Universität Stuttgart

Pattern Recognition
Chapter 1: Introduction

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ifp

Contents

- Course organization
- What is Pattern Recognition?
- Strategies of image analysis
  - Model-based methods
  - Statistical methods
- Basic approaches of image analysis
- Challenges
- Overview of lectures

Course organization

- Lectures:
  - You find scripts as usual on our website
  - Sometimes there are voids which shall be filled in by you

U. Sörgel

- Labs: written report expected

- Dates
  - Wednesday: 11:30 - 13:00, every week, starting 24th of 'October
  - Thursday: 14.00 - 15.30, biweekly, starting 18th of October

- Oral exam of 40 minutes
  (together with Computer Vision)

D. Laupheimer

S. Schmohl

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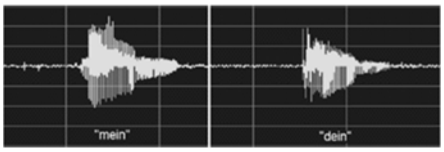
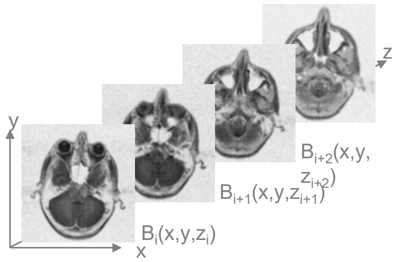
What is Pattern Recognition?

- In general pattern recognition aims at revealing certain regularities, repetitions, or similarities embedded in large amount of data
  - By humans: cognitive neuroscience
  - **By computer algorithms as a branch of machine learning.**

- Which data?
  - Sequential data: all kinds of ordered 1D sequences
    - Speech, text, music, radio, GPS….
  - 2D images → image analysis
  - 3D: image stack temporal, spatial, or spectral
  - Arbitrary types of data → Data Mining
    - Google, Facebook…





Aims of Image Analysis

- Many aims and application of pattern recognition and image analysis exist. For our purpose, we often deal with two major types of tasks, which can be categorized as automated **classification of images**:

  - **Recognition of objects** of interest embedded into some background
    - One class against the rest
    - Example: Face detection in photos

  - **Partition of images** into different classes
    - We want to derive a **map**, which represents the classes present in a scene.

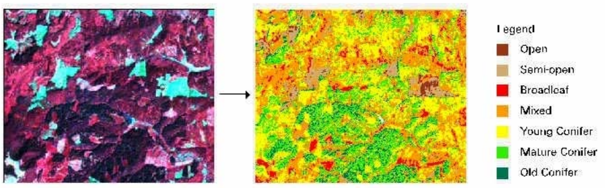


Image analysis versus other techniques

out \ in	image	description
image	Image processing	Generative computer graphics
Descrip-tion	Image analysis	Other stuff

Image Analysis (or):

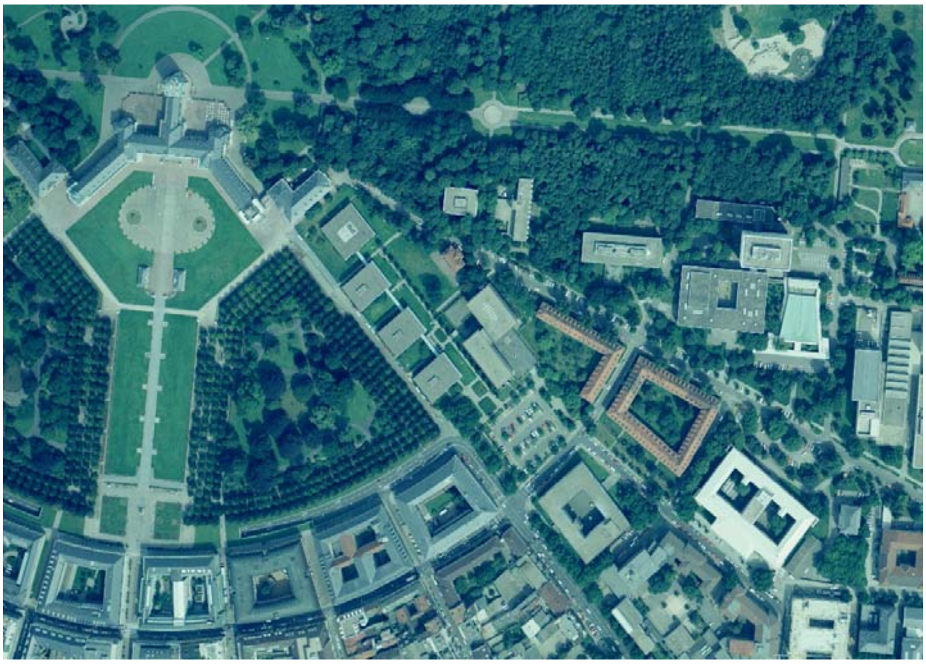
- Image Understanding
- Computer Vision
- Machine Vision

Common goal:

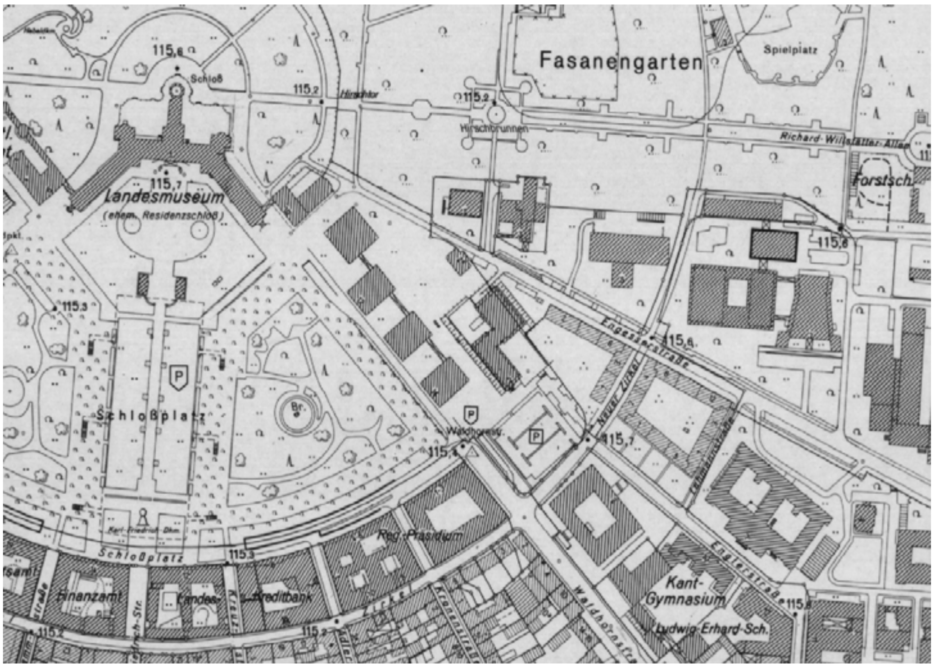
- Derive an image or scene description

Image processing is usually required as **preprocessing of image analysis**

Interpretation of an aerial color image



Map derived from aerial – and other sources!



Differences between images and maps

	Aerial image	*Map*
Data amount	2 GB	some KB
Information	implicit	explicit

⇒ Tasks

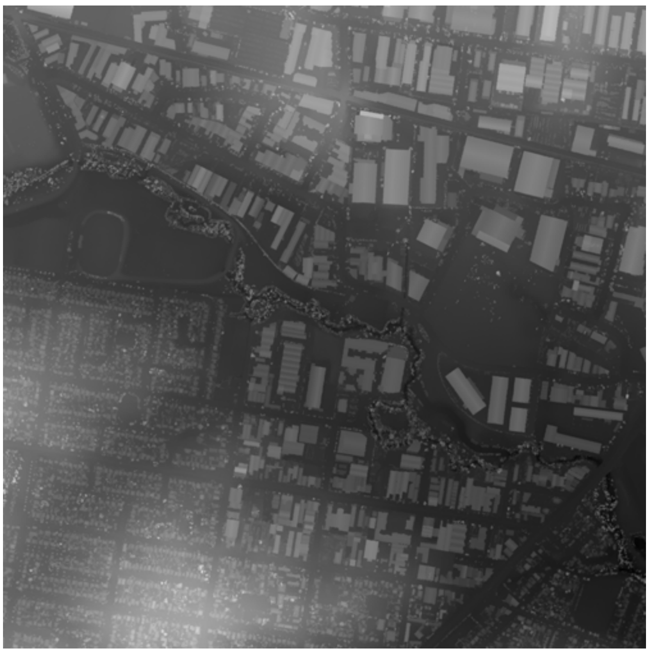
- Reduction (of redundant) data
- Make Information become explicit

Example for application

Input image

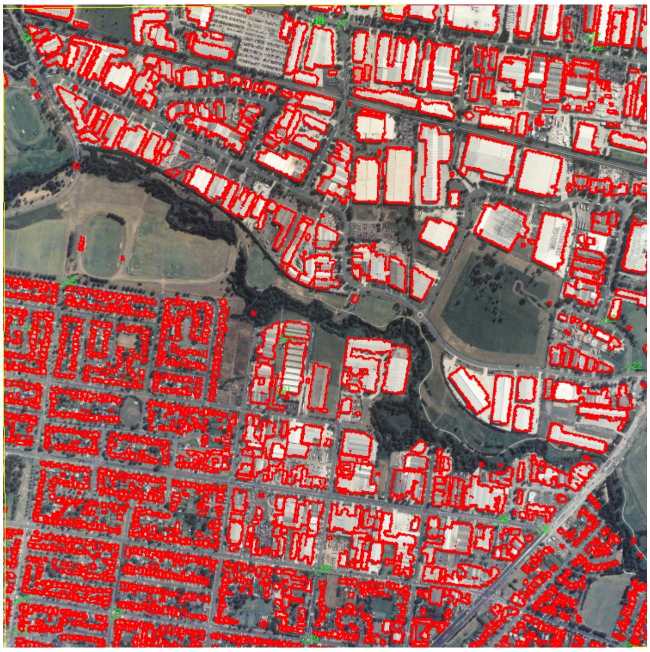
Desired result

Example for application



Digital surface modell

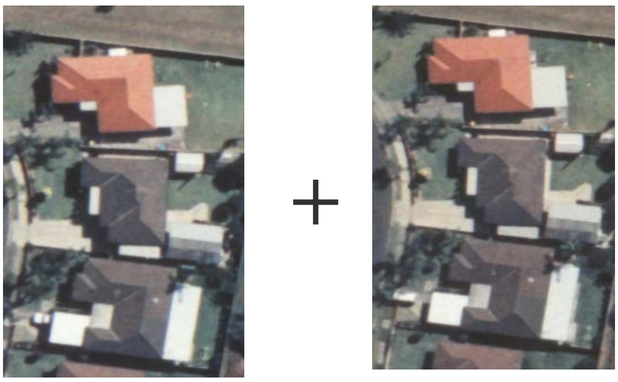
Example for application



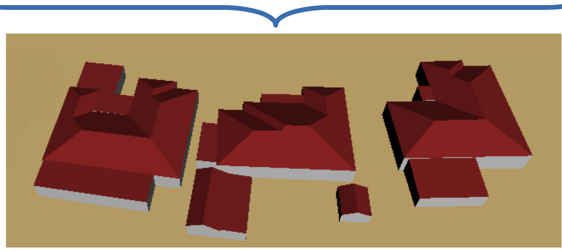
Buildings

Example for application

Stereo images



3D building model



State-of-the art: Real-Time Object Detection for Autonomous Driving

KITTI Vision Benchmark Suite

Redmon et. al., 2016 You Only Look Once: Unified, Real-Time Object Detection
https://pjreddie.com/darknet/yolo

Master theses Geodesy & Geoinformatics, GEOENGINE

„Driver assistance systems“ (2016-2017)

- Estimating Pose and Dimensions of Parked Automobiles on Radar Occupancy Grids, ***Daimler AG***
- Calibration of automotive fish-eye cameras with misaligned camera components, ***Magna Electronics***
- Fusion of Range Data from Multi-View Stereo and LiDAR for Volumetric Surface Reconstruction, ***Daimler AG***
- Schwarm basierte Lokalisierung auf dem Parkplatz mittels GraphSLAM, ***Daimler AG***
- Traffic Sign Detection and Classification using Deep Learning, ***Volvo Car Corporation***
- Detection of Repetitive Parking Lot Boundaries for Near Range Camera Systems, ***Robert Bosch GmbH***
- Analysis of Distortion Parameters for Physical Interpretation of Intrinsic Camera Alignment, ***Robert Bosch GmbH***
- Development of an Algorithm for Ghost Detection in the Context of Stray Light Test, ***Robert Bosch GmbH***

Definition of image analysis

Image analysis/image understanding:

Automatic generation of an explicit meaningful description of physical objects in the real world from images

(Rosenfeld, 1982)

real world → image(s) → description

Real world

Subdivided into objects

- **What are objects?**
  Entities, which have **something in common**
  (e.g. size, color or function)
  and which can be discriminated from others

- **Why objects?**
  In order to structure our environment, a partition into objects is useful.

real world → image(s) → description

Images

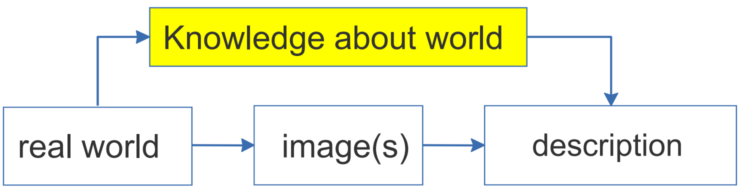
Digital image data

- Intensity images
  - active (Radar)
  - passive (gray value, color, or multi-spectral image)
- Depth maps / Digital surface models (DSM)
- One image / image pair / image sequence

Description

Explicit description

- Should coincide with intuitive understanding of humans
- Requires recognition of objects
- Recognition requires knowledge about object characteristics
- Depending on chosen knowledge representation we distinguish
  - model based
  - statistical methods

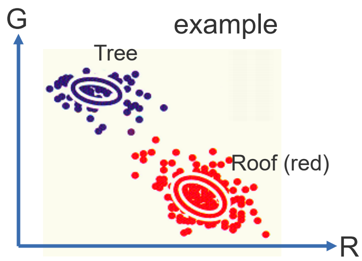


Models of objects

Description
- Name
- Parts
- Features (form, color, texture,...)
- Neighbors
- Context
- ...

Statistical models of objects

Description
- Operator provides samples (training regions) for each class
- Selection of features, whose statistical characteristics shall be modelled, e.g. form, color, texture, context
- Type of statistical model (e.g. normal distribution)
- Parameters of distribution (learned from samples)



GIS objects derived from digital images

Object extraction is usually done in two steps (in particular for 3D objects):

1) **Object detection** (or **object recognition**):
   - „Where is such an object?"
   - This is manly a classification task
   - Provides location and approximate object boundaries

   ⇒ **Region of interest**

2) **Object reconstruction**
   - Vectorization
   - Conducted in regions of interest found in step 1
   - Due to focus on regions of interest, more complex algorithms can be applied.

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Model-based image analysis

- „Knowledge“ = used provided models
  - Geometry: location, size, geometric relations
  - Radiometry: color, texture
  - Topology: neighborhood relations
  - Semantics: name, context, functions, ...

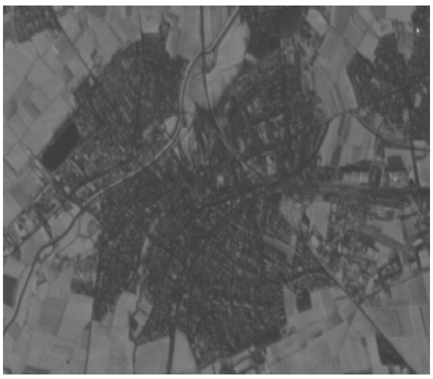
Model-based image analysis

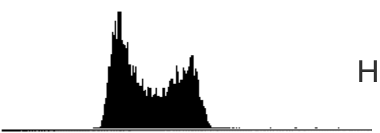
- Extraction relies on knowledge about objects
  - What characterizes the object?
  - What discriminates the object from other objects?
  - Which relation between object of interest to other objects?
- Description and formalization of object and scene model
  - The model depends on human perception of real world
  - The model is restricted by desired application and given input data
- Results yield by automated approaches should coincide with those derived manually by a skillful human operator, however methods may differ.

Level model of model-based image analysis

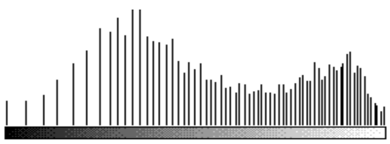
top-down ↓ / bottom-up ↑	**Recognition/Evaluation** Features → Objects	high level
	Segmentation Image → Features	mid level
	Preprocessing Image → Image	
	Image acquisition Scene → Image	low level

Image Contrast Enhancement by Histogram Stretch





Histogram



Original histogram

Histogram after stretch

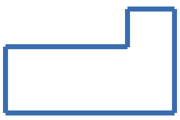
Segmentation: Example

Level model of model-based image analysis

- Recognition/Evaluation (high-level)
  (Input: features, Output: objects)

  - Knowledge about features and object relations required in order to determine the meaning (or class) of an object.

  - Example: Assume we extracted a contour of some region segment as shown below in an areal image. In case the segment area is in between given lower and upper thresholds and its shape consists of straight lines intersecting in right angles, we label it to be a building.



Level model of model-based image analysis

- Strategies of of model-based image analysis:
  - Bottom-up (data driven; methods)
    - Recognize objects starting from plain image.
  - Top-down (model driven; knowledge)
    - Projection of model onto image and search for object components.
  - Mixed mode
    - Alternate between bottom-up und top-down approach.
    - Problem: when to switch direction?

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Statistical methods of image analysis

• „Knowledge“ =

1. Given examples (training data)
2. Selection of features, which are characteristic for the objects desired to detect (analog to model-based method).
3. Assumptions about statistical distributions of features
4. Parameters of these distributions need to be determined from samples $\Rightarrow$ training, learning

▪ Image analysis often requires maximization of probabilities.

Standard approach of statistical methods

1. Image acquisition
2. Image preprocessing

Same as for model-based image analysis

3. Calculation of image features

▪ The feature space can be of very high dimensionality.

▪ Features are not restricted to gray values, in addition further processed entities thereof may be used (e.g. 1. a. 2. derivation, texture, …)

Standard approach of statistical methods

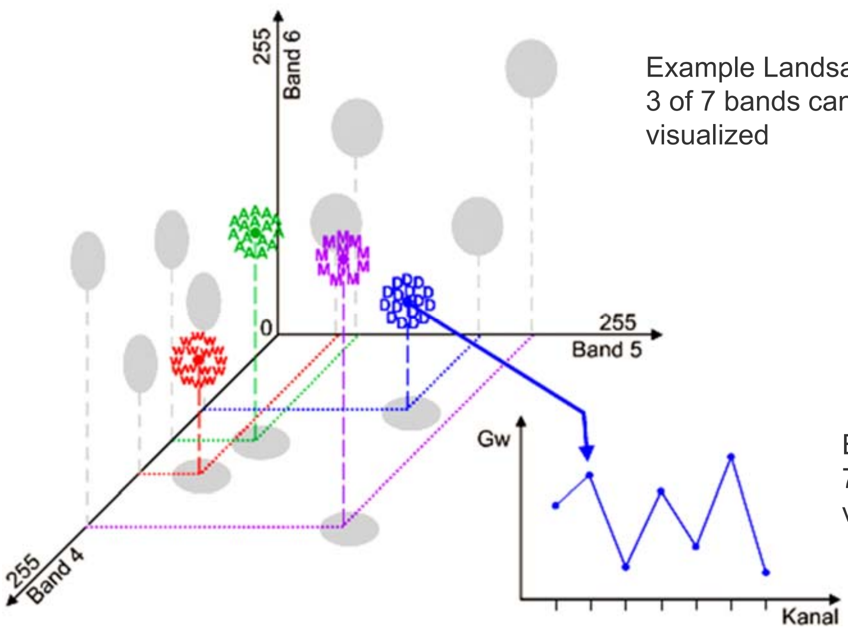
4. Training:

- For each class a sufficient number of samples is needed
  ⇒ Training areas
- Parameters of the statistical model (assumed distribution) are estimated from training data.

5. Application of statistical model

- Usage of same features as in training phase
- Probabilities of occurrence of a certain class are calculated based on trained parameters.
- Choice of object class, for instance, according to Maximum A posteriori Probability (MAP).

Feature Space: Multi-dimensional coordinate system

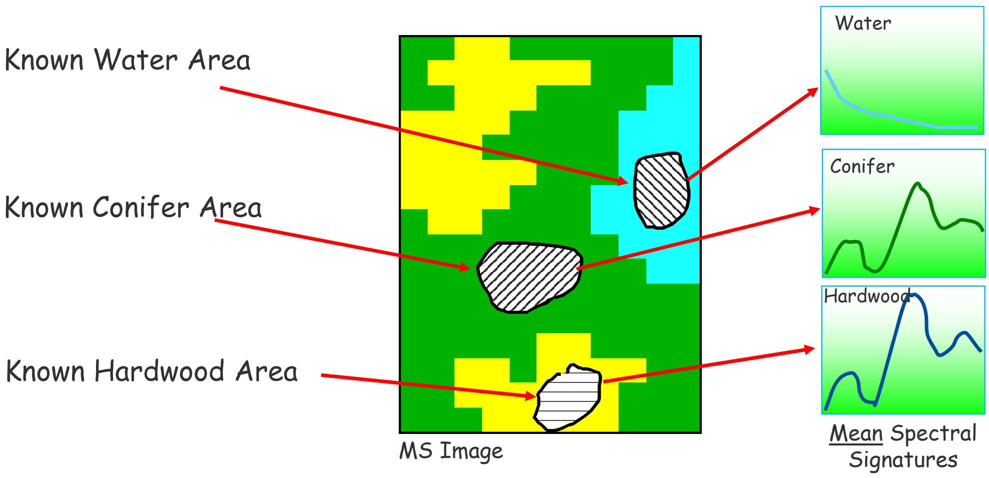


Example Landsat TM:
3 of 7 bands can be visualized

Example TM:
7 bands as vector

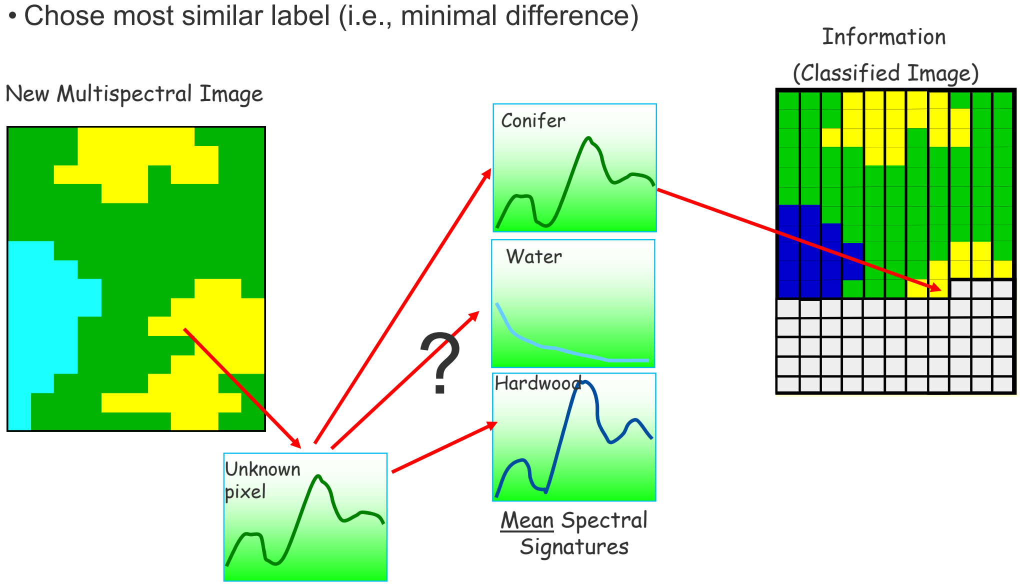
Supervised classification: Training

- Number m and type of land cover classes are known.
- Training regions are created for each class
- Classifier "learns" *mean signature* (n-dimensional vector) each class from set of samples



Classification phase

- Compare features of each pixel with set of signatures
- Chose most similar label (i.e., minimal difference)



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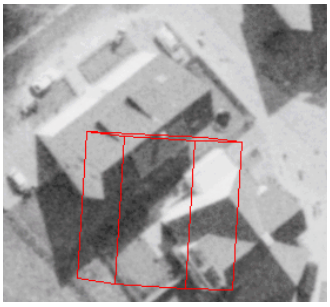
Approaches of image analysis

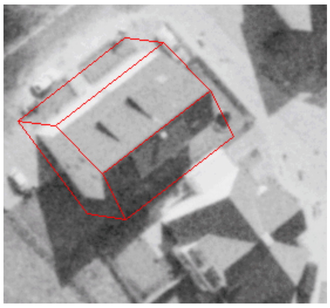
Semi-automated approach:

- Operator: complex tasks
  - Select object type and if applicable object model
  - Provides roughly location or starting point, particularly at difficult spots
  - Gives approximate topology
- Computer:
  - Improves location accuracy locally in course to fine manner
  - Fine-tuning of topological structure
- Operator continuously monitors this process, verifies or corrects results.

Semi-automated approach: Example

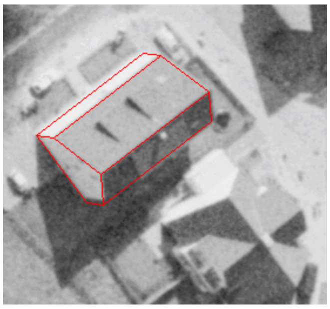
1. Selection of building model

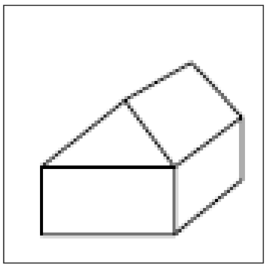




2. Interactive positioning and shaping

3. Result of automated fine tuning





4. 3D model of extracted building

(from: Gülch, Müller, Läbe,'99)

Approaches of image analysis

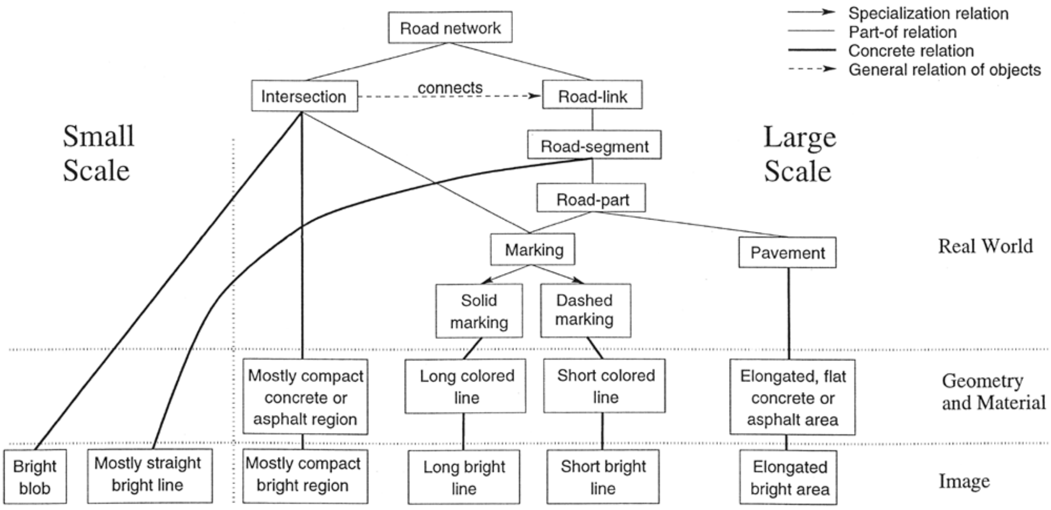
Automated approach (model-based image analysis)

- Complete a priori modelling of objects and their neighborhood according to knowledge about world
  - Geometrical/topological description of objects and their context
  - Appearance of objects in imagery
  - Requirements of application at hand
- Formalization of model, often in form of so-called Semantic Networks.
- Provide a procedure (strategy) to extract objects of interest in geodata.

Model – multi-scale, several levels

Same road in three different scales: 0.08 m, 0,5 m, 2 m

Model – multi-scale, several levels



Approaches of image analysis

Automated approach (statistical method)

- Provide training areas: usually operator involved

- Features can be quite diverse
  - Radiometry, texture, context
  - Choice of features needs to be tailored according task at hand

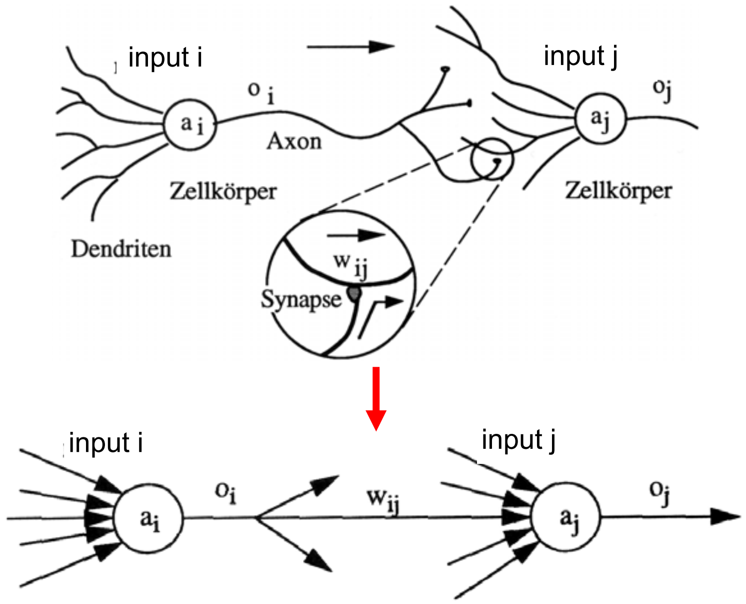
- But: the larger the number of features gets,
  - The more parameters have to be determined
  - The more training data is required!

- There a different statistical model, which we will discuss
- And there are different methods available to estimate model parameters and a posteriori probabilities.

Neuronal Nets: Old approach, but still so up to date

- The human brain is able to recognize objects very fast.
- The brain consists of quite simple structured neural cells (**neurons**), which however interact in a huge network.
- Assumption: The capability of the brain is related to some kind of collaboration of neurons in this network.
- Approach to implement a similar set-up technically in a computer
  $\Rightarrow$ Neuronal Nets
- Early works date back to 40ies of last century! Neuronal nets have been "in fashion" several times since 60ies.
- Recently breakthrough by so-called Convolutional Neural Networks (CNN) .

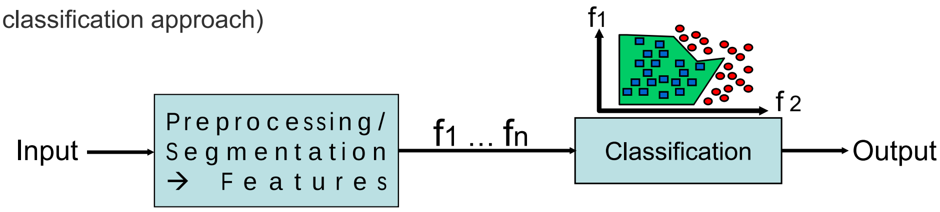
Simulation of neurons



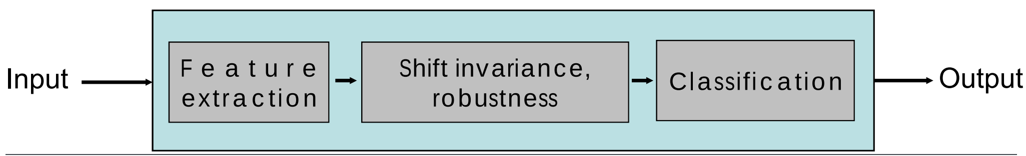
Quelle: Zell (1997), Simulation neuronaler Netze

Concept: End-to-end approach

- Classical approach
  - Preprocessing is chosen according to given knowledge (selection of features etc.)
  - Similarly, the operator picks appropriate method for high-level analysis (here: classification approach)

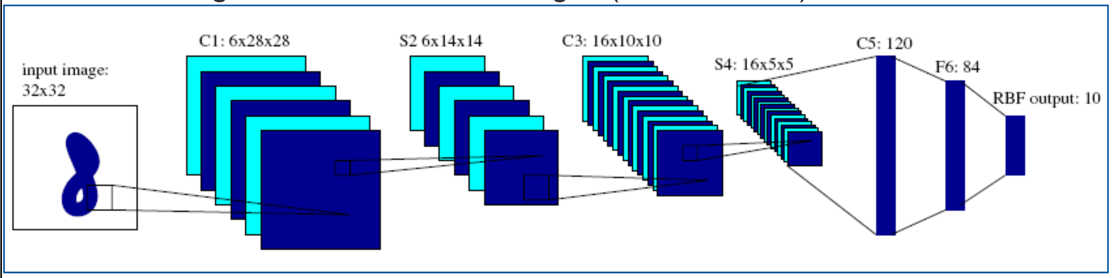


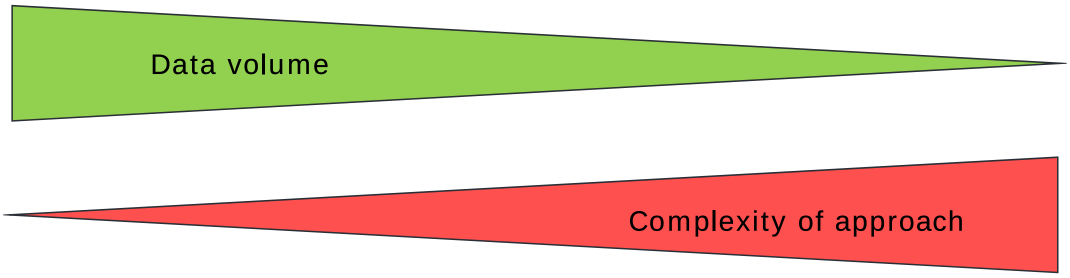
- CNN:
  - No modeling by human required
  - Network learns features and classification on its own based on very many training data



CNN: Usually hierarchical approach

- CNN recognition of hand-written digits (LeCun, 1998).





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Open questions of image analysis (and pattern rec.)

Model-based approaches

- Which kind of, how much knowledge is required ?
- How can knowledge be formalized?
- How should we represent the knowledge?
- How to steer the analysis (sequence of operations etc.) automatically?
- Robustness against parameter choice?
- Which amount and kind of interaction is needed?

Open questions of image analysis (and pattern rec.)

Statistical approaches

- Which is the best kind of statistical model?
- Which is the best kind of learning of parameters and which is the best way of evaluating the a posteriori probabilities?
- How can the required amount of training data be reduced?
- How can we connect statistical and model-based approaches?

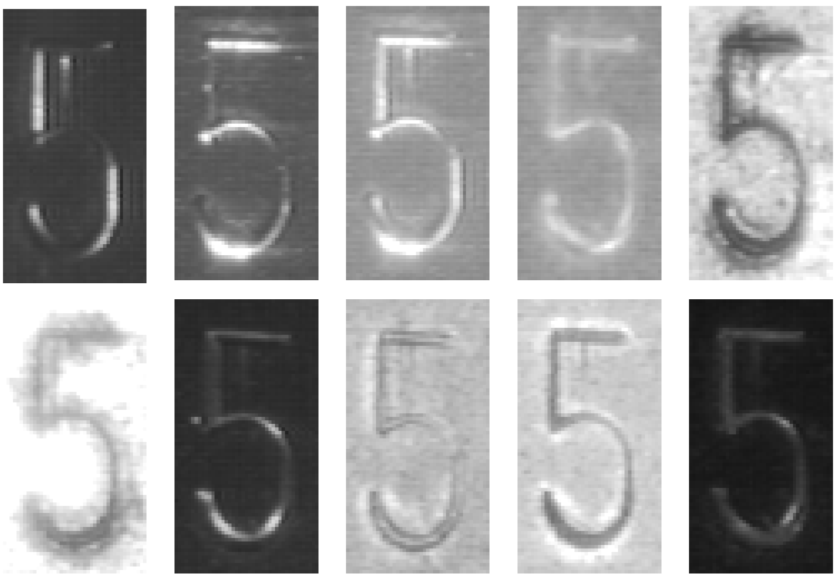
Open questions of image analysis (and pattern rec.)

Convolutional Neural Networks

- How many layers are required?
- How many dimensions in a certain layer appropriate?
- How can the required huge amount of training data be reduced?
- CNN end-to-end on its own or rather as very good preprocessing for subsequent model-based approach?

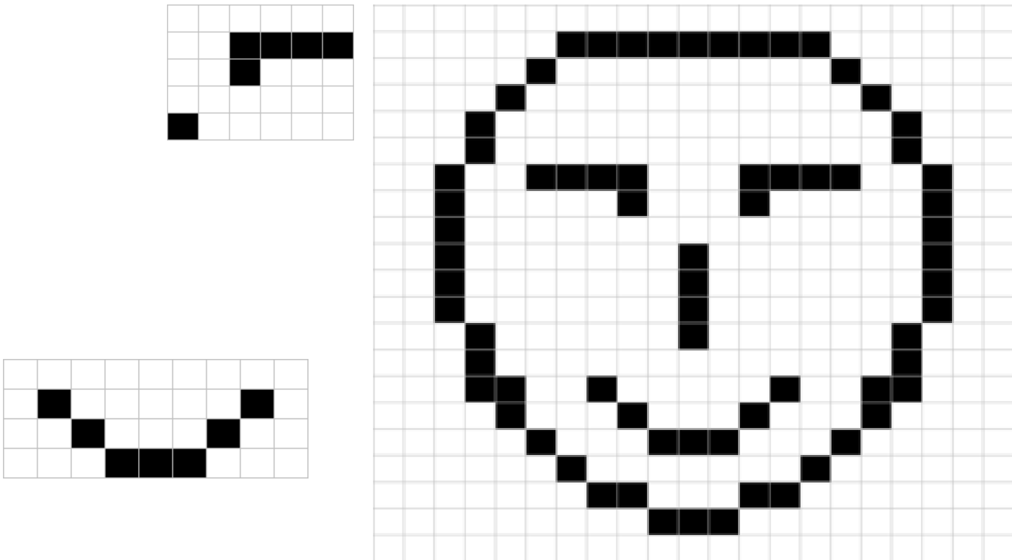
• Today, for none of these questions a sound theoretically founded answer exists.

Challenge: Variation of appearance of objects



The very same individual digit 5 hammered into a metal surface looks very different only due to change of illumination

Challenge: Context



Challenges of image analysis (and pattern recognition)

- Complexity of real world objects
  - Geometrical description of surface
  - Reflection properties of surface
  - Variation of appearance of some object type (e.g. human face)
  - Mapping 3D $\rightarrow$ 2D inevitably comes along with loss of information
  - Recognition of only partly visible objects or clusters thereof instead of detached isolated individual objects
- Complexity of environment
  - Very many objects
  - Relation between all those objects?
- Verification, self-diagnosis

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The topics of this lecture I

- Human visual system
- Preprocessing
  - Image acquisition and preprocessing
  - Scale space
  - Segmentation and post-processing
  - Extraction of features

Statistical methods

- Bayes classification, logistic regression
- Discriminative non-probabilistic classification:
  - Decision trees, random forests
  - Support vector machine

The topics of this lecture II

Statistical methods (continued)

- Deep Learning
  - Basics
  - Applications

- Graphical Models
  - Bayes Nets
  - Markow Random Fields, Conditional Random Fields

- Model-based approach
  - Models
  - Representation an usage of knowledge
  -

Literature: Books about image processing

- Castleman, K. R., Digital Image Processing, Prentice Hall, Englewood Cliff, New Jersey, 1996.
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Literature: Scientific journals

- Photogrammetrie und Fernerkundung:
- Photogrammetrie, Fernerkundung, Geoinformation (PFG), Organ der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation, 6 Hefte / Jahr.
- ISPRS Journal of Photogrammetry and Remote Sensing (P&RS), Internationale Gesellschaft für Photogrammetrie und Fernerkundung, 6 Hefte / Jahr.
- Photogrammetric Engineering and Remote Sensing (PE&RS), Organ der American Society for Photogrammetry and Remote Sensing, 12 Hefte / Jahr.
- Photogrammetric Record, Organ der British Society for Photogrammetry and Remote Sensing, 4 Hefte / Jahr.
- IEEE Transactions on Geoscience and Remote Sensing (IEEE-TGARS), Organ der IEEE Geoscience and Remote Sensing Society (IEEE GRSS), 12 Hefte / Jahr.
- IEEE Journal on Selected Topics in Applied Earth Observation (IEEE-JSTAR), Organ der IEEE GRSS, 12 Hefte / Jahr.

Literature: Scientific journals

- Computer Vision / Bildanalyse:
- IEEE- Transactions on Pattern Analysis and Machine Intelligence (IEEE-TPAMI), Organ der IEEE Computer Society, 12 Hefte pro Jahr.
- International Journal of Computer Vision,15 Hefte pro Jahr.
- Computer Vision and Image Understanding, 12 Hefte pro Jahr.