Key Concepts of Pattern Recognition

An Introduction to Pattern Recognition

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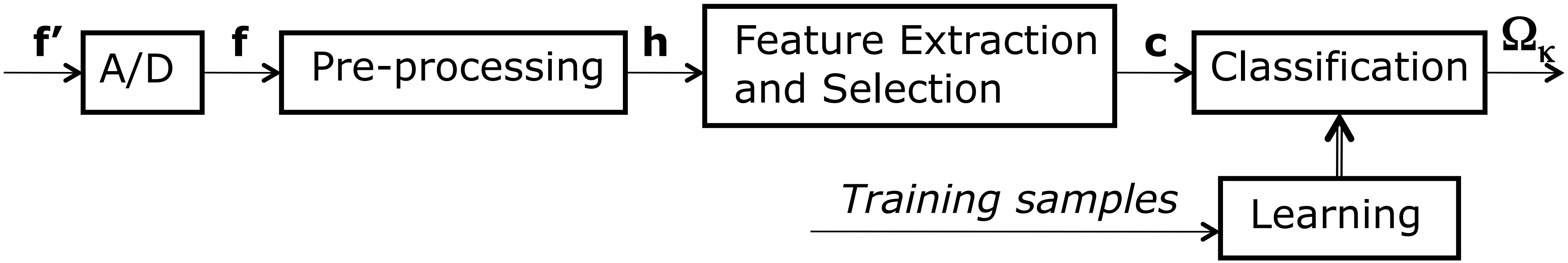
What is Pattern Recognition?

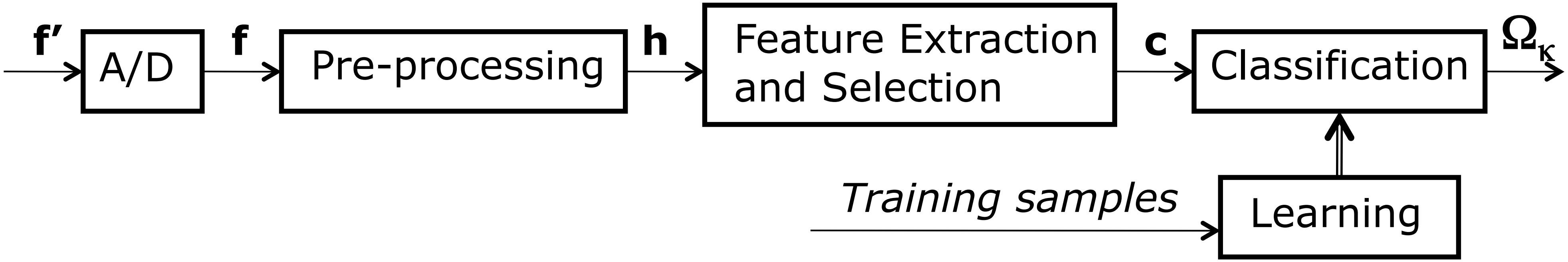
- Definition: Pattern Recognition involves the design of systems that (semi) automatically recognize patterns in sensed data.
- It deals with the mathematical and technical aspects of determining facts from sensor data.
- Thus, the task of Pattern Recognition needs the following components:
  - Sensor
  - Preprocessing Modules
  - Features
  - Classifier

Pattern Recognition Pipeline



- In recognizing a particular pattern, the entire pattern is treated as a single unit. It is assigned as a whole to a particular class Ω_κ out of k possible classes Ω_λ, $\lambda = 1,\ldots,k$, without consideration to other patterns.
- It is also possible to reject a pattern, i.e. to assign it to a rejection class Ω_0.

Properties of the PR Pipeline



- Output of module i is input to module i + 1.
- Simple system structure.
- Each module can be optimized separately (at least partially).
- The sequence of processing steps is relatively independent of the individual pattern.
- Errors in module i will be propagated to i + 1.

Example: Coffee Bean Classification

- Sensor:
  - Color camera
- Features:
  - Color (light, medium, dark)
  - Uniformity of color
  - Size
  - Smoothness
  - Position of the crack (center, or off-center)
  - Curvature of the crack (wrinkly, straight, curved)
- Classes:
  - Grade 1 (specialty grade)
  - Grade 2 (premium grade)
  - Grade 3 (exchange grade)
  - Grade 4 (standard grade)
  - Grade 5 (off grade)

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Example: Coffee Bean Classification

- Sensor:
  - Color camera
  - Scale
- Features:
  - Color (light, medium, dark)
  - Uniformity of color
  - Size
  - Smoothness
  - Position of the crack (center, or off-center)
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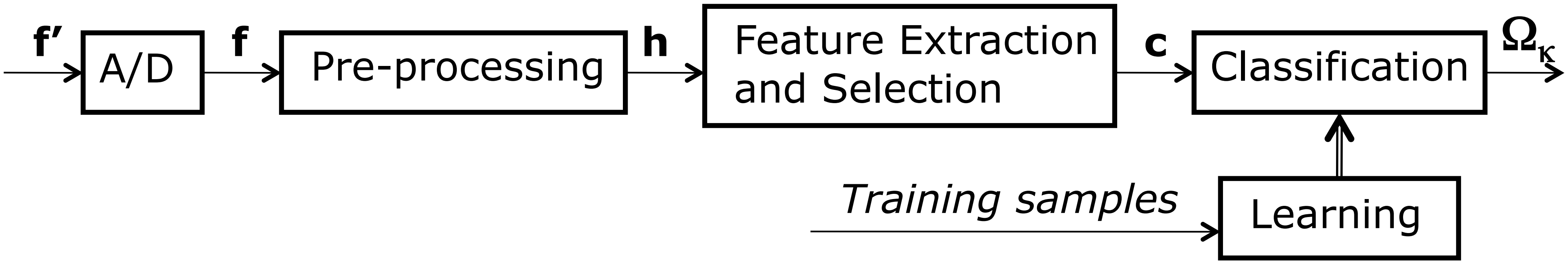
PR Pipeline Reminder



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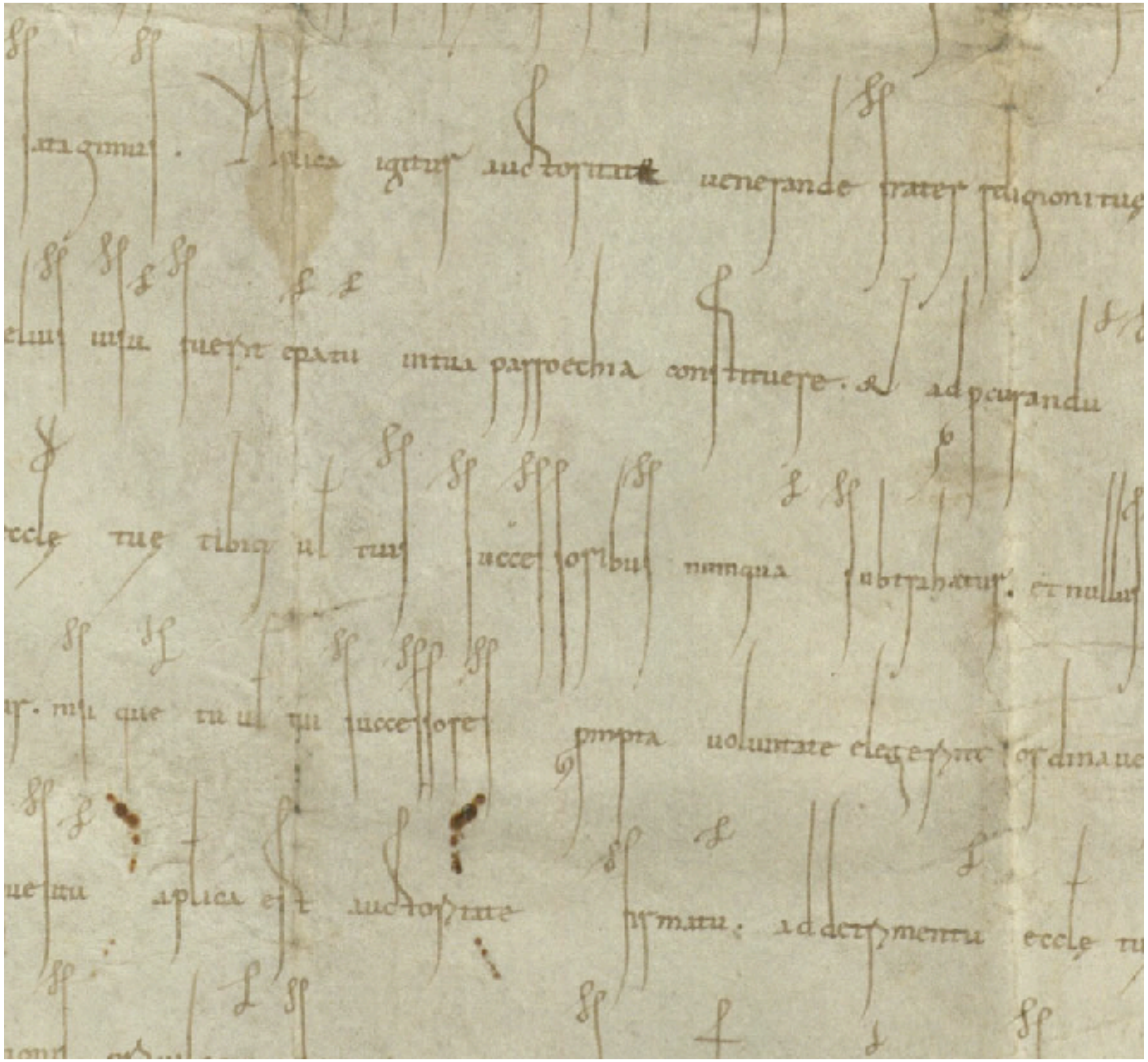
1	5	6	7	a	f	h	q	G	O	Q	S
1	5	6	7	a	f	h	q	G	O	Q	S
1	5	6	7	a	f	h	q	G	o	Q	S
1	5	6	7	a	f	h	q	G	O	Q	S
1	5	6	7	a	f	h	q	G	O	Q	S
1	5	6	7	a	f	h	q	G	O	Q	s
1	5	6	7	a	f	h	q	G	O	Q	S
1	5	6	7	a	f	h	q	G	O	Q	S
1	5	6	7	a	f	h	q	G	O	Q	S
1	5	6	7	a	f	h	q	G	O	Q	S
⇓	⇓	⇓	⇓	⇓	⇓	⇓	⇓	⇓	⇓	⇓	⇓
Ω_1	Ω_2	Ω_3	Ω_4	Ω_5	Ω_6	Ω_7	Ω_8	Ω_9	Ω_{10}	Ω_{11}	Ω_{12}

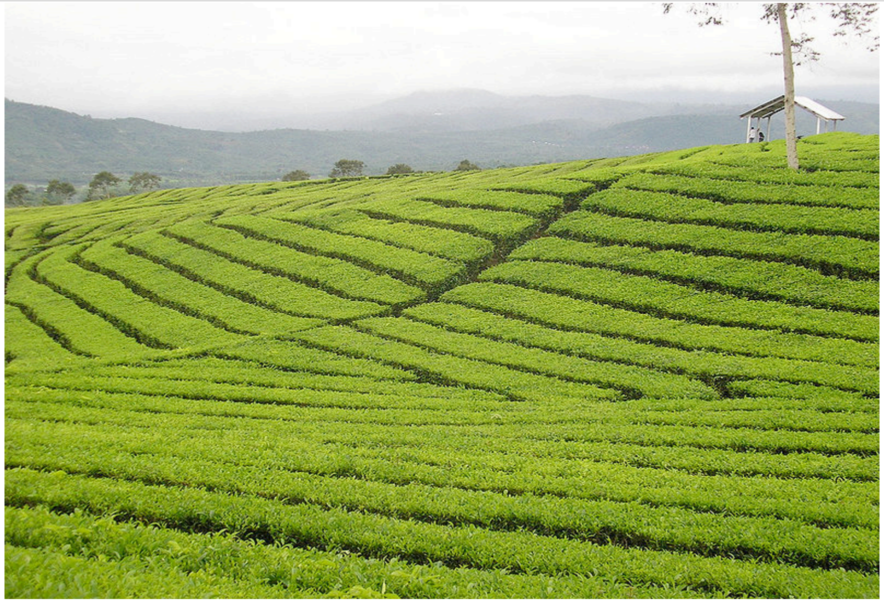
PR on Handwritten Digit Recognition

Our Current Handwriting Recognition Task



Snippet courtesy of the Monasterium archives, www.monasterium.net

PR on Tea Plants



PR on Speech

- The shown speech signal contains the word chain:

  Ich will morgen abend nach Frankfurt

- The recognition of each word and the recognition of the meaning of the entire sentence is part of an automated system for booking train tickets.

On Recognition

- The task of recognition (speech, faces, diseases, animals, etc.) is a difficult task that humans perform exceptionally well.
- According to Z. Pawlak (1991): *Knowledge* is deep–seated in the *classificatory* abilities of human beings and other species.
- Also according to Z. Pawlak (1991): *Classification* on more abstract levels seems to be a key issue in reasoning, learning, and decision making ...

The Postulates of Pattern Recognition

- **Understanding** a pattern by a machine is equivalent to a mapping from the pattern to an internal schema for knowledge representation

- For Pattern Recognition to work we rely on six key postulates:

1. **Sample**:

   We have representative samples for each class

   $f(x) \in \Omega$

   There is no better data than more data!

Postulate 2

2. **Features**:

   Intuitively a feature is a property that we can use to recognize or differentiate units.

   Features for finding a face:

Postulate 2

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Features for finding a face:

- eyes
- nose
- mouth

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Features for identifying a particular face:

Postulate 2

2. **Features**:

Intuitively a feature is a property that we can use to recognize or differentiate units.

Features for finding a face:

- eyes
- nose
- mouth

Features for identifying a particular face:

- shape, size, position and color of eyes
- shape, size and position of nose
- shape, size and position of mouth
- hair color
- scars

Postulate 2

2. **Features**:

A simple pattern has features c_v, v = 1,...,n, that are characteristic for the class the pattern belongs to.

A classifier is as good as its features.

If the features can't describe (don't capture) the difference between O and Q (if we miss the little line at the bottom), then we can't expect the classifier to recognize these two letters as belonging to different classes.

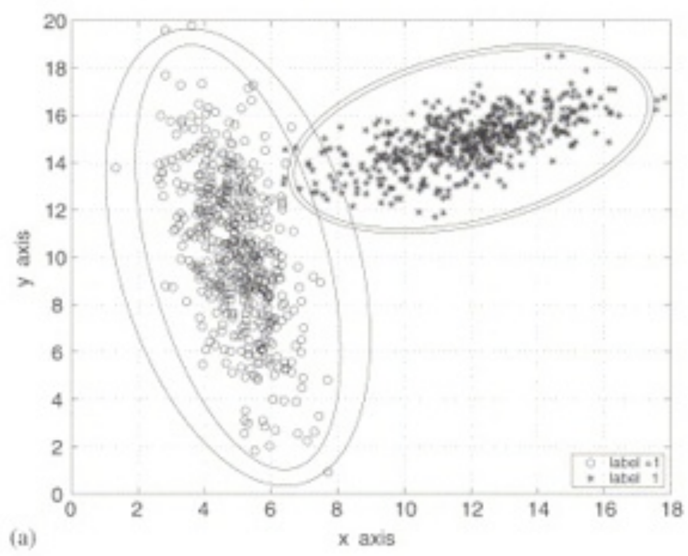
Keep the number of dimensions n low (curse of dimensionality).

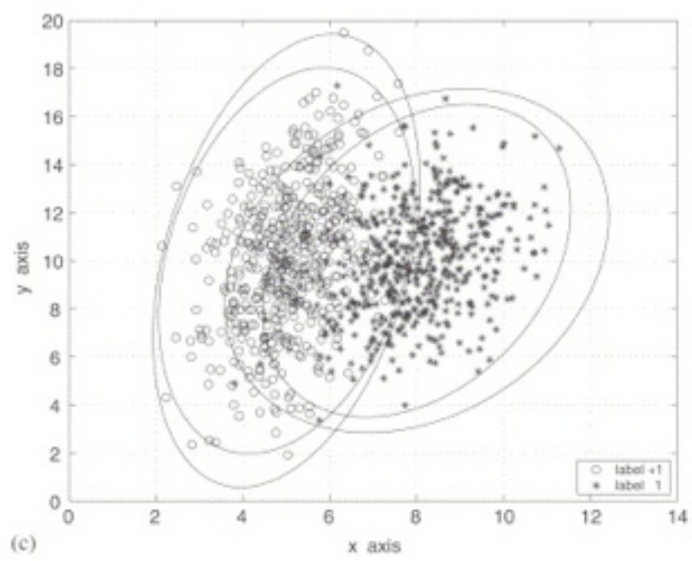
Postulate 3

3. Compactness:

Features of patterns belonging to class Ω_κ occupy a compact area in feature space.

For a better differentiation between classes we want low intra-class distance and high inter-class distance





Plots courtesy of I. Buciu, C. Kotropoulos and I.Pitas “Demonstrating the Stability of support Vector Machines for Classification.”

Postulate 4

4. Decomposition:

A complex pattern can be decomposed into smaller parts whose combined presence makes up the pattern.

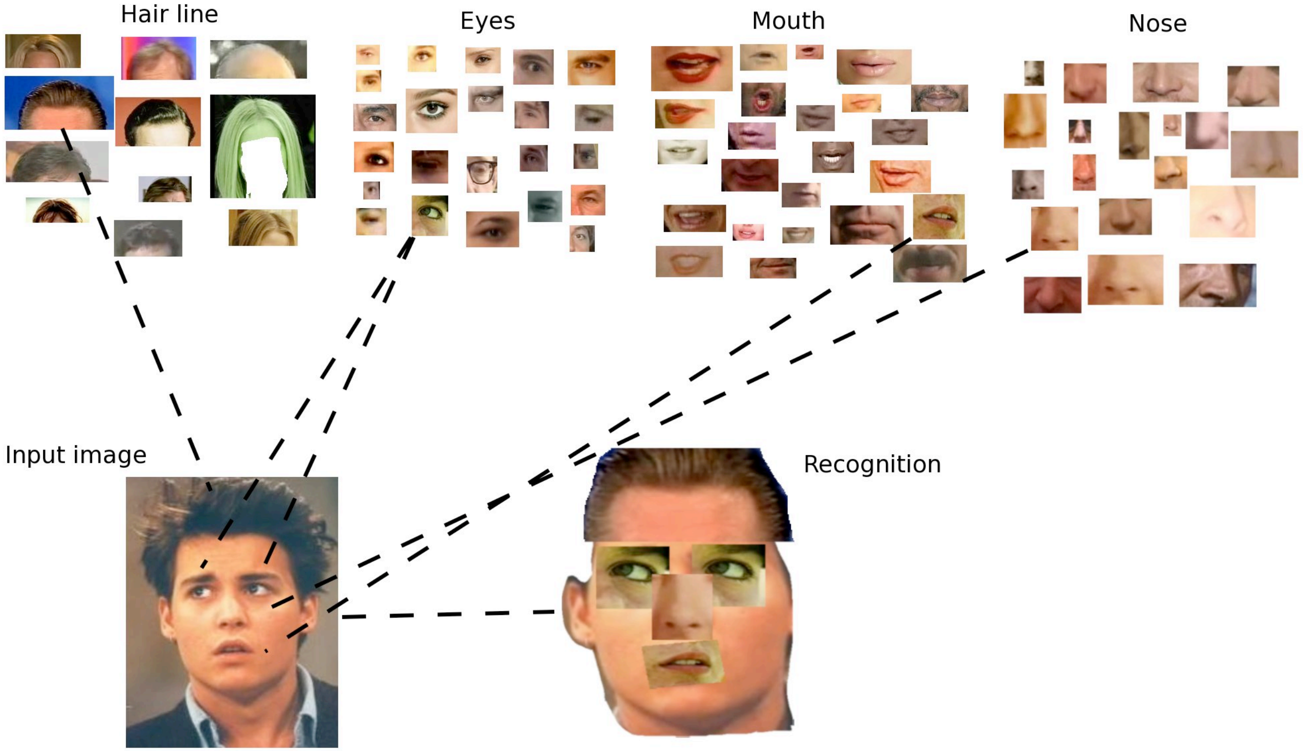
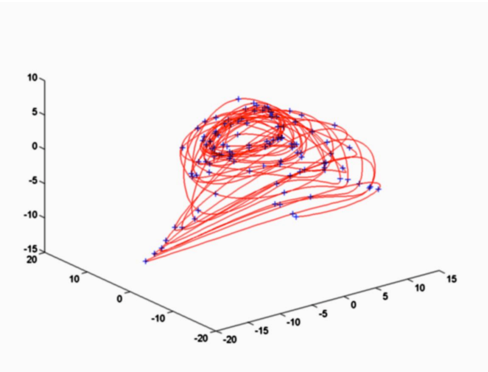


Image courtesy of videosurf, http://www.videosurf.com/blog/the-magic-behind-videosurfs-computer-vision-video-search-engine-56/

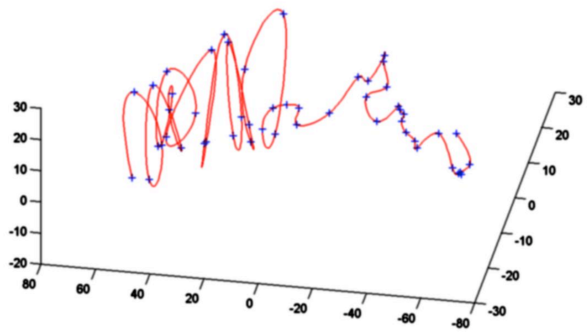
Postulate 5

5. Structure:

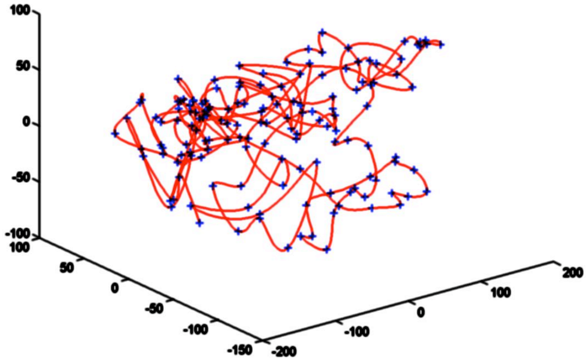
Complex patterns of a specific domain have a certain structure.



Representation of a bird flying. The periodic action of the wings can be clearly seen. As the bird moves towards the camera, its size changes causing a helical structure.



Representation of a bird flying and then gliding. The motion is periodic in the beginning, but the periodicity later stops. This can be seen in the structure of the feature space.



Representation of a water falling in a fountain. The irregularity of the structure in the feature space reflects the lack of regular motion.

Images courtesy of Robert Pless, http://research.engineering.wustl.edu/~pless/wumap.html

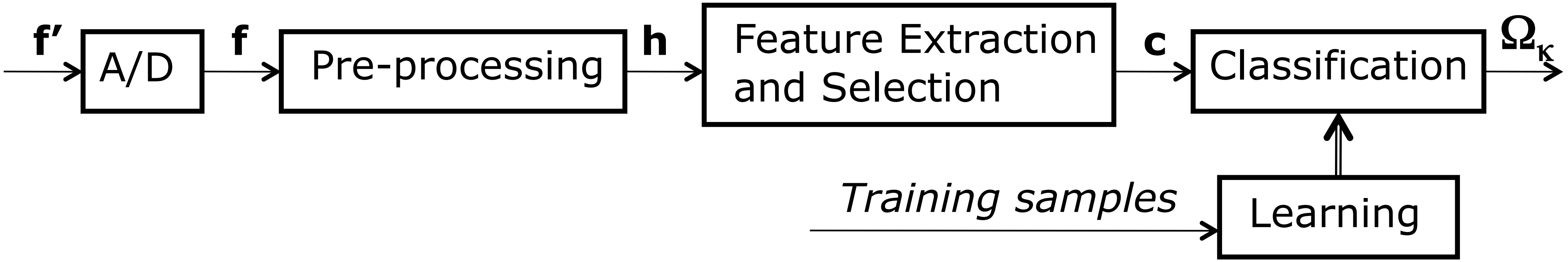
Postulate 6

6. **Similarity**:

   Two representations (of patterns) are similar if a properly chosen distance measure is small.

- Pattern recognition is based mostly on postulates: 1, 2, 3, 6
- Computer vision is based mostly on postulates: 1, 4, 5, 6

Pattern Recognition Pipeline



Simple Example

- Very often in Pattern Recognition we have a training set:

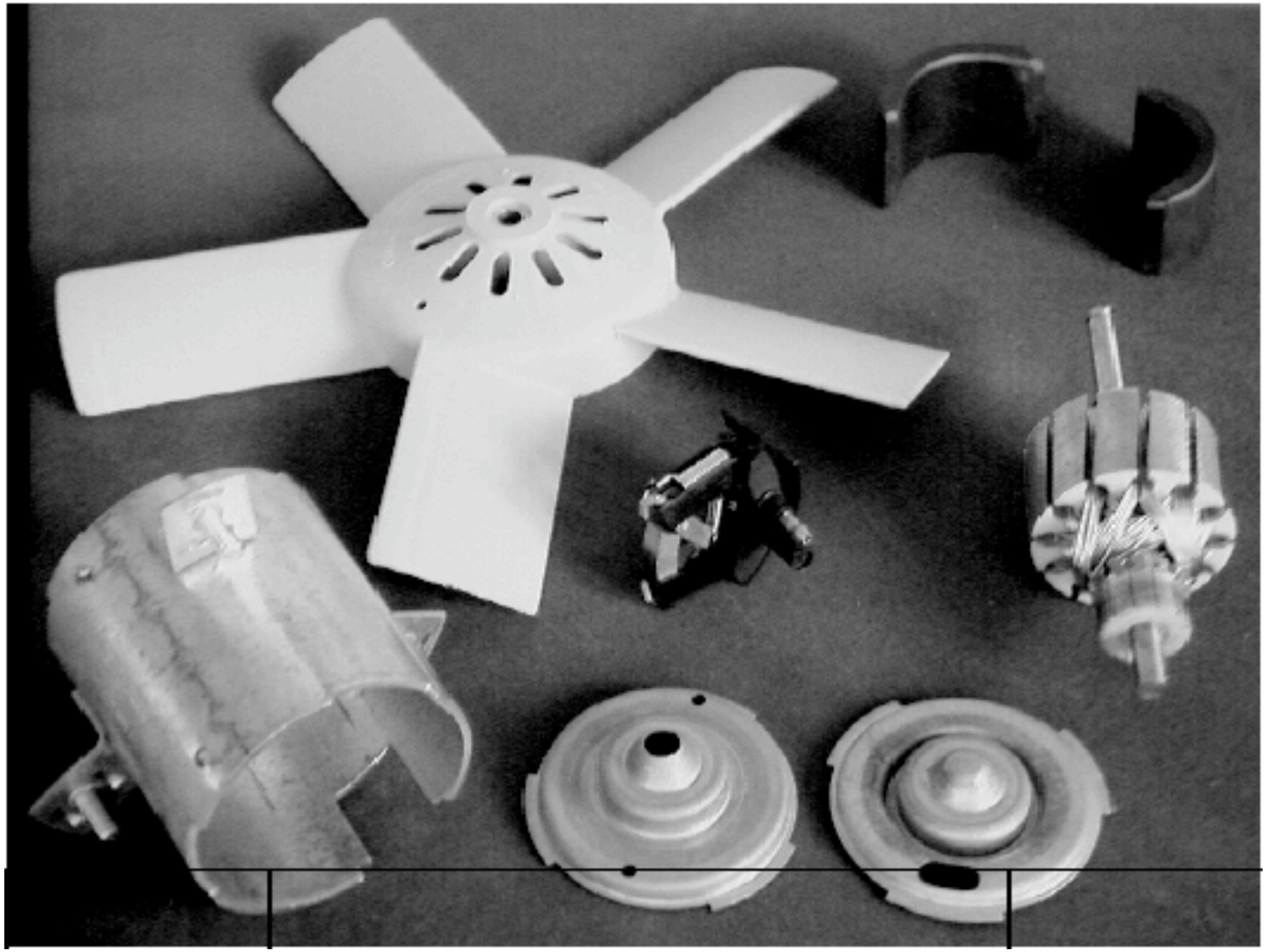
$$T = \{(\vec{f}_1, \Omega_{\kappa 1}), (\vec{f}_2, \Omega_{\kappa 2}), \ldots, (\vec{f}_m, \Omega_{\kappa m})\}$$

- From such a training set we learn how features (signals) that belong to a particular class Ω_κ should look like.
- Given a new feature-vector (signal) we decide that it belongs to the class, which based on our training data, has features (signals) that look the most similar to the new data.

Data Collection

- The first step in a PR system is sensing the environment.
- Data, which is typically in analog form, has to be converted to a digital form so that it can be in a form amenable for further processing.
- There is a very wide variety of what can be used as input in a PR system. It typically depends on the application.
- Selecting the sensor that gives the best quality data at a reasonable cost and speed can be critical in the success of a PR system.

Images: Grayscale 2D data

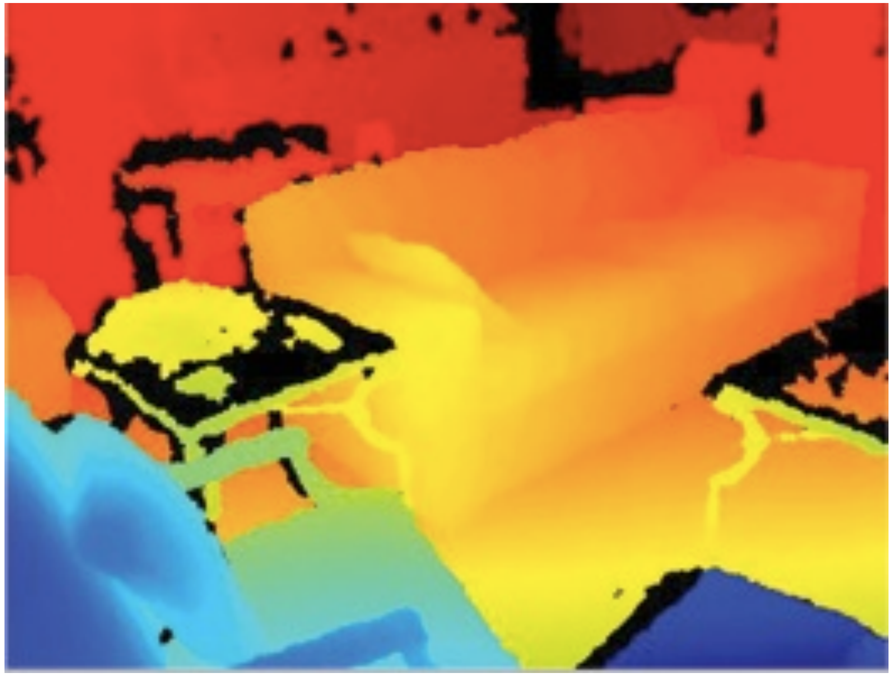


Images: Color Data over Time – 3D Data





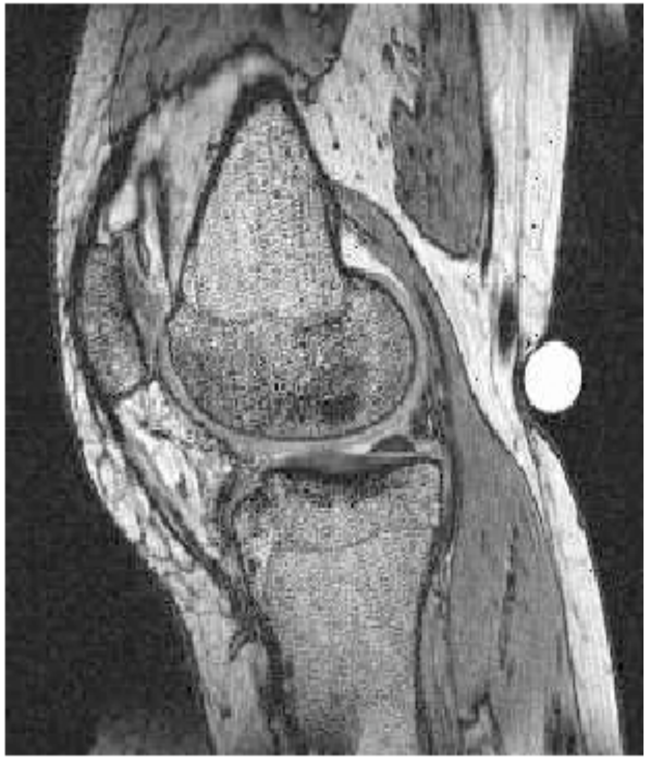

Multiple Sensors: Color and Depth



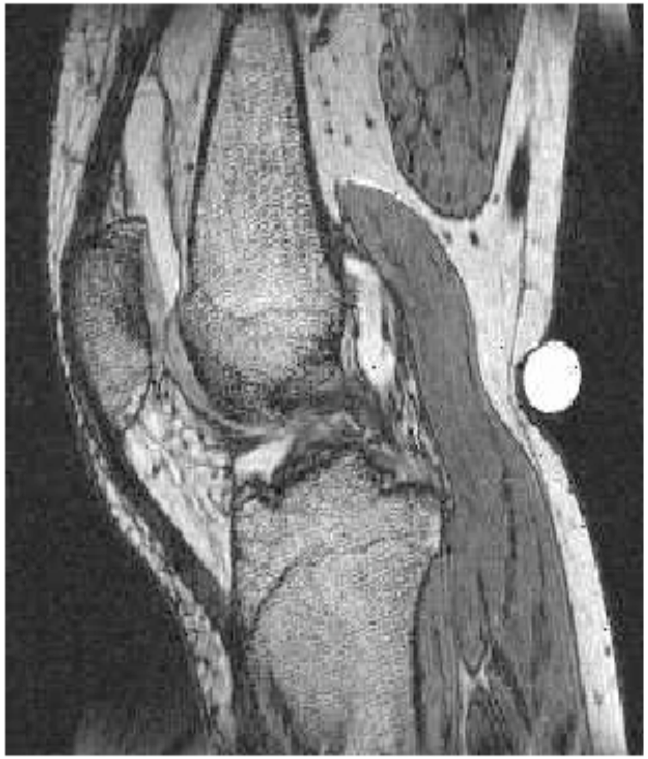
Images from Kinect Sensor courtesy of N. Silberman, P. Kohli, D. Hoiem and R. Fergus from the NUY Depth Dataset V2, http://cs.nyu.edu/~silberman/datasets/nyu_depth_v2.html

Multiple Images: Color plus X-Ray

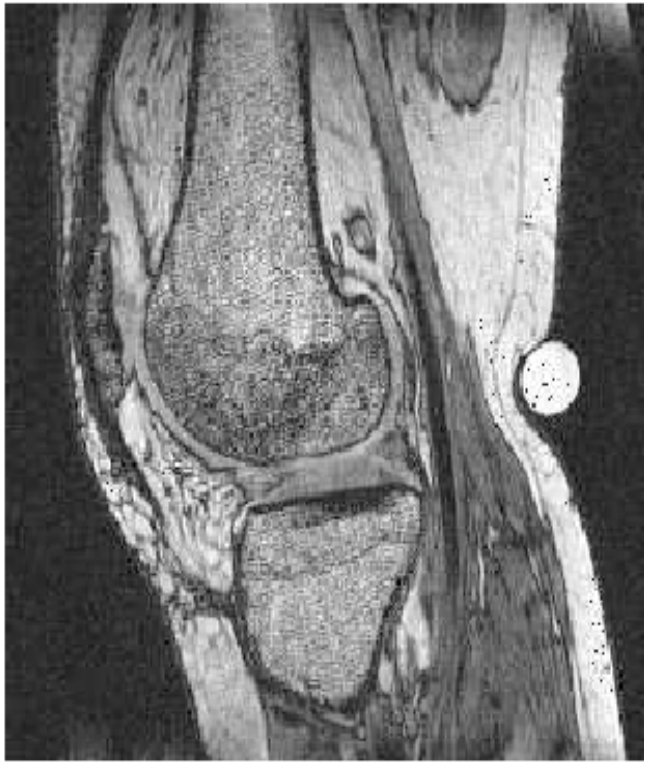
Magnetic Resonance Images: Multiple Slices



Knee slice 16

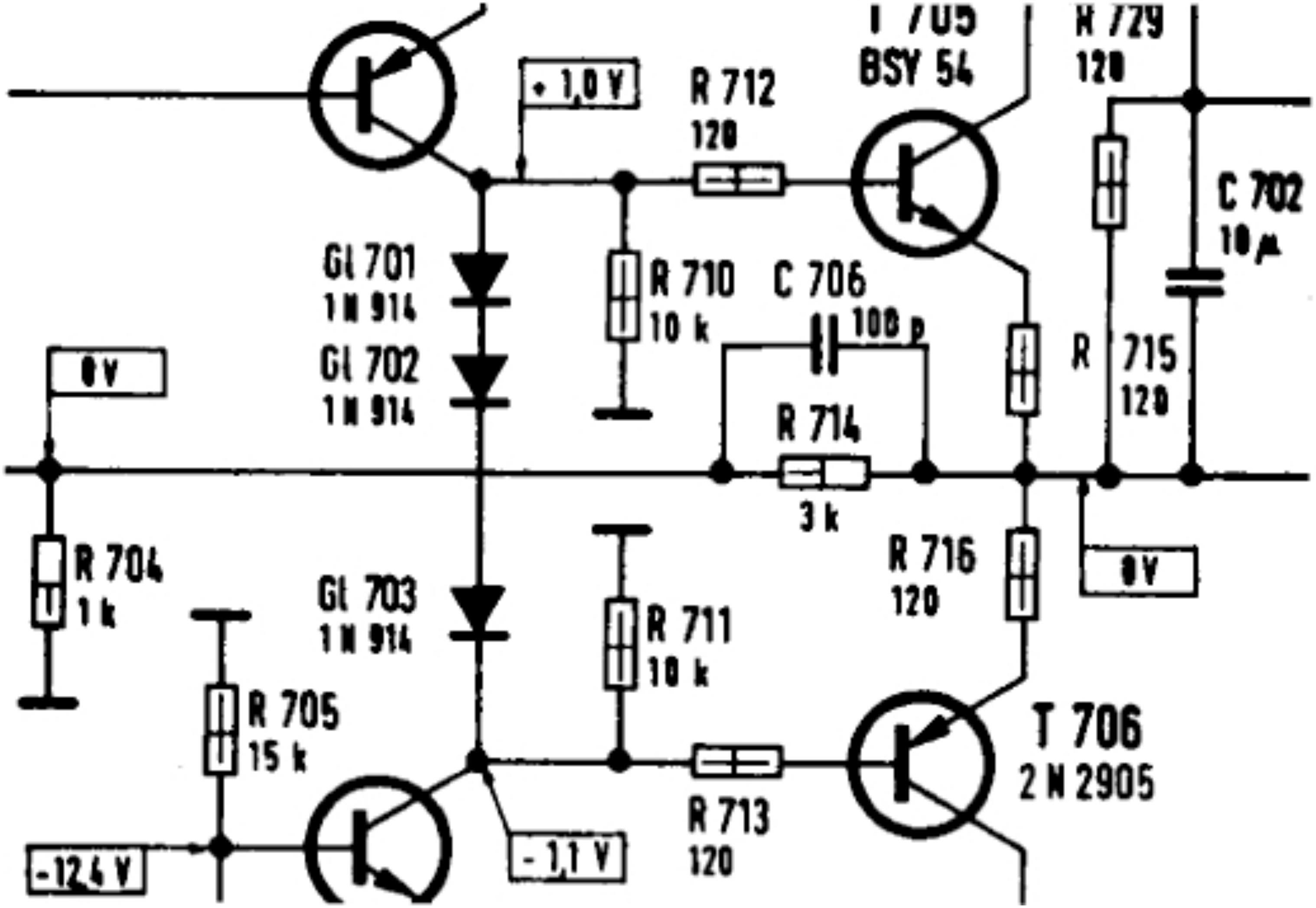


Knee slice 22



Knee slice 34

Schema Images



Seismic Data