Computer Vision and Remote Sensing

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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:

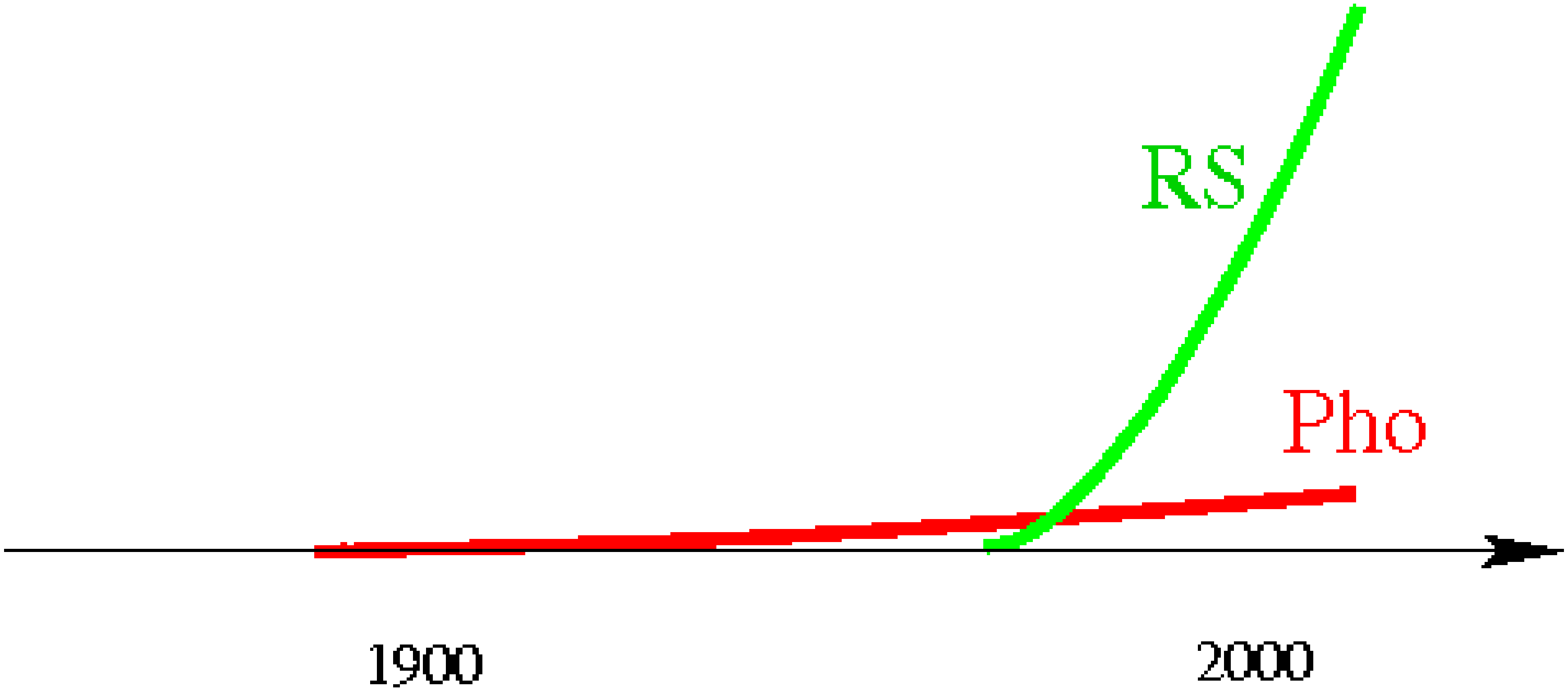
- Physics
- Image Processing
- Pattern Recognition
- Machine Learning
- Artificial Intelligence …

No difference to **Remote Sensing**

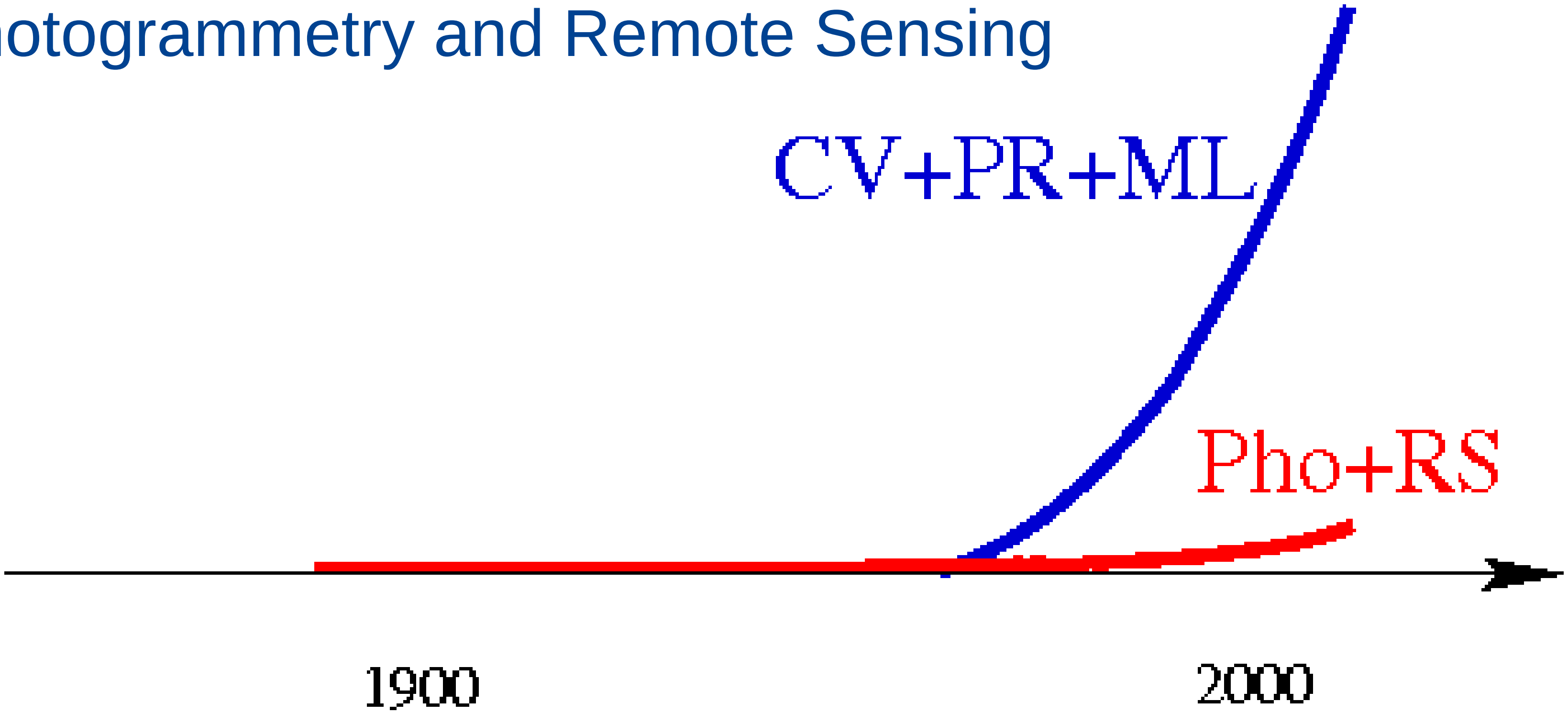
- Geo is one application
- High resolution satellites make geometry essential (in RS)
- Geometric problems solved (in Ph)

→convergence → overlap → indistinguishable

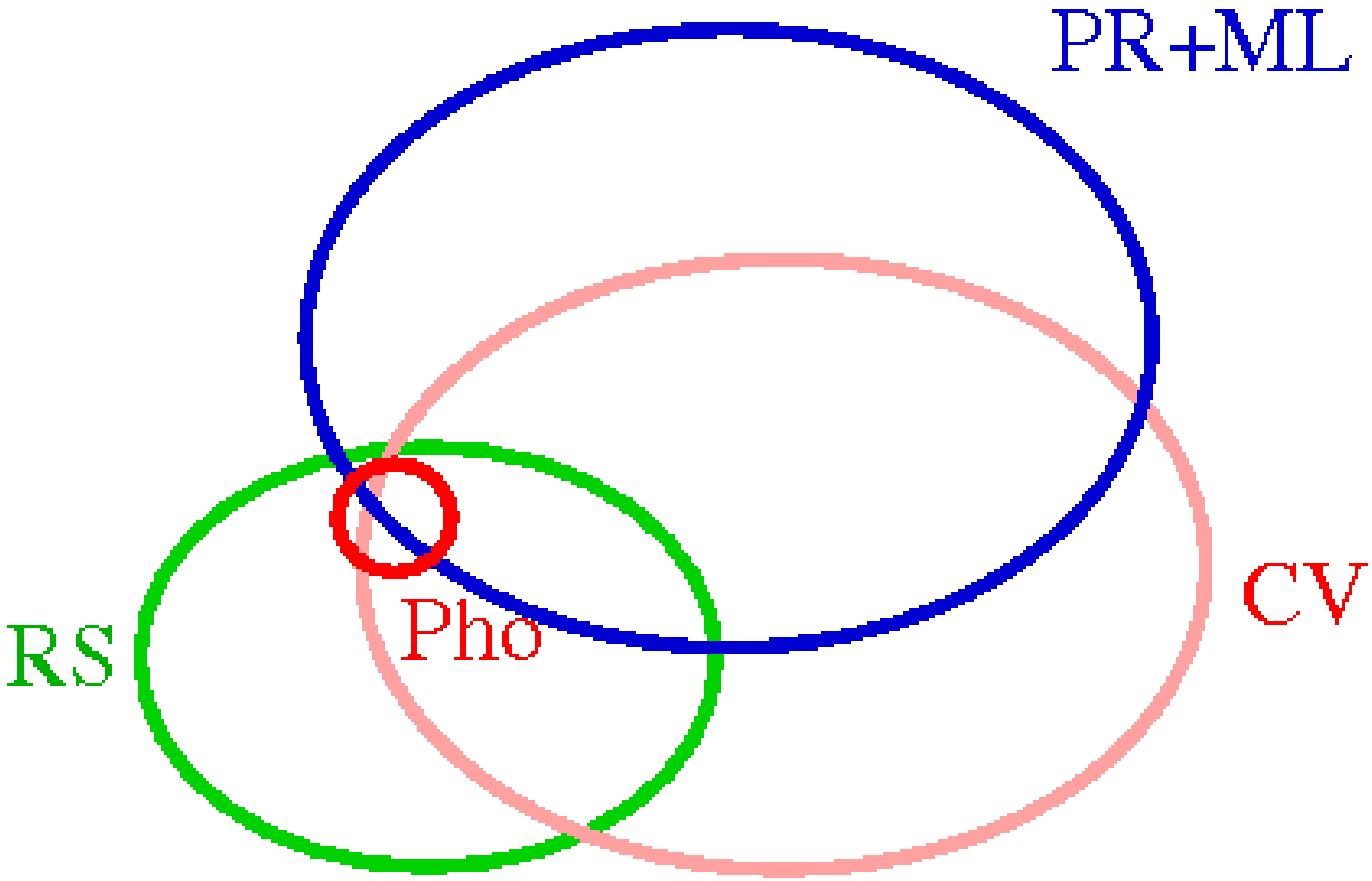
Remote Sensing contains Photogrammetry



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



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

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J!uppl uif pof mftt usbwfmfe cz-!boe!uibu ibt!n bef bmm!uif ejggfsfodf/

Spcfsu!Gsptu

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
  – Opennes 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

What did I learn? (3/3)

- Since 1990
  - Lecturing
  - Research in building extraction
  - Cooperation with CV and PR

  →

  - How to teach Photogrammetry? Need for a common language

$$ {}^k x' = c \frac{r_{11}(X - X_O) + r_{12}(Y - Y_O) + r_{13}(Z - Z_O)}{r_{31}(X - X_O) + r_{32}(Y - Y_O) + r_{33}(Z - Z_O)} $$

$$ {}^k y' = c \frac{r_{21}(X - X_O) + r_{22}(Y - Y_O) + r_{23}(Z - Z_O)}{r_{31}(X - X_O) + r_{32}(Y - Y_O) + r_{33}(Z - Z_O)} $$

$$ \mathbf{x}' = \mathsf{P}\mathbf{X} $$

$$ \mathsf{P} = \mathsf{K}R[I_3 | -\boldsymbol{X}_O] $$

  - 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 putatative 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

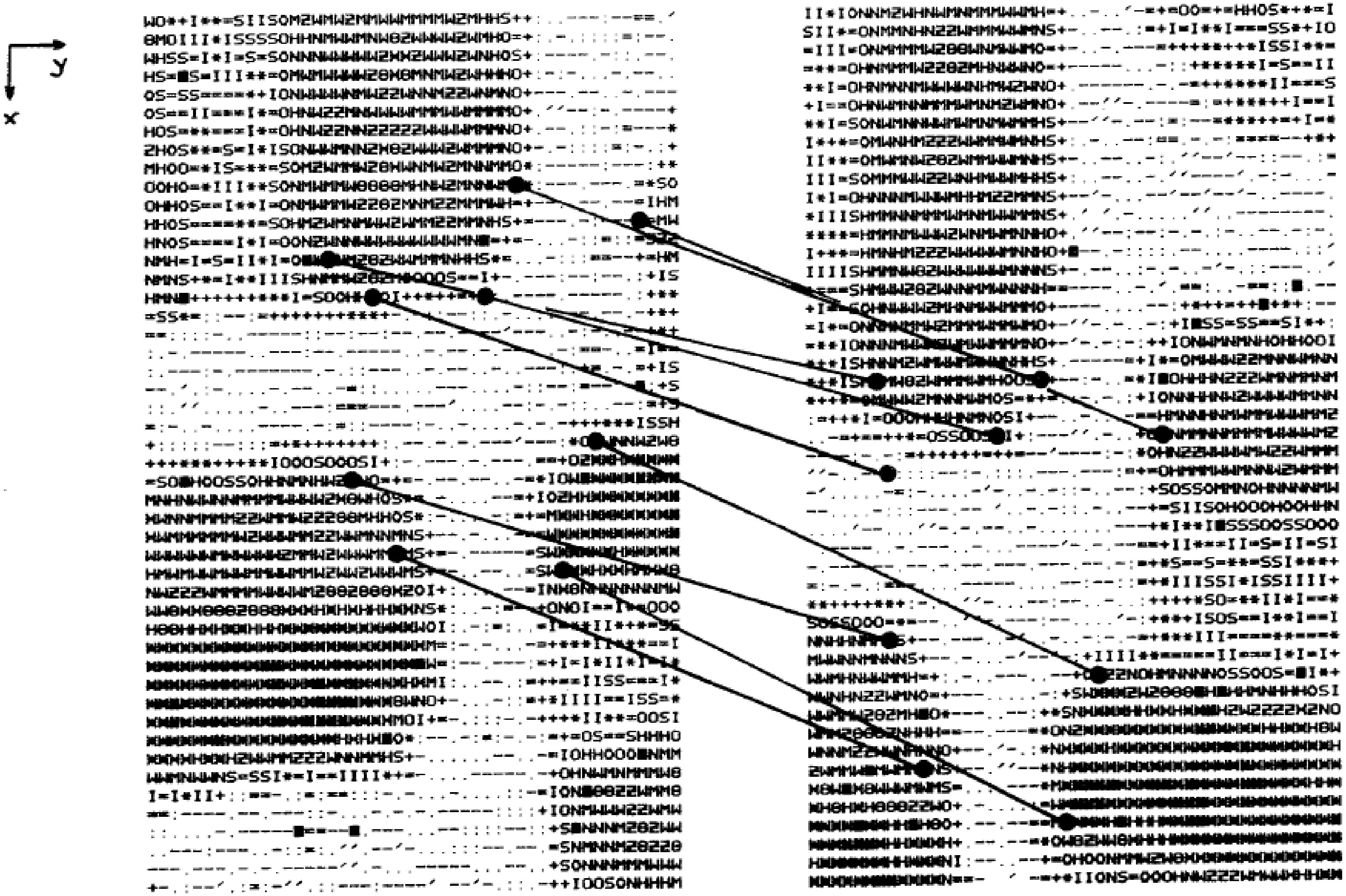
   Estimated precision

3. Find unique correspondencies

   Robust ML-estimate

one theory

Example result



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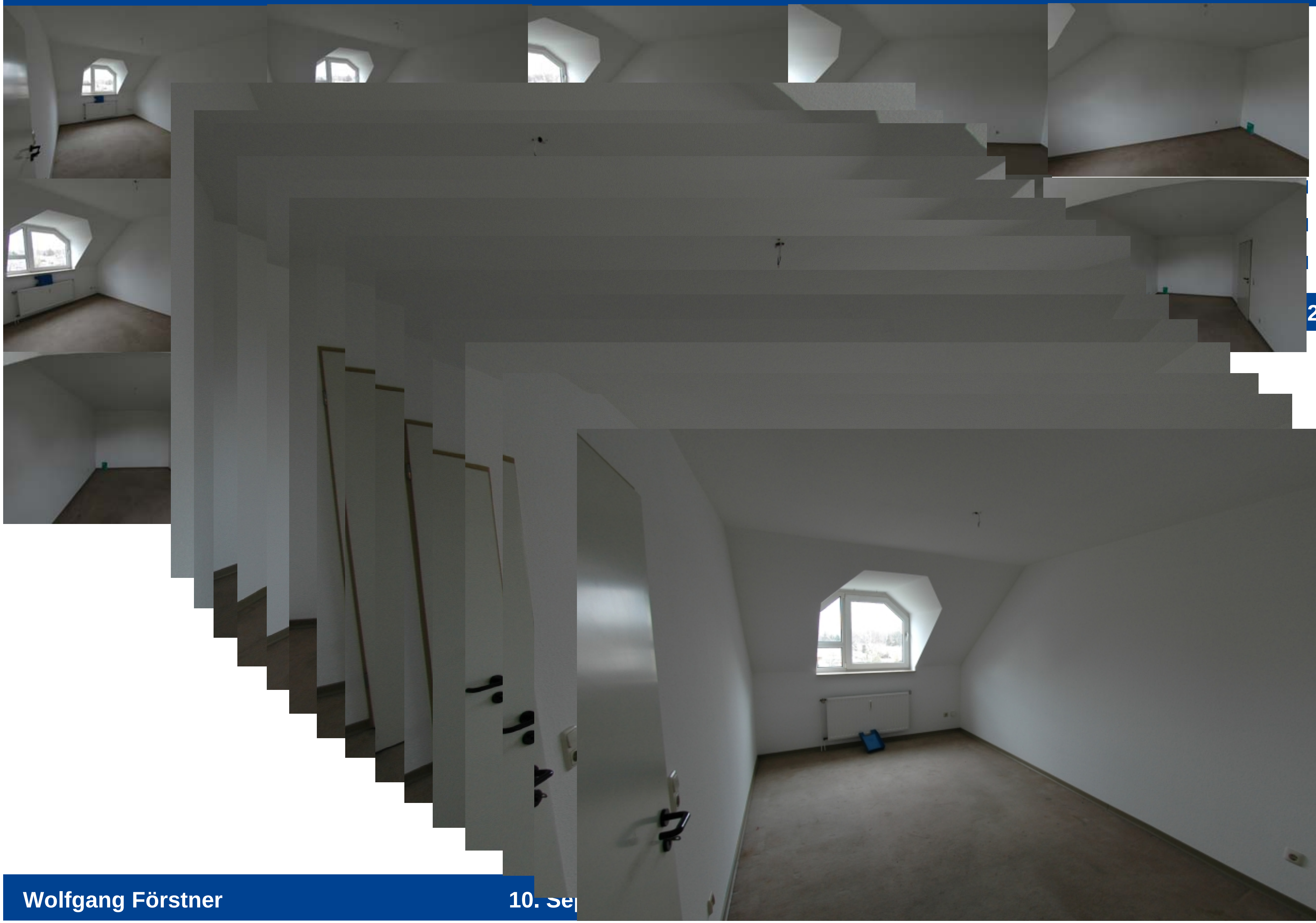
Consequences in Photogrammtry

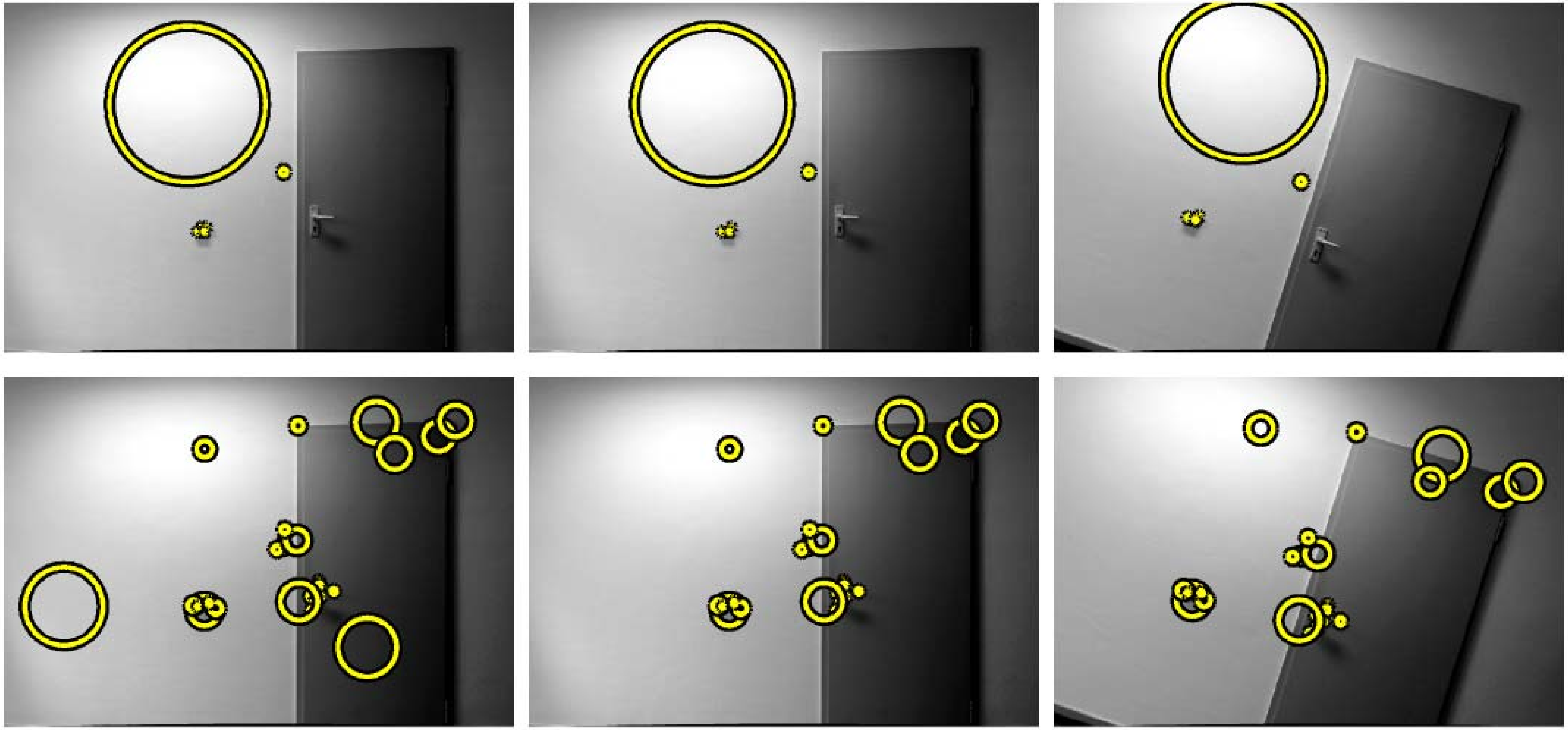
- Basis for many matching algorithms
  - Surface reconstruction
  - Automatic aerial triangulation
- Getting stimulated by CV research
  - Exploitation of scale space methods
    - Pyramids
    - Scale and rotation invariant features →
  - Robust methods
  - Generalization to object recognition
    -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

Orientation of images of weakly textured scenes

… use adequate features

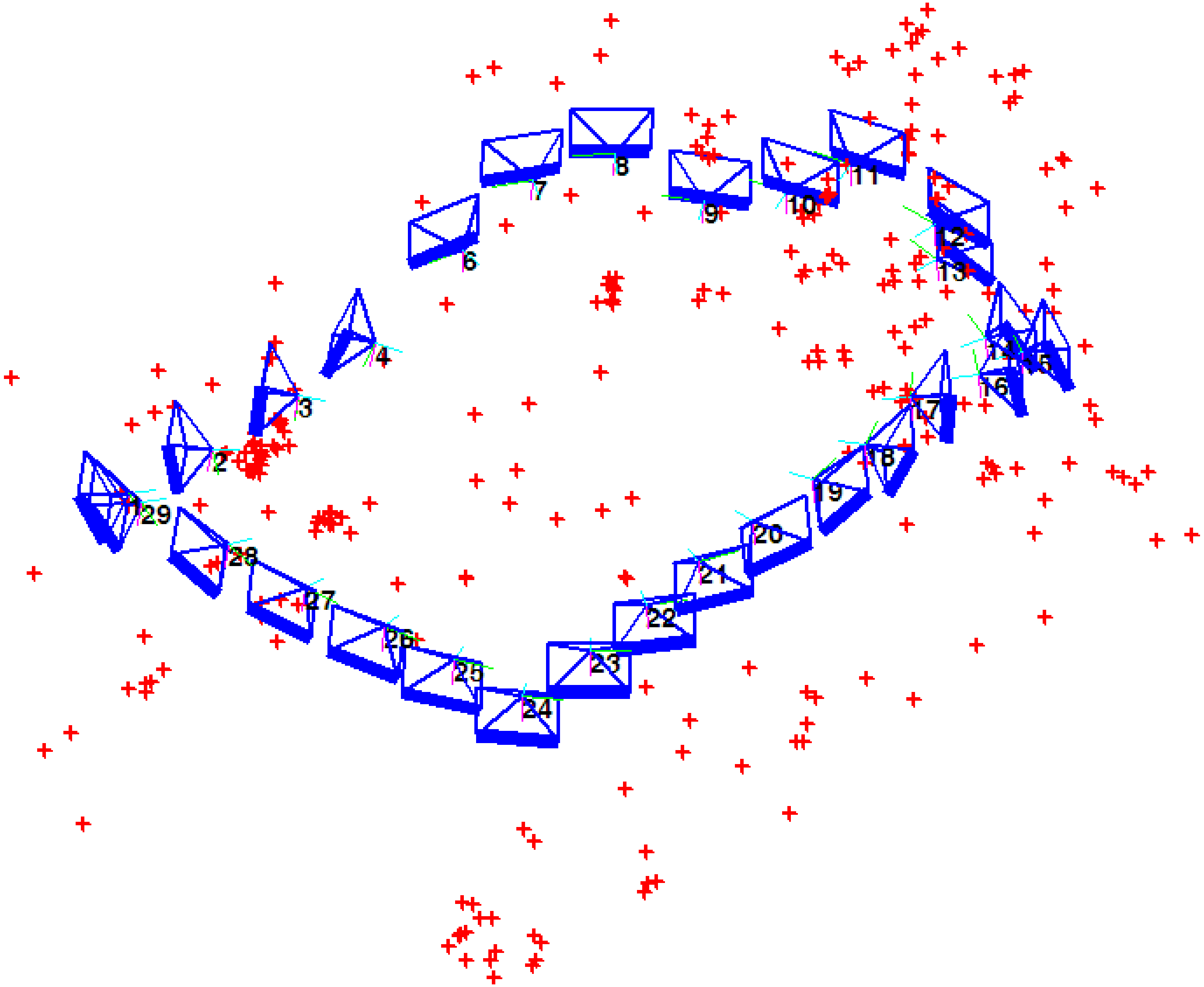


- Lowe (2004): Distinctive image features from scale-invariant keypoints



- Förstner/Dickscheidt/Schindler (2009): Detecting Interpretable and Accurate Scale-Invariant Keypoints

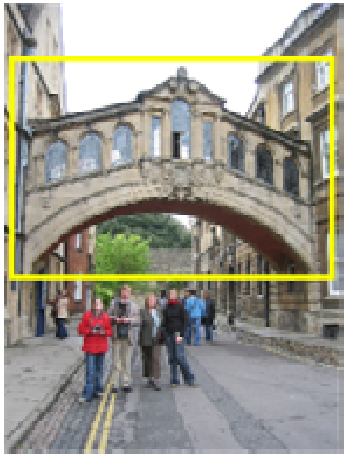
Result of automatic orientation

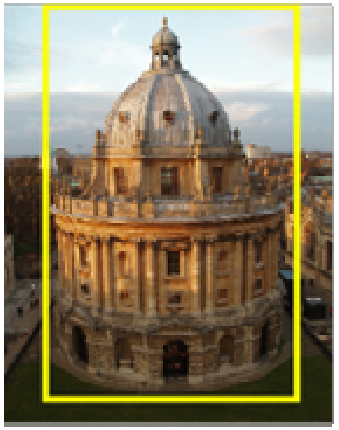


Search objects in large data base

… use configurations of features

Particular object search





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Find these landmarks ...in these images

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Query

Example Results

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Interprete facades

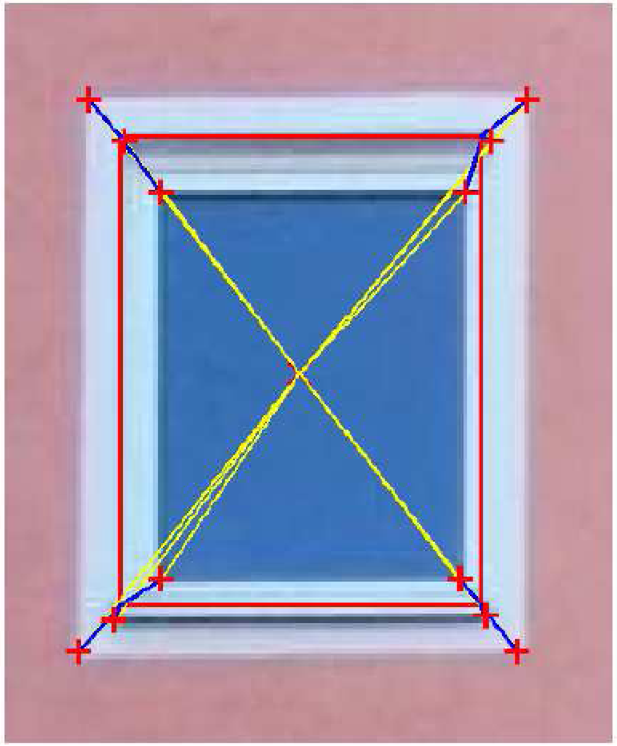
… use configurations of adequate features

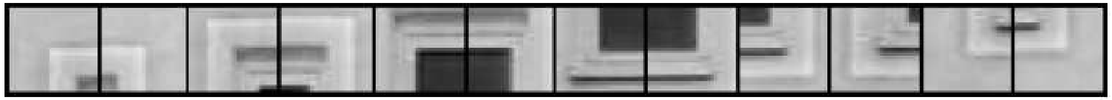
Task: Given: rectified image of a facade

Derive: window structure

Training

- Provide sample
- Learn corners (appearance and position)





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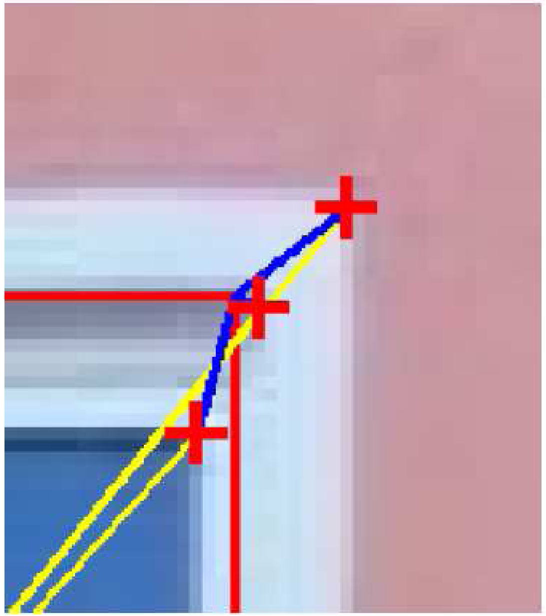
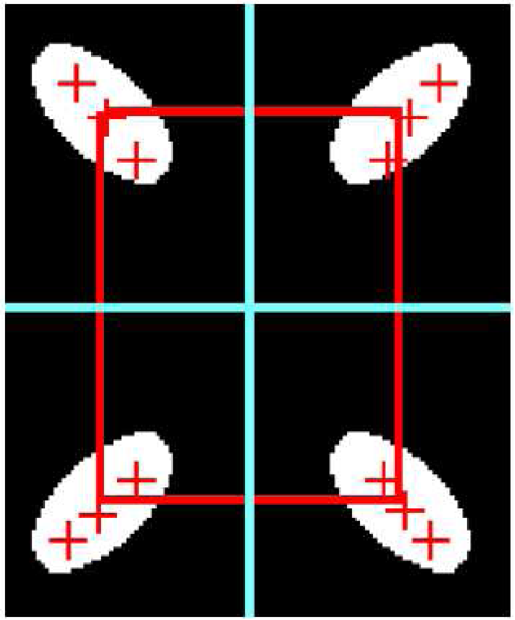
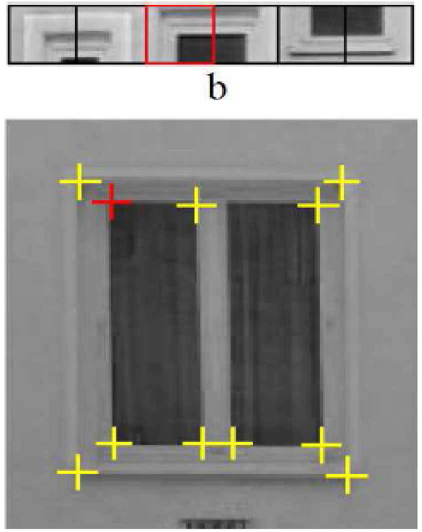
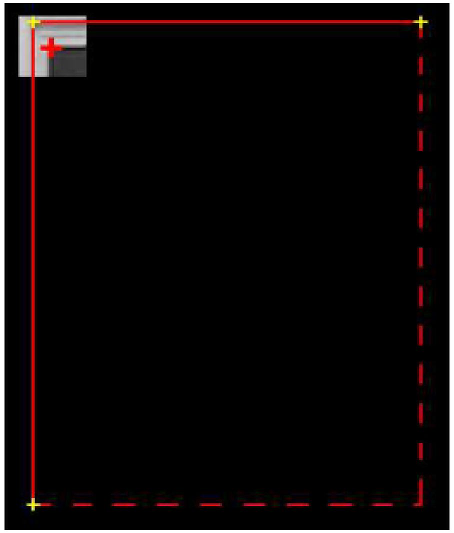
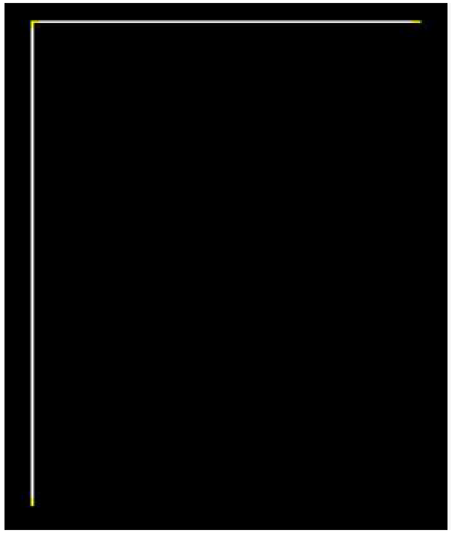




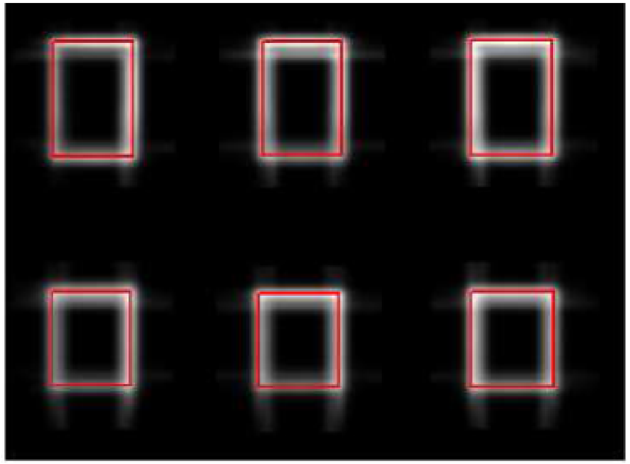
1. Corners

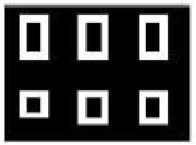






2. Boxes





3. Aggregate

3. Aggregate

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

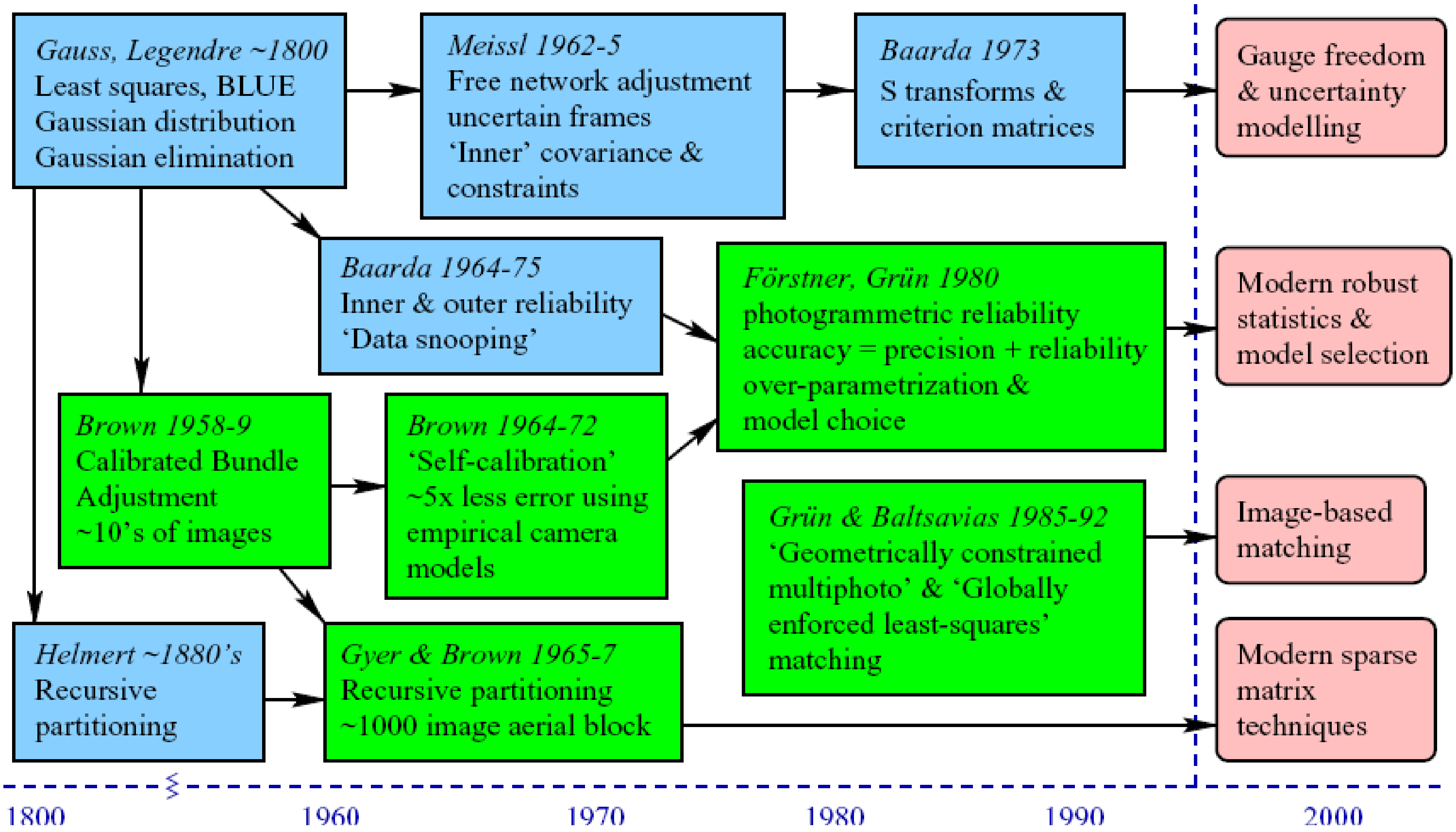
Bill Triggs,
Philip McLauchlan,
Richard Hartley and
Andrew Fitzgibbon

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



Trigss et al. 2000: Bundle adjustment, p. 66:

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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

Site	# images	# image pairs	CPU Time (h)
Dubrovnik	57,845	498,982	22.5
Rome	150,000	2,712,301	21.0
Venice	250,000	6,119,207	65.0

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
    - Opennes
  - Submit papers
  - Cooperate (CV : Pho = 3 : 1)

- Application
  - Send developpers 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