A registration error estimation framework for correlative imaging

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Outline

Image registration

Point-based image registration is the process of searching the best geometric transformation linking two images using a set of fiducial pair of points and a theoretical model.

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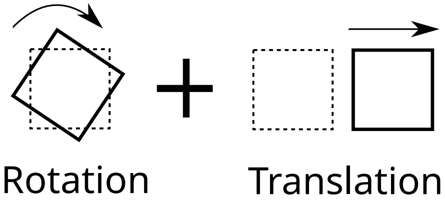
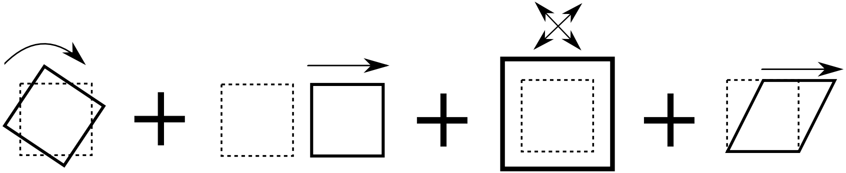
A theoretical model describes how we think the actual transformation between the images looks like.

Rigid transformation

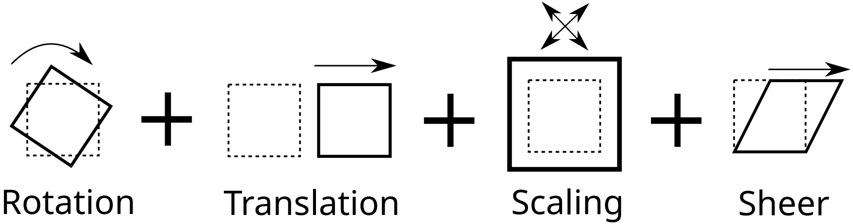


Affine transformation



Rotation Translation Scaling Sheer

Affine transformation



The affine model is the most general of all linear models.

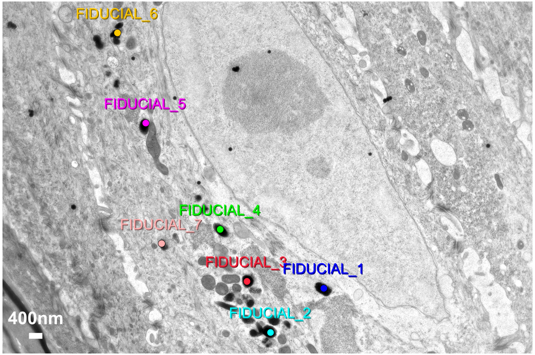


Figure: Electron microscopy with fiducial points set on cellular components

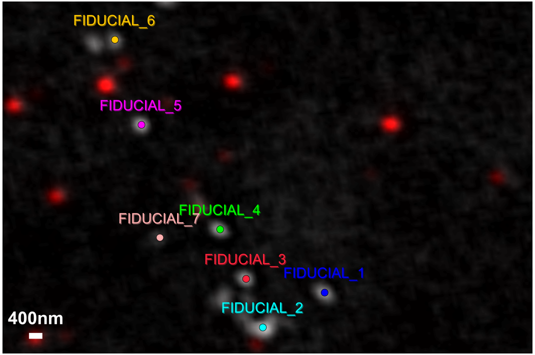


Figure: Fluorescence microscopy, white: cellular components , red: qdots

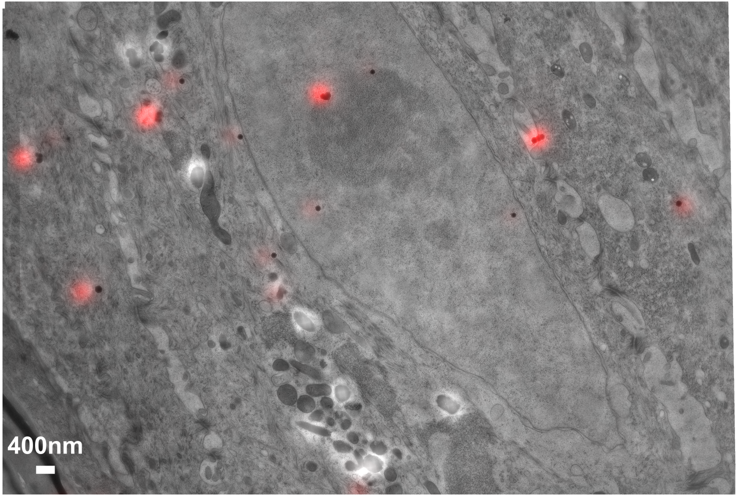
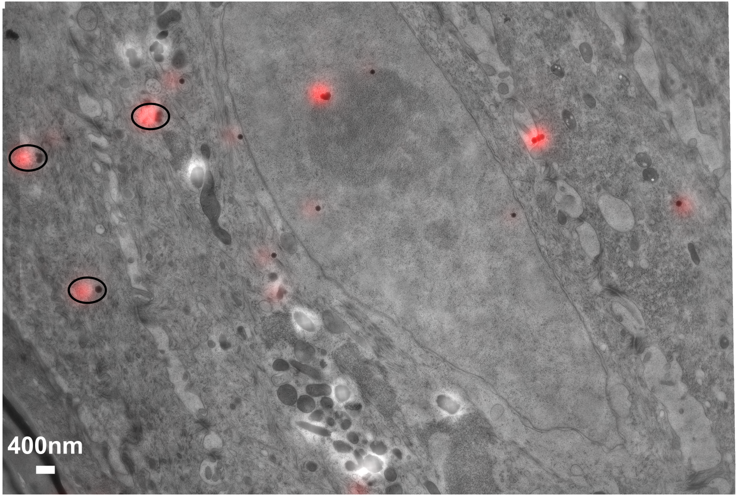


Figure: overlay of registered source and target, showing discrepancy of points of interest (black and red)



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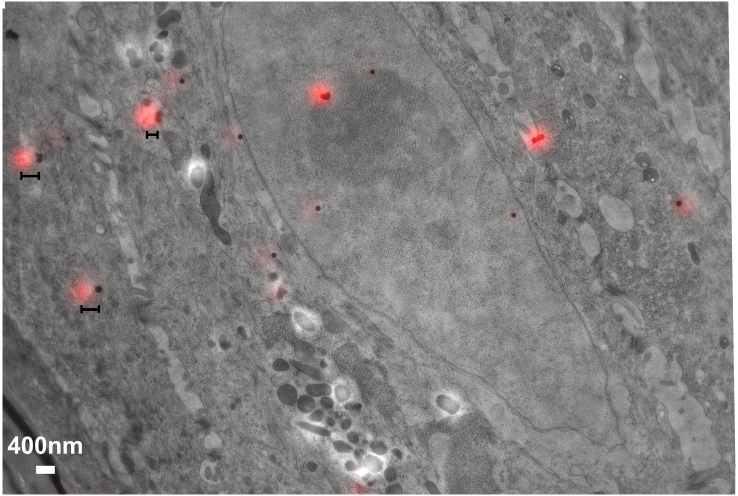

Figure: overlay of registered source and target, showing discrepancy of points of interest (black and red)

How to compute an estimate of the registration error ?

Error estimation methods

Leave-one-out cross validation

1. For each pair of fiducial points :
    1. Perform registration using all fiducial pairs of points but one
    2. Measure error between the pair of points not used for registration
2. Compute the mean or median or 95th percentile of measured errors and use it as the registration error estimation at any location

Leave-one-out cross validation

- Computes a rough average
- Does not take the location of the point of interest into account
- Does not take the registration model into account
- Leads to a poor and sometimes completely wrong error estimate

Analytic registration error estimation framework

1. Start from the registration model
2. Derive an analytic expression for the covariance matrix of the prediction error
3. Construct a confidence area enclosing the registration error at a given point of interest

Analytic registration error estimation framework

Rigid model

1. Find the rigid transformation in the general case using a numerical solver
2. Use the Cramer-Rao asymptotic lower bound to get an estimate of the covariance matrix of the prediction error
3. Construct an asymptotic confidence area enclosing the registration error at a given point

Affine model

1. Find the affine transformation in the general case by **casting the problem as a multivariate linear regression**
2. Derive the prediction error covariance matrix using the linear regression theory
3. Construct a confidence area enclosing the registration error at a given point

Results

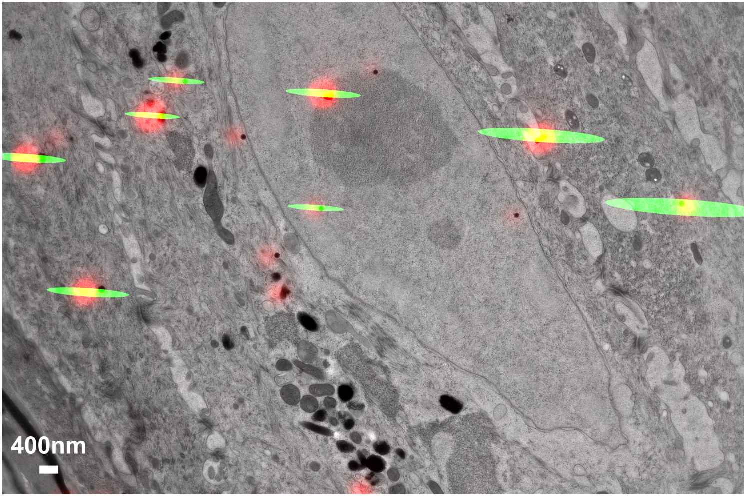

Figure: Computed confidence ellipses at 95% for points of interest

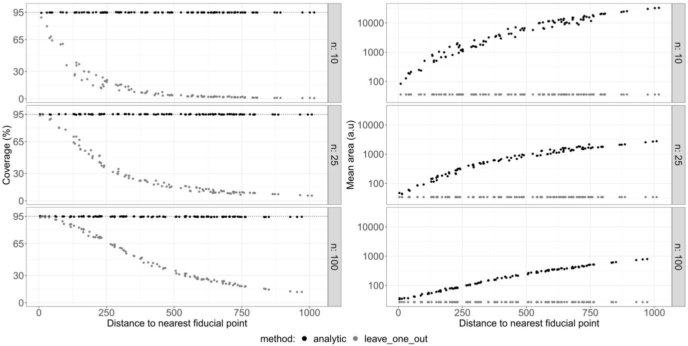

Figure: Coverage and mean area of 95% prediction ellipses at different test points for an affine model computed with analytic and LOOCV methods using 10, 25, or 100 fiducial points under an affine transformation. Coverage is the proportion of times the registered target point fall inside the confidence area during a stochastic simulation. For a 95% confidence area, the theoretical value of the coverage is 95%.

Transformation	Model	Coverage% n=10 mean/STD	Coverage% n=100 mean/STD
rigid	rigid	99.35 / 0.08	95.68 / 0.21
rigid	affine	94.98 / 0.14	94.57 / 0.22
affine	rigid	3.53 / 17.51	2.00 / 14.07
affine	affine	95.05 / 0.21	94.62 / 0.34

Table: Distribution of the coverage rate of 95% prediction ellipses (Coverage%, target value is 95%) for rigid and affine models (model) computed with analytic method under rigid and affine transformations (Transformation) using 10 and 100 fiducial points

Conclusion

- Leave-one-out methods fail to estimate registration error reliably
- Analytic expressions can be derived for rigid and affine registration models
- Fast and robust registration error estimation is provided for the affine registration model through multivariate linear regression
- Affine registration model being more general supersedes rigid registration model unless specific hypothesis are required