Automatic Image Registration

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Syllabus

- Registration problem
  - Definitions, examples
  - Main components
- Automatic registration approaches
  - Extracted geometric feature-based
  - Voxel similarity-based
- Some applications
  - Medical
  - Neutron tomography

Image Registration

Task:

To find geometrical correspondence between images.

Why:

The images were taken
- from different viewpoints and/or
- by different imaging devices and/or
- at different times.

Terms:

- *Image registration*
- *Image alignment*
- *Image fusion*

Geometric Image Transformations

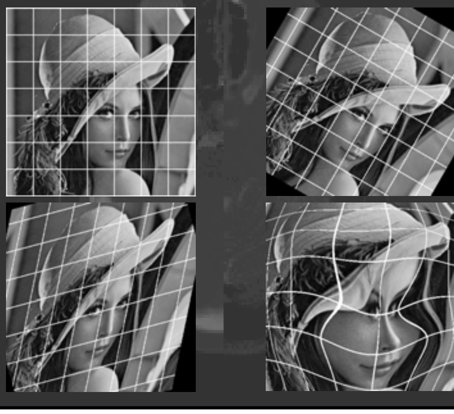

Image Mosaicking

Vision Research Lab, UCSB

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Image Mosaicking

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Image Mosaicking

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Image Mosaicking

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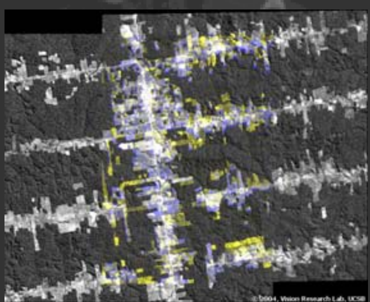
Detecting Temporal Changes

1992 1994

Amazonian Deforestation Progress Vision Research Lab, UCSB

Detecting Temporal Changes



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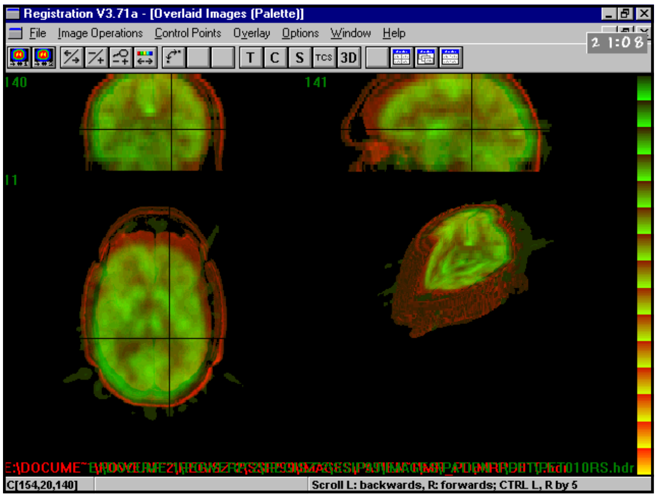
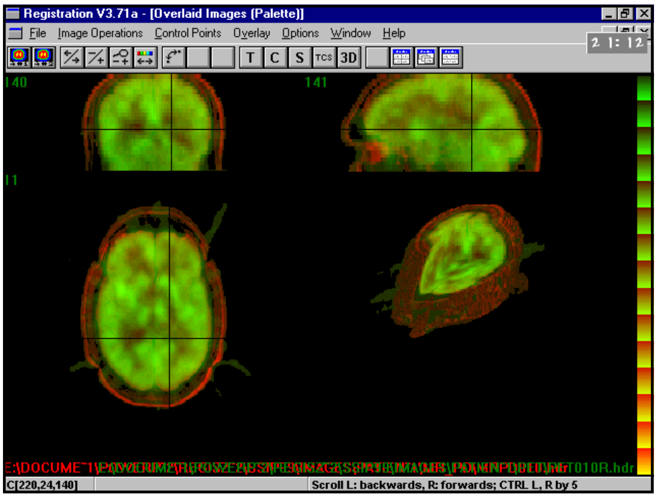




Major Research Areas

- Computer vision and pattern recognition
  - segmentation, motion tracking, character recognition, stereo vision, template matching
- Medical image analysis
  - combining information from multiple imaging modalities
  - monitoring changes in size, shape, or image intensity over time intervals
  - relating preoperative images and surgical plans to the physical reality of the patient
  - relating an individual's anatomy to a standardized atlas
- Remotely sensed data processing
  - geology, agriculture, oceanography, oil and mineral exploration, forestry, military
- ...

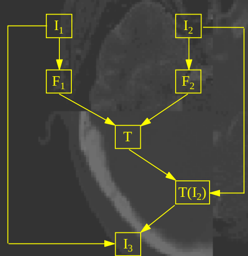
Variations Between Images

- Corrected distortions (easier)
  - Distortion which can be modeled (e.g. geometric differences due to viewpoint changes).
- Uncorrected distortions (medium)
  - Distortions which are difficult to model (e.g. lighting and atmospheric conditions, shadows, occlusion, multimodality).
- Variations of interest (harder)
  - Differences we would like to detect (e.g. object movements or growth).

Main Components

- Search space
  - Type of geometric transformation.
    - Linear: rigid-body, similarity, affine, projective.
    - Non-linear: polinomial, spline-based, based on physical model, etc.
- Feature space
  - What features to use to find the optimal transformation.
    - Detected geometic features: points, edges, curves, contours, surfaces.
    - Image intensity values.
- Similarity measure
  - Defines how similar two images are.
    - Distance between geometric features (Euclidean, Hausdorff, etc.).
    - Similarity between image intensities: differences, correlation, information theory based.
- Search strategy
  - How to find the global optimum of the similarity measure.
    - Direct methods, multiresolution techniques, genetic algorithms, heuristic search, etc.

Registration Process



Feature extraction

Determining the optimal transformation

Applying the transformation

Image fusion

Interactivity

- Manual
  - Decent visualization software is necessary, labour intensive.
- Semi-automatic (interactive)
  - Reliable, fast, but trained user might be required.
    - User initializes (e.g. point selection, segmentation).
    - User decides (accept/reject).
    - Combined together.
- Automatic
  - Easy to use.
  - Usually accurate, but visual inspection is necessary.
  - Can take a lot of time (especially in nonlinear cases).

Automatic registration is preferred, especially when registration is a „building block” of a bigger project.

Automatic Registration Algorithms

- Extracted geometric features
  - Point-based methods,
  - Contour/surface fitting methods,
  - Unique templates.
- Voxel similarity measures
  - Intensity differences,
  - Correlation techniques,
  - Measures based on information theory.

Point Pair Selection

- Feature extraction
  - E.g. corner points.
  - Should be invariant against geometric deformations.
- Determining point correspondences
  - Outlier detection!
- Determining transformation
  - E.g., least squares fit of corresponding points.

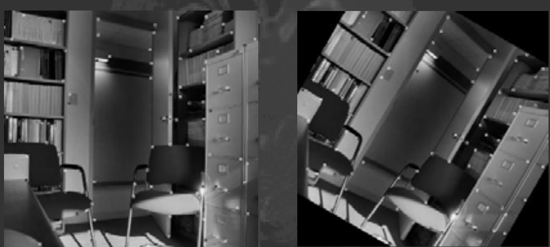
Cornerness Measures

- Inertia matrix $C(x,y)=\begin{bmatrix}\overline{I_x(x,y)\cdot I_x(x,y)} & \overline{I_x(x,y)\cdot I_y(x,y)}\\ \overline{I_y(x,y)\cdot I_x(x,y)} & \overline{I_y(x,y)\cdot I_y(x,y)}\end{bmatrix}$
- Harris and Stephens $R=\frac{k}{(k+1)^2}\cdot\left[\det(C)-tr(C)\right]$ $k=\frac{\lambda_1}{\lambda_2}$
- Kitchen and Rosenfeld $\frac{I_{xx}I_y^2-2I_{xy}I_xI_y+I_{yy}I_x^2}{I_x^2+I_y^2}$
- Hartkens, Rohr
  - Measures based on the first order derivatives are the best for multimodal medical images.

Detecting Corner Points

- Selecting stable corners
  - By examining different sizes of circular local neighbourhoods.
- Decrease the number of points
  - Only one corner point in a local neighbourhood.
- Speed up the search
  - Calculate the edges of the images.

Stable Corners Example



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Determining Correspondence

- Matching using scene coherence
  - Three non-colinear point pairs are selected, others are used for verification.
  - Checking all combinations (for small point sets), using points on the convex hull, minimum-spanning trees, RANSAC (randomly selected subsets of the point sets).
- Matching using clustering
  - The most probable transformation parameters are determined using accumulator arrays.
- Matching using invariance
  - Comparing the affine invariant property of three point pairs.

Voxel Similarity Measures

- Preprocessing
  - No feature detection is necessary.
  - Intensity range may be transformed.
    - E.g., scaling from [-1000,4000] to [0,255].
    - Applying Window/Level technique.
  - Selection of regions of interests (masking).
- Search
  - Using a multi-resolution approach is popular.

Intensity Differences

$$\mathrm{SSD} = \frac{1}{N} \sum_{x_A \in \Omega_A} \left| A(x_A) - B^T(x_A) \right|^2 ,$$

$$\mathrm{SAD} = \frac{1}{N} \sum_{x_A \in \Omega_A} \left| A(x_A) - B^T(x_A) \right|$$

- Optimal when the noise is Gaussian.
  - For unimodality registration.
  - Unimodality problems
    - Noise is not Gaussian in MR.
    - Contrast agents can cause big intesity differences.

Correlation Techniques

$$\mathrm{C} = \frac{1}{N} \sum_{x_A \in \Omega^T_{A,B}} A(x_A) \cdot B^T(x_A)$$

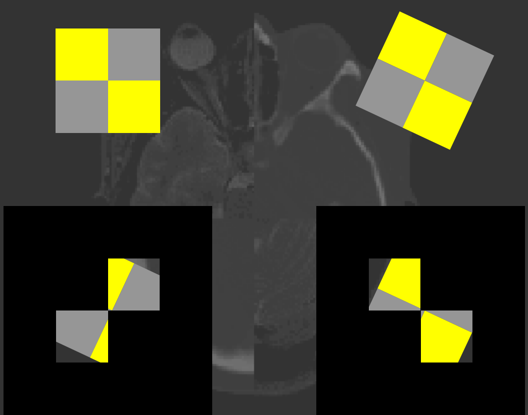
$$\mathrm{CC} = \frac{\sum_{x_A \in \Omega_A} \left(A(x_A) - \bar{A}\right) \cdot \left(B^T(x_A) - \bar{B}\right)}{\sqrt{\sum_{x_A \in \Omega_A} \left(A(x_A) - \bar{A}\right)^2 \cdot \sum_{x_A \in \Omega_A} \left(B^T(x_A) - \bar{B}\right)^2}}$$

- Optimal when the relationship is linear between intensities of the images.
  - For unimodality registration.

Partitioned Image Uniformity

$$\mathrm{PIU} = \sum_a \frac{\mathrm{n_a}}{\mathrm{N}} \cdot \frac{\sigma(a)}{\mu(a)} \qquad n_a = \sum_{\Omega_a} 1 \qquad \mu(a) = \frac{1}{n_a} \cdot \sum_{x_A \in \Omega_a} B^T(x_A) \qquad \sigma(a) = \sum_{x_A \in \Omega_a} \left(B^T(x_A) - \mu(a)\right)^2$$

- Assumed: an intensity value describes a tissue type well in both images.
- For MR-PET registration (Woods, 1992)
  - Remove parts outside of brain from PET.
  - Transform MR intensity scale to 256 values.
  - Maximizes the uniformity of the intensities from PET paired with intensities of MR.



Mutual Information

MI(X,Y) = H(X) + H(Y) - H(X,Y)
NMI(X,Y) = (H(X) + H(Y)) / H(X,Y)

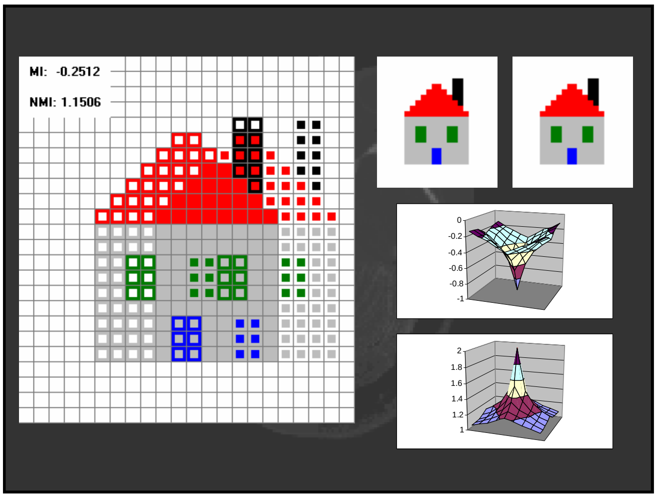
H(X), H(Y): entropy
H(X,Y): joint entropy

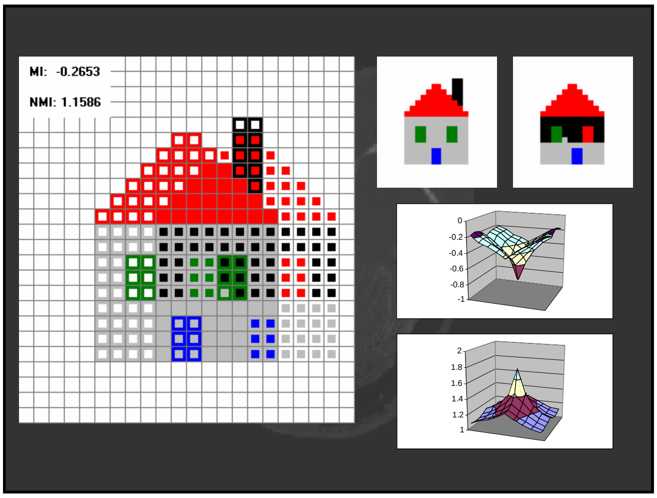
$$\mathrm{H(A)} = -\sum_a p_A(a) \cdot \log p_A(a)$$

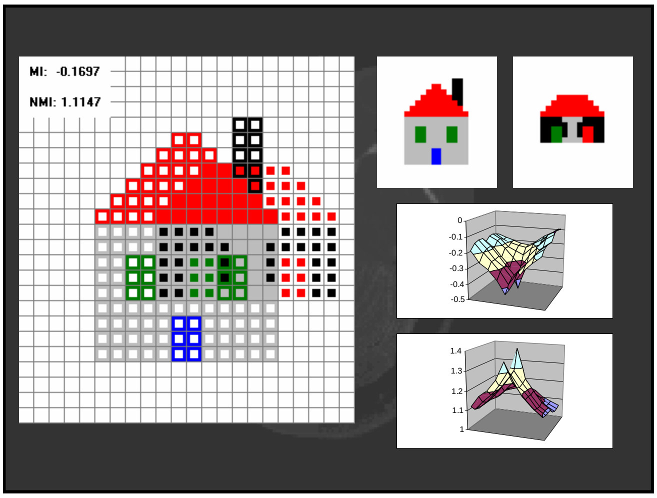
$$\mathrm{H(B^T)} = -\sum_a p_{B^T}(a) \cdot \log p_{B^T}(a)$$

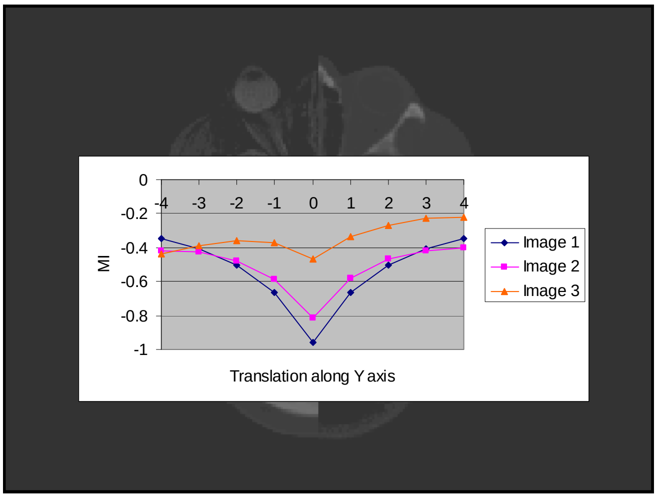
$$\mathrm{H(A,B^T)} = -\sum_a \sum_b p_{AB^T}(a,b) \cdot \log p_{AB^T}(a,b)$$

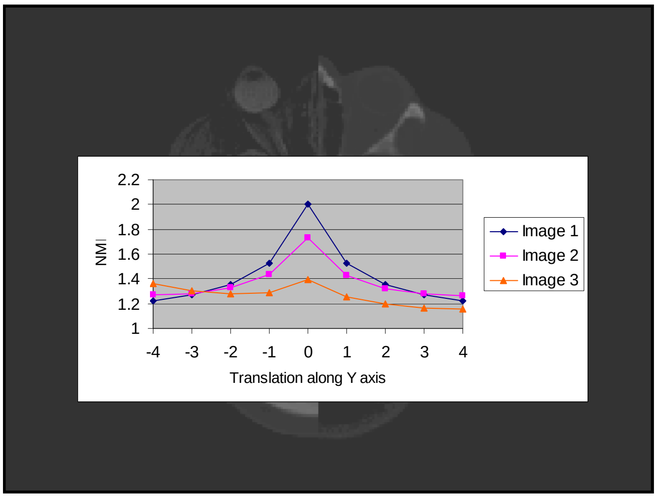
(Collignon, Viola 1995)





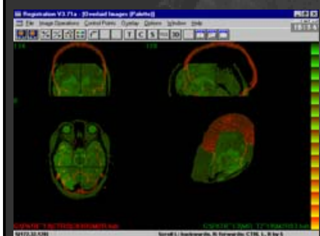


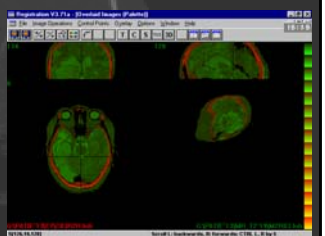




Applications

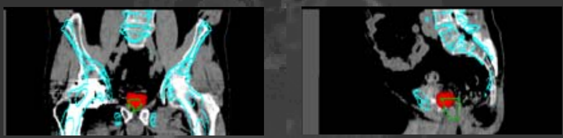
- MR-CT and MR-PET validation
  - Vanderbilt database



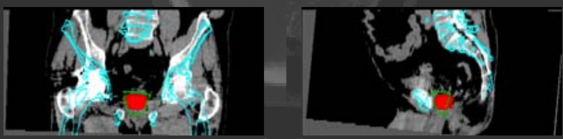


Applications

- Registering CT images of different patients



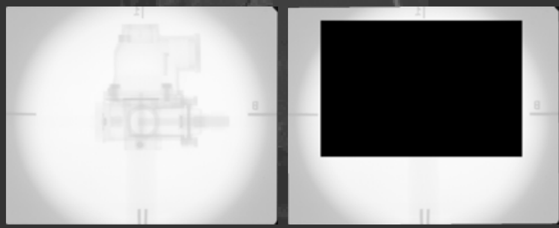
Global registration



Local refinement

Applications

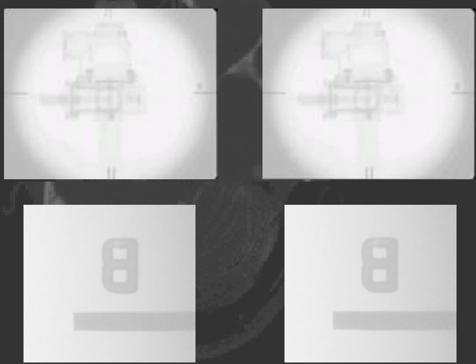
- Registering neutron tomography projections
  - Masking



Before registration | After registration

Whole image

Marker cut



Automatic Registration Algorithms

- Extracted geometric features
  - Intuitive for unimodal problems.
- Voxel similarity measures
  - Can be used for unimodal and multimodal problems.

Selected Surveys and Books

- General
  - Brown, L.G.: A survey of image registration techniques. ACM Computing Surveys 24 (1992) 325-376
  - Modersitzki, J.: Numerical Methods for Image Registration. Oxford University Press (2004)
  - Goshtasby, A.A.: 2-D and 3-D Image Registration for Medical, Remote Sensing, and Industrial Applications. Wiley and Sons (2005)
- Medical
  - Maintz, J.B.A., Viergever, M.A.: A survey of medical image registration. Medical Image Analysis 2 (1998) 1-36
  - Studholme, C.: Measures of 3D Medical Image Alignment. PhD Thesis, University of London (1997)
  - Hajnal, J.V., Hill, D.L.G., Hawkes, D.J. (eds.): Medical Image Registration. CRC Press (2001)
- Internet
  - http://vision.ece.ucsb.edu/registration/imreg/
  - http://www.imgfsr.com/