Digital image processing and analysis

Advanced topics 1: Image registration

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In this lecture we shall find out about:

- Image registration: what it is and what it is for
- What we try to align
  - Image features
  - Image values
- How we carry out image transformations
  - Rigid and affine
  - Elastic
- How we measure the success of registration
- How we compute the final pixel values

***Acknowledgement**: A number of slides come from: cs.haifa.ac.il/hagit/courses/CP/Lectures/CP05_FeaturesRegistX4.pdf*

Image registration

- Alignment of one image with another.
- Two broad approaches:
- **Feature-based registration**
  - Find a few matching features in both images
  - Compute alignment
- **Direct (appearance-based) registration**
  - Search for alignment where most pixels agree

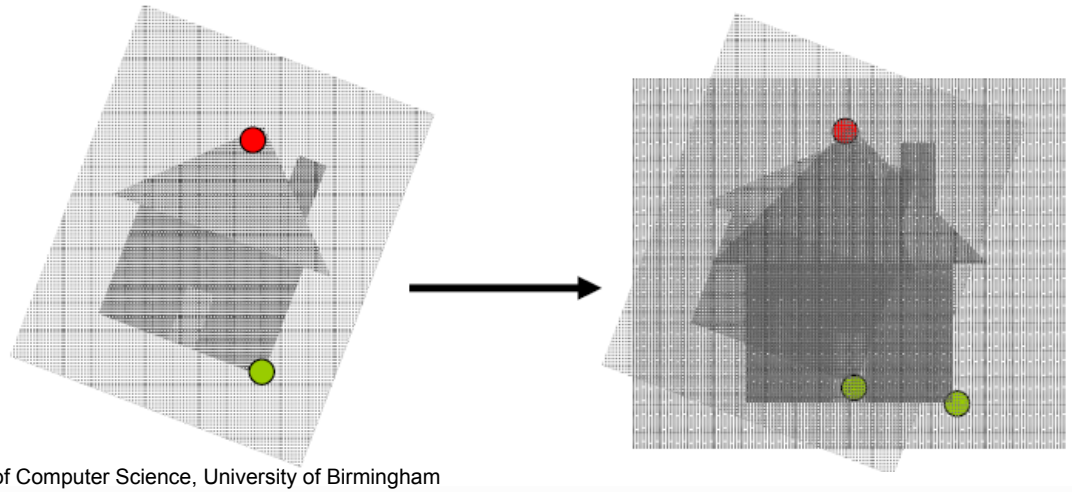


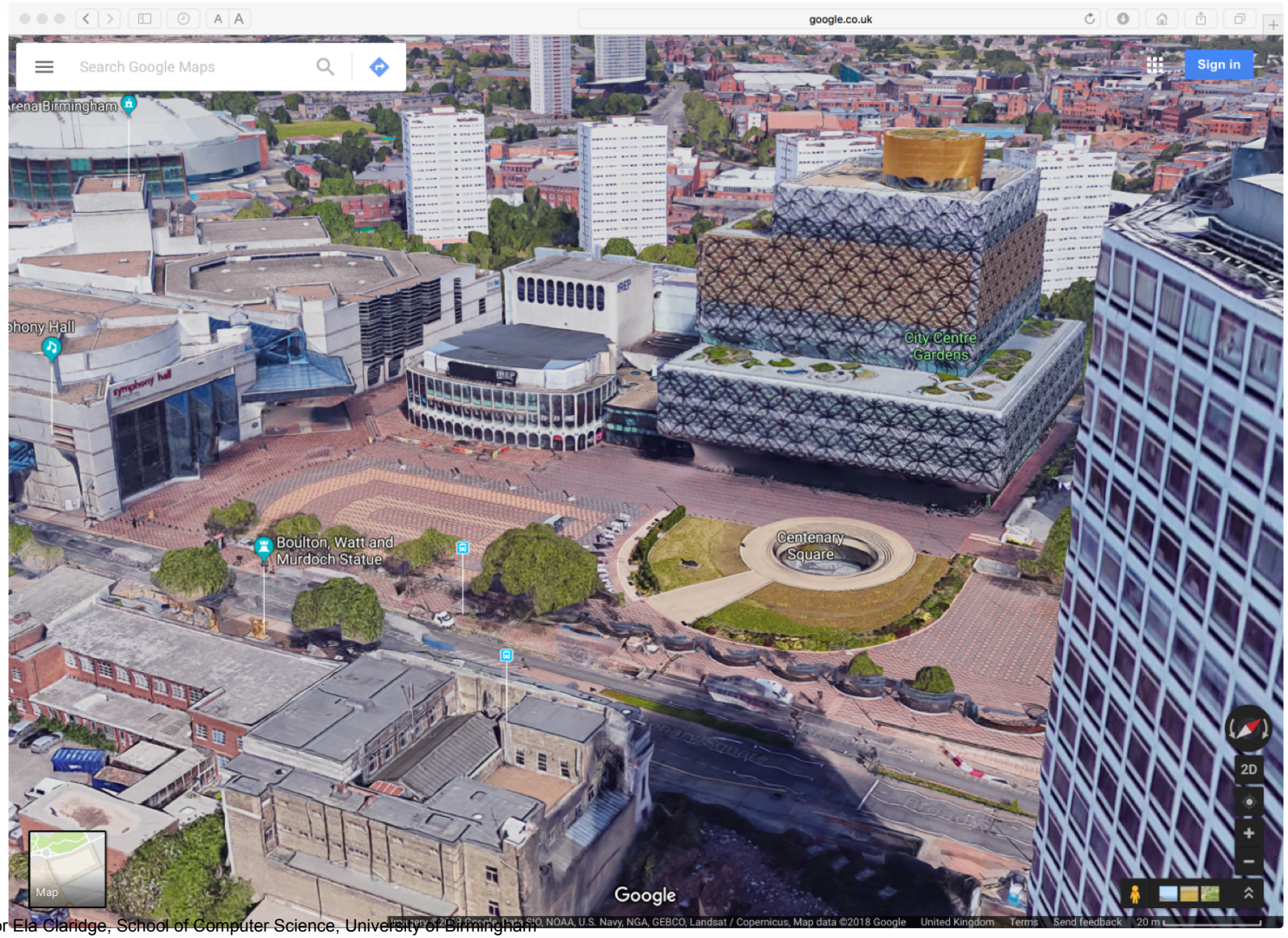
Image registration

- Implemented as the process of estimating an *optimal transformation* between two images.
- Images may be of same or different types.
- Many applications in different fields of image processing and computer vision.

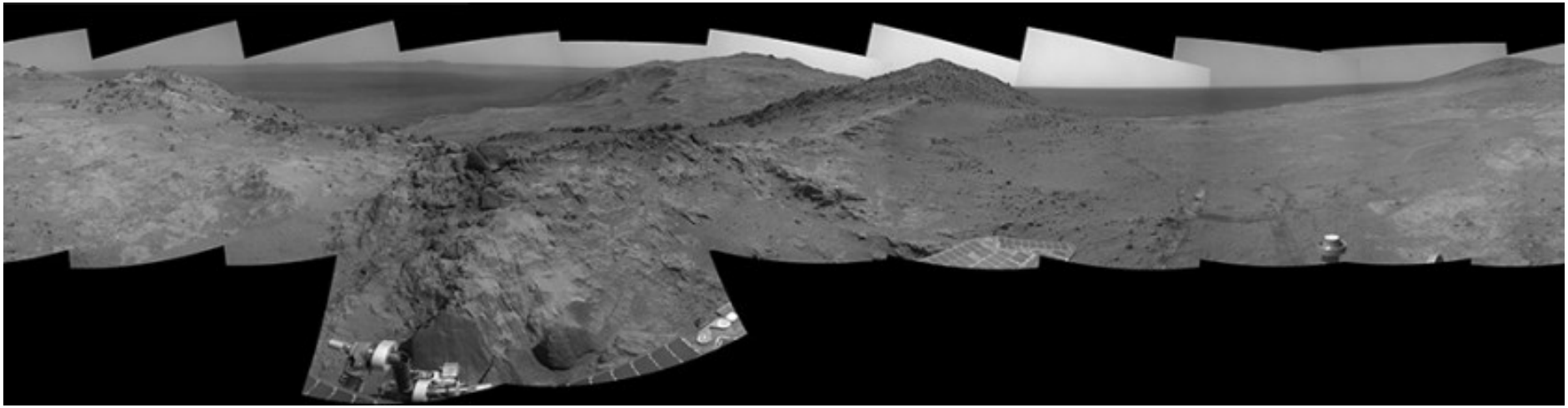
Image mosaicing (stitching)

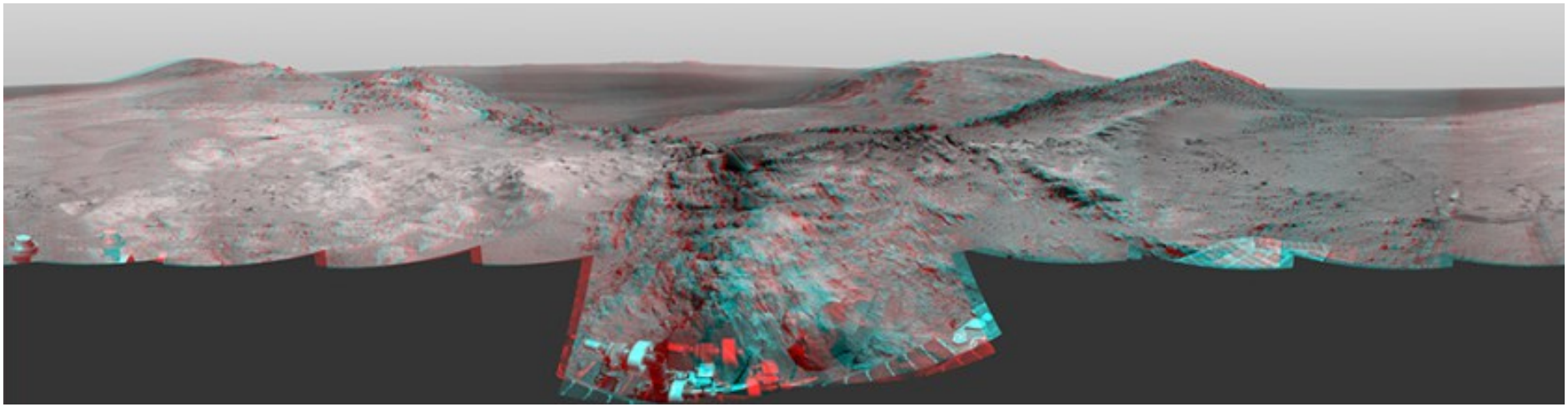
Source: Wikipedia

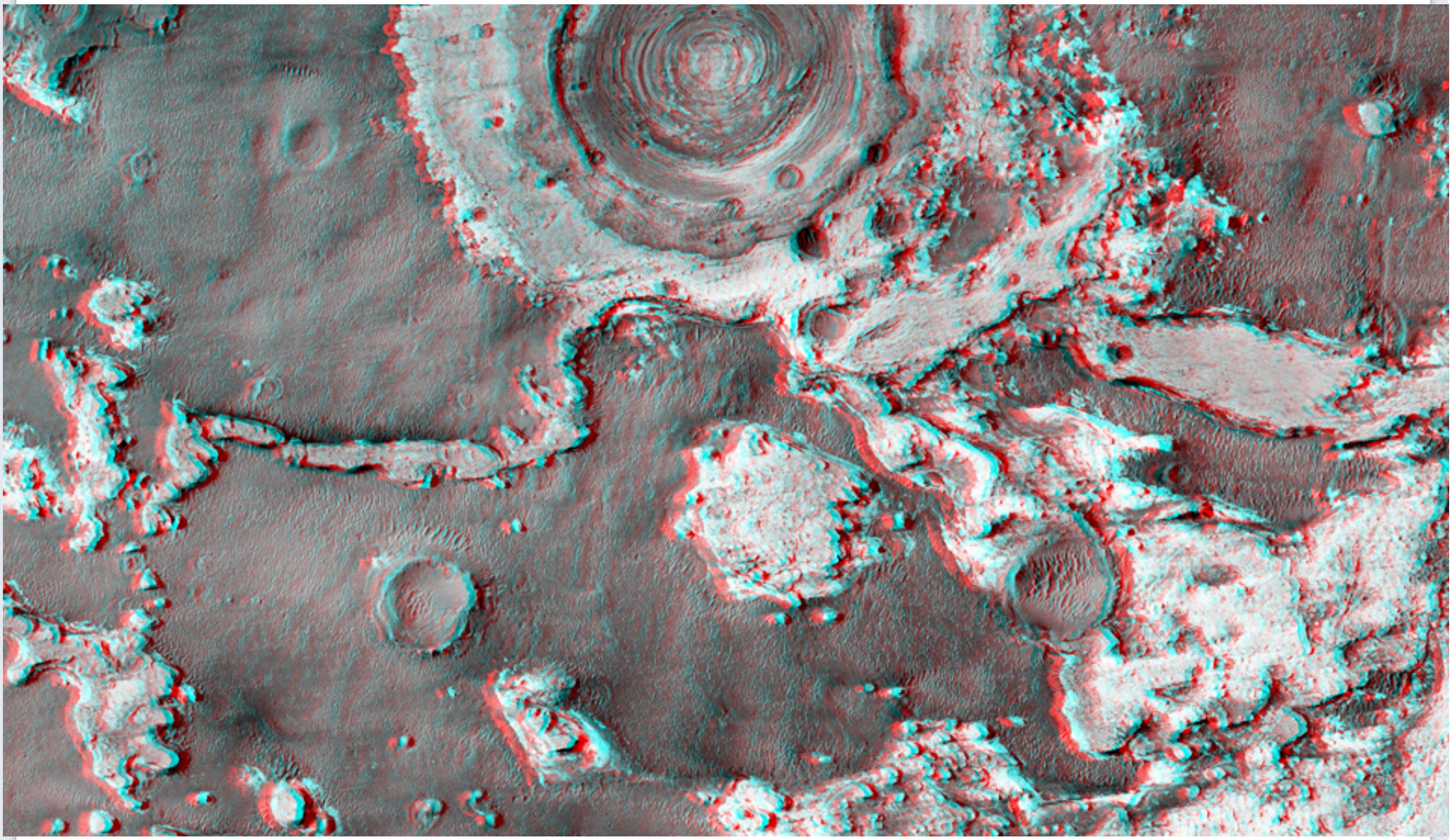
3D reconstruction



Stereo viewing

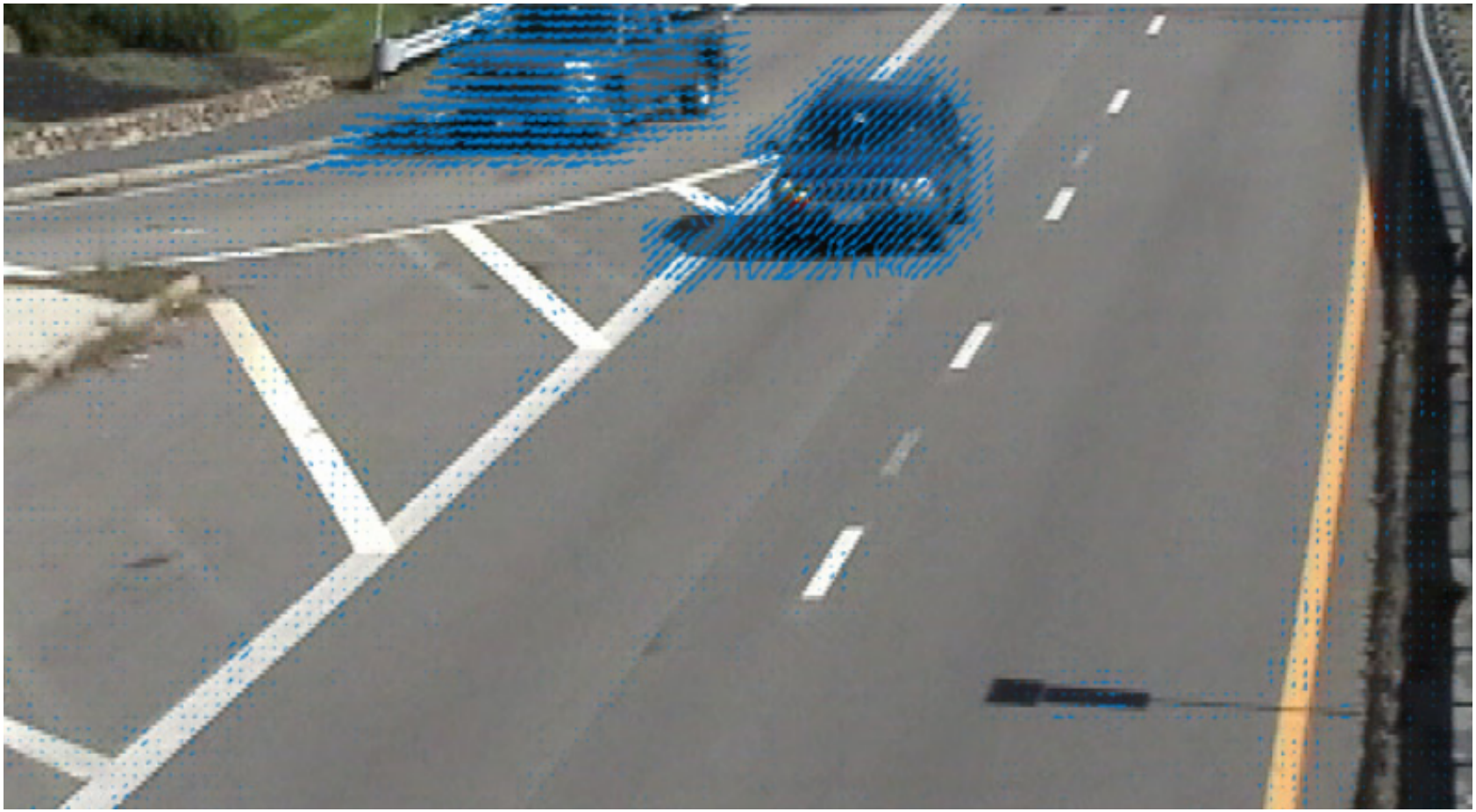






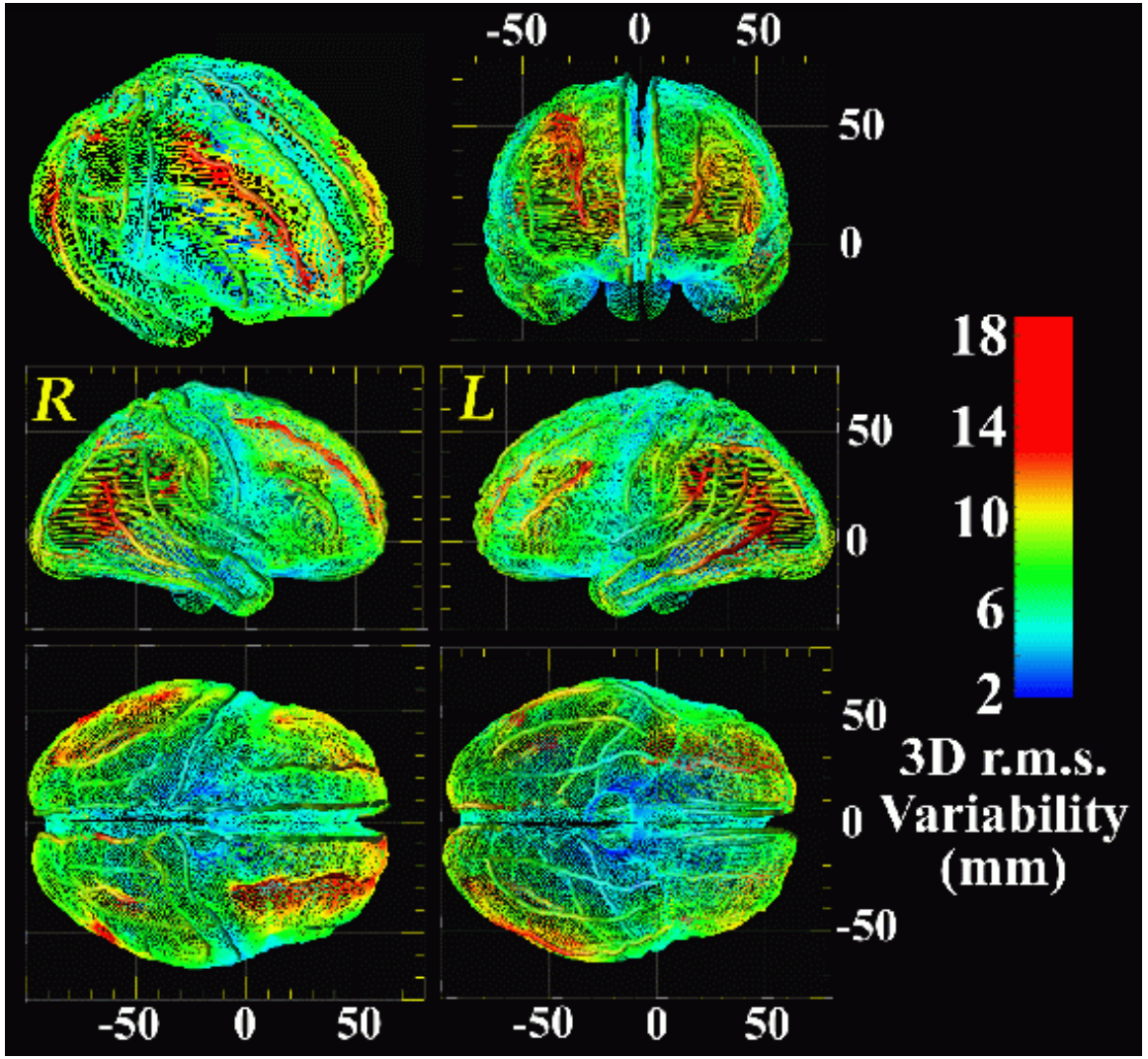
See some amazing images at http://mars.nasa.gov/mars3d/

Motion estimation



Source: Wikipedia

Diagnosis of diseases



Source: http://users.loni.usc.edu/~thompson/HBM99absAD.html

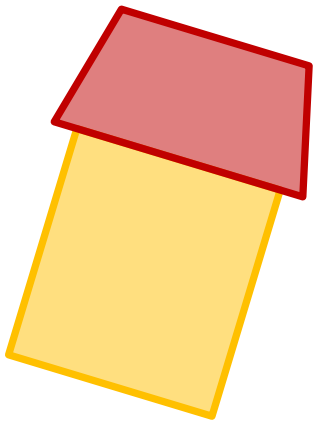
Examples of image registration

- Individual
  - Aligning an image taken now with one taken on a previous occasion.
  - Aligning two images of different sorts (e.g. map and an aerial photograph).
  - Aligning images taken with different modality (e.g. visible light and infrared).
- Groups
  - Stitching images taken at different angles and orientations
  - Aligning the images of patients to develop a statistical model of variation associated with a disease.

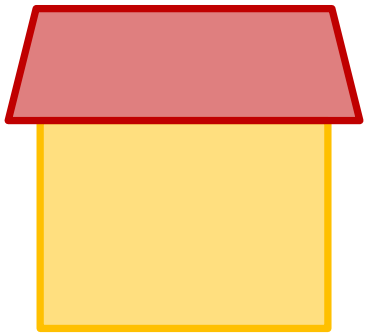
Components of registration

The registration problem for two images can be mathematically formulated as follows:

Find transformation that minimises the difference between the reference image and target image



Reference

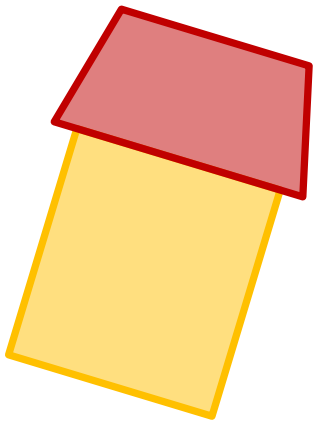


Target

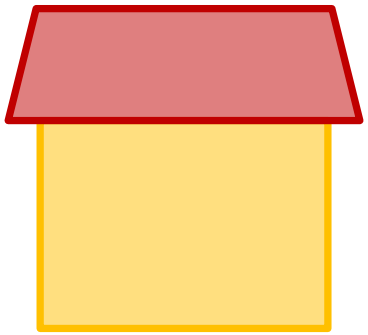
Components of registration

The registration problem for two images can be mathematically formulated as follows:

Find transformation that minimises the difference between the reference image and target image



Reference



Target

Components of registration

Issues to consider

- What entities do we match? Features, intensities, ...
- What kinds of transforms? Rigid, elastic, ...
- What similarity criterion to use?
- How to find the best transformation?
- What interpolation method to use? Bilinear, spline, ...

Components of registration

- What entities do we match? Features, intensities, ...
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- How to find the best transformation?
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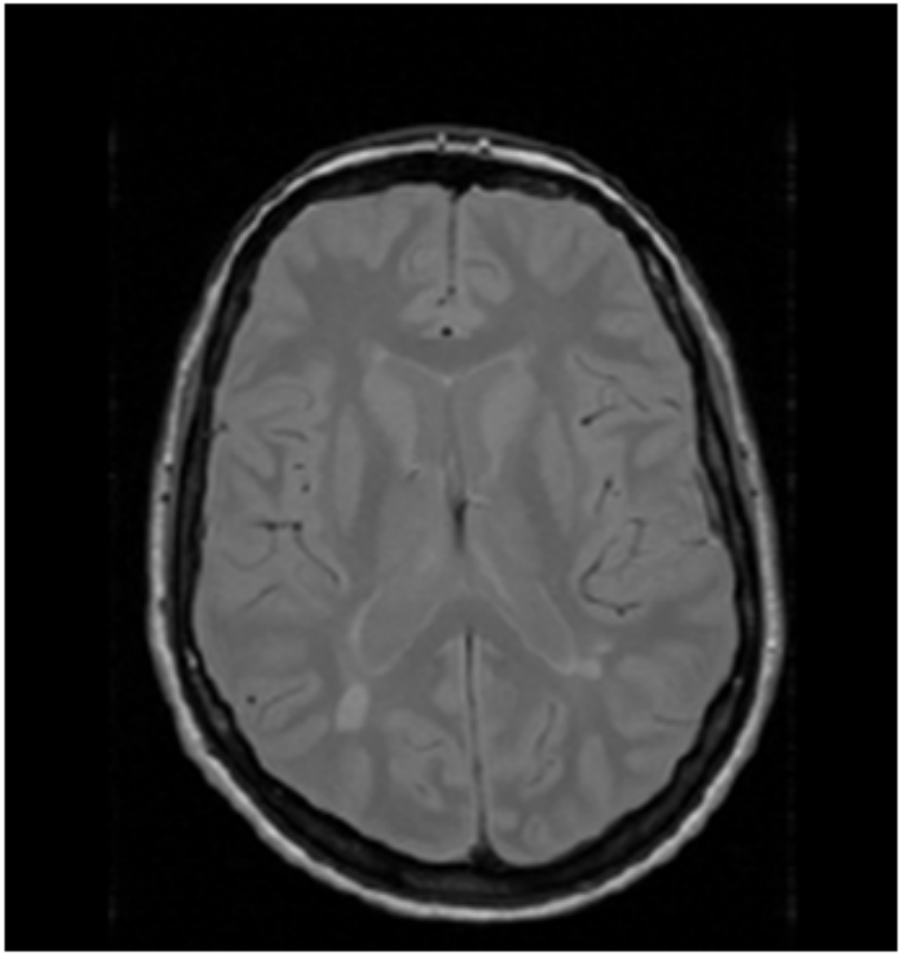
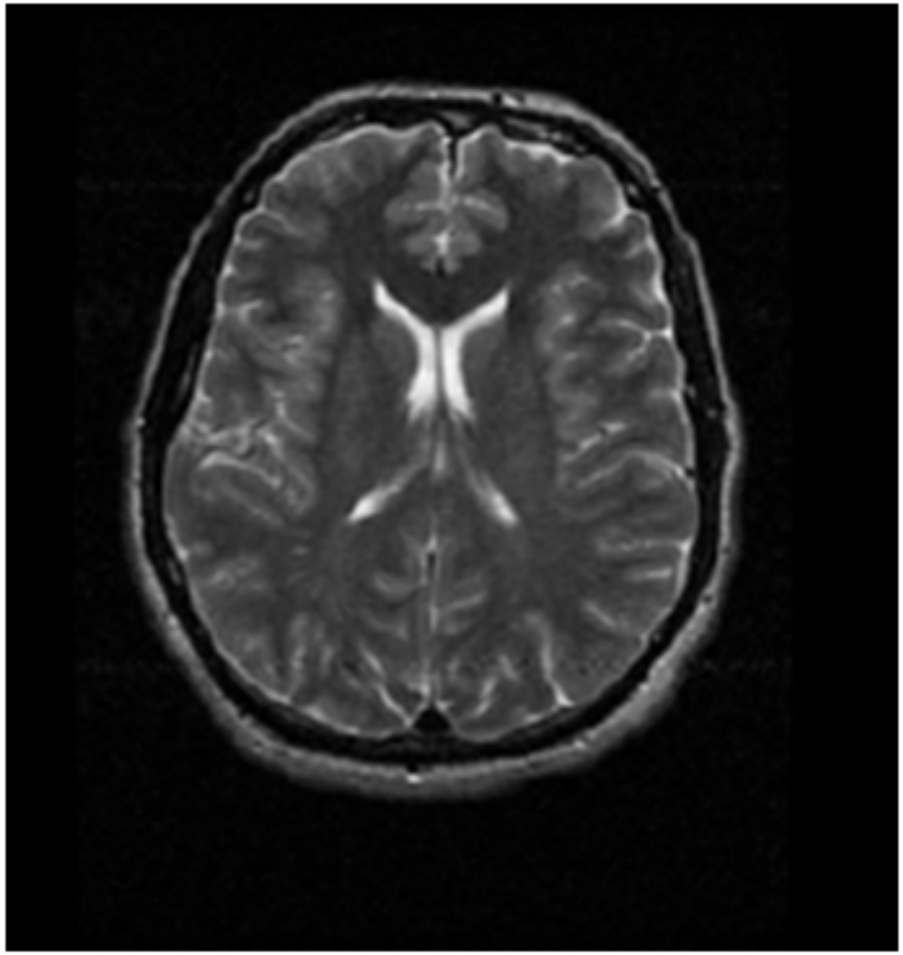
Feature based registration

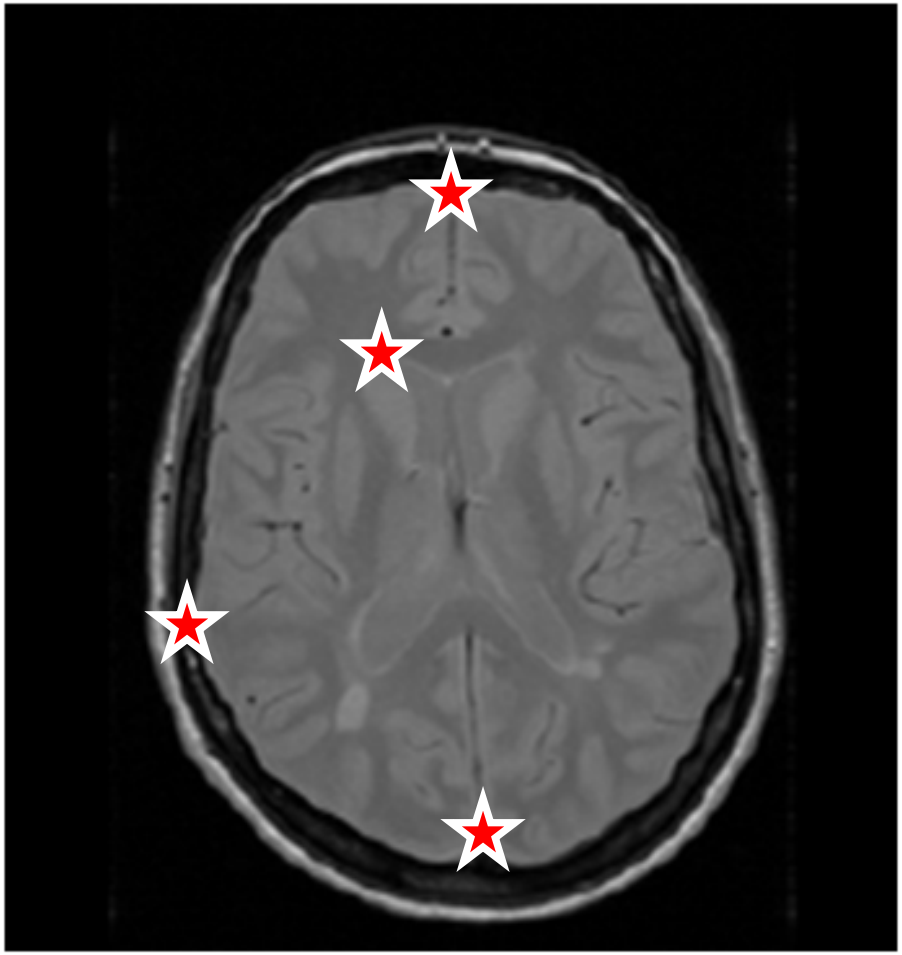
- Landmarks (normally a small number)
- Edges, contours or surfaces
- Salient features
  - Corners
  - Centres
  - Points of high curvature
  - Line intersections
- Can be chosen manually or automatically

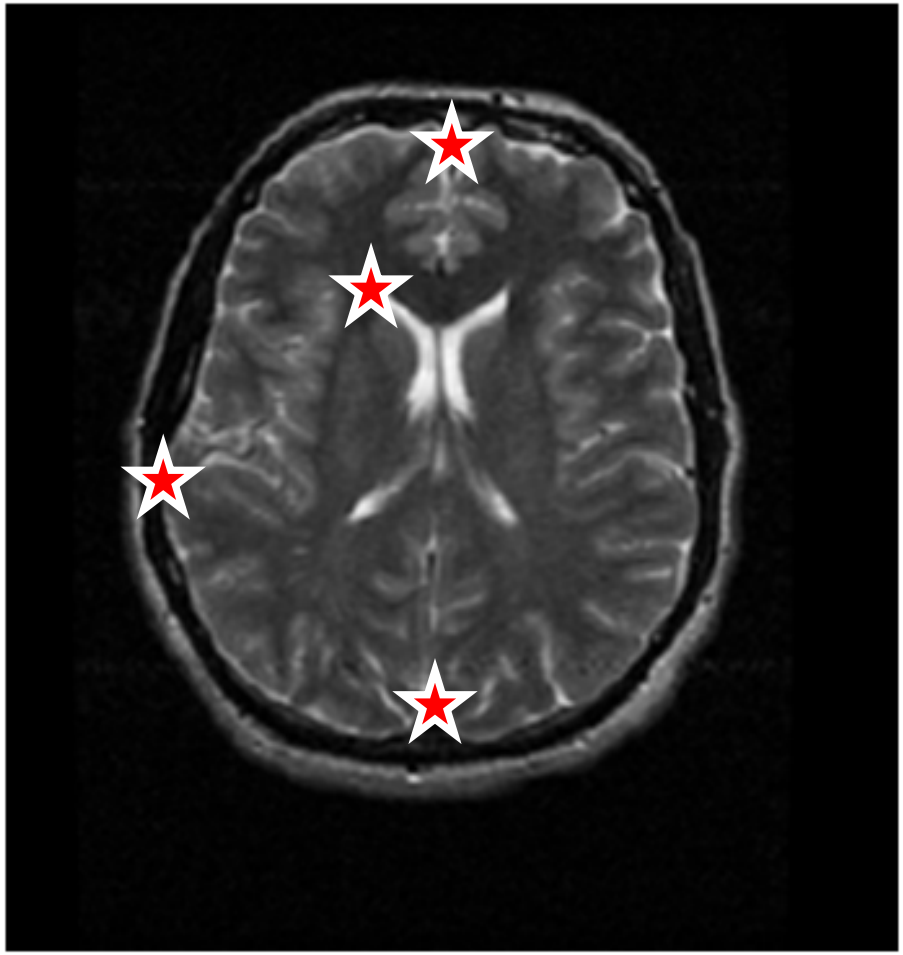
Feature based registration
Landmarks



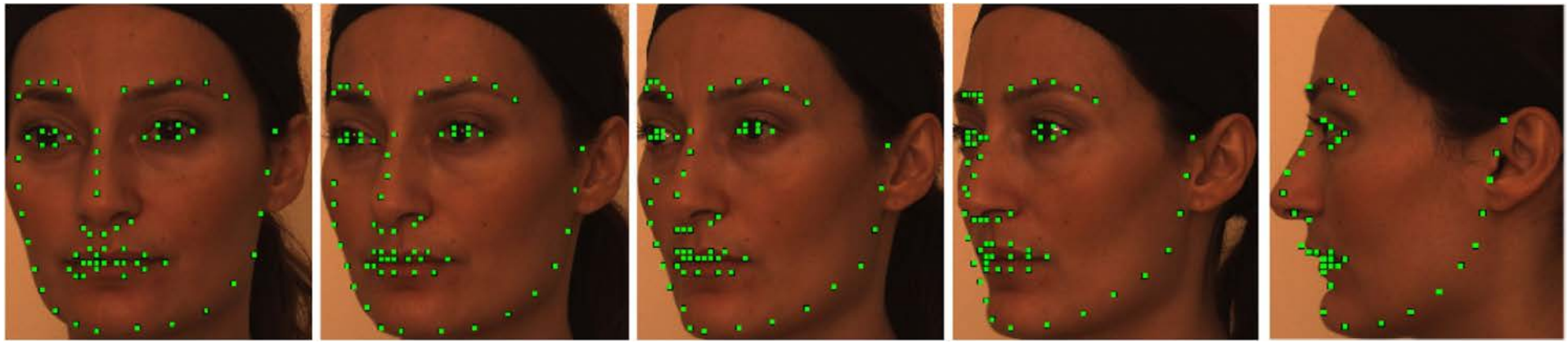


Feature based registration
Landmarks

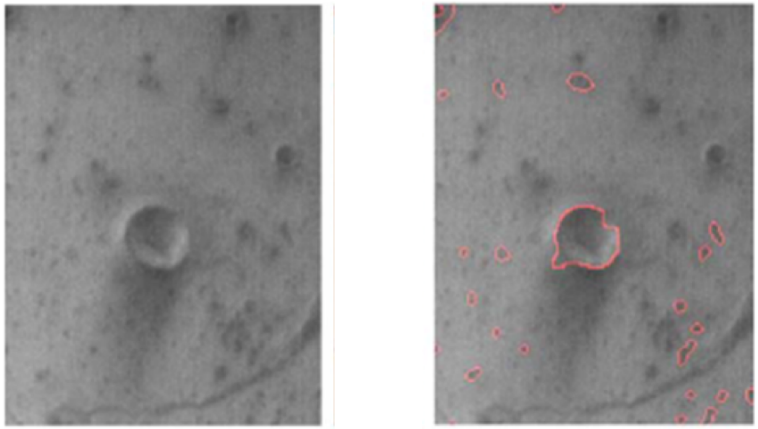


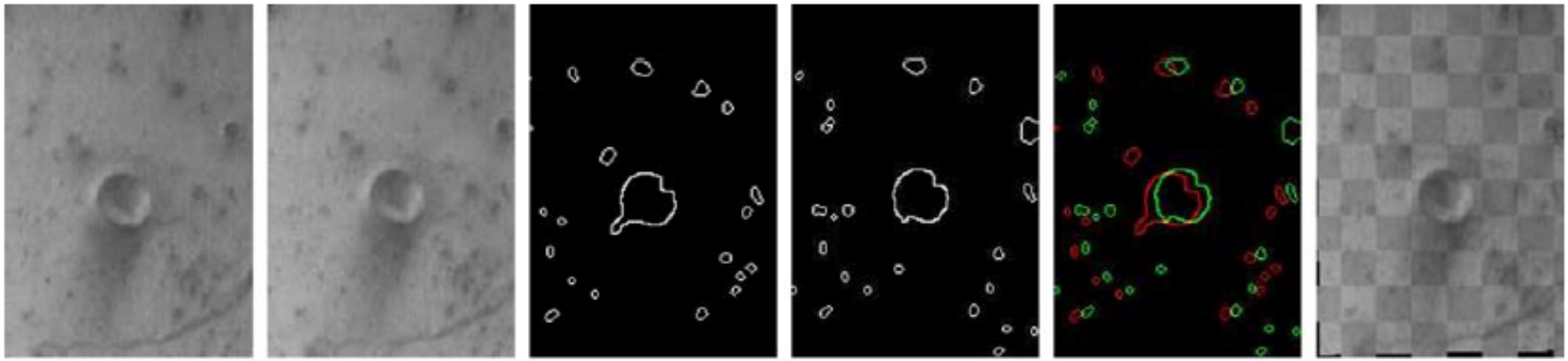


Feature based registration
Landmarks



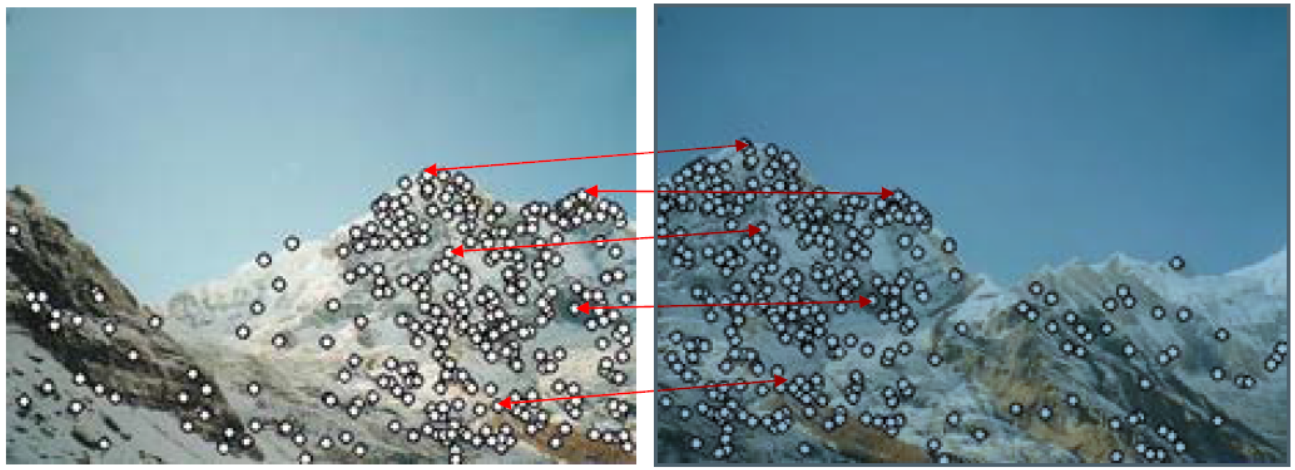
Feature based registration
Edges / Contours





Automatic Extraction of Ellipsoidal Features for Planetary Image Registration, IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 9, NO. 1, JANUARY 2012

Feature based registration
Salient features



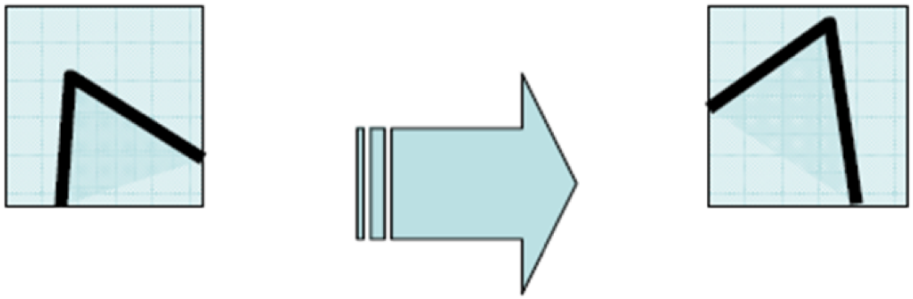
SIFT - Scale Invariant Feature Transform

Salient features

- Invariant to (do not change after) rotation, scaling, change of brightness / colour
- Descriptors
  - What
  - Where
- Popular methods
  - Harris corner detector
  - SIFT (Scale Invariant Features Transform)

Harris corner detector

- A corner is a salient feature: it is the intersection of two edges and represents a point in which the directions of these two edges change.
- The gradient of the image (in both directions) have a high variation, which can be used to detect it.
- Corner response is ***invariant*** to image rotation



SIFT
Scale Invariant Feature Transform

- SIFT selects feature points and for each stores:
  - Location,
  - Orientation
  - Scale.

David G. Lowe,"Distinctive image features from scale-invariant keypoints", International Journal of Computer Vision, 60, 2 (2004), pp. 91-110

SIFT: Invariant point descriptors

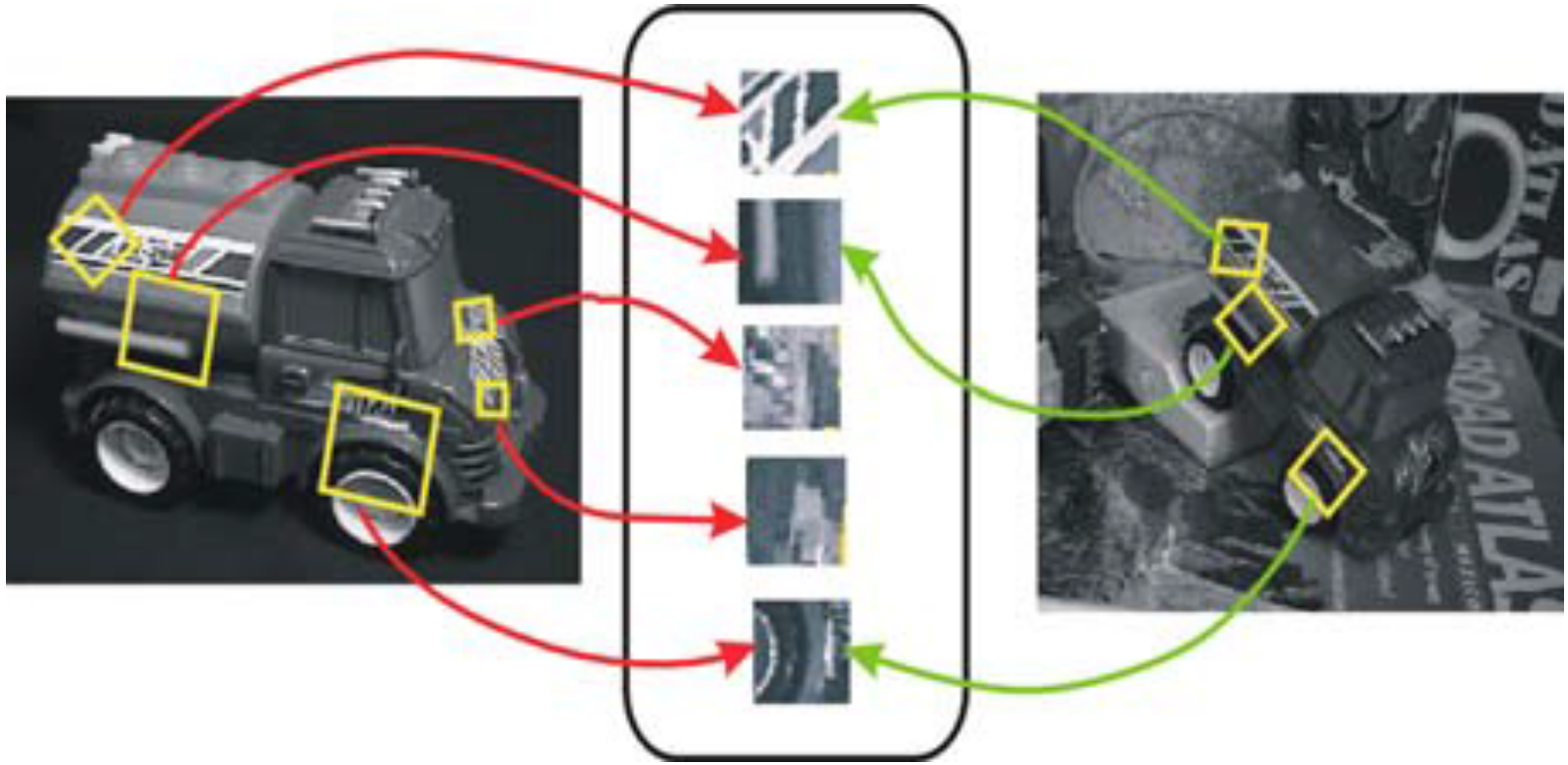
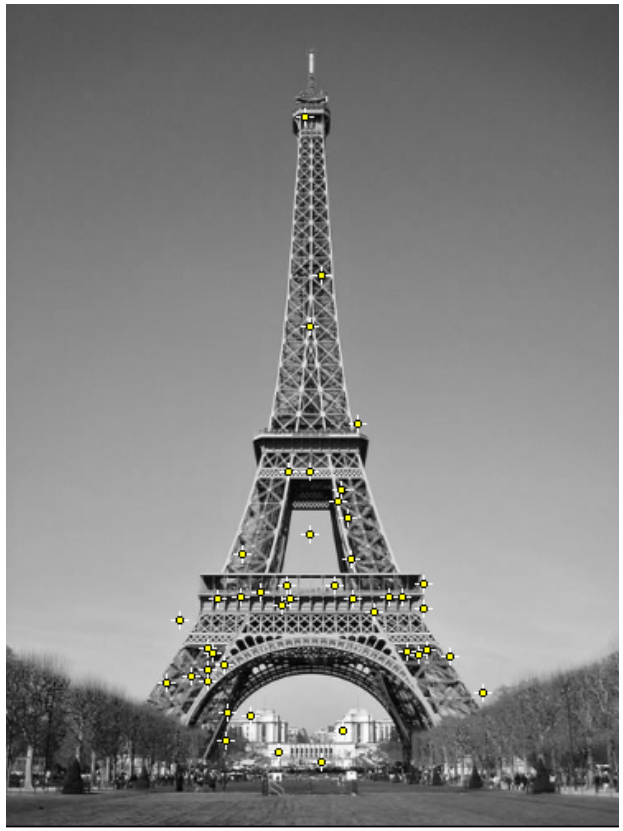


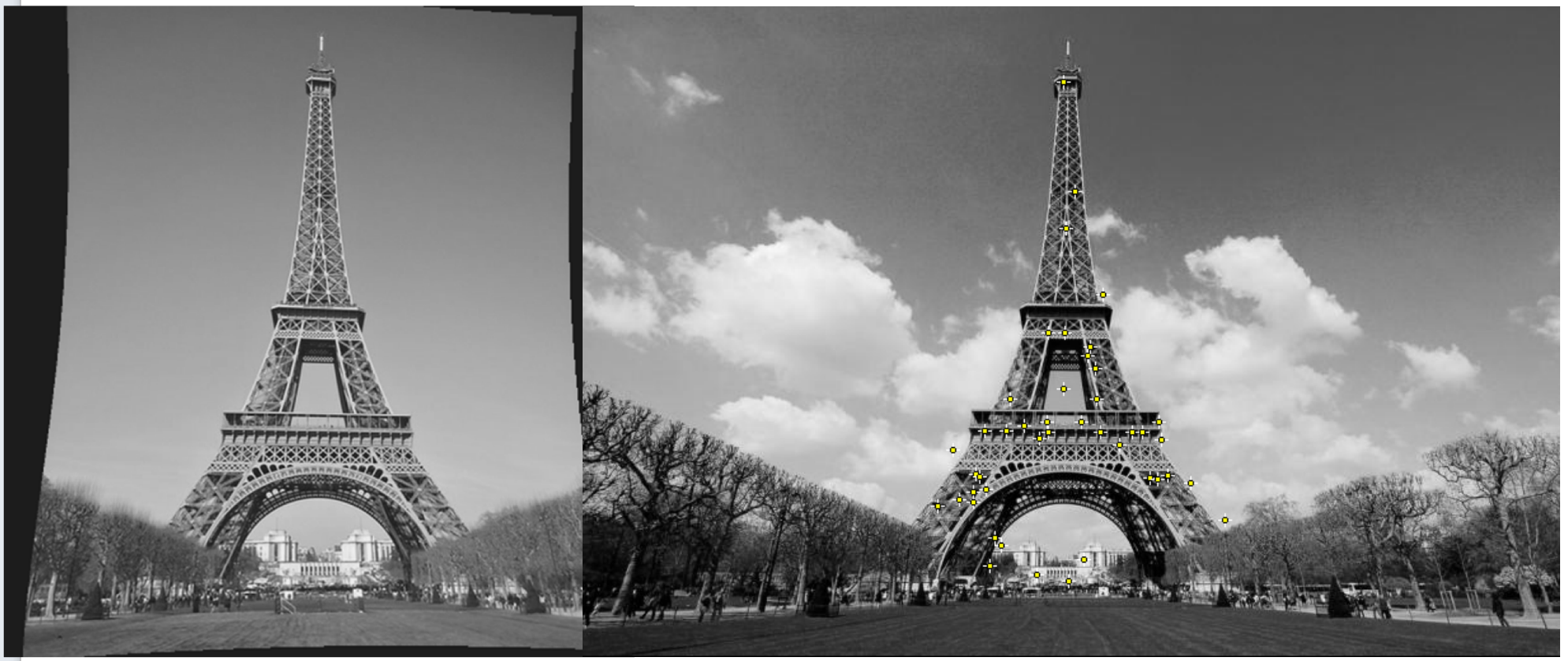
Image content is transformed into local feature coordinates that are invariant to translation, rotation, scale, and other imaging parameters

SIFT-based registration - example



Before registration
Yellow markers indicate points selected by SIFT

SIFT-based registration - example



After registration
Yellow markers indicate points selected by SIFT

Components of registration

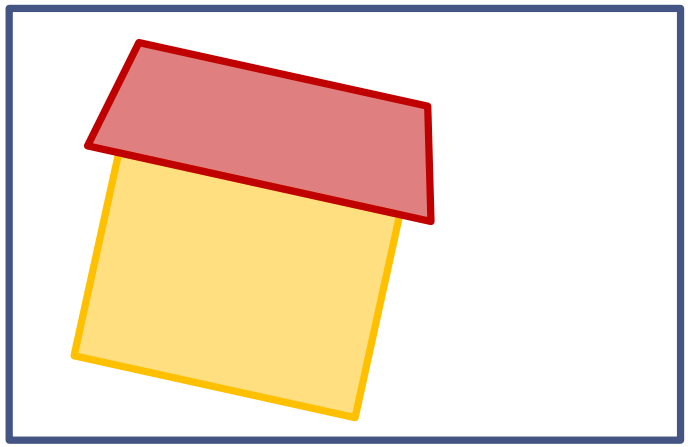
- What entities do we match? Features, intensities, ...
- What kinds of transforms? Rigid, elastic, ...
- What similarity criterion to use?
- How to find the best transformation?
- What interpolation method to use? Bilinear, spline, ...

Transformation Model

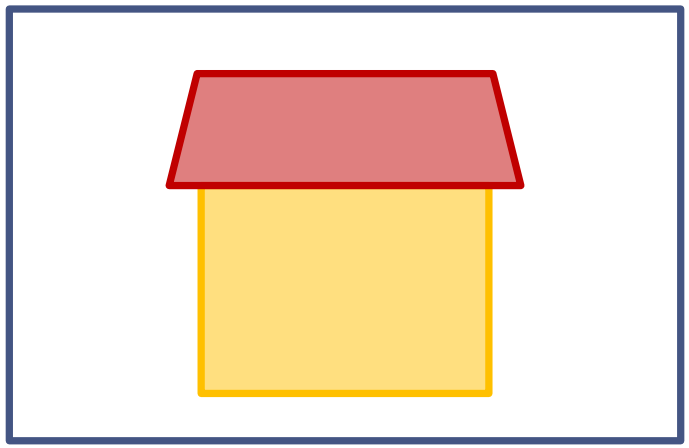
- Rigid
- Affine
- Elastic (non-rigid)

Rigid Transformation Model

- Used for registration when there is no image distortion
- Composed of rotations and translations (shifts)



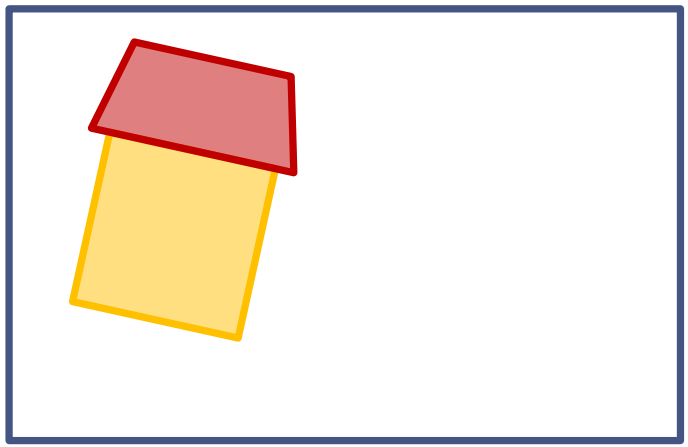
Reference



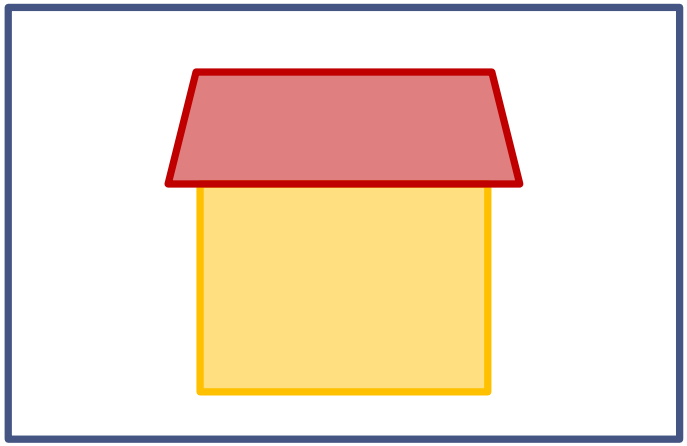
Target

2D Affine Transforms

- Used for registration when there is global gross-overall distortion
  - Translations
  - Rotation
  - Scaling
  - Shear (skew)



Reference



Target

Non-rigid (elastic) transformation

- Think of the original image as an "elastic surface" acted upon by two types of forces
- External forces drive deformation
- Internal forces provide constraints

Demos

- Coherent Point Drift Registration (CPD)

  (points, rigid and affine)

  https://sites.google.com/site/myronenko/research/cpd

- MIRT

  (images, elastic)

  https://sites.google.com/site/myronenko/research/mirt

Components of registration

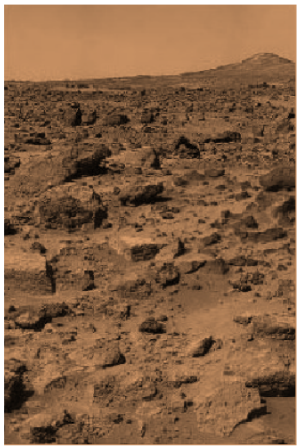
- What entities do we match? Features, intensities, ...
- What kinds of transforms? Rigid, elastic, ...
- What similarity criterion to use?
- How to find the best transformation?
- What interpolation method to use? Bilinear, spline, ...

Similarity Metrics

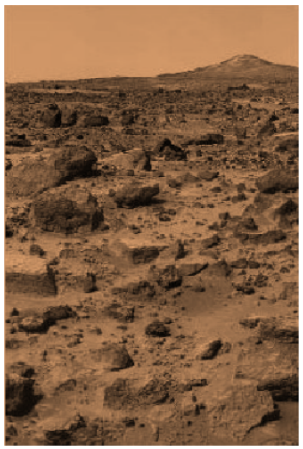
- Feature-based methods (using corners, edges, etc)
  - Geometric distance between corresponding points
  - Similarity metric between feature values
    - Similar curvature
    - Similar angles of the detected corners, etc
- Intensity-based Methods (i.e. using image values)
  - Mean Squared Difference / Sum of Squared Differences
  - Mutual Information

Example: Mars surface, stereo-pair

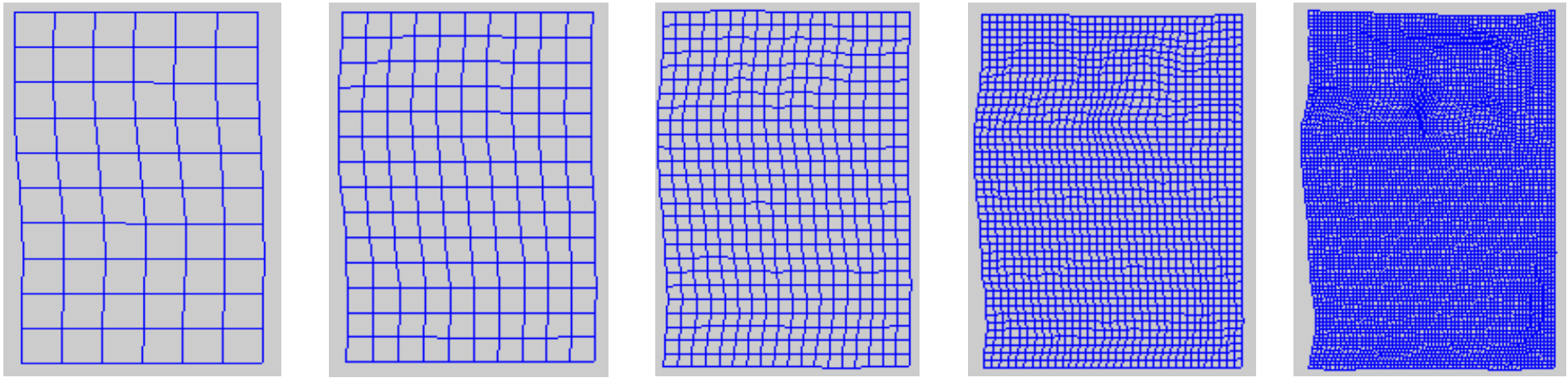
Elastic registration using mutual information as a metric



Base image

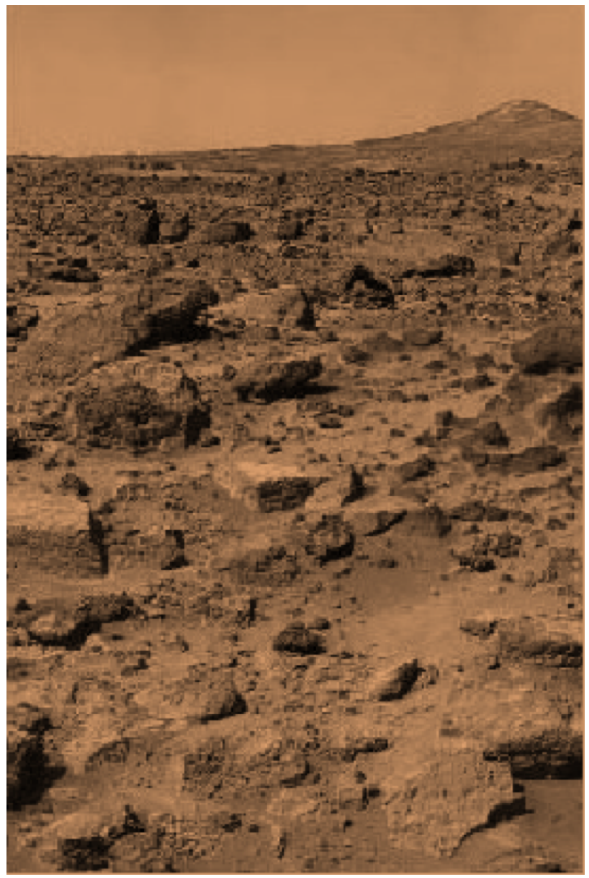


Floating image

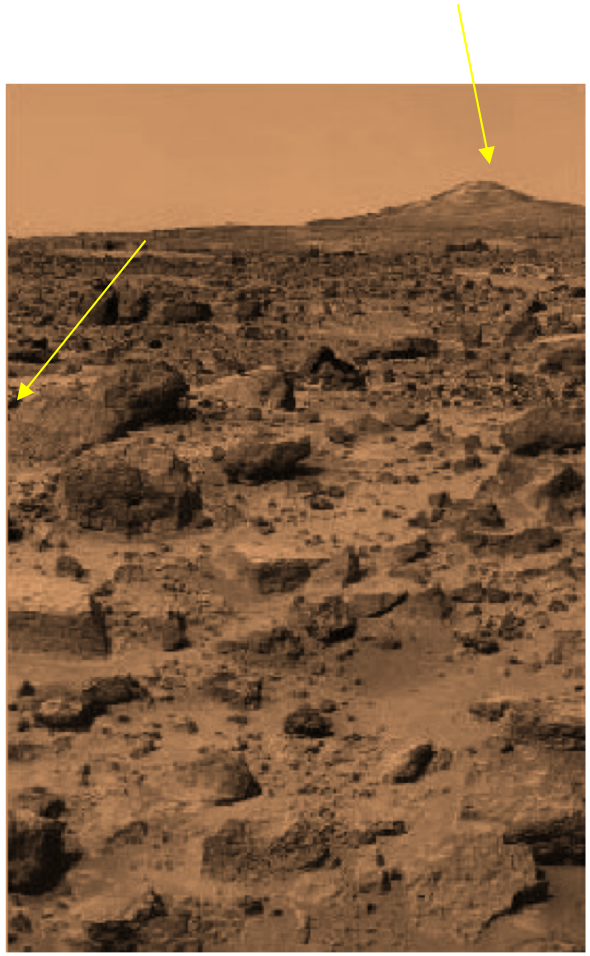


Elastic deformation at the increasing level of detail

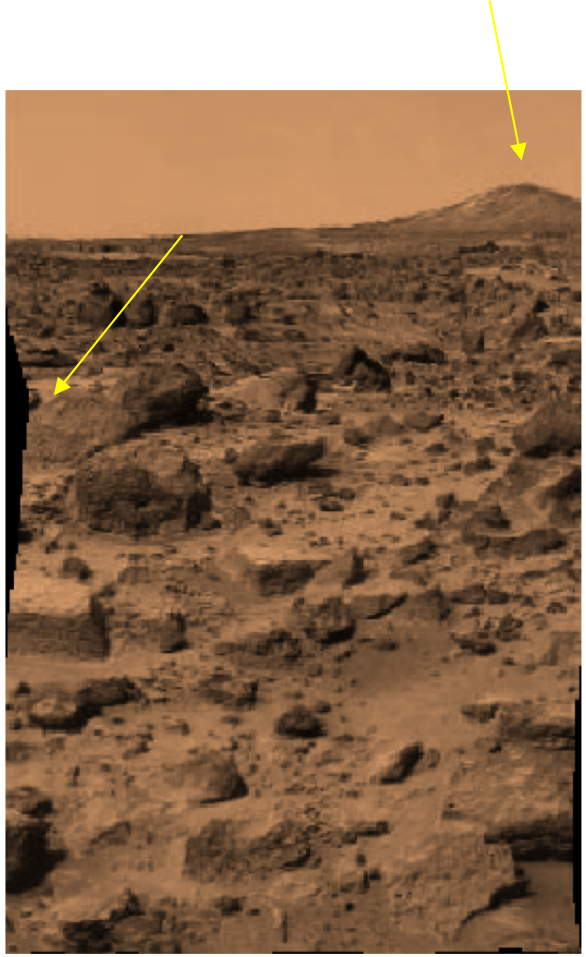
Example: Mars surface, stereo-pair



Base image



Floating image
before registration



Floating image
after registration

Components of registration

- What entities do we match? Features, intensities, ...
- What kinds of transforms? Rigid, elastic, ...
- What similarity criterion to use?
- How to find the best transformation?
- What interpolation method to use? Bilinear, spline, ...

Optimisation

Optimisation involves finding some "best" parameters of transformation according to an "objective function"

- Gradient Descent
- Conjugate Gradient Descent
- Multi-resolution search
- Deterministic Annealing

Components of registration

- What entities do we match? Features, intensities, ...
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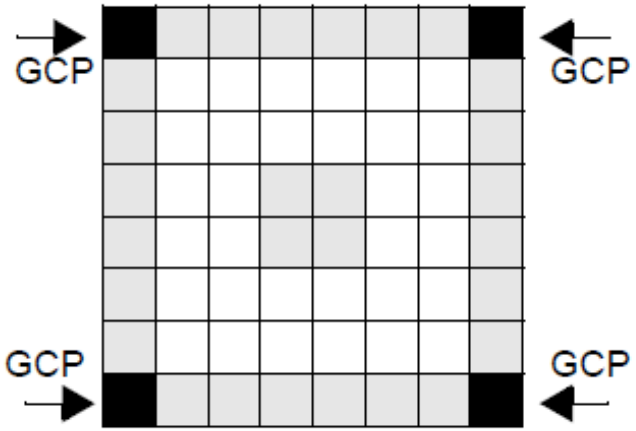
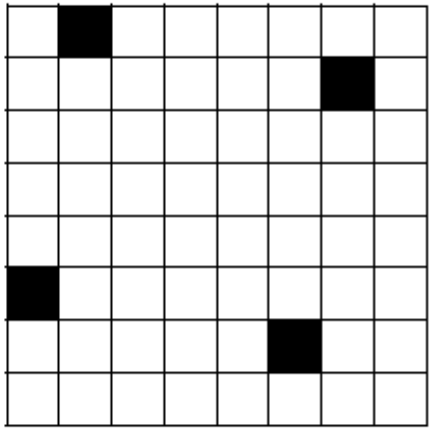
Resampling and interpolation

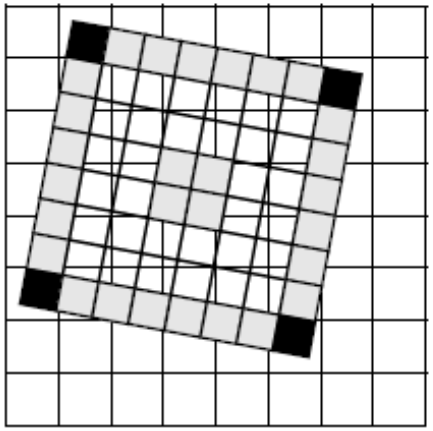
Resampling



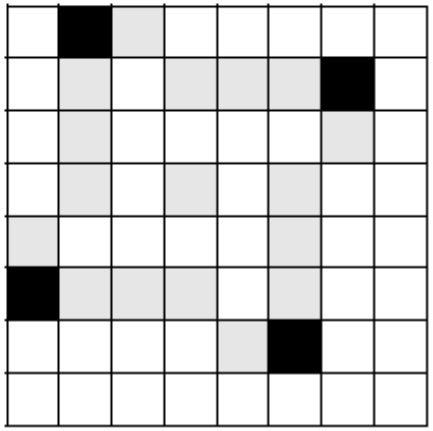
1. The input image with source GCPs.



2. The output grid, with reference GCPs shown.



3. To compare the two grids, the input image is laid over the output grid, so that the GCPs of the two grids fit together.



4. Using a resampling method, the pixel values of the input image are assigned to pixels in the output grid.

Resampling and interpolation

- Resampling is used to determine the digital values to place in the new pixel locations of the transformed output image
- New pixel / voxel values are computed using various interpolation methods
  - Linear
  - Piecewise-linear
  - Polynomial
  - Cubic spline
  - Others …

In this lecture we have covered:

- Image registration: what it is and what it is for
- What we try to align
  - Image features
  - Image values
- How we carry out image transformations
  - Rigid and affine
  - Elastic
- How we measure the success of registration
- How we compute the final pixel values

Next lecture: Advanced topics 2

- Statistical shape models
  - What they are
  - What they are used for
- Principal Component Analysis (PCA)
  - What it is
  - How it is used for shape modelling
- Point distribution models
- Active shape models
- Active appearance models

Further reading and experimentation

- **Image registration – general resources**
- http://cecs.wright.edu/~agoshtas/CVPR04_Registration_Tutorial.html

- **Harris corner detection**
- http://docs.opencv.org/2.4/doc/tutorials/features2d/trackingmotion/harris_detector/harris_detector.html

- **SIFT features**
- http://opencv-python-tutroals.readthedocs.io/en/latest/py_tutorials/py_feature2d/py_sift_intro/py_sift_intro.html

- *HIPR2 resources*
- **Geometric transformations**
- http://homepages.inf.ed.ac.uk/rbf/HIPR2/geomops.htm