Pattern Recognition

Introduction to Pattern Recognition

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2016

Cite this document as:
Wang, Yuan-Kai, "Introduction to Pattern Recognition,"
Lecture Notes of Wang, Yuan-Kai, Fu Jen University, Taiwan, 2016.

- This is the first lecture note of the course PATTERN RECOGNITION in English in 104-2 semester, EE, FJU.
- In this lecture note, I will introduce basic concept of an image recognition system.
- Web site of this course: http://pattern-recognition.weebly.com.

Goal of This Unit

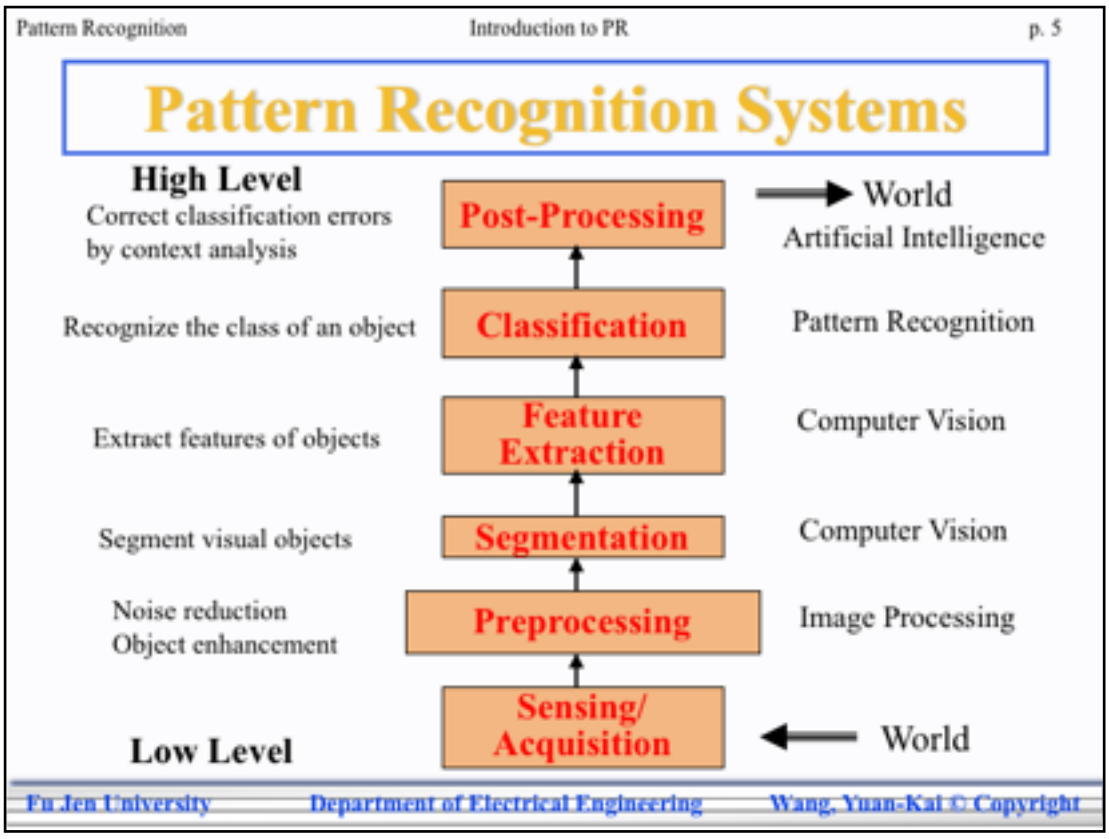
- Explain PR with a systematic view
  - From sensor input to recognition output
- Discriminate among three courses
  - Pattern recognition, computer vision, digital image processing

References

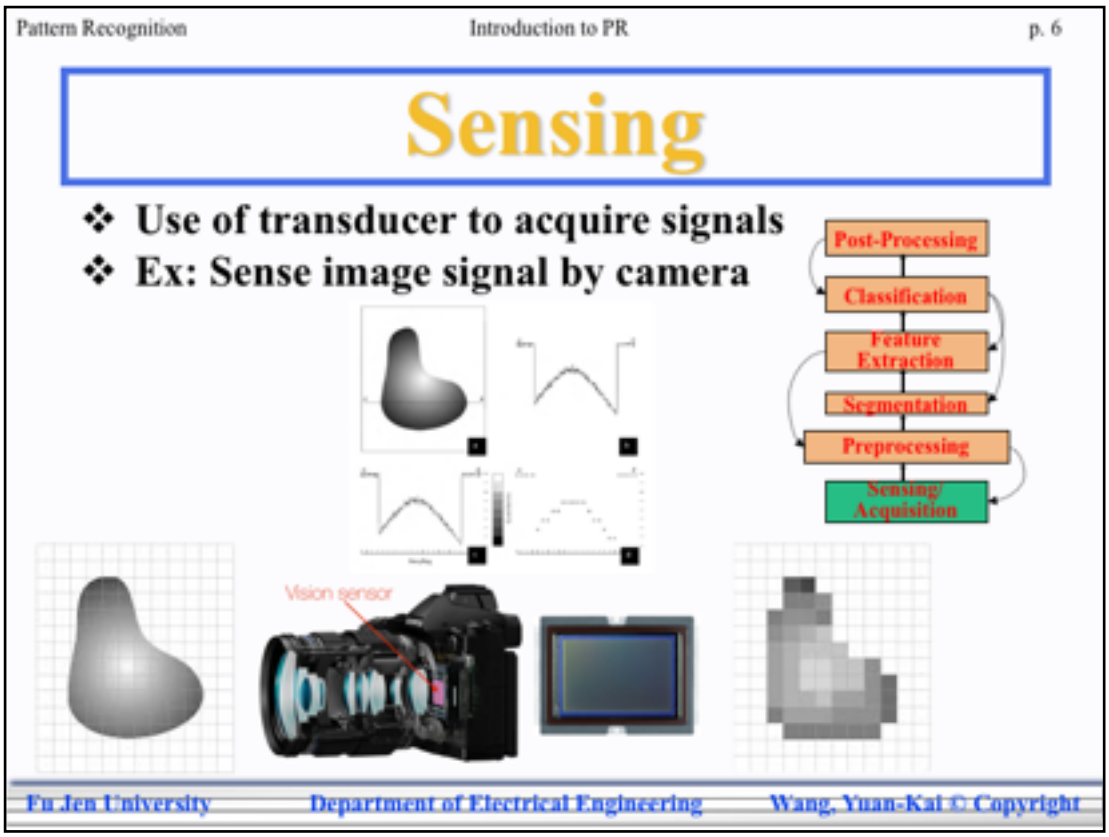
- **Pattern Recognition Engineering,**
  M. Nadler & E. P. Smith
  - **Chapter 1 - Introduction**
- **Pattern Recognition, 4th,**
  S. Theodoridis & K. Koutroumbas
  - **Chapter 1 - Introduction**
- **Pattern Classification, 2nd,**
  R. O. Duda, P. E. Hart & D. G. Stork
  - **Chapter 1 – Introduction**

Contents

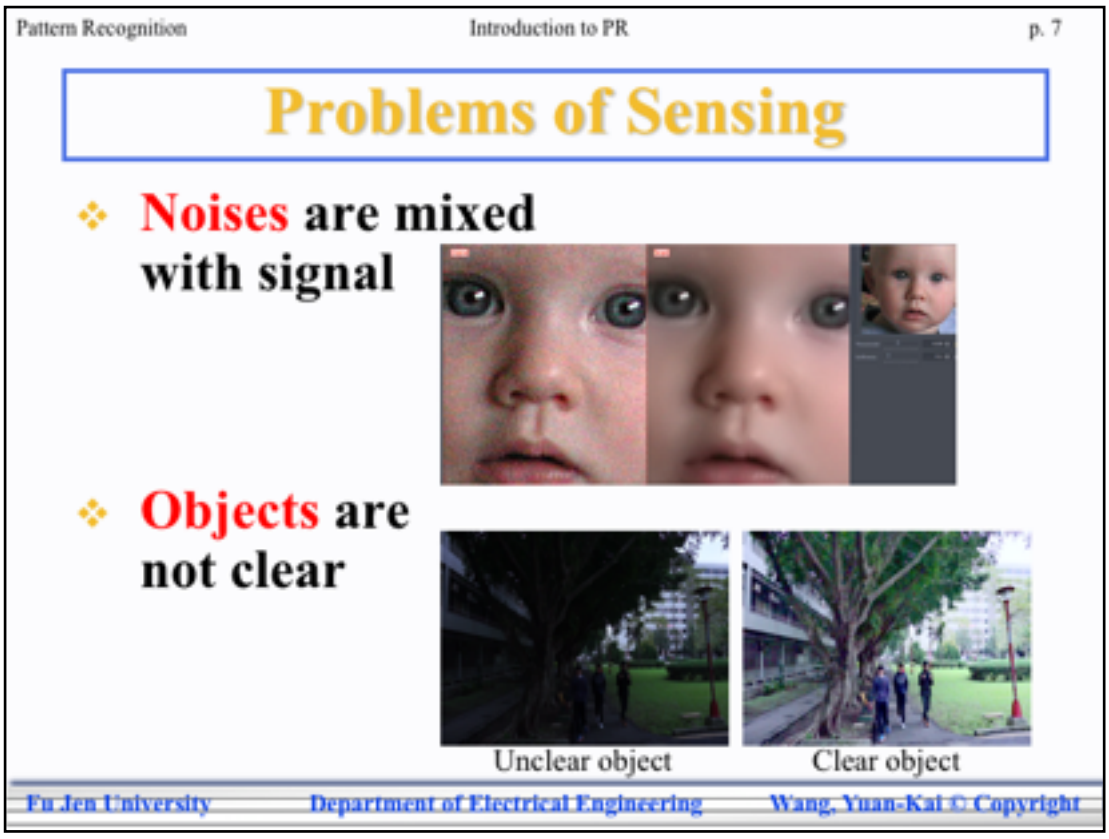
- Pattern Recognition Systems
- Performance Evaluation



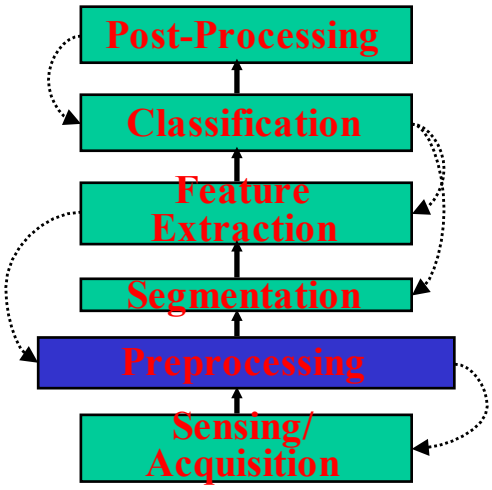
- A pattern recognition (PR) system is not identical to pattern recognition (PR) algorithms
  - A PR system is more complete than a PR algorithm.
  - A PR system needs to implement related techniques such as sensor, filtering and so on.
  - But PR algorithms are just a key component of a PR system.
- PR systems and algorithms can be used to a lot of signals, such as speech, image, video, music, text, and so on.
  - But this course will use only image signal as examples.



- Sensing is the first stage for a pattern recognition system.
  - It is usually hardware, but not software.
- Terminologies about transducer
  - Transduce: transform one energy form into another energy form
  - Transducer: an instrument to transduce energy
    - Ex.: microphone: a transducer to transform air vibration energy to electron energy
    - Ex.: camera: a transducer to transform photon energy into electron energy
  - Digital transducer: a transducer with the digitization of electron energy
    - Ex.: digital camera vs. analog camera: digital camera uses IC chip to digitize electron energy into digital signals(images), but traditional (analog) camera uses film to get images.
- Terminologies about image sensing
  - Image signals, image sensing, image sensor, camera
  - Could you differentiate the difference among these terminologies?
- Sampling and quantization: AD (Analog to Digital) Conversion
  - What is sampling: digitization in temporal domain
  - What is quantization: digitization of intensity/quantity



- Why are noises generated?
  - Dust, light, sampling, quantization, …
- Why are objects unclear?
  - Insufficient light(night), under exposure(wrong exposure setting of camera), de-focus (lens focus is not right), …
- Both noise removal and object enhancement are done in next stage: preprocessing



- Intrinsic noise
  - The measured physical signal is already noisy, because the sensor will have its own intrinsic noise level, from thermal and other noise sources.
  - Even the raw un-quantized signal is accompanied by noise.
  - Example noise intrinsic to the system
    - The hiss on a cassette recording
    - The rumble from a turntable
- Sampling and quantization noise
  - It is the noise generated by the analog to digital signal process (AD conversion). It includes two steps: sampling and quantization.
  - Any physical measurement from sensors (image sensors such as Photoresistive target or vidicon-like, or solid-state arrays) are usually analog quantities that must be quantized in order to become machine variables.
  - Sampling and quantization generates error(noise)
    - Sampling and quantization produce approximate discrete data,
    - There are errors between original continuous signal and discrete data.
  - Sampling and quantization noise is produced by the approximation error
    - The finer the quantization, the smaller is the noise
    - The cost of equipment increases as some power of the fineness of quantization - resolution
- Interference noise
  - *Interference effects* cause slight variations of shape to occur between repeat scans of the same object
  - No two acquisitions of the same original are identical

Noises with Different Characteristics

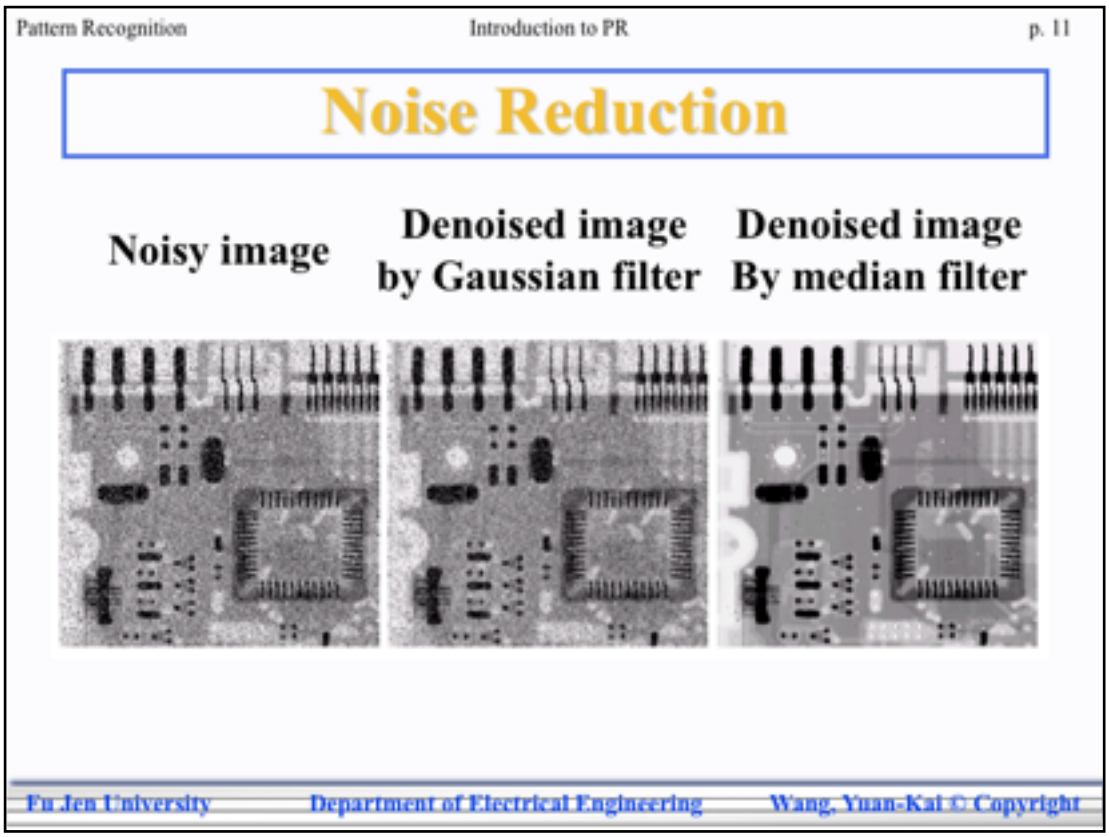
- **Mathematical**
  - **Additive noise**
  - **Mulplicative noise**
- **Statistical**
  - **Gaussian noise**
  - **Poisson noise**
  - **Impulse noise**

- Materials in Wikipedia to study noises
  - Gaussian noise:
  - Poisson noise:
  - Impulse noise:

Preprocessing

- Noise reduction
- Object enhancement

- Preprocessing is the second stage for a pattern recognition system.
- The following slides will give some examples to explain these two goals.

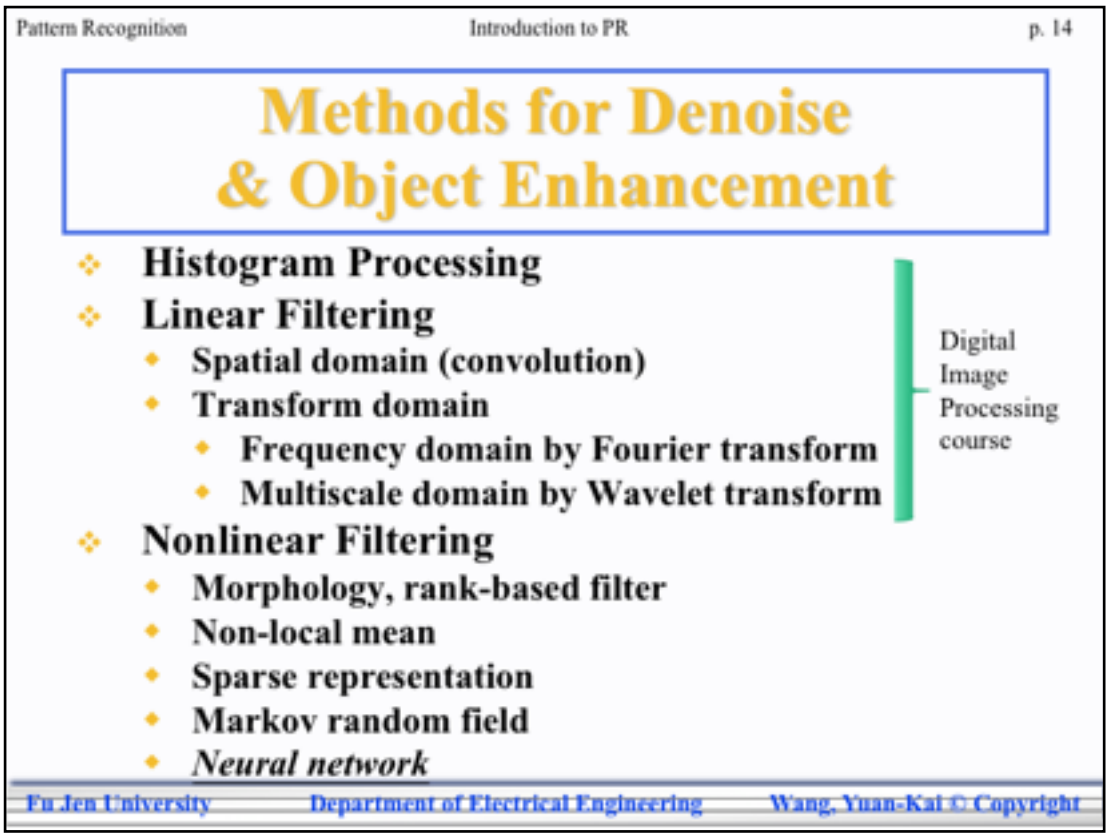


- Noise reduction is a process to reduce/remove noises in the image
  - It is also called: noise removal, denoise, …
- The noise in the left image of this slide is : salt-and-pepper noise (a kind of impulse noise)
  - Salt-and-pepper noise cannot be well-processed by Gaussian filter
  - Salt-and-pepper noise can be well-processed by median filter.

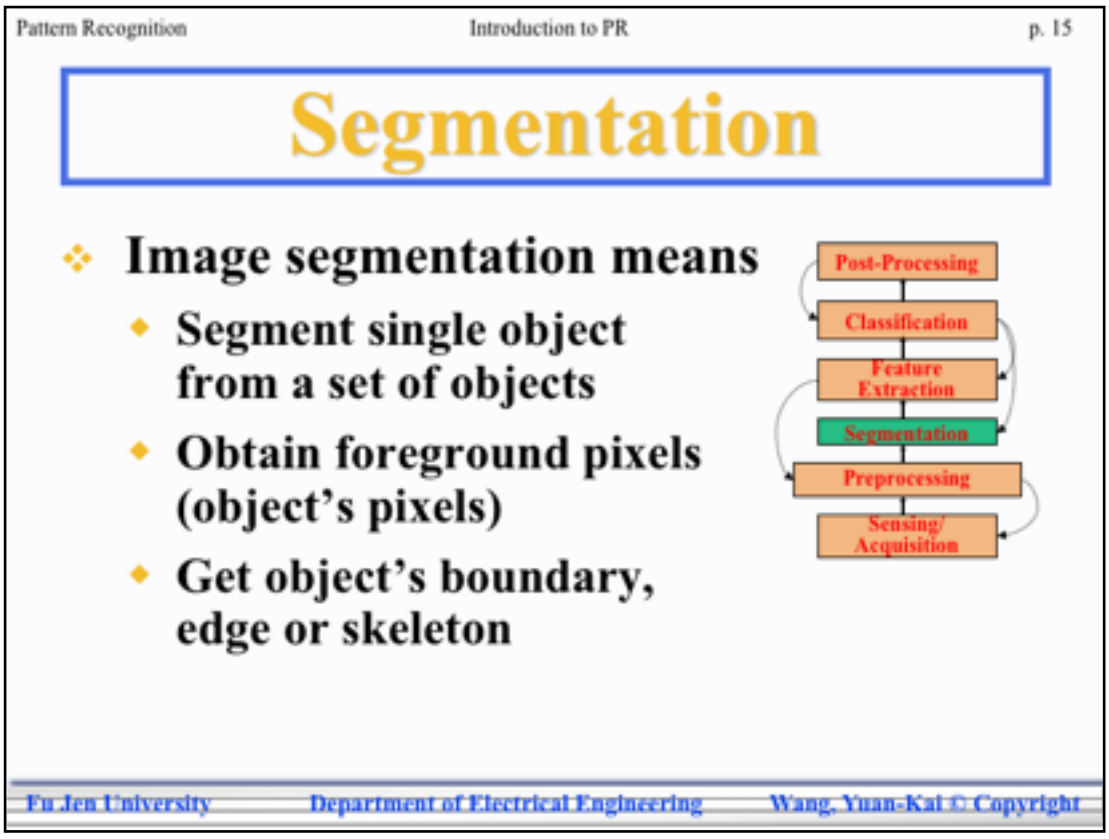
- What are the applications of these examples:
  - Black regions on the planet: astronomy research to study the history of the planet damaged by comet hits
  - Face object: face recognition
  - License plate: license plate recognition

Object Enhancement: License Plate

- License plate enhancement and recognition is a well-known and important application in ”intelligent video surveillance”.
- Two situations that make the object, license plate, looks bad
  - Blur due to high-speed car driving or low-speed of camera shutter
  - Strong light due to car head light



- You should learn preprocessing techniques in the "digital image proessing" course.
  - The course will teach histogram processing and linear filtering
  - You can then learn nonlinear filter by yourself based on the foundation of the course.
- This course is pattern recognition, so we will not teach preprocessing and image processing.

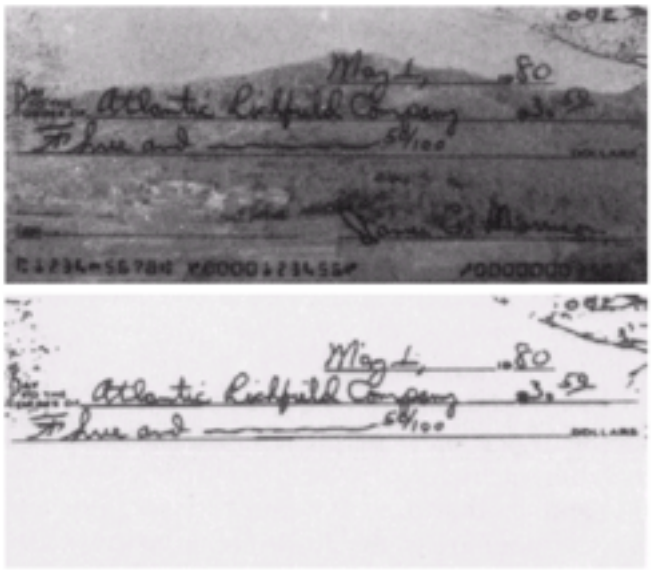


- Segmentation is the third stage of a pattern recognition system.
- Segmentation isolates the objects in the image into a new small image
  - In order to carry out segmentation, it is necessary to detect certain features that may not enter into the list of features utilized for recognition.
  - They are obtained from the direct (or preprocessed) measurements that are related to certain properties of pre-attentive vision.

Object's Pixels (1/2)

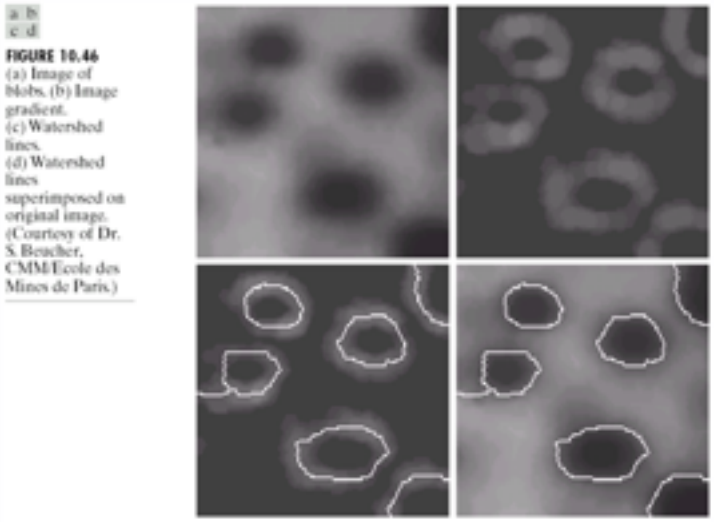
a
b

FIGURE 10.37
(a) Original image. (b) Image segmented by local thresholding. (Courtesy of IBM Corporation.)



- This figure comes from the textbook of digital image processing written by Gonzalez.
- In this example,
  - The top image is a check of a commercial bank.
  - The bottom image is a segmentation image with only signed name and numbers, without the watermark of the check (i.e., the background of the image).
  - This example uses a very simple segmentation technique: thresholding.

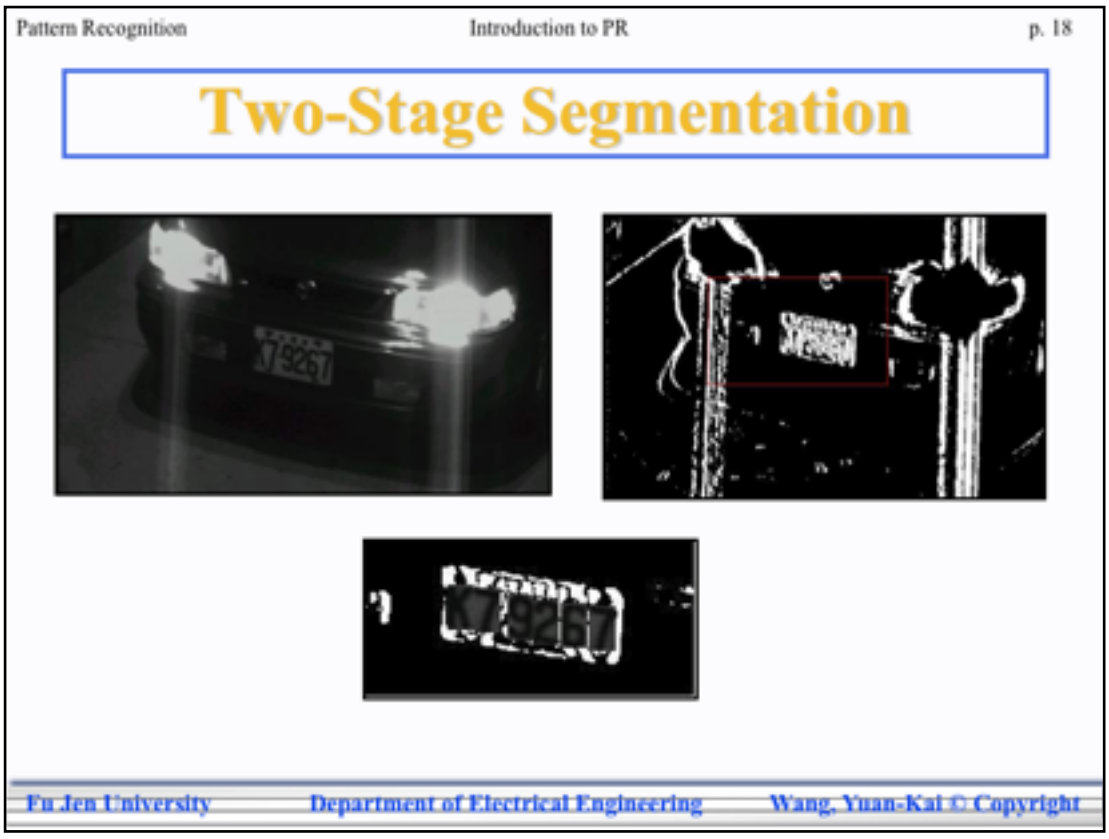
Object's Boundary/Edge



a b
c d

FIGURE 10.46 (a) Image of blobs. (b) Image gradient. (c) Watershed lines. (d) Watershed lines superimposed on original image. (Courtesy of Dr. S. Beucher, CMM/Ecole des Mines de Paris.)

- This figure comes from the textbook of digital image processing written by Gonzalez.
- In this example
  - (a) image is a blur image. The black circles in this image are to be segmented.
  - (b) and (c) images are temporary processed results.
  - (d) image is segmentation result. The white contours of all black regions illustrate the segmentation results.

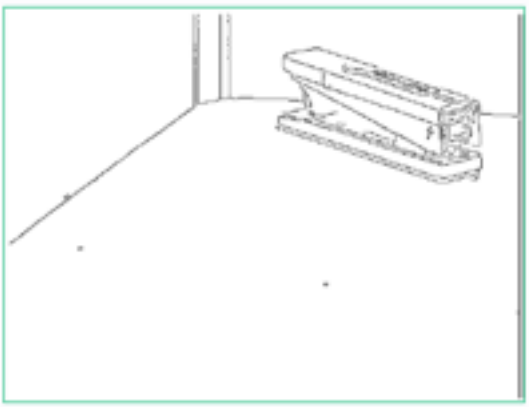


- To segment objects in complex images, we usually need to perform two segmentation steps: first step to find rough place of the object, and second step to find the exact locations of objects
- This example is for license plate recognition, and we need to firstly segment license plate, and then secondly segment the alphanumerics.
  - Left top image is the original image captures at night.
  - Right top image is a temporary processed image. Red rectangle in this image represents the first segmentation result that indicates the license plate.
  - Bottom image show the final results of second segmentation. Six alphanumeric in the license plate is isloated. These six characters can be later recognized.

Edge Detection (1/2)

- **What is edge detection**

Original image



Edge image

- Edge detection is a very useful for image/object segmentation.
- Edge image can be obtained by linear or nonlinear filtering.

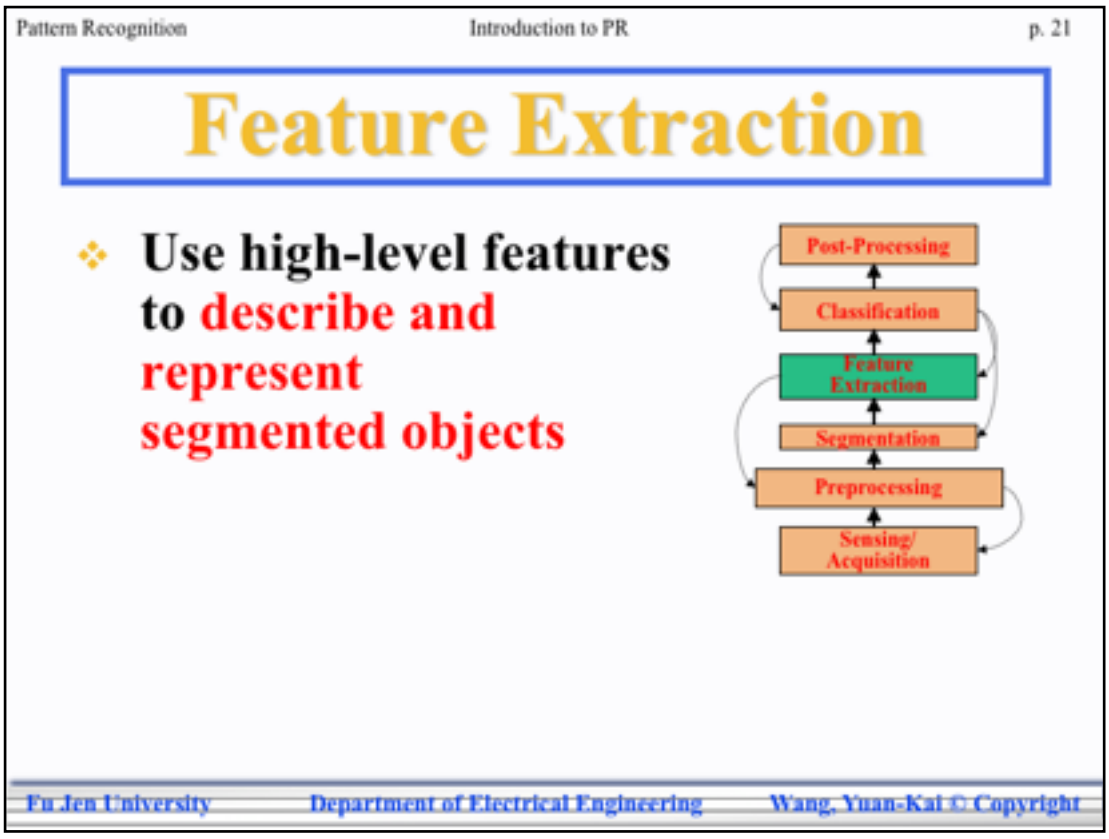
Color Segmentation

- **Usually use 3 planes (R,G,B) for segmentation**

(a) Color Labels (b) Texture Classes

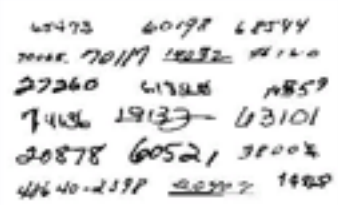
(c) Crude Segmentation (d) Final Segmentation

- Color image segmentation is more difficult than grayscale image segmentation.
- We have to find texture, color and edge information in all three channels, and then use these information to segment the color image.

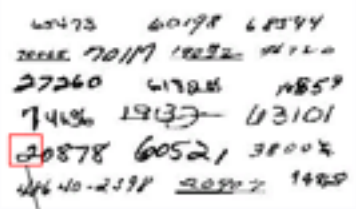


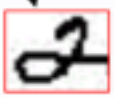
- Feature extraction is the fourth stage of a pattern recognition system.

Example 1



Segmentation





Features

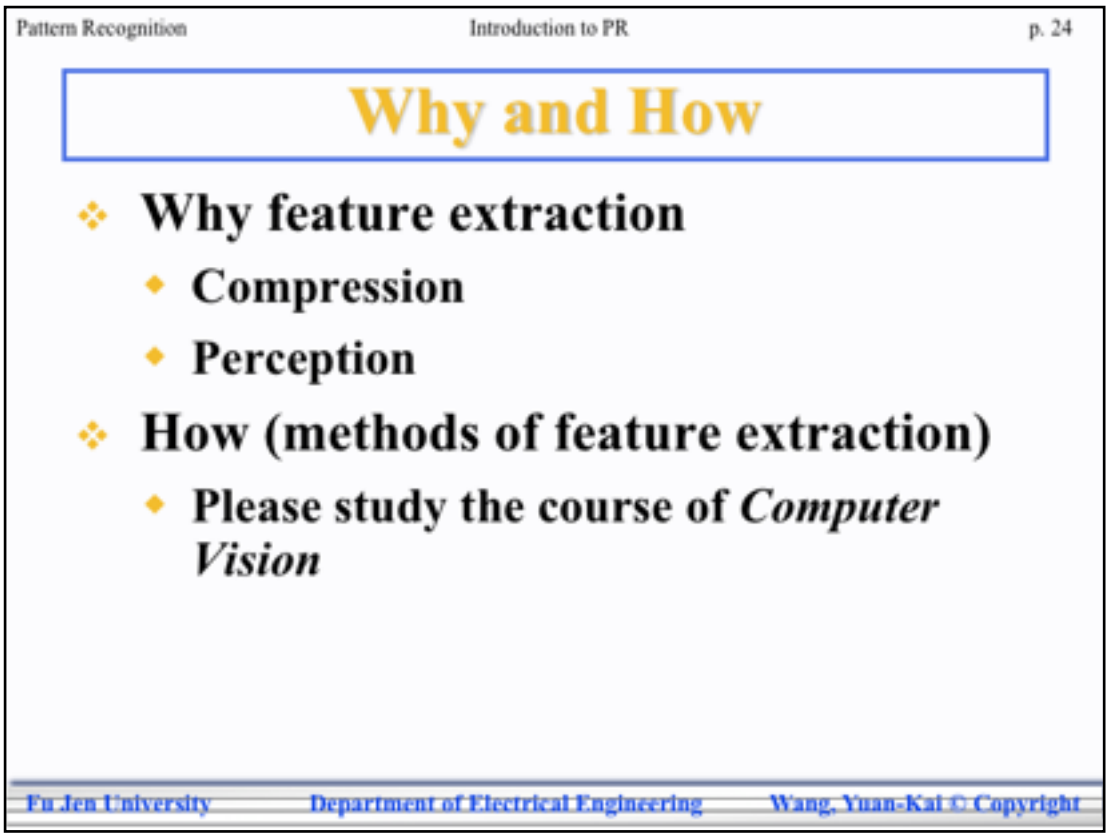
1. Boundary
2. Line Segments
3. Shape: Fourier descriptors
4. Statistical moments
5. Topological descriptors
6. ...

Example 2

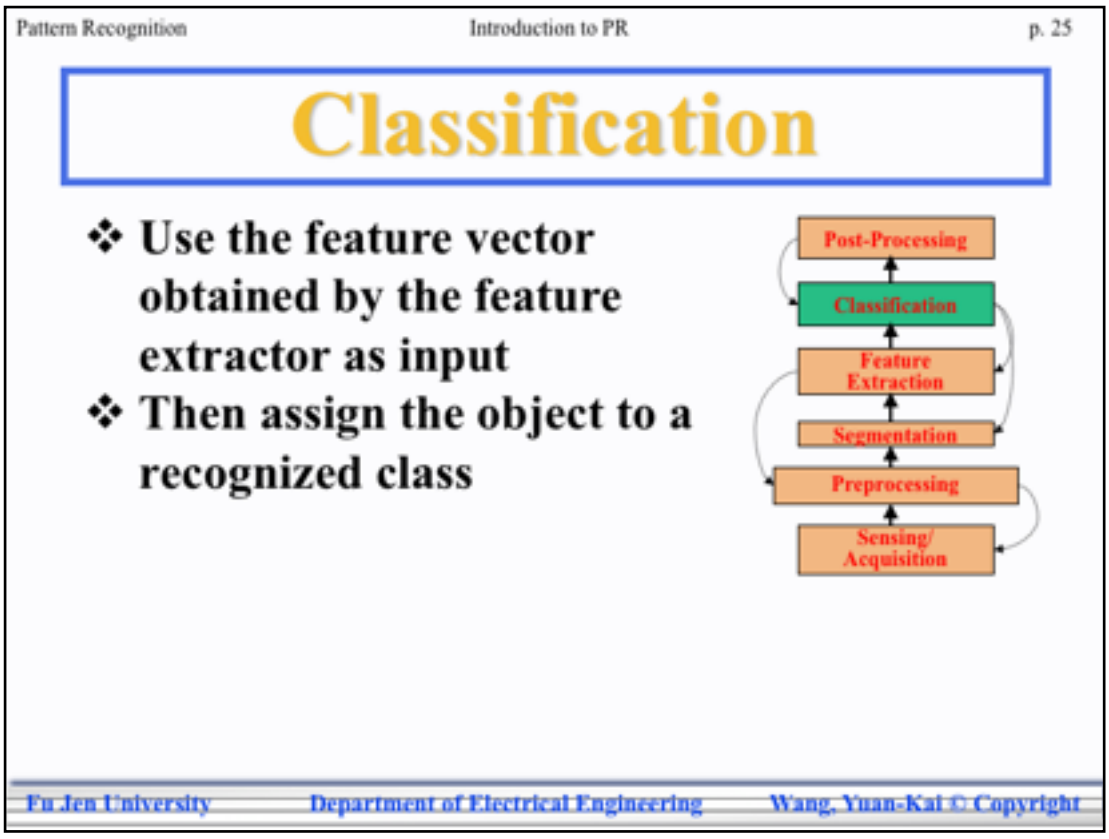
Segmentation

Features

1. Eyes: length, shape
2. Eyebrows: length, shape
3. Nose: length, shape
4. Mouse: length, shape
5. ...



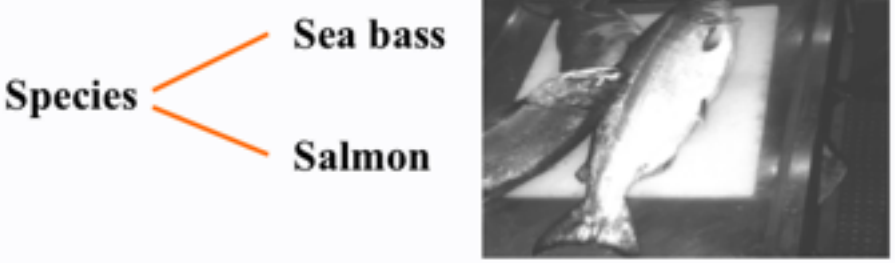
- Two goals of feature extraction
  - **Compression:** Reduction of dimensionality in pattern space
    1. There are too many measurements after acquisition/preprocessing/segmentation.
    2. Many or most of them may not even help to distinguish the class of the object from other classes.
    3. Feature extraction is the attempt to extract meaningful features from measurements.
  - **Perception:** Rendering the features more suitable for the decision process
    1. When we look at a printed page, scene, or an electroencephalogram(EEG腦波圖), we don't see an array of optical values.
    2. When we hear a speech, a siren, or an engine turning, we don't hear a time series of acoustic pressures.
    3. Our primary sensory systems do these.
    4. But we *perceive* letters, trees, α-waves, spoken words, loud high-pitched sounds, and so on.
- Feature extraction of image objects is a complex technique.
  - This course has not time to teach this technique.
  - Please go for the course of Computer Vision.



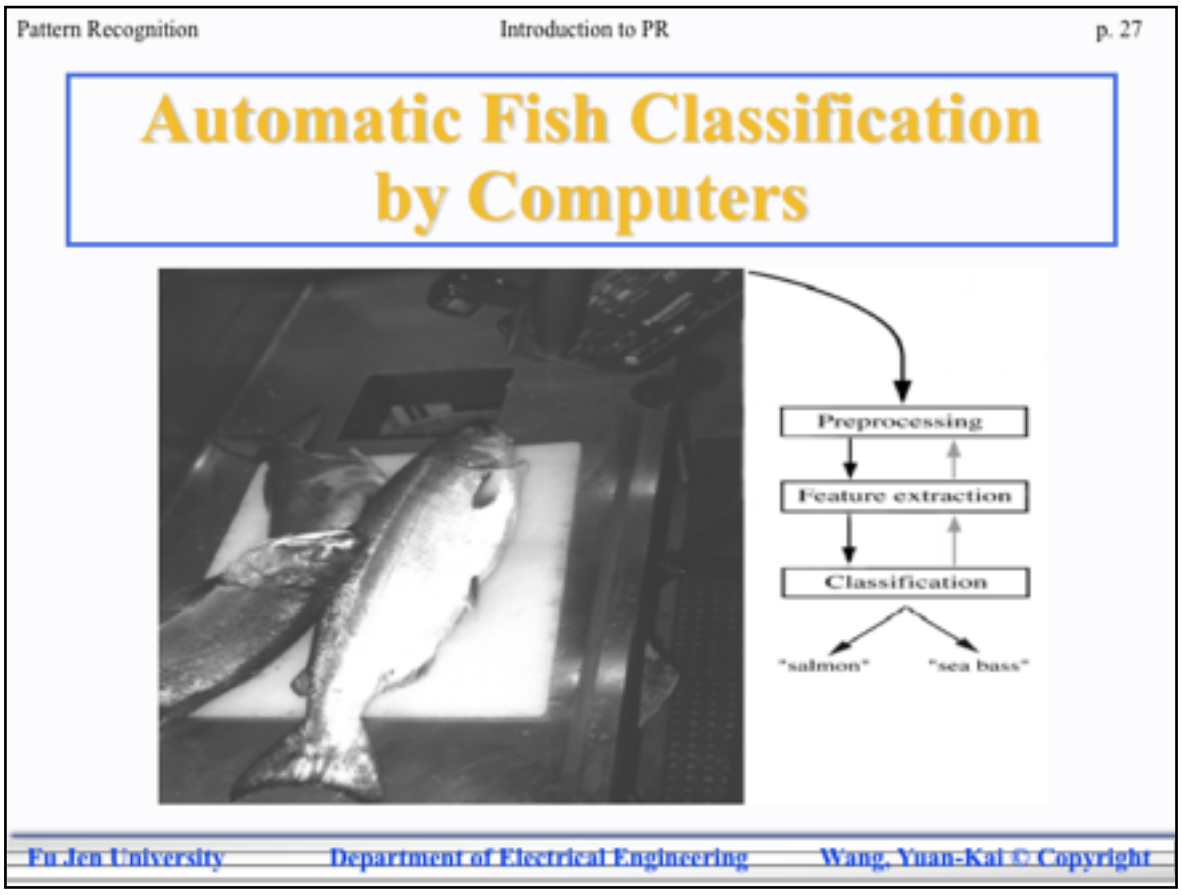
- Classification is the fifth stage of a pattern recognition system.
- This is exactly the stage that will be explained in this course.

An Example

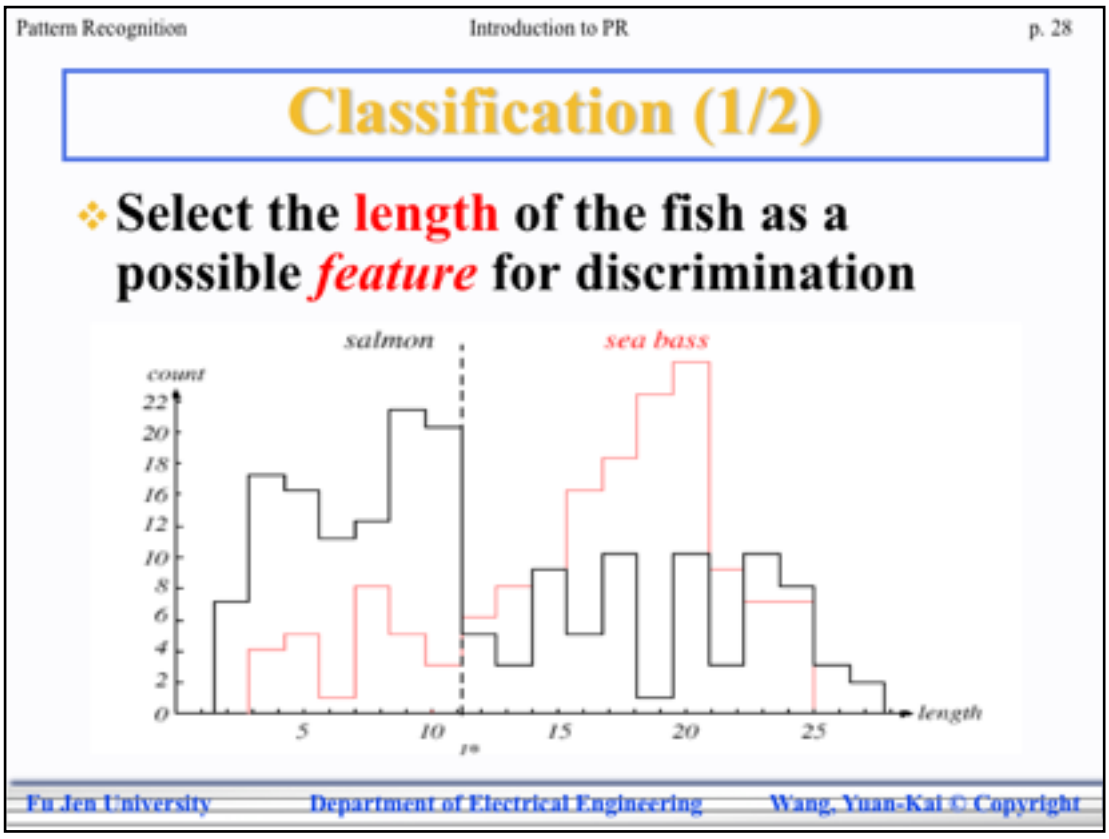
- Sort fish on a conveyor according to species using optical sensing



- How to do this by humans?
  - Classify fish species by its size, length, width, lightness, …
- How to do this by computers?
  - Image preprocessing, feature extraction, and pattern recognition: a pattern recognition system.



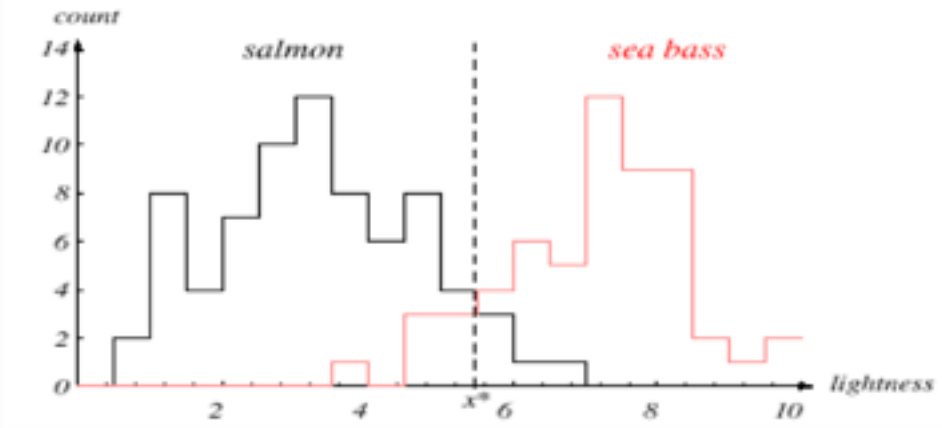
- Set up a camera on a platform that can places a fish
- Take a picture of the fish
- Write a program to
  - Segment the fish: Isolate fishes from backgrounds. It includes denoising, enhance the image by filtering, and segmentation.
    - This is *not* the topic of this class. But it will be taught by the class ”Digital Image Processing”
  - Extract features of fish: Length, lightness, width, number and shape of fins, position of the mouth, etc…
    - This is *not* the topic of this class. But it is taught by the class ”Computer Vision”
  - **Classify the species of the fish: Use pattern recognition algorithms to do this.**
    - **This is the topic of this course**
- Let us suppose that we can write a program to successfully
  - Segment the fish object in an image.
  - Extract the features of the fish, such as length, width, lightness, and so on.
- So next slide we go further to the ”classification”step.



- Horizontal axis is the length of fishes.
- Vertical axis is the number of fishes with respect to fish length.
- Black line shows the histogram of salmon. Red line shows the histogram of sea bass.
  - For example, the number of salmon with length 5 is 16. The number of sea bass with length 20 is 22.
- Black dotted line represents "threshold" to classify salson and sea bass.
  - If we set the threshold to be 11.1, as shown in this figure.
  - Then all fishes with length less than 11.1 is classified to be salmon. All fishes with length larger than 11.1 is classified to be sea bass.
  - So, some sea bass fishes with length less than 11.1 is mis-classified, and so are sea bass fishes with length larger than 11.1
- Mis-classified fishes are called classification error. With these errors we can then calculate error rate or accuracy of this classification with respect to this threshold: 11.1.
  - Each threshold has an error rate.
  - Some thresholds have higher error rates, and they are not good thresholds.
  - The best threshold is the threshold with minimum error rate. But
- Two questions
  - What is the best threshold in the example?
  - If the error rate of the best threshold is not good enough, can we get better classification by other ways?

Classification (2/2)

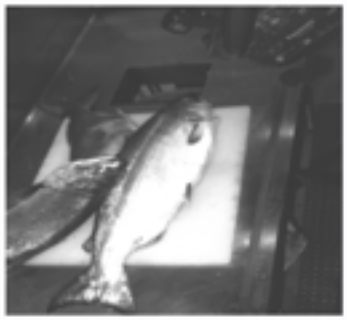
- Now use lightness of fishes as the feature for classification

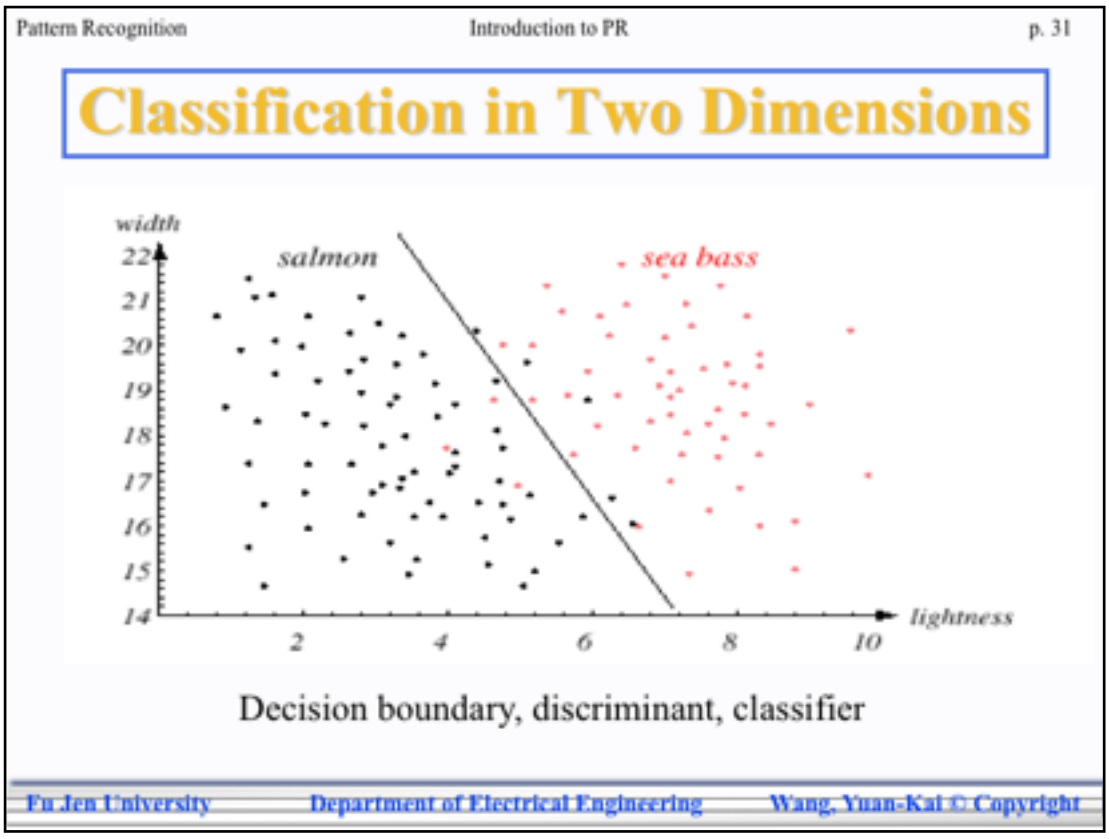


- The length feature in previous slide is a bad feature.
- Let us change the feature to be lightness of fishes.
  - The graph seems to be better than the graph of length, because the two histograms of two fish species are not ”seriously overlapped”.
- What is the best threshold in this example?
  - Suggestion: move the threshold (decision boundary) toward smaller values of lightness in order to minimize the cost (reduce the number of sea bass that are classified salmon!)
- Question
  - Can we get more better accuracy than using the lightness feature?

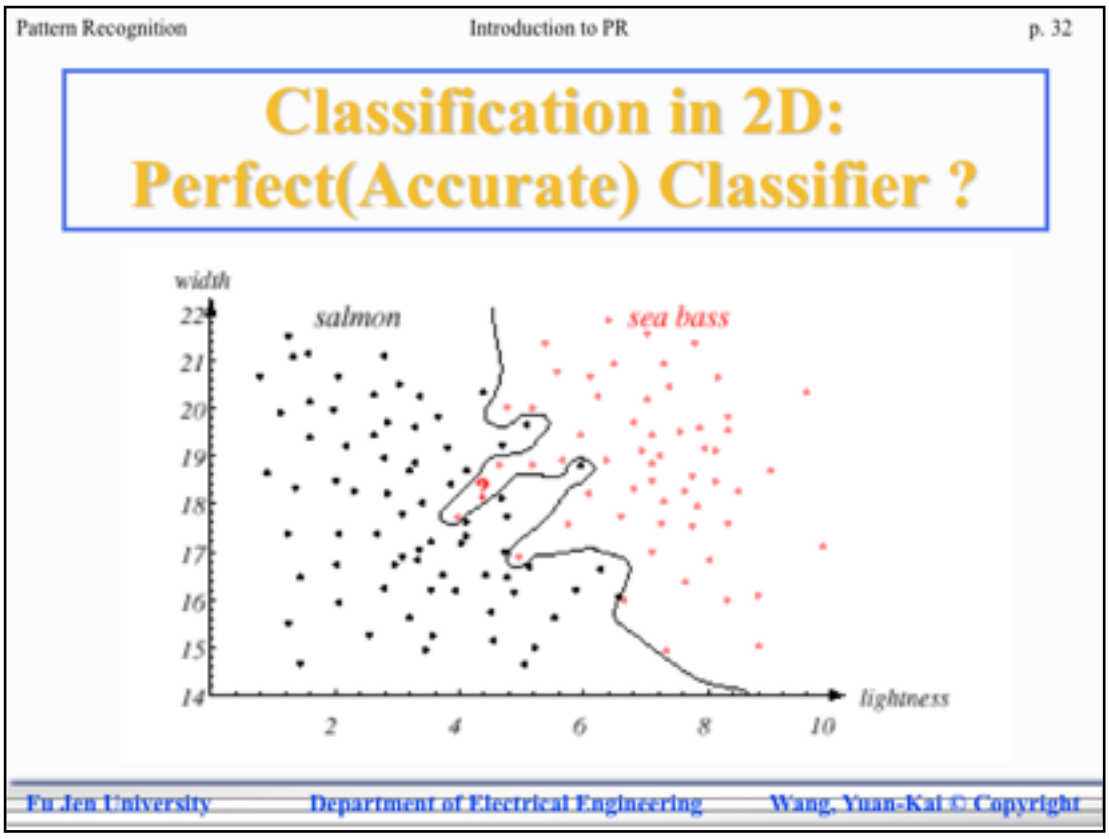
Add One More Feature

- Now let us use two features
  - Combine the *lightness* feature with the *width* feature of fishes



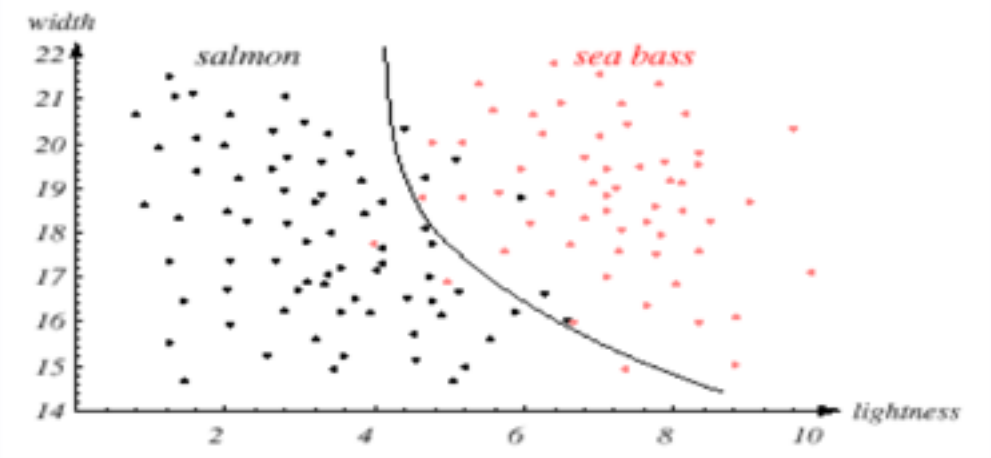


- Now both axes represent features for classification.
- Important concepts shown in this illustrated figure
  - Decision boundary (also called threshold in 1D example)
  - Noise (some salmons locate in the region of sea bass, and vice versa)
  - Currently we use **straight line** to be decision boundary
- We can move the line and change its direction(slope)
  - Lines at different location and with different slope have different error rate.
  - We have to find he best line (decision boundary) that has the minimum error rate.
- Classifier and discriminant
  - The decision boundary (straight line) is also called classifier and/or discriminant.
- Discussions
  - Could we add more features than two?
  - We might add other features that are not correlated with the ones we already have. A precaution should be taken not to reduce the performance by adding such "noisy features"
- Questions
  - How to find the discriminant/classifier/decision boundary?
    - **Machine learning and pattern recognition**
  - Could we use non-straight line or curve to be decision boundary?



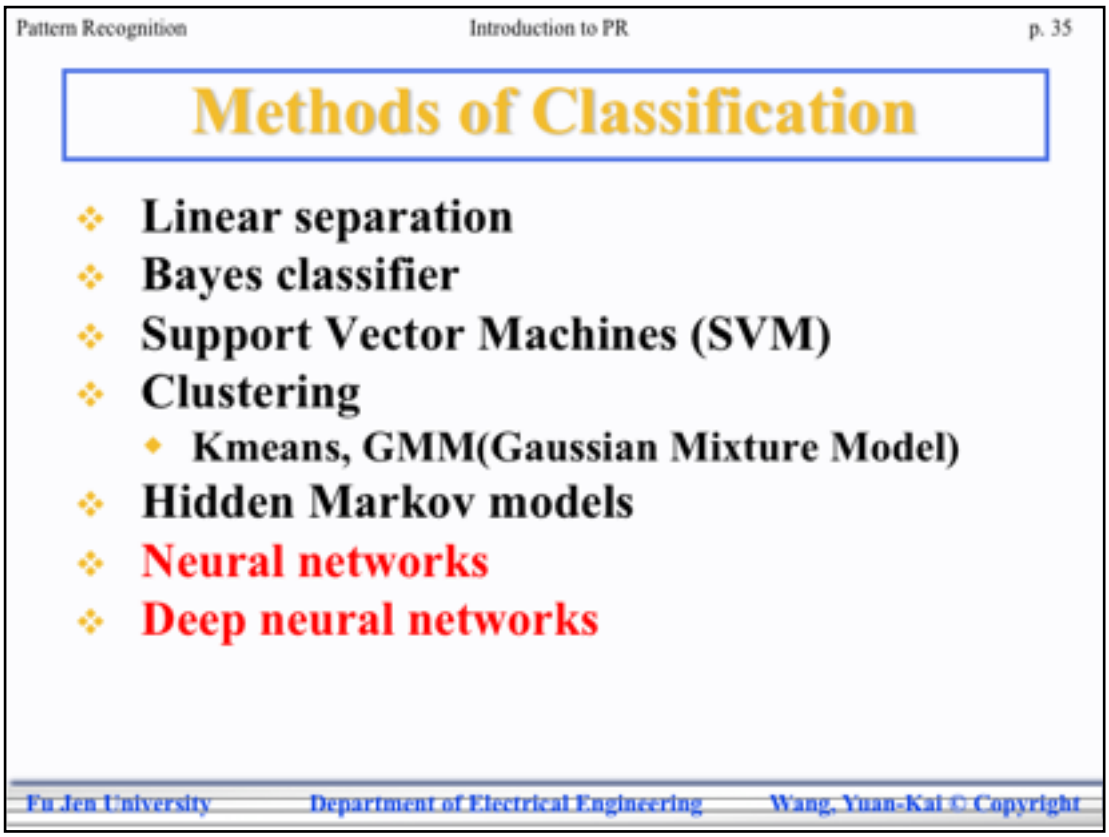
- Ideally, the best decision boundary should be the one which provides an optimal performance such as in this figure.
  - In this figure the decision boundary is a high-order curve, but not a straight line.
  - This curve looks like a very good classifier, because it has zero error.
- However, it is not a good classifier because of the issue of **generalization**
  - Its accuracy for current fishes is 100%.
  - Will it be still good for new unknown fishes? No, absolutely not.
  - Practically, this classifier is too specialized for current fishes, thus it has no generalization for future unknown fishes.

Classification in 2D: A Compromised Classifier

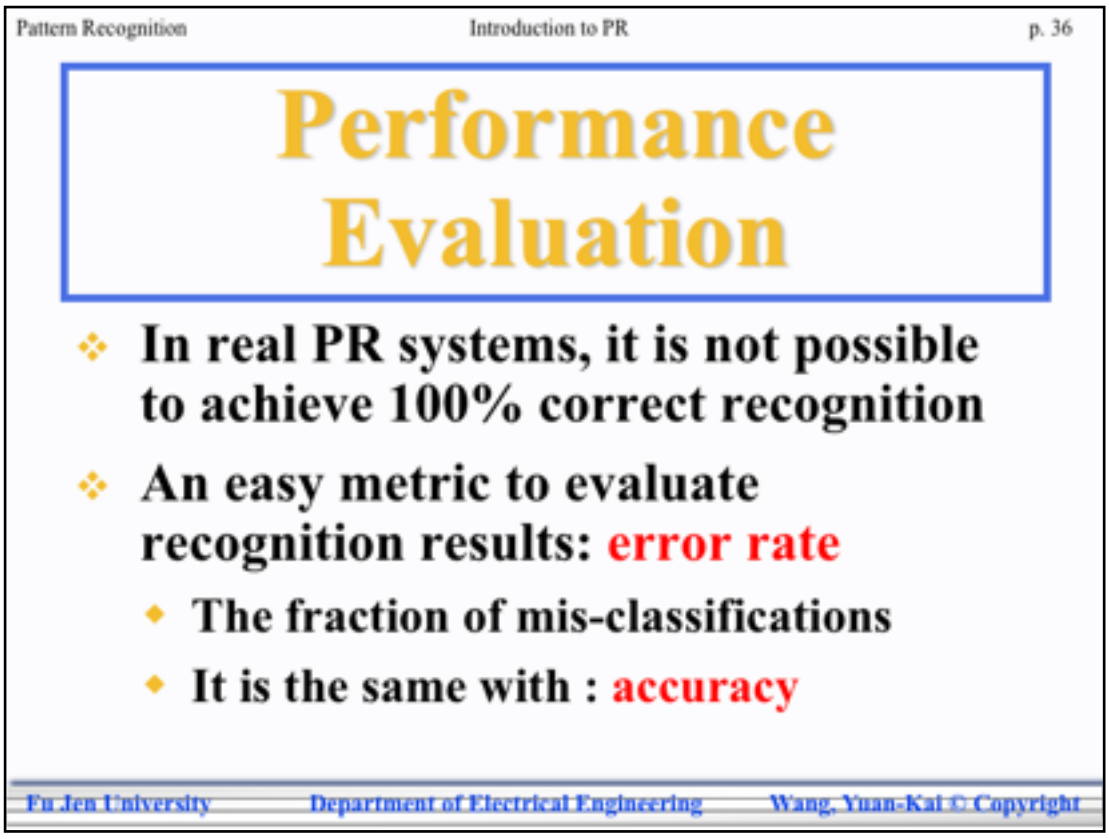


- In reality, this may be the best classifier.
  - This classifier(decision boundary) is a second-order curve.
- For current fishes
  - Its accuracy is better than straight lines, but is lower than the high-order curve in previous slide.
- For new unknown fishes
  - Its accuracy should be better than those accuracies of straight lines and high-order curve.

- How can a computer program "automatically" find the best classifier?
- We need two things
  - Training algorithm
  - Training data
- What is training algorithm
  - Training algorithm uses training data to find the best classifier. But how?
  - Remember that each classifier has an error rate. And the best classifier has the minimum error rate.
  - We have infinite number of classifiers: infinite straight lines and infinite curves. Each classifier has an error rate.
  - We can find the best classifier only if we calculate all of the error rates of classifiers and find the minimum of these error rate values.
  - But it is a mission impossible.
  - Therefore a lot of complex algorithm are developed to conquer this difficulty.
- Next slide shows some popular training algorithms.



- In this course, we will focus more on neural networks and deep neural networks.



•In most real PR system, it is not possible to achieve 100% correct recognition.

•For example: OCR, Fingerprint Recognition

•All we want is to achieve "the lowest possible" error rate.

Error Types

- **False Negative (Type-I Error)**
  - **An object is classified as not the class but it is .**
- **False Positive (Type-II Error)**
  - **An object is classified as the class that it is not.**

Conclusion

- This course teach only the classification step in a PR system
  - Sensing → Sensor course
  - Preprocessing
    → Digital Image Processing course
  - Segmentation, Feature extraction
    → Computer Vision course
  - Classification → This course
    - Focus on deep neural network
  - Post processing
    → Artificial Intelligence course