



Image Processing Fundamentals

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Agenda

- Objectives and Motivations
- Enhancing Images
- Checking for Presence
- Locating Parts
- Measuring Features
- Identifying and Verifying Components



Class Goals

- Teach the fundamental image processing tools available in machine vision software
- Provide some background into how the algorithms work
- Accelerate your machine vision learning curve
- What not to expect
 - Learn how to develop a complete vision system
 - Learn specific, proprietary functions
 - 3D vision, color or other advanced topics
 - Discussion of the benefits of different application development environments



Image Processing for Machine Vision

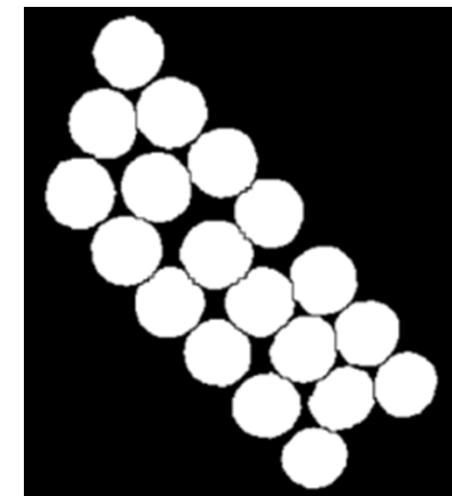
- Objective
 - To extract useful information present in an image, in a limited time
- Secondary
 - To display an image for users
- Not
 - Improve appearance of image in general
- Used for
 - Image pre-processing
 - Minimize variations of information in the image
 - Prepare the image for processing and measurement
 - Application specific processing
 - Use image to count, locate, and measure attributes



Image Types

- Grayscale
 - 8 bit: pixel values range from 0 to 255
 - 12 bit: pixel values range from 0 to 4095
 - 16 bit: pixel values range from 0 to 65535
- Color
 - Composed of 3 grayscale images (RGB)
- Other types
 - Binary: pixel values: 0 and 1
 - Commonly used to identify objects of interest in an image
 - Usually the result of image processing step
 - Floating point: pixel values range from – X.xx to X.xx
 - Usually a result of a computation

Grayscale Image



Binary Image



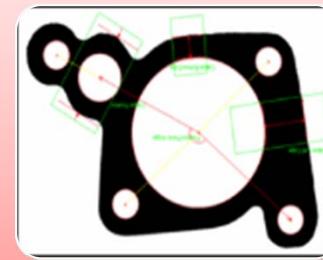
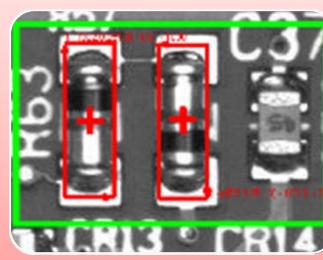
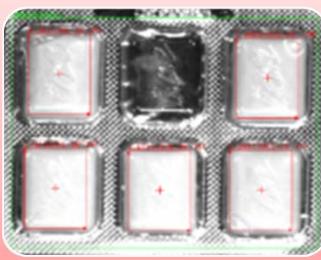
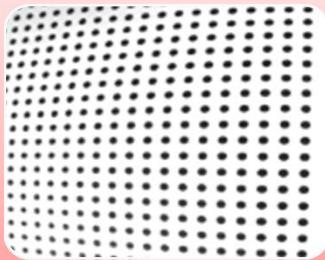
What is an Ideal Image?

- Range of grayscale values
 - Spread out between 0 and 255
 - No pixels “saturated” at 255 (for most applications)
 - Impossible to distinguish between saturated pixels
- Good contrast
 - Between the “right” parts of the image
- Repeatable

In short, an ideal image requires the least number of image processing steps to obtain the result.



Class Organization



Enhance

- Filter noise or unwanted features
- Remove distortion
- Calibrate images

Check

- Create Particles
- Measure intensity
- Analyze particles

Locate

- Match patterns
- Match geometry
- Set-up coordinate systems

Measure

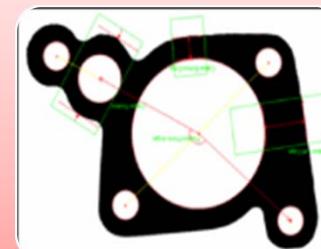
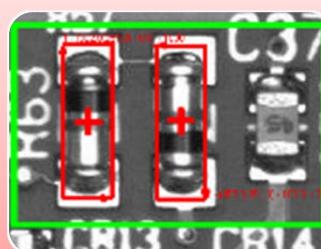
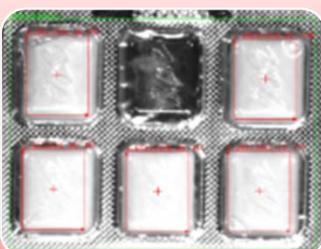
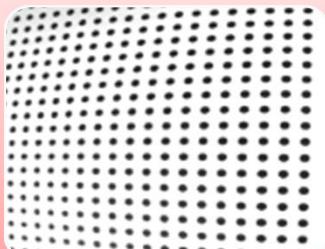
- Detect edges
- Measure distance
- Calculate geometry

Identify

- Read text (OCR)
- Read 1D barcodes
- Read 2D codes



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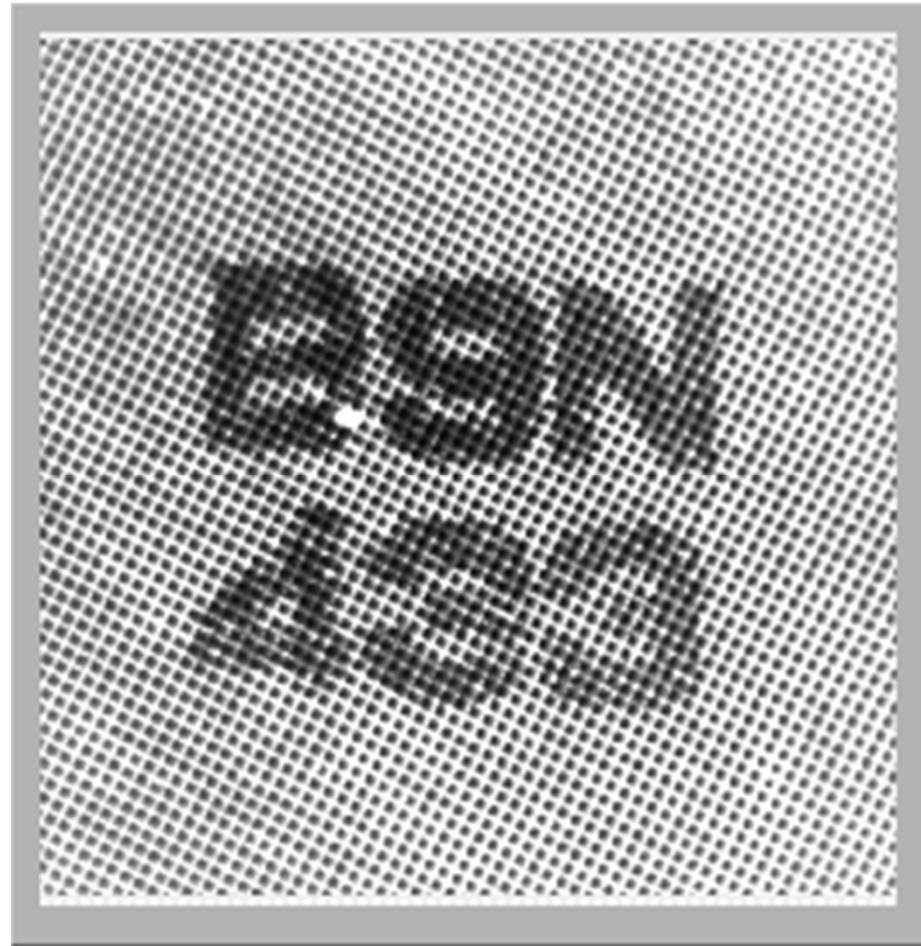
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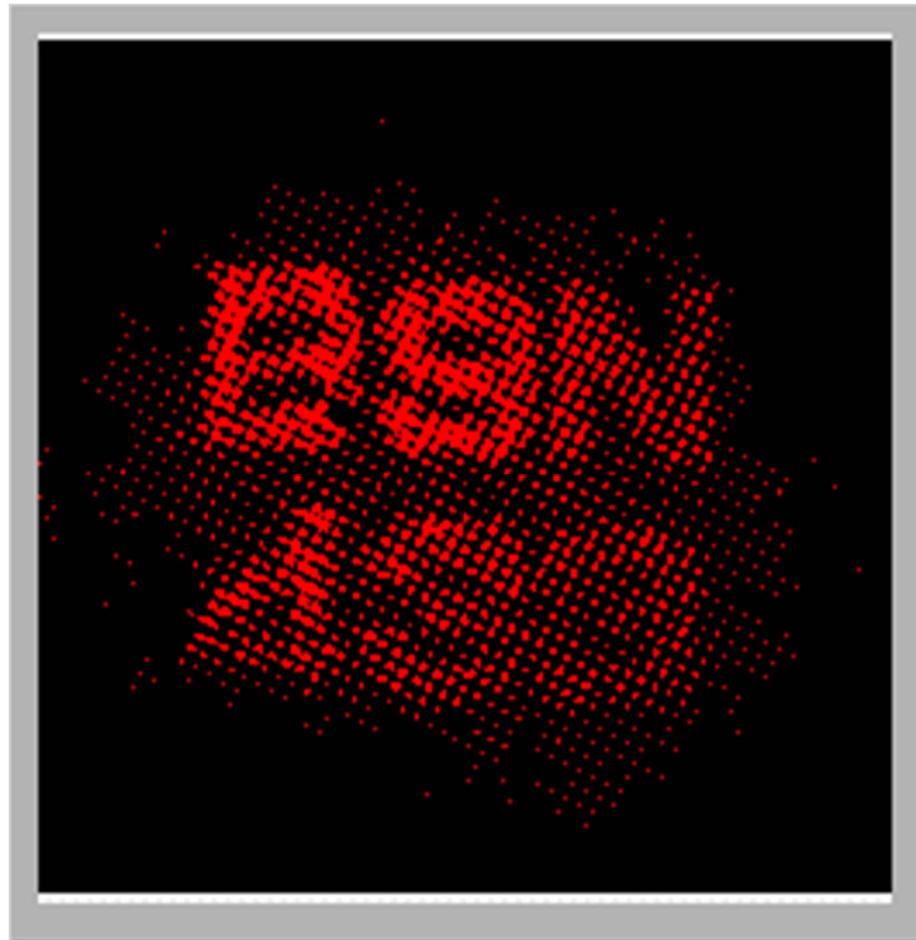
Motivation



Read characters on a textured surface



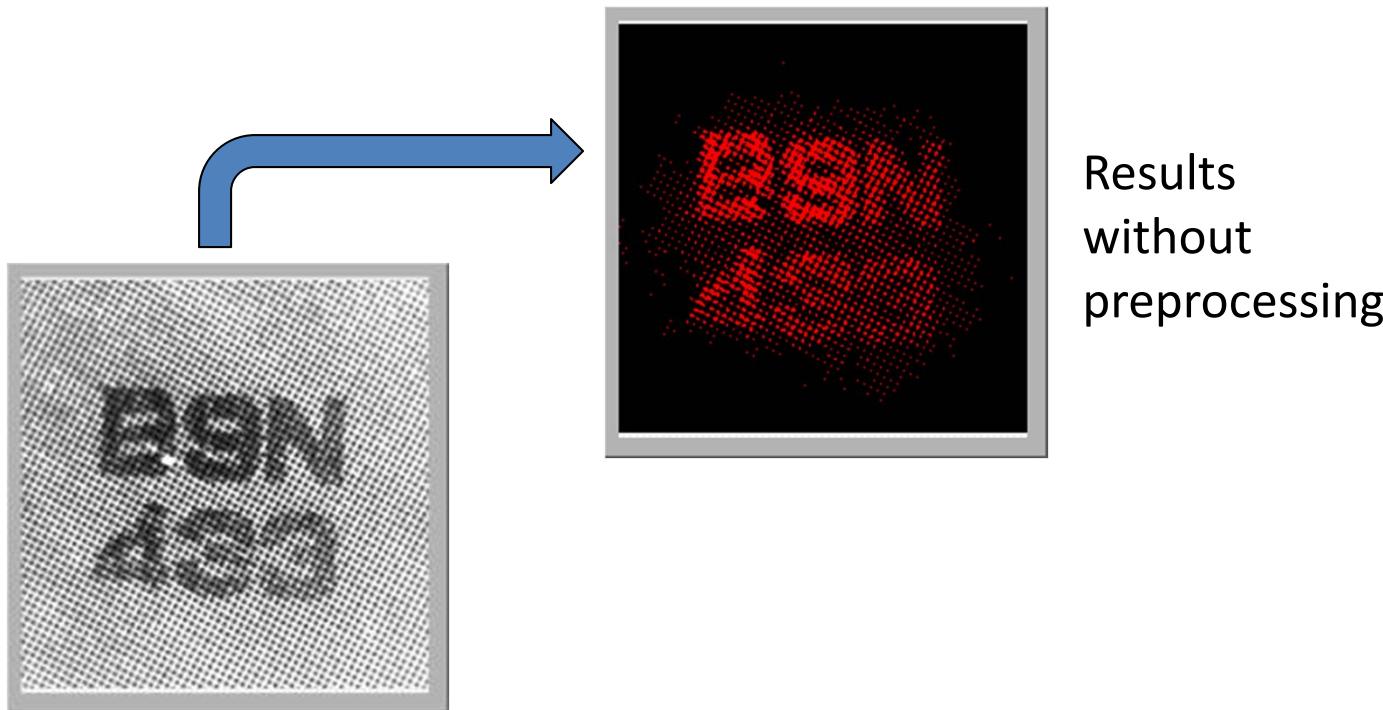
Motivation



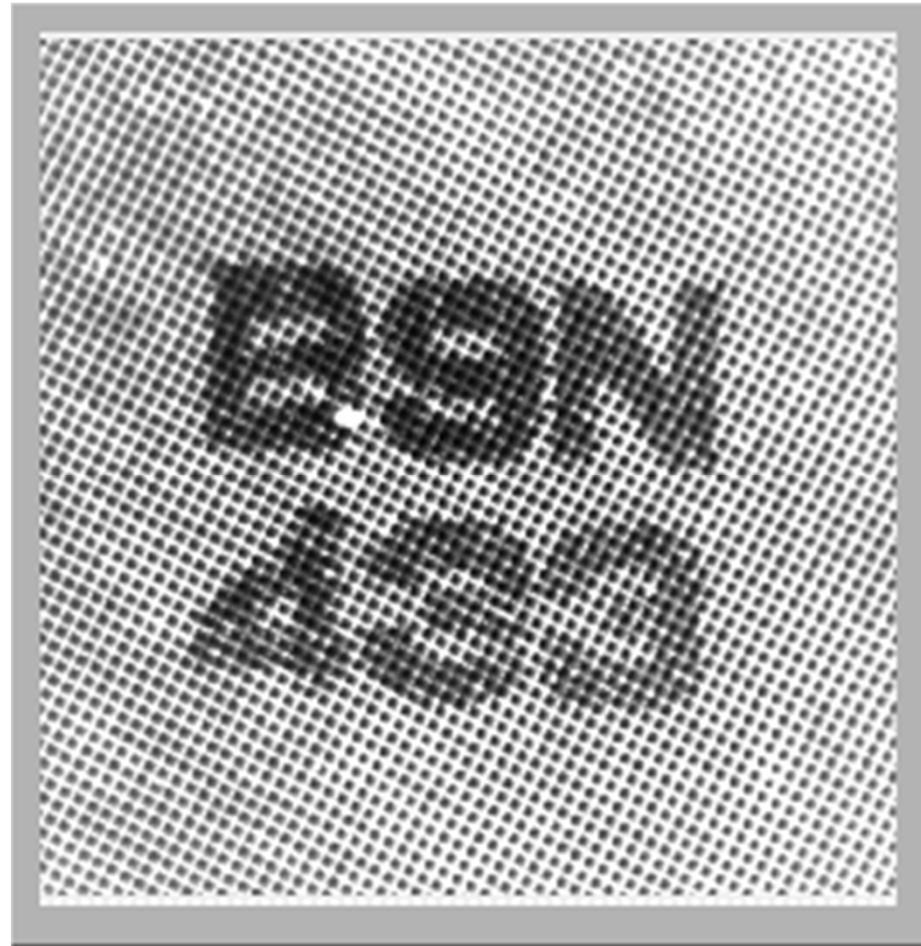
Not possible to cleanly segment characters



Motivation



Motivation



Read characters on a textured surface



Motivation



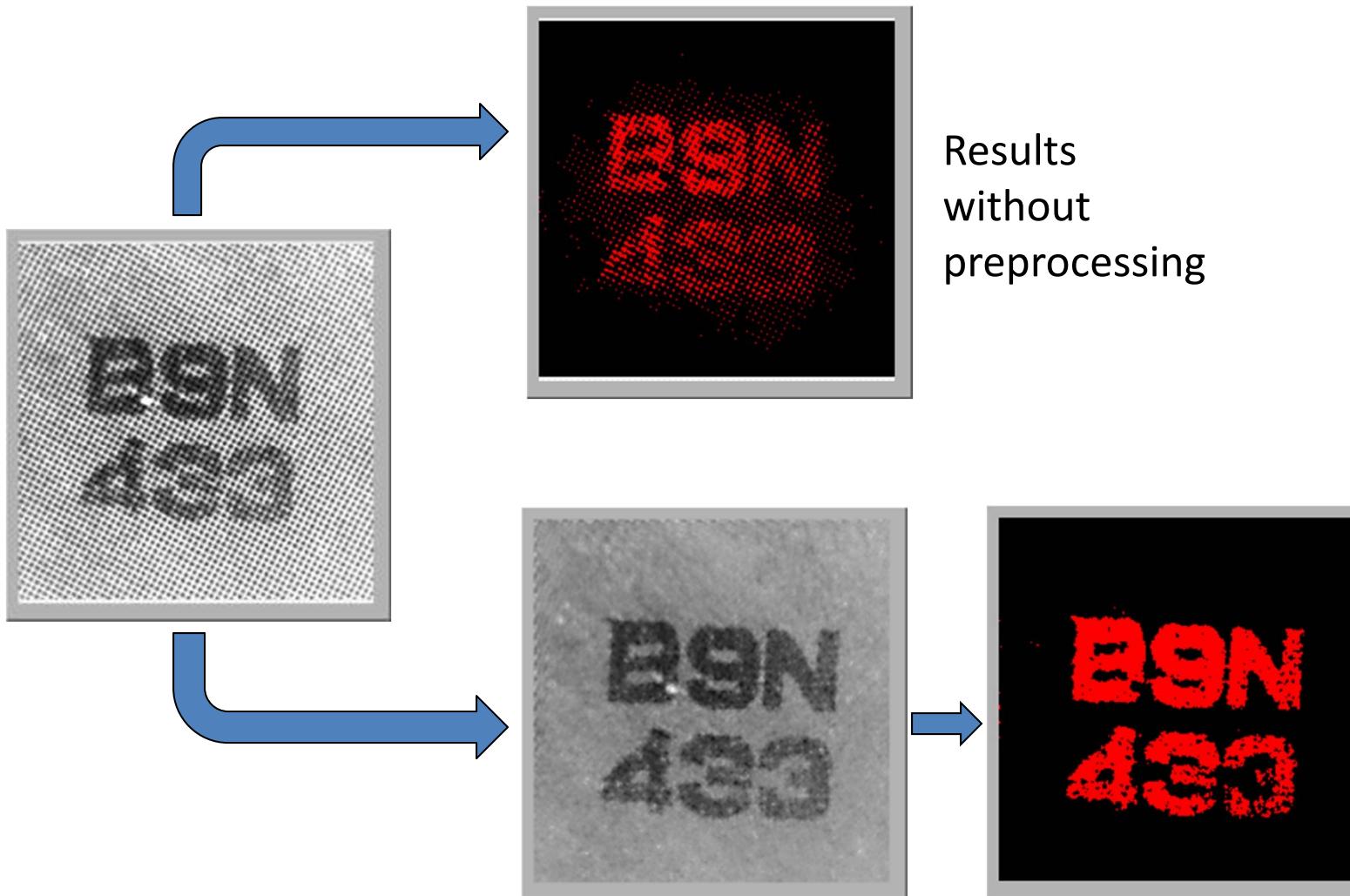
Image after periodic pattern is removed



Motivation



Motivation



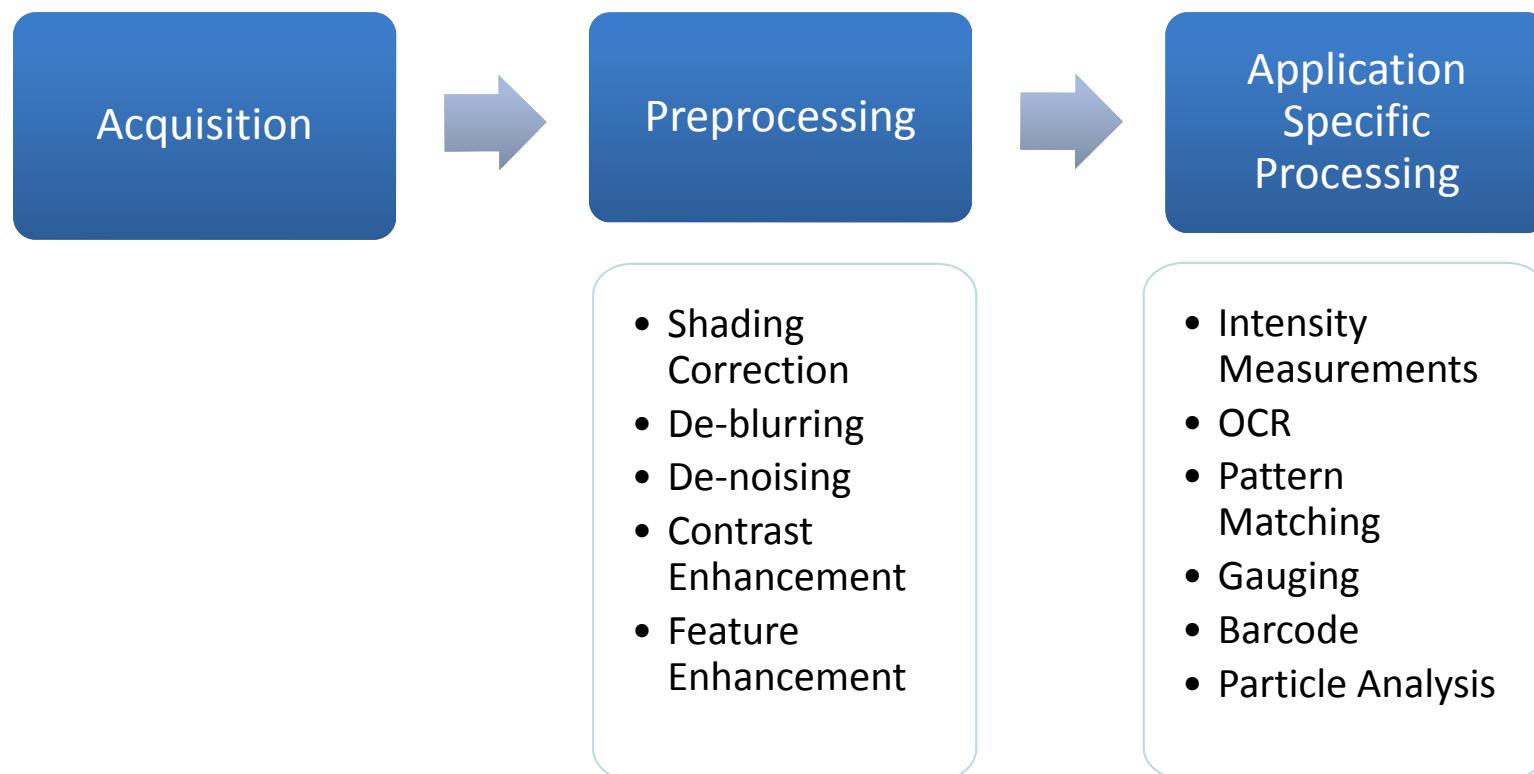
Objective of Image Preprocessing

- Process an image so that the resulting image is more suitable than the original for a specific application
- A preprocessing method that works well for one application may not be the best method for another application



Image Preprocessing

- Pre-processing occurs before the application specific processing



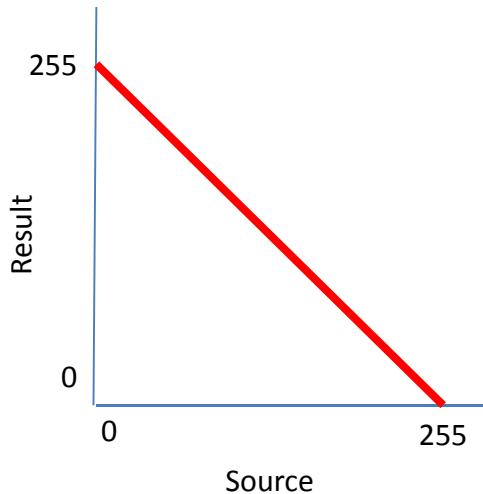
Enhancement Techniques

- Spatial Domain: pixel-wise operations
 - Brightness, contrast and gamma
 - Lookup tables
 - Gray morphology
 - Filtering (smoothing, median, general convolution)
- Frequency Domain
 - Deblurring
 - Filtering

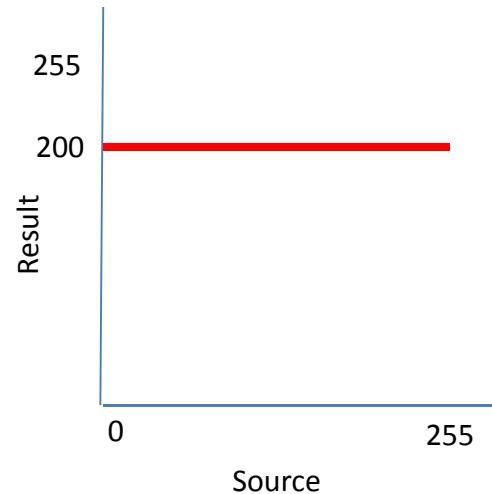


Lookup Tables

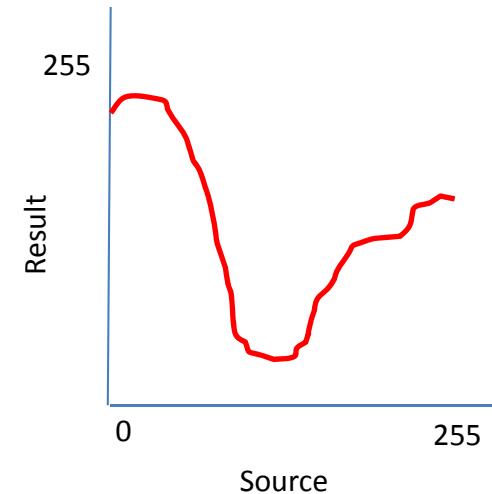
- A lookup table is a function that maps grayscale values in an image to new grayscale values, to create a new result image



| Source | Result |
|--------|--------|
| 0 | 255 |
| 1 | 254 |
| 2 | 253 |
| .. | .. |
| 255 | 0 |



| Source | Result |
|--------|--------|
| 0 | 200 |
| 1 | 200 |
| 2 | 200 |
| .. | .. |
| 255 | 200 |

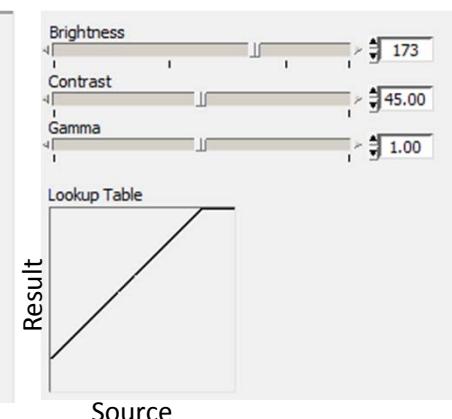
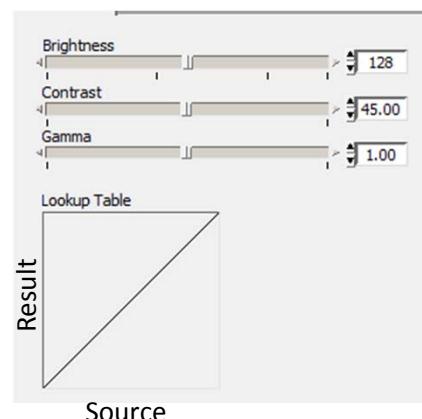


| Source | Result |
|--------|--------|
| 0 | 240 |
| 1 | 245 |
| 2 | 246 |
| .. | .. |
| 255 | 171 |



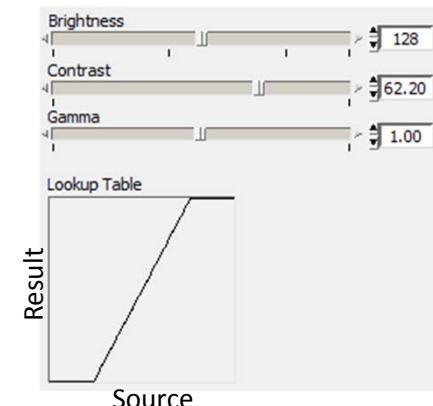
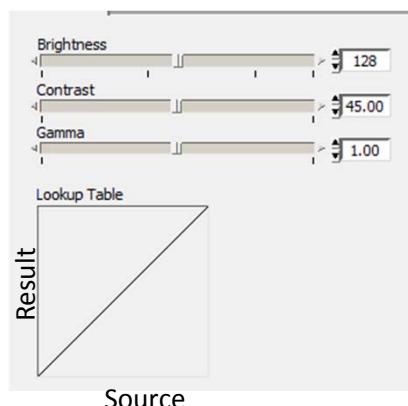
Brightness

- Adds a constant grayscale to all of the image
- Can improve appearance but not useful for most image processing steps



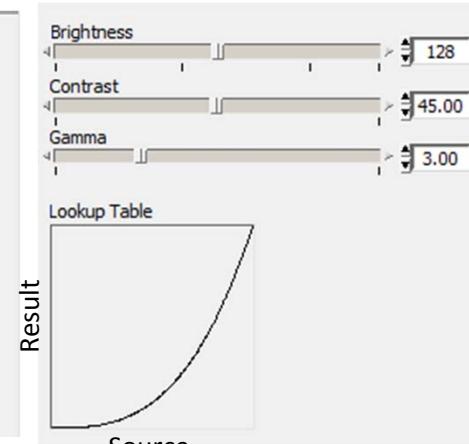
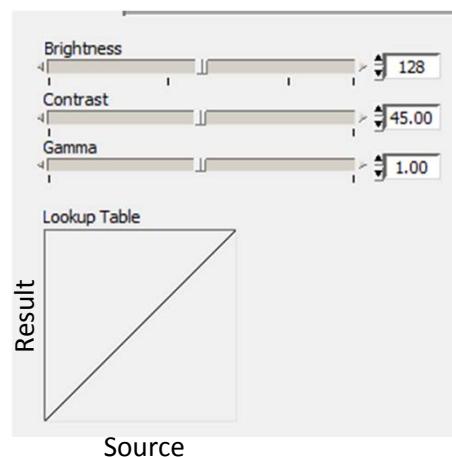
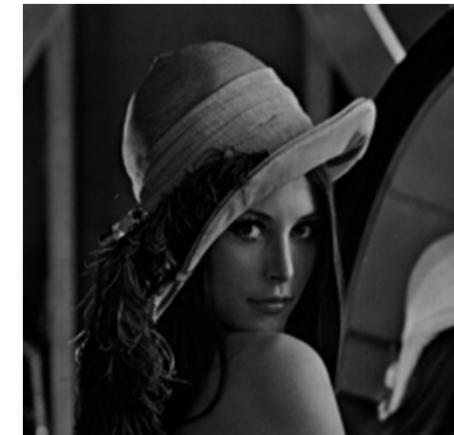
Contrast

- Used to increase or decrease contrast
- Normal = 45 (degree line)
 - High = Higher than 45
 - Low = Lower than 45
- Typical use is to improve edge detection
- Sacrifices one range of values to improve another



Gamma

- Nonlinear contrast enhancement
- Higher gamma improves contrast for larger grayscale values
- Does not cause saturation



Histogram Equalization

- Alters grayscale values of pixels so that they become evenly distributed across the full grayscale range
- The function associates an equal number of pixels per constant grayscale interval
- Takes full advantage of the available shades of gray
- Enhances contrast of the image without modifying the structure

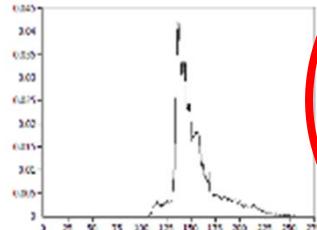
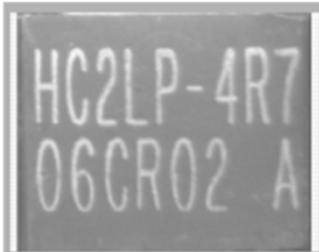


Equalized

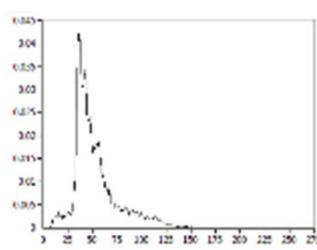
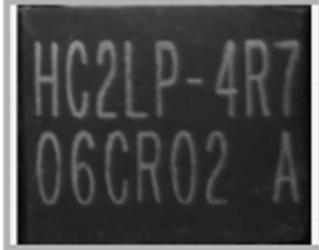


Histogram Equalization

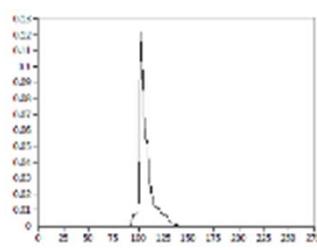
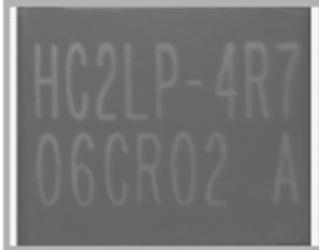
Bright



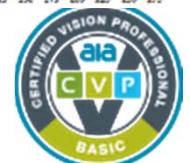
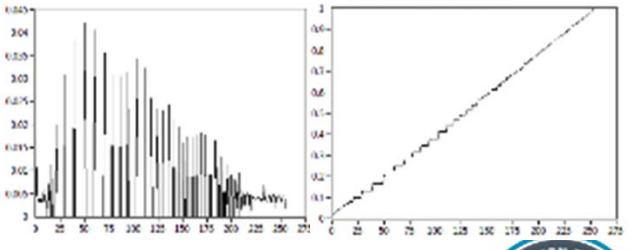
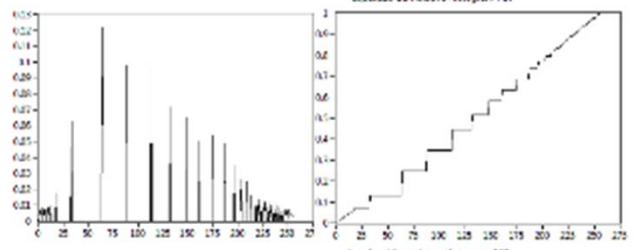
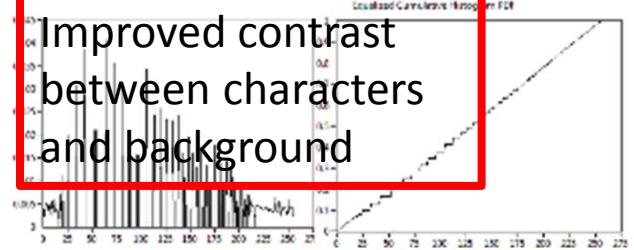
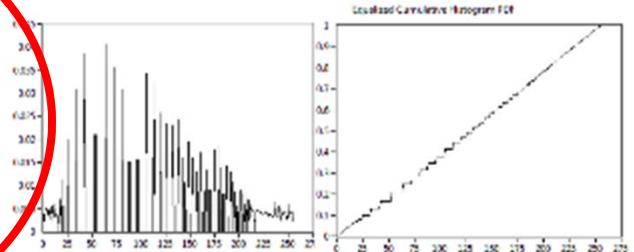
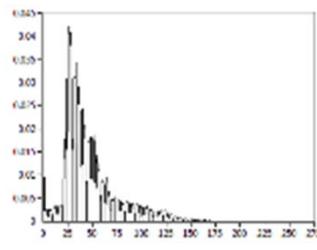
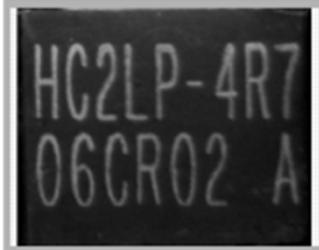
Dark



Low
Contrast



High
Contrast



Other Lookup Tables

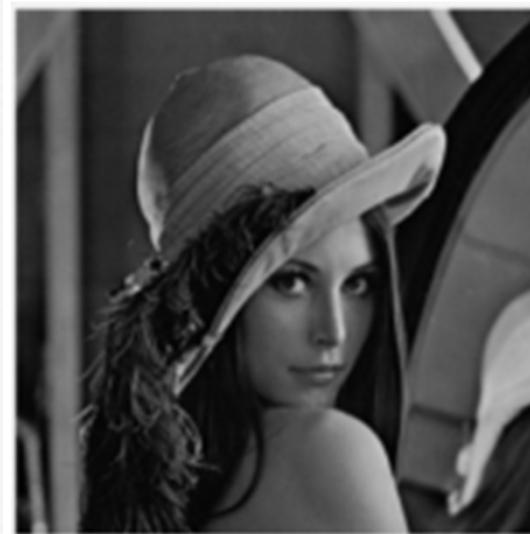
Original



Reverse



Square

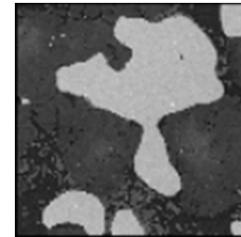


Power 1/x

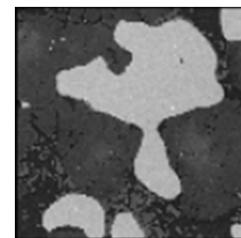
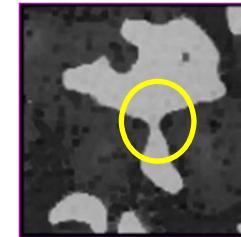


Gray Morphology

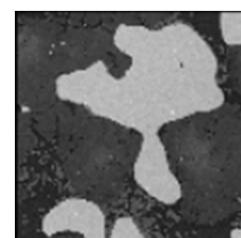
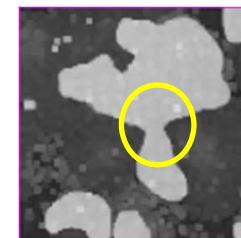
| Morphology | Function |
|------------|--------------------------------------|
| Erosion | $\text{Min}(\text{Neighbors})$ |
| Dilation | $\text{Max}(\text{Neighbors})$ |
| Open | $\text{Dilation}(\text{Erosion}(I))$ |
| Close | $\text{Erosion}(\text{Dilation}(I))$ |



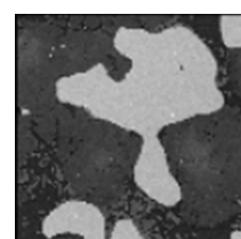
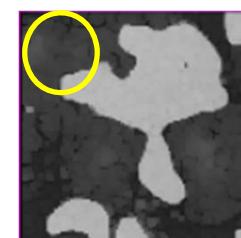
Erosion →



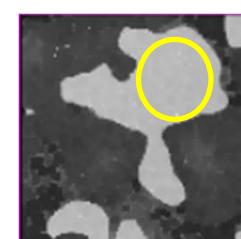
Dilation →



Open →

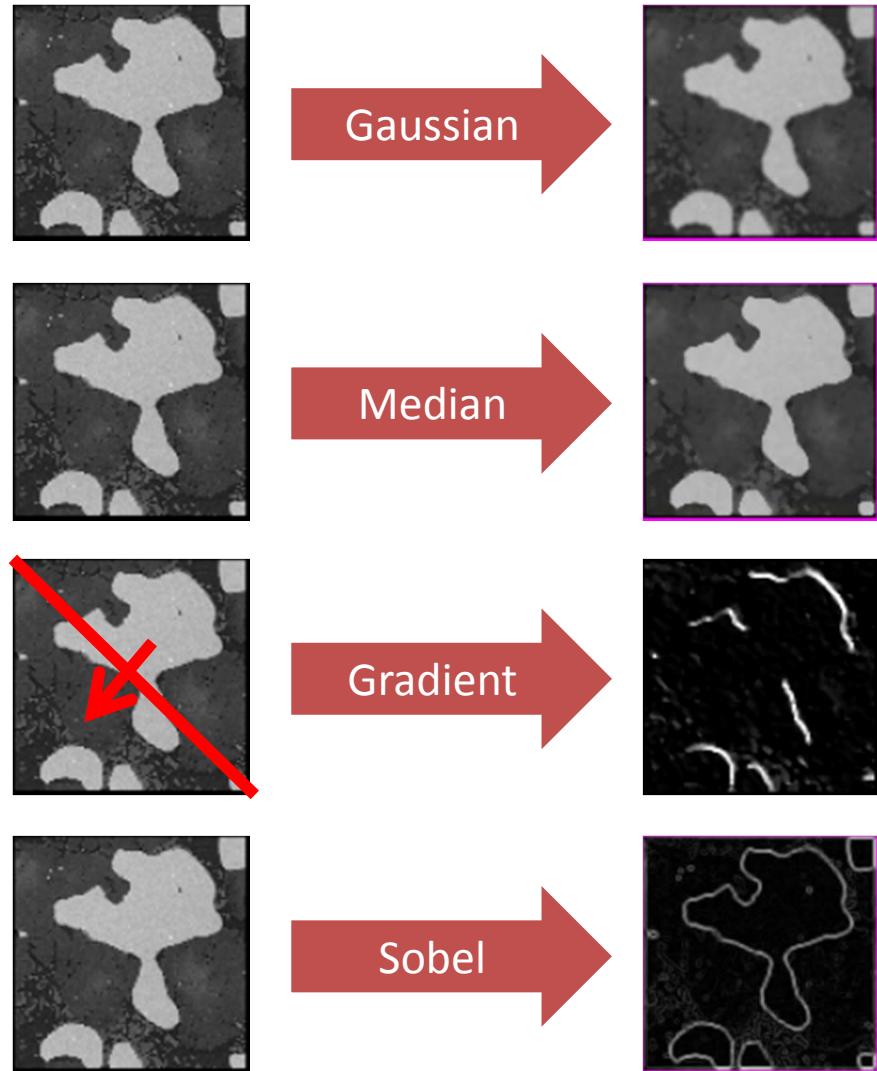


Close →



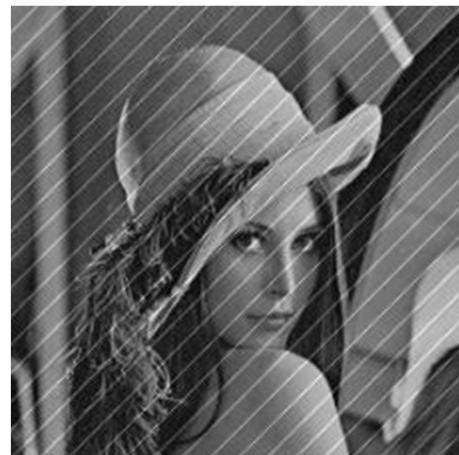
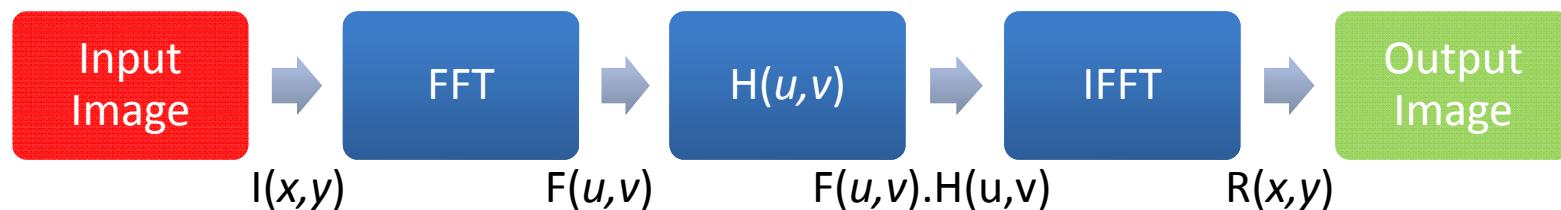
Spatial Filtering

| Filter Type | Filters |
|-------------|--|
| Lowpass | <ul style="list-style-type: none">• Smoothing• Gaussian• Median• Nth Order |
| Highpass | <ul style="list-style-type: none">• Gradient• Laplacian• Roberts• Sobel• Prewitt |



Frequency Domain Filtering

- Standard filtering can be done in frequency domain
 - Low Pass, High Pass, Band Pass, Band Stop, etc.
- Compute the Fourier transform of the image
- Multiply with the transfer function of the filter
- Take the inverse Fourier transform to get the filtered image



Periodic noise

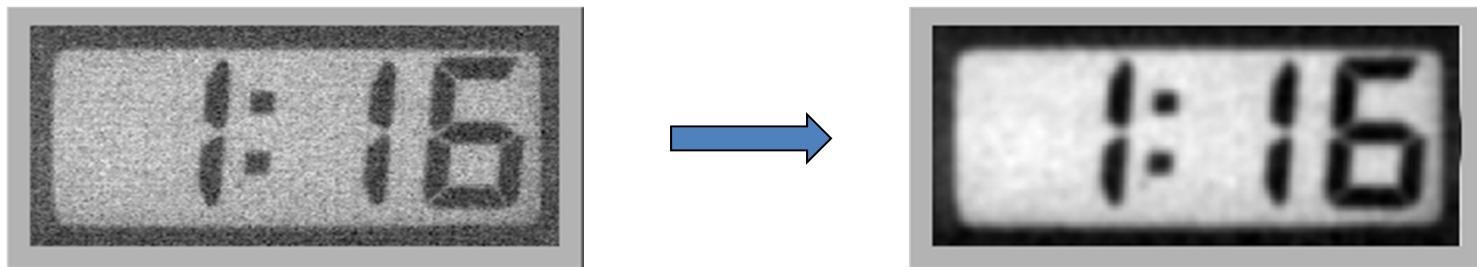


Bandstop filtered

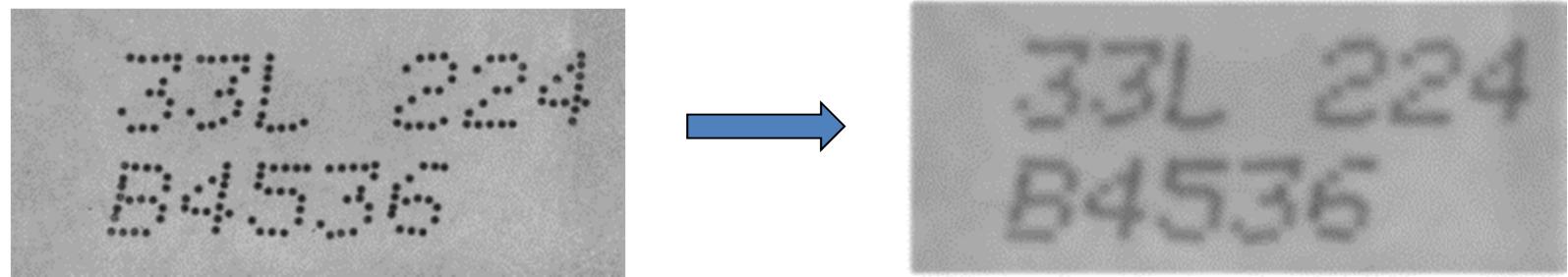


Low Pass Filter Examples

- Low Pass with Frequency Domain Filter



- Low Pass with Gaussian Filter



High Pass Filtering Examples

- Detect edges



- Sharpen image

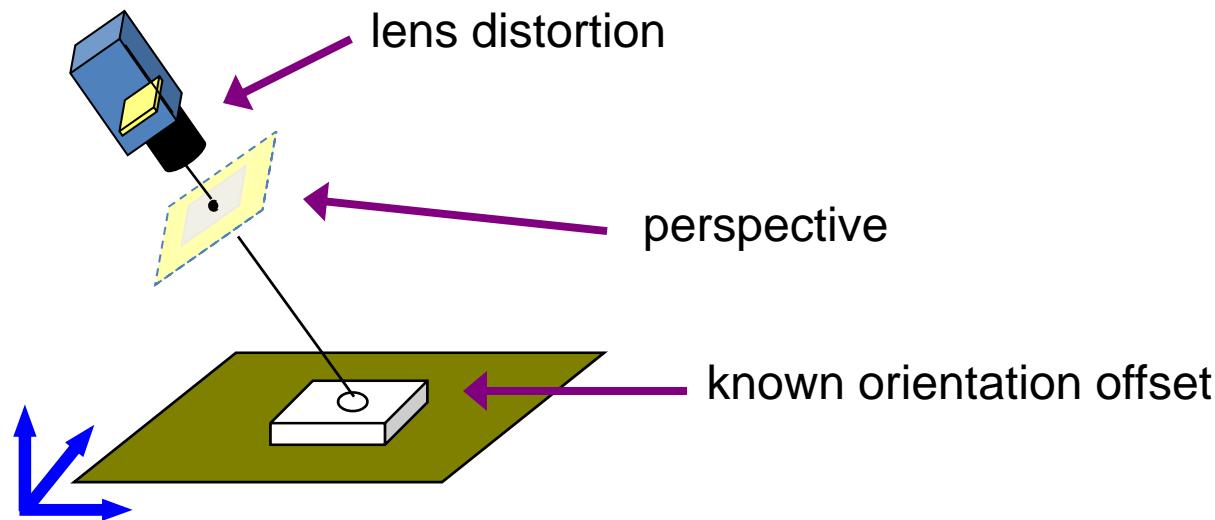


ENHANCE IMAGES: IMAGE CALIBRATION



Spatial Calibration

- Corrects for lens and perspective distortion
- Allows the user to take real-world measurements from image based on pixel locations.



Calibrating Your Image Setup

- Acquire image of a calibration grid with known real-world distances between the dots
- Learn the calibration (mapping information) from its perspective and distortion
- Apply this mapping information to subsequent images and measurements

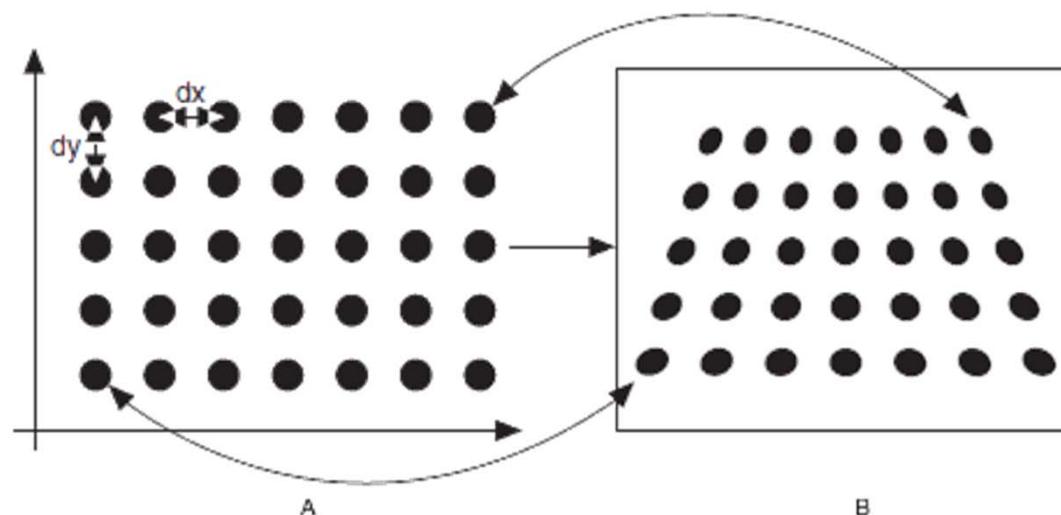
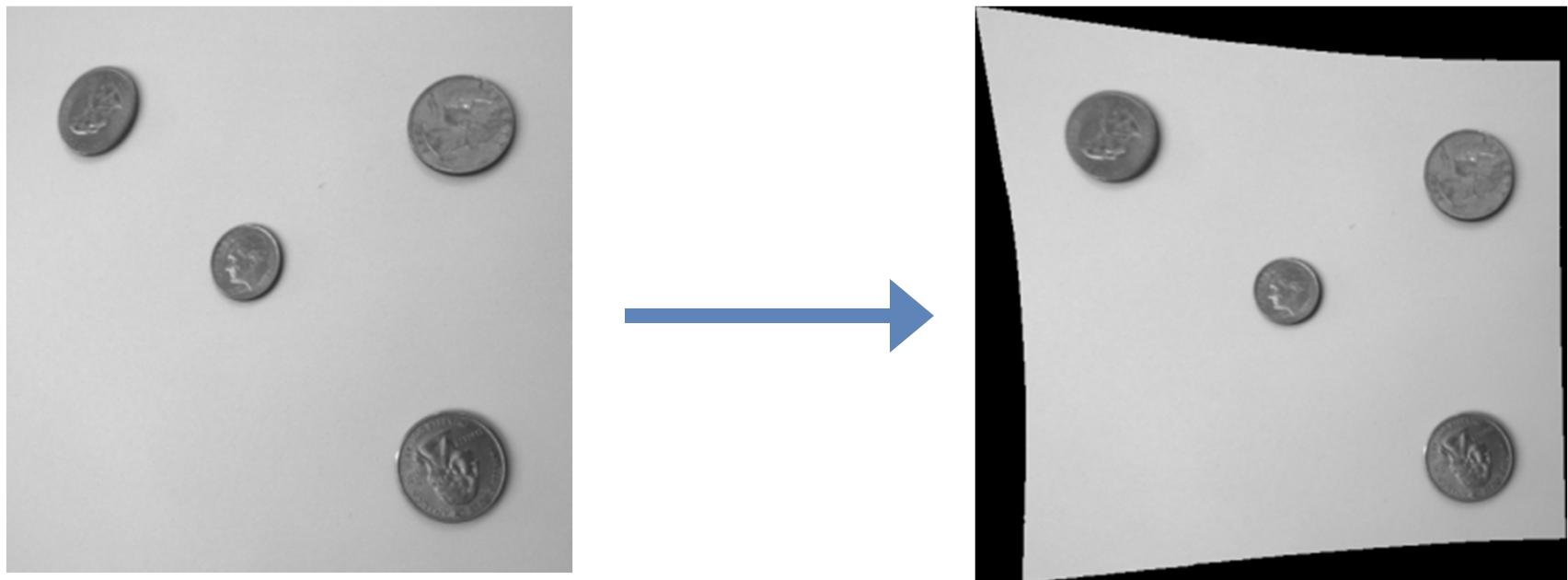


Image Correction

- Use calibration to adjust image geometry so features are represented properly.

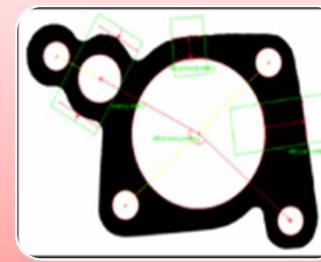
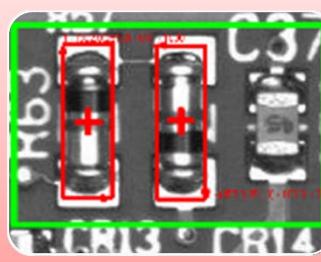
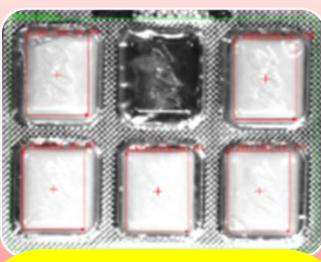
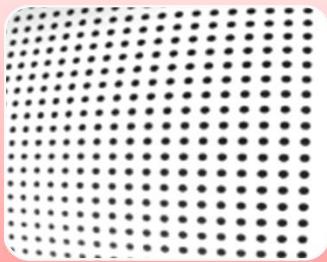


Types of Calibration

- 2D spatial calibration
 - Applied only to a plane
 - Corrects for lens and perspective distortion
 - Does not improve resolution of a measurement
 - Cannot compensate for poor lighting or unstable conditions
- 3D spatial calibration: x, y, z
- Flat field calibration
 - Corrects for lighting variations
- Color



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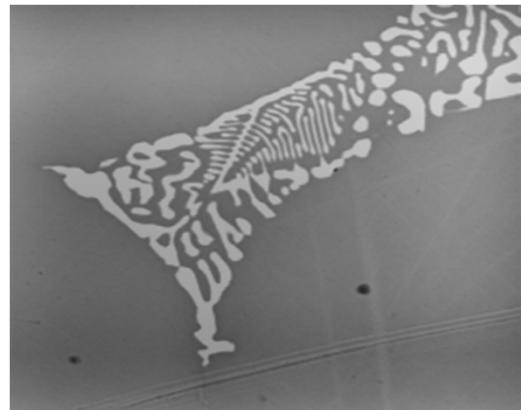


Histograms and Thresholding

- Histogram
 - Provides a quantitative distribution of pixels in an image
 - Indicates the number of pixels at each gray level
- Thresholding
 - Converts each pixel value in an image to 0 or 1 according to the value of the original pixel
 - Helps extract significant structures in an image



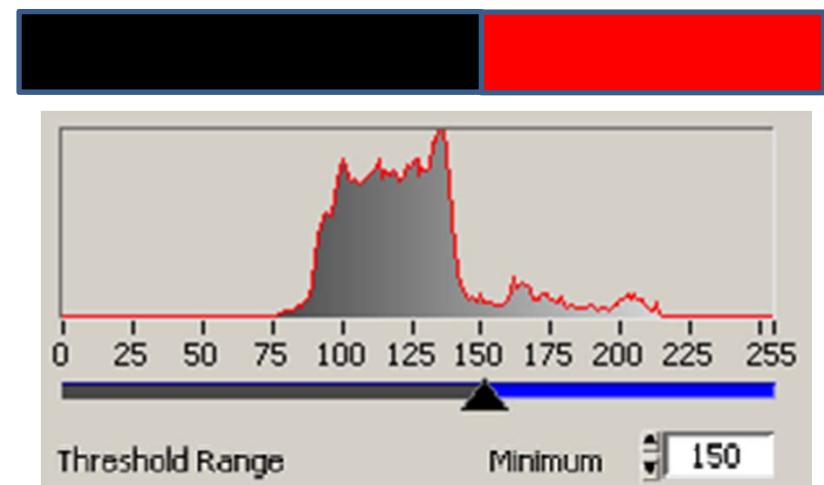
Histogram and Thresholding



Original Image

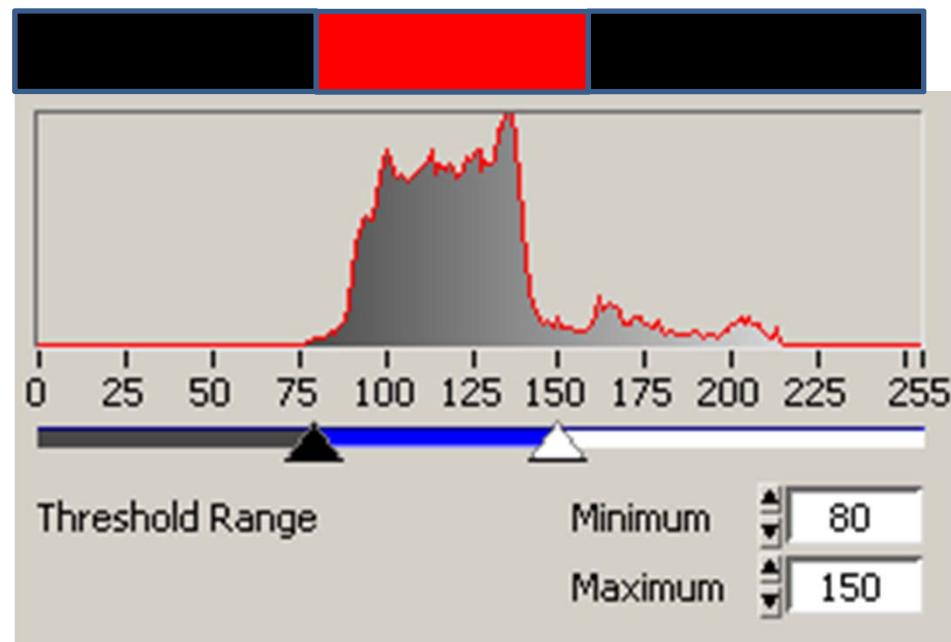


Binary Image

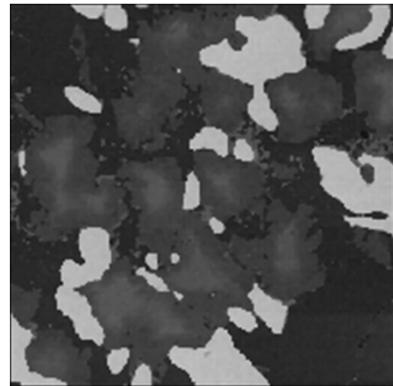


Finding Gray Objects

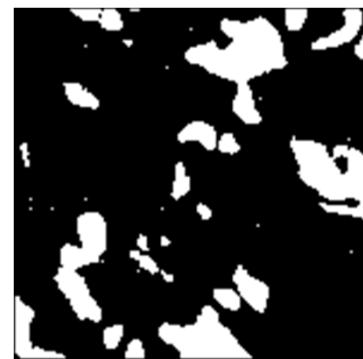
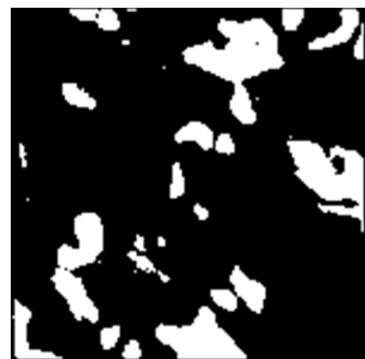
- Can also set upper and lower limits for pixel values
- Pixels inside the bounds of the limit (blue region) are set to 1, and those outside the limit are set to 0



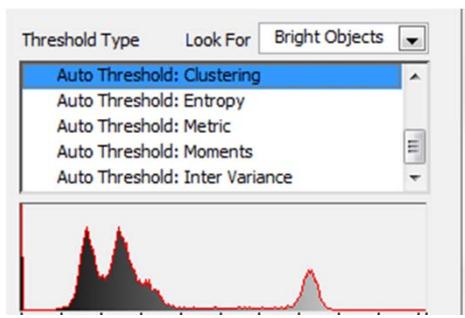
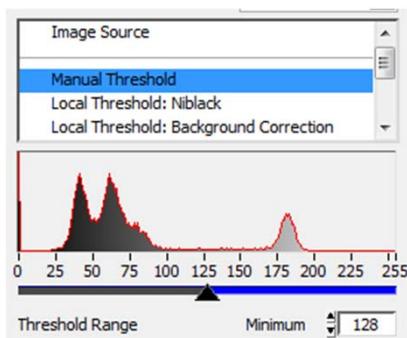
Automatic Thresholding



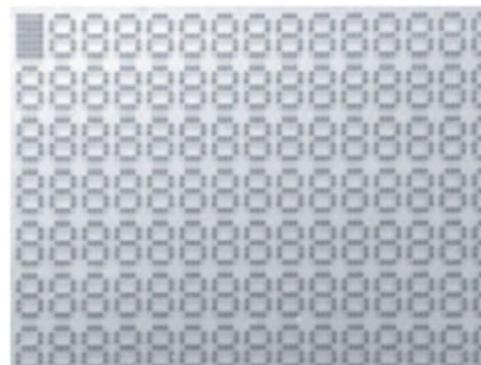
**Manual
Threshold**



**Auto
Threshold**

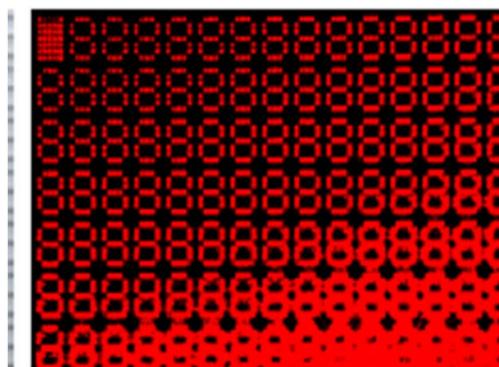


Local Thresholding



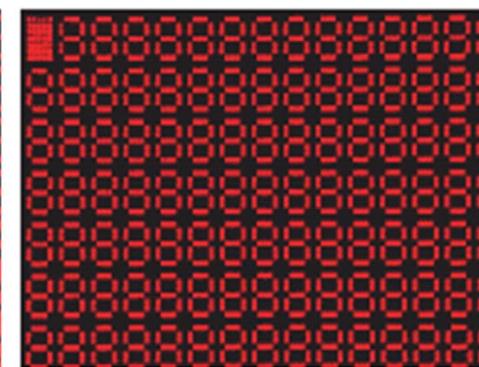
A

**Global
Threshold**



B

**Local
Threshold**

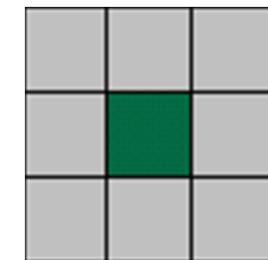
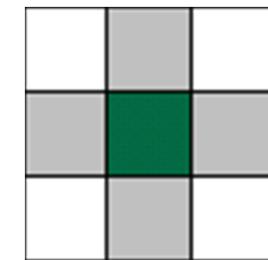


C



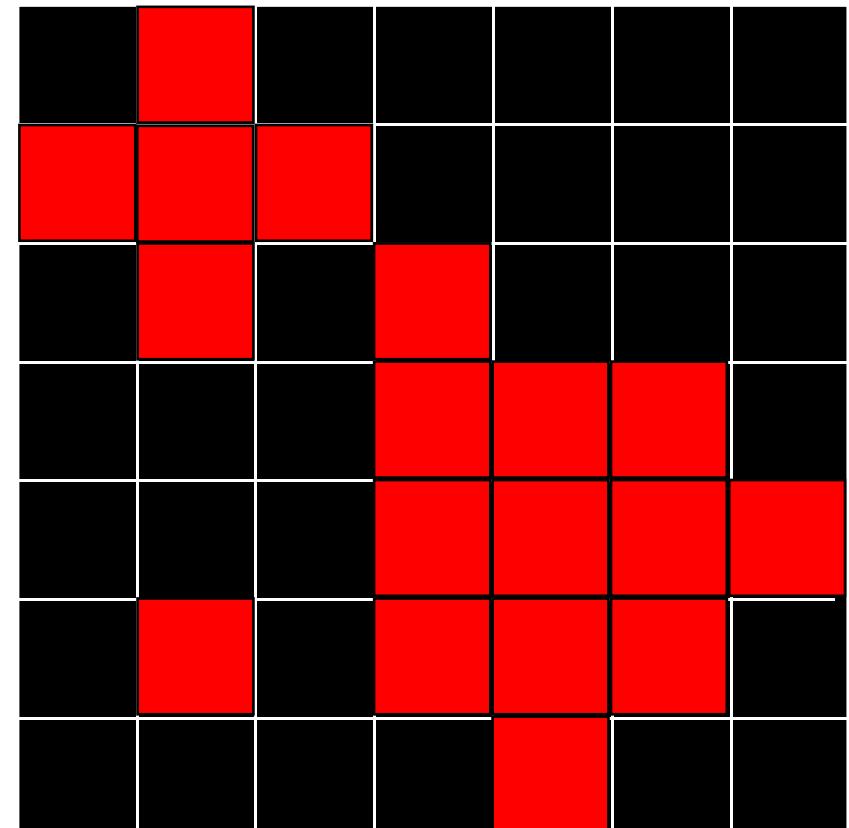
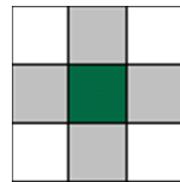
Particles and Connectivity

- Thresholding creates binary image:
 - Pixels are either ‘0’ or ‘1’
- A particle in a binary image is a group of connected ‘1’ pixels
- Defining connectivity
 - Connectivity-4: two pixels are considered part of the same particle if they are horizontally or vertically adjacent
 - Connectivity-8: two pixels are considered part of the same particle if they are horizontally, vertically, or diagonally adjacent.



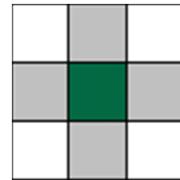
How Connectivity Affects a Particle

- How many particles with connectivity-4?

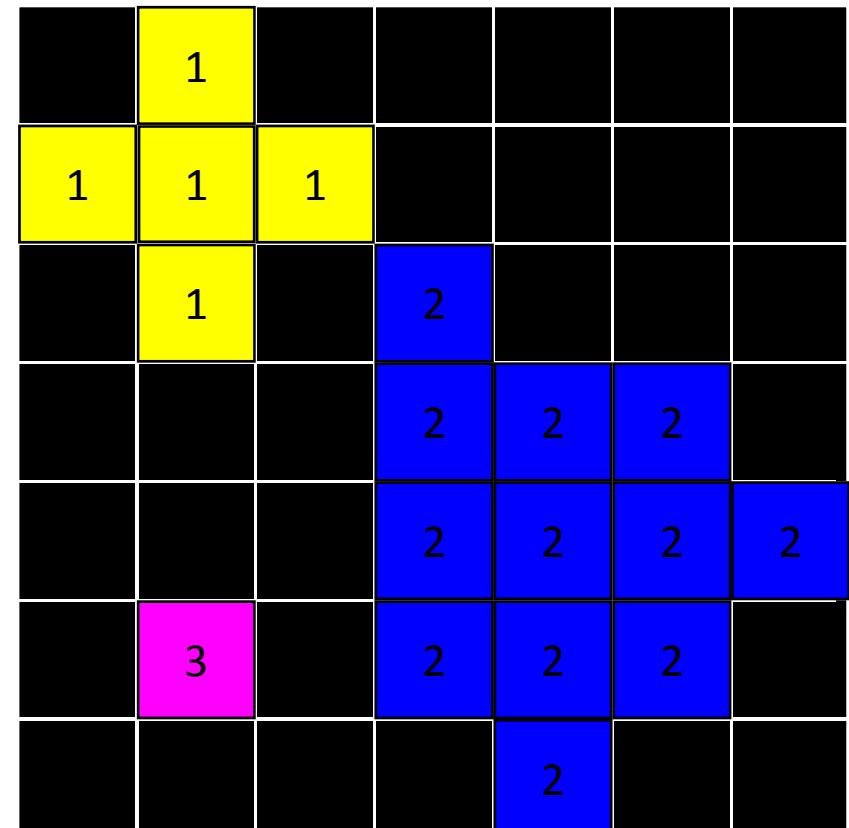


How Connectivity Affects a Particle

- How many particles with connectivity-4?

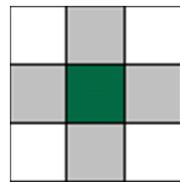


3

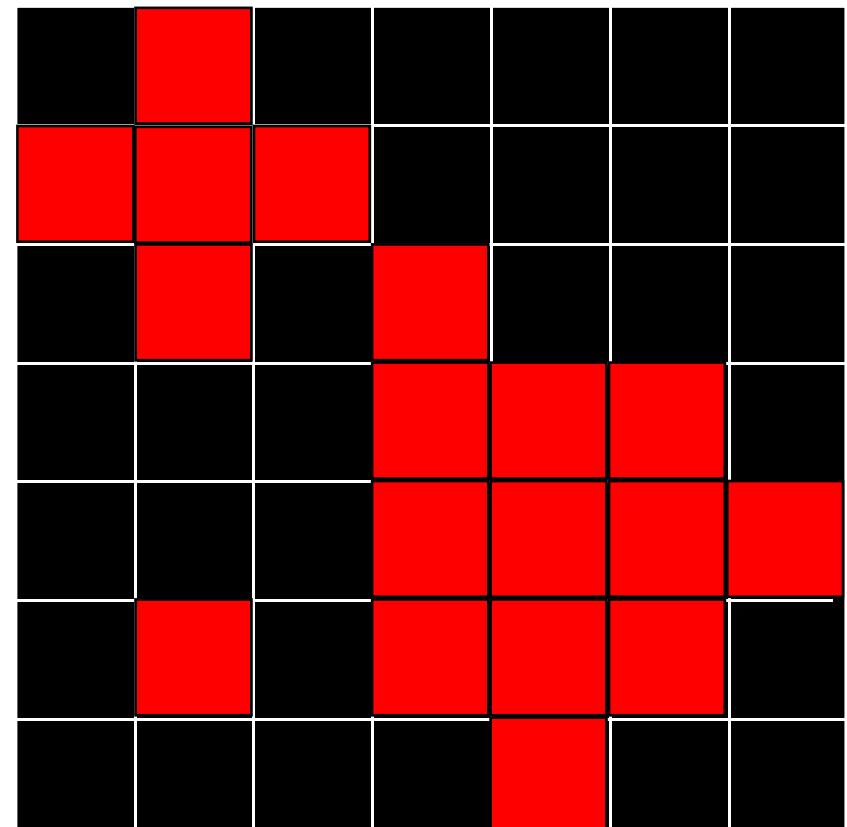
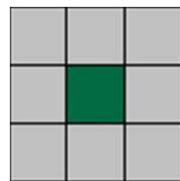


How Connectivity Affects a Particle

- How many particles with connectivity-4?

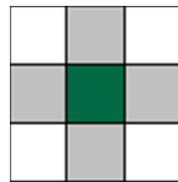


- How many particles with connectivity-8?

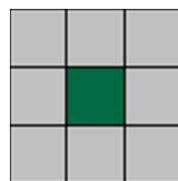


How Connectivity Affects a Particle

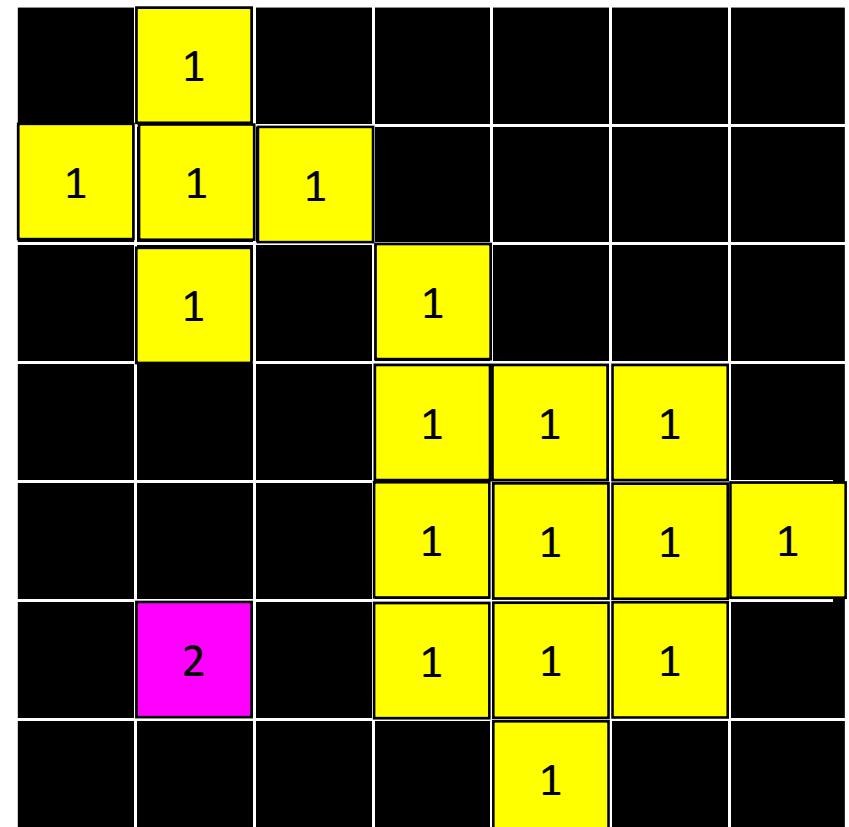
- How many particles with connectivity-4?



- How many particles with connectivity-8?



2



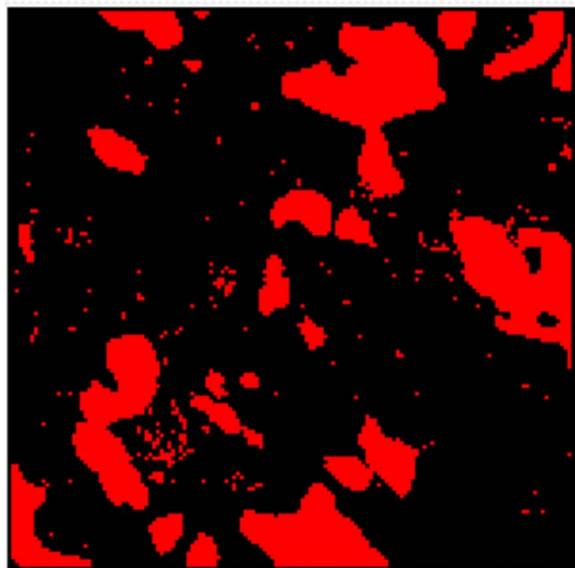
Binary Morphology

- Binary morphological functions extract and alter the structure of particles in a binary image
- Morphological functions remove unwanted information caused by the thresholding process:
 - Noise particles
 - Particles touching the border of an image
 - Particles touching each other
 - Particles with uneven borders

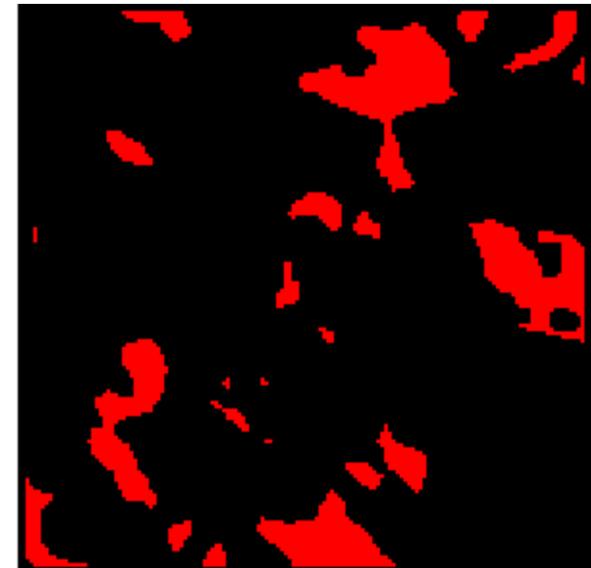


Erosion

- Decreases the size of objects in an image
 - Removes a layer of pixels along the boundary of the particle
 - Eliminates small isolated particles in the background and removes narrow peninsulas
- Use Erode to:
 - Separate particles for counting

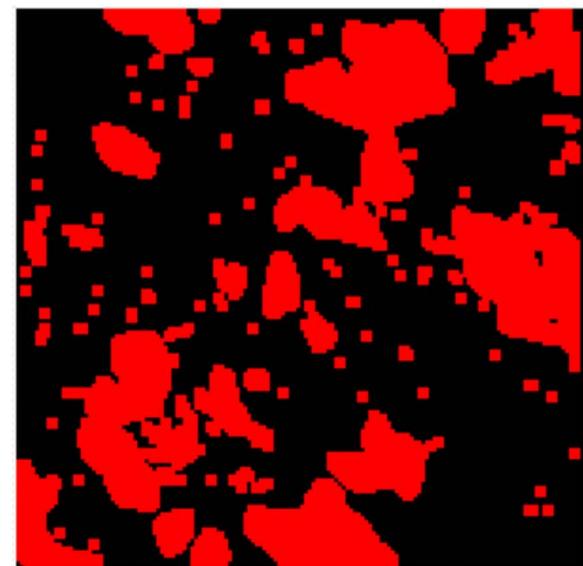
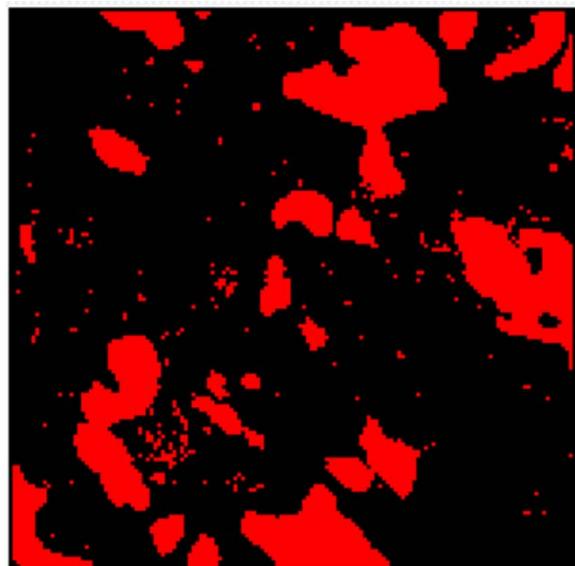


Erosion →

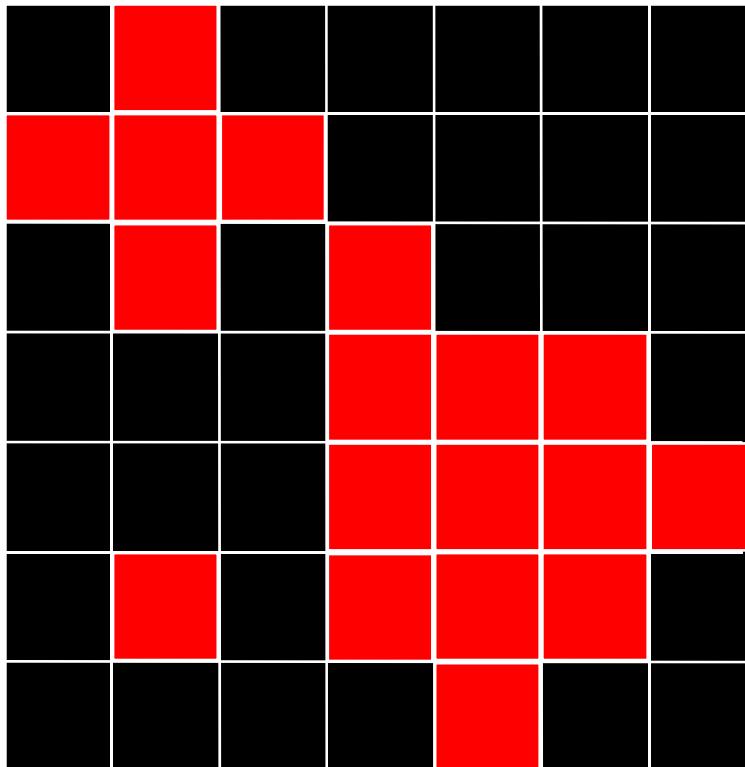


Dilation

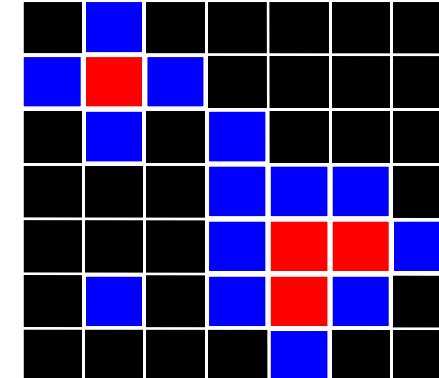
- Increases the size of objects in an image
 - Adds a layer of pixels around the boundary of an object (including the inside boundary for objects with holes)
 - Eliminates tiny holes in objects
 - Removes gaps or bays of insufficient width
- Use Dilate to:
 - Make particles touch



Erosion vs. Dilation



Erosion →

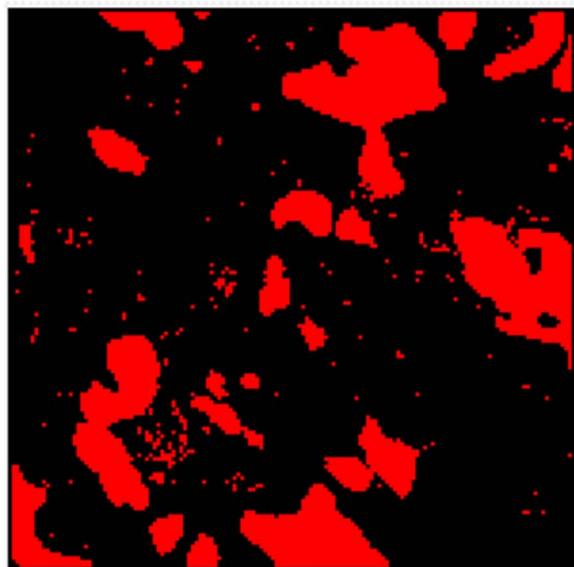


Dilation →

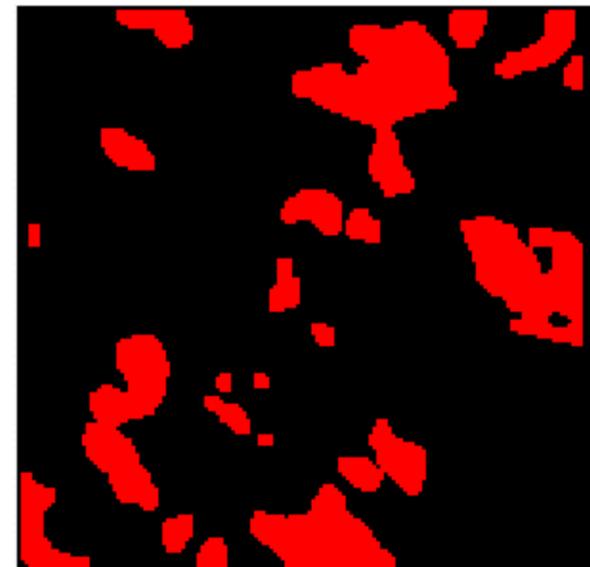


Open

- An erosion followed by a dilation
 - Remove small particles and smooth boundaries
 - Does not significantly alter the size or shape of particles
 - Borders removed by the erosion process are replaced by the dilation process
- Use Open To:
 - Eliminate small particles that constitute noise

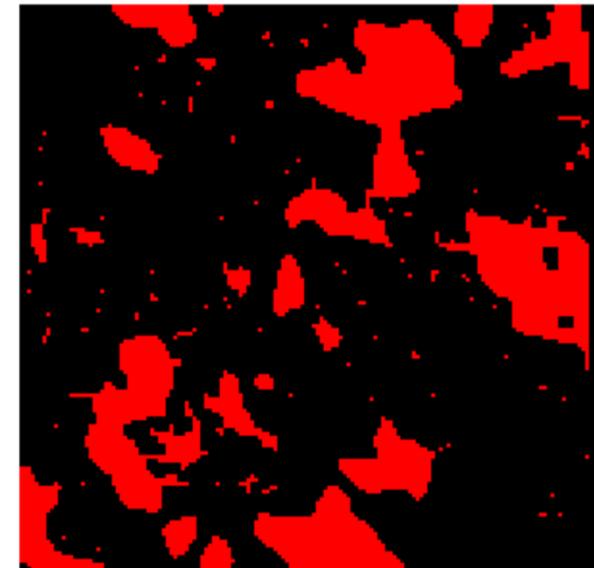
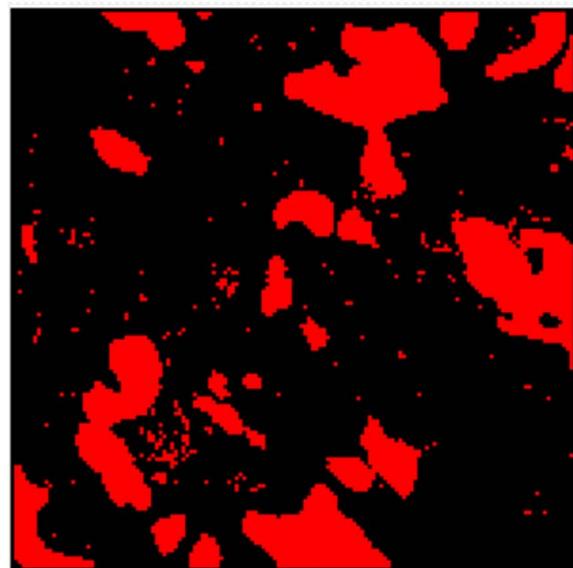


Open →



Close

- A dilation followed by an erosion
 - Fills holes and creates smooth boundaries
 - Does not alter the size or shape of particles
 - Particles that do not connect after the dilation are not changed
- Use Close To:
 - Eliminate small holes that constitute noise



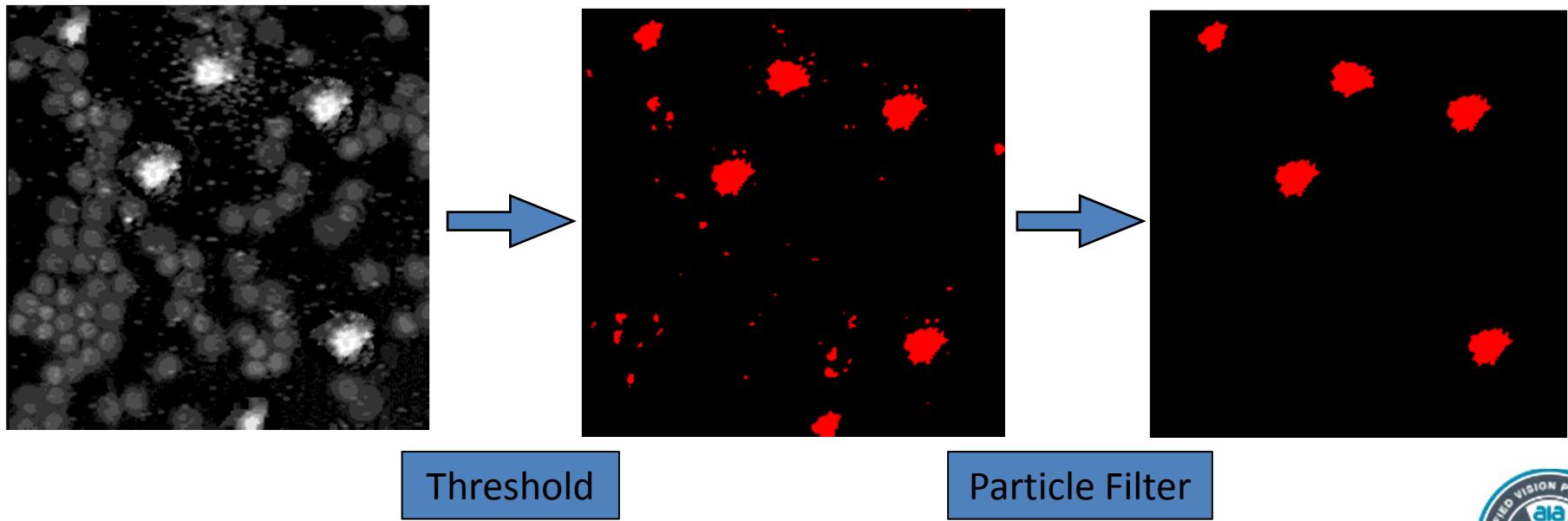
Advanced Morphology

- Advanced morphological functions are combinations of operations, each of which is responsible for a single operation
- These functions execute the following tasks:
 - Separate particles
 - Remove small or large particles
 - Keep or remove particles identified by morphological parameters
 - Fill holes
 - Remove particles from an image border
 - Segmenting the image



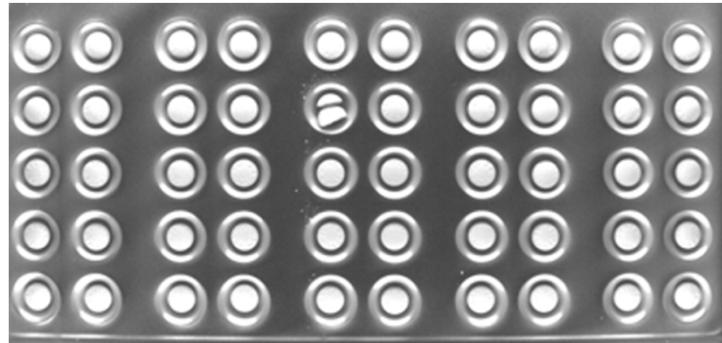
Particle Filtering

- Keeps or removes particles based on geometric features
 - Area, length, aspect ratio and other features are commonly used to filter
- Typically used on binary images
- Cleans up noisy images

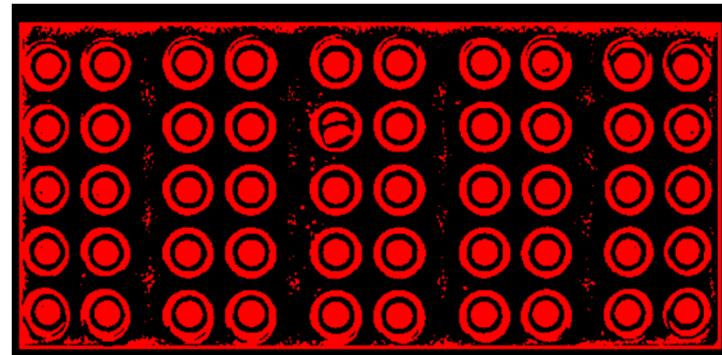


Application: Analyze Particles

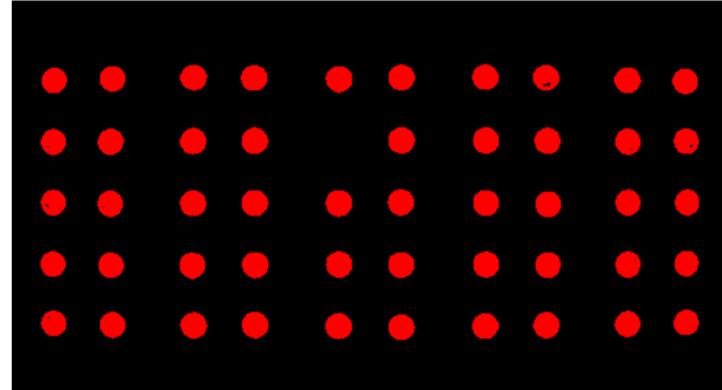
Original



Threshold



Particle Filter



✓ Area
Holes' Area
Particle & Holes' Area
Convex Hull Area
Image Area

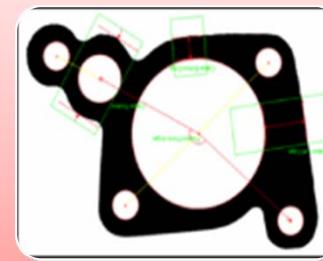
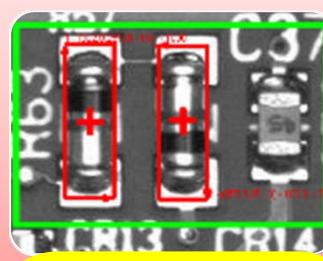
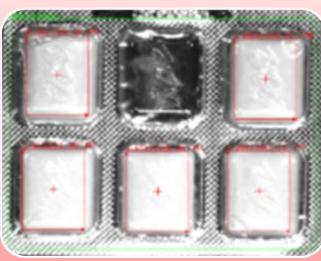
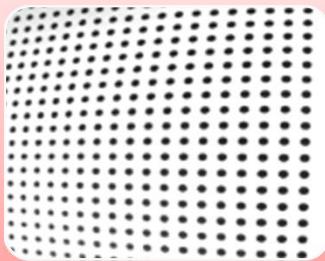
Parameter Range
Minimum Value Pixels
Maximum Value Real-World
 Exclude Interval

Current Parameter
Minimum Value 305
Maximum Value 350
Mean Value 330.612244

Action
 Remove
 Keep



Class Organization



Enhance

- Filter noise or unwanted features
- Remove distortion
- Calibrate images

Check

- Create Particles
- Measure intensity
- Analyze particles

Locate

- Match patterns
- Match geometry
- Set-up coordinate systems

Measure

- Detect edges
- Measure distance
- Calculate geometry

Identify

- Read text (OCR)
- Read 1D barcodes
- Read 2D codes

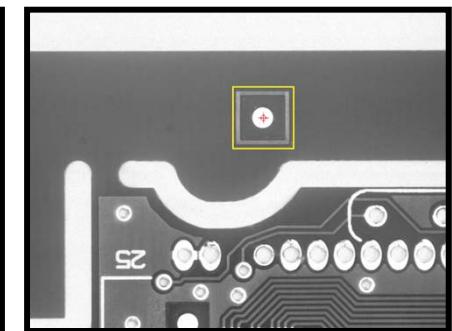
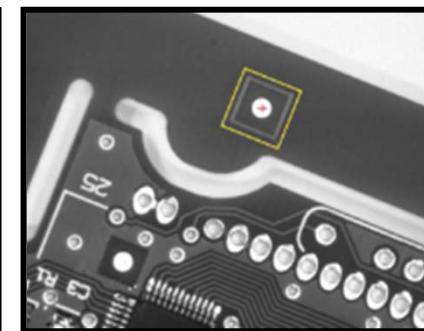
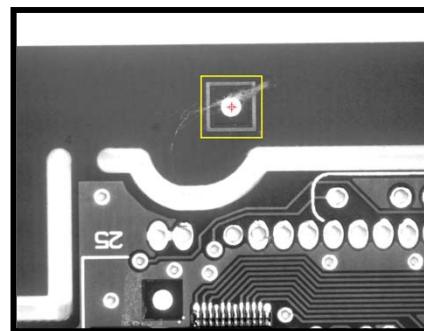
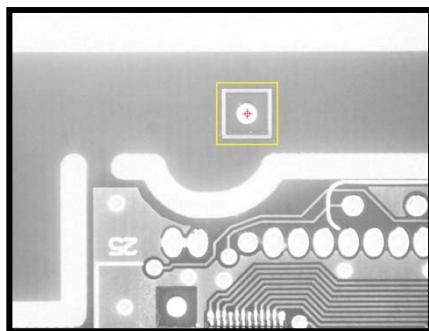


LOCATING PARTS: PATTERN MATCHING



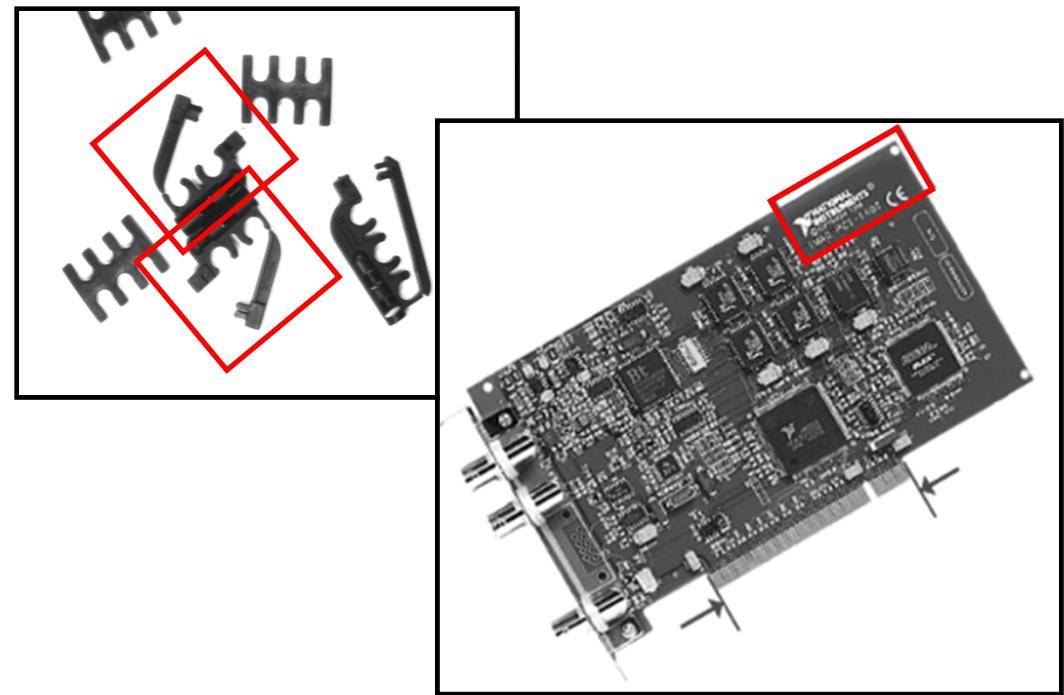
Introduction to Matching

- Locates regions of a grayscale image that match a predefined template
 - Calculate a score for each matching region
 - Score indicates quality of match
- Returns the XY coordinates, rotation angle and scale for each match



Applications

- Presence Detection
- Counting
- Alignment
- Inspection



How It Works

- Two step process:
 - Step 1: Learn Template
 - Extract information useful for uniquely characterizing the pattern
 - Organize information to facilitate faster search of the pattern in the image
 - Step 2: Match
 - Use the information present in the template to locate regions in the target image
 - Emphasis is on search methods that quickly locate matched regions



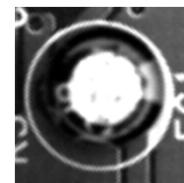
Pattern Matching Methods

- Different ways to perform pattern matching based on the information extracted from the template
- Two common methods:
 - Correlation Pattern Matching
 - Relies on the grayscale information in the image for matching
 - Geometric Pattern Matching
 - Relies on edges and geometric features in the image for matching

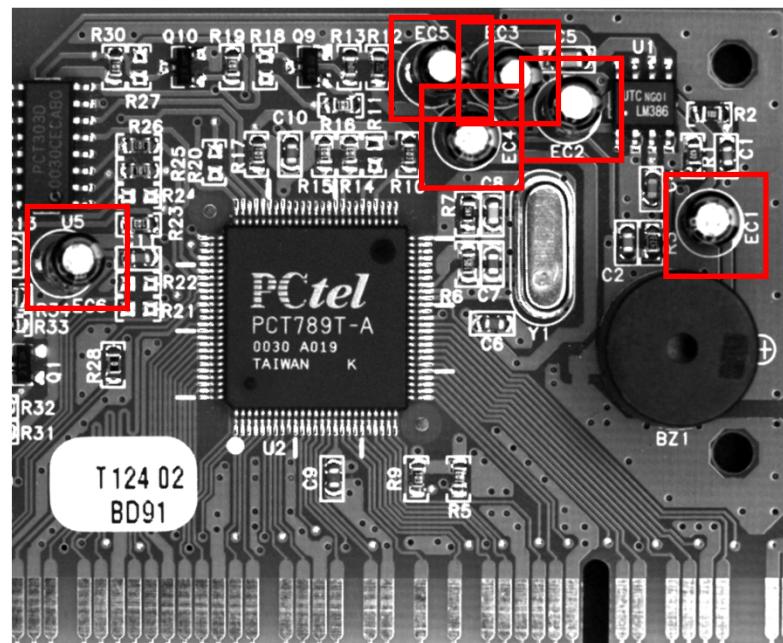


Correlation Pattern Matching

- Grayscale information present in the image
- Directly uses the underlying grayscale distribution in the image for matching
- Grayscale values in the pattern are matched to regions in the image using **normalized cross-correlation**
- Score ranges from 0-1000
 - Used to allow imperfect match

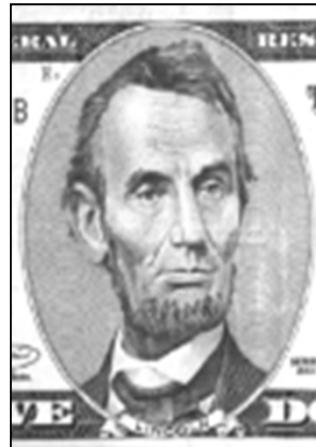


Template (Pattern)

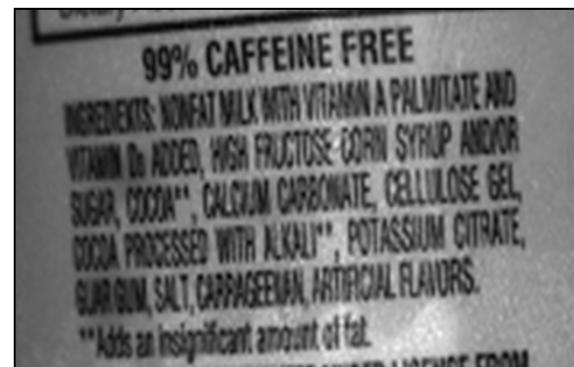


Correlation Pattern Matching

- When to use:
 - Template primarily characterized by grayscale information
 - Matching under uniform light changes
 - Little occlusion and scale changes in image
 - Good for the general case



Good template



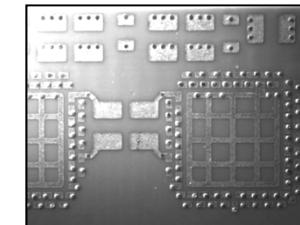
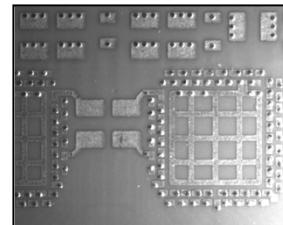
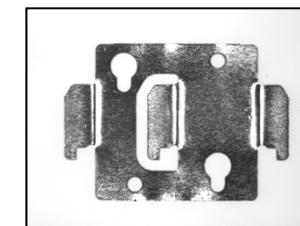
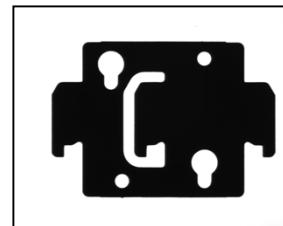
Bad template



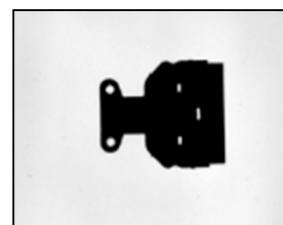
Correlation Pattern Matching

- When NOT to use:

- Non-uniform lighting



- Occlusion more than 10%

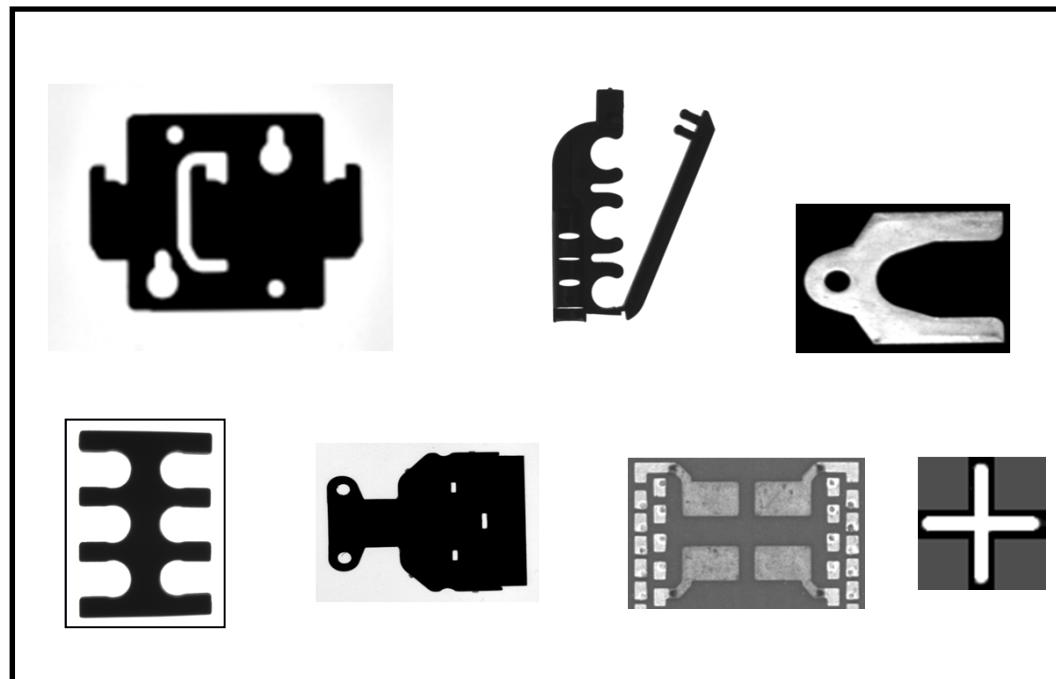


- Scale changes



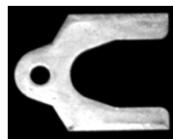
Geometric Pattern Matching

- Matching tool you can use to locate parts that contain distinct edge information
- Not useful when template is predominantly defined by texture



GPM is Tolerant to...

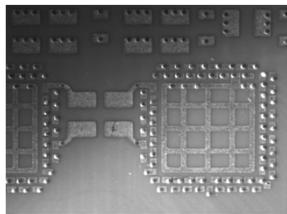
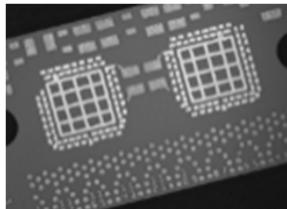
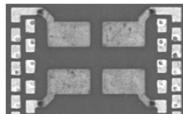
Occlusion



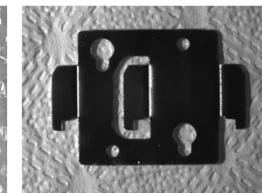
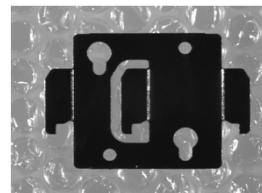
Scale Changes



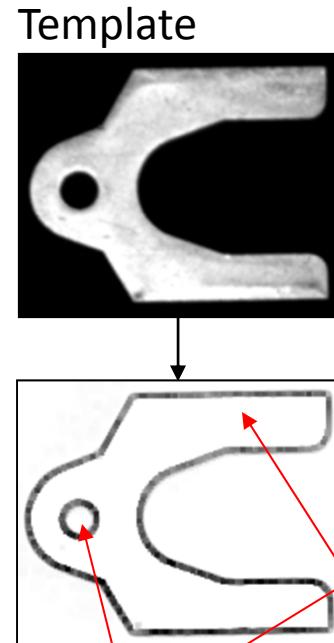
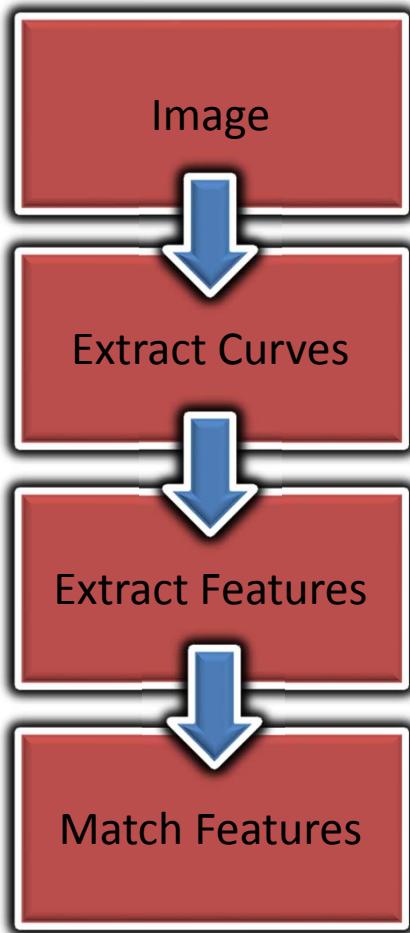
Non-uniform
Lighting



Background
Changes



GPM – Feature-based



Target Image



circles

parallel lines



Feature Comparison

| Feature | CPM | GPM |
|--|-----|-----|
| Template contains texture-like information | Yes | |
| Template contains geometric information | Yes | Yes |
| Find multiple match locations | Yes | Yes |
| Rotation | Yes | Yes |
| Scale | | Yes |
| Occlusion | | Yes |
| Matching under non-uniform lighting | | Yes |
| Sub-pixel match locations | Yes | Yes |

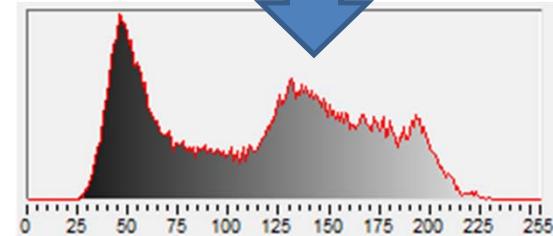
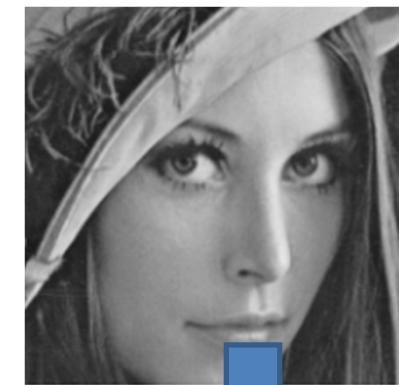
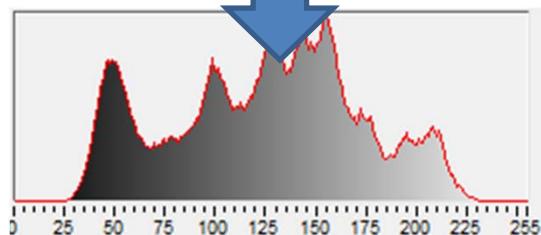


LOCATING PARTS: COORDINATE SYSTEMS



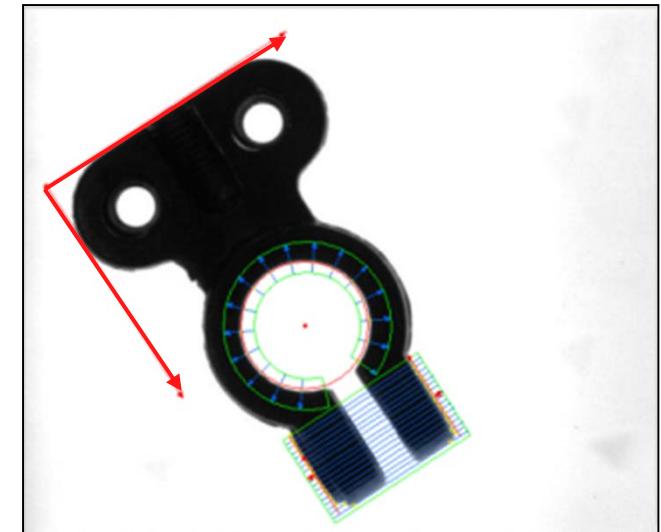
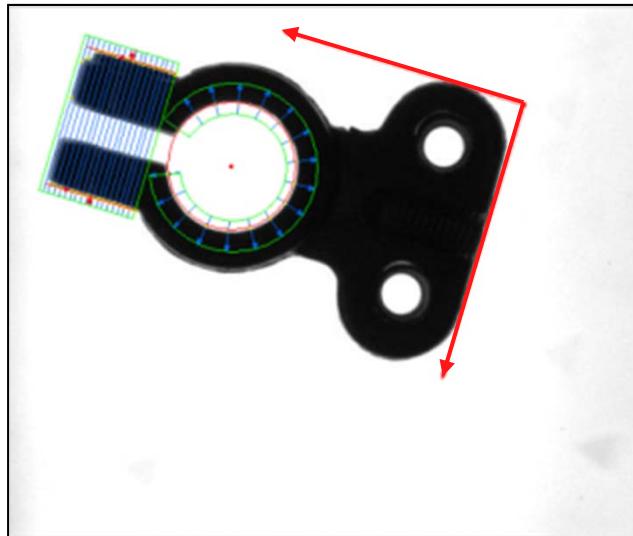
Region of Interest

- Region of Interest
 - A portion of the image upon which an image processing step may be performed
 - Can be defined statically (fixed)
 - Or dynamically: based on features located in the image
- Used to
 - Process only pixels that are interesting



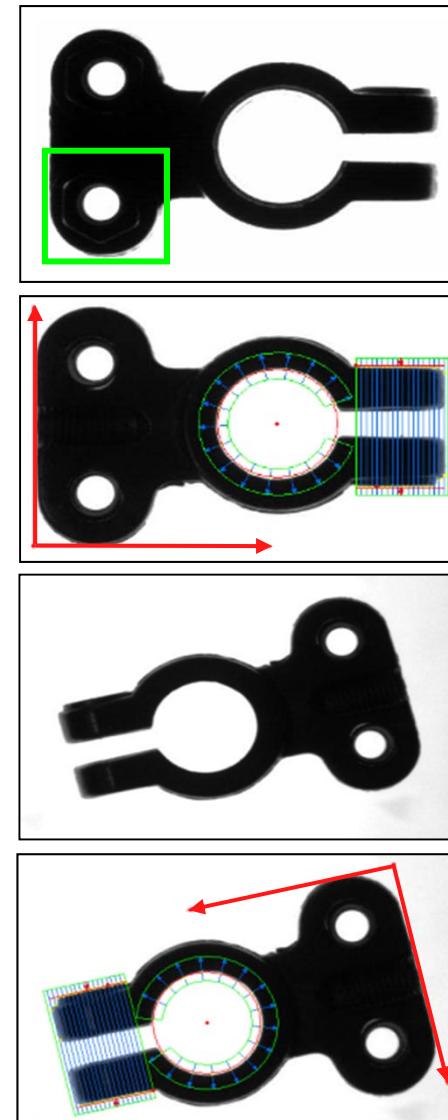
Coordinate Systems

- Defined by a reference point (origin) and angle within the image, or by the lines that make up its axes
- Allows you to define search areas that can move around the image with the object you are inspecting
- Usually based on a characteristic feature of the object under inspection
 - Use pattern match to locate features
 - Use features to establish coordinate system

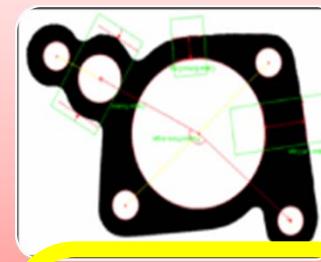
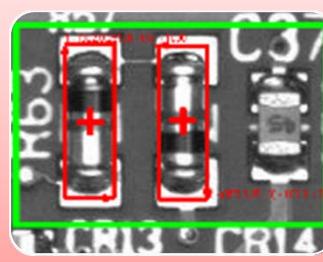
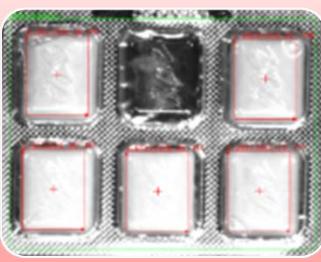
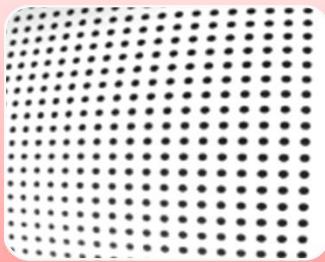


Coordinate Systems – Set Up

- Define an origin
 - Locate an easy-to-find feature in your reference image
 - Set a coordinate system based on its location and orientation
- Set up measurement ROIs in reference to the new origin
- Acquire a new image
- Locate reference point
- Adjust measurement ROIs



Class Organization



Enhance

- Filter noise or unwanted features
- Remove distortion
- Calibrate images

Check

- Create Particles
- Measure intensity
- Analyze particles

Locate

- Match patterns
- Match geometry
- Set-up coordinate systems

Measure

- Detect edges
- Measure distance
- Calculate geometry

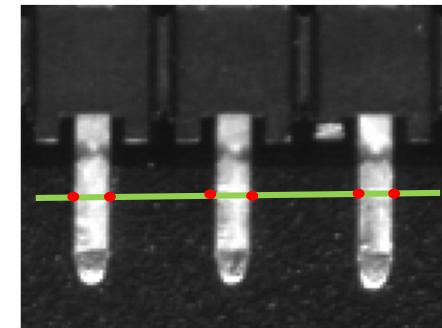
Identify

- Read text (OCR)
- Read 1D barcodes
- Read 2D codes



Edge Detection Overview

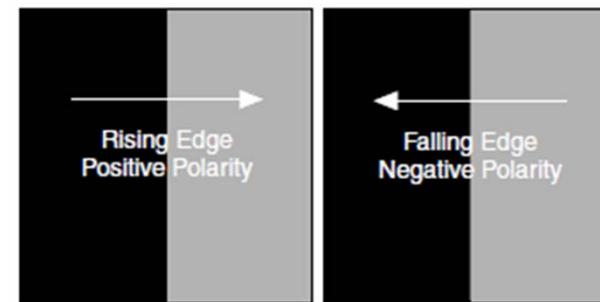
- Process of detecting transitions in an image
- One of the most commonly used machine vision tools
- Attractive because:
 - Simple to understand and use
 - Localized processing – fast
 - Applicable to many applications



Different Illuminations

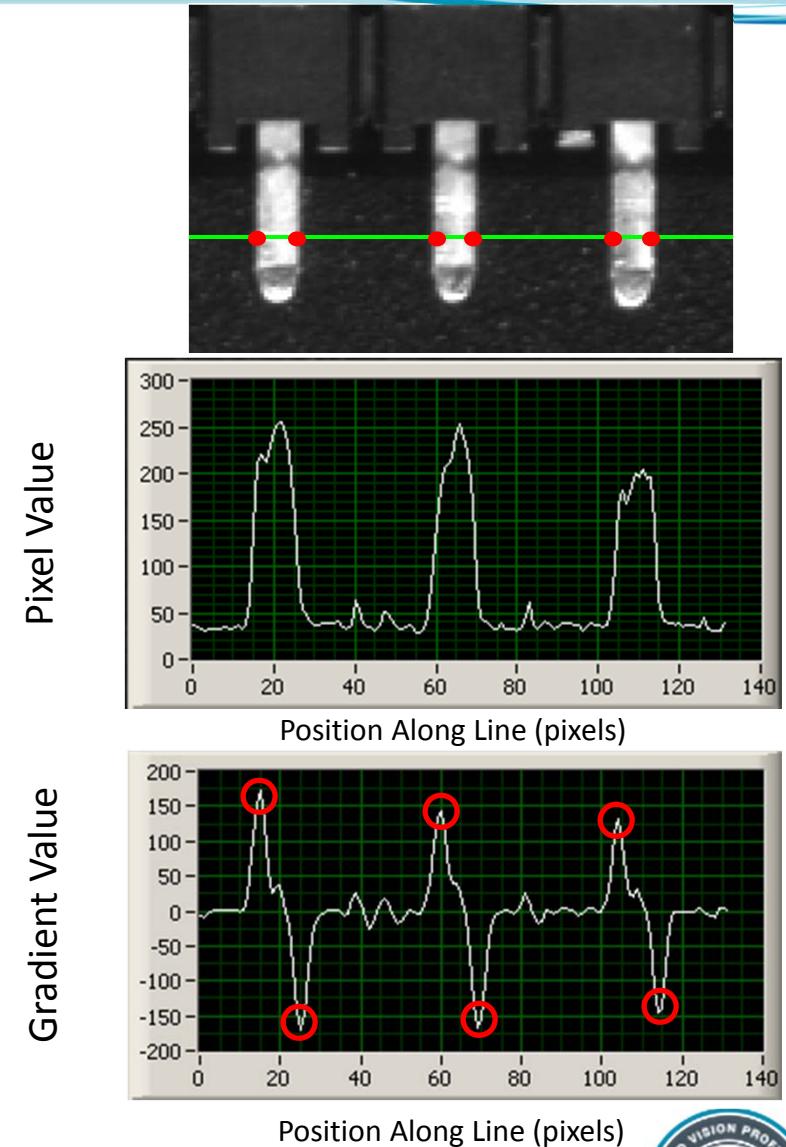


Different Edges



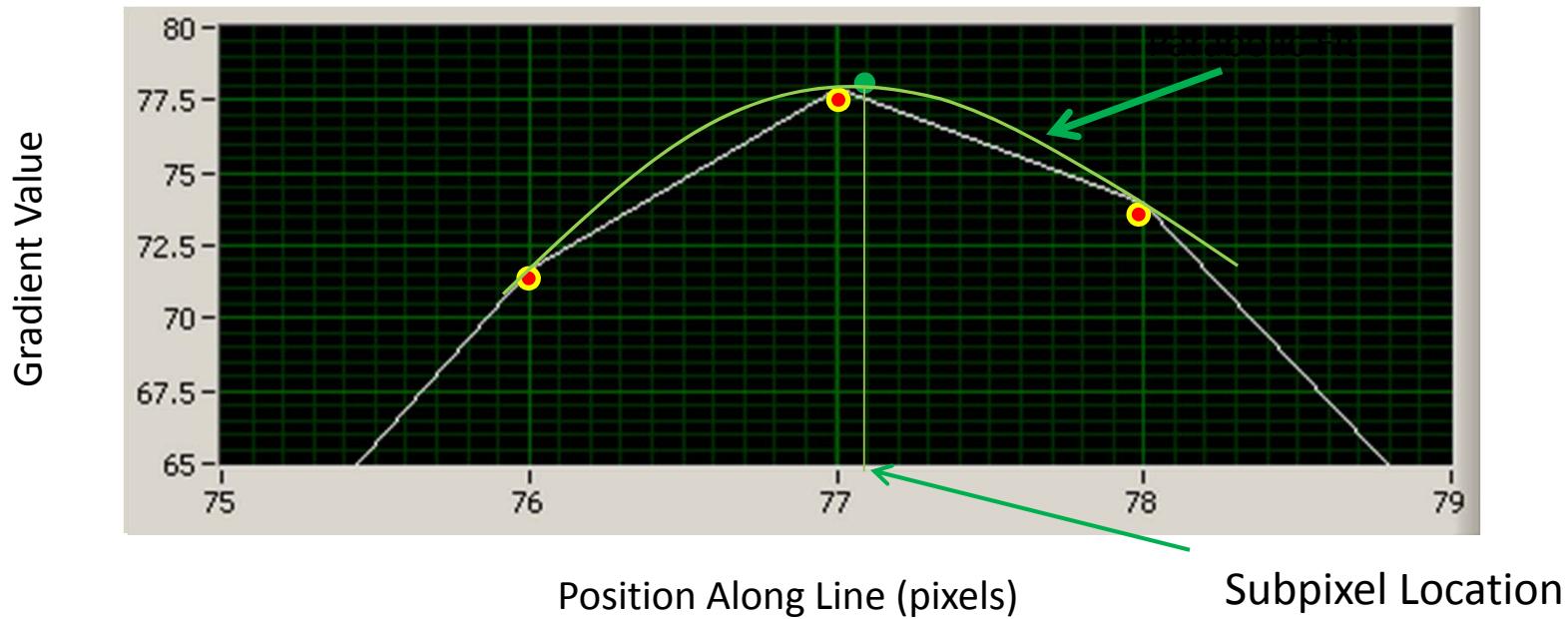
1D Edge Detection

- Detect edge points along a line
- Basic operation:
 - Get pixel values along the line
 - Compute gradient information
 - Peaks and valleys represent edge locations
 - Get first, first & last, best, or all edges



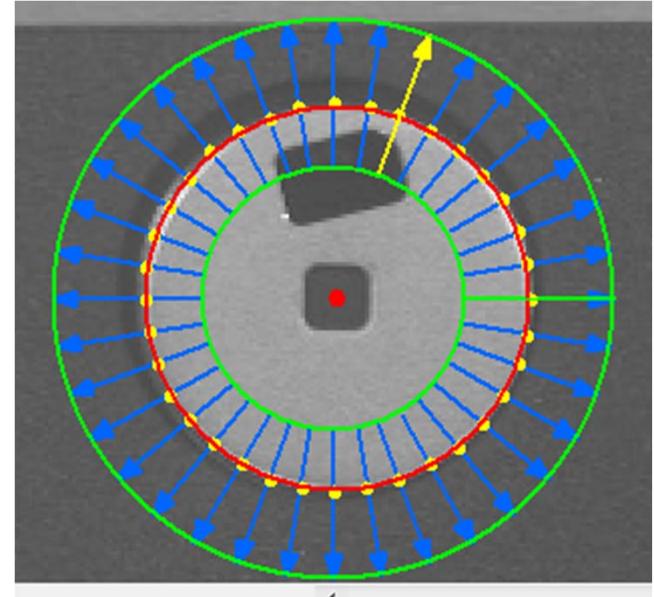
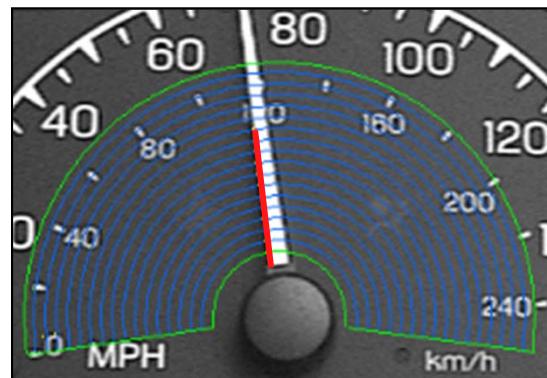
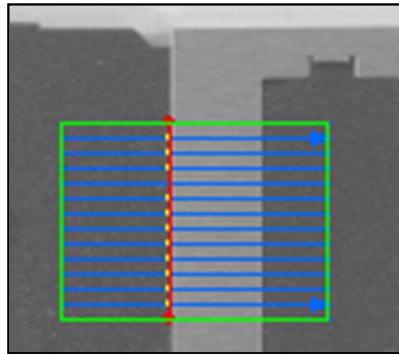
Subpixel Accuracy

- Subpixel location of edge can be computed using parabolic interpolation



Edge Detector Tools

- High level tools based on the edge detectors
- Rake:
 - Used to find multiple edges and fit a shape through them
- Configurable search directions, sub-sampling ratios, and display settings

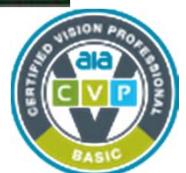
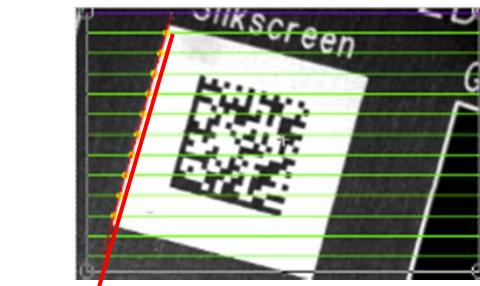
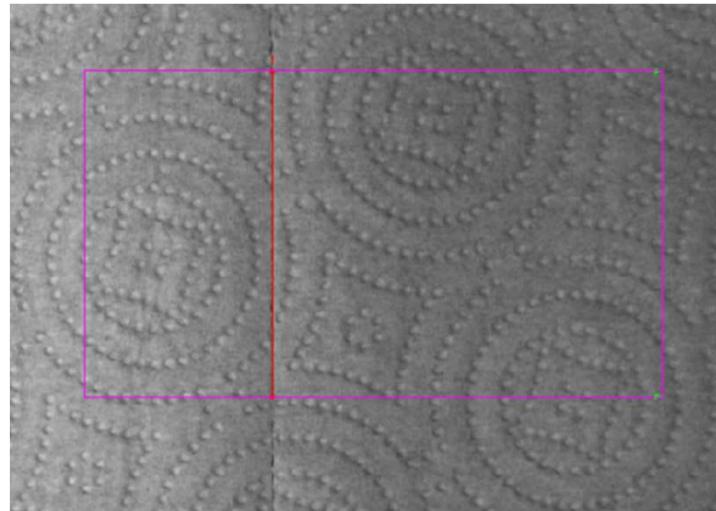


| | |
|-------------------------------------|---------------------|
| Direction | Inside to Outside |
| Edge Polarity | Bright to Dark Only |
| Look for | Best Edge |
| <input type="checkbox"/> Auto Setup | |
| Minimum Edge Strength | 30 |
| Kernel Size | 3 |
| Projection Width | 3 |
| Gap | 10 |



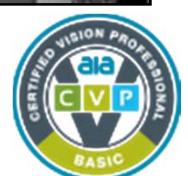
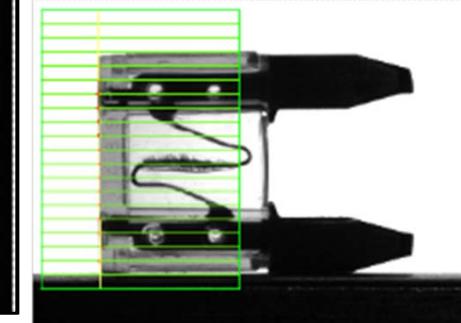
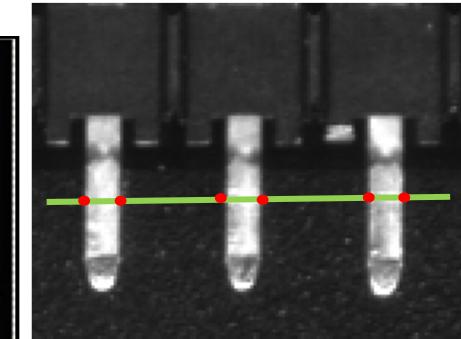
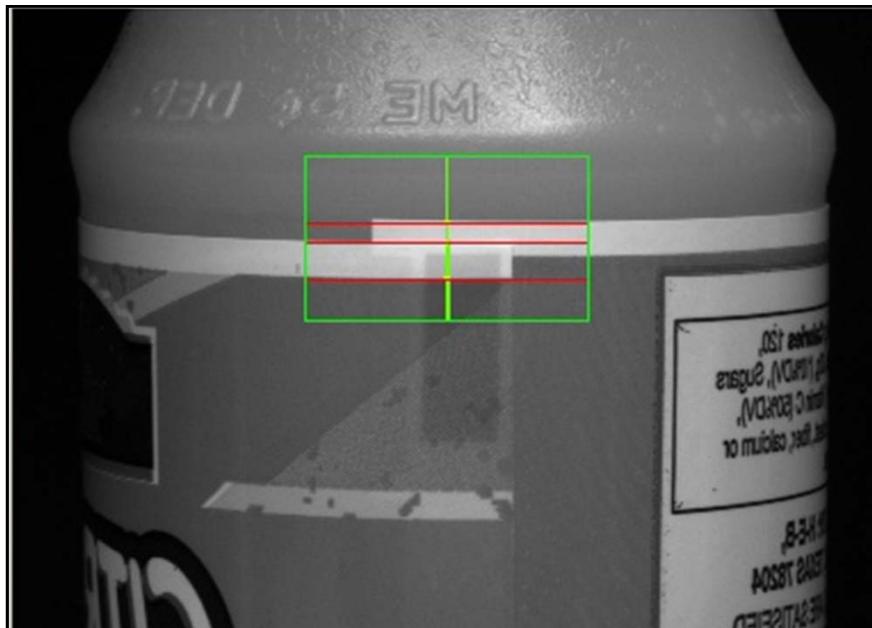
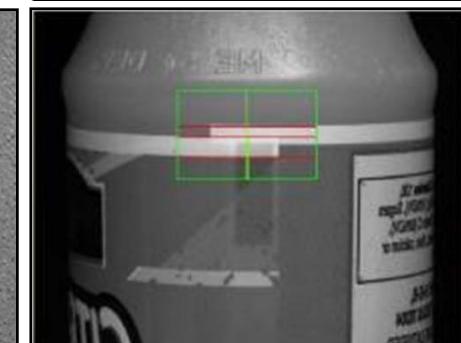
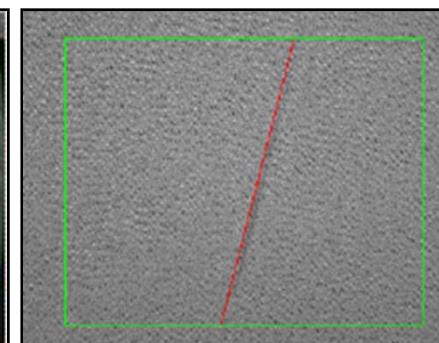
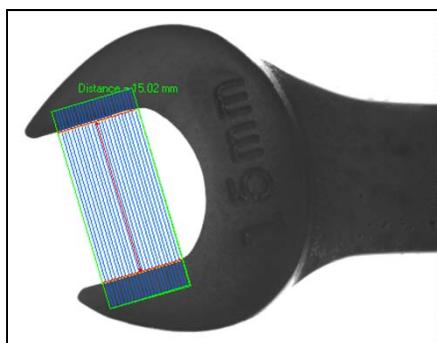
Straight Edge (Line) Detection

- Detect straight lines in an image
 - Extension of 1D edge detection
- Straight edge detection options:
 - Rake-based
 - Projection-based

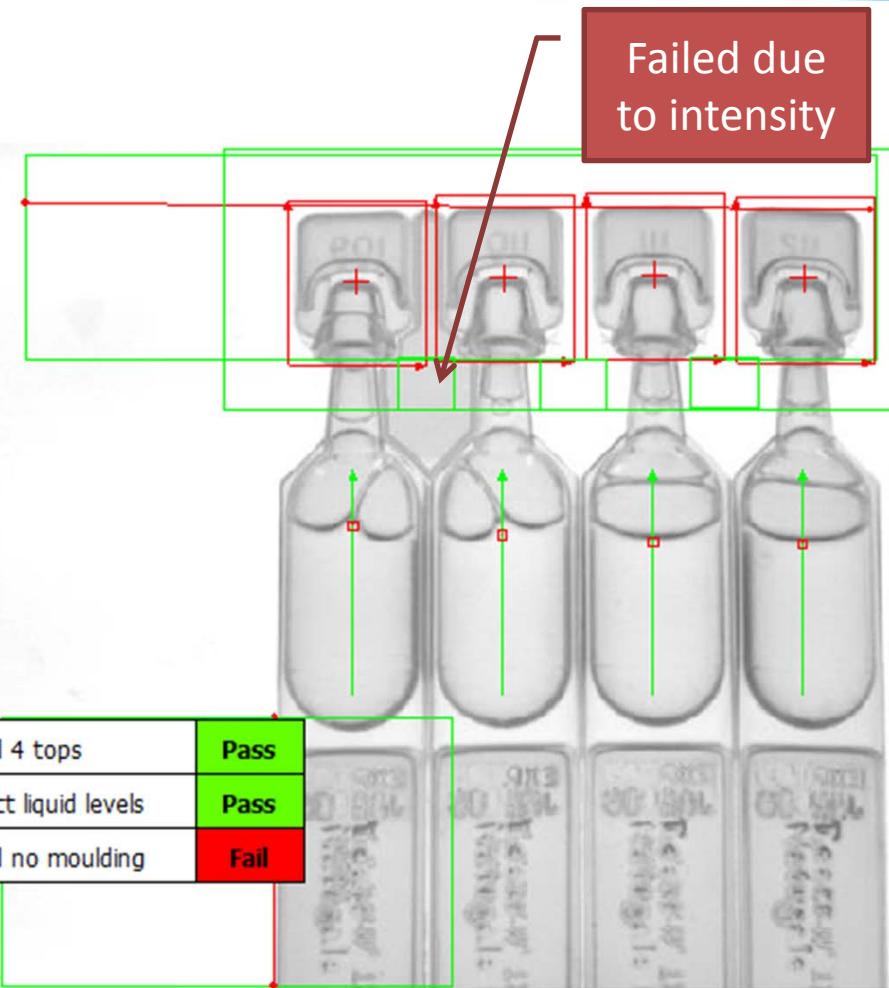
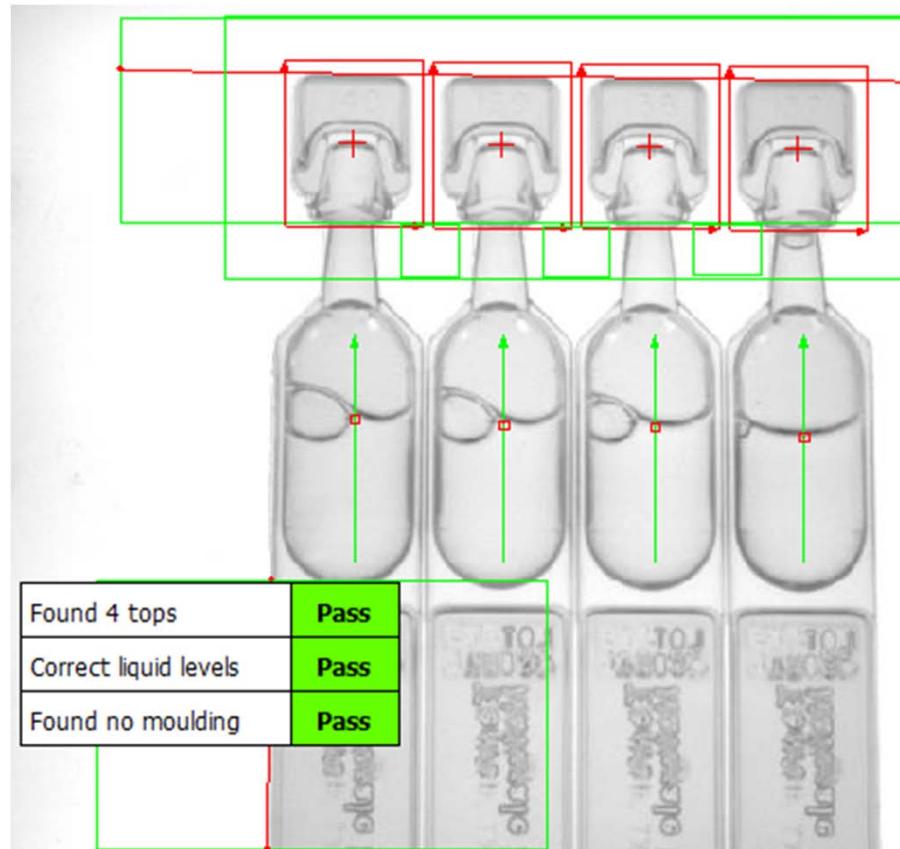


Edge Detection Applications

- Detect Features
- Alignment
- Gauging
- Inspection

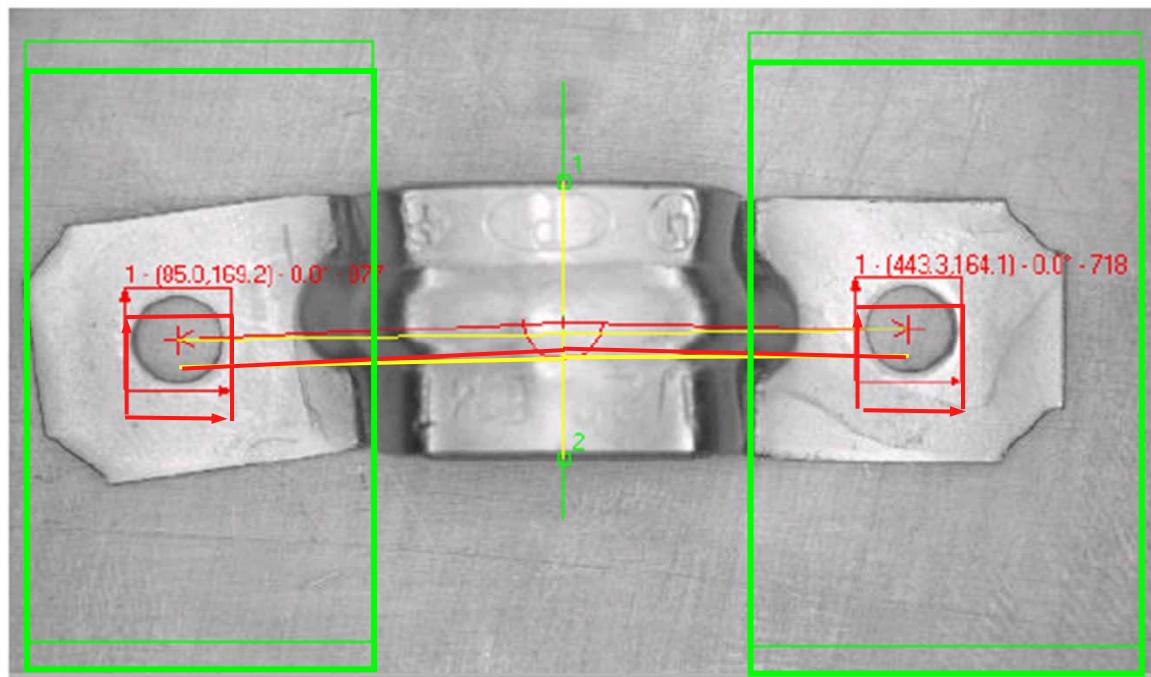


Application: Locating Parts

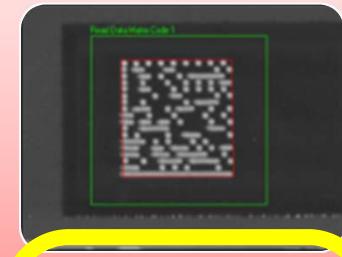
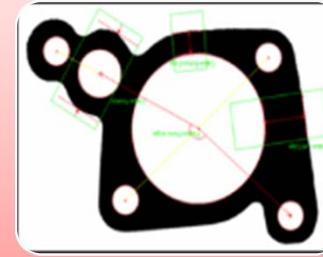
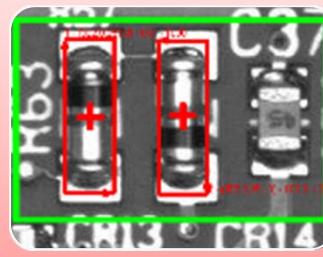
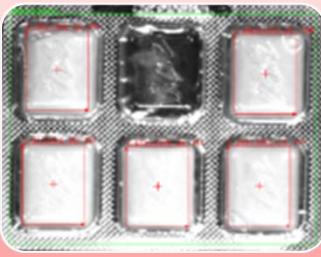
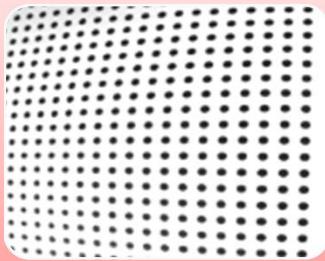


Application: Dimension Verification

- Dimensional measurements, such as lengths, distance, and diameter
 - Inline gauging inspections are used to verify assembly and packaging routines
 - Offline gauging is used to judge product quality according to a sample



Class Organization



Enhance

- Filter noise or unwanted features
- Remove distortion
- Calibrate images

Check

- Create Particles
- Measure intensity
- Analyze particles

Locate

- Match patterns
- Match geometry
- Set-up coordinate systems

Measure

- Detect edges
- Measure distance
- Calculate geometry

Identify

- Read text (OCR)
- Read 1D barcodes
- Read 2D codes



Identify

- 1D and 2D Codes
- Marking methods
- Reading
- Examples



1D Codes

- Applications using 1D bar codes have been around for over 35 years
- Barcode data is an index into a large central data storage
- Code is easily read by laser scanners
- Low data capacity in large footprint



Code 3 of 9



Code 128



EAN 13

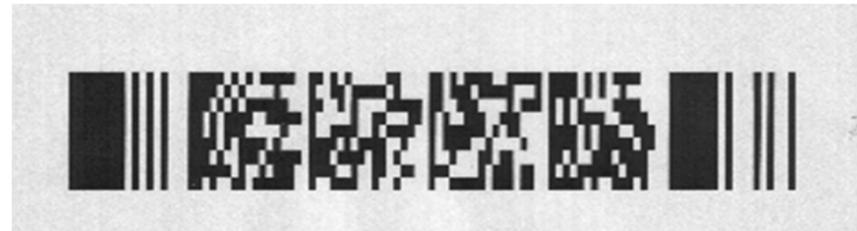


2D Codes

- Usually not an index into a database
- Camera-based vision systems are preferred reading method
- High data capacity in small footprint



Data Matrix



PDF 417

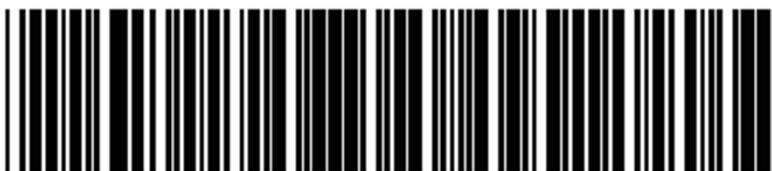


QR Code



1D vs 2D

| 1D Codes | 2D Codes |
|----------------------------------|------------------------------|
| Low data capacity | High data capacity |
| Index into large database | Self contained data |
| Large footprint | Small footprint |
| Redundancy in Y dimension | Error correction capability |
| Readable by laser scanner | Requires camera based reader |
| Requires as much as 80% contrast | Can be read in low contrast |



A1B2C3D4E5
This bar code contains only
10 characters



A 52 mm Data Matrix
(approx. 3/10th of an inch)
can contain 400 characters
of information



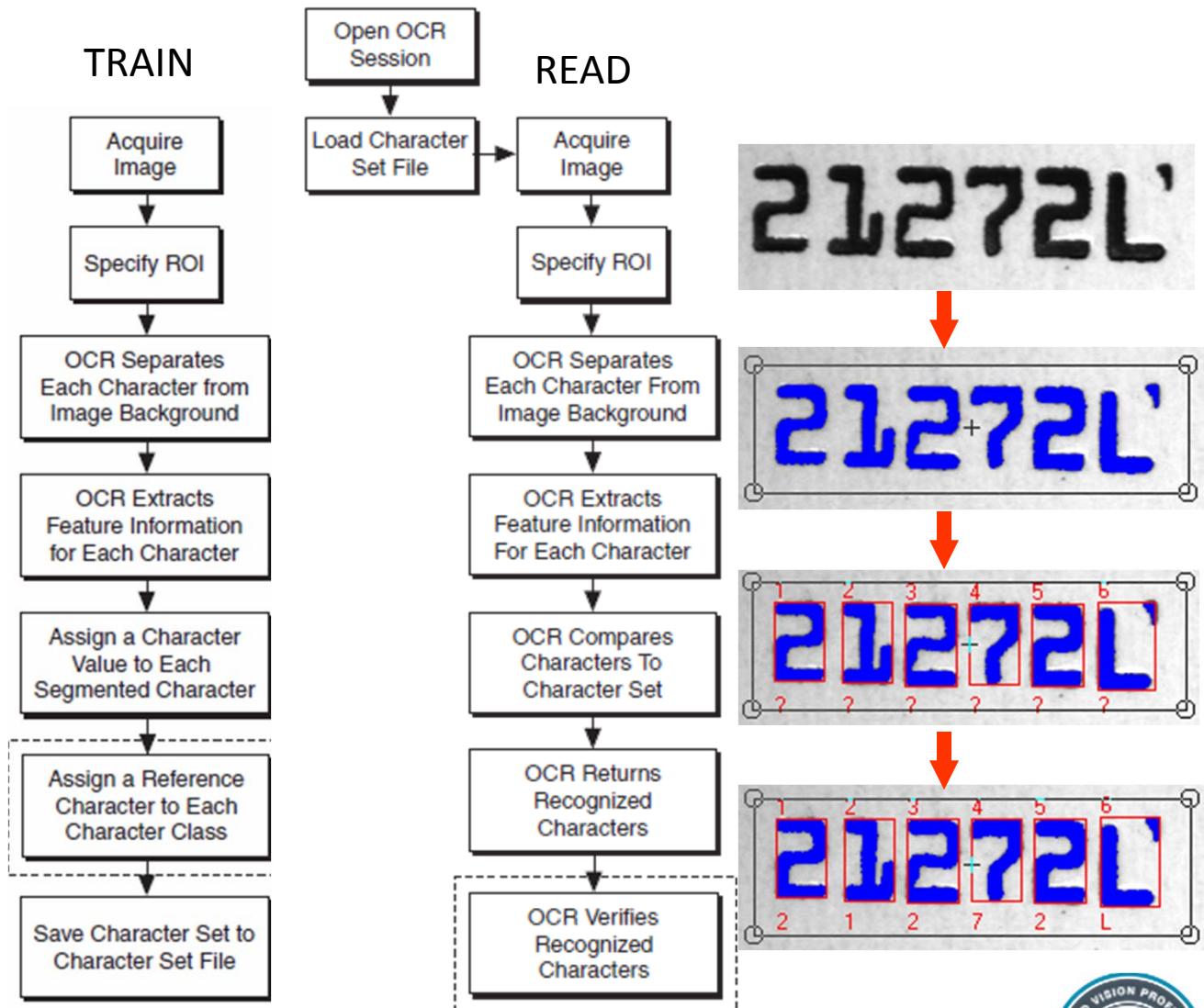
Optical Character Recognition



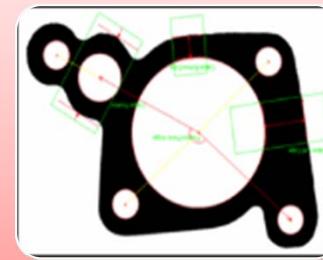
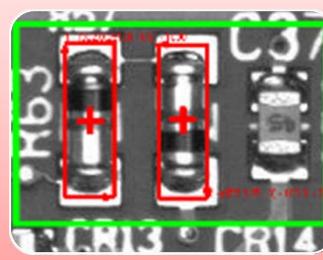
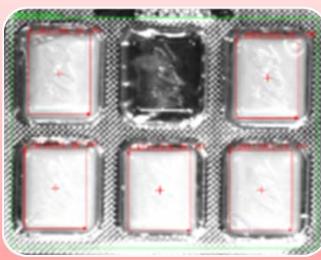
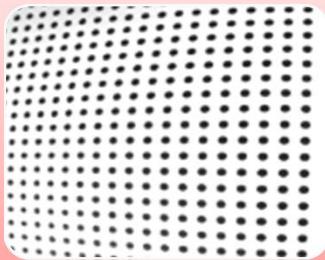
Particle-based OCR

Typical steps:

- Region of interest around line of text
- Threshold
- Character segmentation
- Compare to library
- Character is learned or recognized



Class Organization



Enhance

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- Remove distortion
- Calibrate images

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- Create Particles
- Measure intensity
- Analyze particles

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- Match geometry
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