Detecting and Reconstructing Buildings from Aerial Images and LIDAR Data

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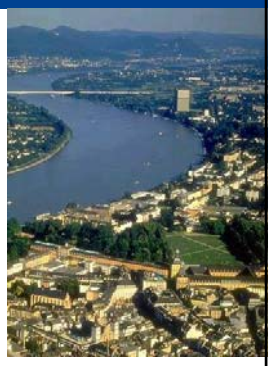
Bonn
- 300000 inhabitants
- At river Rhine

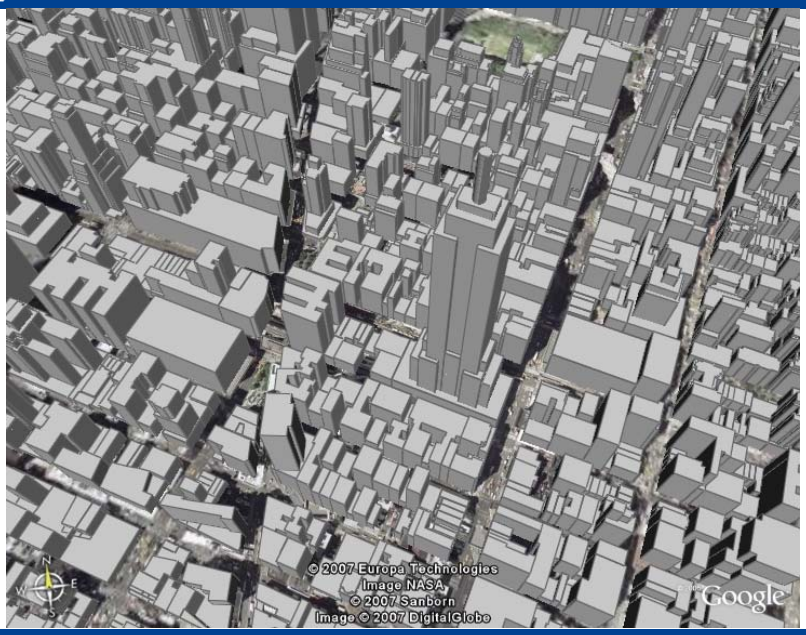


University:
30000 students
- 7 faculties
  - Agricultural faculty
    - Institute for Geodesy and Geoinformation
      - Department of Photogrammetry

Research in Photogrammetry

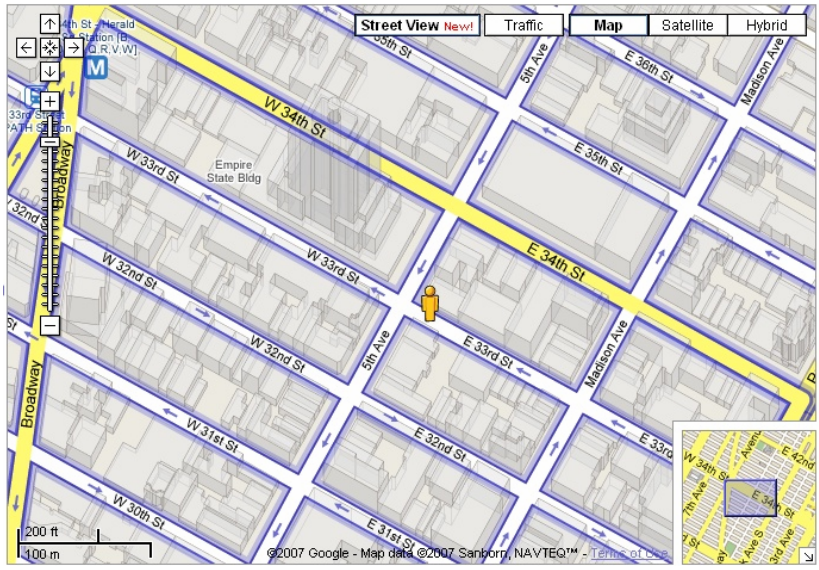
- Buildings from images
- Statistical methods for image analysis
- Modeling in geosciences
- Calibration and orientation procedures (wednesday)
- Quality of godata
- Geometry and statistics (thursday)
- Machine learning for image interpretation

3D City Model in Google Earth



Aerial Image in Google Maps

Choosing street view in Google Maps



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Streetview in Google Maps

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Outline

- Motivation
- Notions and data
- Models for buildings
- Strategies for building extraction
- Example: Detection and Reconstruction
- Efficient reconstruction
- Uncertainty of building data
- Summary

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Notions and Data

Notions

- Detection
  Given: Image(s) and model
  Sought: existence and rough position

- Reconstruction
  Given: Image(s) and model
  Sought: geometric/thematic description

Images: intensity, color and range images

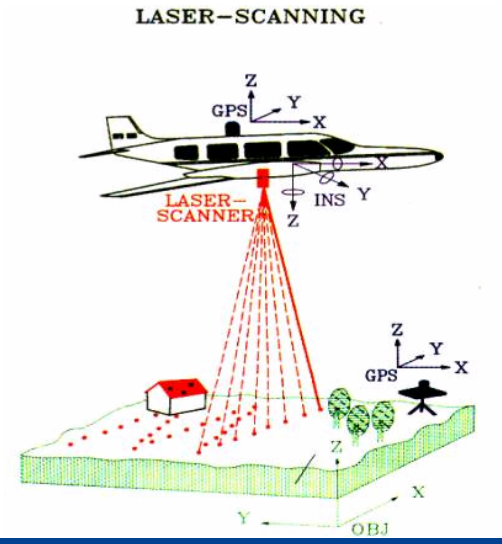
Question

How many buildings belong to Lafayette?

What is a building?

Airborne LIDAR

Light detection and ranging



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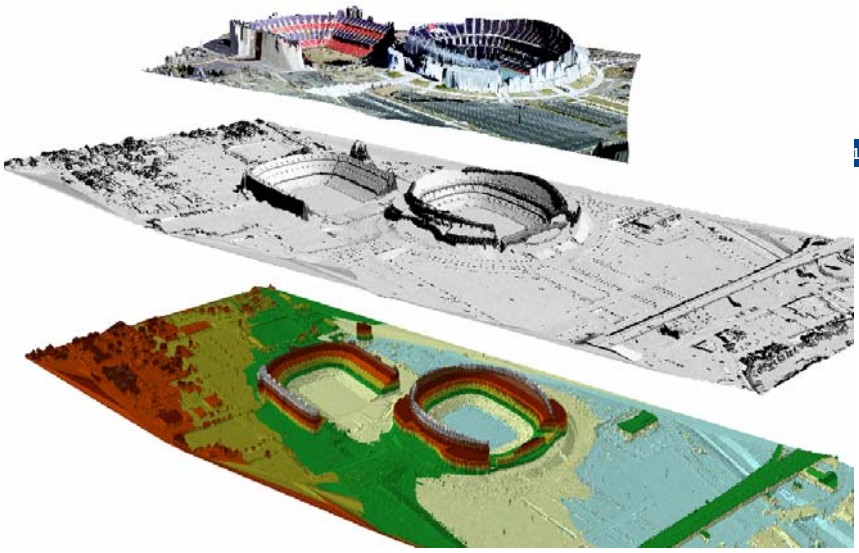
Digital Surface Model (DSM)

http://www.merrick.com/servicelines/gis/lidarsamples.aspx



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Feature extraction

Feature:

- Image feature
  - point,
  - line segment,
  - ...
- Cartographic feature:
  - building,
  - river,
  - ...
- In pattern recognition:
  property of 2D or 3D-element to be classified

Feature extraction

Extraction (cartographic)
- The feature is not in the image!
- The feature is in our mind
- The feature is part of our model of the world

Link between image x and feature/class ω

Bayes formula

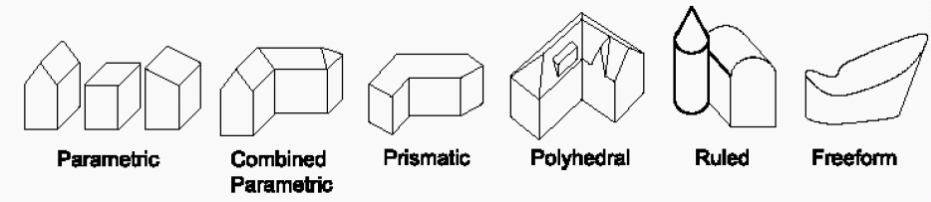
$$P(\omega|x) = P(x|\omega)\, P(\omega) / P(x)$$

Likelihood $P(x|\omega)$ establishes link: Modeling appearance
Prior $P(x)$: states structure of model
Motivation for statistical methods in image interpretation

Models for buildings

Building Models

- Examples



- Representation?
- General enough?
- To be learnt

Aggregation levels

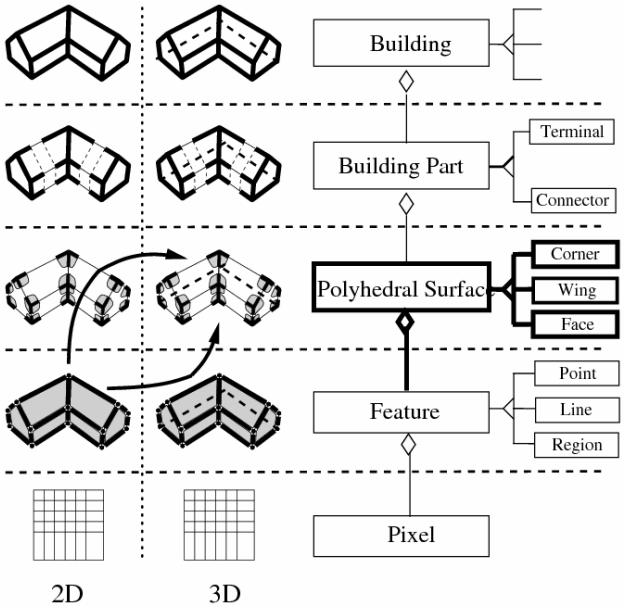


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Image and image features

Appearance of buildings

image

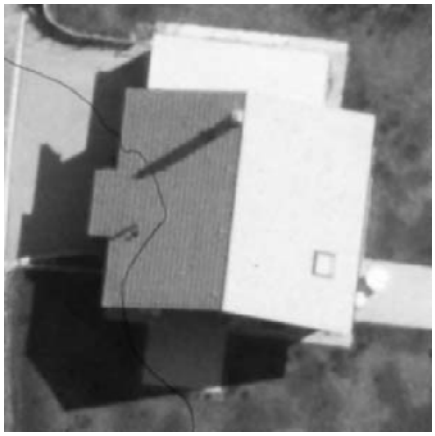


image features

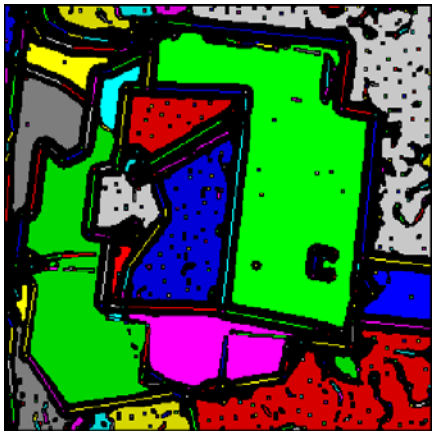
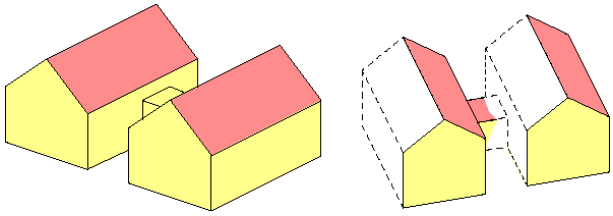
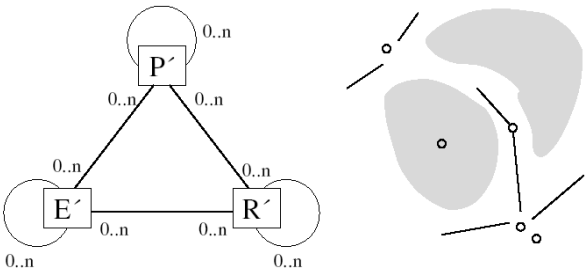


Image model: incomplete image of polyhedra

- Occlusions



- Imperfectness of feature extraction



Strategies

Strategies

- Bottom up:
  from the data to the description

  A sequence of aggregation steps

  Usual approach

- Top down:
  From the model to the instances

  A sequence of search steps: hypothesize and verify

  Future approaches

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Examples

Bottom up procedures

A two step-procedure:
(http://www.ipf.tuwien.ac.at/research/fr_buildings_lidar/buildings_lidar.htm)

Detection

Buildings are higher than ground

Reconstruction

Roofs are planar

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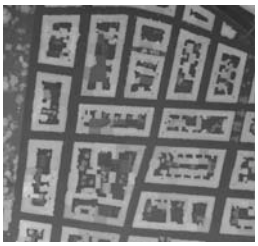
Building detection

Buildings are higher than ground

- Find ground = *DEM* (dgital elevation model)
  - Minimum filter
  - Opening (1. minimum, 2. maximum)
- Determine difference: *d=DSM-DEM*
- Threshold
- Connected components



http://www.ipf.tuwien.ac.at/research/fr_buildings_lidar/buildings_lidar.htm

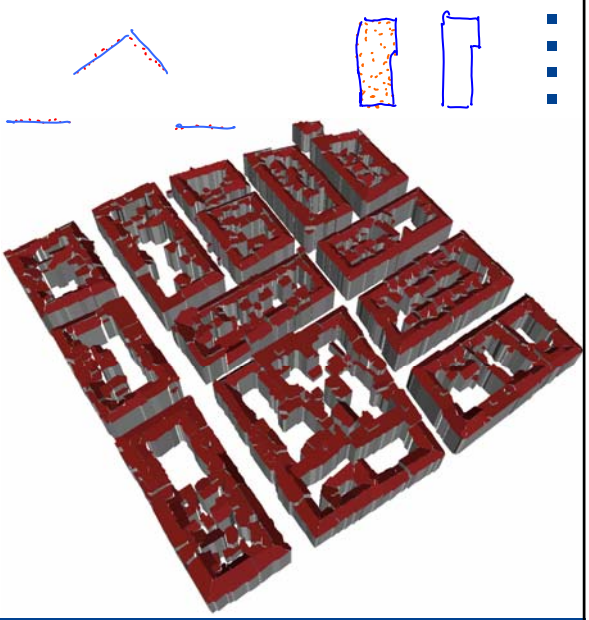
Building reconstruction

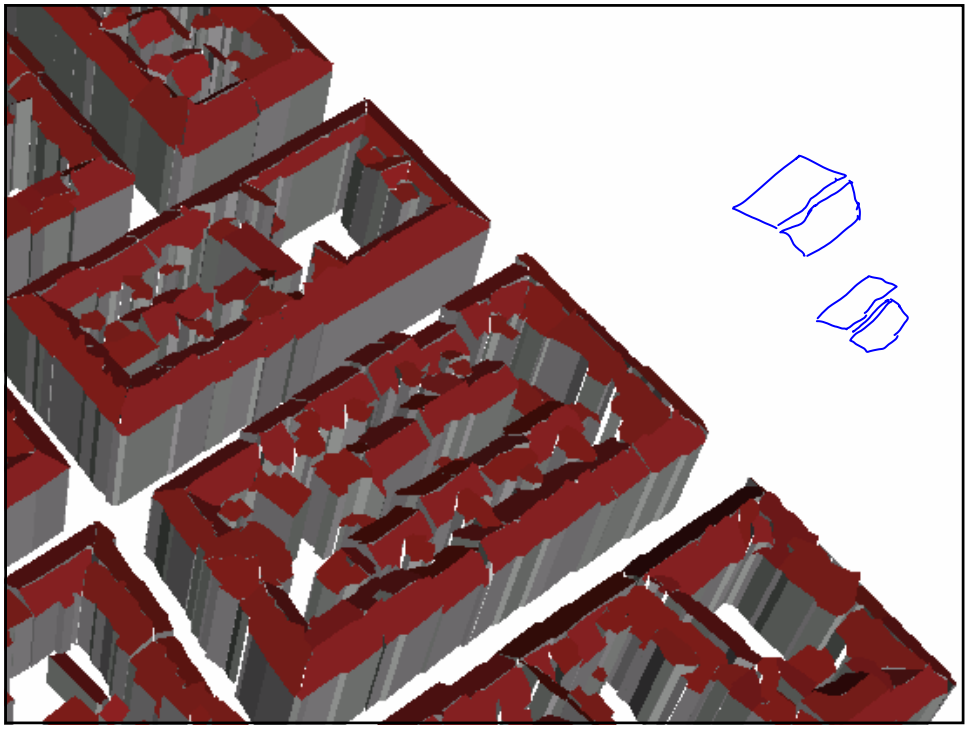
Roofs are planar

- Find flat regions
- Find neighbors
- Fit planes
- Find boundaries

+ Set of planes

- No polyhedra



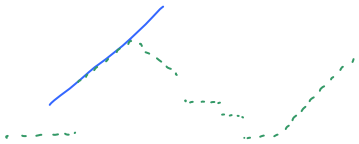


Fit planes

A one-step procedure

(Dorninger/Nothegger PIA 07, Schnabel/Wahl/Klein 07)

- Find all planes
- Intersect planes



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Problem:

Outliers on roof planes

- Chimneys
- Small dormers
- Overhanging trees
- All other planes

→ Robust estimation of planes

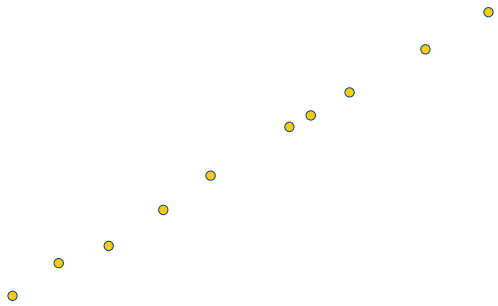
→ Random sample consensus

  – Principle

  – Efficient solution for large data sets

RANSAC: line fitting

Good points



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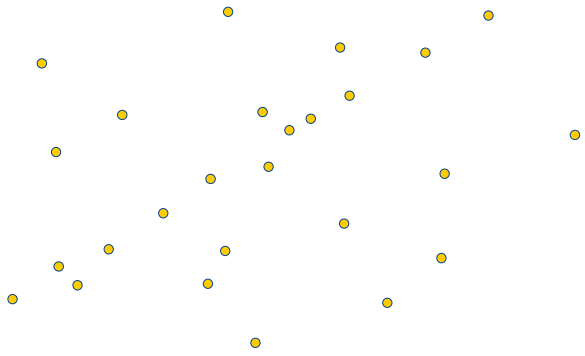
RANSAC: line fitting

All points



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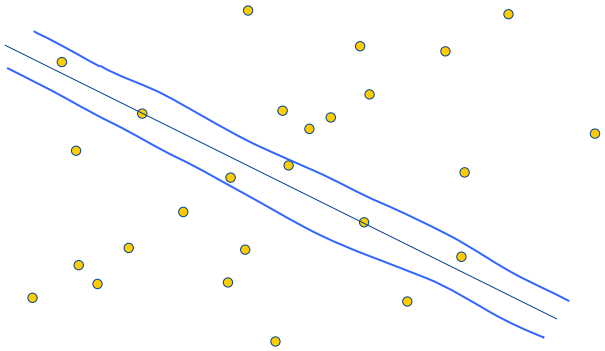
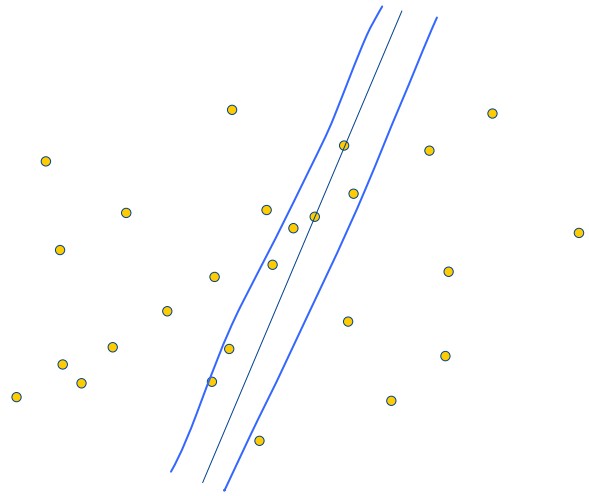
RANSAC: line fitting

1. trial



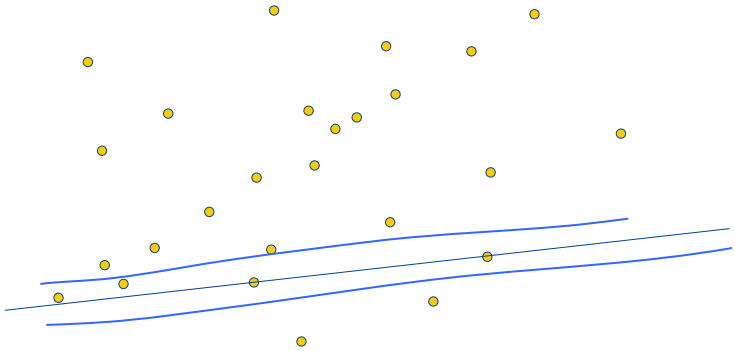
RANSAC: line fitting

2. trial



RANSAC: line fitting

3. trial



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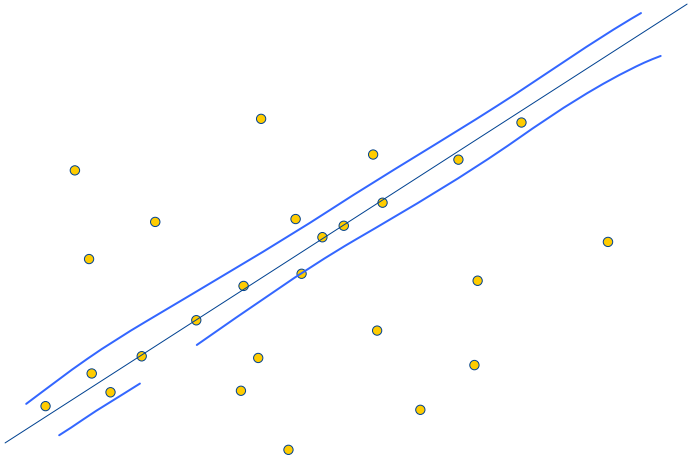
RANSAC: line fitting

4. trial



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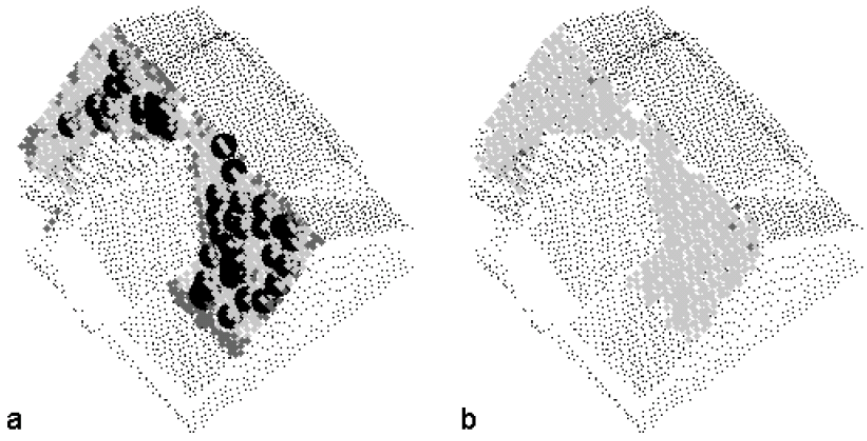
Number of trials

Probability of success (e. g. 99 %)
Error rate ε (e. g. 50 %)
Number *n* of constraints (here 3)

n \ ε	20	30	40	50	60	70	80
2	5	7	10	(16)	26	49	113
3	6	11	19	***34***	70	168	***573***
4	9	17	33	71	178	566	2876
5	12	25	57	145	447	1893	14389
6	15	37	96	292	1122	6315	71953
7	20	54	162	587	2808	21055	359777
8	25	78	272	1177	7025	70188	1798892

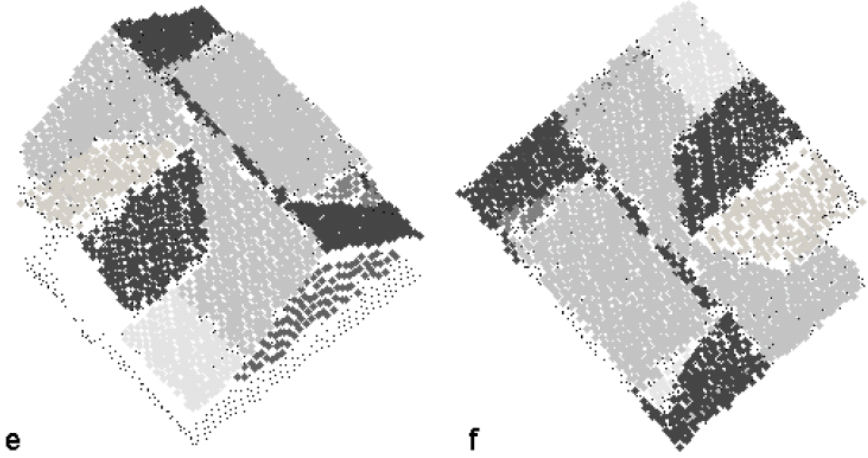
→ Direct solution with minimum number of points (3 here) useful
→ Reduce error rate

RANSAC



Dorninger/Nothegger PIA 07

... all roof planes



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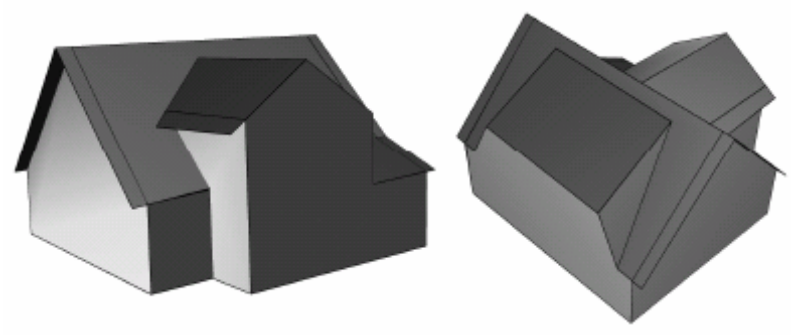
Reconstructed 3D-model



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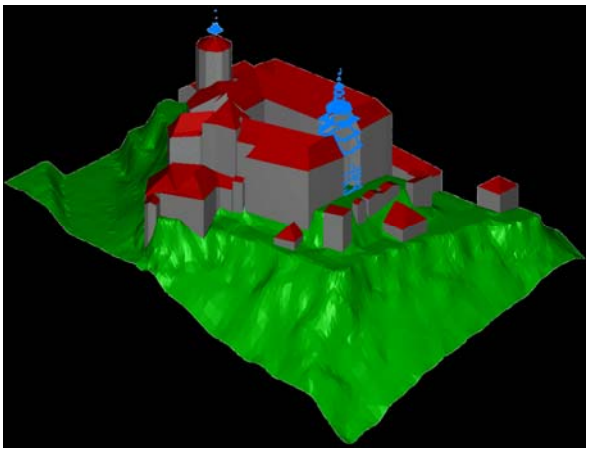
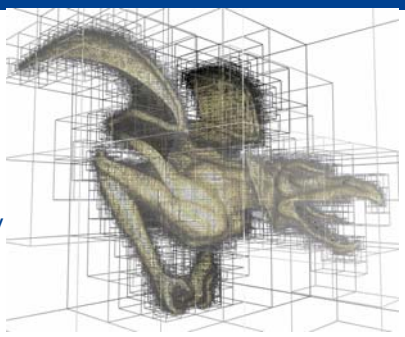
… with surrounding DEM



Efficient reconstruction

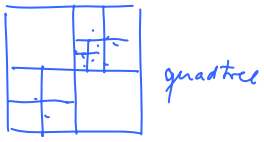
Efficient solution

Schnabel/Wahl/Klein 07



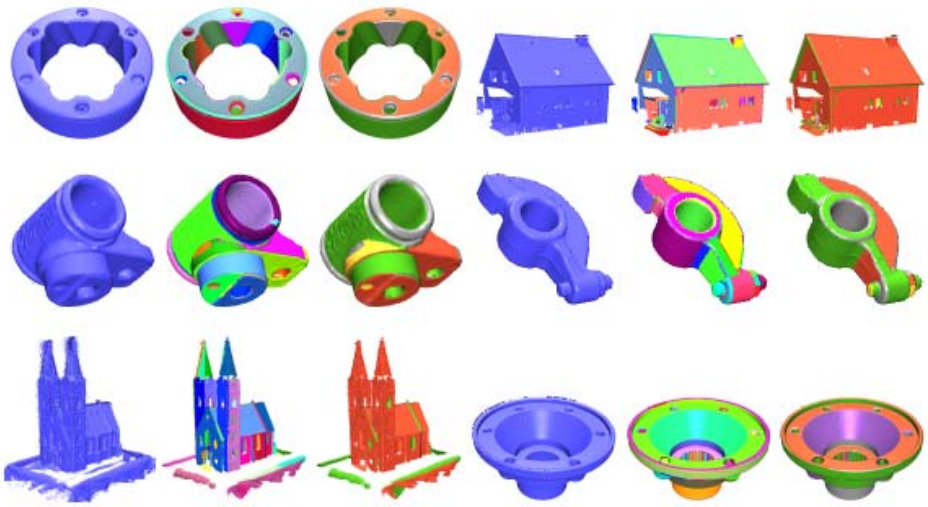
- Use Octree
- Use Normals
- Adapt sampling to local density
- Exploit connectivity of points

- Shapes (number of points, possibly with normals)
  Planes (3)
  Spheres (2)
  Cylinders (2)
  Cones (2)
  Tori (4)



http://www-evasion.imag.fr/Membres/Sylvain.Lefebvre/these/

object/ranom colours/shape classes



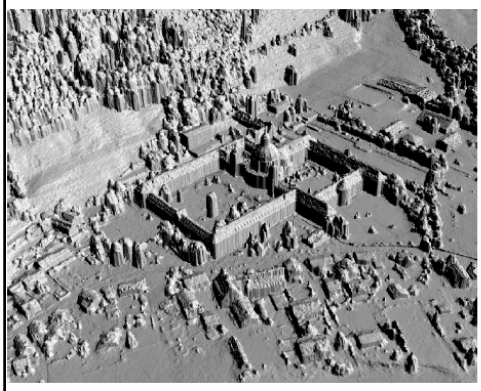
Efficiency

model	$\|\mathcal{P}\|$	ε	α	τ	$\|\Psi\|$	$\|\mathcal{R}\|$	sec
fandisk	12k	0.01	10	50	24	38	0.57
rocker arm	40k	0.003	20	50	73	1k	6.5
carter	546k	0.001	20	200	138	47k	29.1
rolling stage	606k	0.003	20	300	61	16k	15.1
oil pump	542k	0.0015	30	100	202	15k	30.9
master cyl.	418k	0.003	35	300	37	7k	12.1
house	379k	0.002	20	100	130	19k	10.7
church	1,802k	0.002	20	1000	160	690k	40.7
choir screen	1,922k	0.002	20	4,000	81	543k	20.8
				500	372	236k	61.5

- $|\mathcal{P}|$ number of points
- ε threshold [m] for points
- α threshold [°] for normal
- t number of points per shape
- $|\Psi|$ number of shapes
- $|\mathcal{R}|$ number of remaining points
- sec computing time in seconds

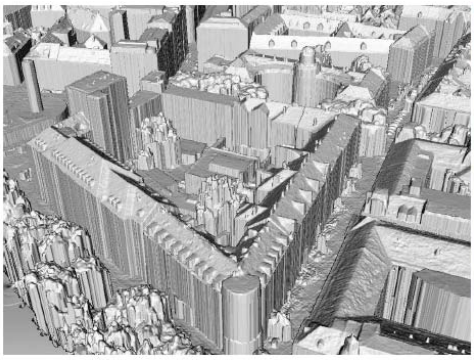
From images?

Kreuzbefligung des Klosters Ettal mit HRSC mit 15 cm/Pixel. 4 Flugstreifen.



http://www.robotic.dlr.de/Heiko.Hirschmueller/

Graz (images from Vexcel)



http://www.robotic.dlr.de/Heiko.Hirschmueller/

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Uncertainty of building data

Aerial image with acquired data

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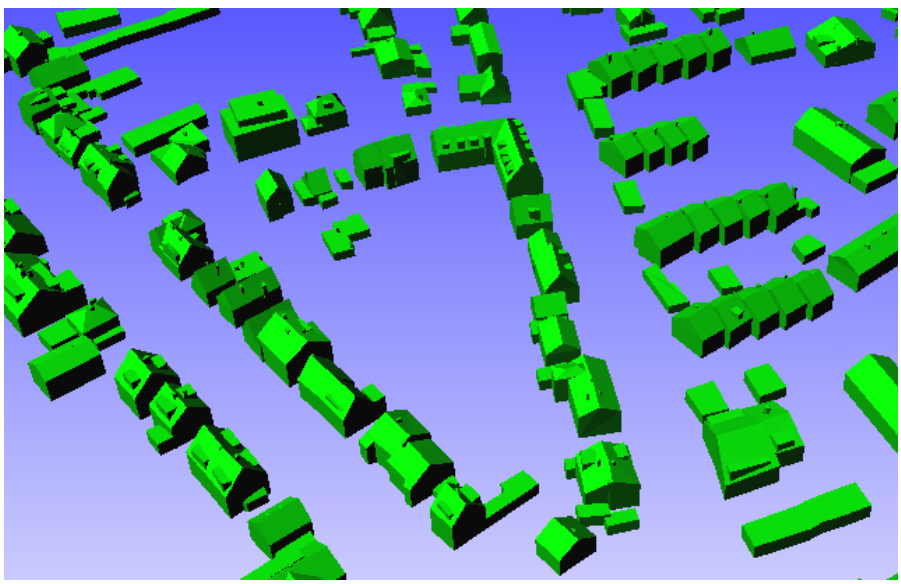
Manually acquired 3D Data



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Goal

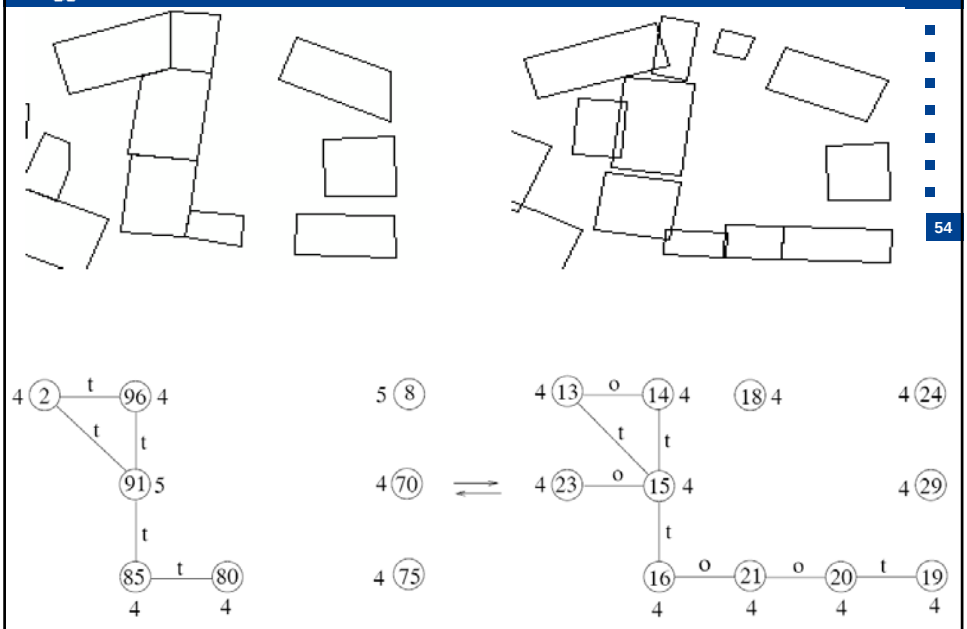
- Characterizing quality of acquired complex 3D objects
  - 3D-geometry
  - 3D-structure
  - → specification and verification of data
- Characterizing the model of complex 3D-objects
  - Variability of attributes
  - Variability of relations
    - Network of neighbourhood relations
    - Hierarchy of aggregation
  - → prior model for data interpretation

Uncertainty

- Uncertainty = Quality of data
  Specification and Validation
  - External Validation
  - Internal Validation
- Uncertainty = Variability of GIS-Models
  Prior for automatic data acquisition
  - Topology
  - Geometry
  - Structure
  - Labels

Uncertainty = Quality of data

Comparison with ground truth

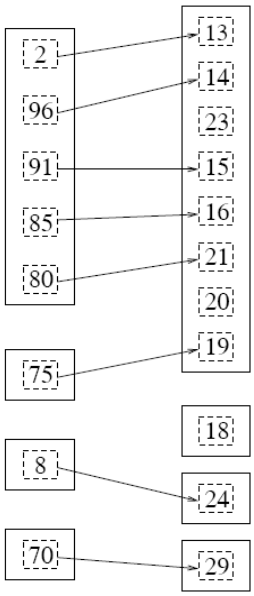


Structural matching

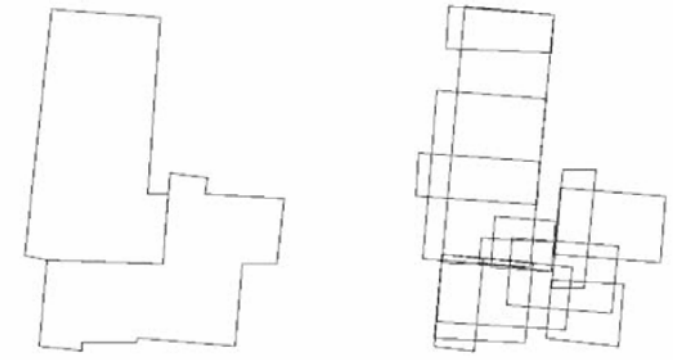
Building = union of primitives

Data sets
- A: disjunct, irregular, few
- B: overlapping, regular, many

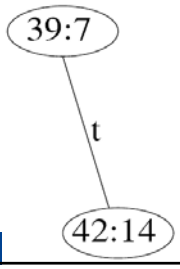
Structural matching
- False positives, false negatives
- Structural errors (cf. below)

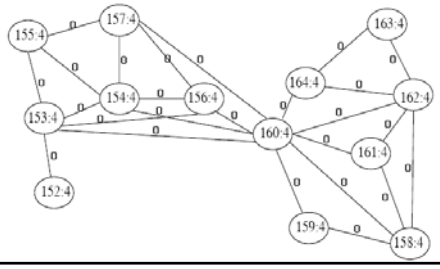


Datasets of different complexity



(Ragia 1999)





Completeness: # or area?

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1. Acquisition (Vector)

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1. Acquistion (Raster, S)

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2. Acquisition (Raster, ^S)

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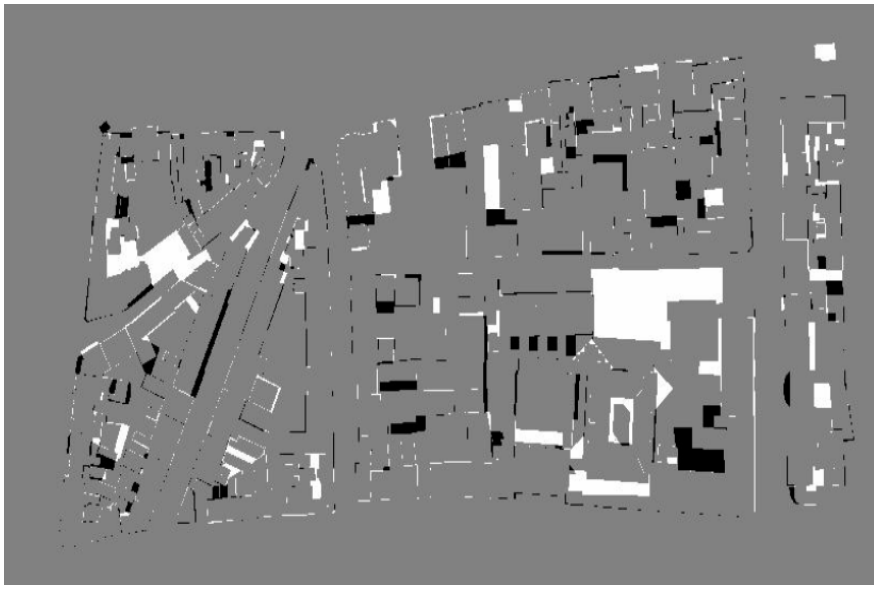
Differences $\hat{\mathcal{S}} \setminus \mathcal{S}$ and $\mathcal{S} \setminus \hat{\mathcal{S}}$



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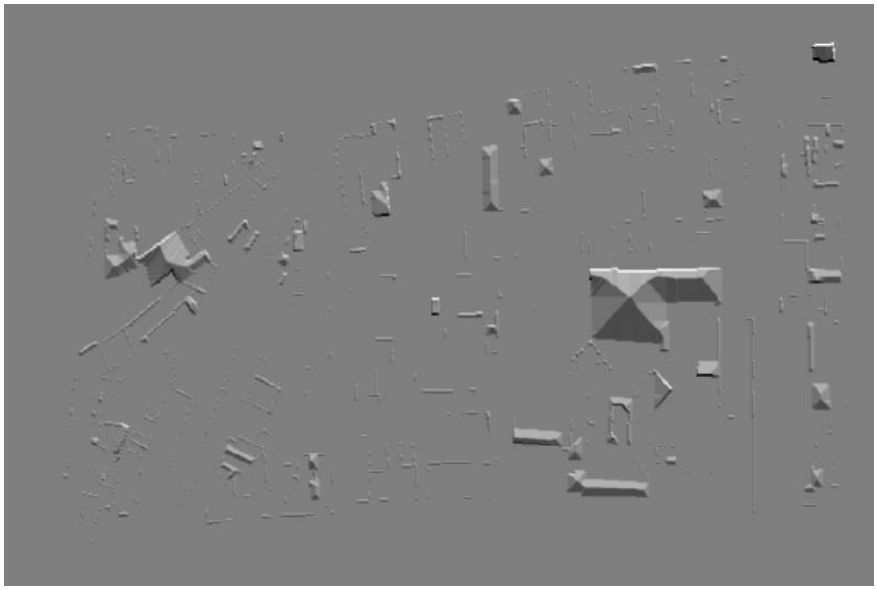
Distance transform of $\hat{\mathcal{S}} \setminus \mathcal{S}$



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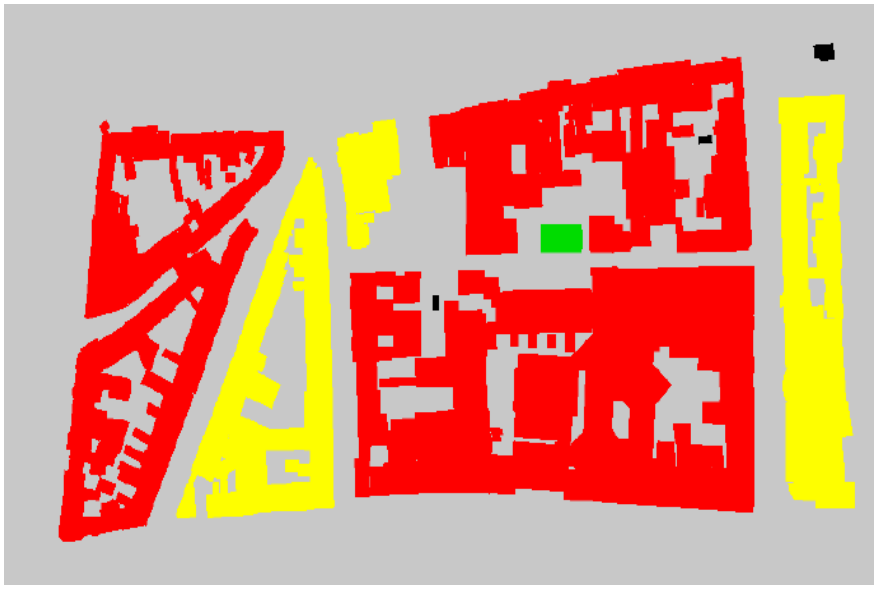
Evaluation by LVermA (2.8 m)



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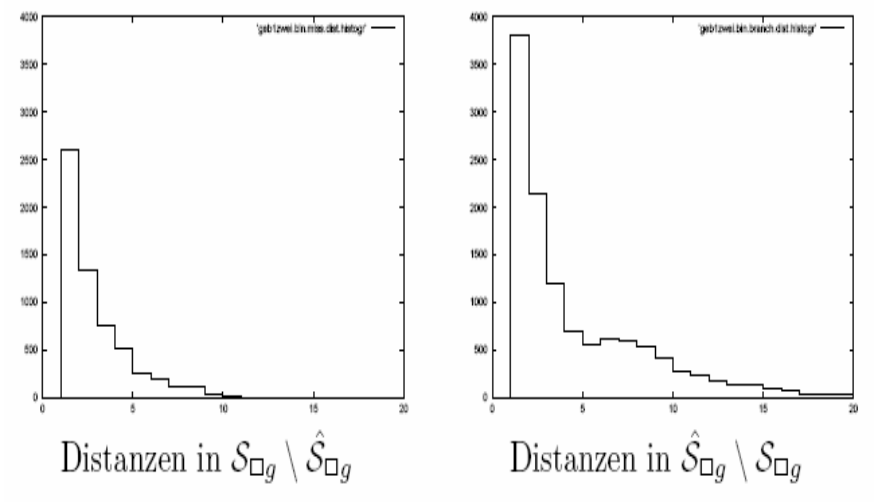
Distance histograms



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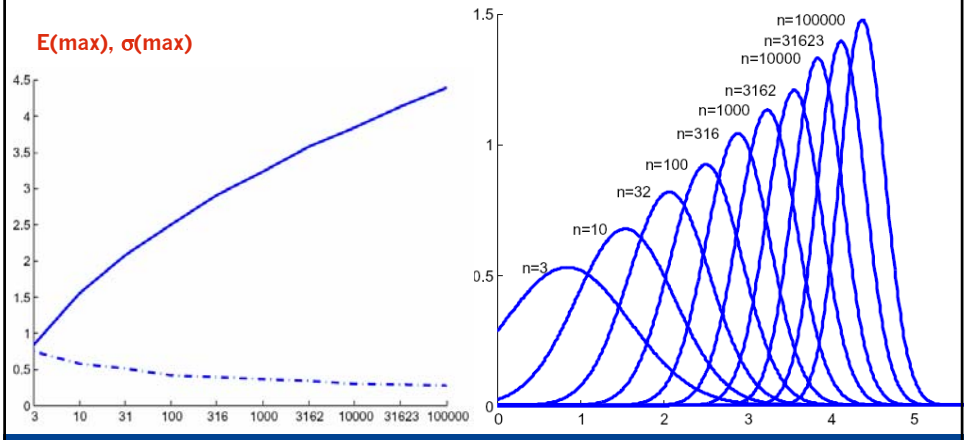
Distribution of maxima

- Maximum = f(sample size)
  → Needs to be specified



Accuracy?

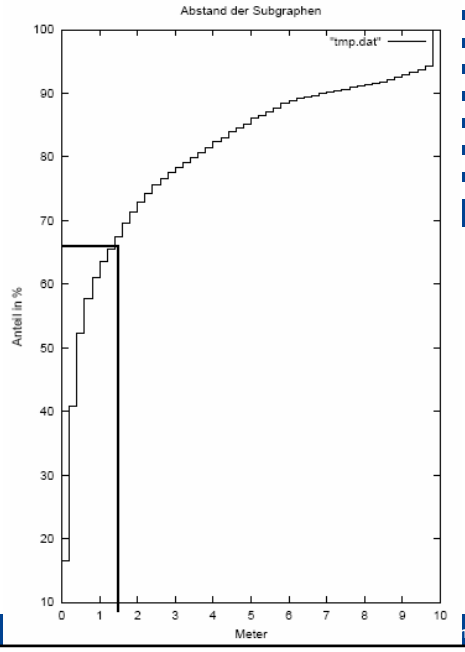
- Standard deviation σ
- 2 σ -tolerance
- 3 σ -tolerance
- One-sided (2 σ , 3 σ)
- Two-sided (4 σ , 6 σ)

Range of factor 6!

→ Needs to be specified

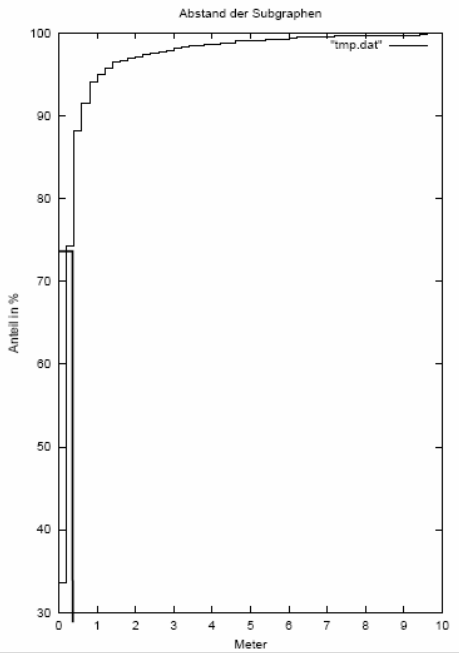
Metric quality

- Cumulative histogram of distances
  - Large σ (1.5 m)
  - very large deviations



... better metric quality

- Cumulative histogram of distances
  - Small σ (0.35 m)
  - Few outliers



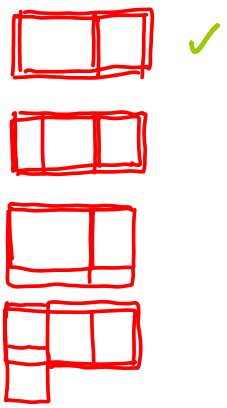
Challenges I

- Reference data set
  - Representativity (Size, Structure,Numer of sites)
  - Quality (completeness, geometrical and structural accuracy)
- Quality measures
  - Vast number of measures (more than a dozen)
  - Interpretability for normal user
  - Structural validation →
  - Internal vs. External validation

Structural validation

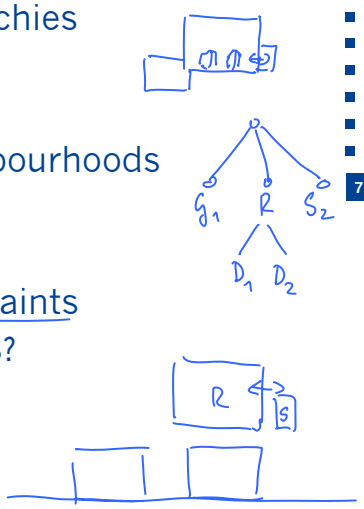
Cases

1. + boundary, + structure ✓
2. + boundary, - structure
3. - boundary, + structure
4. - boundary, - structure



Challenges II

- Representing uncertain hierarchies
  Bayesian networks for GIS?
- Representing uncertain neighbourhoods
  Markov-Random fields for GIS?
- Representing uncertain constraints
  Conditional probabilities for GIS?



Goal

Develop rich model for GIS objects
  legend

Primitive objects with attributes

Spatial relations between objects

Hierachical relations (partonomies)

Uncertainty →Probabilistic models

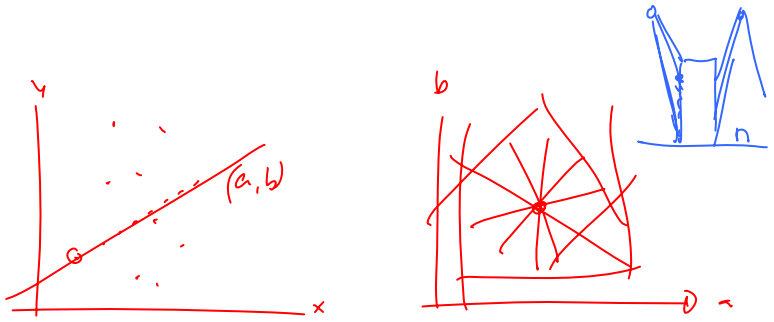
Uncertain notions → fuzzy sets

Summary

- Relevance of 3D-building models increasing
- Automatic methods for gross modeling
- Challenge: Quality evaluation
- Fine modeling requires top-down procedures

→Machine learning techniques:
Training a computer to interprete images

Thank you !



$y = a\,x + b \qquad b = y - a\,x$

$x\ y\ z,\ g,\ r,\ s\ b$