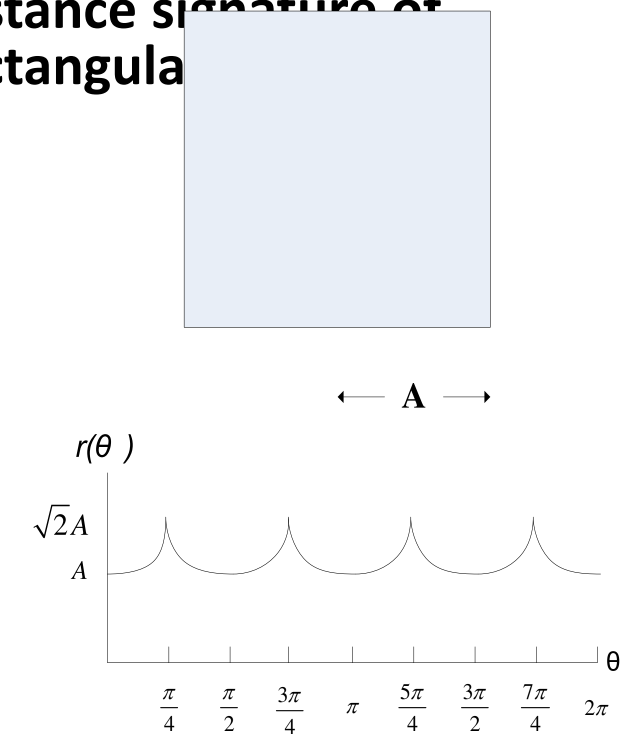
Representation

signature

Distance signature of circle shapes



Distance signature of rectangula

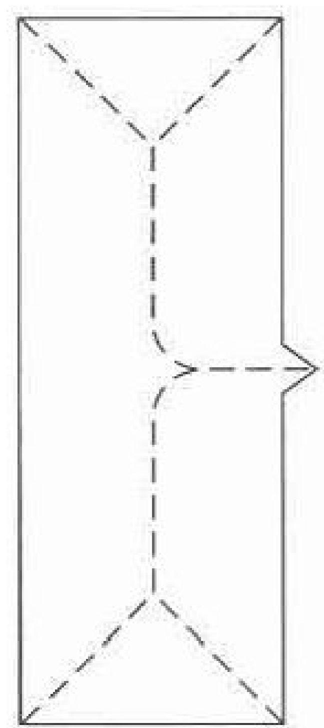


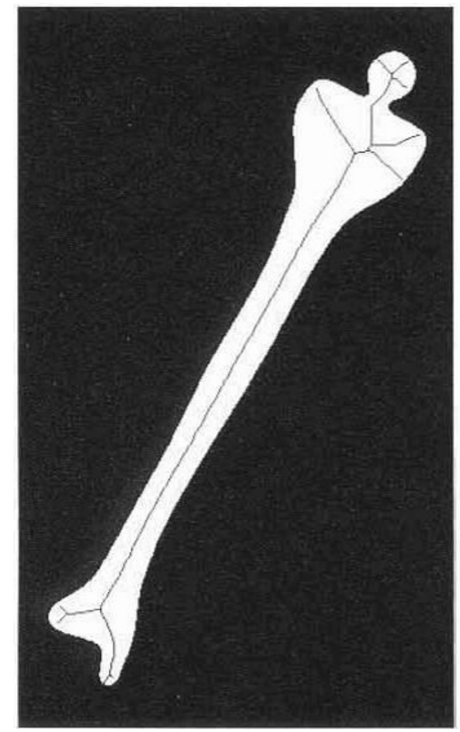
Representation
skeletons

- Step1:
  - (a) $2 \le N(p_1) \le 6$
  - (b) $T(p_1) = 1$
  - (c) $p_2 \cdot p_4 \cdot p_6 = 0$
  - (d) $p_4 \cdot p_6 \cdot p_8 = 0$
- Step2:
  - (c') $p_2 \cdot p_4 \cdot p_8 = 0$
  - (d') $p_2 \cdot p_6 \cdot p_8 = 0$

p_9	p_2	p_3
p_8	p_1	p_4
p_7	p_6	p_5

0	0	1
0	p_1	1
0	0	1

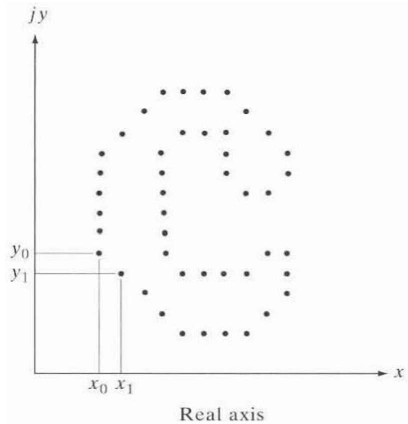


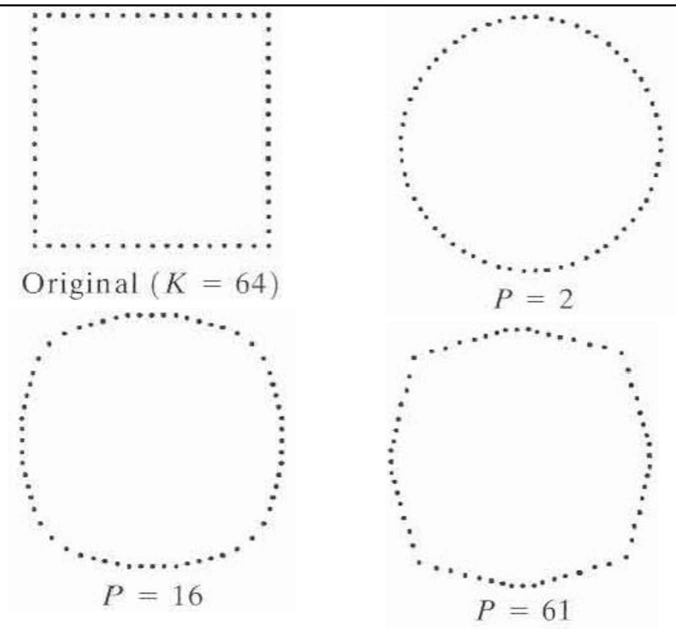


Descriptors

boundary descriptor: Fourier descriptor, polynomial approximation

Boundary Descriptors
Fourier descriptors (1)





- Step1: $s(k) = x(k) + jy(k)$
- Step2: (DFT)

$$a(u) = \frac{1}{K} \sum_{k=0}^{K-1} s(k) e^{-j2\pi uk/K}$$

- Step3: (reconstruction)

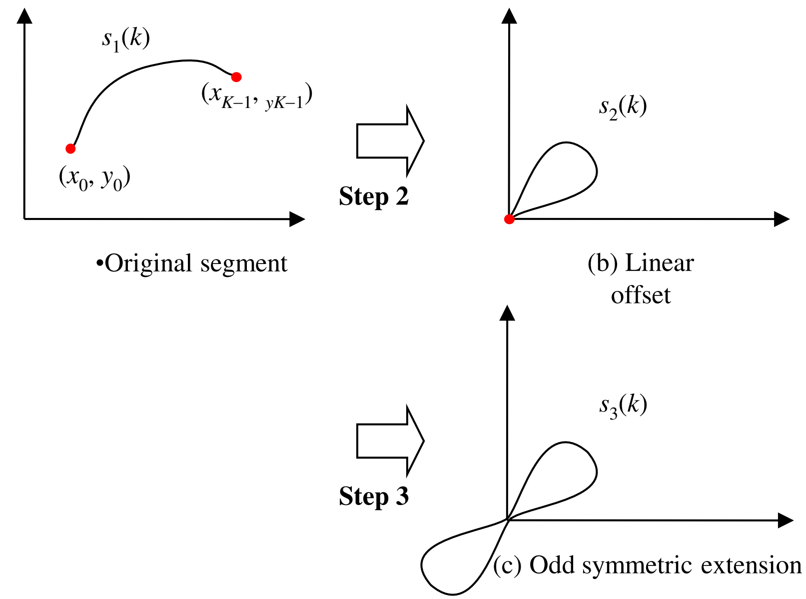
if a(u)=0 for u>P-1

$$\hat{s}(k) = \sum_{u=0}^{P-1} a(u) e^{j2\pi uk/K}$$

- Disadvantage:
  - Just for closed boundaries

Boundary Descriptors
Fourier descriptors (2)

- What's the reason that previous Fourier descriptors can't be used for non-closed boundaries?



- How can we use the method to descript non-closed boundaries?

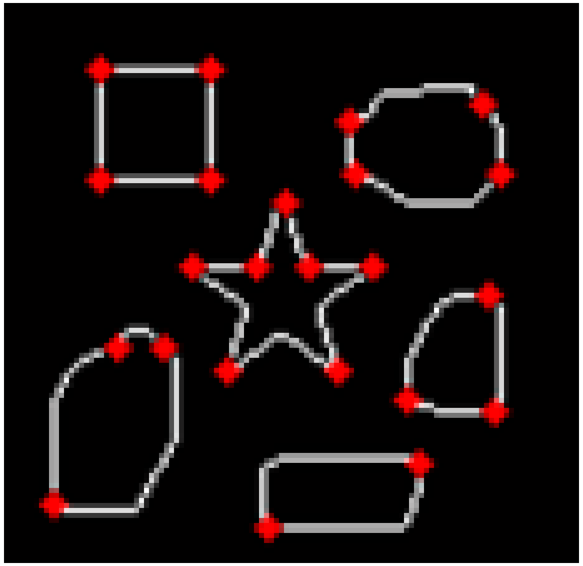
(a)linear offset

(b)odd-symmetric extension

Boundary Descriptors
Fourier descriptors (3)

- The proposed method is used not only for non-closed boundaries but also for closed boundaries.

- Why we used proposed method to descript closed boundaries rather than previous method?



Boundary Descriptors

polynomial approximation(1)

- Lagrange Polynomial

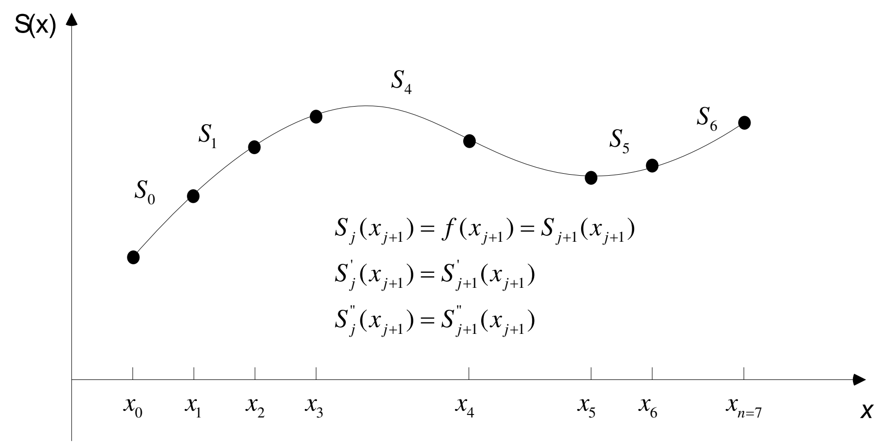
$$P(x) = f(x_0)L_{n,0}(x) + \cdots + f(x_n)L_{n,n}(x) = \sum_{k=0}^{n} f(x_k)L_{n,k}(x)$$

$$L_{n,k}(x) = \frac{(x-x_0)\cdots(x-x_{k-1})(x-x_{k+1})\cdots(x-x_n)}{(x_k-x_0)\cdots(x_k-x_{k-1})(x_k-x_{k+1})\cdots(x_k-x_n)}$$

$$f(x) = P(x) + \frac{f^{(n+1)}(\xi(x))}{(n+1)!}(x-x_0)(x-x_1)\cdots(x-x_n)$$

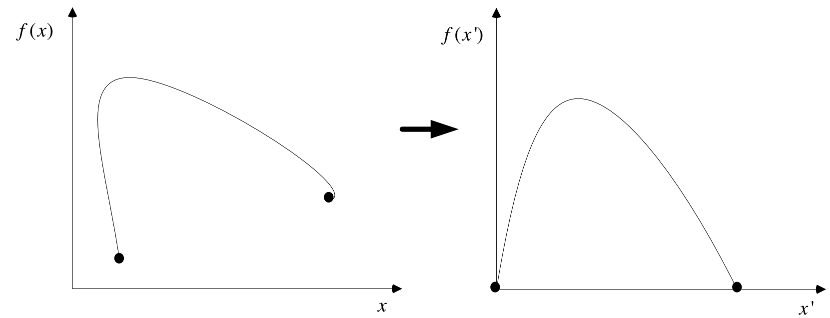
$$e = \left| f(x) - P(x) \right|$$

- Cubic Spline Interpolation



Boundary Descriptors
polynomial approximation(2)

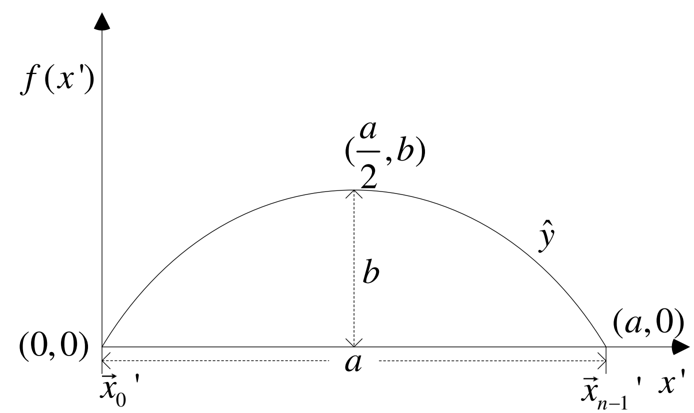
- Proposed method(1)
  - Step1: rotate the boundary and let two end point locate at x-axis



  - Step2: use second order polynomial to approximate the boundary

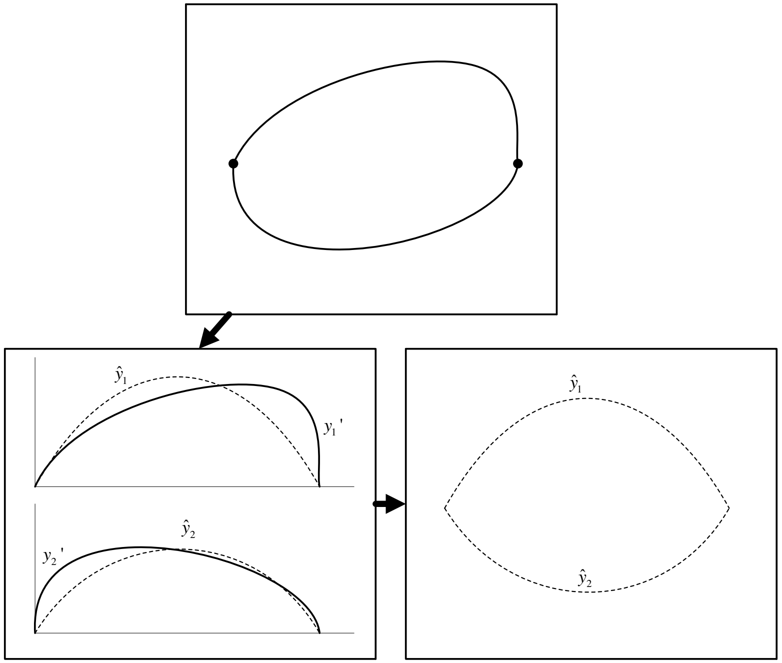
$$\hat{y} = \frac{-4b}{a^2}(x' - \frac{a}{2})^2 + b$$

$$e = \left| y' - \hat{y} \right|^2 = \sum_{j=0}^{n-1} \left| y_j' + \frac{4b}{a^2}(x_j' - \frac{a}{2})^2 - b \right|^2$$



Boundary Descriptors
polynomial approximation(3)

- Proposed method(2)
  - If the boundary is closed, how can we do?
  - Step1: use split approach divide the boundary to two parts.
  - Step2: use parabolic function to fit the boundary.

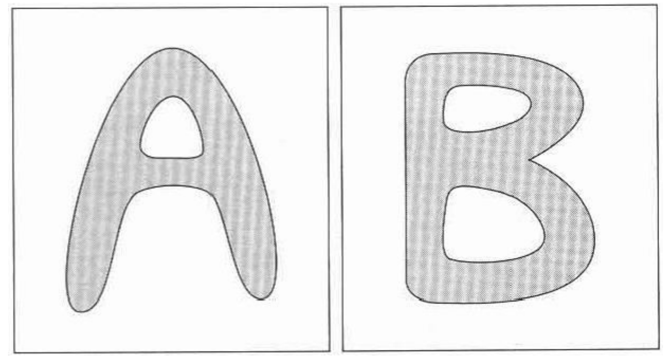


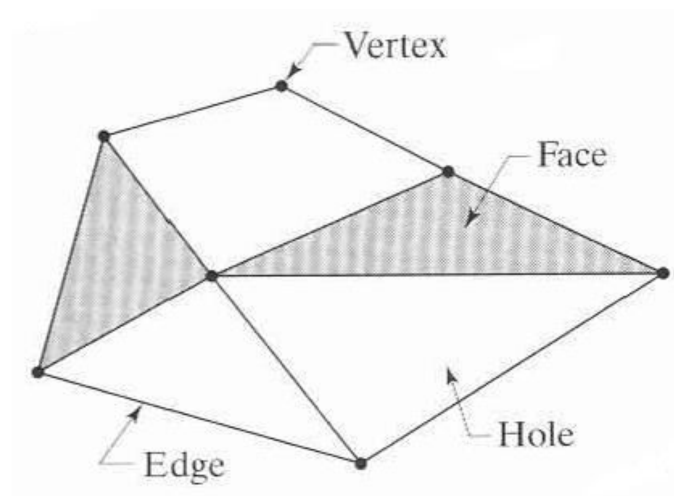
Descriptors

Regional descriptors: Topological, Texture

Regional Descriptors
Topological

- $E = V - Q + F = C - H$
  - E: Euler number
  - V: the number of vertices
  - Q: the number of edges
  - F: the number of faces
  - C: the number of connected component
  - H: the number of holes

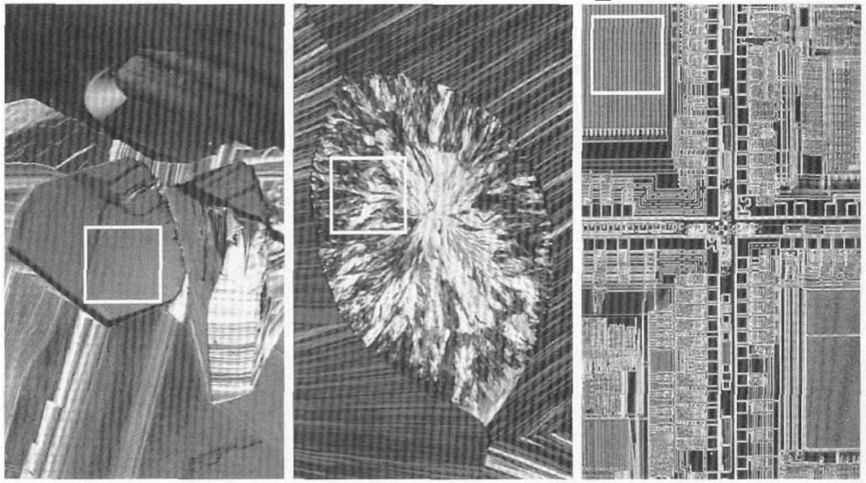




Regional Descriptors

Texture

- Statistical approaches
  - smooth, coarse, regular



- nth moment:

$$u_n(z) = \sum_{i=0}^{L-1} (z_i - m)^n p(z_i)$$

$$m = \sum_{i=0}^{L-1} z_i p(z_i)$$

  - 2th moment:
    - is a measure of gray level contrast(relative smoothness)
  - 3th moment:
    - is a measure of the skewness of the histogram
  - 4th moment:
    - is a measure of its relative flatness
  - 5th and higher moments:
    - are not so easily related to histogram shape

Conclusion

- Image segmentation
  - speed, connectivity, match physical objects or not…
    - match physical objects:
      - morphological: how to choose foreground or background?
      - geometric mathematic: wrong connection

- Representation & Description
  - Boundary descriptor:
    - rotation, translation, degree of match boundary, closed or non-closed boundary

Reference

- [1] R.C. Gonzalez, R.E. Woods, Digital Image Processing second edition, Prentice Hall, 2002
- [2] J.J. Ding, W.W. Hong, Improvement Techniques for Fast Segmentation and Compression
- [3] J.J. Ding, Y.H. Wang, L.L. Hu, W.L. Chao, Y.W. Shau, Muscle Injury Determination By Image Segmentation
- [4] J.J. Ding, W.L. Chao, J.D. Huang, C.J. Kuo, Asymmetric Fourier Descriptor Of Non-Closed segments

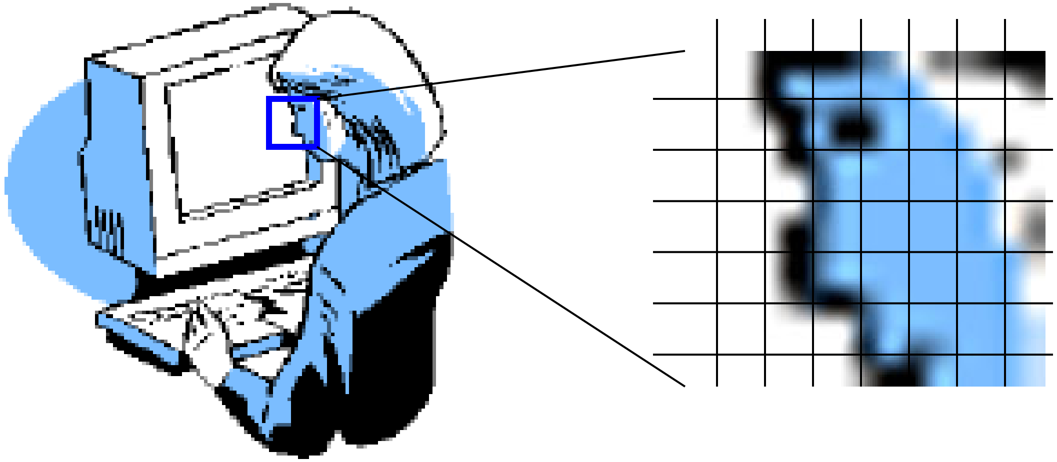
Image Representation

Digital Image Sources

- Digital Cameras
- Scanned Film & Photographs
- Digitized TV Signals
- Computer Graphics
- Radar & Sonar
- Medical Imaging Devices (X-Ray, CT)
- The Internet

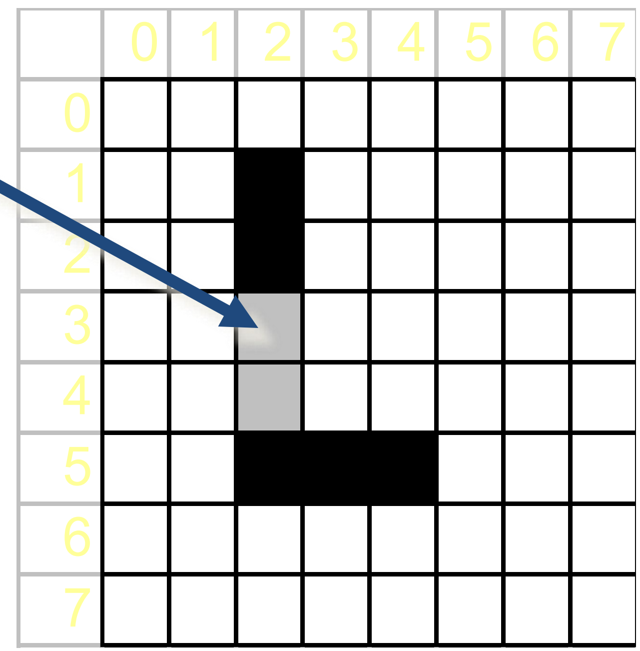
Images - 2D array of values = pixels

- Pixel = "Picture Element"
- Image [x,y] = pixel value (number)



Pixels and Pixel Values

- Pixel – an element of the 2-D image array



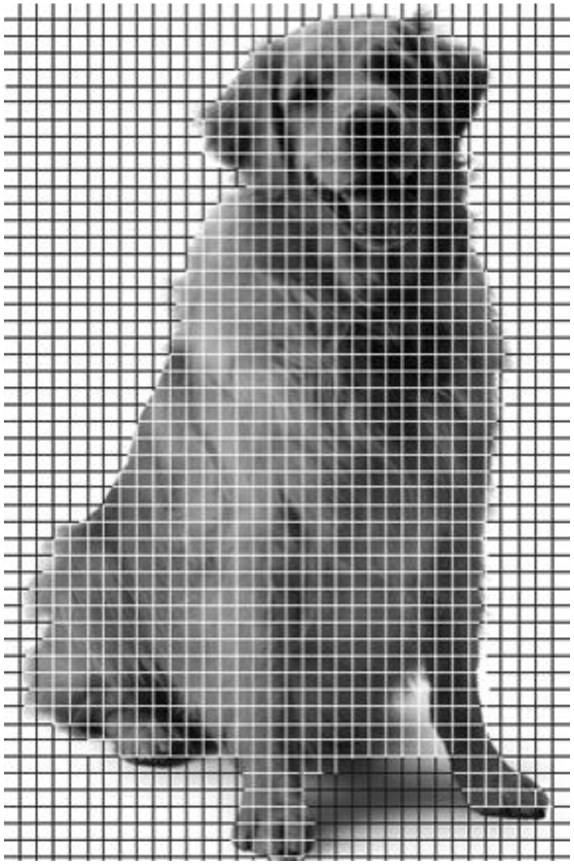
- Pixel Value = brightness
- - black = 0
- - gray = 128
- - white = 255
- - many shades over the 0-255 range

Digitizing Images

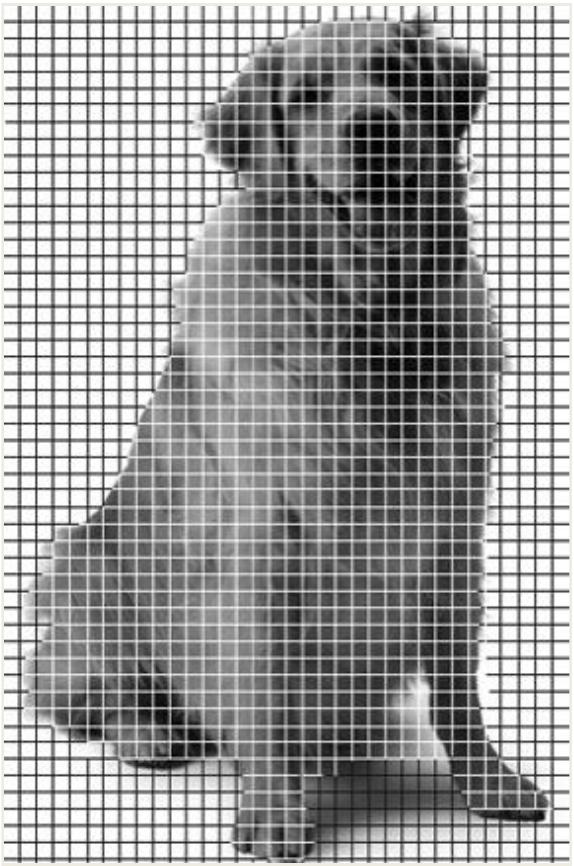
Images are digitized using a two step process:

1. sampling the continuous tone image
2. quantizing pixels

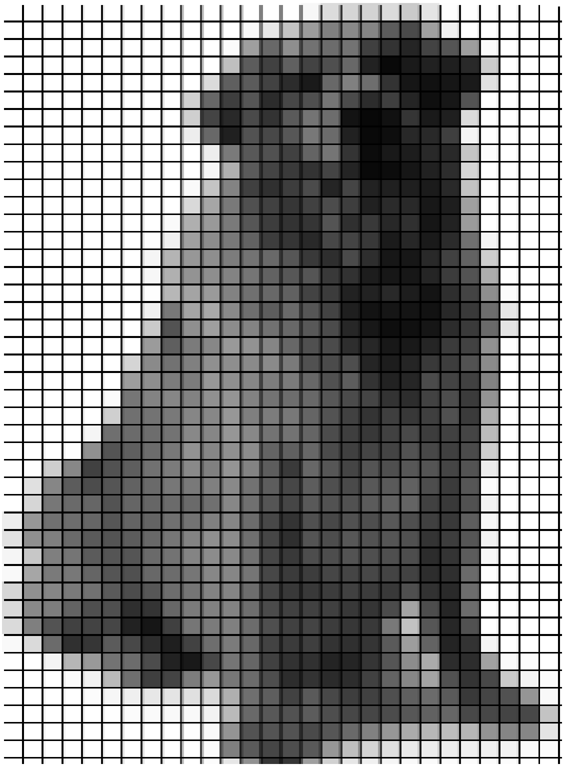
Sampling



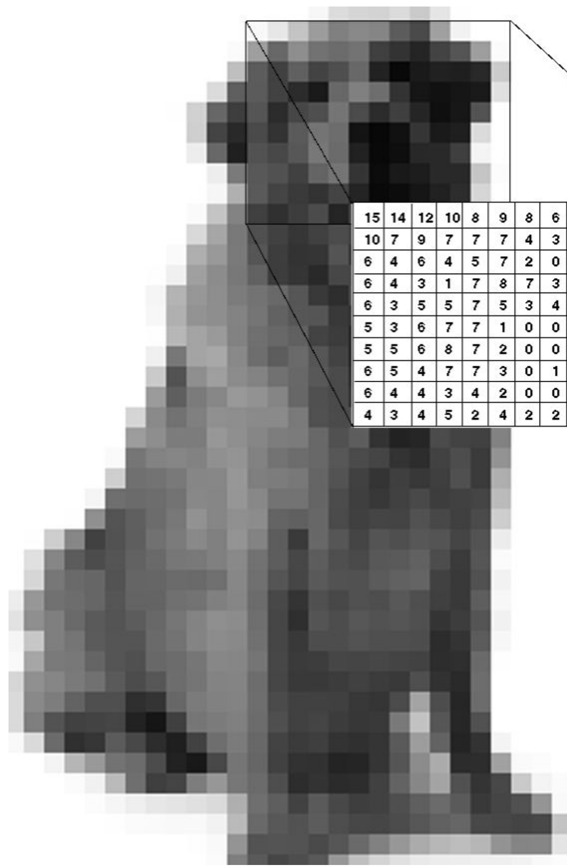
Quantization



pixel’s samples are averaged

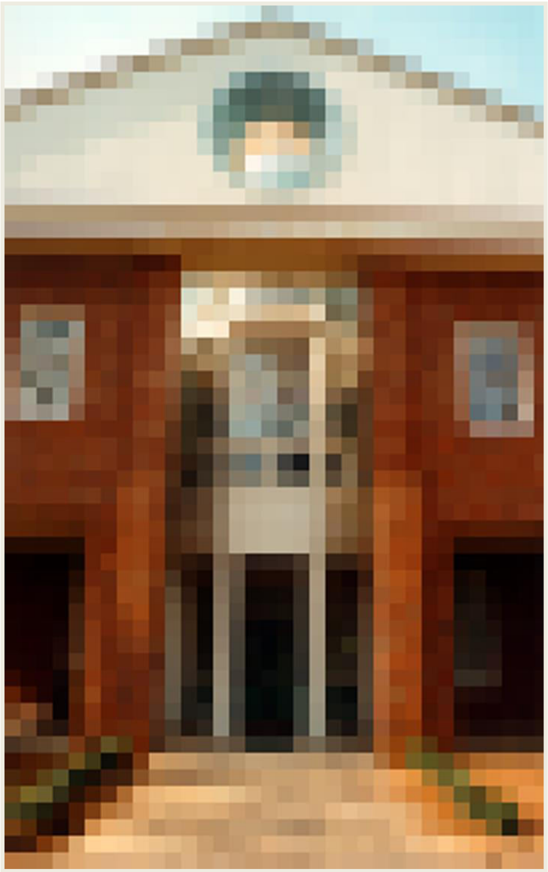


Quantization Example

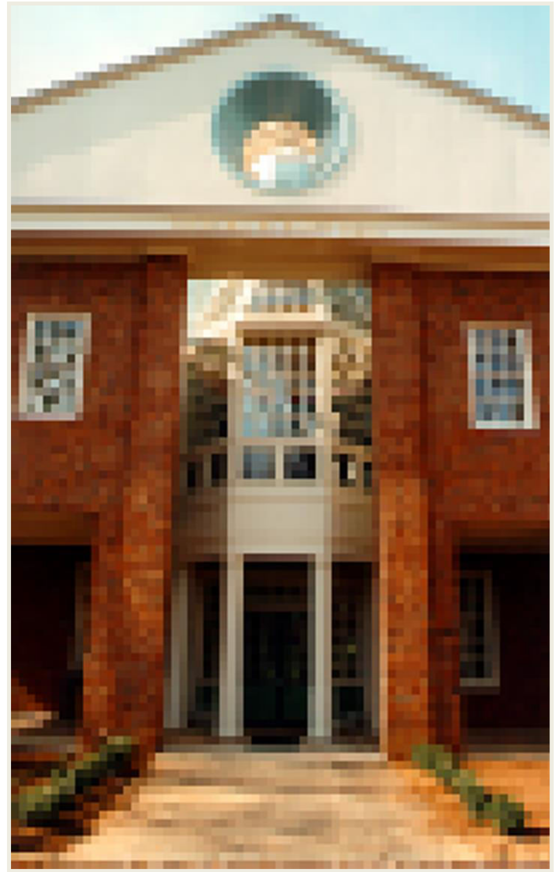


15	14	12	10	8	9	8	6	5	10	14	15	15
10	7	9	7	7	7	4	3	2	4	6	10	15
6	4	6	4	5	7	2	0	1	2	2	2	12
6	4	3	1	7	8	7	3	1	0	1	1	14
6	3	5	5	7	5	3	4	2	0	1	5	15
5	3	6	7	7	1	0	0	3	1	2	13	15
5	5	6	8	7	2	0	0	2	3	4	14	15
6	5	4	7	7	3	0	1	1	3	3	12	15
6	4	4	3	4	2	0	0	1	2	3	13	15
4	3	4	5	2	4	2	2	2	1	2	12	15

Image Resolution



68 x 104



136 x 208

272 x 416

less detail

less storage

more detail

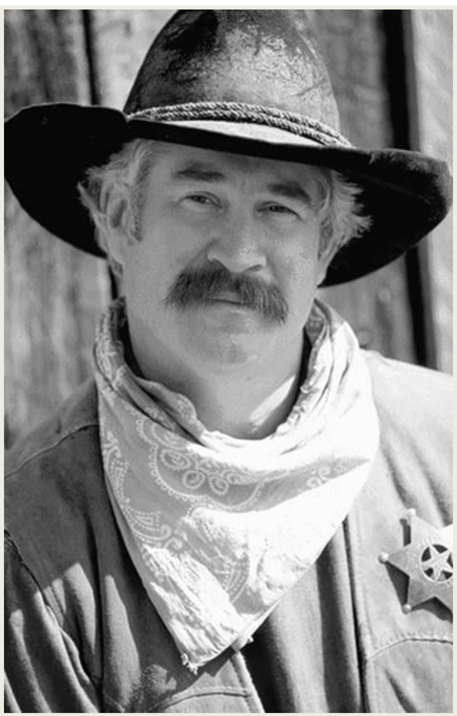
more storage

Digital Cameras

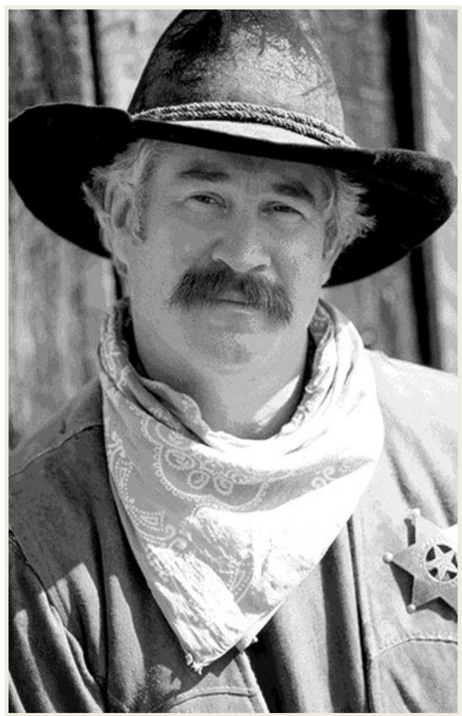
- Very Low Res 640x480 (TV grade)
- Medium-Low Res 1024x768
- Medium Res 2048x1536
- Medium-Hi Res 3072x2048
- Hi-Res 3264x2448

Dynamic Range

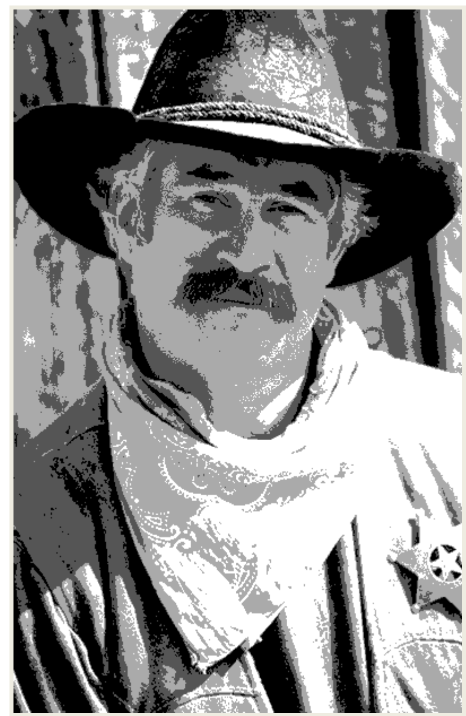
- **The number of quantized pixel values:**



256 levels



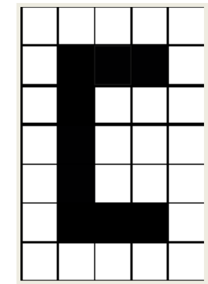
16 levels



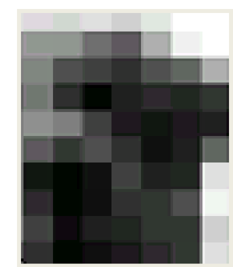
4 levels

2 levels

Images - 2D array of values



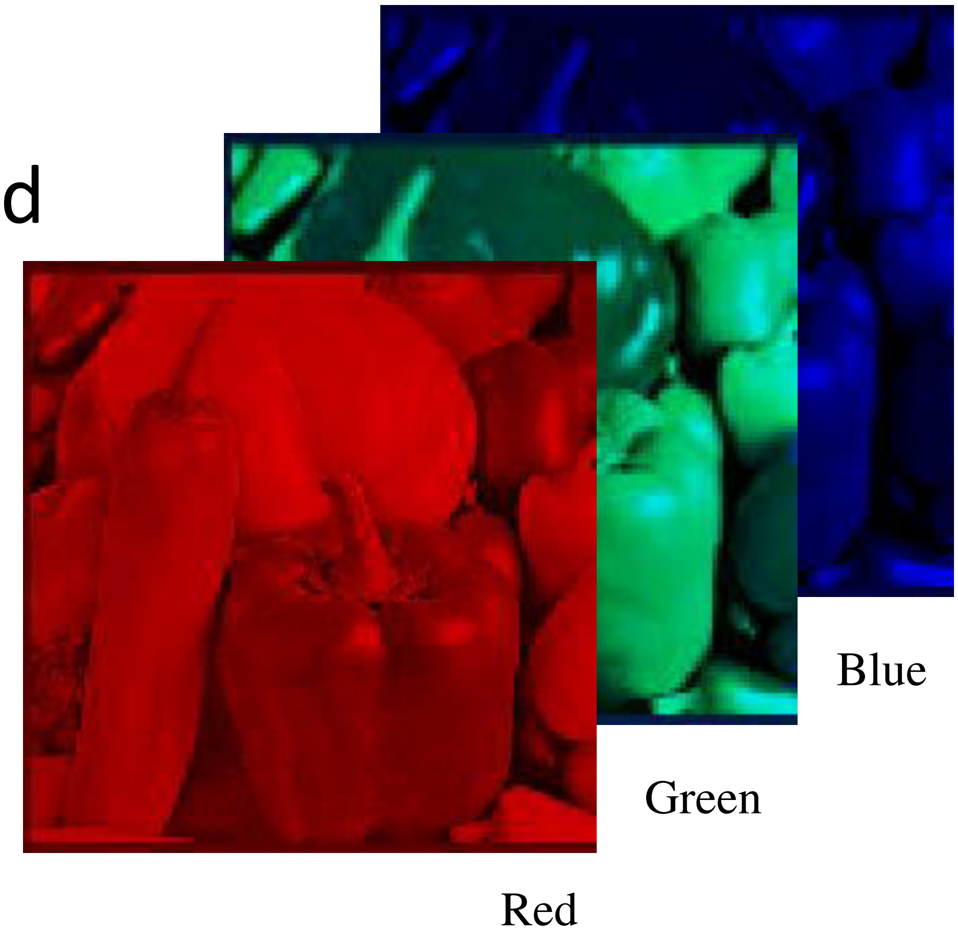
- Binary Images (pixel values = 0,1)
- Grayscale Images (pixel values = 0-255)



- Color Images
  - Each pixel has three color components
    - For example, (red, green, blue) or RGB
  - Each color component is 0-255

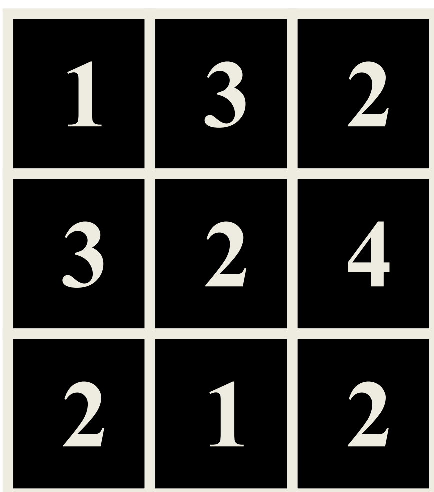
Color Images

3 Images Overlayed

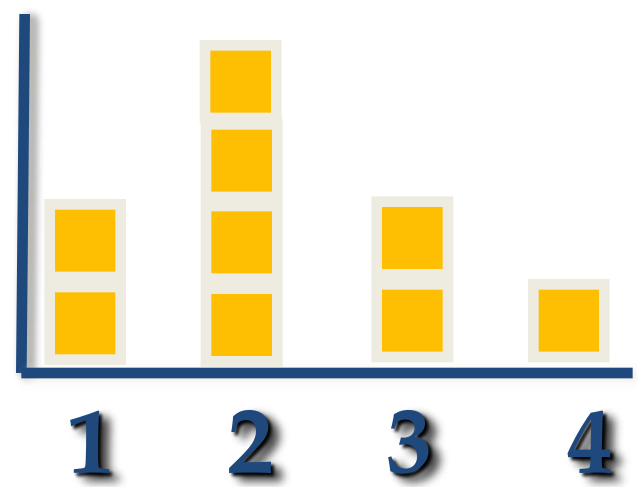


Histograms: What's in the image?

- What is a histogram?
- Simple numeric example



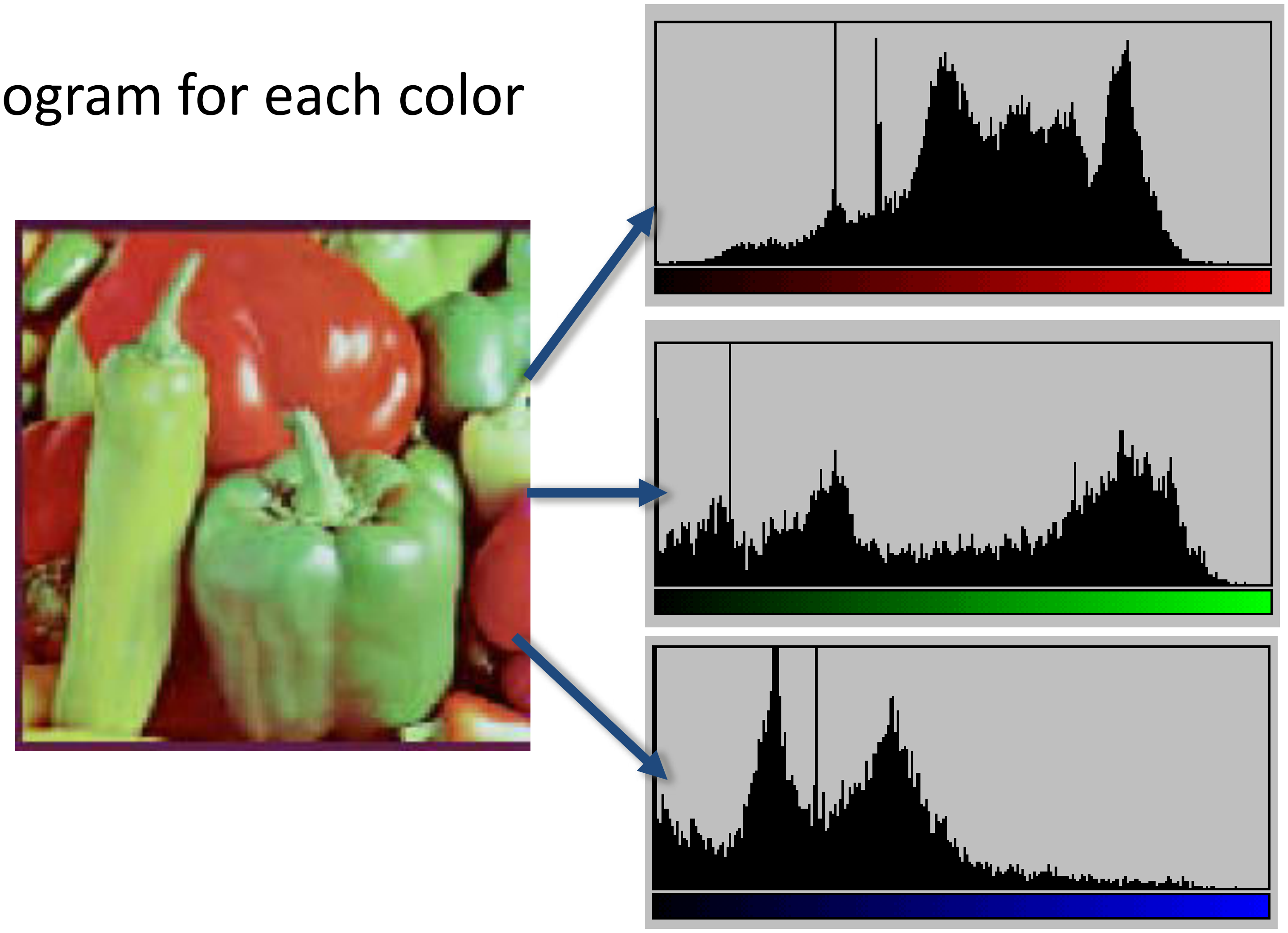
Image



Histogram

Color Image Histograms

- Histogram for each color

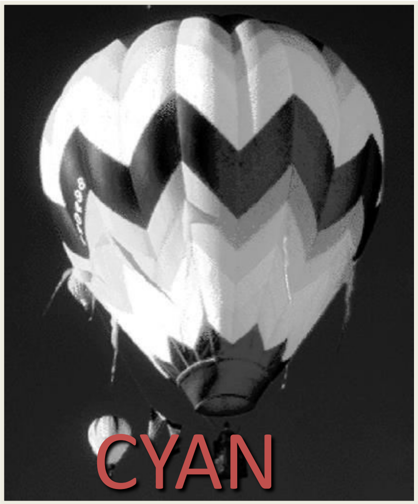


RGB Additive Color Model

bright values => high amounts of that color

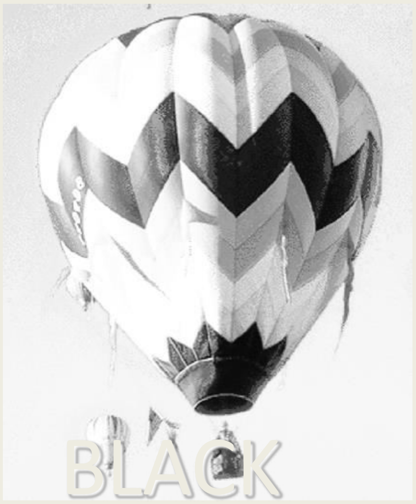
dark values => low amounts of that color

CMYK Subtractive Color Model



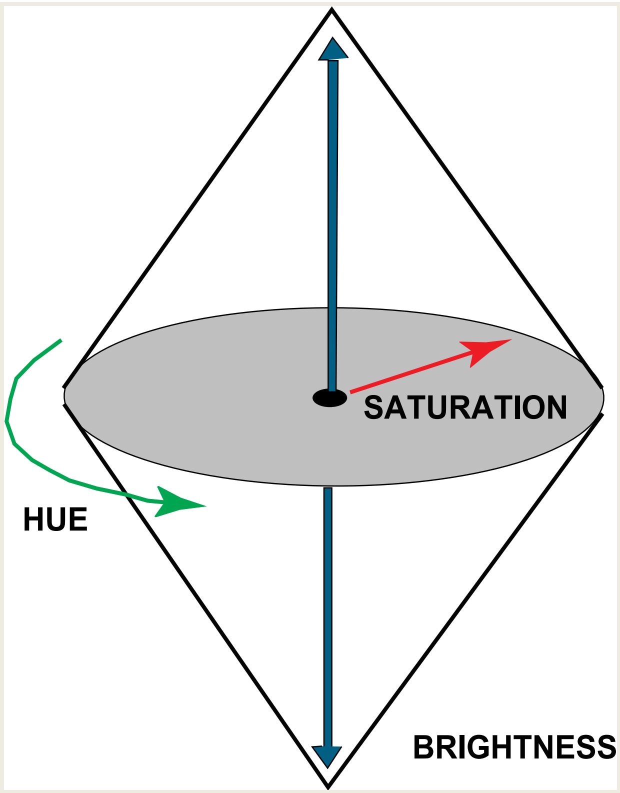
Bright => use less of that ink color

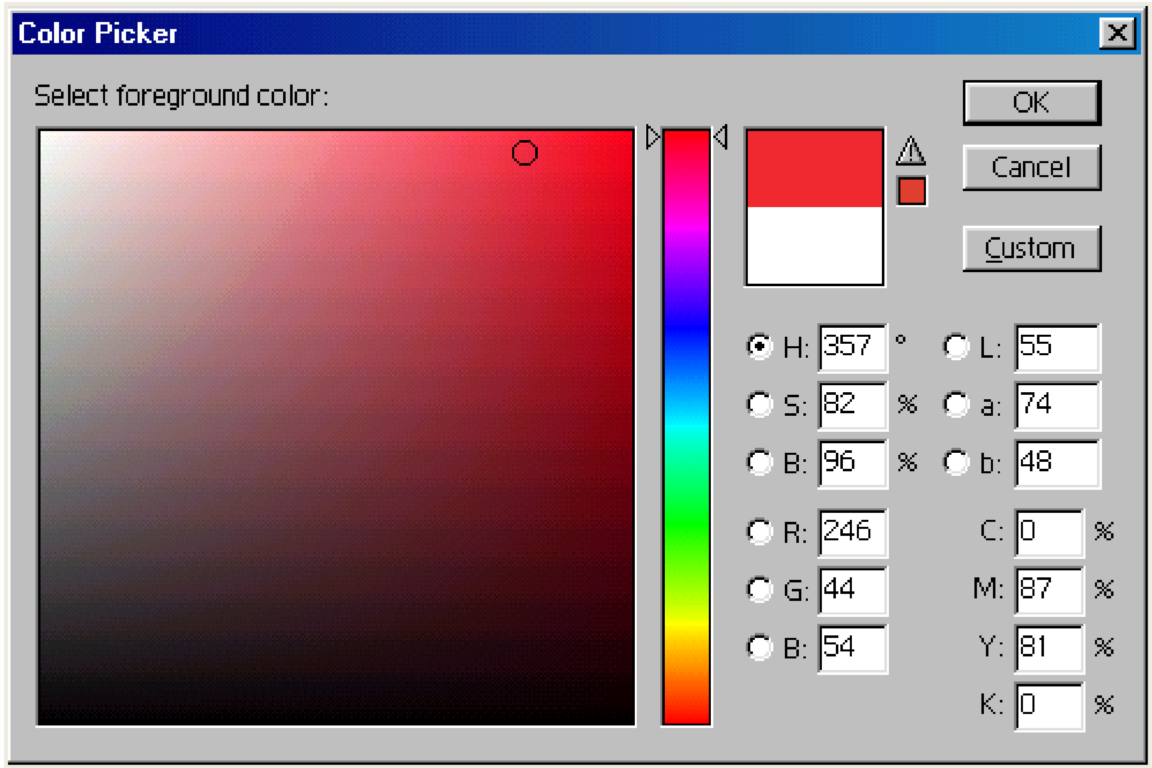
Dark => use lots of that ink color



HSB Visual Color Model

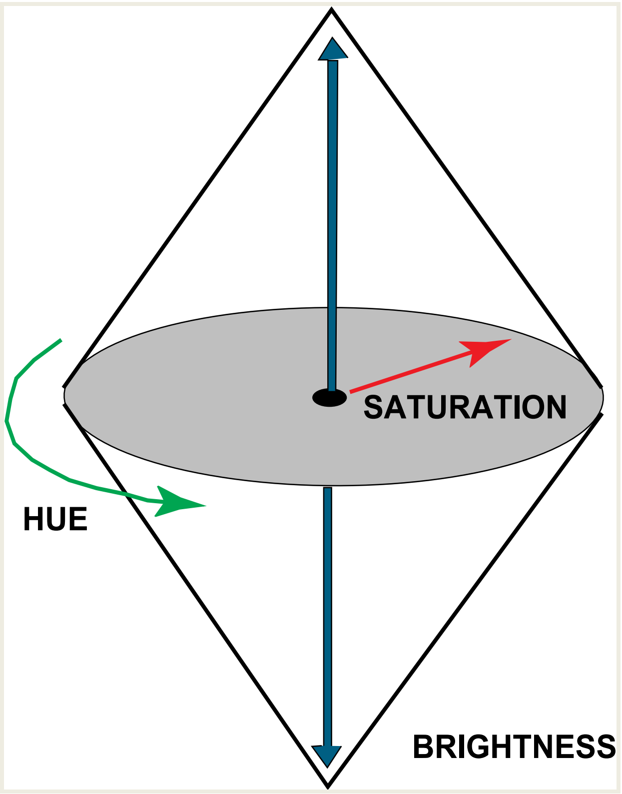
HSB: how artists perceive color properties

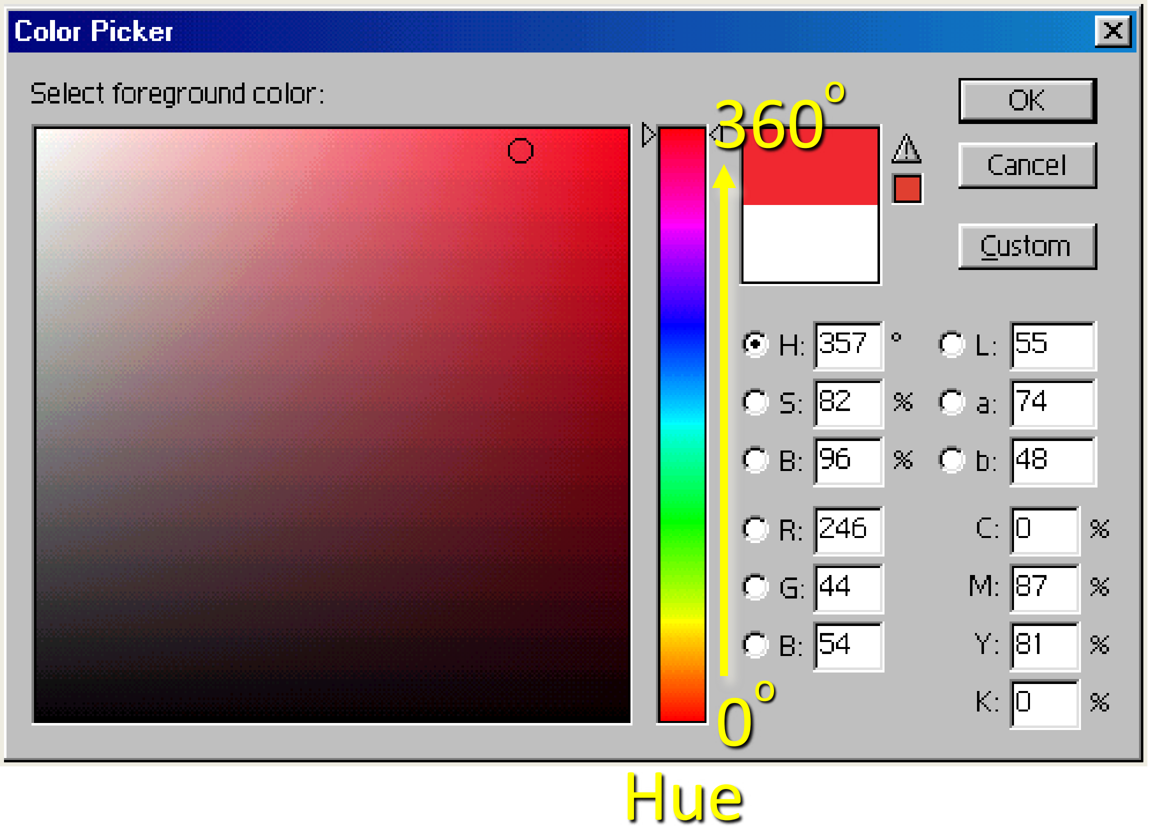




HSB Visual Color Model

HSB: how artists perceive color properties

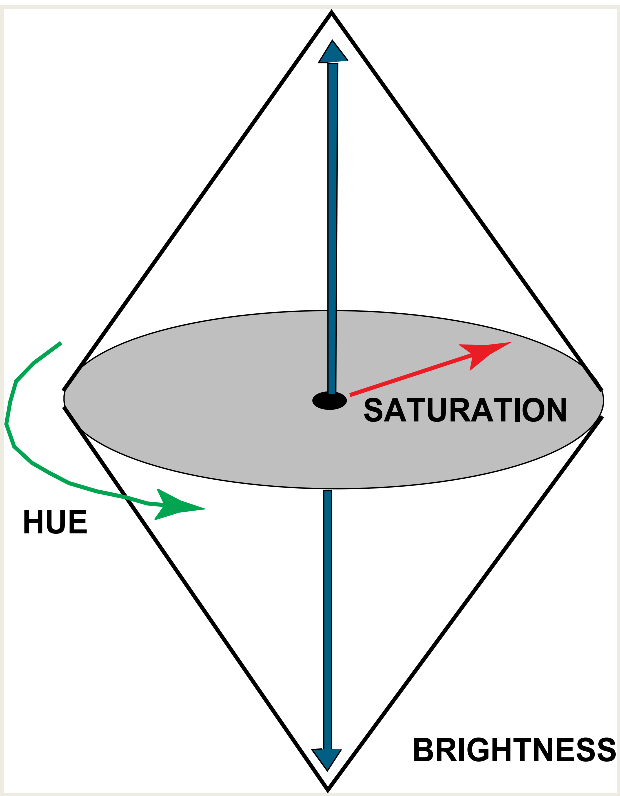


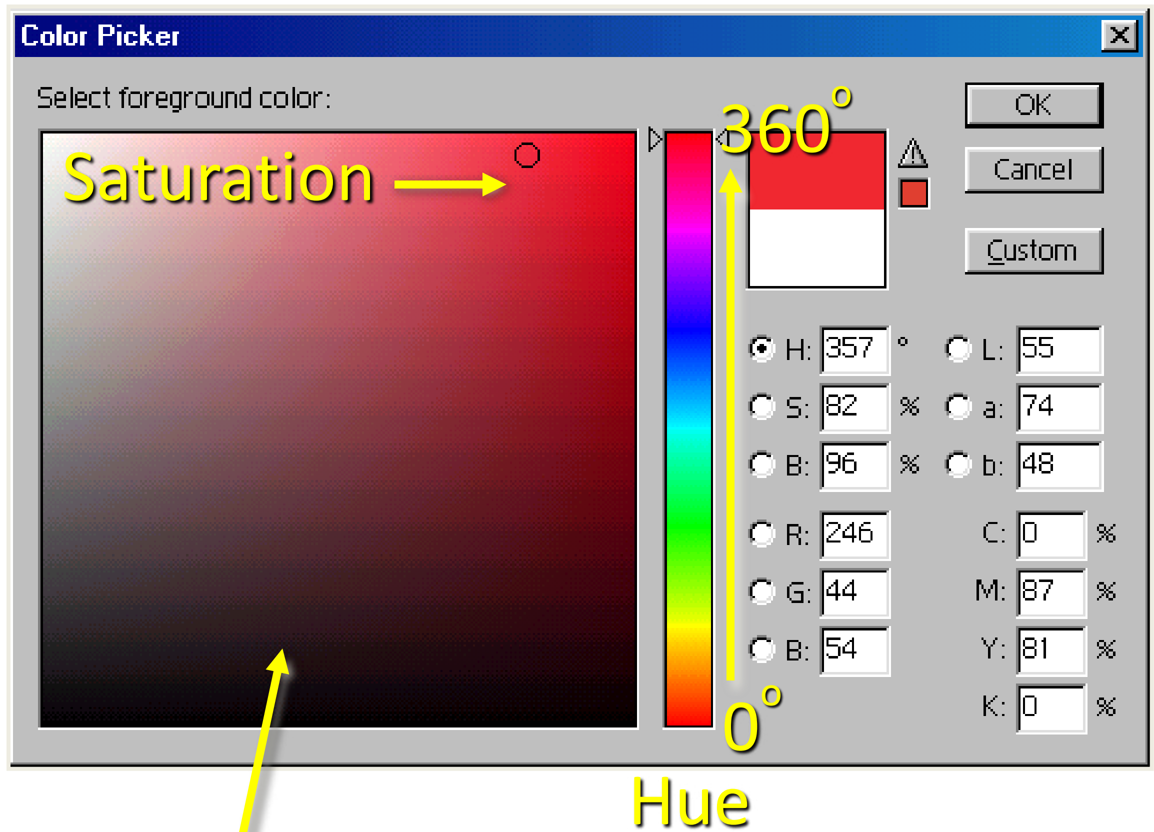


Select Hue

HSB Visual Color Model

HSB: how artists perceive color properties

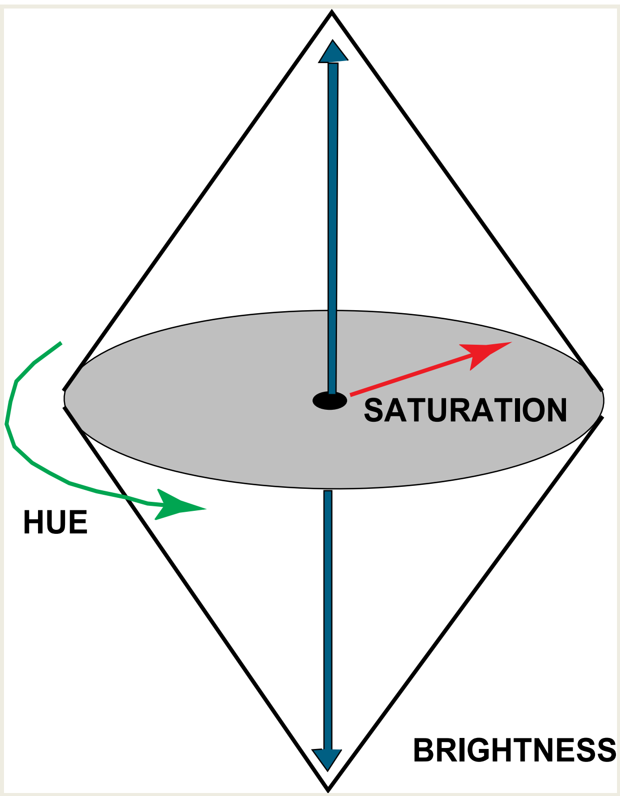


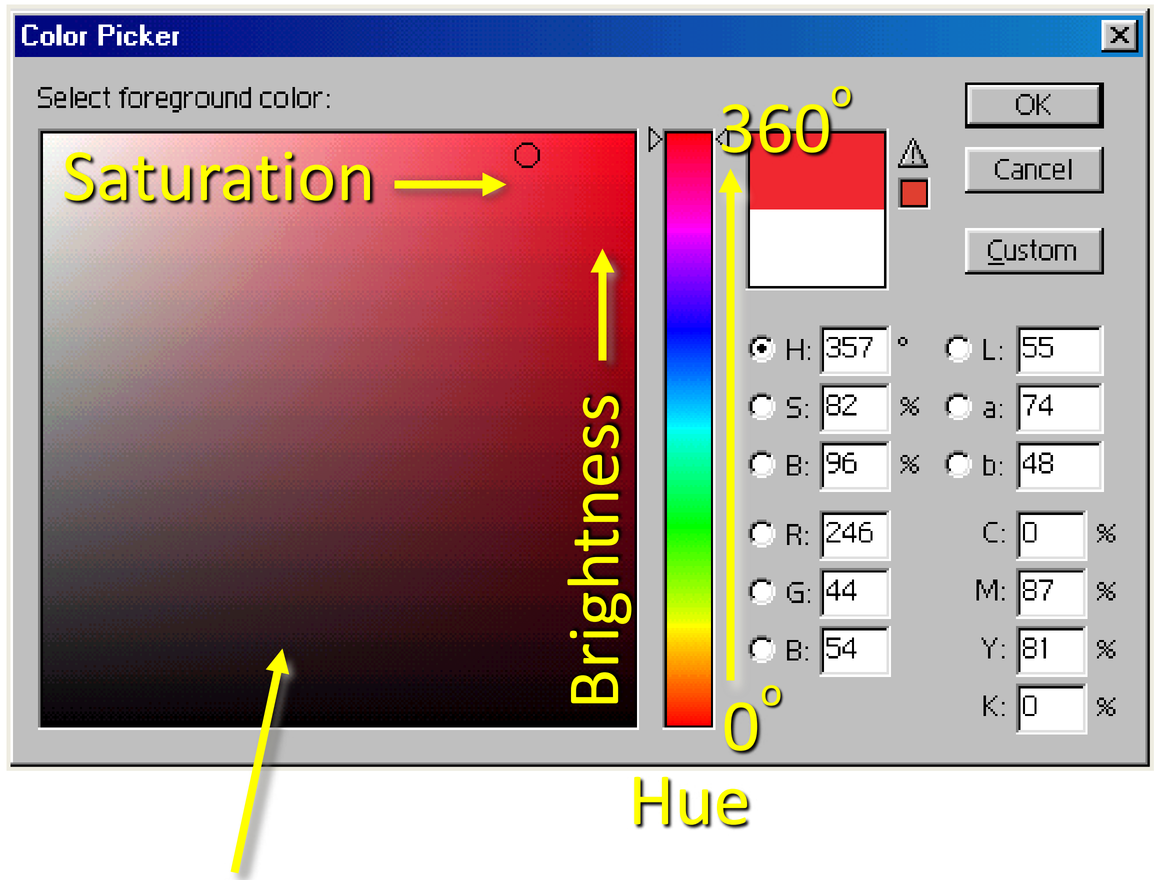


Select Hue - then click in box for saturation, brightness

HSB Visual Color Model

HSB: how artists perceive color properties





Select Hue - then click in box for saturation, brightness

Storing Digital Images

- Digital images are converted to files for storage and transfer
- The file type is a special format for ordering and storing the bytes that make up the image
- File types or formats are not necessarily compatible
- You must often match the file type with the application

Storing Digital Images

- **GIF** (Graphic Interchange Format)
  - indexed color (up to 256 colors)
  - compressed
  - used in Web applications
- **JPEG** (Joint Photographic Experts Group)
  - lossy compression with variable controls
  - also used in Web applications

Storing Digital Images

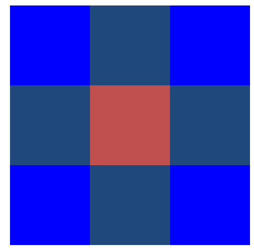
- **PNG (Portable Network Graphics)**
  - designed for online viewing (e.g., Web)
  - patent-free replacement for GIF
  - lossless compression
- **BMP**
  - MS Windows image format

How Many Bytes to Store an Image?

- Suppose we a have an image that is 500x500 pixels in size
- That's a total of 250,000 pixels
- Binary image (1 bit/pixel) = 31,250 bytes
- Grayscale image (8 bits/pixel) = 250,000 bytes
- Color image (24 bits/pixel) = 750,000 bytes

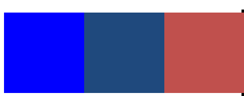
Indexed Color

- "Indexed Color" can be used to reduce the size of a color image file



255	255	255	255	0	255	255	255	255
0	255	0	255	255	255	0	255	0
0	0	0	0	255	0	0	0	0

= 27 bytes



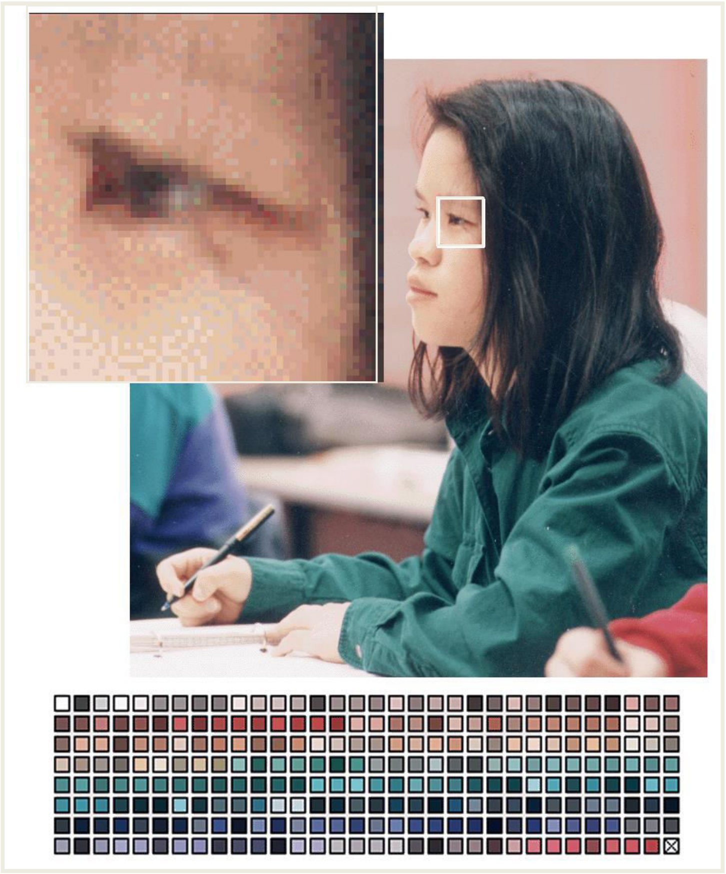
0	1	0	1	2	1	0	1	0

= 18 bytes

0 1 2

Indexed Color Images

- are derived from full color images
- are smaller or more compact in storage
- are composed of pixels selected from a limited palette of colors or shades



Demo: GIMP Posterize

Image Processing II

2 Classes of Digital Filters

- Global filters transform each pixel uniformly according to the function regardless of its location in the image
- Local filters transform a pixel depending upon its relation to surrounding ones

Global Filters: REVIEW

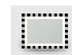
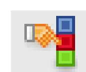
- Brightness and Contrast control
- Histogram thresholding
- Histogram stretching or equalization
- Color corrections
- Inversions

Image
Editing

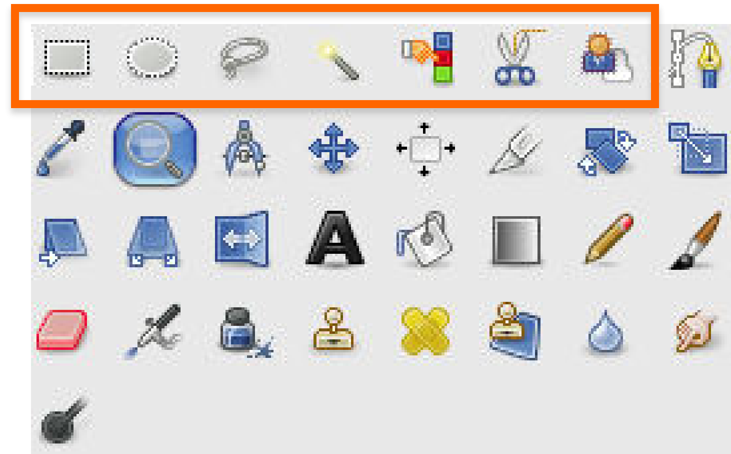
Image Editing

- ➢ Selection Tools
- Painting Tools
- Cut & Paste
- Cloning
- Layers and Blending

Selection Tools

- Rectangular Selection 
- Oval Selection 
- Lasso Tool 
- Magic Wand 
- Color Select Tool 
- Intelligent Scissors 
- Foreground Select Tool 

Tool Bar

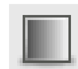
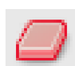


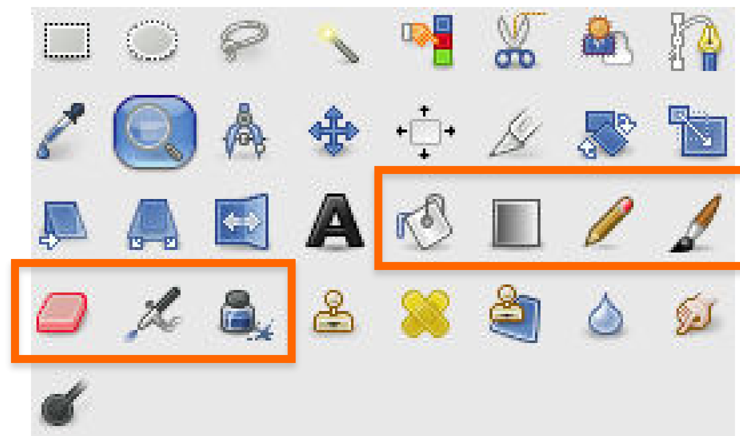
DEMOS

Image Editing

- Selection Tools
- ➢ Painting Tools
- Cut & Paste
- Cloning
- Layers and Blending

Painting Tools

- Paint Bucket Tool 
- Gradient Shade 
- Pencil Tool 
- Paintbrush Tool 
- Eraser 
- Airbrush Tool 
- Ink Tool 



DEMOS

Image Editing

- Selection Tools
- Painting Tools
- ➢ Cut & Paste
- Cloning
- Layers and Blending

Cut & Paste

- Word Processors

  - cut & paste strings of characters (1D arrays)

  A string

A		s	t	r	i	n	g
65	32	115	116	114	105	110	103
0	1	2	3	4	5	6	7

- Image Editing

  - cut & paste pixels (2D arrays)

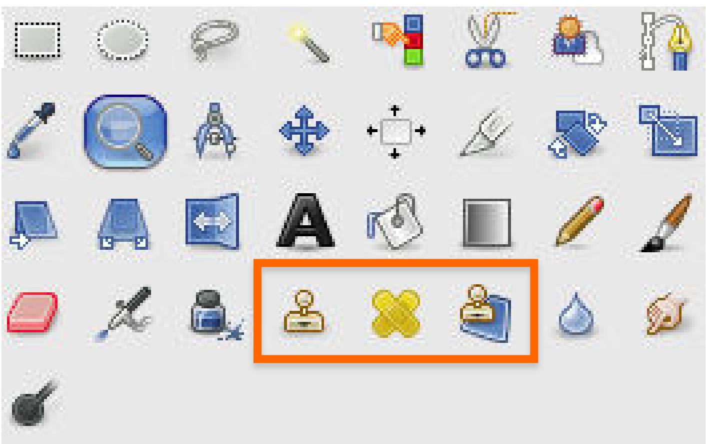
  - replace old pixels with new pixels

Image Editing

- Selection Tools
- Painting Tools
- Cut & Paste
- ➢ Cloning
- Layers and Blending

Cloning

- Copy pixels from
  one part of an image



- to another part of an image ... Interactively

DEMO

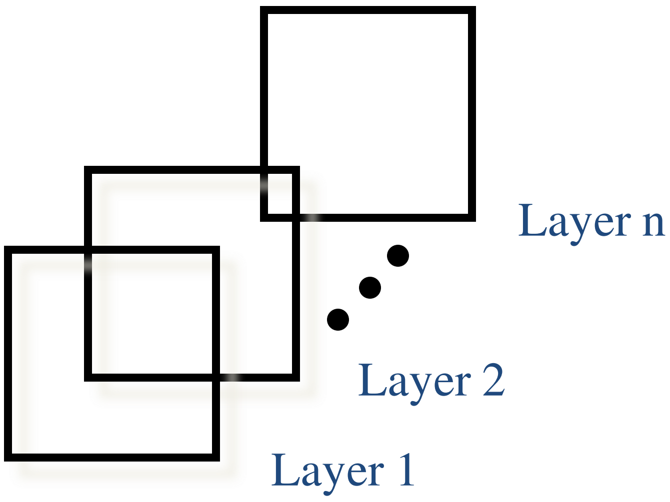
Image Editing

- Selection Tools
- Painting Tools
- Cut & Paste
- Cloning
- ➢ Layers and Blending

Layers and Blending

Can create arbitrary number of layers for

- animation
- special effects in movies
- morphing



Blending

- The idea: Blended image

  = .3 x + .7 x

  is a weighted combination (sum) of two or more other images.

Example Blend

.3 x  +.7 x 

= Bearastronaut 

Masking

- The idea: Create another image where the value of pixels is the weighting term for a blend operation: