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Multi-Sensor Fusion

Graph-Entropic Approaches for Multi-Sensor Image Registration

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Agenda

- Outline of Graph-Entropic Registration Approach
- Model-based georeferencing with a DEM reference
- Graph matching and the tie-point matching problem
- Examples & Applications

Two key elements of our approach

- Use of digital elevation model (DEM) as reference
  - **Significant reduction** in registration parameter search space:

    {All perspective/projective transforms & associated perturbations}
    -> {collection geometry parameters}
- Novel graph-entropic cost function
  - **Generalizes** pixel-to-pixel mutual-information (MI) image registration to more conventional tie-point based registration
  - **Statistically robust** procedures to allow for missing/extra tie-points due to mismatch between multi-sensor phenomenologies
  - **Reduced computational complexity** relative to previous MI based approaches

Multi-Sensor Registration Approach

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- Nominally a three-step process for SAR <-> HSI/MSI image registration:
  1. **SAR <-> DEM:** Georeference SAR imagery via DEM-based registration
  2. **HSI/MSI <-> DEM:** Georeference EO imagery to DEM ref.
  3. **SAR <-> HIS/MSI:** Reproject both image sets onto common viewing plane; further refine registration by matching common tie-points
- Each step requires solution of a similar image matching problem

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Example: Multi-Sensor Registration Approach

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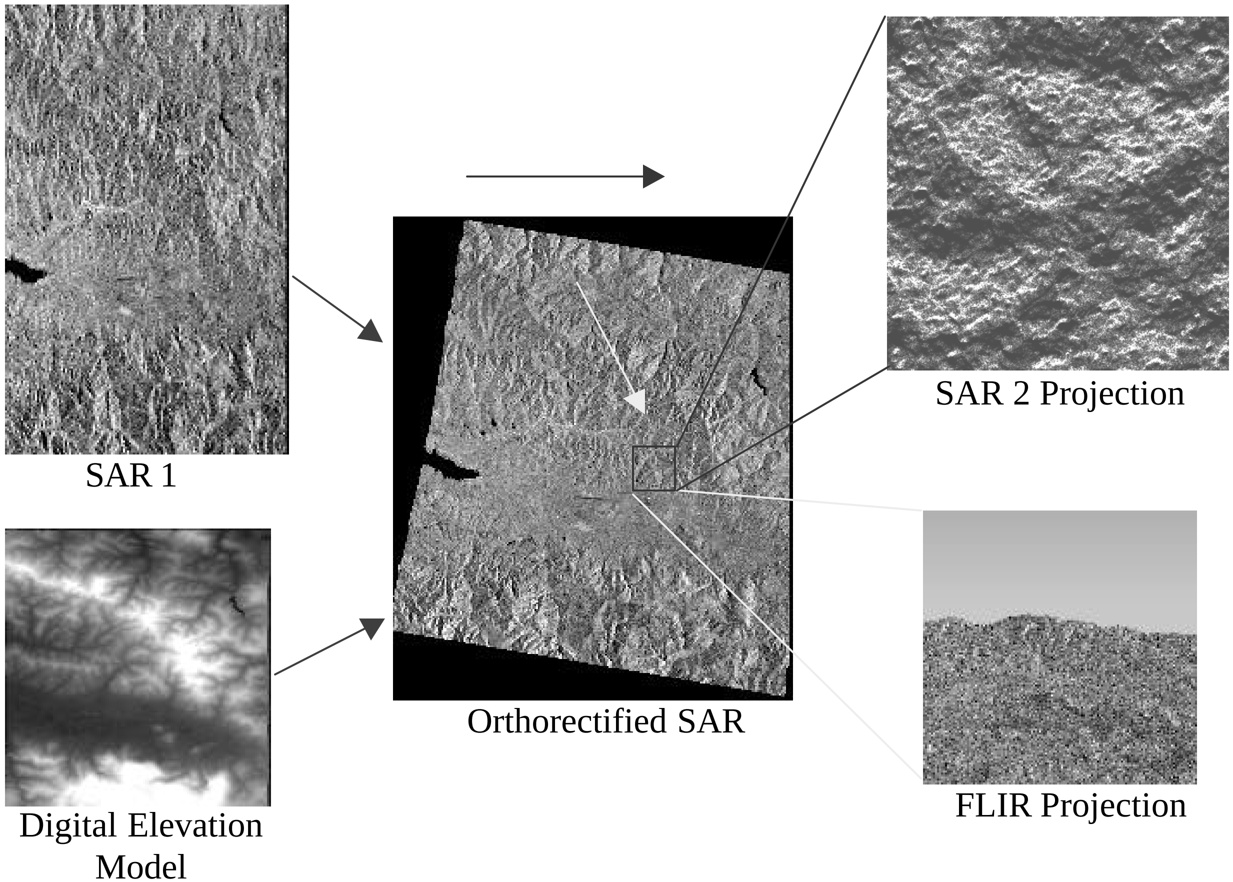

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Tie-point Based Image Registration

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- Assume the existence of tie-points, common spatial landmarks:
  - $\{Y_1, Y_2, ..., Y_M\}$ from the test image
  - and $\{X_1, X_2, ..., X_N\}$ from the reference image
- Tie-points can be selected via various means:
  - Natural terrain features such as shadows & discontinuities caused by terrain relief, features from man-made objects such as roads, buildings, agriculture, etc.
- Registration Problem: estimate and invert the mapping T: X -> Y
  - For flat terrain: degenerates to {projective, rotation, scale} transformations

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Graph-Entropic Tie-point registration

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- Basic Setup: $\{X_j\}_{j=1}^{M}$ $\{Y_k\}_{k=1}^{N}$ are spatial point processes in R^d representing tie points from a pair of images to be registered

- Assume *a priori* unknown distributions: $X_j \sim f$ $Y_k \sim g$

- Also assume there exists a (possibly non-differentiable) mapping $T : X \rightarrow Y$ that relates the tie points

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Graph-Entropic Tie-point registration

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- Define: $D_n\left(f \parallel g\right) = \frac{1}{1-n} \ln \int_{R^d} f^n(x) g^{1-n}(x) dx$
  - ν=1: Kullback-Leibler number (pseudo metric)
  - ν= 1/2: Hellinger distance (symmetric, true metric)
- Minimization problem: $T^* = \arg\min_{T \in \Psi} D_n\left(f \parallel g\right)$
  - D_n is Renyi “divergence” of order ν between *f* and *g*
  - Ψ is set of all mappings consistent with 3D->2D projections of DEM reference

Registration parameters T obtained via minimizing* D_n

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Computational Strategies

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- **Indirect**, via density estimation: estimate f, g and integrate
  -> computationally intensive, problematic for large-dimensions (i.e., vector images), density estimates can be unstable

- **Direct**, via minimum spanning tree (MST): [Beardwood, Halton, Hammersly]
  -> ***Renyi entropy*** R_n <-> ***weighted length*** L_n ***of MST***

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Computational Strategies

- By BHH theorem, L_n converges to R_n for large enough n

- Also, the joint Renyi entropy of X, Y satisfies:

$$R_v(X,Y) \geq R_v\left(X,T^{-1}X\right) \geq R_v(X)$$

- Therefore, can equivalently select T to minimize the Renyi entropy of the joint tie-point set, $\left\{X,T^{-1}X\right\}$

- Equivalently (via BHH theorem): choose the T for which we find the smallest length minimum spanning tree

Synthetic Data Example: SAR <-> EO

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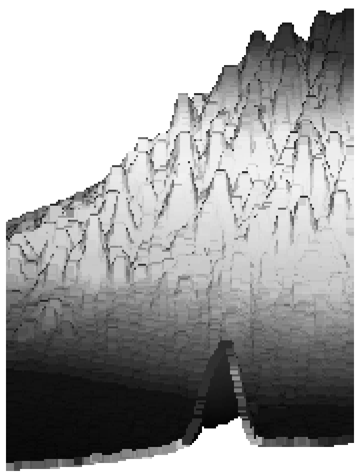
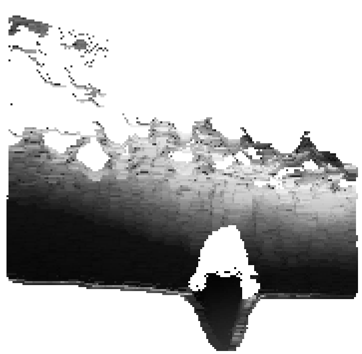
- Projections of a DEM into EO & SAR viewing planes



EO projection formed at {300,0,90} with solar illumination at {300,0,90}

Colormap indicates terrain height



SAR projection taken from {300,0,90}

Synthetic Data Example: SAR <-> EO

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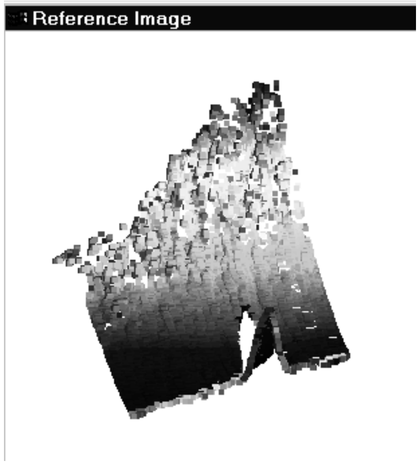
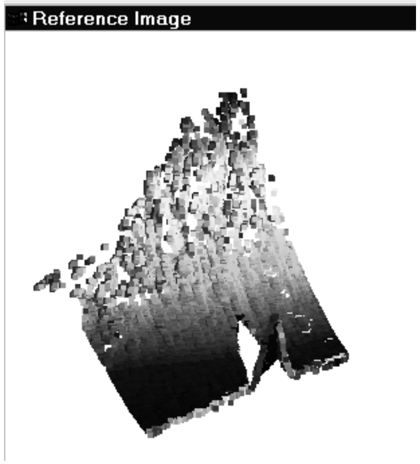
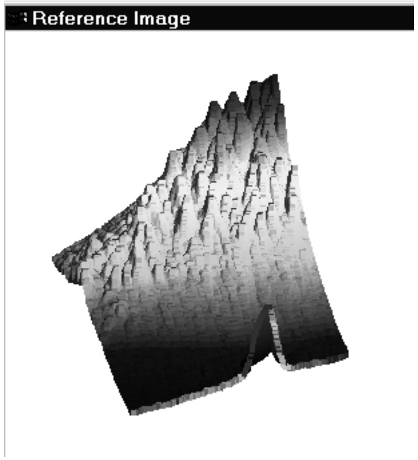
- Matching a reprojected SAR view to an EO view [colormap indicates height]
  - Gaps show missing information in SAR -> EO reprojection due to shadowing



SAR plane reprojected to *correct* EO view (300,0,110)



SAR plane reprojected to an *incorrect* EO view (300,0,120)



reference image: EO projection at (300,0,110)

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Minimum-Divergence Matching of Edges

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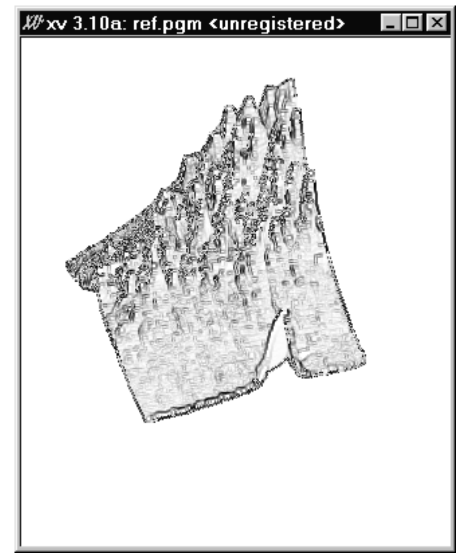
- Edges as tie-points: edge maps extracted from intensity images (via Marr-Hildreth operator)

SAR plane reprojected to *correct* EO view (300,0,110)

SAR plane reprojected to an *incorrect* EO view (300,0,120)



reference image: EO projection at (300,0,110)

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MST length for various poses (i.e. various T)

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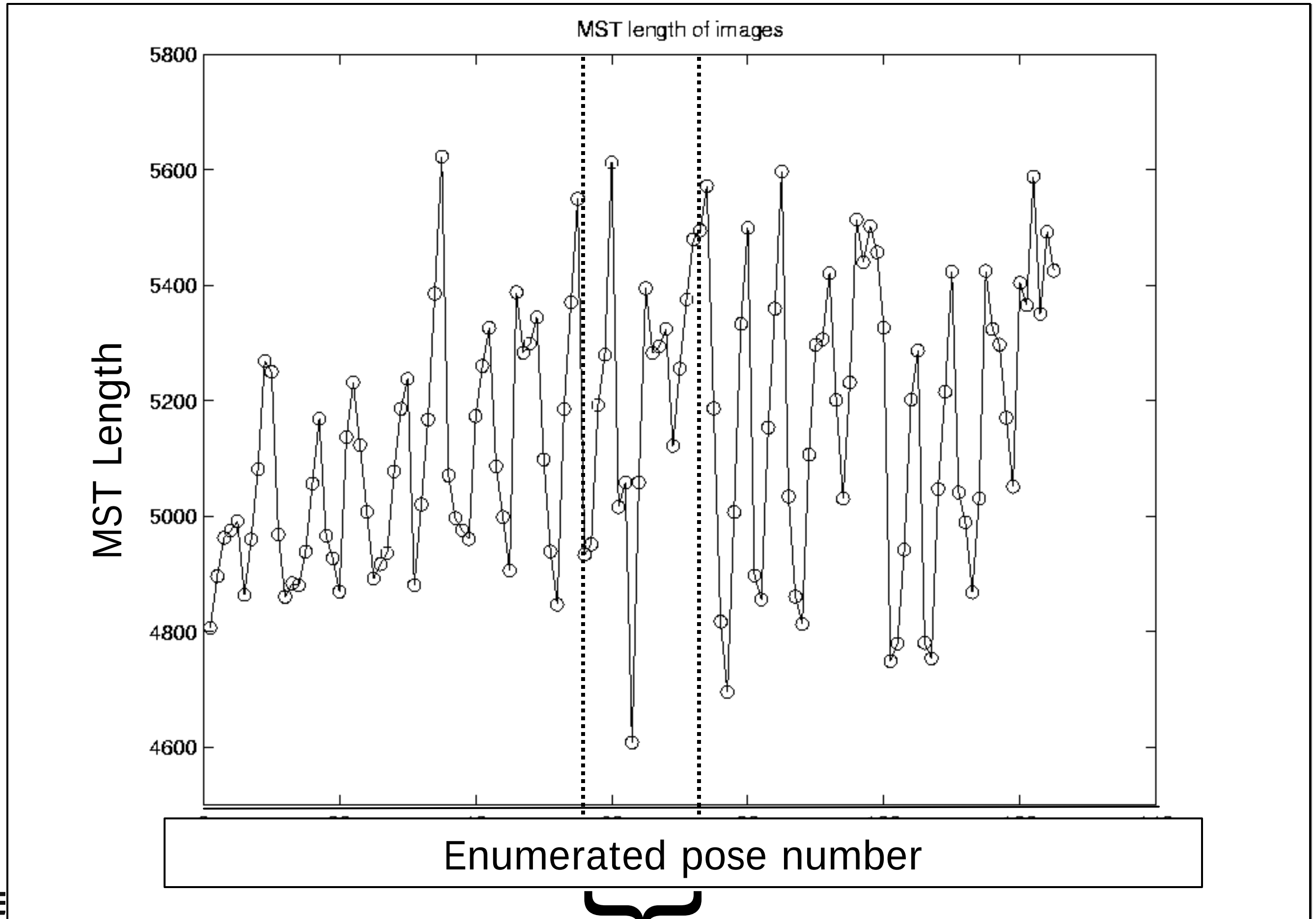

Capture range: w/in +/- 20^{o} of true pose

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Project Status

- Graph-entropic image registration approach currently being developed on Delivery Order under AFRL STIL MSF program
- Current capabilities:
  - Portable C/OpenGL based code for rendering arbitrary SAR, EO/IR views (Solaris, Linux, WinNT)
  - Automatic tie-point extraction from edges or local entropy
  - Correlation-based matching
  - Soon to arrive: Graph-entropy based matching

Summary

- Novel approach for tie-point based image registration
- Generalizes notion of pixel-based mutual information registration to mutual information on graphs induced by tie-points
- Ongoing research into robustness: impact of mismatch due to sensor differences in phenomenology, viewing geometries, illumination conditions
    - Approach: model f and g as contaminated mixtures w/ unknown contaminating distributions

Backup Charts...

- How does this compare to MI approach of Viola et. al.?
  -> We're looking at the entropy of the graph induced by the tiepoints
  -> This should be compared to their pair-wise pixel-pixel MI approach

Mutual Information Metrics

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- $\boldsymbol{i_1}$ and $\boldsymbol{i_2}$ -- two images to be registered
- Assume $\boldsymbol{i_2(\underline{y}) = F[i_1(T(\underline{x})), \underline{p}\,]}$,
  - $\boldsymbol{T(\underline{x})}$ represents the unknown geometric distortion between the images, and
  - $\boldsymbol{F[.]}$ is a possibly unknown function that maps pixel intensities in image $\boldsymbol{i_1}$ into intensities in $\boldsymbol{i_2}$.
- One approach: parameterize $\boldsymbol{T(\underline{x})}$ according to sensor collection geometry, illumination models, say $\boldsymbol{T_f(\underline{x})}$
- Select ϕ^* to maximize the mutual information between $\boldsymbol{i_1}$ and $\boldsymbol{i_2}$: $\phi^* = \text{argmax}_\phi \, I(\boldsymbol{i_1}, \boldsymbol{i_2}(\, T_f^{-1}(\underline{y})\,)\,)$

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Image Alignment via Maximization of MI

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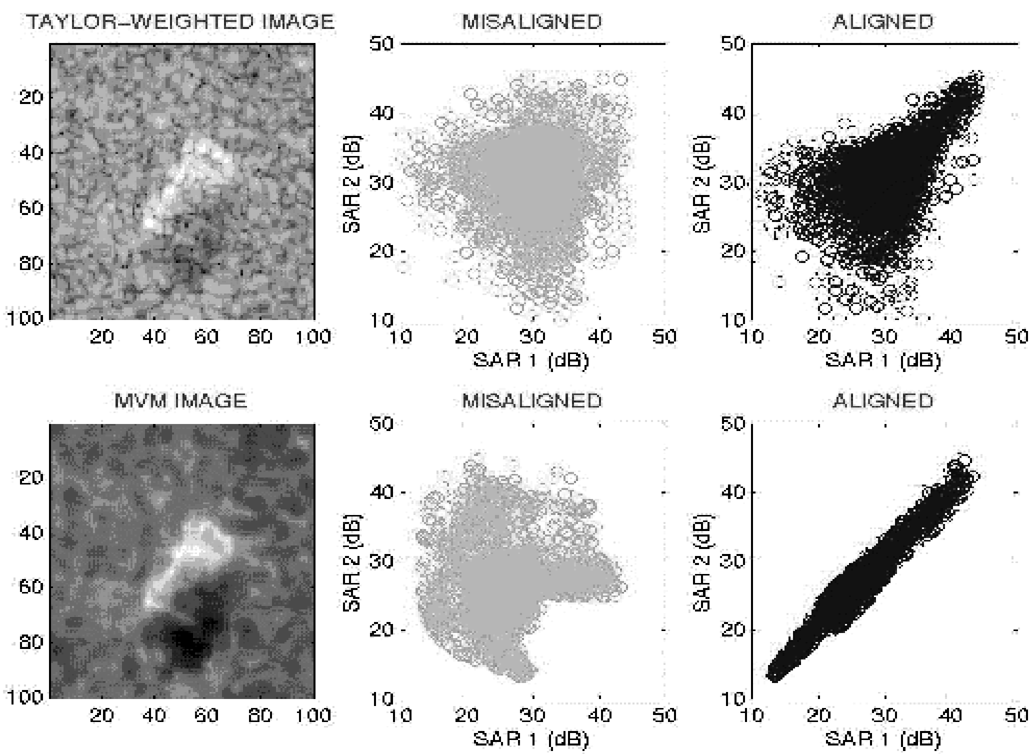
- Pixel-pixel SAR-SAR matching:
  - Plot of single-pixel intensities in misaligned test image vs. pixel intensities in ref. image.



Heuristic:

Mutual information <-> spread of the plot

Smaller spread -> Larger MI

Observation:

SAR speckle noise destroys the image-image correlation and efficacy of pixel-pixel MI

Alternative: look for “stable” match features