Review of the Literature & Investigation of Image Registration Algorithms with Applications to NIF Optics Inspection

Presentation to
Casis 2006

National Ignition Facility

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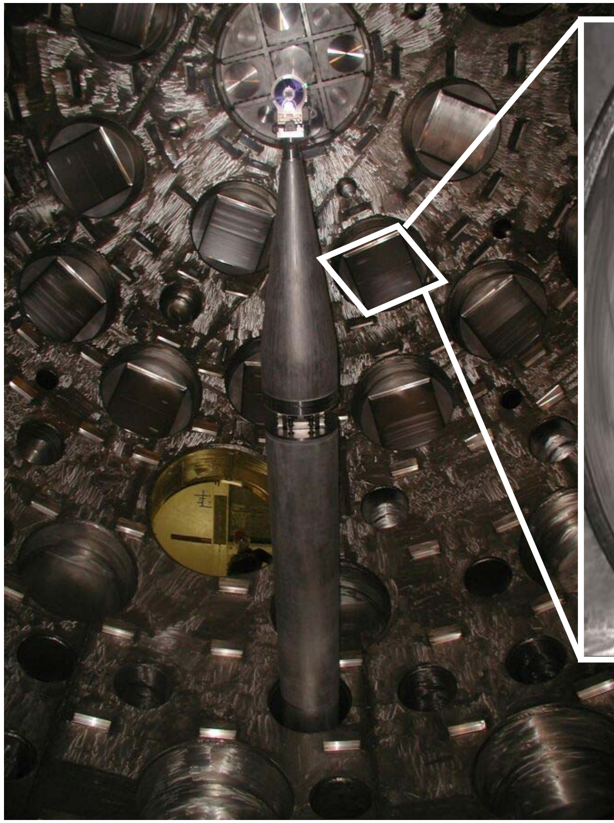
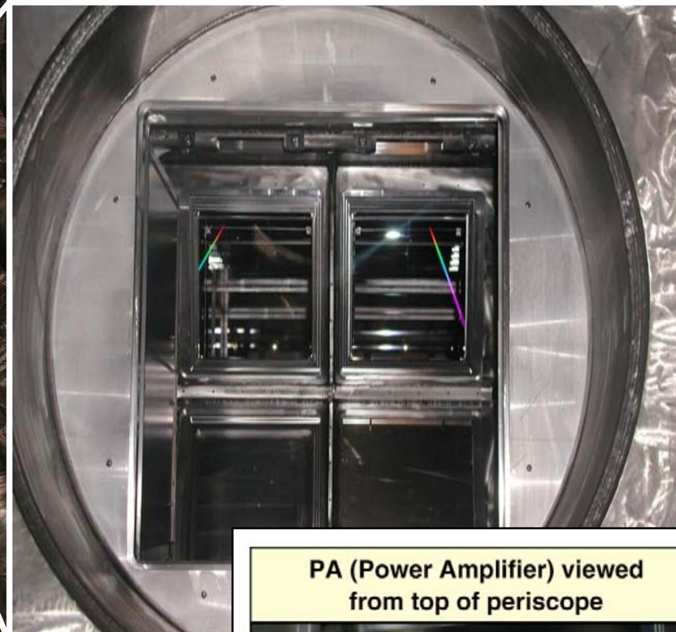
NIF Optics Inspection

November 17th, 2006
UCRL-PRES-226175

NIF Optics – Lots of them!





Looking into the beamline through the final optics section is like looking into a house of mirrors

PA (Power Amplifier) viewed from top of periscope

LM3 mirrors viewed from top of periscope

Track Sites on NIF Optics: Register Through Focus

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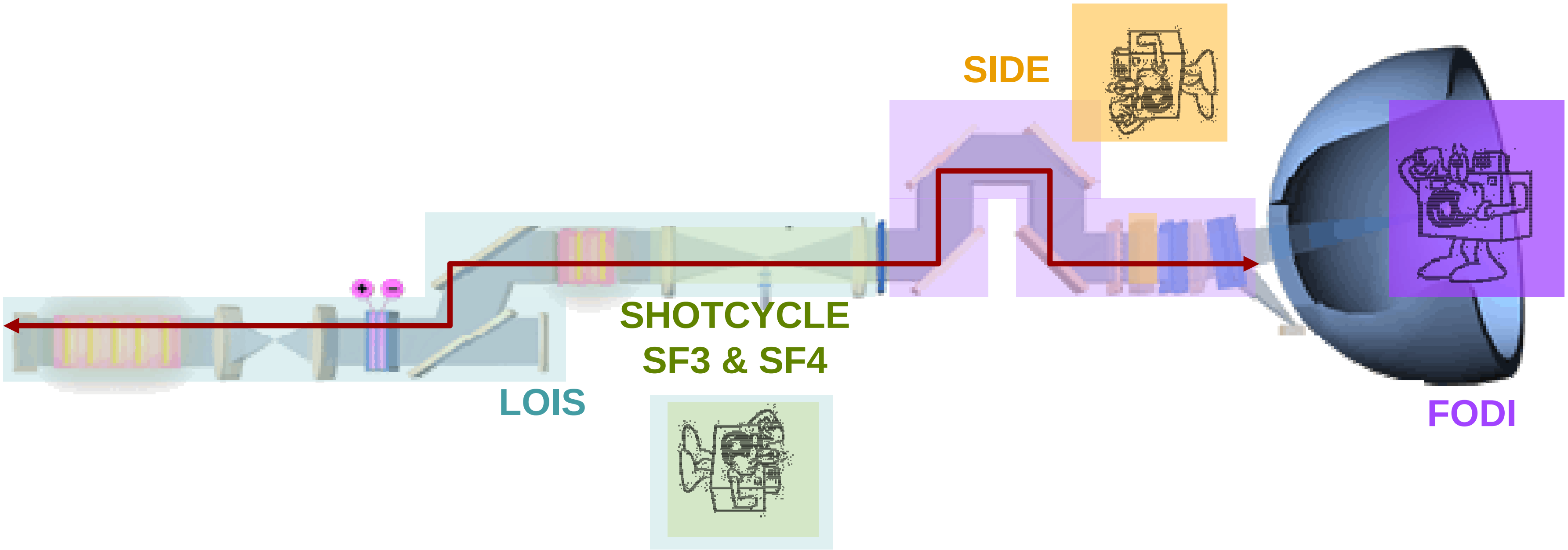
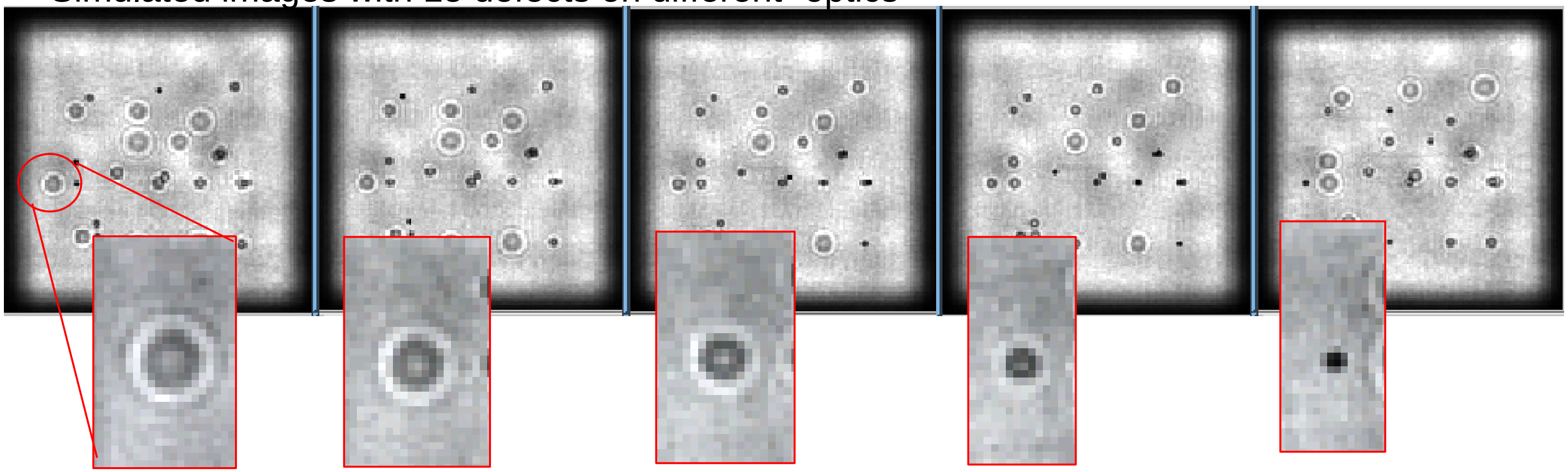


Simulated images with 15 defects on different “optics”



Track Sites on NIF Optics: Register Through Time

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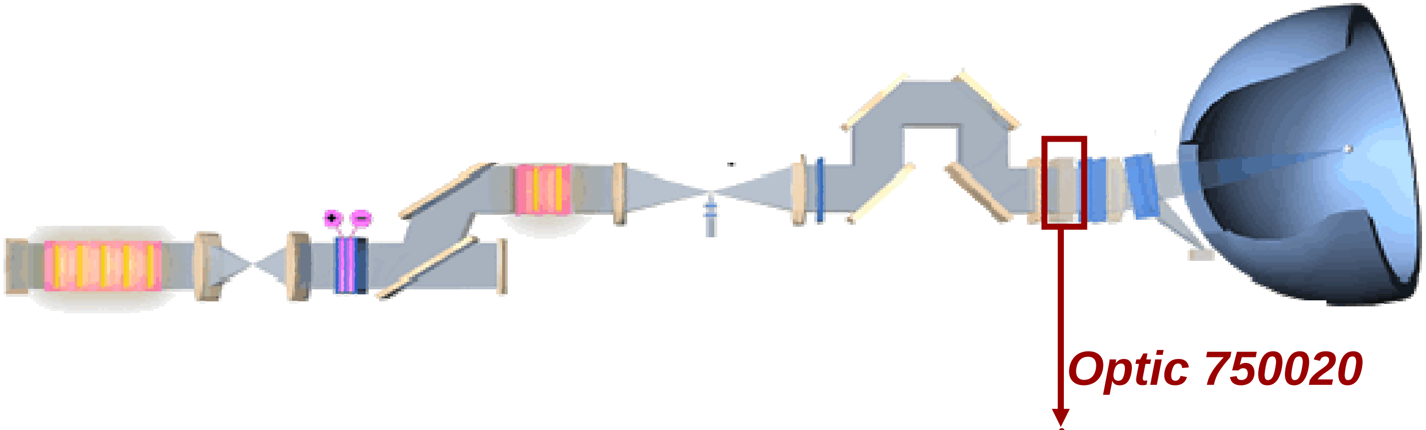
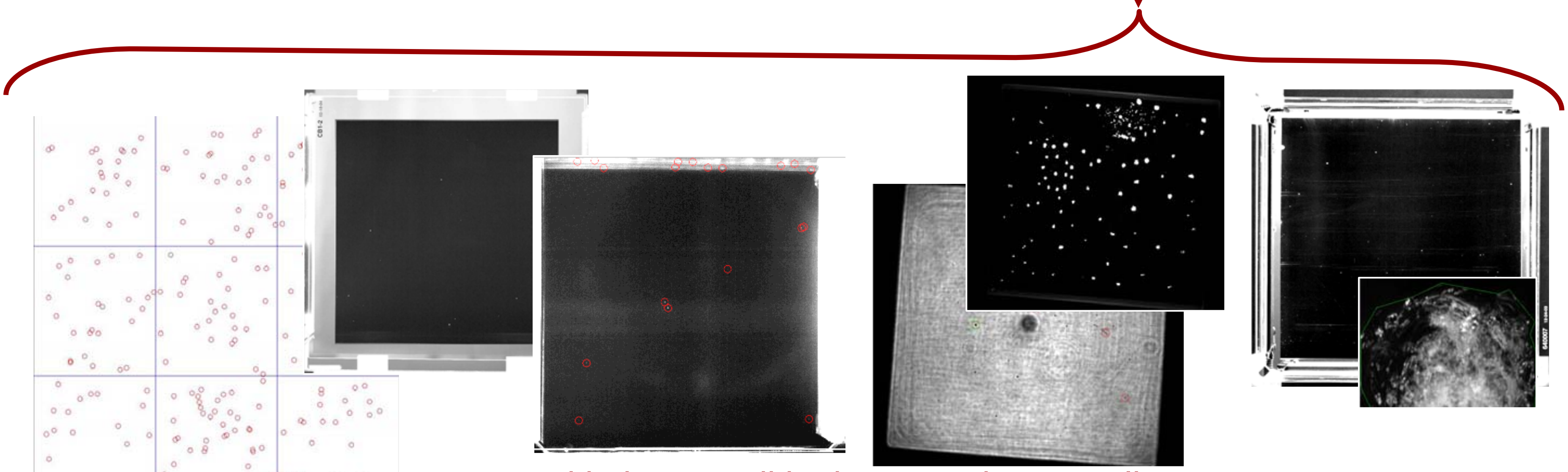
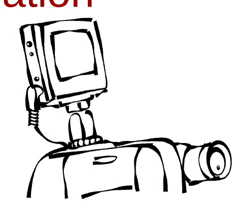
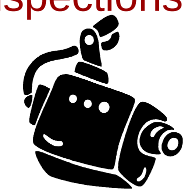
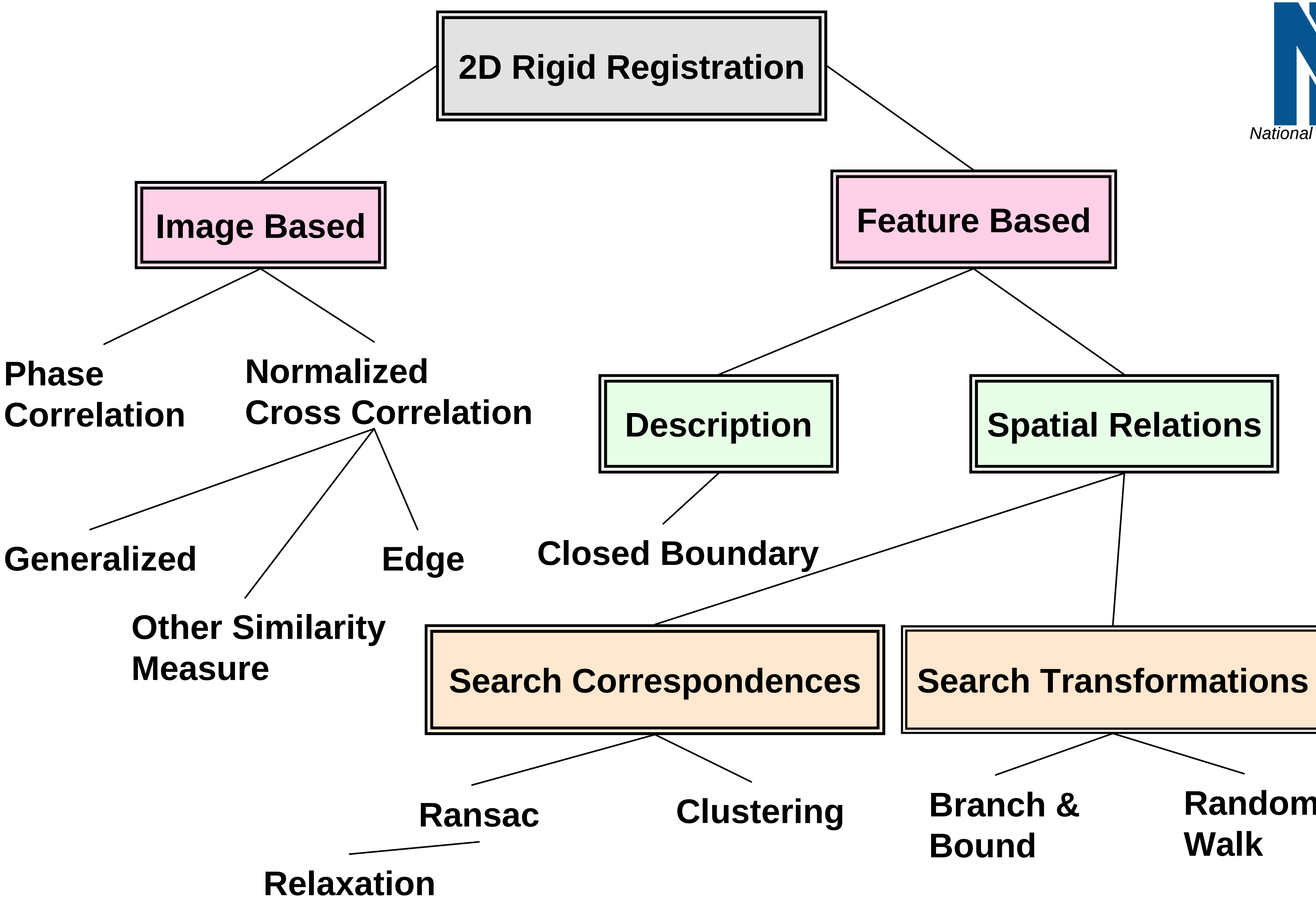




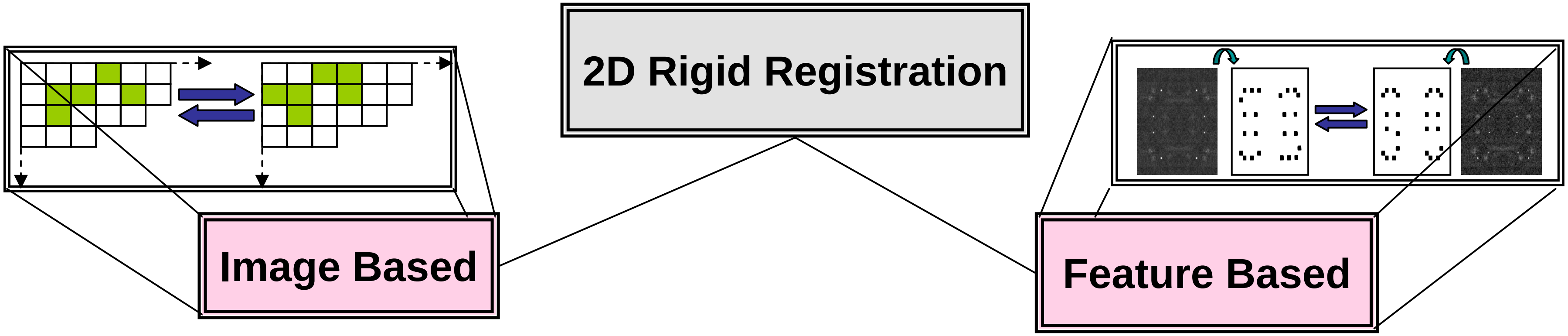
Initial Offline Inclusion Mapping System → Initial DMS → Initiation Conditioning & Mitigation → In-Situ Beamline Inspections → DMS & micrograph Images

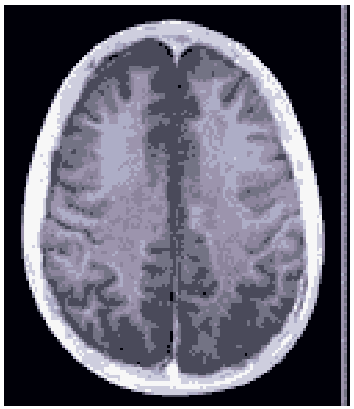


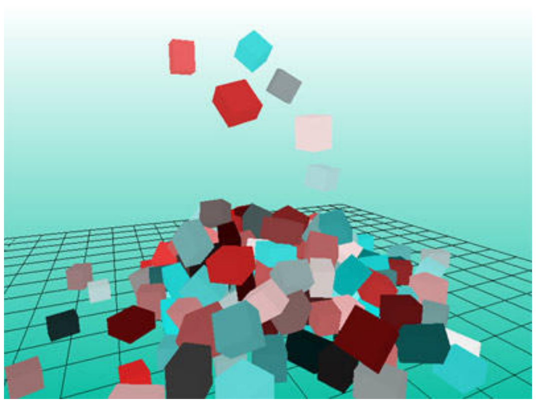



- *Algorithm tree derived from image registration literature research*
- *Different registration problem characteristics are handled at each fork*





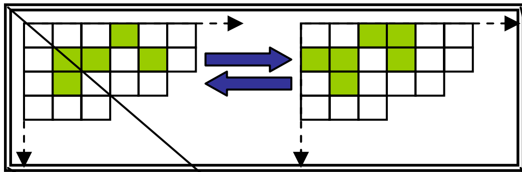
Prominently used in medical imaging:
- *Lack of stable or detectable features*
- *Images with similar intensity profiles*



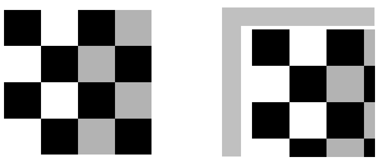
Typically used in computer vision:
- *Many stable or detectable features*
- *Images with varying intensity profiles*

2D Rigid Registration

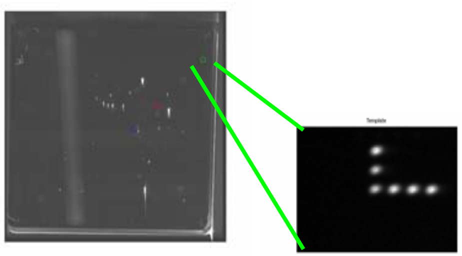
Image Based



- Handles translation with only small rotation and magnification differences

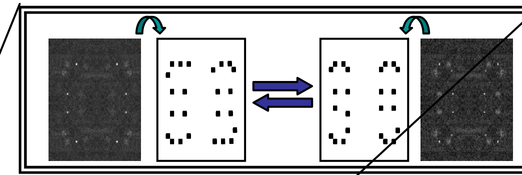


- Speed depends on image size, fast for small images or sections

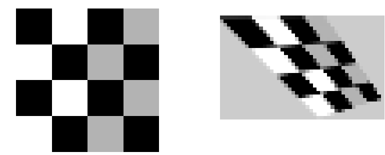


- Usually requires similar relative pixel intensities between sensed and reference images

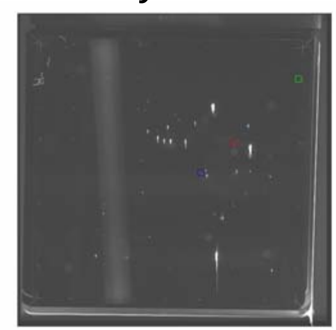
Feature Based



- Can handle higher order transformations



- Speed depends mainly on # of features



- Independent of image intensity
- Requires stable, detectable features

2D Rigid Registration

Image Based

Handles frequency dependent noise

Phase Correlation

Normalized Cross Correlation

Handles more complex transformations, increase computational complexity

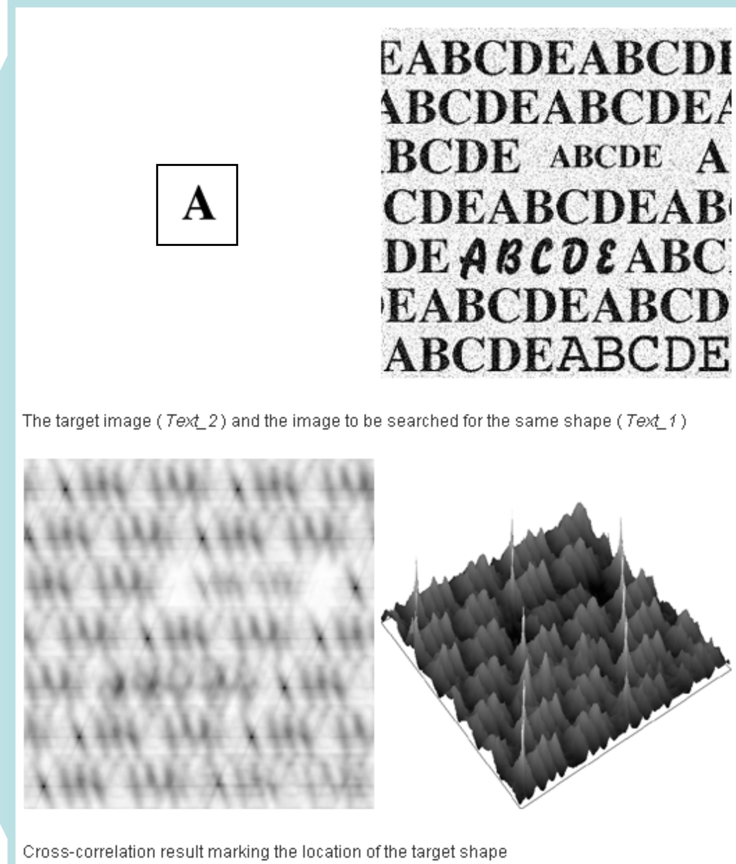
Generalized

Other Similarity Measure

Faster, use of L1 norm etc

Edge

Reduced dependence on intensity uniformity



The target image (*Text_2*) and the image to be searched for the same shape (*Text_1*)

Cross-correlation result marking the location of the target shape

See reference 5

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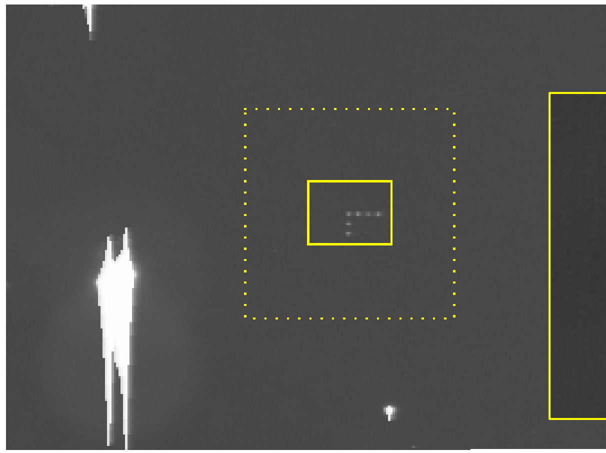
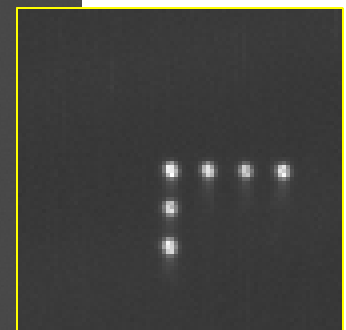
2D Rigid Registration

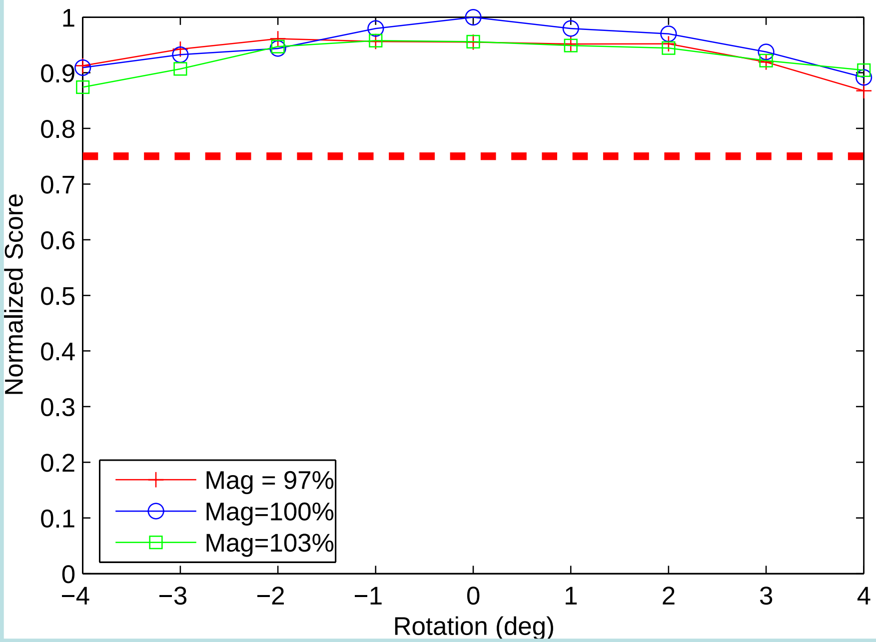
Image Based

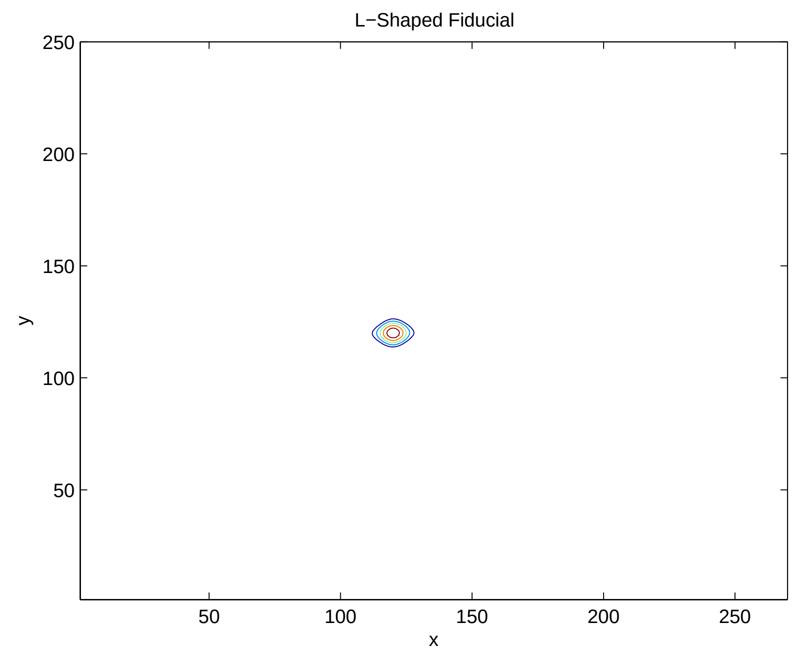
Normalized Cross Correlation





Cross Correlation in use for NIF Optics Inspection

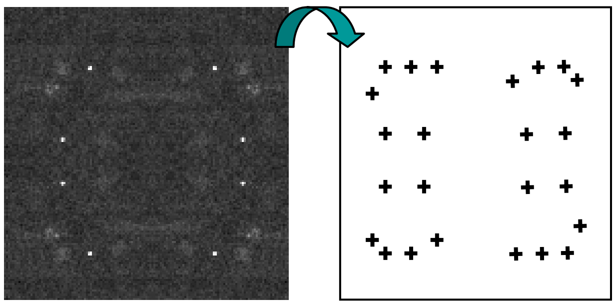




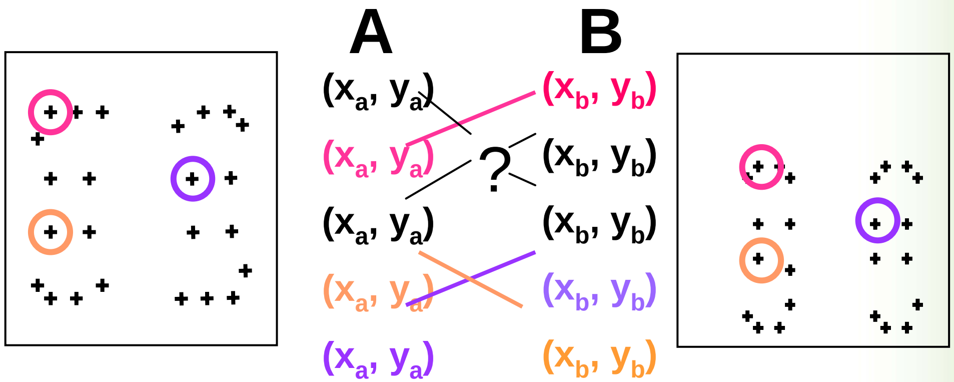
2D Rigid Registration

Feature Based

1) Feature Detection



2) Feature Matching or Correspondence



3) Transformation Estimation

Find $\tau \in T$ to minimize: $\tau(A) - B$

Steps 2 & 3 are chicken & egg problem!

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2D Rigid Registration

Feature Based

Solve correspondence problem with invariant, unique, & stable descriptions of features

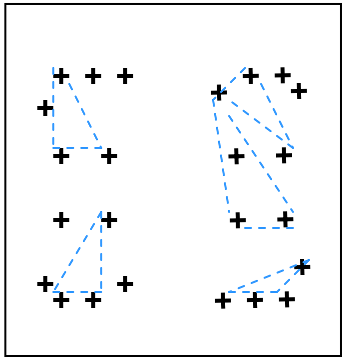
Description

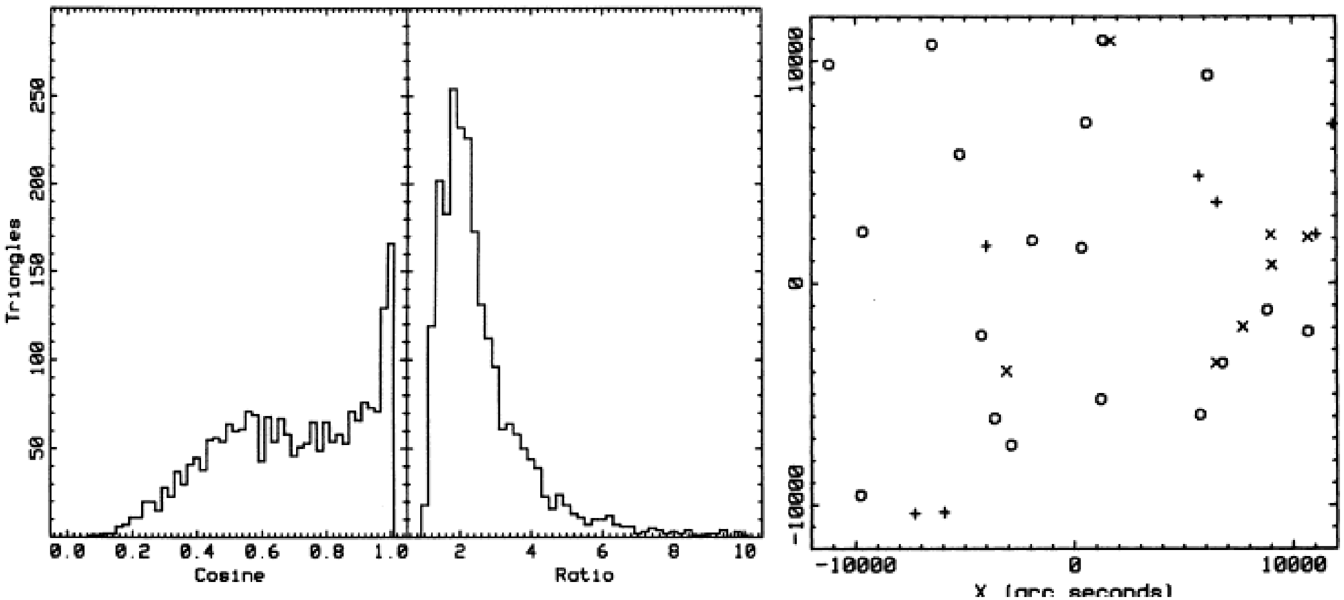
Shape descriptions

Closed Boundary

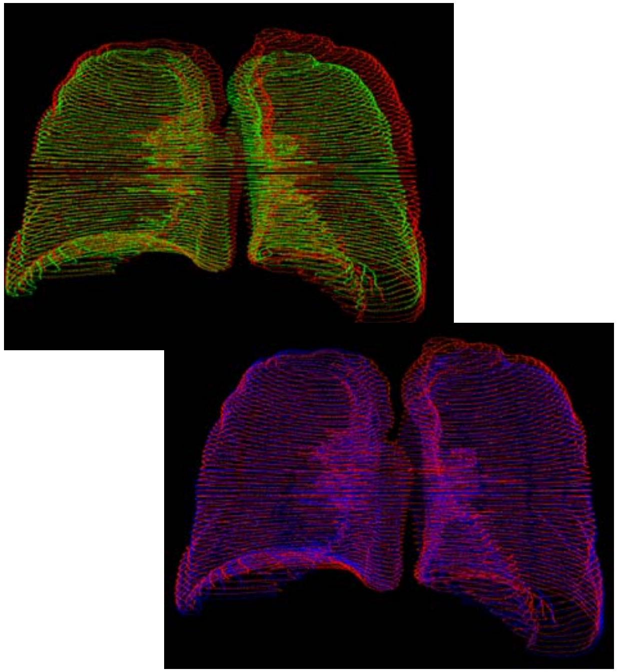
Spatial Relations

Ambiguous descriptions available, use relative positions only





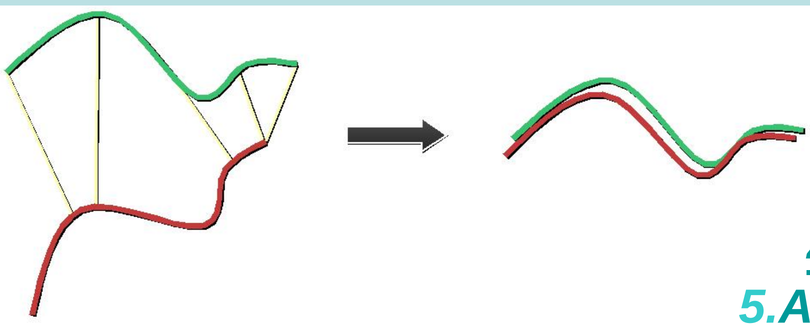
See reference 2



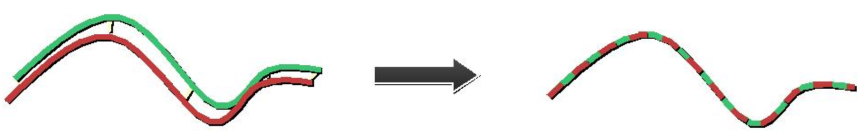
2D Rigid Registration

Feature Based

Description ----- Iterative Closest Point ----- Spatial Relations



1. Select source points
2. Match to points in the other mesh
3. Weight the correspondence
4. Reject certain noisy (outlier) point pairs
5. Assign an error metric and minimize the error
6. Iterate through steps



See reference 7

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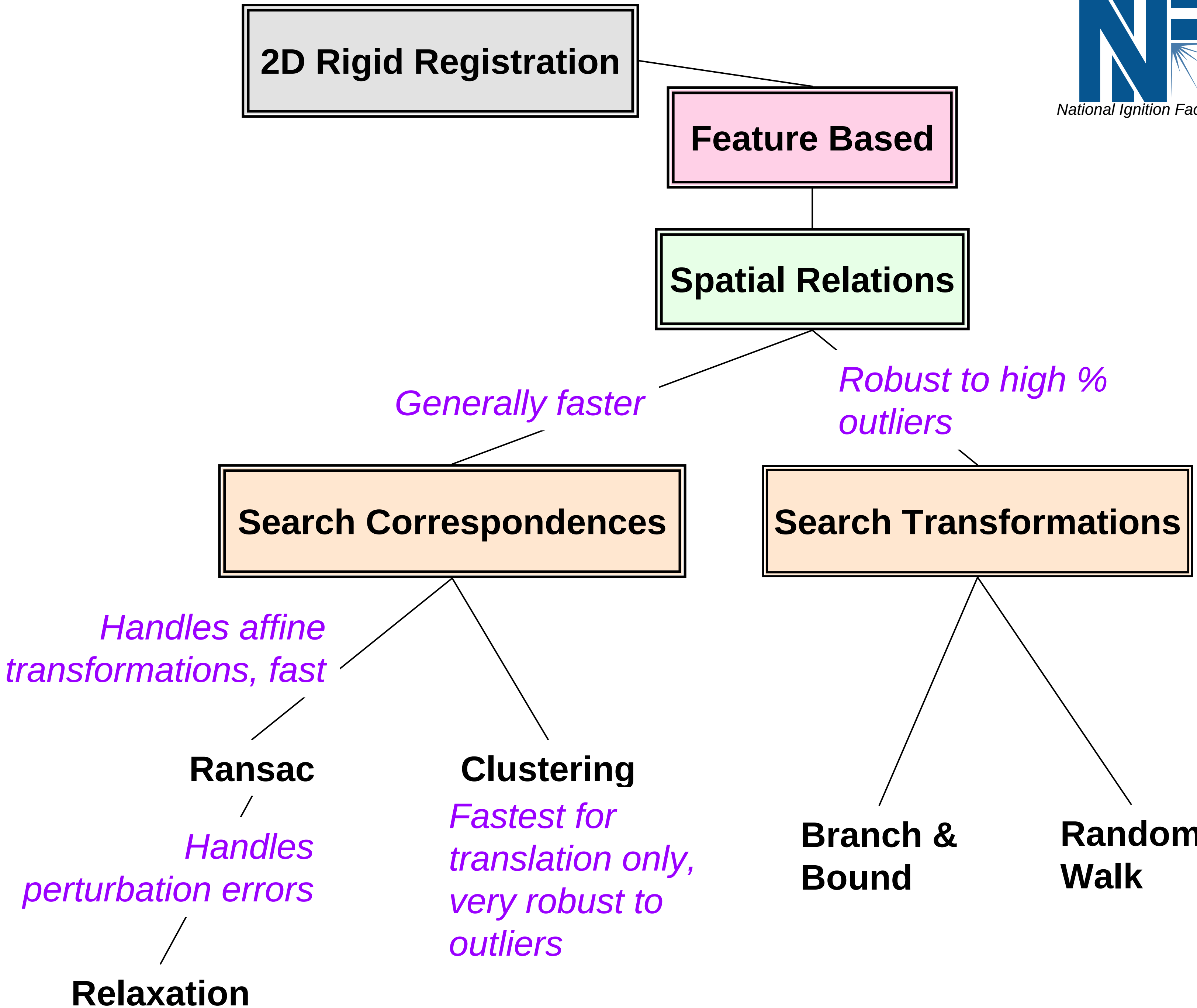

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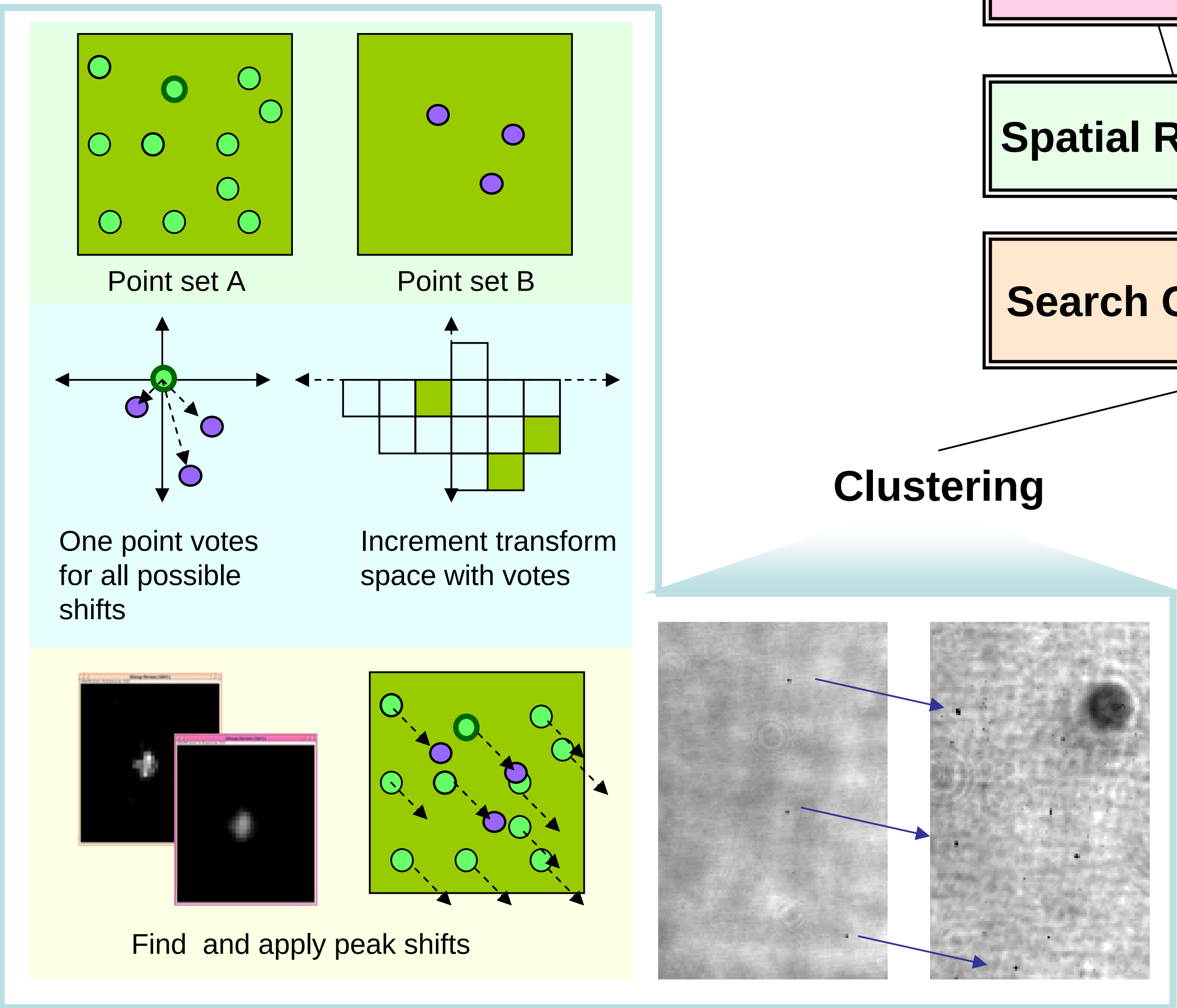
2D Rigid Registration

Feature Based

Spatial Relations

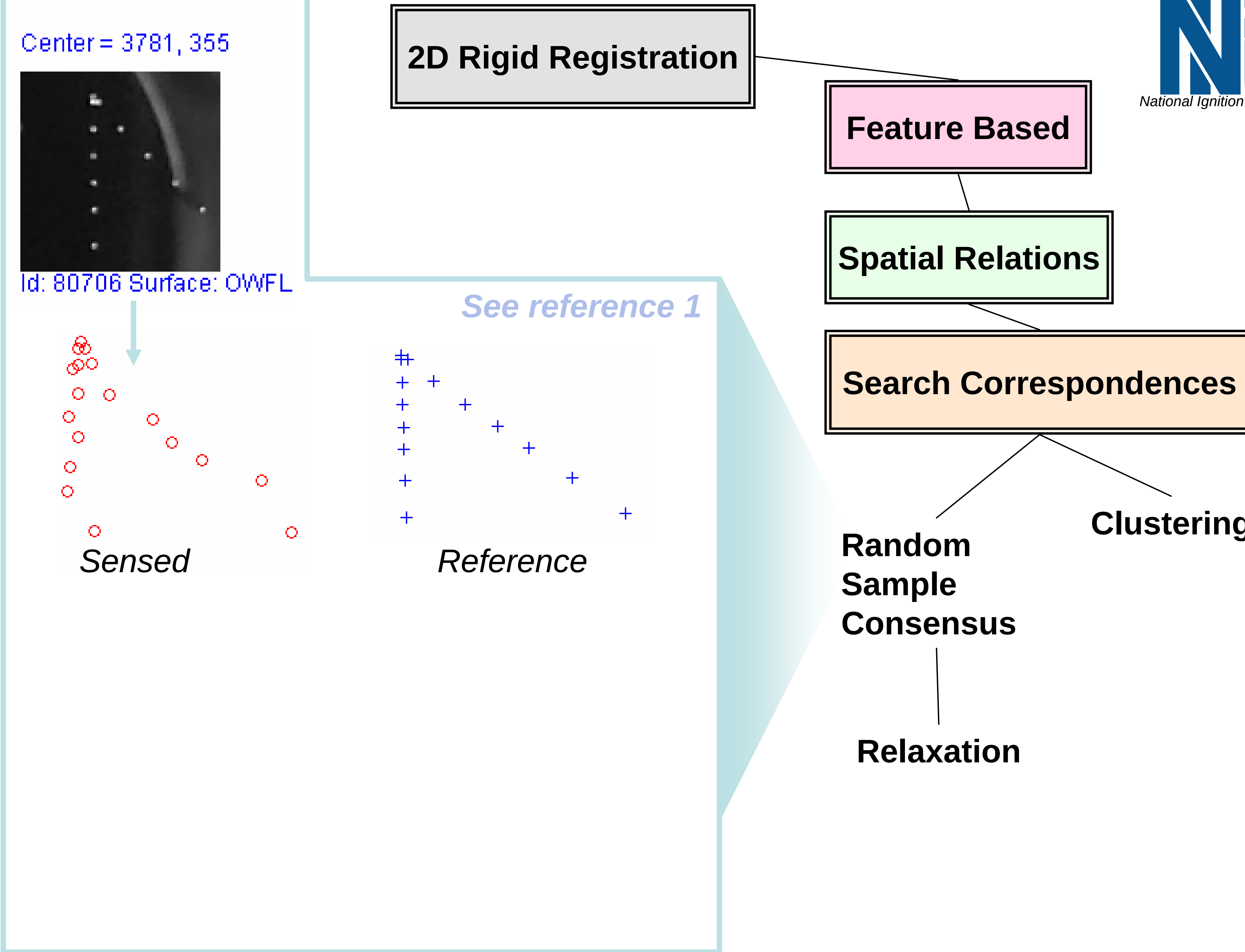
Search Correspondences

- Clustering
- Ransac
  - Relaxation



Can be extended to rotation & magnification using point pairs

See reference 6



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2D Rigid Registration

Feature Based

Spatial Relations

Search Correspondences

Ransac

Clustering

Relaxation

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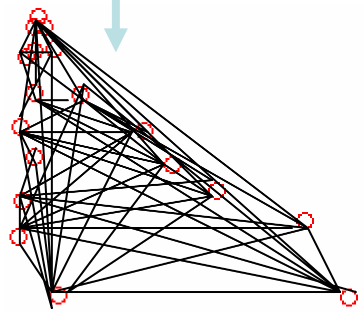
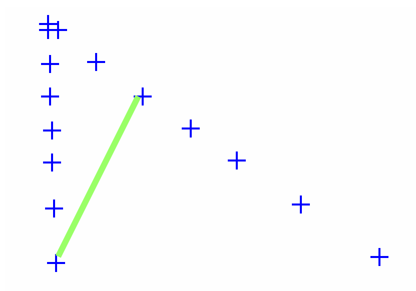
See reference 1



Prepare all pairs of sensed points



Randomly choose pair of reference points

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2D Rigid Registration

Feature Based

Spatial Relations

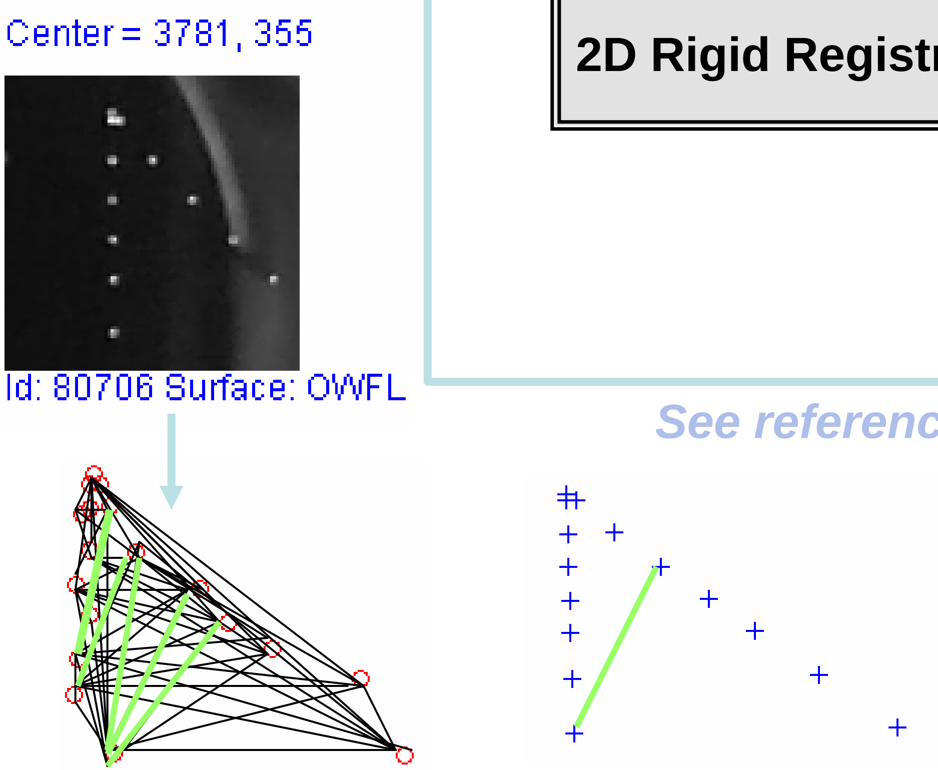
Search Correspondences

Ransac

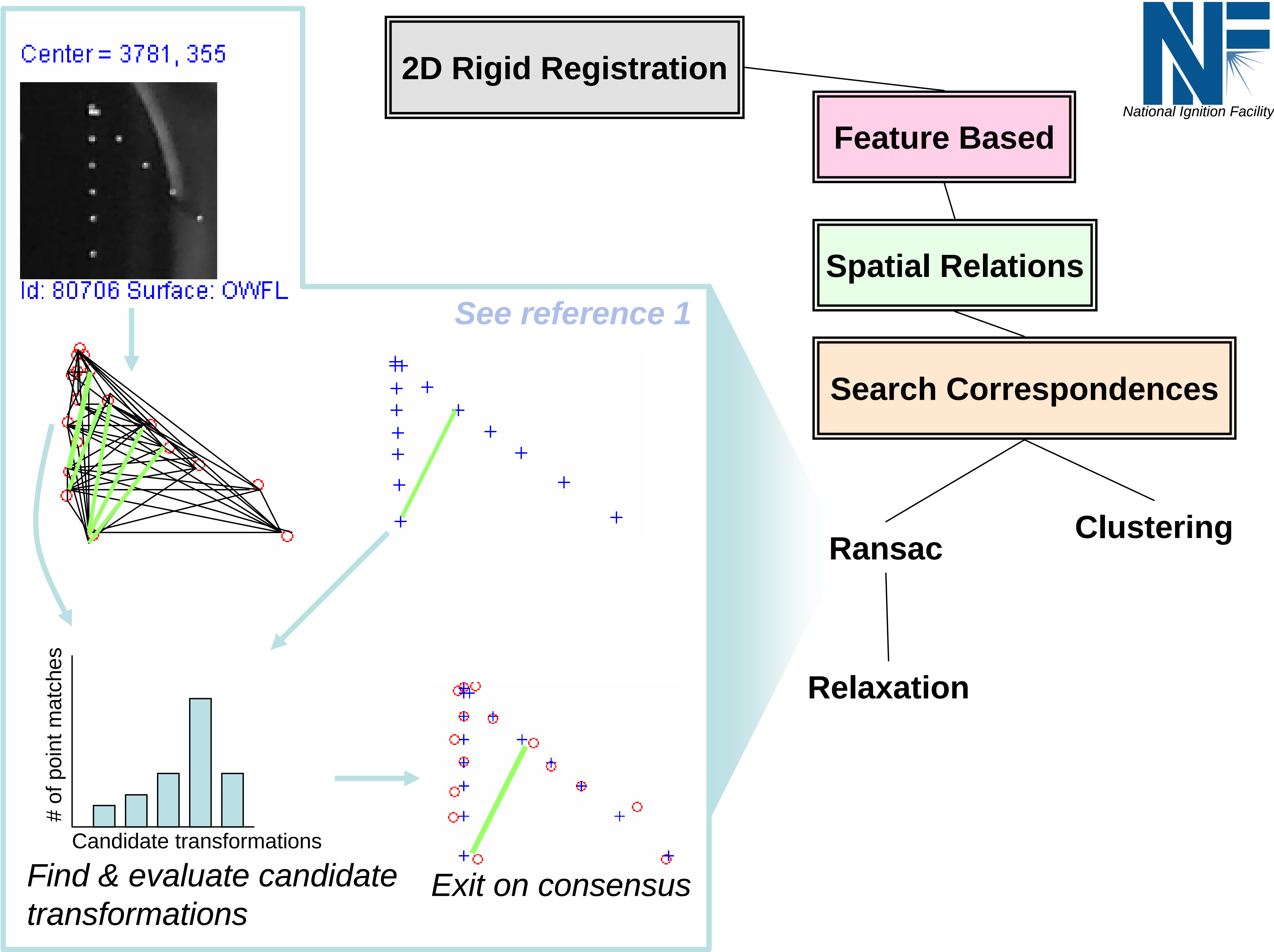
Clustering

Relaxation

See reference 1



Find candidate sensed point pairs


2D Rigid Registration
Feature Based
Spatial Relations
Search Correspondences
Ransac
Clustering
Relaxation
Center = 3781, 355
Id: 80706 Surface: OWFL
See reference 1
# of point matches
Candidate transformations
Find & evaluate candidate transformations
Exit on consensus
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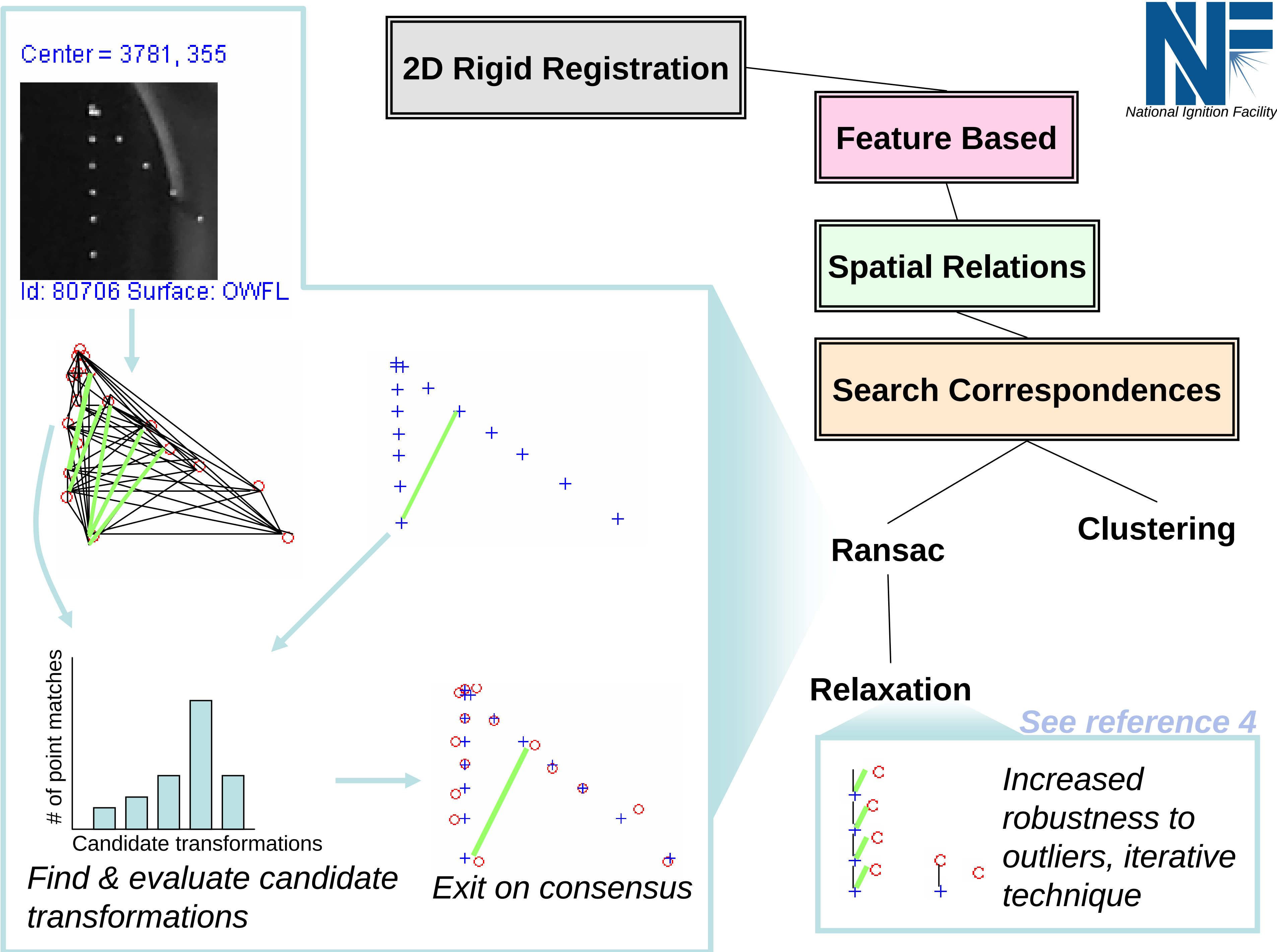

2D Rigid Registration
Feature Based
Spatial Relations
Search Correspondences
Ransac
Clustering
Relaxation
See reference 4
Increased robustness to outliers, iterative technique
Center = 3781, 355
Id: 80706 Surface: OWFL
# of point matches
Candidate transformations
Find & evaluate candidate transformations
Exit on consensus
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2D Rigid Registration

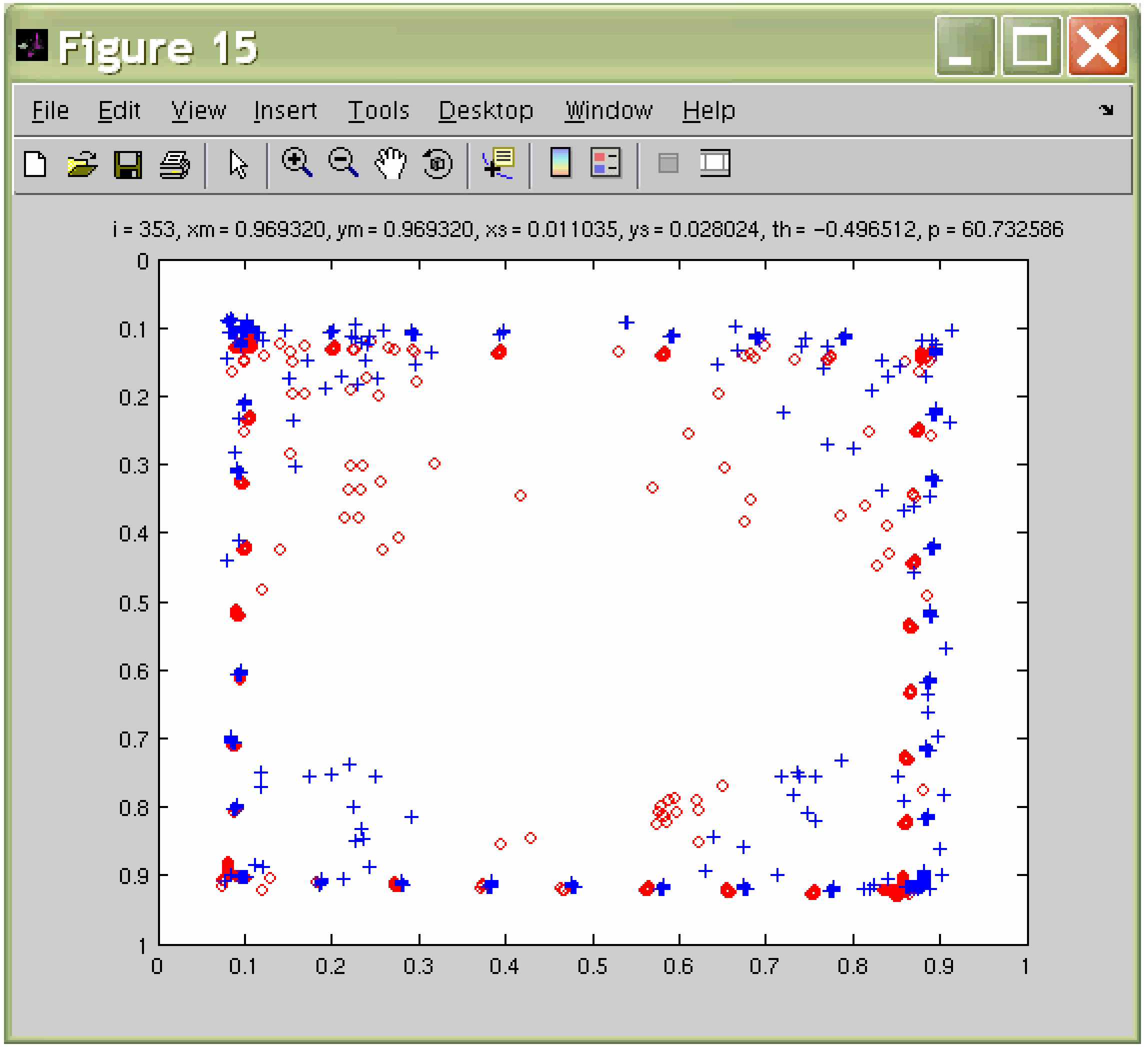
Feature Based

Spatial Relations

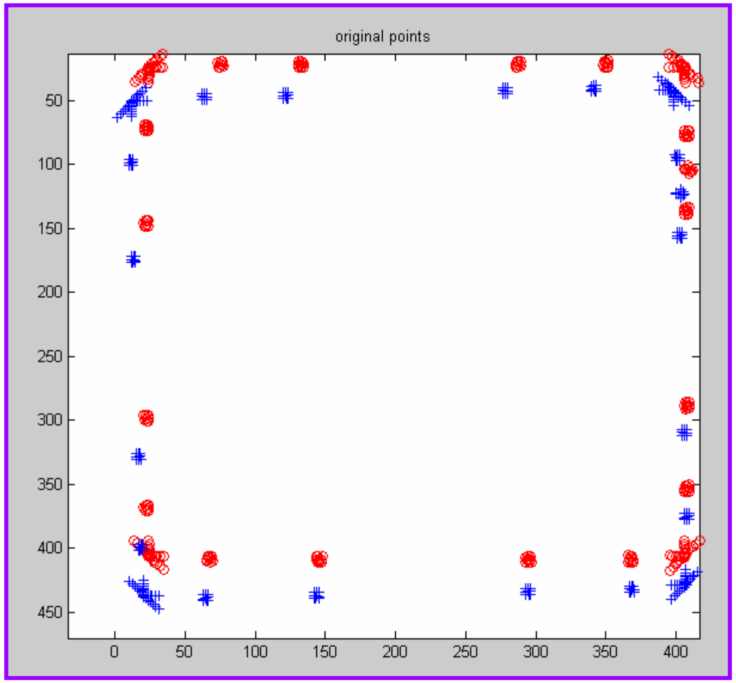
Search Transformations

Random Walk

Branch & Bound



Random walk to transformations, at each step apply algorithm for consensus ranking: finds large transformations while requiring only small % of points to have a match



Putting it All Together

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Many successful proposals use a pyramid of rough-to-fine techniques, iterations, and combinations of algorithms with different strengths.

NIF Optics Inspection example of algorithm combination & rough-to-fine currently being developed to register fiducial patterns.

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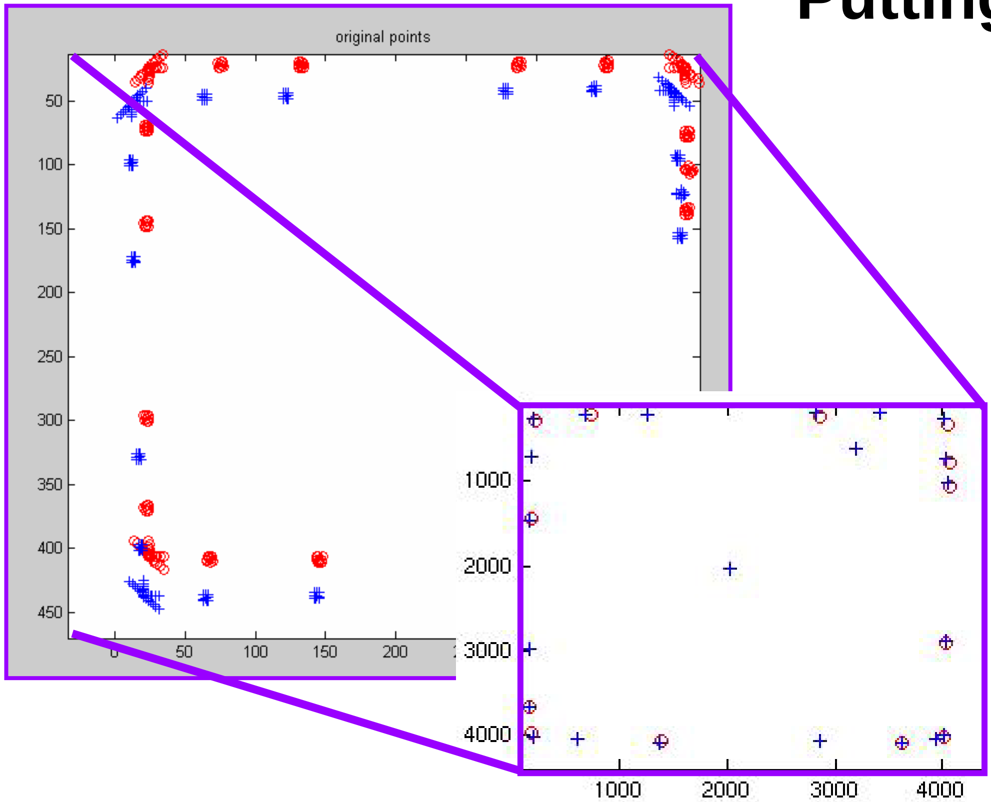
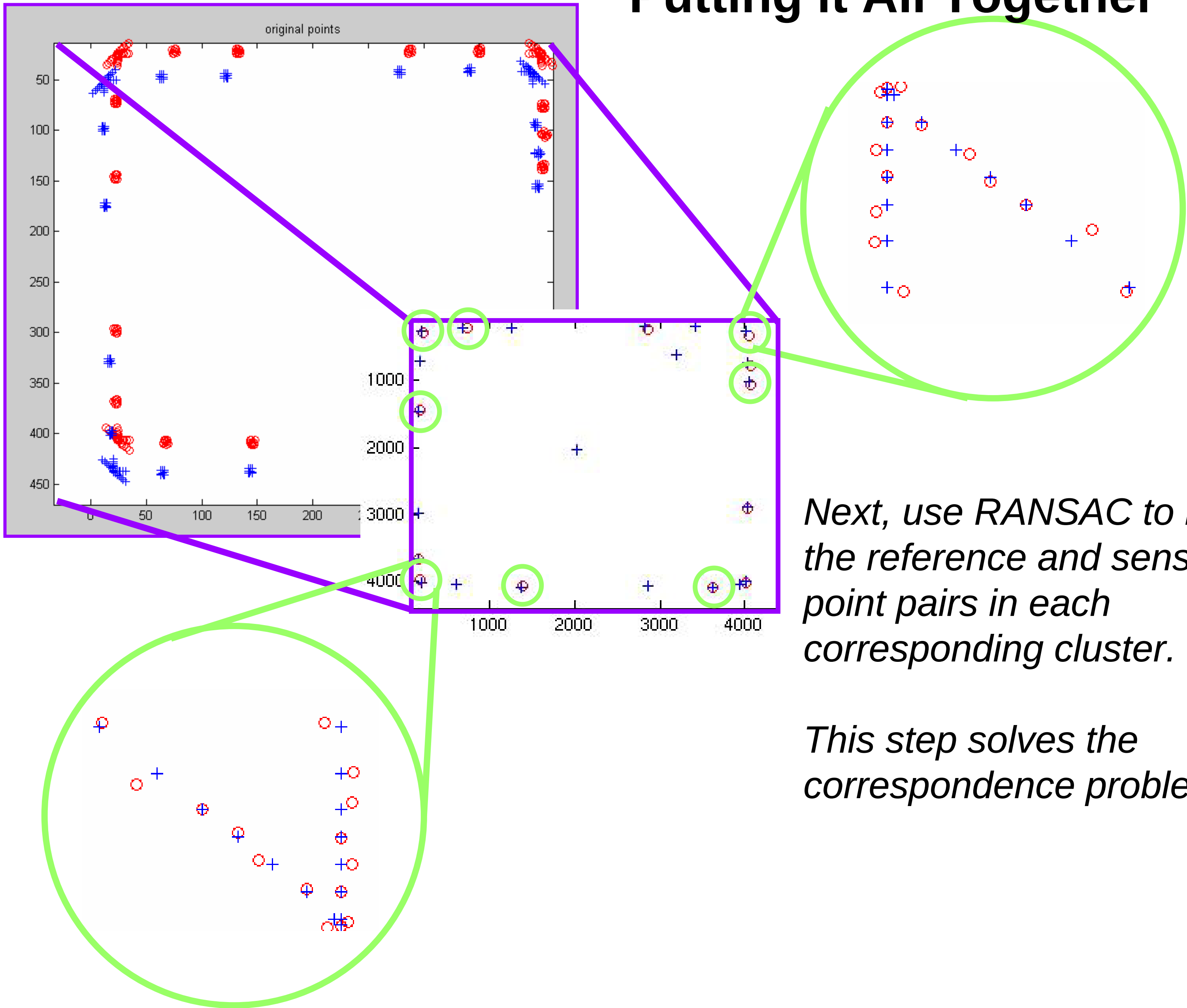


First cluster the fiducials into groups, then use RANSAC to find approximate matches between the sensed clusters and the reference clusters.

This is the initial & roughest result, giving an approximate linear conformal transformation.

Putting it All Together



Next, use RANSAC to match the reference and sensed point pairs in each corresponding cluster.

This step solves the correspondence problem.

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Putting it All Together

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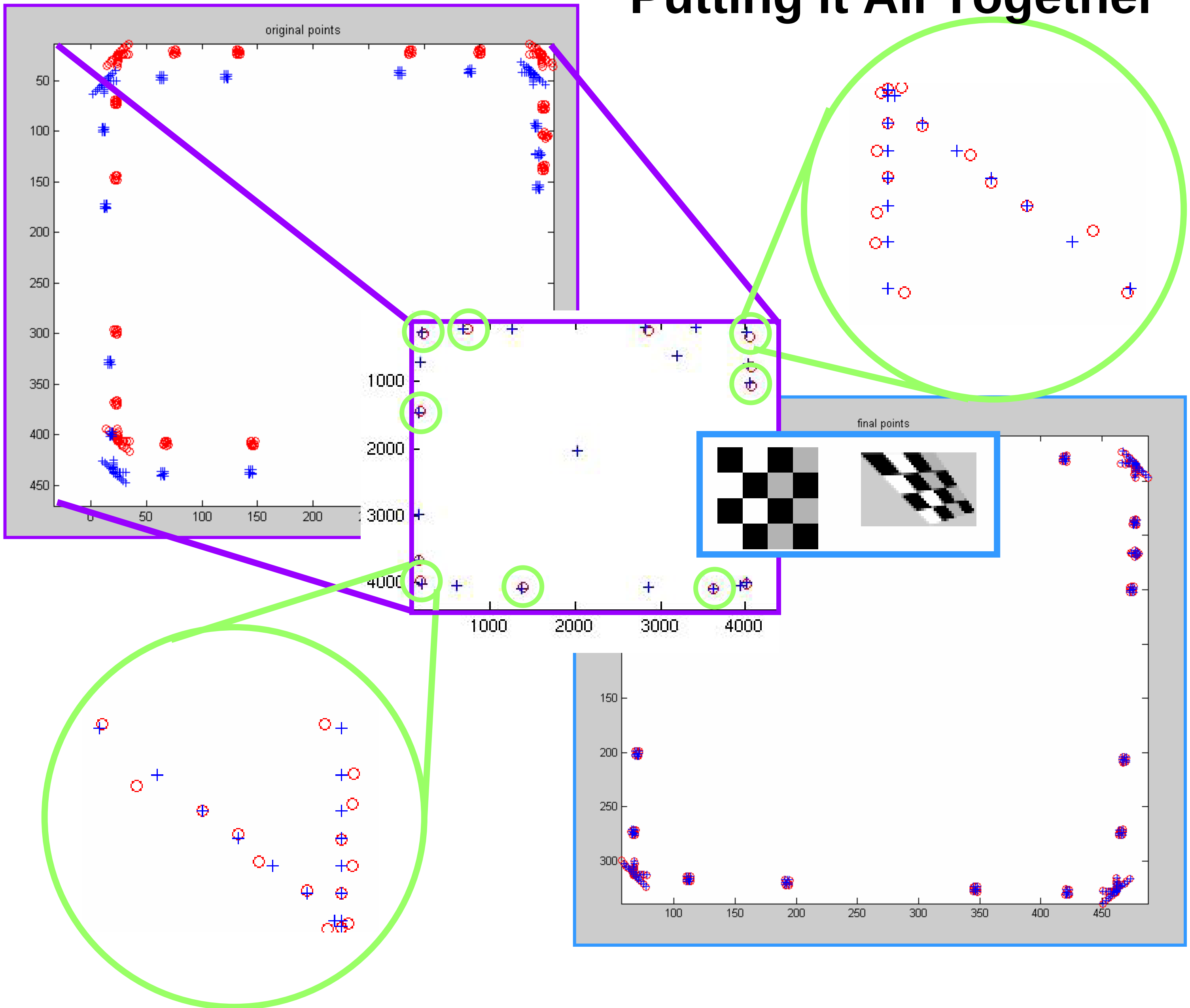

Now use those correspondences to find the best fit projective transformation between the sensed and reference points.

Putting it All Together

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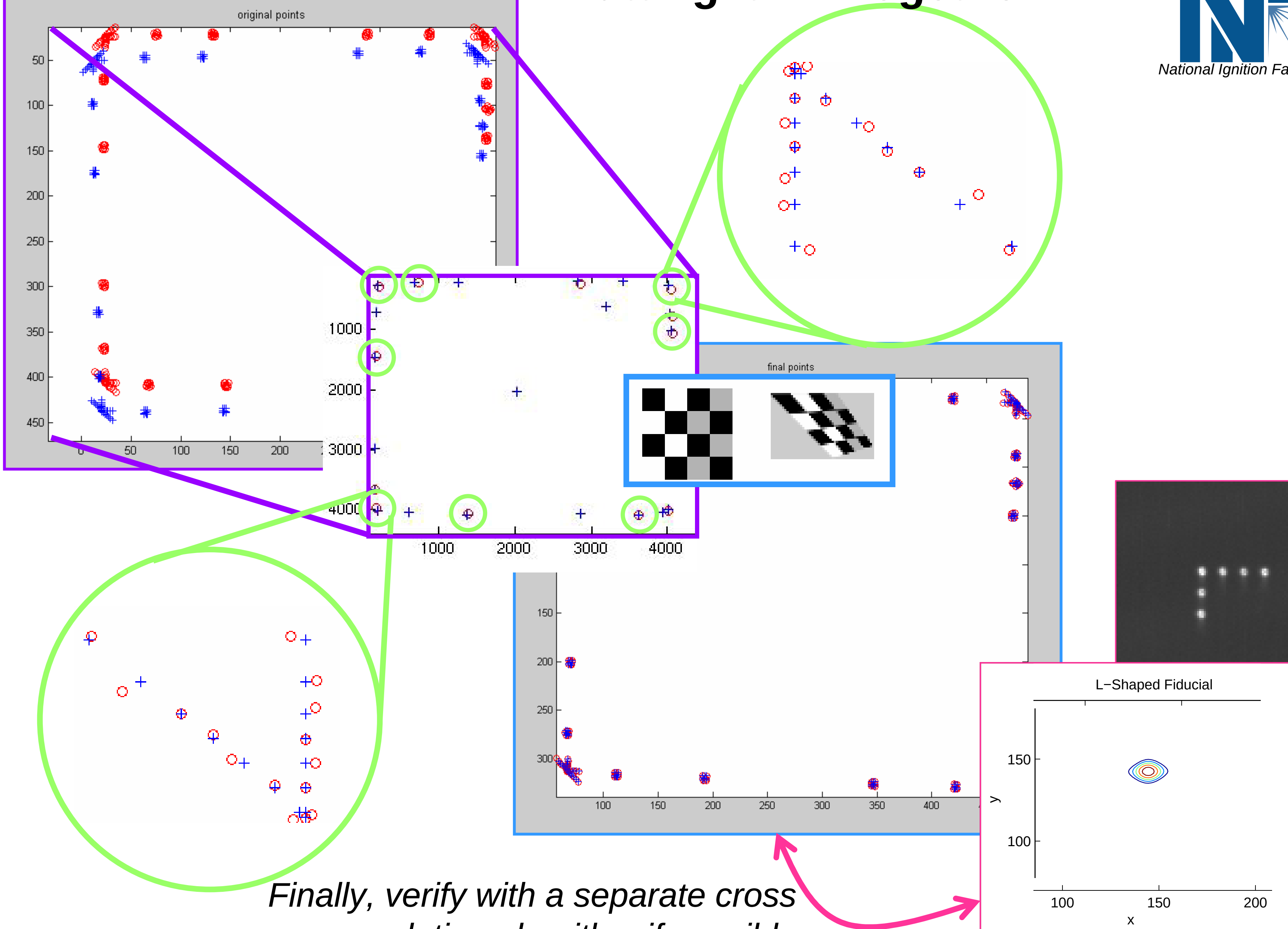
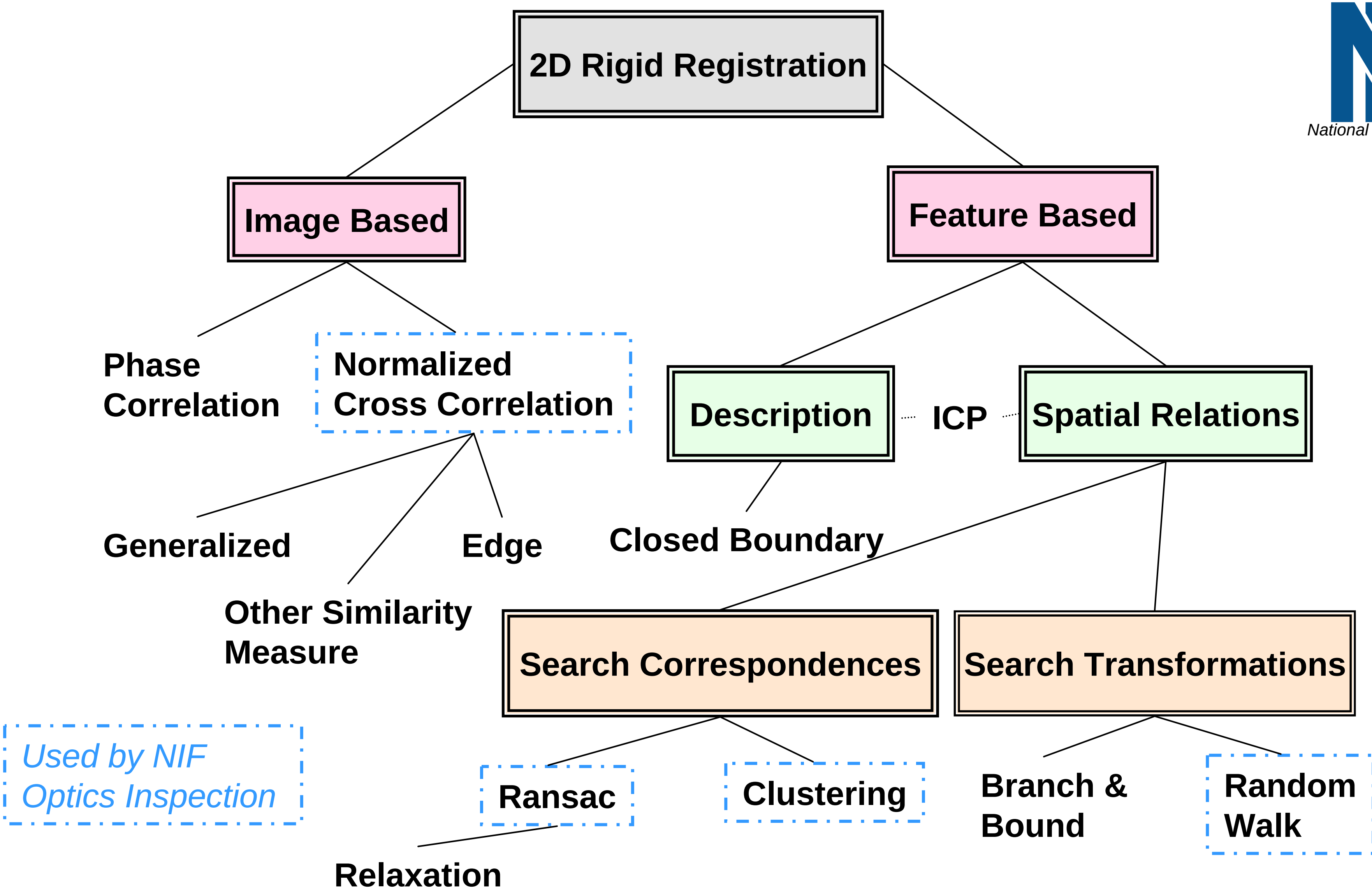


Finally, verify with a separate cross correlation algorithm if possible



- *Identified viable candidate registration algorithms with good performance based on both features and images.*
- *Combined & applied algorithms to successfully solve varied NIF Optics Inspection registration problems.*

References:

[1] Fischler, M. A. and Bolles, R. C.: 1981, Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography, Graphics and Image Processing, Communications of the AMC Vol. 24 Number 6, (381-395).

[2] Groth, E. J.: 1986, A Pattern-Matching Algorithm for Two-Dimensional Coordinate Lists, The Astronomical Journal, Vol. 91 Number 5, (1244-1248)

[3] Mount, D., Netanyahu, N., and Moigne, J.: 1998, Efficient Algorithms for Robust Feature Matching, Pattern Recognition.

[4] Ranade, S. and Rosefeld, A.: 1979, Point Pattern Matching by Relaxation, The Journal of the Pattern Recognition Society, Vol. 12 Number 4, (269-275).

[5] Russ, John C.: 2002, The Image Processing Handbook Fourth Edition: Figure 65. Cross-correlation example: (b) Target letter.

[6] Stockman, G., Kopstein S., and Benett S.: 1982, Matching Images to Models for Registration and Object Detection via Clustering, Transaction on Pattern Analysis and machine Intelligence, Vol. PAMI-4, NO. 3, (229-241).

[7] Zhang, Z.: 1993, Iterative Point Matching for Registration of Free-Form Curves and Surfaces, International Journal of Computer Vision, 13:2, (119-152) 1994.

[8] Zitova, B. and Flusser J.: 2003, Image Registration Methods: a Survey, Science Direct – Image and Vision Computing, (1-21).