Multiple Plane Detection in Image Pairs using J-Linkage

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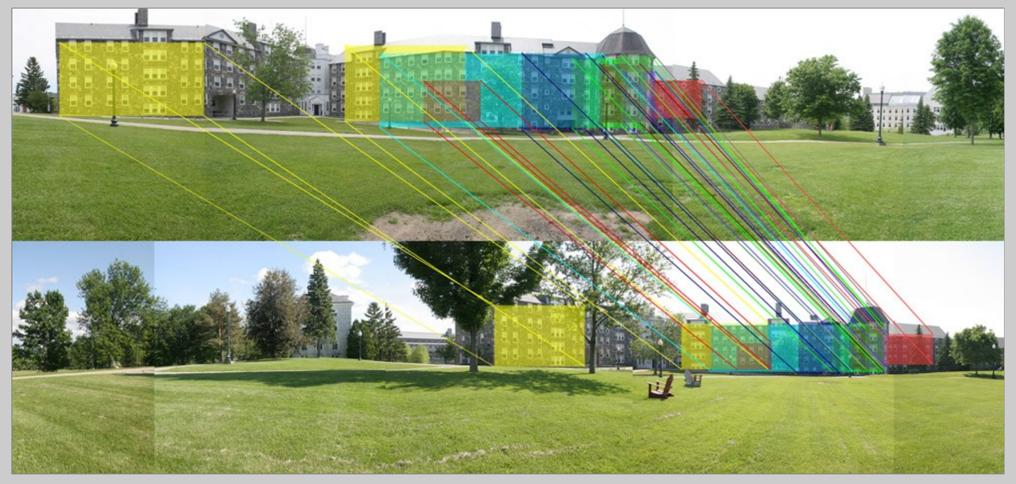
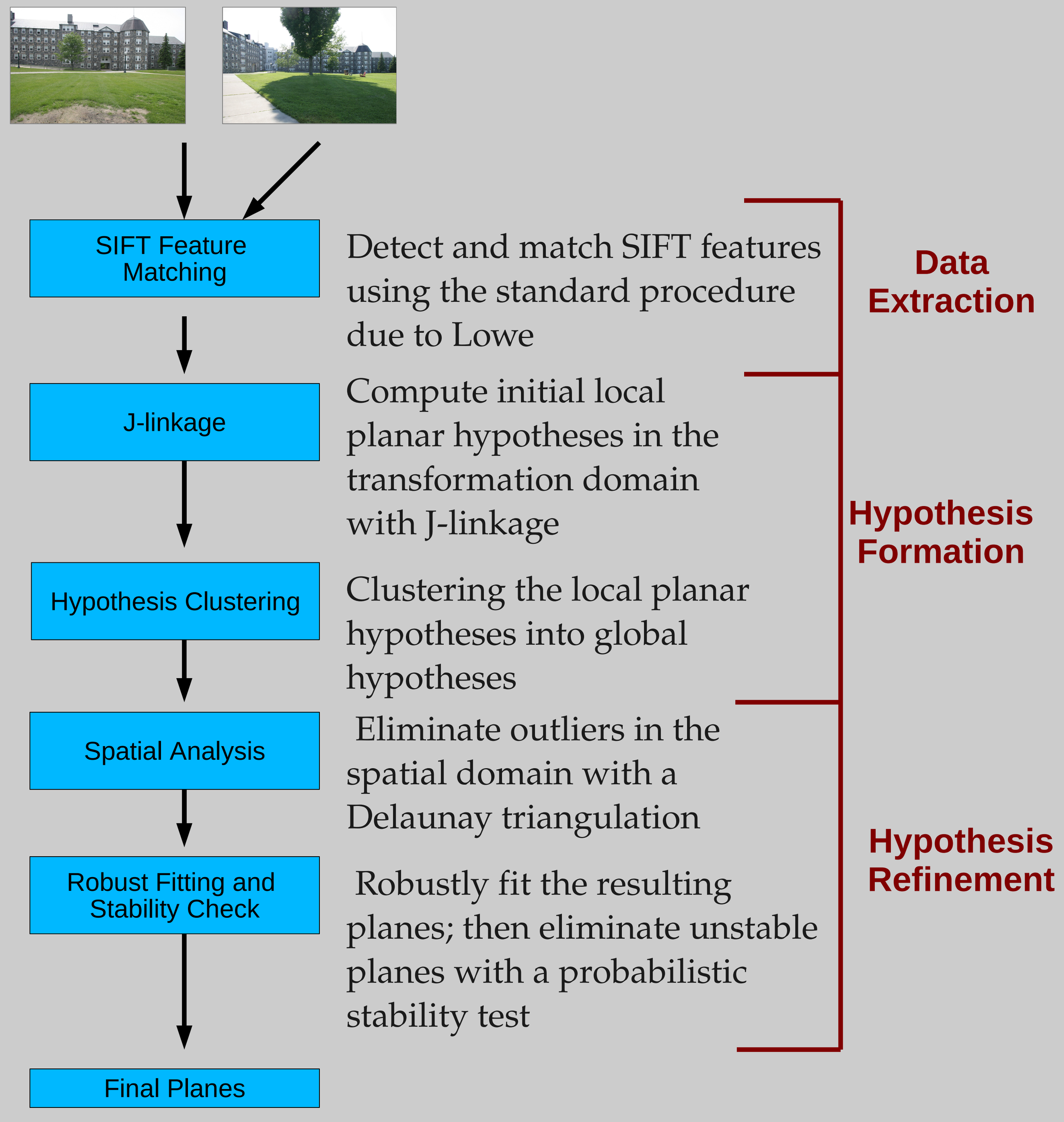
Motivation and Overview

The detection of planar surfaces has many applications, including camera calibration, 3D architectural reconstruction and robot navigation. We propose an approach for detecting multiple planes in image pairs from feature correspondences. Our method establishes correspondences between the two images using SIFT [1]. Then it clusters these correspondences into initial planar hypotheses with the recently developed J-linkage [7] randomized multi-model estimation technique followed by a global merging step to ensure detection of planes across the entire image.

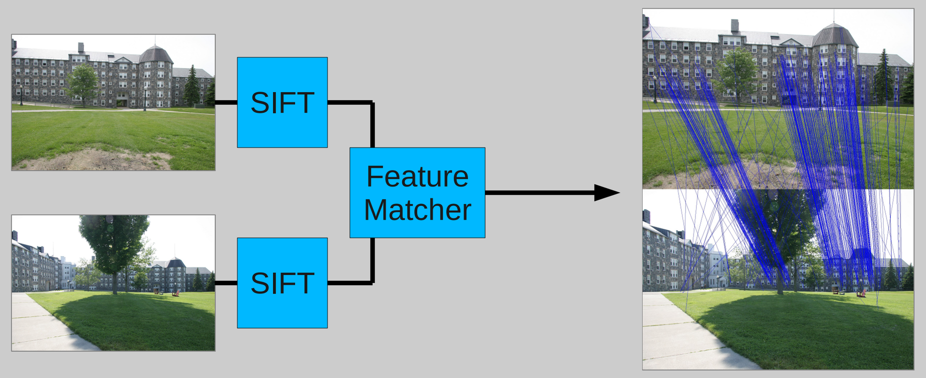
In our tests on a challenging real-world data set (which will be released soon) with over 30,000 image pairs, our method detected 72% of sufficiently textured plane pairs while also yielding no false positives.



The approach used on the pairwise images from a 360-degree views on Middlebury's campus and the matches were merged into a single panorama pair. Corresponding planes share a color and have lines between them.



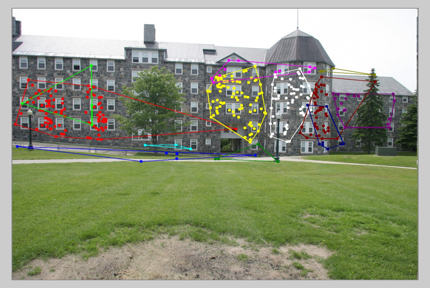
SIFT Feature Matching



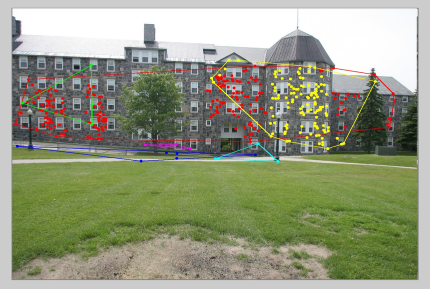
SIFT Correspondences

- We use the SIFT feature detector and descriptor [1] to find correspondences between two images. The descriptor encodes regions as 128-dimensional vectors such that matching may be done with a nearest neighbor search.
- While these provide a large number of correct correspondences, repetitive textures introduce outliers.

Hypothesis Formation: J-Linkage and Global Merging



Initial Hypotheses from J-Linkage

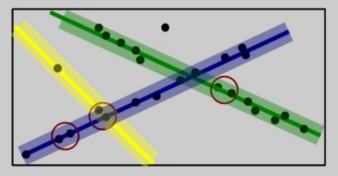


Results after Global Merging

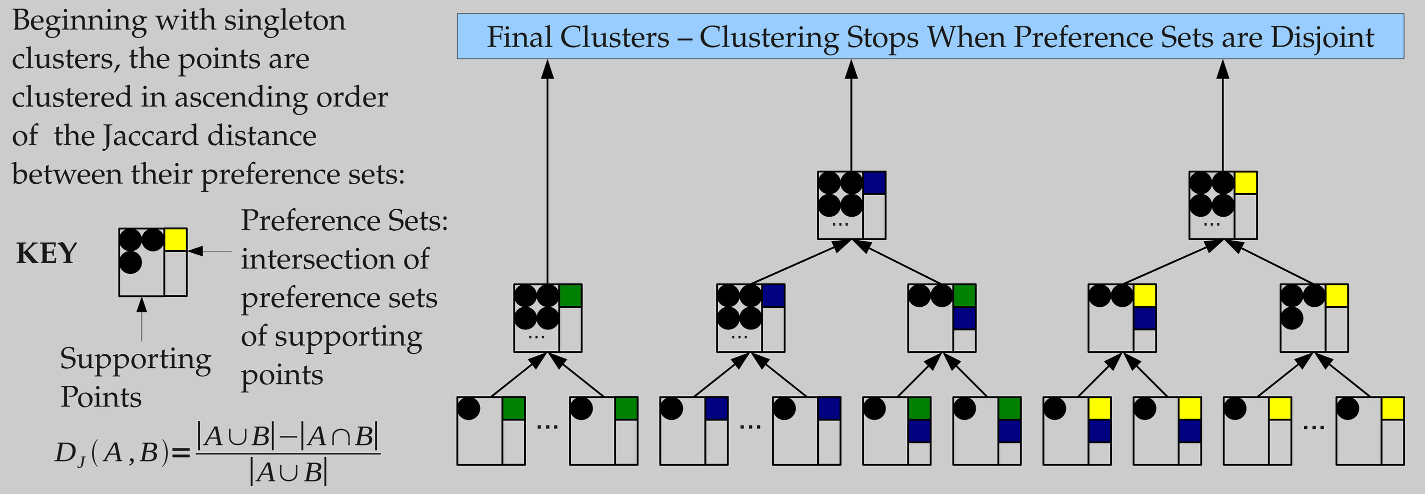
- J-linkage is a recent approach to fitting multiple models to noisy and outlier contaminated data that uses randomly drawn minimum sample sets (i.e. 2 points for a line, 4 correspondences for a homography). It is illustrated below for line fitting.
- We draw points close together ton increase the probability of picking inlier models; this may result in underdetermined homographies. We recover global planes by merging in order of average reprojection error for the union of two hypotheses, stopping when that error exceeds a threshold.

J-linkage: an example in 2 dimensions

Models (colored lines) are generated from randomly selected minimum samples (circled in red); a model is in a point's preference set if it matches within an error bound (semi-transparent areas).

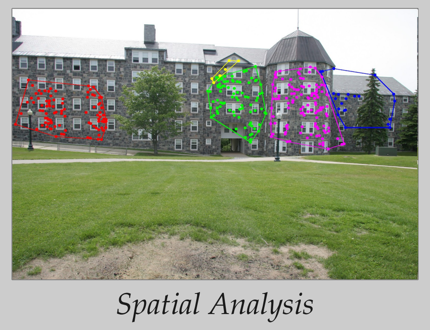


Beginning with singleton clusters, the points are clustered in ascending order of the Jaccard distance between their preference sets:



$$D_J(A,B)=\frac{|A\cup B|-|A\cap B|}{|A\cup B|}$$

Hypothesis Refinement: Spatial Analysis and Stability Checks



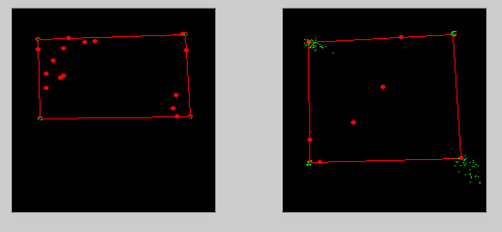
Spatial Analysis

- We found that in our data set, there were incorrect correspondences that due to chance fit a planar hypothesis.
- For each plane hypothesis, we computed a Delaunay triangulation. We removed long edges and treated each disjoint component as its own hypothesis.

Part of a processed triangulation; note that while in this case the isolated points fall on a plane parallel to the dominant one, including of these points would extend the plane over outlier areas.

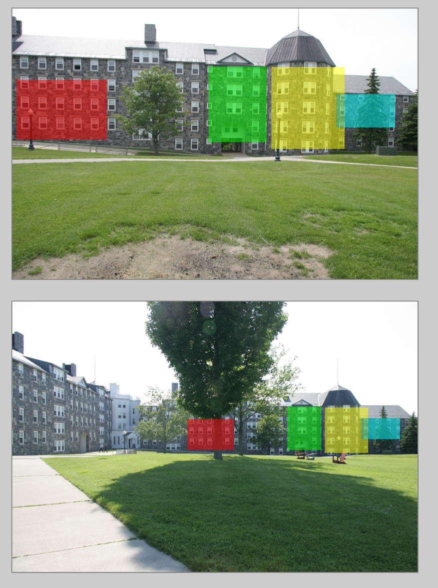
- We compute a final model by iteratively computing a homography and rejecting correspondences whose reprojection error exceeds a decreasing series of thresholds.
- This provides a final plane pair, homography and a set of correspondences that lie within a known bound

- To increase repeatability of detection, we wish to consider only stable planes (with well-determined transformations). To detect unstable ones (e.g. points primarily on a line), we compare the variance of the supporting region's bounding box under transformations fitted to random perturbations of the supporting correspondences.



Green points are bounding box corners; On left: a stable hypothesis; on right: an unstable hypothesis.

- If the variance of the bounding box exceeds that of the noise, we reject the pair



Final Detection Results

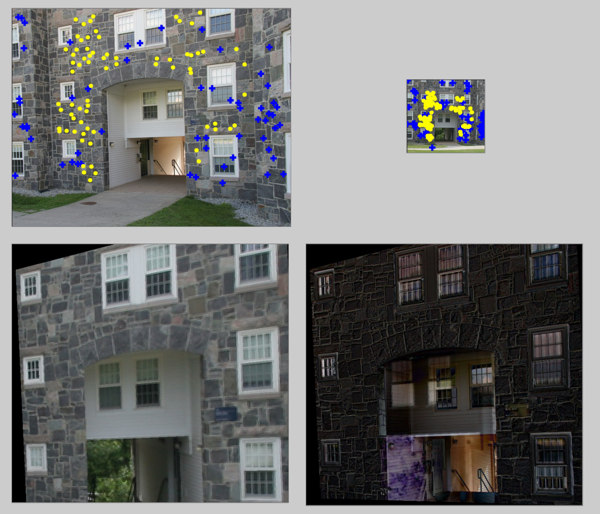
Results

We tested the approach on a data set containing 32,455 image pairs from 31 360-degree panoramas taken at Middlebury, which had been corrected for radial distortion and scaled. We established that there were 330 total planes. Of these,

- 108 planes had too little texture for SIFT;
- 87 planes that were too small or underwent too severe a viewpoint shift; and
- 135 remaining planes.

Our approach detects 97 (72%) of the 135 planes while also yielding no false positives.

One of the remaining 135 planes is shown to the right (with proper relative scaling for image 1 and image 2). Despite a scale change of 300%, content change (the doorway), and significant viewpoint shift our approach successfully detects and accurately registers the plane.



A plane detected by the approach.
Upper Left / Right: plane in image 1 and 2; inlier correspondences colored yellow, outlier in blue.
Lower Left: image 2 warped to match image 1.
Lower Right: difference image

We are in the process of organizing and releasing our raw data to the community in the hopes that it will encourage further work in plane detection and provide challenging test data. The data will be posted at the primary author's personal website by mid-October 2010 at the latest:

http://www.cs.middlebury.edu/~dfouhey/ICPR2010/

References

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Acknowledgments

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