Image Registration and 3D Reconstruction in Computer Vision

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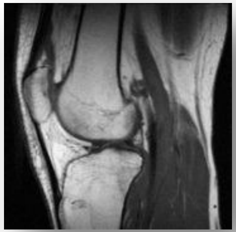
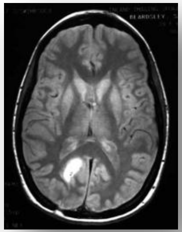
Clermont Université, France



















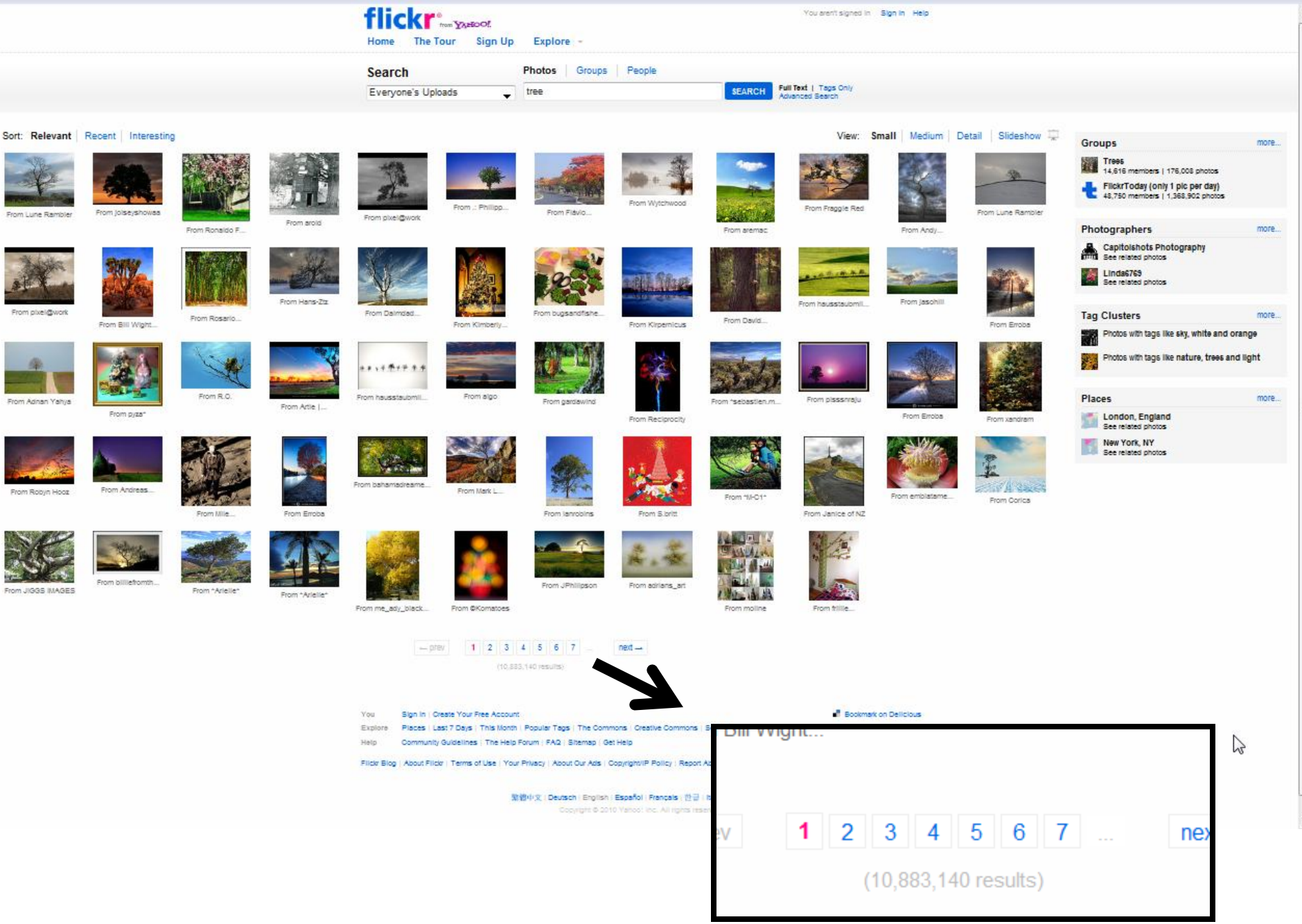








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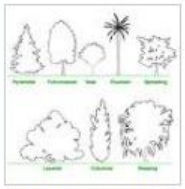
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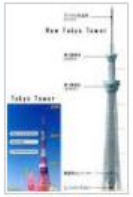
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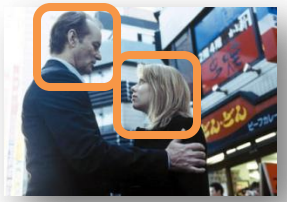
Image Understanding

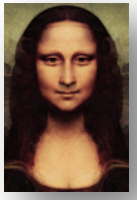


Object detection

Photogrammetry

Object recognition

Rendering

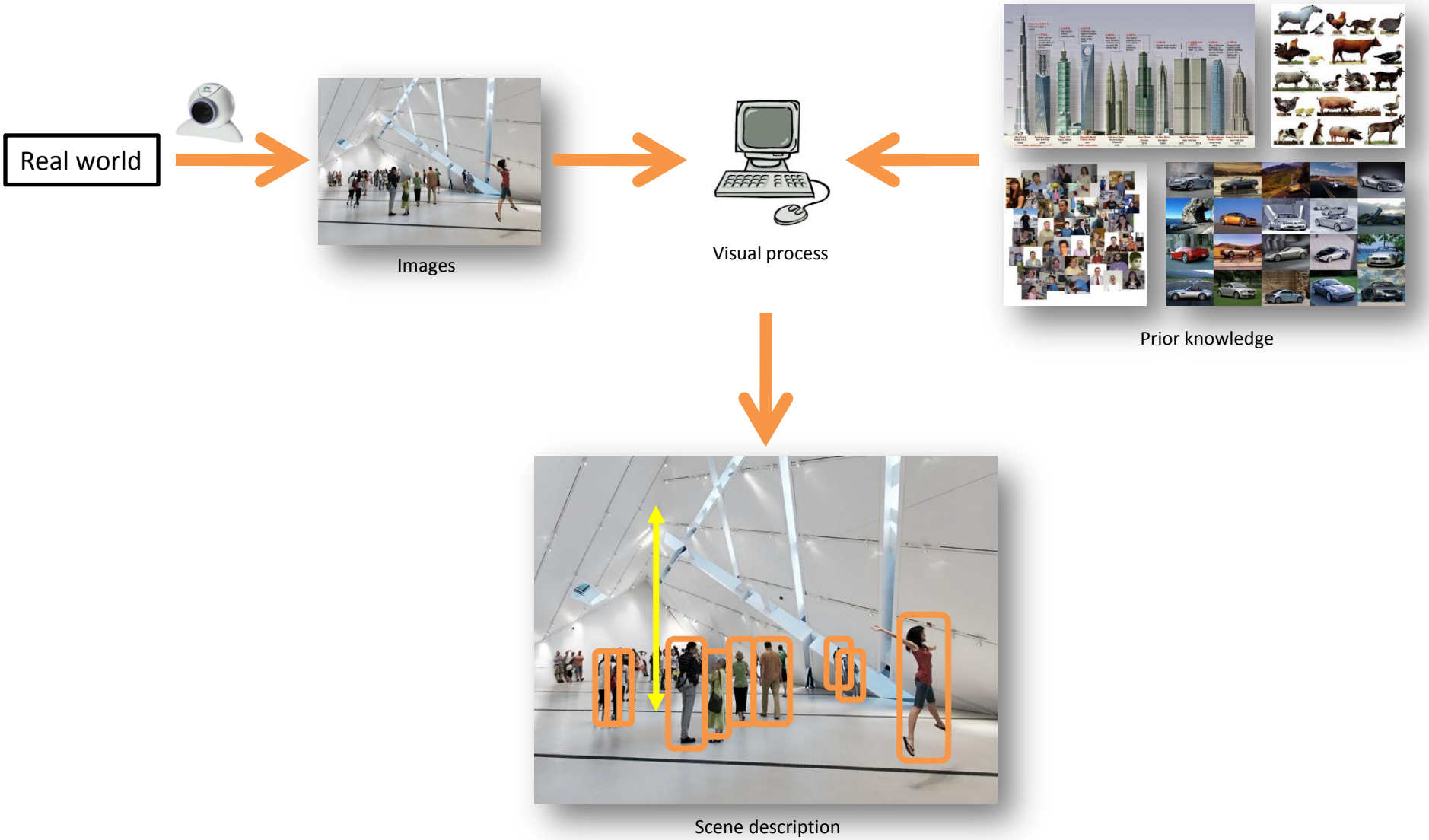


View morphing

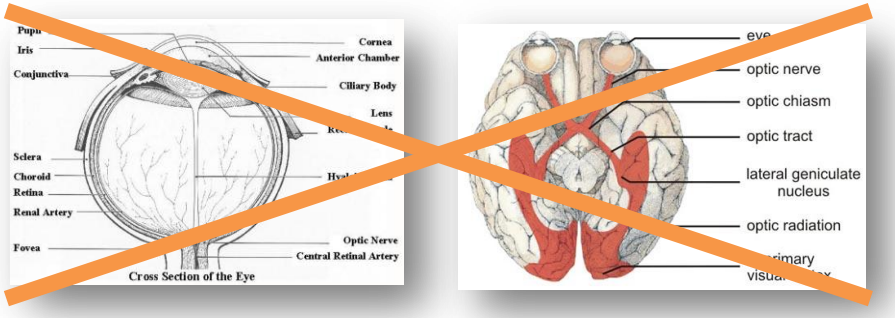
Augmented reality

Special effects, motion capture, …

"Vision is the act of knowing what is where by looking."
- Aristotle



Computer Vision



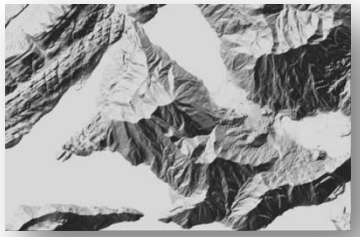
Does not study biological vision

Uses simple models

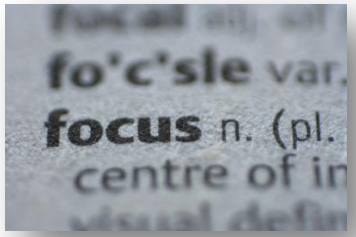
From [Baker *et al.*, CVPR'01]

Handles various types of camera

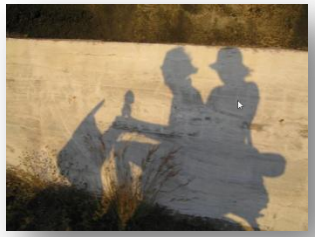
3D Computer Vision: Shape-from-X



Shading

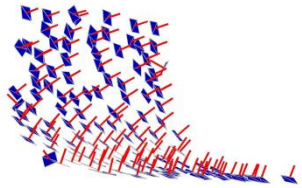


Focus



Shadows

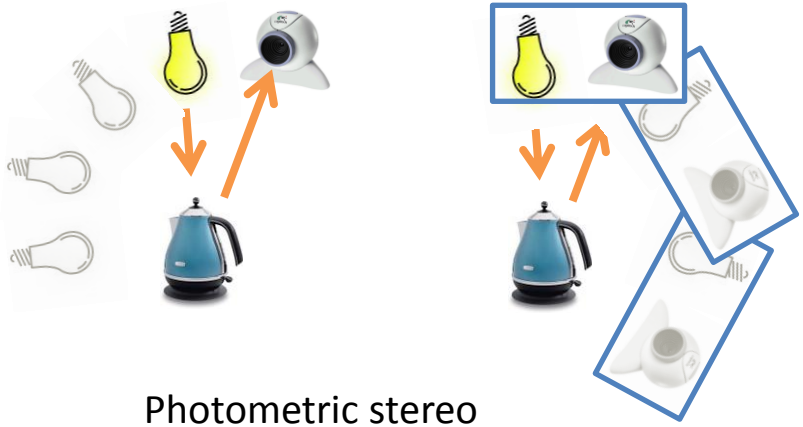
Occlusions, silhouettes, …



Texture

Techniques with Multiple Views

Image formation

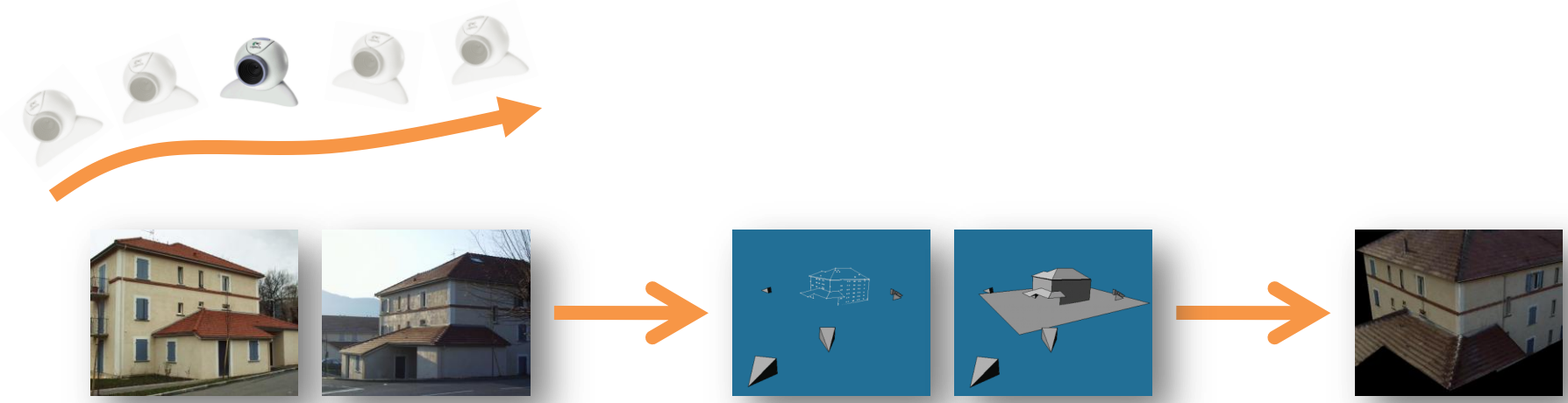


Photometric stereo

From [Higo *et al.* ICCV'09]

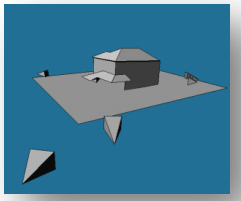
Structure-from-Motion - SfM

SfM – Structure-from-Motion



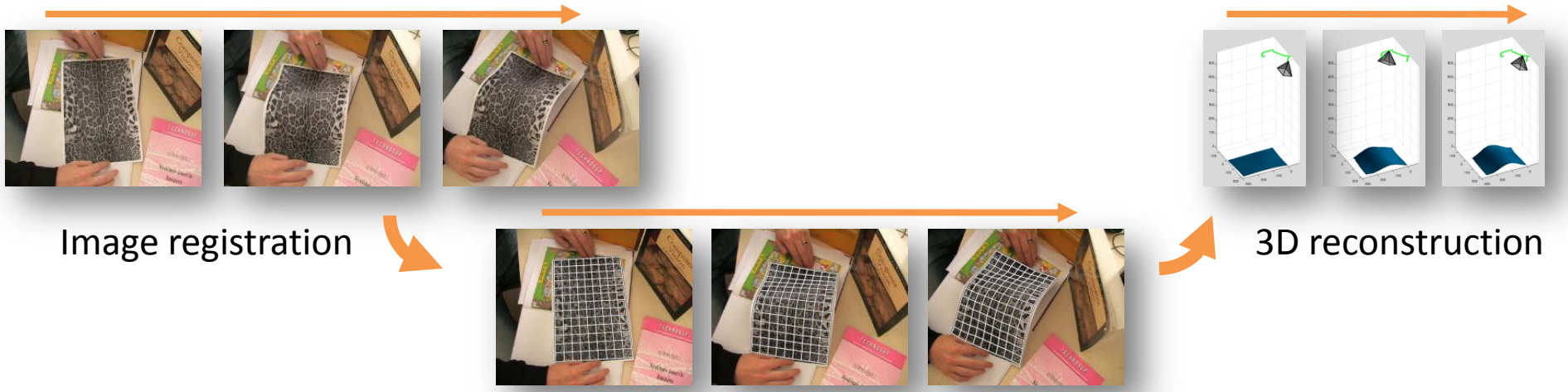
SfM has Two Main Steps

Image registration

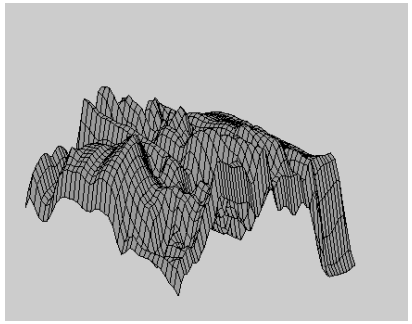


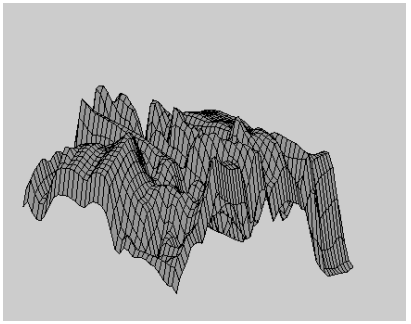
3D reconstruction

Rigid vs Deformable SfM



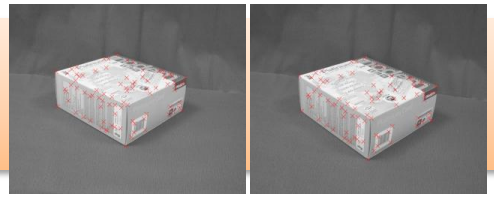
Why is Registration Difficult?





Rigid SfM: A Mature Paradigm

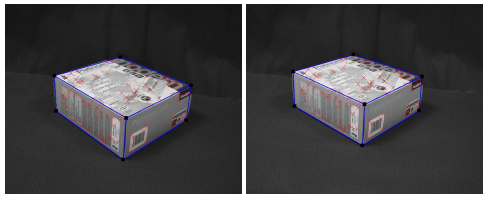
Inputs: a set of images



1 – registration

2 – projective reconstruction

3 – camera self-calibration



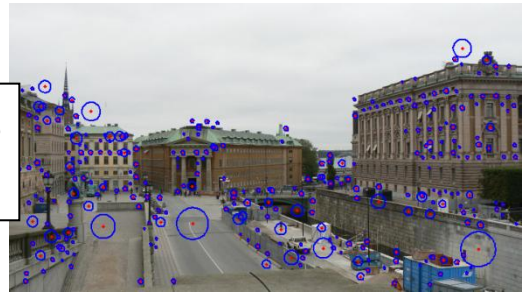
4 – surface reconstruction

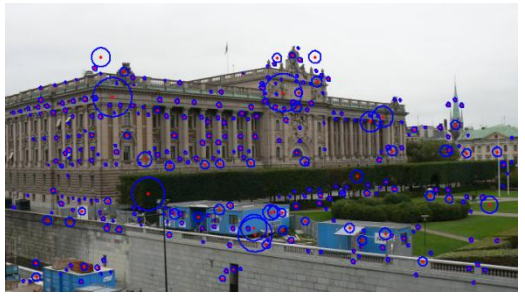
Outputs: camera parameters and scene structure

Keypoint Detection and Matching

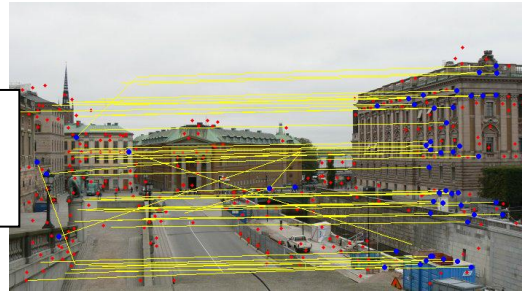
- Feature-based methods: abstract the images by features
- Keypoints lie at local maxima in intensity variations
- They should be stable under change of viewpoint
- They are matched by comparing invariant descriptors

Detected keypoints (with scale)



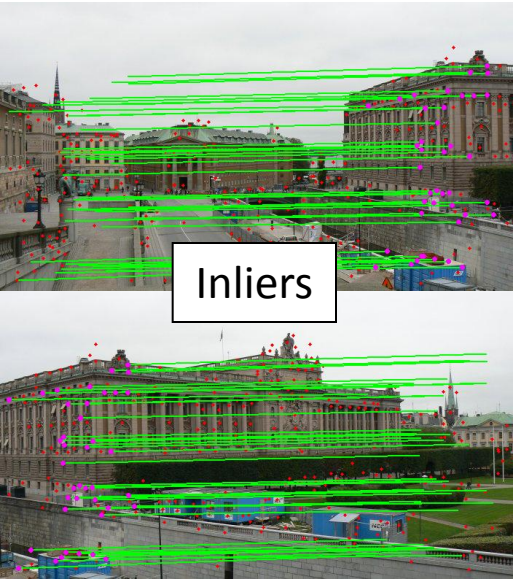


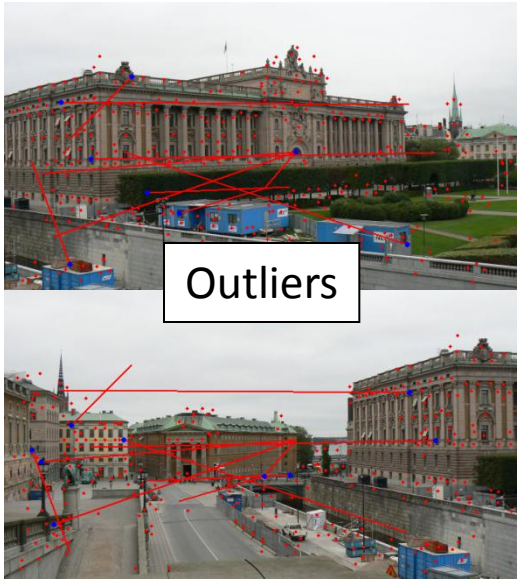
Matched keypoints (using winner-takes-all)



Robust Estimation Methods

- Objective: estimate the model parameters and classify each datum as valid or erroneous
- This is a chicken-and-egg problem
- RANSAC (Random Sample Consensus)
  - Handles more than 50% outliers in the data
  - Basic idea: sample minimal data sets and maximize the support



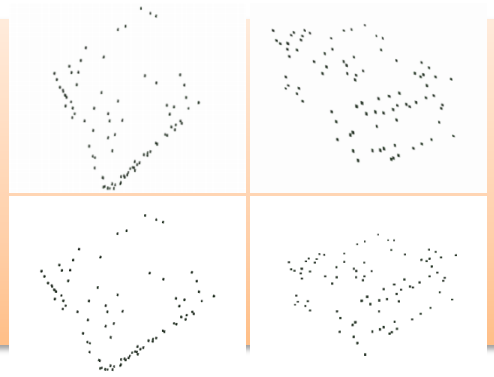


Homography based panorama

Rigid SfM: A Mature Paradigm

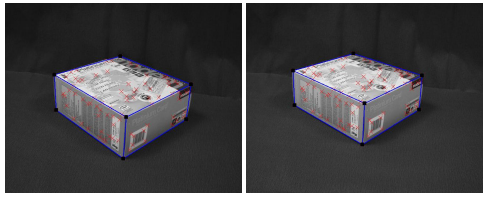
Inputs: a set of images

1 – registration



2 – projective reconstruction

3 – camera self-calibration



4 – surface reconstruction

Outputs: camera parameters and scene structure

The Projective Camera

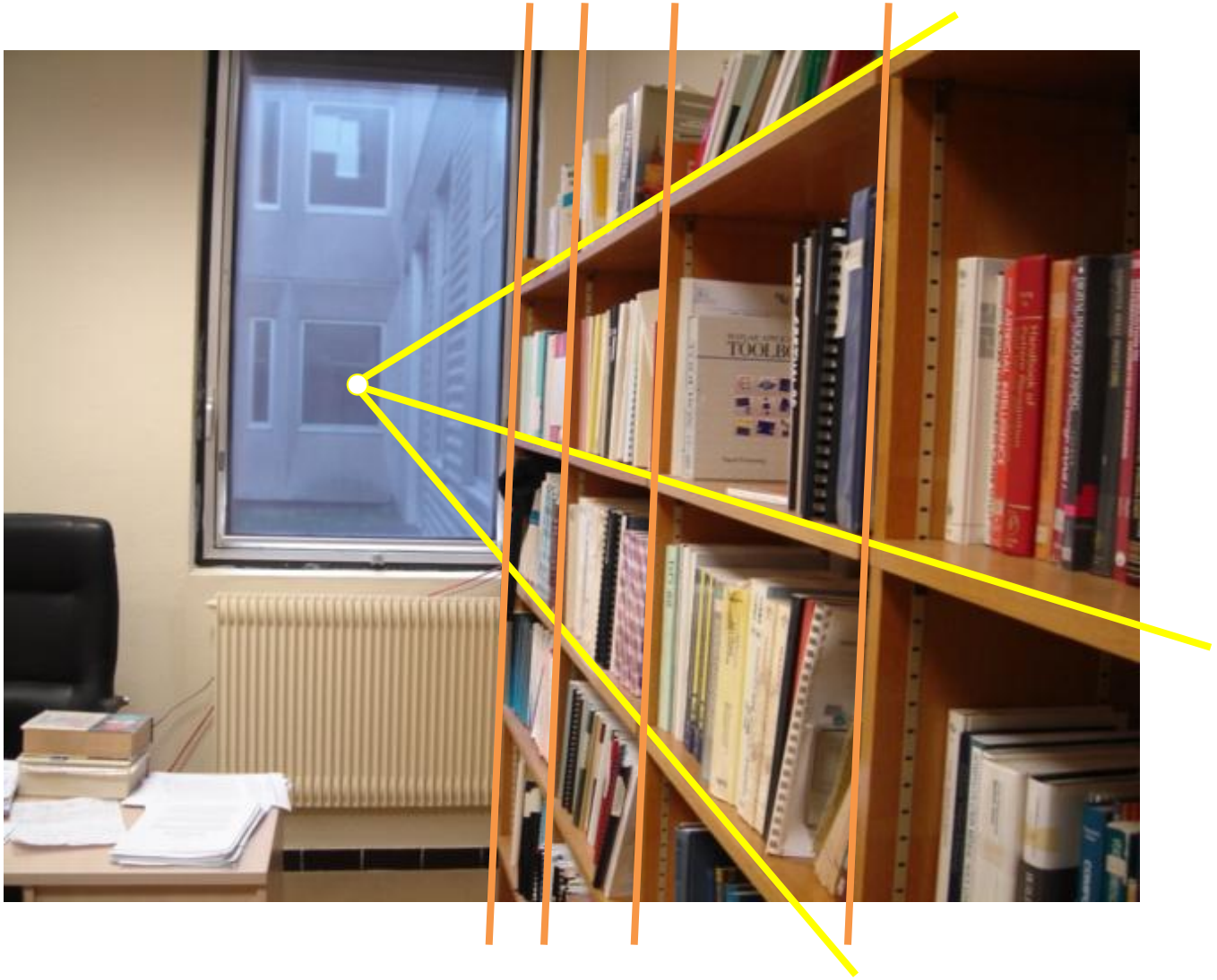
Image point $= \frac{1}{\square} \begin{bmatrix} \square \\ \square \\ \square \end{bmatrix}$

$\begin{bmatrix} \square \\ \square \\ \square \end{bmatrix} =$ Intrinsics $\begin{bmatrix} \square & \square & \square \\ & \square & \square \\ & & \square \end{bmatrix}$ Extrinsics $\begin{bmatrix} \square & \square & \square & \square \\ \square & \square & \square & \square \\ \square & \square & \square & \square \end{bmatrix}$ $\begin{bmatrix} \square \\ \square \\ \square \\ \square \end{bmatrix}$ 3D point

Rational in euclidean coordinates

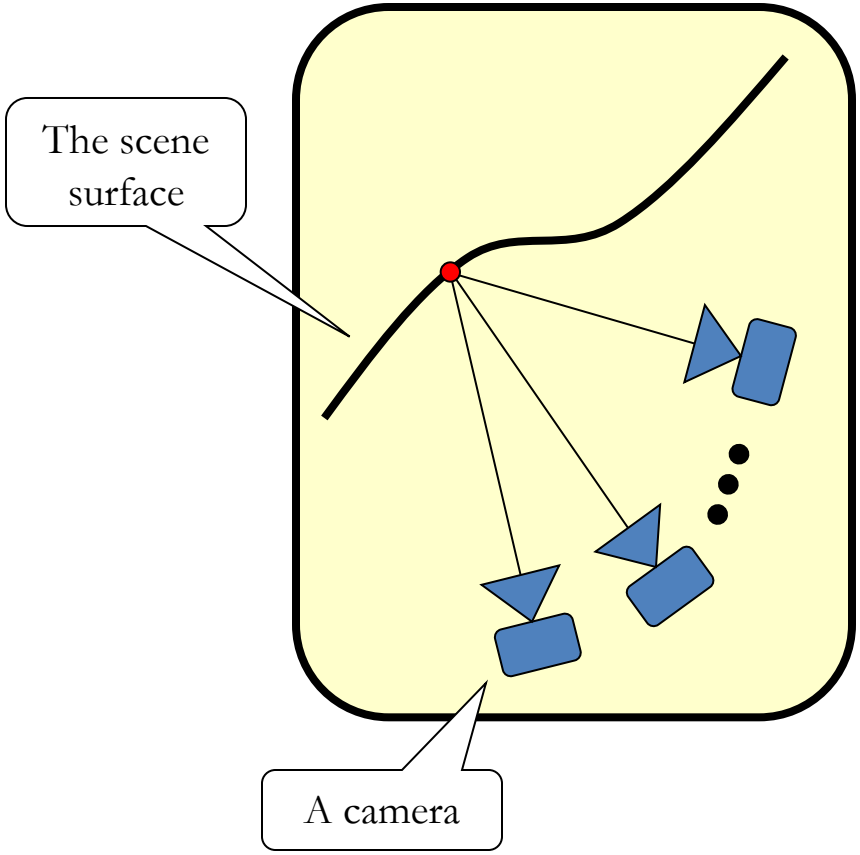
Linear in homogeneous coordinates

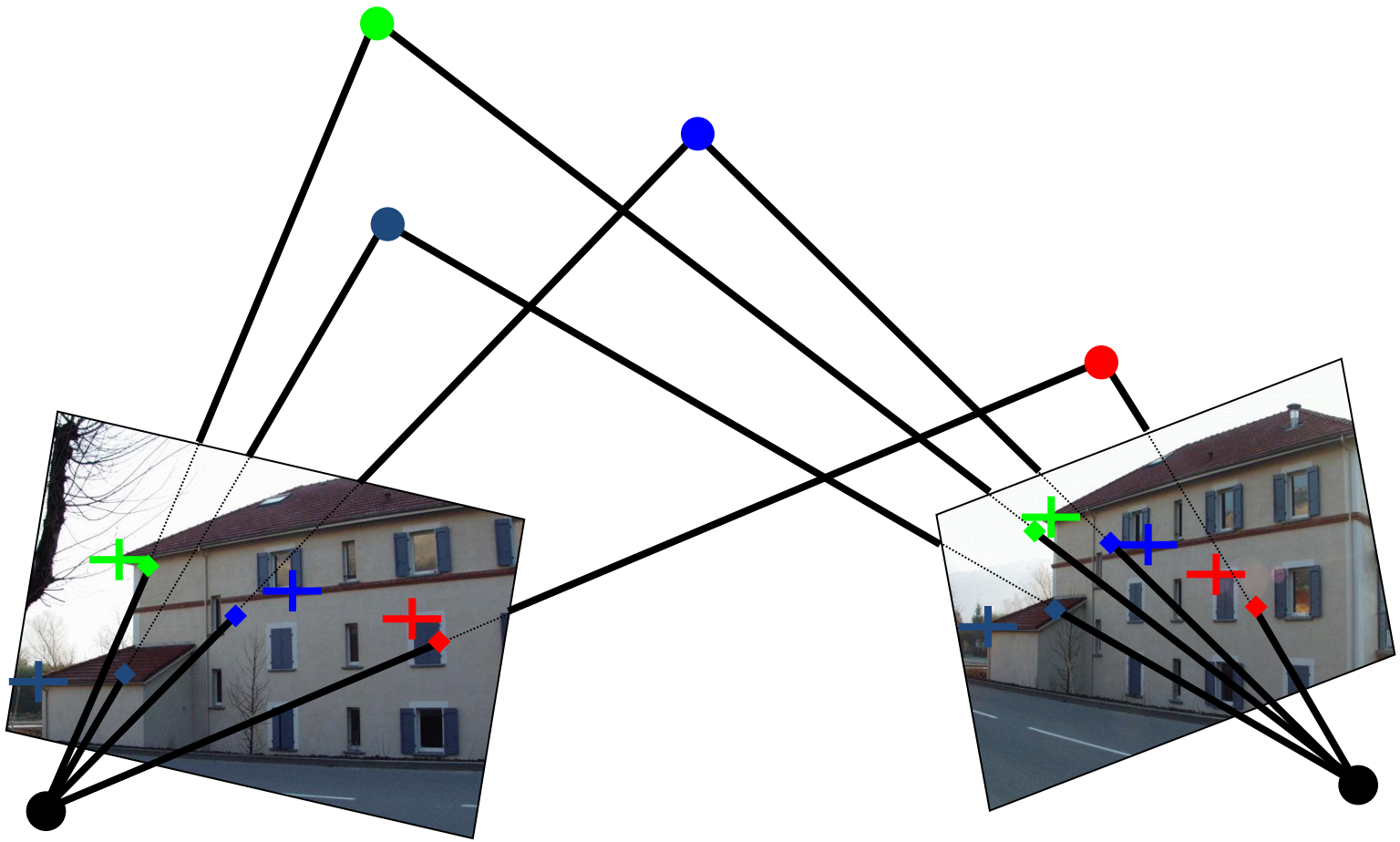
Projective Geometry



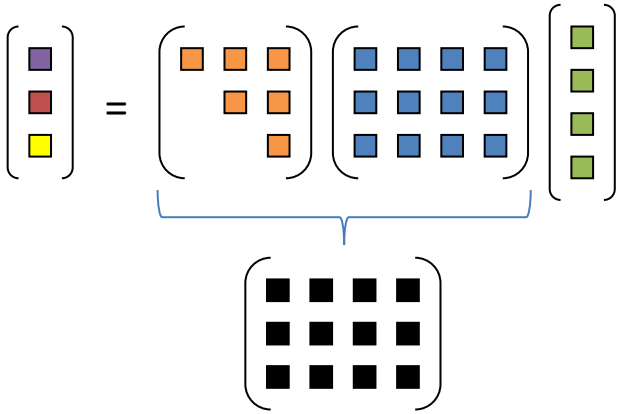
3D Reconstruction

- The basic constraint: intersection of the viewing rays for matching points





Projective Reconstruction



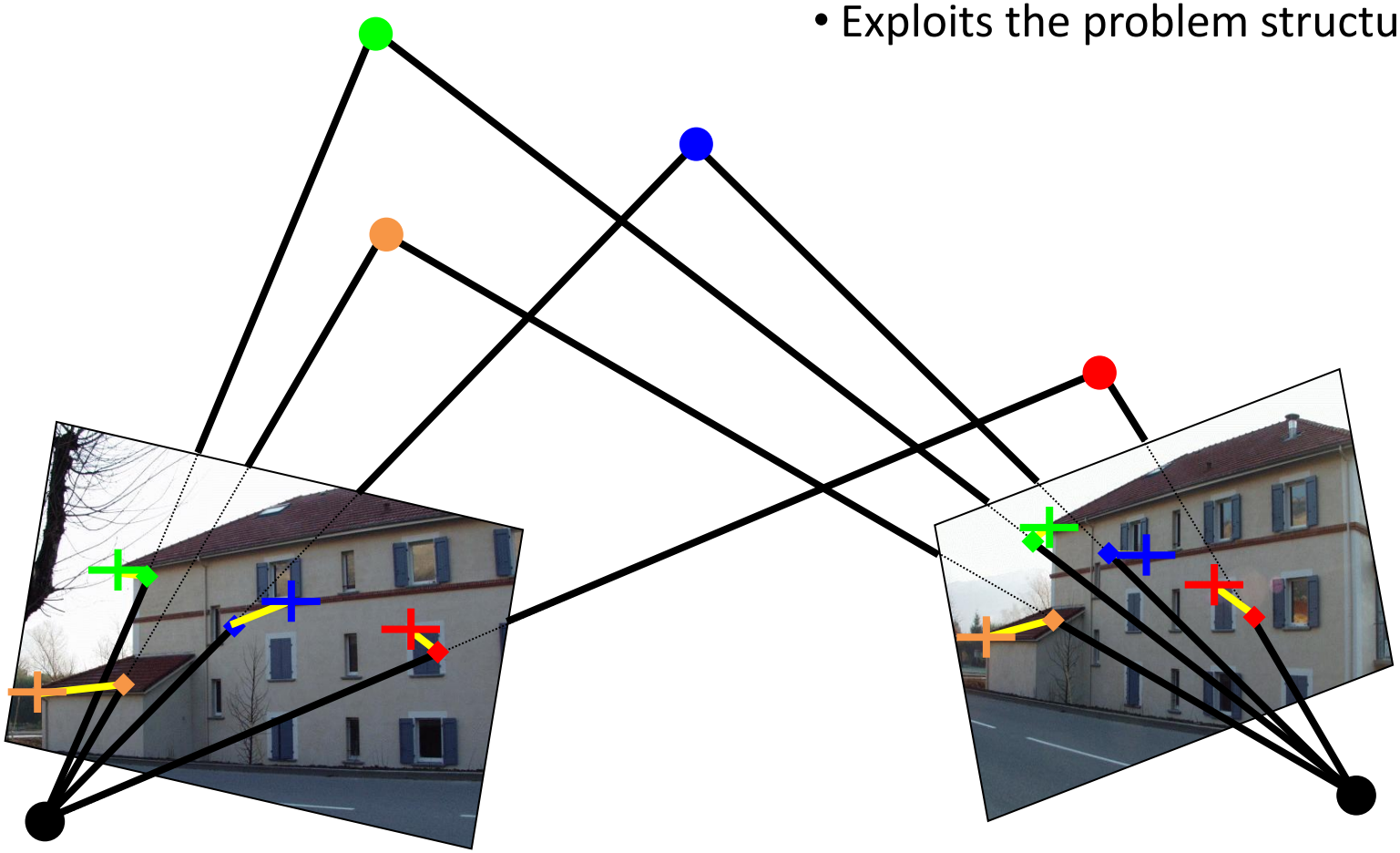
- Nonlinear optimization problem
- Initialization
  - Split the image set
  - Reconstruct from 2 – 4 views
  - Merge the reconstructions
- Refinement: bundle adjustment

Camera Self-Calibration

- Uses constraints on the intrinsics, such as
  - Constant intrinsics for all cameras
  - Known intrinsics, except the (varying) focal length
- Linear or nonlinear least squares
- Why using camera self-calibration?
  - Flexibility: no prior knowledge on structure and extrinsics
  - Simplicity: projective is easier than metric
- Bundle adjustment

Bundle Adjustment

- Minimization of the reprojection error
- Thousands of unknowns
- Exploits the problem structure



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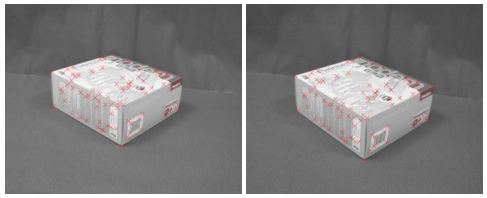

1 – registration

2 – projective reconstruction

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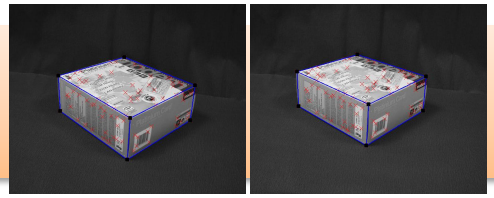
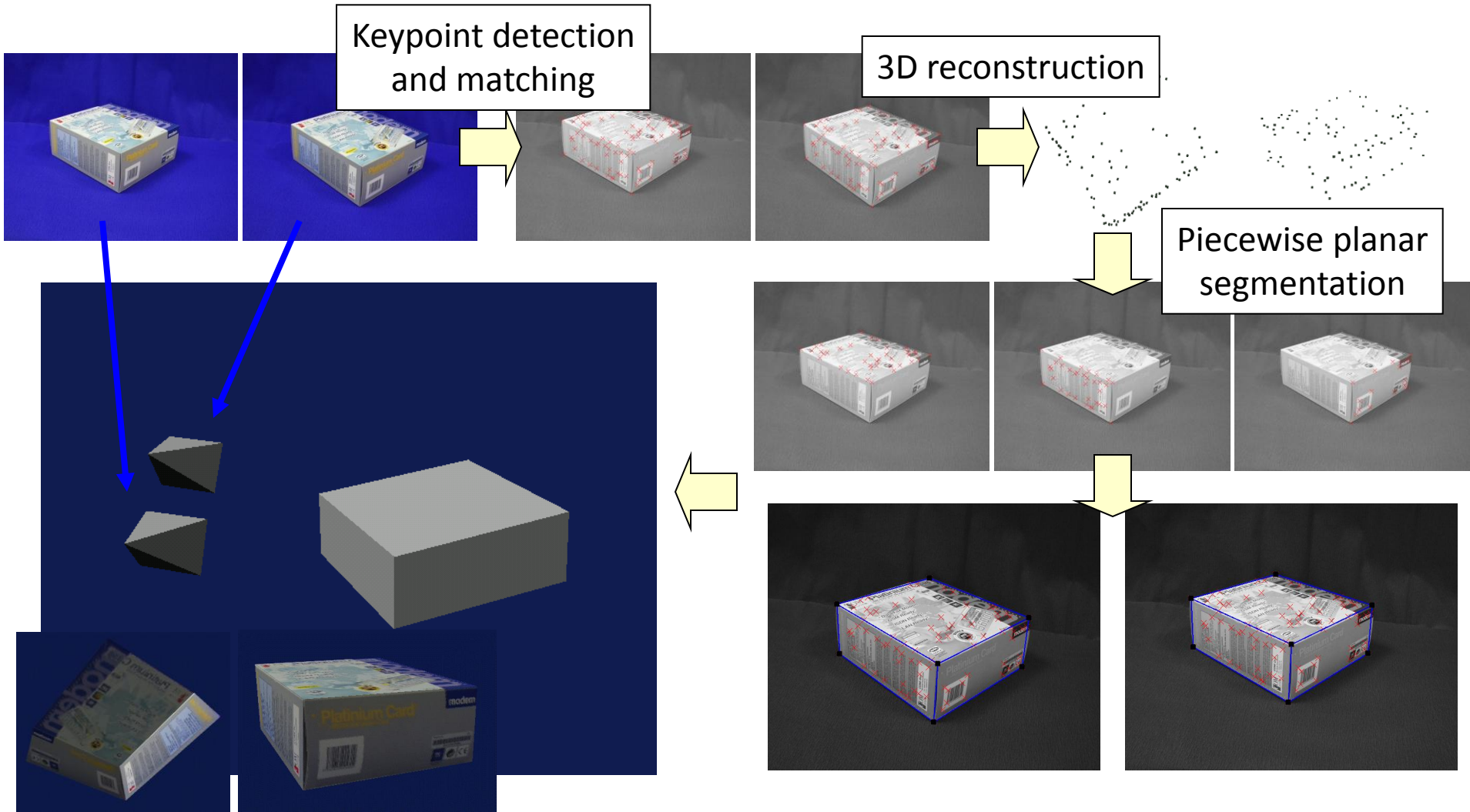


4 – surface reconstruction

Outputs: camera parameters and scene structure

Dense 3D Reconstruction

- Based on geometric primitives (planes, cubes, *etc*)



Dense 3D Reconstruction

- Stereopsis, voxel colouring
- Based on matching colours between the images

One of two images

Disparity map

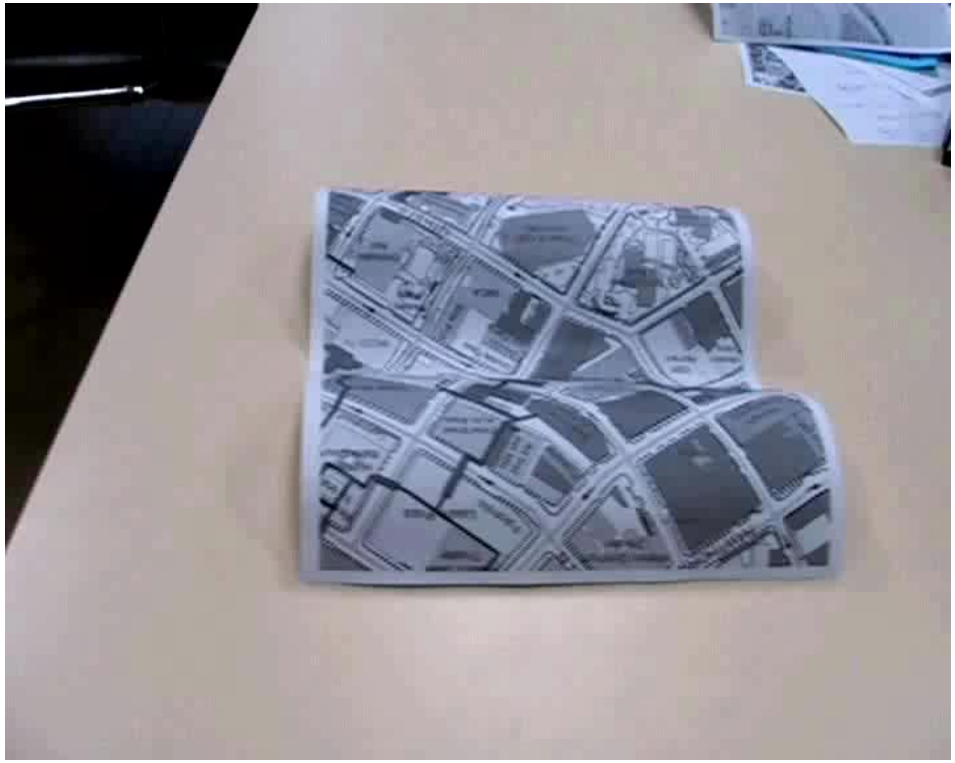
Results from
[Boykov *et al*, PAMI'04]

One of many images

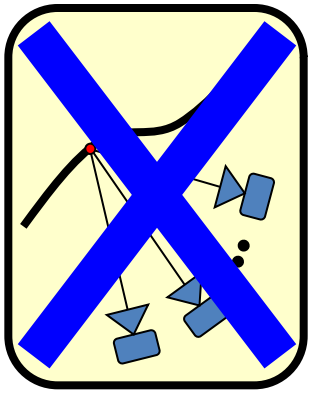
3D model

Results from
[Furukawa *et al*, CVPR'07]

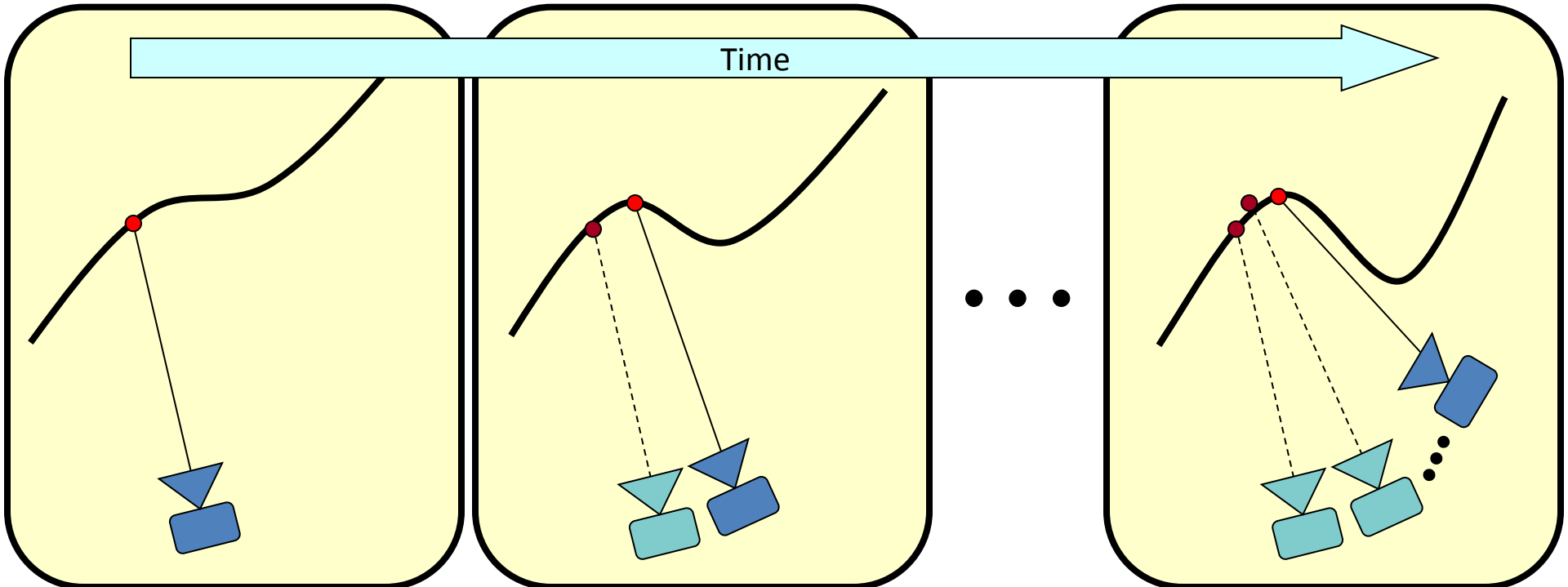
Augmentation



Deformable Structure-from-Motion

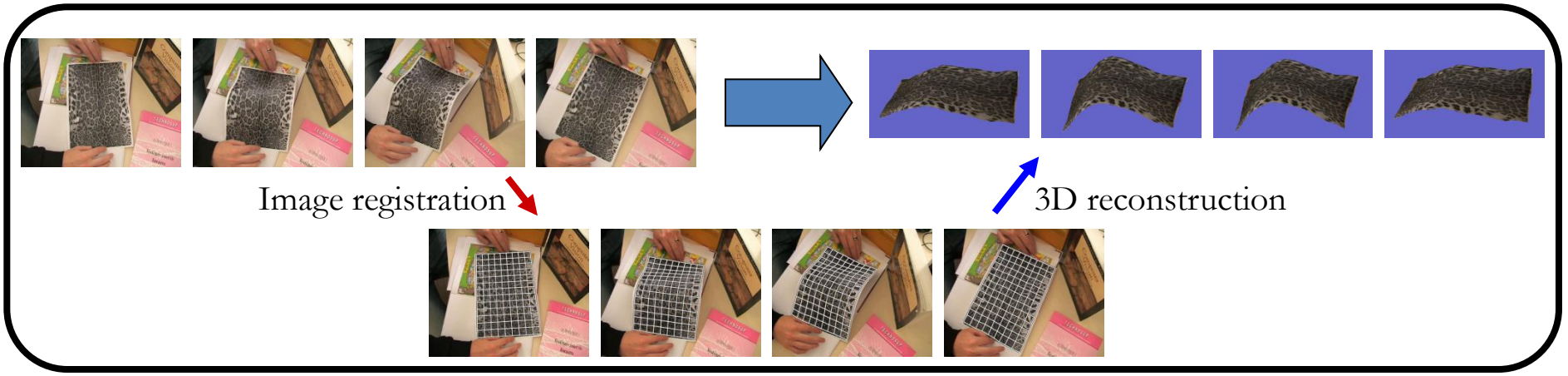


- The viewing rays for matching points do **not** generally meet
- The problem is generally ill-posed



Deformable Structure-from-Motion

- Priors on the structure
  - Single object
  - Empirical: smoothness, *etc*
  - Physical: inextensibility, developability, mechanical models, *etc*
  - Statistical: face, body, *etc*



Deformable Surface Registration

- Find transformations that make the input images similar
- Geometric transformation: changes pixel locations
- Photometric transformation: changes pixel colours
- Sequential registration

Template

Deformable Surface Registration

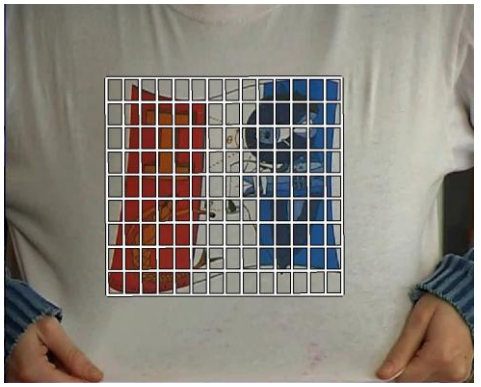
Current image

Unknown transformation

Template

Transformed image

Difference image



$\| \quad \|^2$

→ minimization over the transformation parameters

Explicit Photometric Transformation

Template

Current image

Videos of the difference image

No photometric model

Affine photometric model

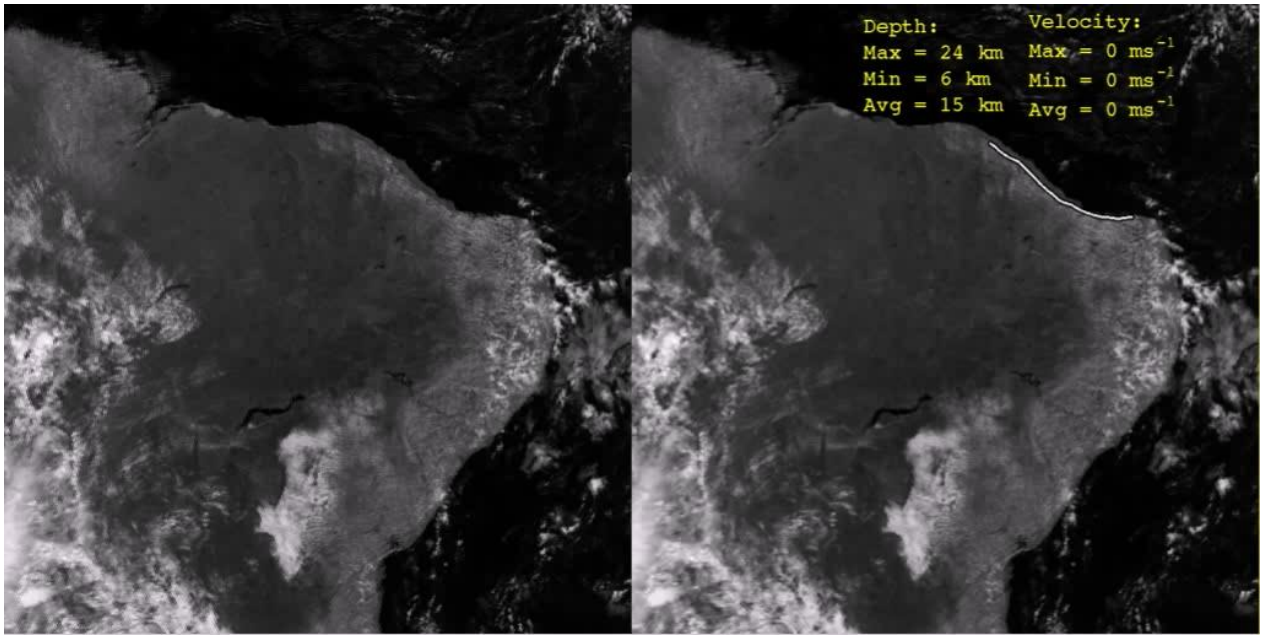
Other Registration Results and Methods

Curve-based registration

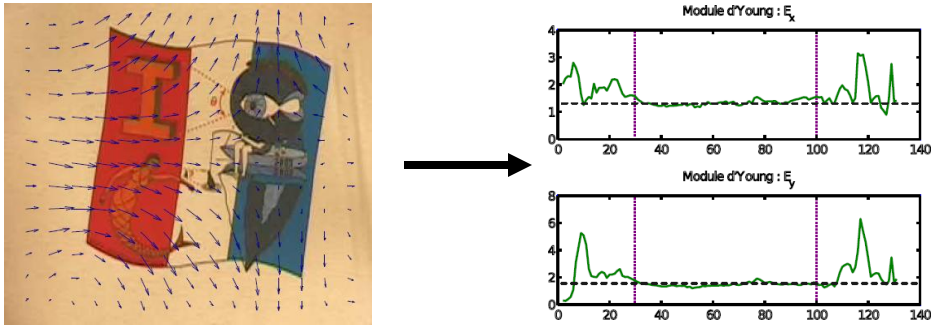
Retexturing

Other Registration Results and Methods

Sea breeze tracking

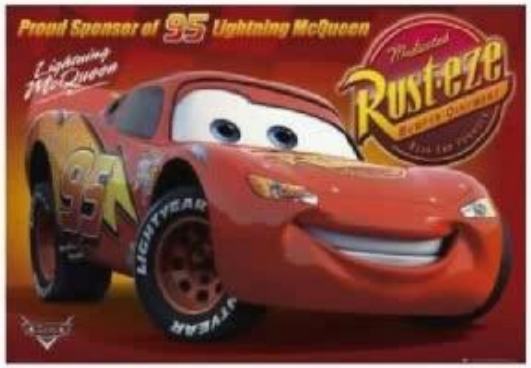


Computation of mechanical constants



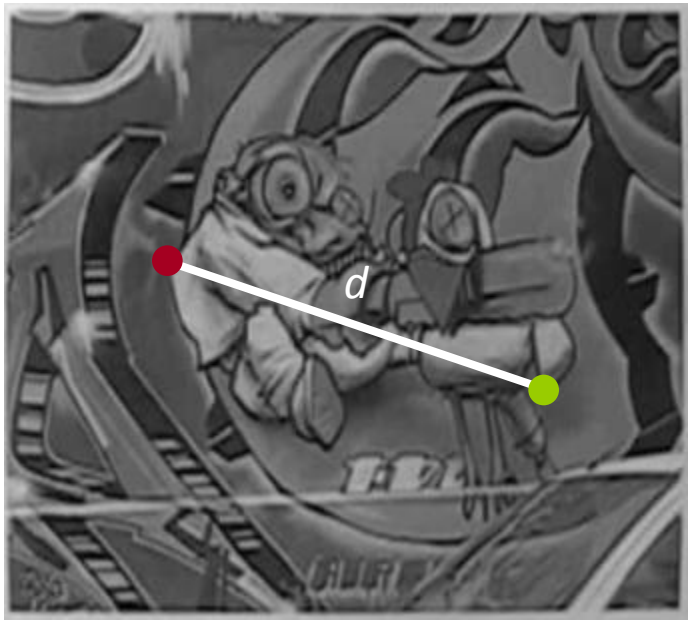
Fluid flow registration

Retargetting

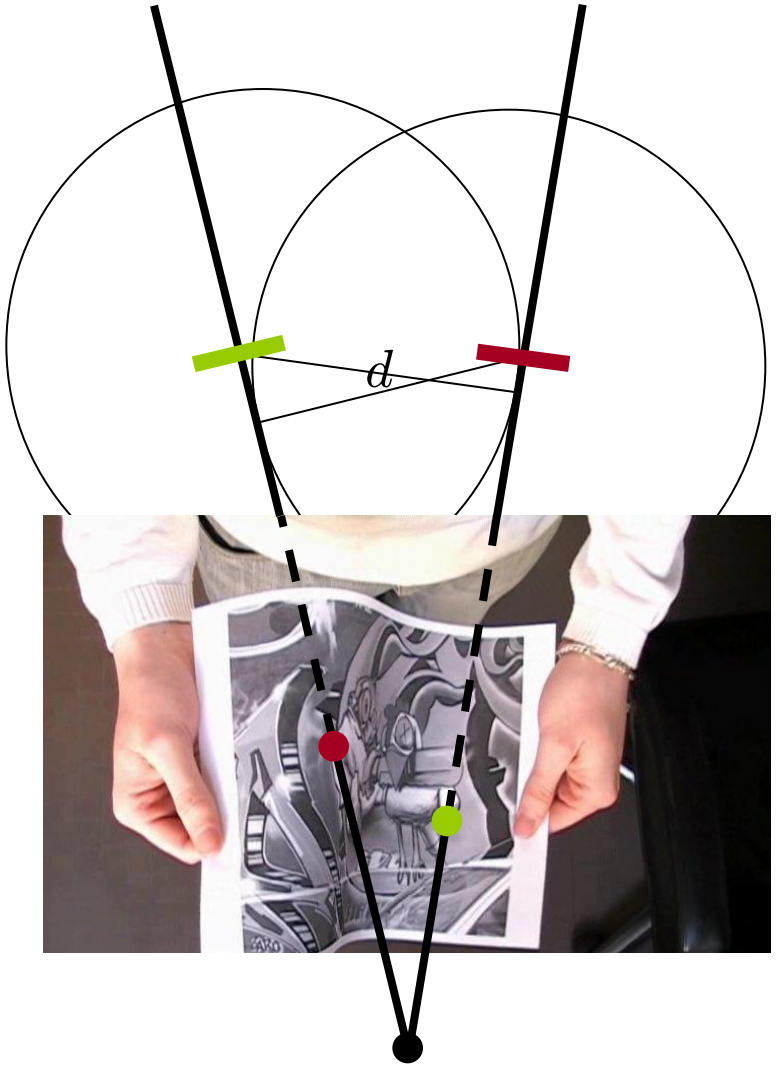


Deformable Surface 3D Reconstruction

- Highly dependent on the surface (cloth, paper, skin, *etc*)
- Example algorithm for isometric surfaces

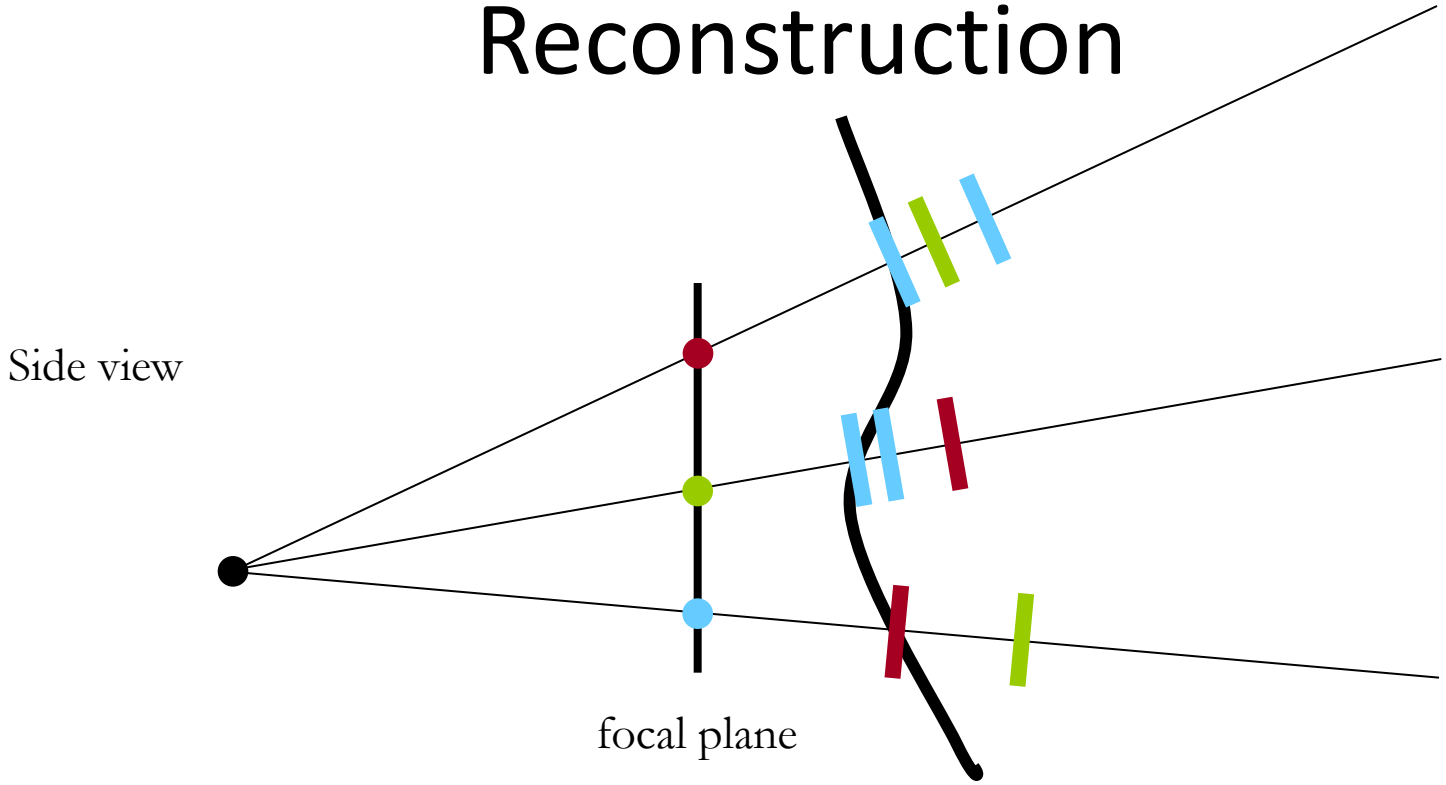


Template

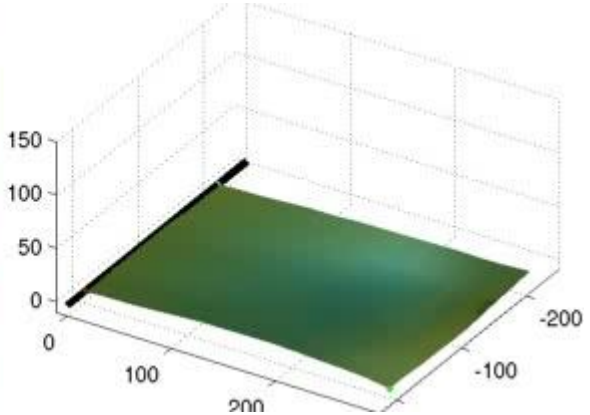


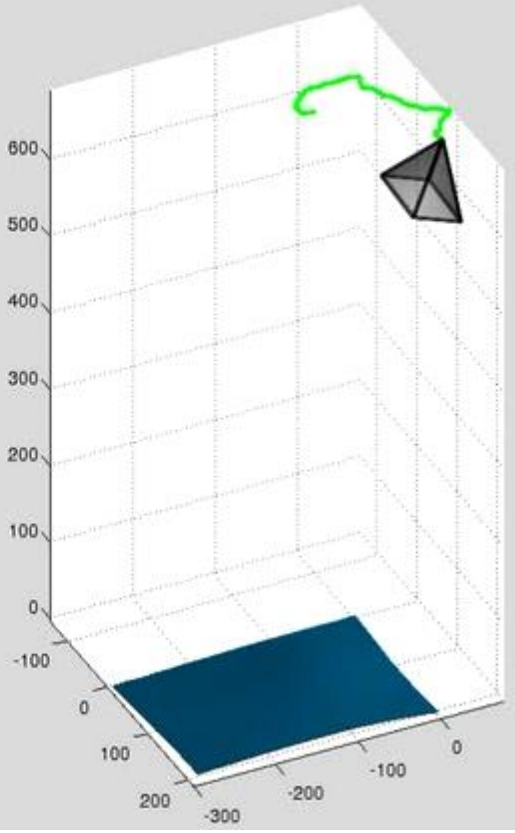
Current image

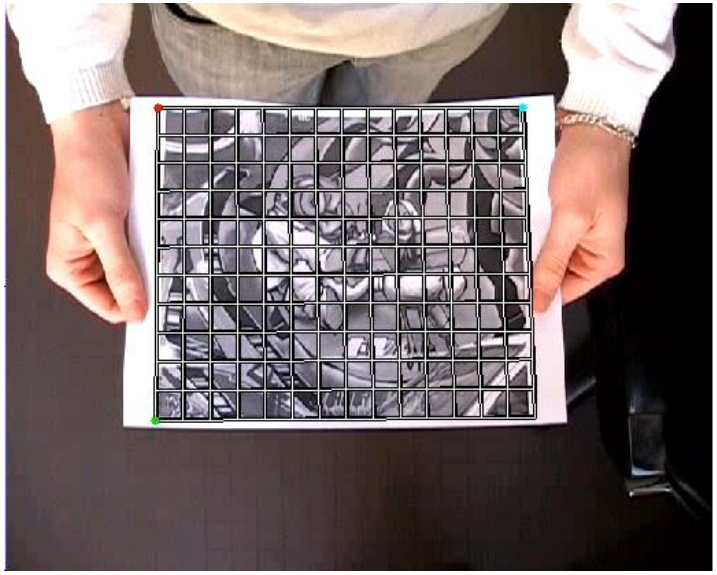
Isometric Deformable 3D Reconstruction

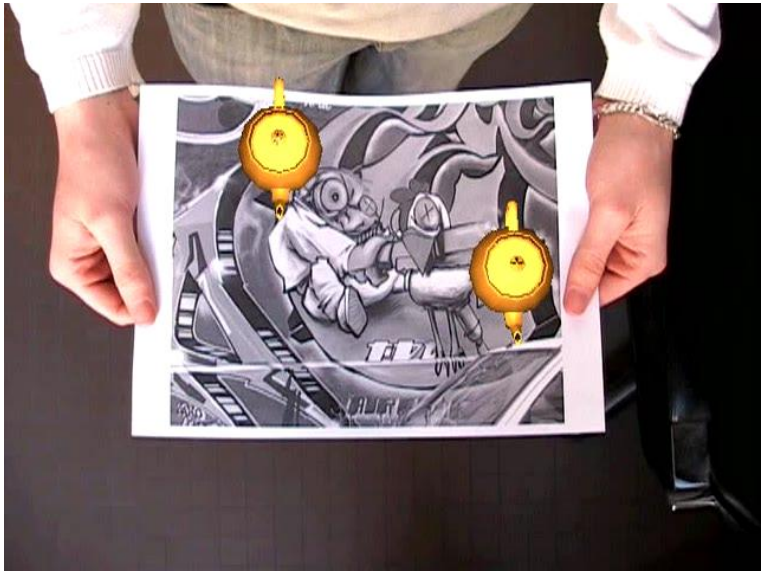


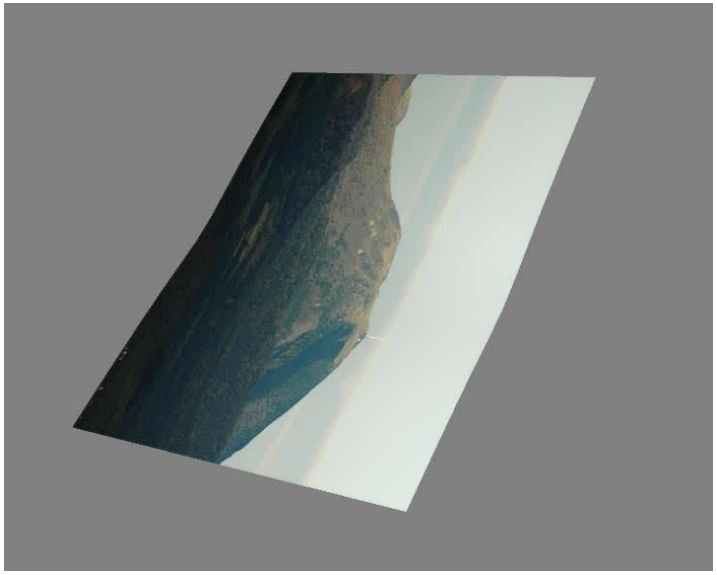
1. Compute the upper bounds for each pair of points
2. Keep the tightest upper bounds
3. Recompute the bounds and loop to 2
4. Interpolate the upper bounds to get a surface


150
100
50
0
0
100
200
-200
-100


600
500
400
300
200
100
0
-100
0
100
200
-300
-200
-100
0

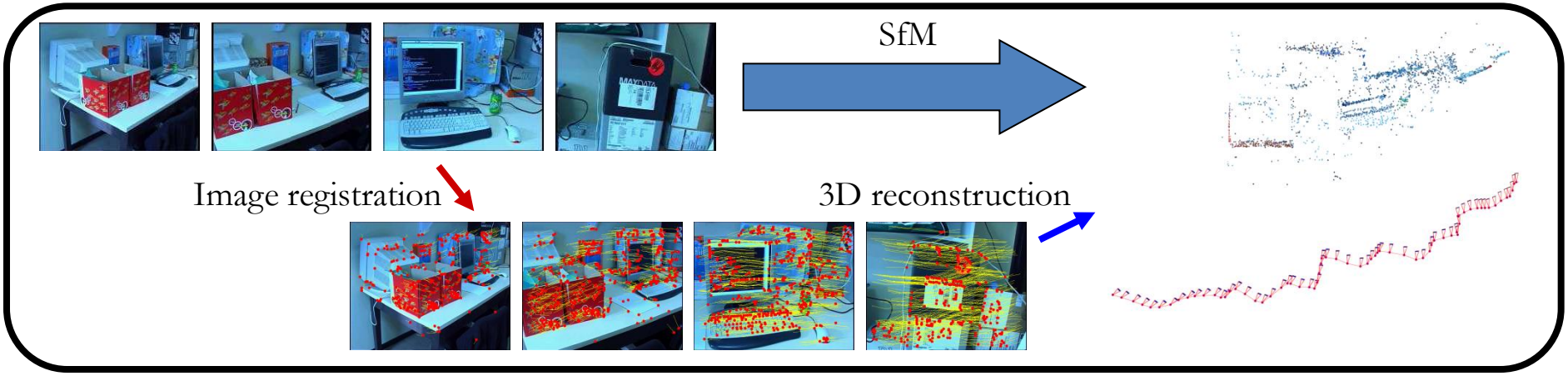






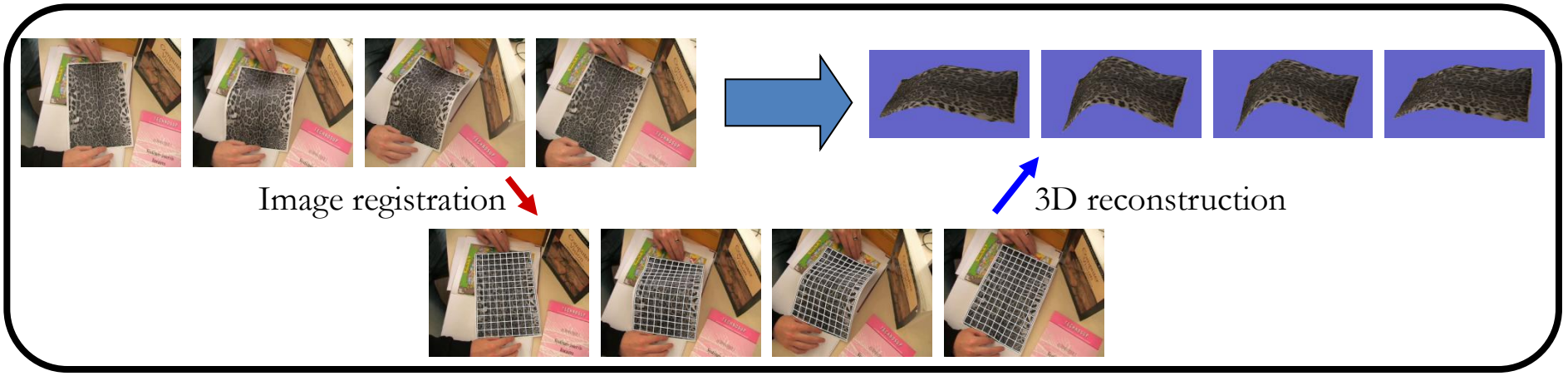
Summary for Rigid Structure-from-Motion

- Mature for textured environments
- Camera and ‘sparse’ structure recovery, self-calibration
- Companies: 2d3 (University of Oxford then Vicon), RealViz (INRIA then Autodesk), *etc*
- Textbooks: [Hartley *et al*, 03 ; Faugeras *et al*, 01 ; Forsyth *et al*, 03]



Summary for Deformable Structure-from-Motion

- Some results in the ‘surface’ case for registration and 3D reconstruction
- Image registration for fluid flow
- The general case is completely open
- Prior knowledge on the environment is required



Bibliography

- Keypoint detection, description and matching:
  [Lowe, IJCV'04 ; Mikolajczyk *et al*, IJCV'05]
- Robust estimation (RANSAC): [Fischler *et al*, CVGIP'81]
- Projective reconstruction: [Nister, PhD-Thesis'00]
- Bundle adjustment: [Triggs *et al*, VA'00]
- Self-calibration: [Gurdjos *et al*, ICCV'09]
- (Rigid) dense stereo:
  [Boykov *et al*, PAMI'04 ; Strecha et al, CVPR'08]
- Deformable surface registration:
  [Gay-Bellile *et al*, PAMI'10; Pilet *et al*, IJCV'07]
- Deformable surface reconstruction:
  [Perriollat *et al*, IJCV'10; Salzmann *et al*, ICCV'09]

Image Registration and 3D Reconstruction in Computer Vision

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