Automatic Orientation of Images

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The Problem

A central task of photogrammetry

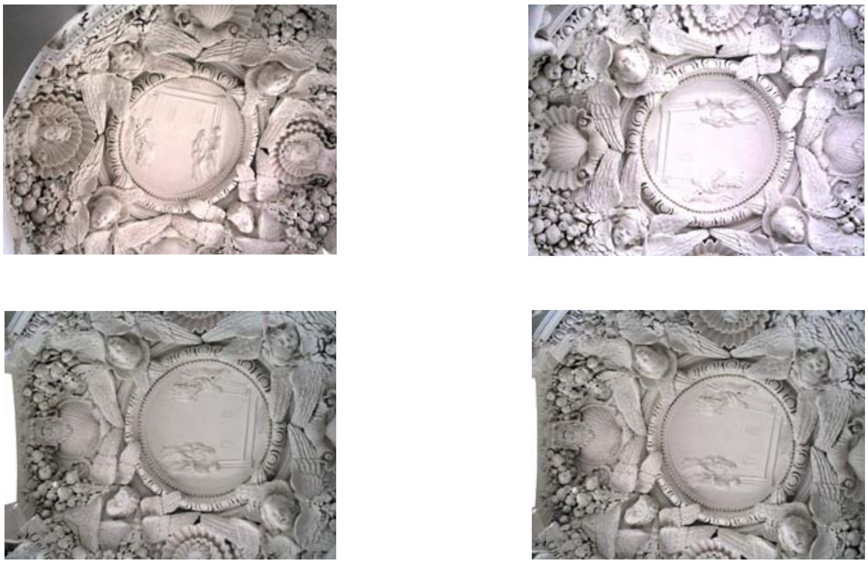
- Input: several images of an object
- Output: computer model of object

Use

- Digital elevation model for topgraphic maps
- Computer model of new carossery model
- Documentation of cultural inheritage
- Computer models for special effects in films

http://homes.esat.kuleuven.be/~cstrecha/demos/3d/

Peter and Paul's Kathedral: Four images ...

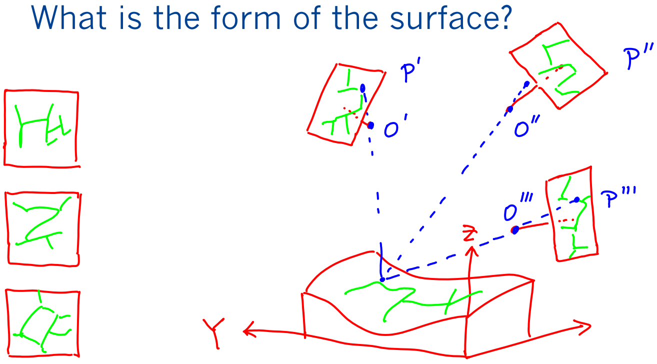


3

Subtasks

1. Orientation
   Where was the camera during exposure of images?

2. Surface Reconstruction
   What is the form of the surface?



4

Automation in image analysis

Why automation?

- It is possible (cf. this talk)
- It is done (cf. automatic aerial triangulation)
- It is useful (cost savings)

What means Automatic image orientation?

Task

- Given: digital images
- Determine: 6 parameters per camera
  (three coordinates for the projection centre,
  Three angles for the rotation matrix)

Conditions

- No manual point mensuration
- No manual interaction
- No final editing

Why is it difficult?

- What is an image for a computer? A dull image.

255	251	244	236	227	222	221	228	232	230	237	243	242	239	225	201	184	183	174	163	164	167	171
249	246	241	231	225	220	215	221	220	225	230	230	234	238	224	198	185	173	178	182	166	156	160
238	238	238	228	221	216	211	217	228	235	235	226	228	233	220	196	178	180	188	197	190	164	146
229	228	228	222	218	220	217	217	223	235	238	230	230	228	215	199	184	174	181	183	168	169	182
224	216	211	210	212	219	220	209	213	224	225	212	208	211	210	203	188	184	189	175	145	145	168
217	210	205	205	198	206	220	204	203	201	191	178	179	189	196	192	189	181	173	176	180	177	168
212	209	205	210	198	206	234	214	194	158	127	122	137	160	184	191	176	163	165	168	159	163	174
213	207	203	217	212	227	255	230	160	108	85	108	132	143	152	157	163	166	163	159	157	157	158
214	216	215	223	221	230	255	254	148	71	69	92	112	120	131	137	154	154	158	154	143	146	153
225	233	232	233	223	220	246	255	156	68	87	87	94	107	129	151	153	153	155	149	138	141	148
237	241	234	235	230	226	250	255	165	89	102	100	99	109	127	153	153	156	157	150	140	139	142
233	234	229	231	232	233	246	249	188	130	100	117	127	132	129	136	156	159	158	150	142	137	137
223	227	233	234	226	228	236	224	211	172	131	144	149	148	151	153	164	163	158	150	142	134	130
216	218	223	226	220	227	236	221	217	184	176	173	164	164	182	184	176	169	162	154	142	135	132
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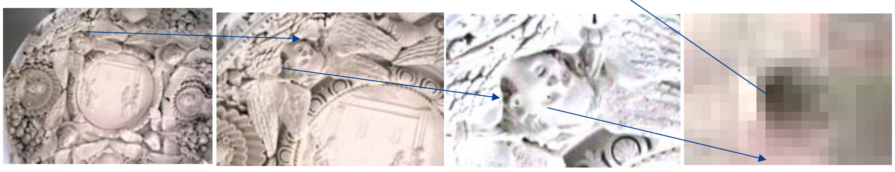
209	202	200	209	216	214	219	225	219	210	210	205	202	204	195	187	167	156	157	154	144	139	143
209	207	212	216	216	213	211	218	219	218	219	219	218	218	209	196	173	158	157	155	150	150	150



7

Why is it difficult?

- How to find points in an image?
- How to find the same point in another image?
- Where do we get approximate values for the orientation parameters from?
  - 6 parameters, no a priori information
  - in contrast to aerial photogrammetry

8

Point identification ...

Good
Point?

Where is it in the other three images?

... and point transfer

... after identifying 90° and 180° rotation.

The classical procedure

- Identify distinct points in one image
  Operator: good points to measure, experience
- Measure the image coordinates
  Operator:
    measuring mark in high precision instruments (analog images)
    computer mouse (digital or digitized images)
- Transfer these points into the other images
  Operator: using stereo vision capabilities or visual memory
- Provide approximate values for the orientation
  Standard geometry, GPS, ‚Camera man‘, or ...
- Linearize the collinearity equation
  Computer
- Perform an adjustment
  Computer
- Evaluate Result
  Operator: requires experience

Problems for automating orientation

- Arbitrary orientation
  rotation, distance, perspective distortion
- Wrong matches
  Matching procedures are not perfect →
  Large percentage of gross errors (up to 80 %)

Finding points

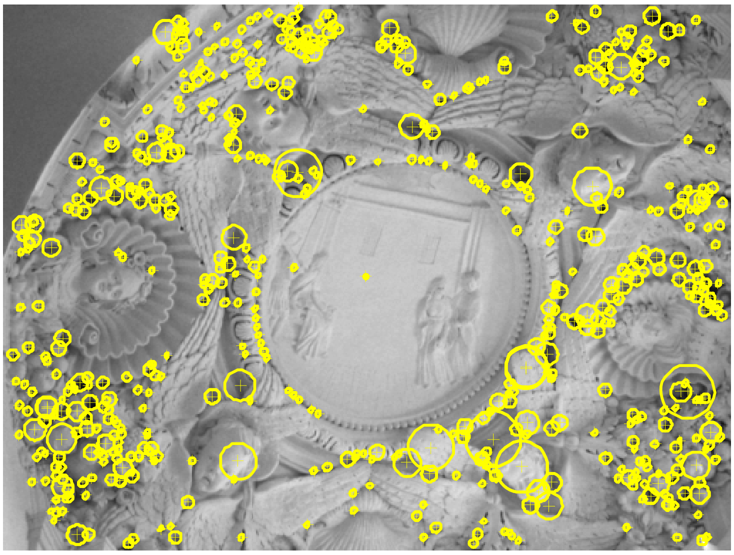
Bright and dark spots

- Position in the image
- Diameter of spots
  (Scale)
- Set of blurred images

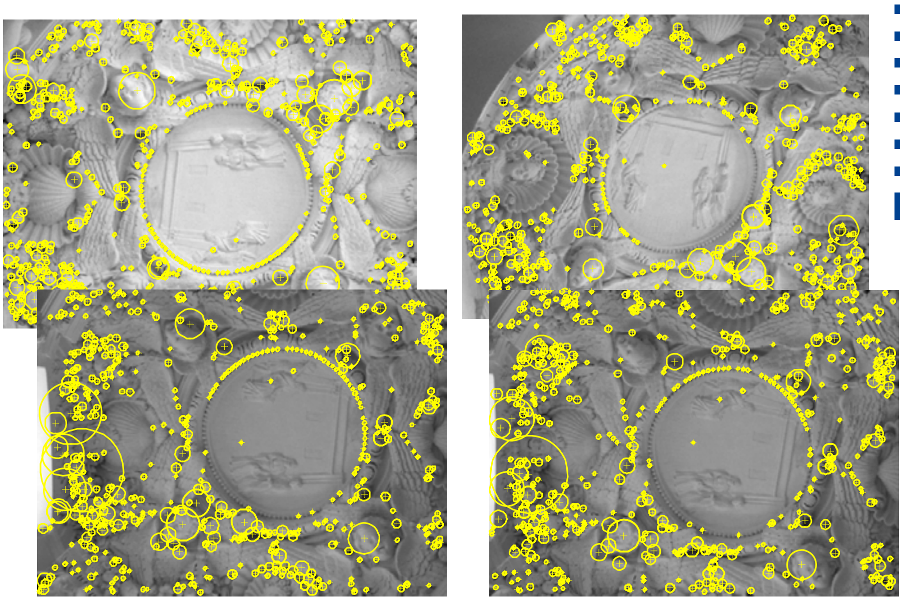
For each image

Detected points with scale

1.



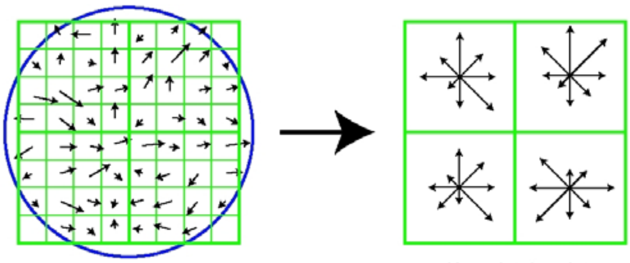
Points in all images



Point transfer: image matching

Compare image content

- For each image pair
- Take rotation and scale differences into account



- 128 characteristic features (Lowe 2004)
- Compare features

→ list of possibly correct matches

Relative orientations

For each image pair:

- Determine relative orientation (5 parameters)
  Rotation (3) + direction of translation (2)
- Take outliers into account (up to 80 %)

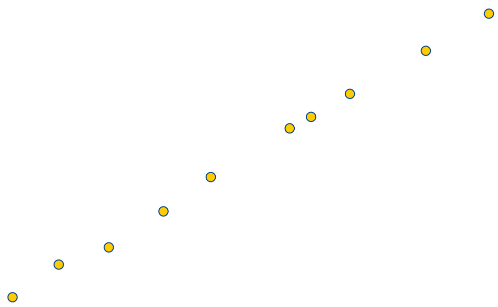
Method: Random sample consensus (RANSAC)

1. Select 5 matches
2. Determine 5 parameters
   direct solution (Nister 2003)
   from coplanarity equation
1. Try to confim by other matches
2. Otherwise goto 1.

Fast, robust ← → may fail

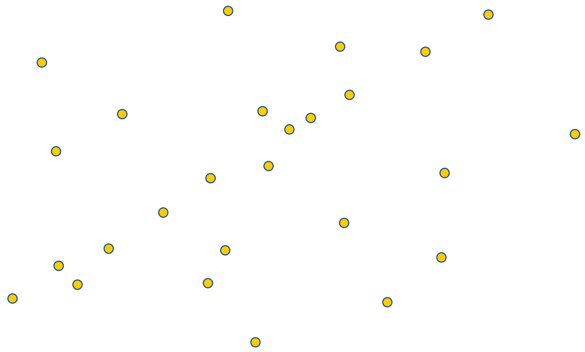
RANSAC: line fitting

Good points



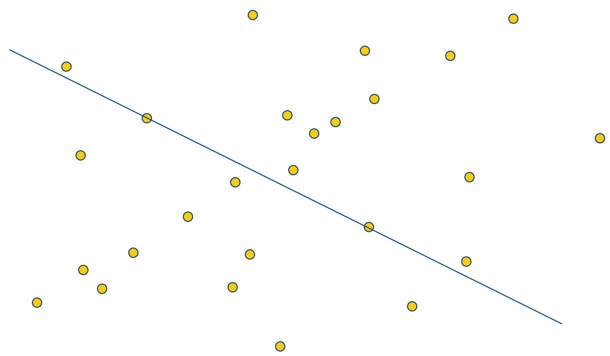
RANSAC: line fitting

All points



RANSAC: line fitting

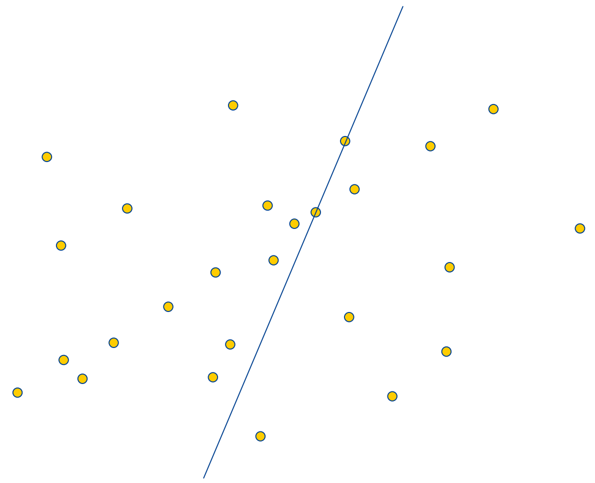
1. trial



RANSAC: line fitting

21

2. trial



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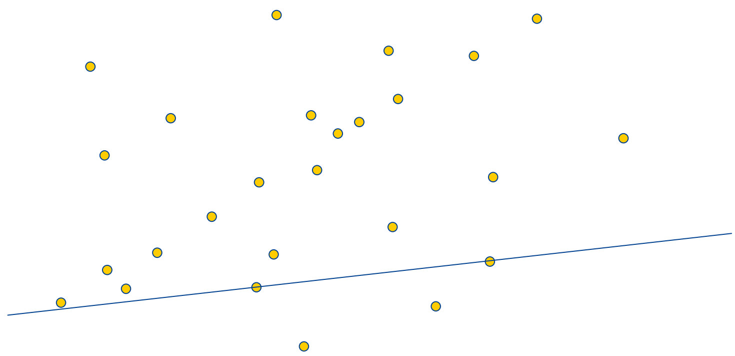
RANSAC: line fitting

22

3. trial



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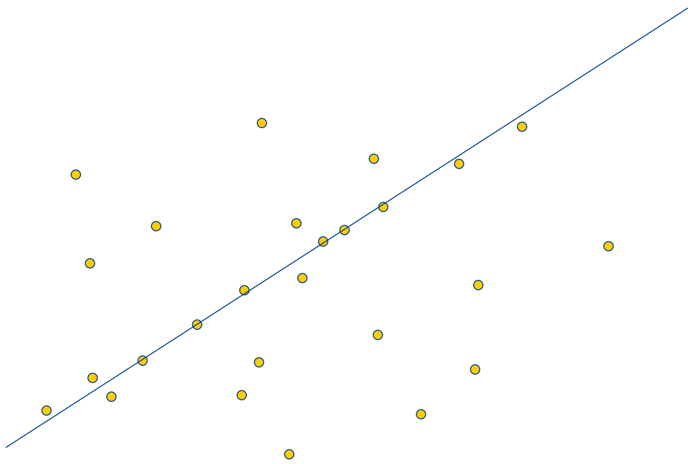
RANSAC: line fitting

4. trial



23

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Number of trials

Probability of success (e. g. 99 %)
Error rate ε (e. g. 50 %)
Number *n* of constraints (here 5)

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 (5 here) useful

→ Reduce error rate

24

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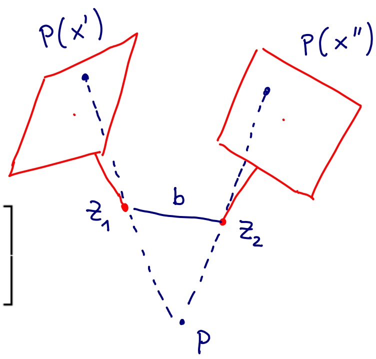
Direct solution for relative orientation

- Coplanarity constraint with basis b= Z_2-Z_1

$$[\mathbf{x}' \;\; \mathbf{b} \;\; R^T\mathbf{x}''] = \mathbf{x}' \cdot \mathbf{b} \times (R^T\mathbf{x}'') = \mathbf{x}'^T S(\mathbf{b})\, R^T \mathbf{x}'' = \mathbf{x}'^T \mathsf{E}\, \mathbf{x}'' = 0$$

with skew matrix S(**b**)



$$S(\mathbf{b}) = \begin{bmatrix} 0 & -b_z & b_y \\ b_z & 0 & -b_x \\ -b_y & b_x & 0 \end{bmatrix}$$

- Observe 5 pairs (**x**',**x**'') → solve for elements of **E**
  Solution by Nister 2003

Direct 5-point solution for relative orienation

- Coplanarity constraint for essential 3 x 3-matrix E

$$\mathbf{x}_m'^T \mathsf{E} \mathbf{x}_m'' = 0 \qquad m = 1, 2, 3, 4, 5$$

- 3-fold underdetermined, as only 5 constraints for 8 unknowns

$$\mathsf{E} = u\mathsf{E}_1 + v\mathsf{E}_2 + w\mathsf{E}_3 + \mathsf{E}_4$$

- E_n from SVD of a linear equation system
- 10 cubic constrantis from properties of E

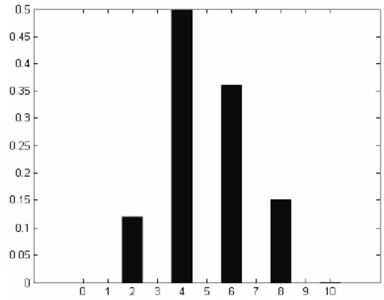
$$|\mathsf{E}| = 0 \qquad \frac{1}{2}\mathrm{tr}(\mathsf{E}\mathsf{E}^T)\mathsf{E} - \mathsf{E}\mathsf{E}^T\mathsf{E} = \mathbf{0}$$

- Reducable to 10 x 10 eigenvalue problem for monoms in *u, v, w* up to 2. degree

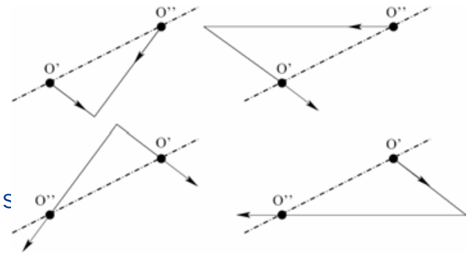
Properties

- Number of soultions: 2-10
  (10 solutions: 2 out of 10^7)

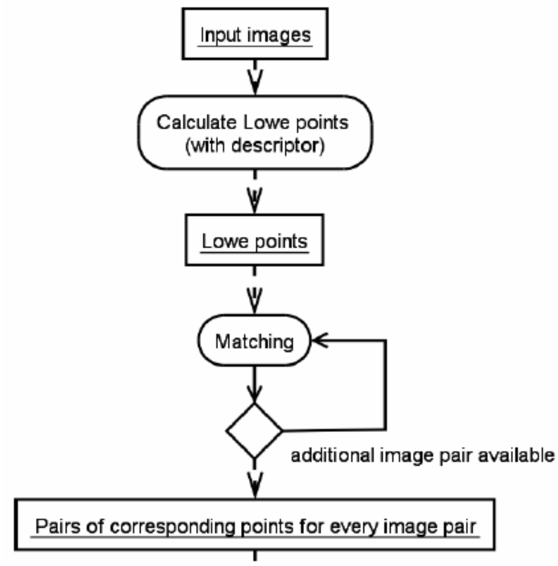
$$
\begin{array}{lcl}
[\ 0.067,\ \ 0.287\ ] & \leftrightarrow & [\ 0.329, 1.297\ ] \\
[\ 0.254,\ \ 0.0646] & \leftrightarrow & [\ 0.523, 1.0807] \\
[\ 0.239, -0.213\ ] & \leftrightarrow & [\ 0.517, 0.645\ ] \\
[-0.710, -0.693\ ] & \leftrightarrow & [-0.141, 0.157\ ] \\
[\ 0.661, -0.307\ ] & \leftrightarrow & [\ 0.950, 0.773\ ]
\end{array}
$$



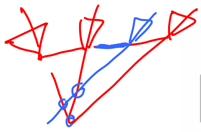
- Integration into RANSAC simple
- Partitioning of **E** = **S**(b) R^T via SVD of **E**
  mathematically: four solutions
  physically: unique

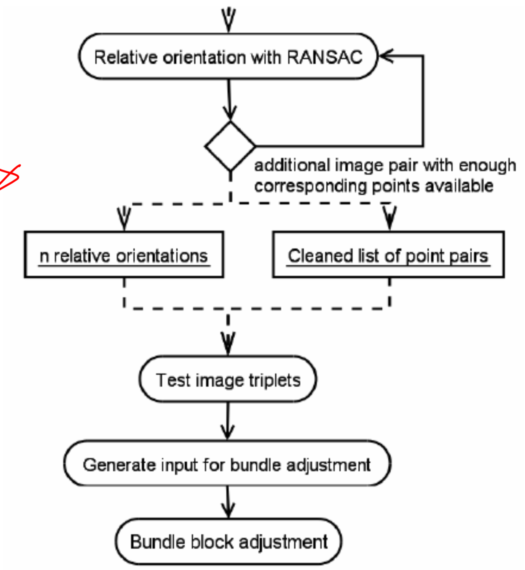


Complete procedure (1/2)



Complete procedure (2/2)





Check on triplets: closure

- Scale transfer

$$\mathbf{b}_{12} + \lambda_{23}\, \mathbf{b}_{23} + \lambda_{31}\, \mathbf{b}_{31} = \mathbf{0}$$

- Constraints

  3 relative orientations: 15 parameters

  relative orientation of triplet: 11 Parameter

  →

  4 constraints

  - Rotations (3 constraints):

$$R_{12} R_{23} R_{31} = I_3$$

  - Translations (1 constraint):

$$|\ \mathbf{b}_{12}\ \ \mathbf{b}_{23}\ \ \mathbf{b}_{31}\ | = 0$$

Check of triplet: intersection (1/2)

Intersection of rays

- 6 observed image coordinates
- 3 unknown coordinates
- → 3 constraints

Exploit geometry of triplet

- 2 coplanarity constraints

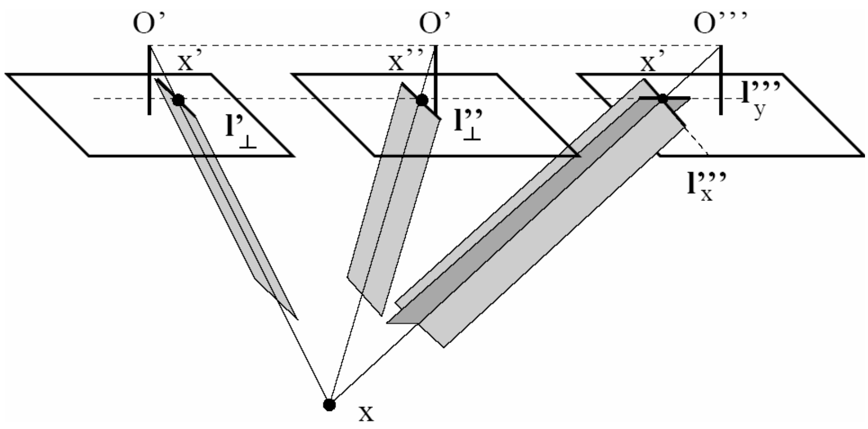
$$\mathbf{x}' \; E_{12} \, \mathbf{x}'' = 0 \qquad \mathbf{x}'' \; E_{12} \, \mathbf{x}''' = 0$$

(third is linear dependent in case of collinear projection centres)

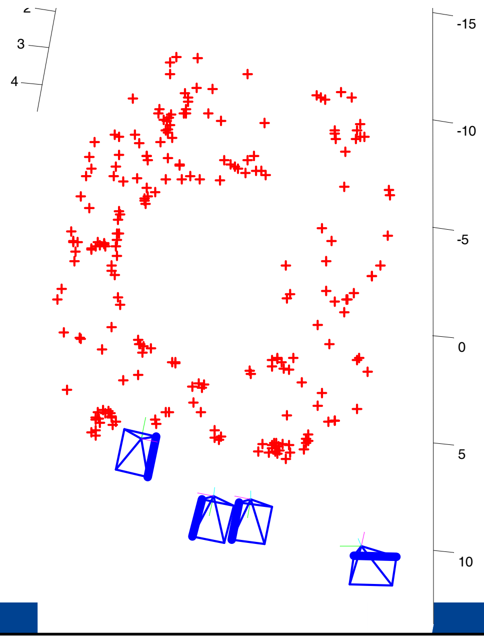
Check of triplet: intersection (2/2)

- 1 trifocal condition (necessary)

$$|A_{lo'} \; A_{lo''} \; A_{lo''} \; A_{lp'} \; | = | \mathbf{l}_0' \quad P_2^T \, \mathbf{l}_0'' \quad P_3^T \, \mathbf{l}_0''' \quad P_3^T \, \mathbf{l}_p''' \; | = 0$$



Peter and Paul's Kathedral



33

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… rotation invariant

34

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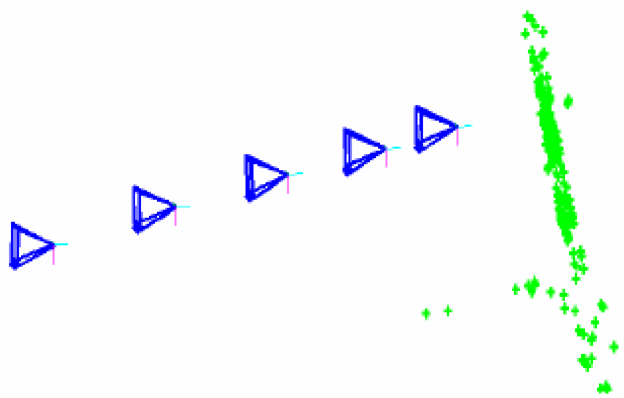
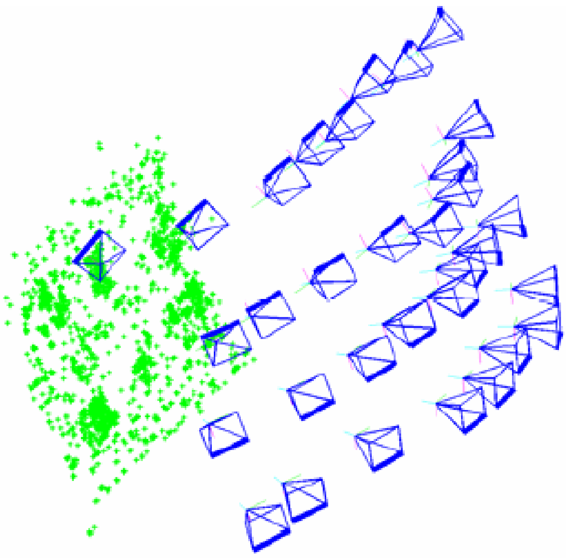
… scale invariant



… many images



Results: Rostock, a real case

37

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Rostock: oblique images

38

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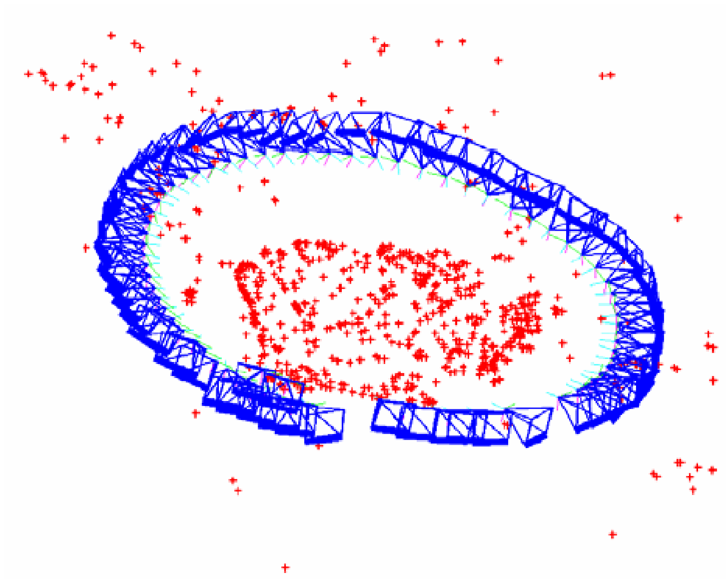
Rostock: a round flight



39

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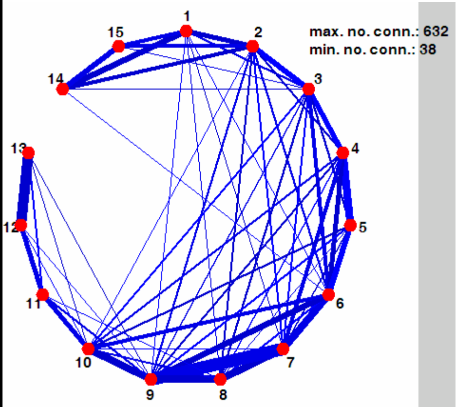
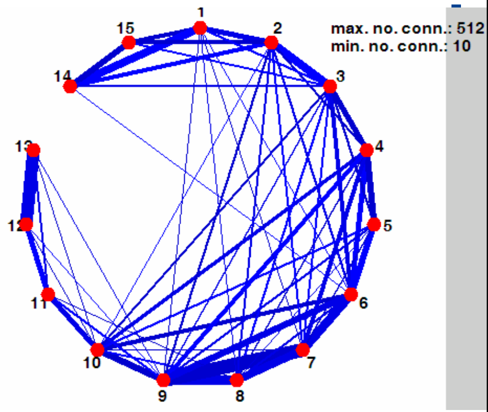
Entrance of Union Club Hotel

Connection graph

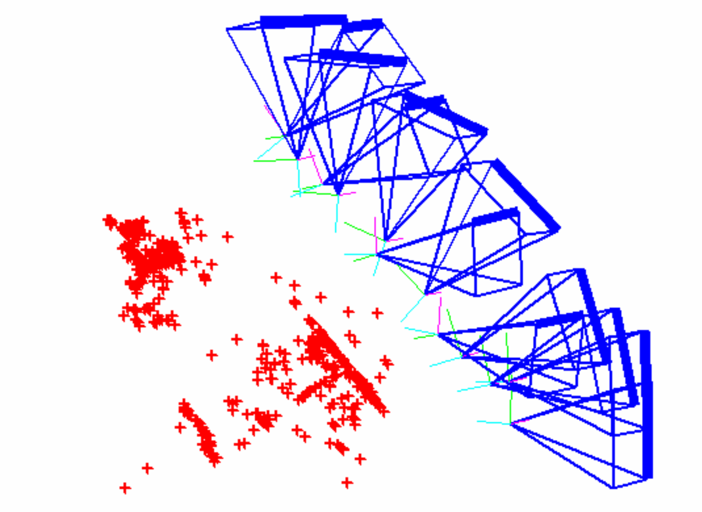
initial

after cleaning for outliers





Cameras and 3D-points



Closing

Result

- Access of computer to images allows full automation
- Automation of image orientation is possible

Extensions

- Increase efficiency
- Report weak configurations
- Uncalibrated cameras
- Images with weak texture (use lines)
- Autonomous calibration without targets

Thank you !