Computer Vision and Remote Sensing

Lessons Learned

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Outline

• Photogrammetry and its relatives
  – Remote Sensing: the family
  – Computer Vision: the cousin

• What did I learn?

• What did we learn from each other?
  – Feature based matching
  – Bundle adjustment
  – Bag of words model for object recognition

• What can we learn?
  – In research
  – In applications
Photogrammetry
• Since 19th century
  after invention of photography
• For mapping
• For close range applications
• Focus on exploitation of geometry

Remote Sensing
• Since 1970
  after launch of first satellites
• For geosciences
• For exploration
• Focus on exploitation of physics
Definition of Photogrammetry

Narrow sense:

*Science to derive metric information from images*

Wide sense:

*Science to derive information from images*

Difference to Computer Vision →
No difference to Remote Sensing →
Difference to **Computer Vision**
(e. g. subdomain „Physics based vision“)

*application* - vs. *method*-driven

**same methods:**
- Physics
- Image Processing
- Pattern Recognition
- Machine Learning
- Artificial Intelligence …
No difference to **Remote Sensing**

Geo is one application

High resolution satellites make geometry essential (in RS)

Geometric problems solved (in Ph)

- convergence
- overlap
- indistinguishable
Remote Sensing contains Photogrammetry
Our cousins

Computer Vision (CV) including Pattern Recognition (PR) and Machine Learning (ML) grow faster than Photogrammetry and Remote Sensing.
Situation

PR/ML most important partner for Computer Vision
What did I learn? (1/3)

• 1983 first contact:
  Franz Leberl's ISPRS WG 'Pattern Recognition in Photogrammetry'
  - 'Knowledge based aerial photo interpretation'
  - 'Saliency of Points'
  - 'Surfaces from mono (!) and stereo images'
  →
  - Seeing a wide new and field
  - Hearing a new language
  - New classes of problems

Everything vague

highly interesting

stimulating my curiosity
"Two roads diverged in a wood, and I—
I took the one less traveled by, and that has made all the difference."

Robert Frost
What did I learn? (2/3)

• 1984-1989
  – 3 months stay at Purdue
  – Workshops on Computer Vision
  – Visit of Stanford Research Labs
  
  →
  – Need for learning new tools
    information theory, heuristic search, graph matching
  – Openness of community
    personally, software exchange
  – Need for overcoming the language barrier (technical)
    What is structure from motion?
  – Accepting that CV people do Digital Photogrammetry
    Snakes, automatic stereo, interactive 3D building extraction
• Since 1990
  – Lecturing
  – Research in building extraction
  – Cooperation with CV and PR

→
  – How to teach Photogrammetry? Need for a common language

\[
k_x' = \frac{r_{11}(X - X_O) + r_{12}(Y - Y_O) + r_{13}(Z - Z_O)}{r_{31}(X - X_O) + r_{32}(Y - Y_O) + r_{33}(Z - Z_O)}
\]

\[
k_y' = \frac{r_{21}(X - X_O) + r_{22}(Y - Y_O) + r_{23}(Z - Z_O)}{r_{31}(X - X_O) + r_{32}(Y - Y_O) + r_{33}(Z - Z_O)}
\]

\[
x' = PX
\]

\[
P = KR[I_3 - X_O]
\]

– Questions: How to represent and use semantics and context? →
– Need for submitting papers at CV and PR conferences
  Double blind review process, acceptance rates of < 30 %
Examples of fruitful interaction

- Feature based matching
- Bundle adjustment
Basic idea from CV:

1981 Barnard/Thomson

Trans. on Pattern Analysis and Machine Intelligence

1. Detect distinct points
   *Moravec operator: maximal minimal gradient*

2. Find putative correspondences
   *Measure graylevel differences*

3. Find unique correspondencies
   *Relaxation procedure*

*Three different theories*
Modification from Geodesy:
1984 Paderes et al.
NASA Symp. on Math. Pattern Rec. and Image Analysis

1. Detect distinct points
   *Maximal local expected precision*

2. Find putatative correspondences
   *Estimated precision*

3. Find unique correspondencies
   *Robust ML-estimate*

*one theory*
Example result
Consequences in Photogrammetry

- Basis for many matching algorithms
  - Surface reconstruction
  - Automatic aerial triangulation
- Getting stimulated by CV research
  - Exploitation of scale space methods
    - Pyramids
    - Scale and rotation invariant features
  - Robust methods
  - Generalization to object recognition
    - Search in large data bases (CV)
    - Facade interpretation (Pho)
Orientation of images of weakly textured scenes

... use adequate features
Poorly textured room
• Lowe (2004): Distinctive image features from scale-invariant keypoints

• Förstner/Dickscheidt/Schindler (2009): Detecting Interpretable and Accurate Scale-Invariant Keypoints
Search objects in large data base

… use configurations of features
Particular object search

Find these landmarks ... in these images
Interprete facades

... use configurations of adequate features
Task: Given: rectified image of a facade
Derive: window structure
• Provide sample
• Learn corners (appearance and position)
1. Corners

2. Boxes

3. Aggregate
3. Aggregate
Bundle adjustment
Bundle adjustment

Basic idea from Photogrammetry
(Schmid 1957)

- Model perspective projection with distortions
- Take image measurements as noisy projections
- Optimally estimate all parameters
Consequences in CV

- The reference for all reconstruction tasks
- The workhorse for reconstructing large scenes
- Provide free code
Bill Triggs,
Philip McLauchlan,
Richard Hartley and
Andrew Fitzgibbon

This paper is a *survey* of the theory and methods of bundle adjustment *aimed at the computer vision community*, …

Most of the results *appeared long ago in the photogrammetry* and geodesy literatures, but many seem to be little known in vision, where they are gradually being *reinvented*.

By providing an accessible modern synthesis, we hope … to speed progress in visual reconstruction by promoting *interaction between the vision and photogrammetry communities*. 
Trigss et al. 2000: Bundle adjustment

- **Gauss, Legendre ~1800**
  - Least squares, BLUE
  - Gaussian distribution
  - Gaussian elimination

- **Meissl 1962-5**
  - Free network adjustment
  - Uncertain frames
  - ‘Inner’ covariance & constraints

- **Baarda 1973**
  - S transforms & criterion matrices

- **Brown 1958-9**
  - Calibrated Bundle Adjustment
  - ~10’s of images

- **Brown 1964-72**
  - ‘Self-calibration’
  - ~5x less error using empirical camera models

- **Gyer & Brown 1965-7**
  - Recursive partitioning
  - ~1000 image aerial block

- **Baarda 1964-75**
  - Inner & outer reliability
  - ‘Data snooping’

- **Förstner, Grün 1980**
  - Photo-grammetric reliability
  - Accuracy = precision + reliability
  - Over-parametrization & model choice

- **Grün & Baltsavias 1985-92**
  - ‘Geometrically constrained multiphoto’ & ‘Globally enforced least-squares’ matching

- **Gauge freedom & uncertainty modelling**

- **Modern robust statistics & model selection**

- **Image-based matching**

- **Modern sparse matrix techniques**

**Timeline:**
- 1800
- 1960
- 1970
- 1980
- 1990
- 2000
References


Free software: bundle adjustment

Wolfgang Förstner

10. September 2009 CV+FE – lessons learned

Mbtuvqebufe Bvh/42-311
Bundler: Structure from Motion for Unordered Image Collections

Software written by Noah Snavely
Latest version: 0.3
Release date: May 4, 2009
Agarval et al.: Building Rome in a day (ICCV 2009)

Goal:
1. Use all images of rome from the internet (> 2 Mio.)
2. Make automatic bundle adjustment in 24 hours

Today: one order of magnitude slower
62 nodes with dual quad core processors

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<th># image pairs</th>
<th>CPU Time (h)</th>
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Video

Dubrovnik

11,839,682 observations
2,662,981 points
57,845 images

Point cloud and cameras (varying focal length!) from bundle adjustment
Next step:

3D surface reconstruction

(➔ PhoWo 2013 ?)
What can we learn?

- **Research**
  - Educate our students
    - Techniques from CV/PR/ML
    - Openness
  - Submit papers
  - Cooperate (CV : Pho = 3 : 1)

- **Application**
  - Send developers to CV/PR conferences
  - Cooperate with universities:
    - Photogrammetrists which intensively cooperate with CV/PR
    - Photogrammetrists and CV/PR groups

... but ...
To travel is to discover that everyone is wrong about other countries

Aldous Huxley