

# **Super widefield particle tracking in near real-time via image stitching**

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ECE 278A

# Introduction

## Microscopy's fundamental relation $\text{resolution} \propto \text{range}$

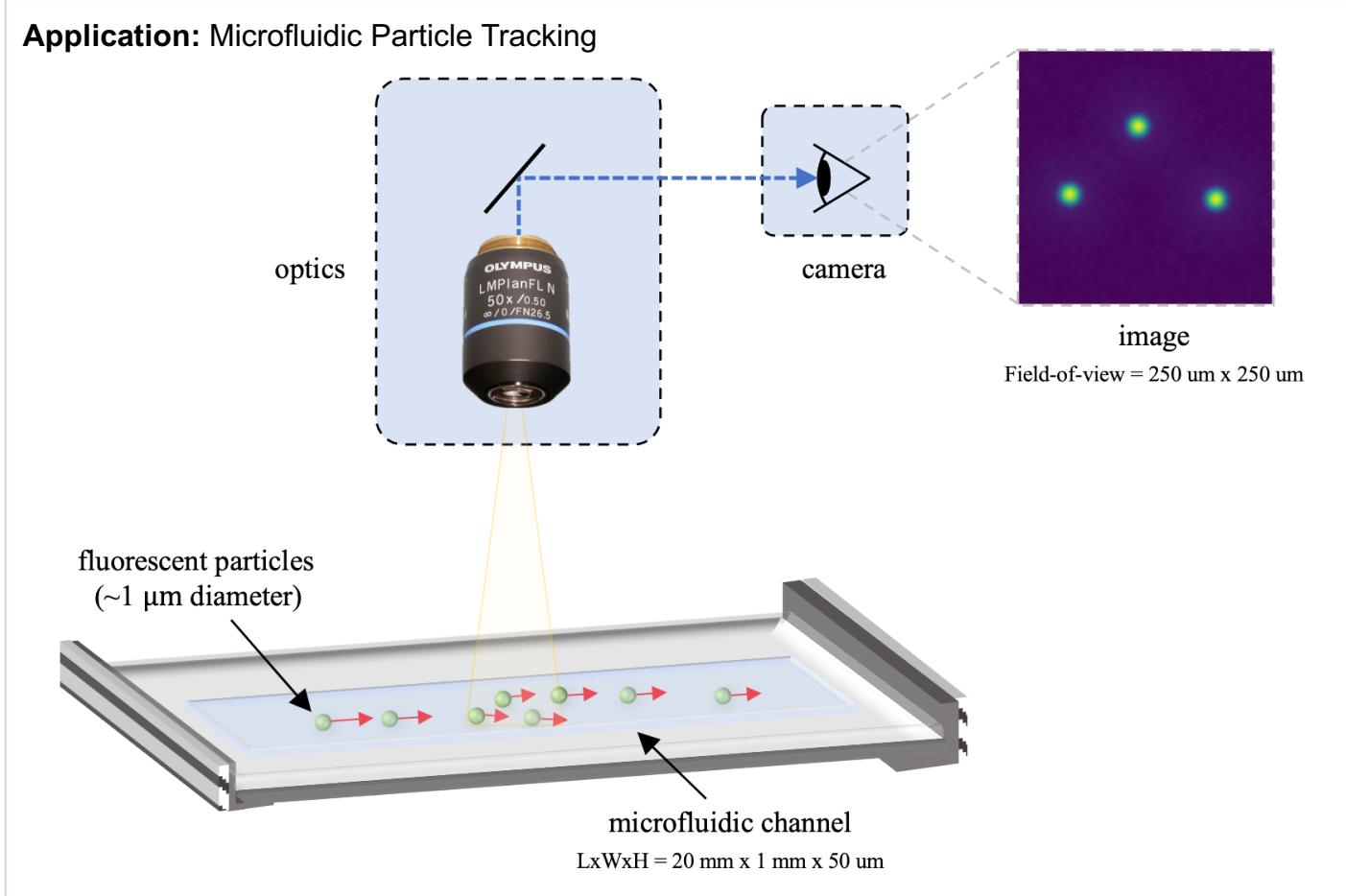
For example, for 20X magnification:

- Field-of-view (FoV; i.e. range) is  $\sim 250 \text{ }\mu\text{m}^2$ .
- spatial (x, y, z) resolution is  $\sim \text{FoV} / 100$ .

**Wants:**  $\text{FoV} \sim 1 \text{ mm}^2$

**Needs:**  $\sigma_{x,y,z} \sim 1 \text{ }\mu\text{m}$

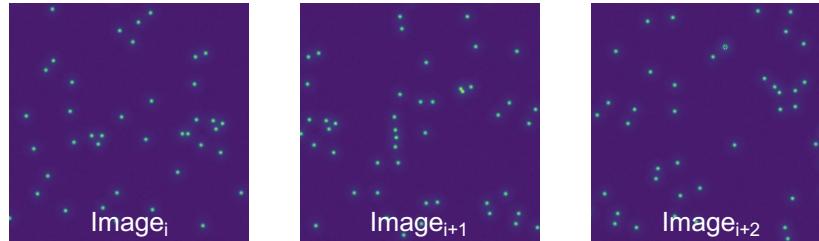
**Limitations:**  $\sigma_{x,y,z} \sim \text{FoV}^{-1}$



# Super widefield imaging via image stitching

## Step 1. Image Acquisition

$\text{Image}_N(x, y, z, \text{time})$



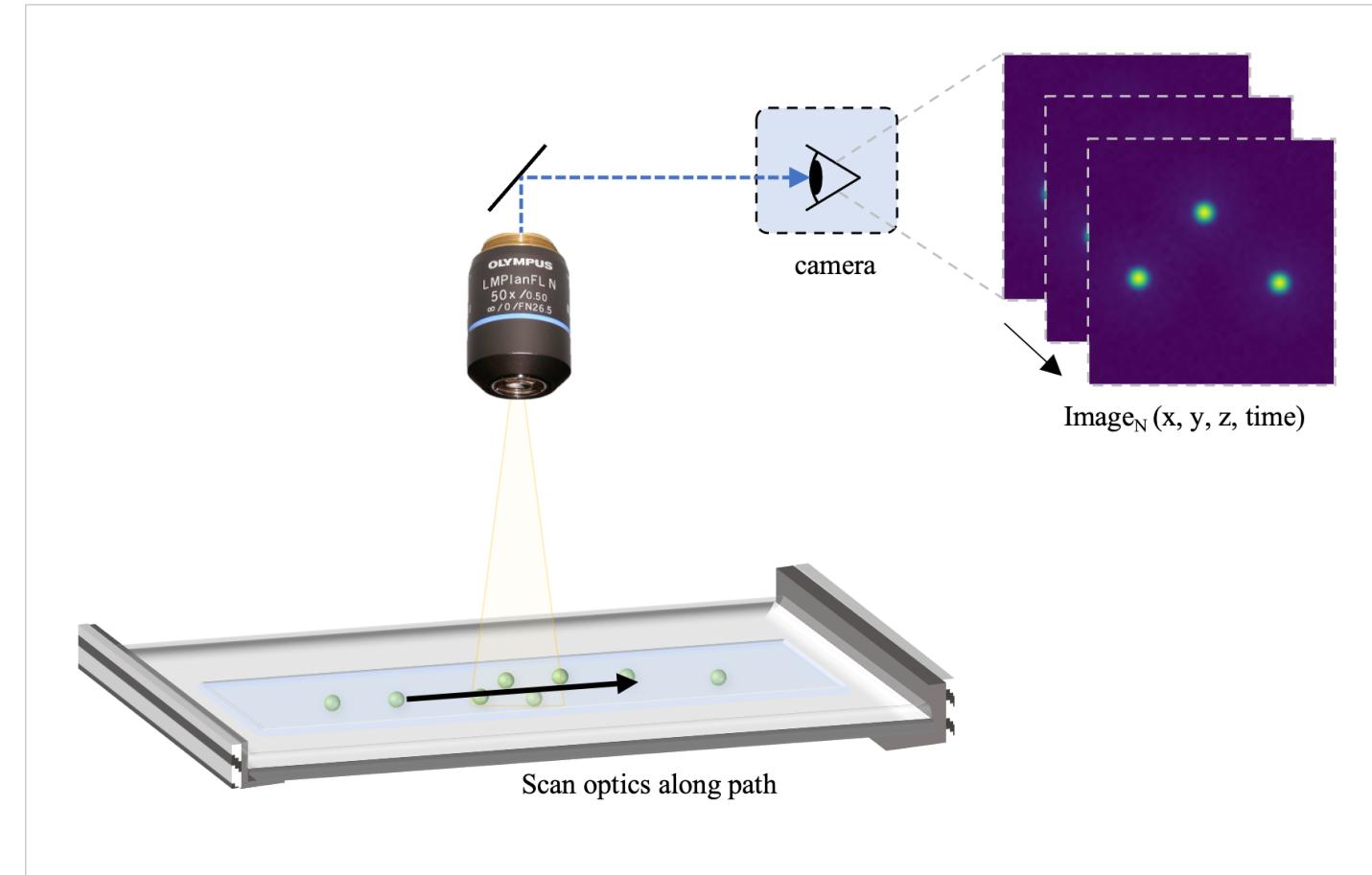
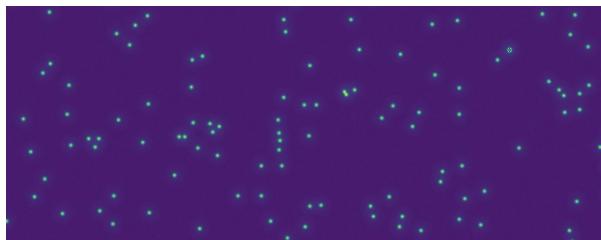
## Step 2. Image-to-image stitching

$\text{Image}_i(x_i, y_i, z_i, t_i) \rightarrow \text{Image}_{i+1}(x_i + \Delta x, y_i + \Delta y, z_i + \Delta z, t_i + \Delta t)$



## Step 3. Super widefield image reconstruction

$\text{Image} = \sum_{i=0}^n \text{Image}_i(x, y, z, t)$

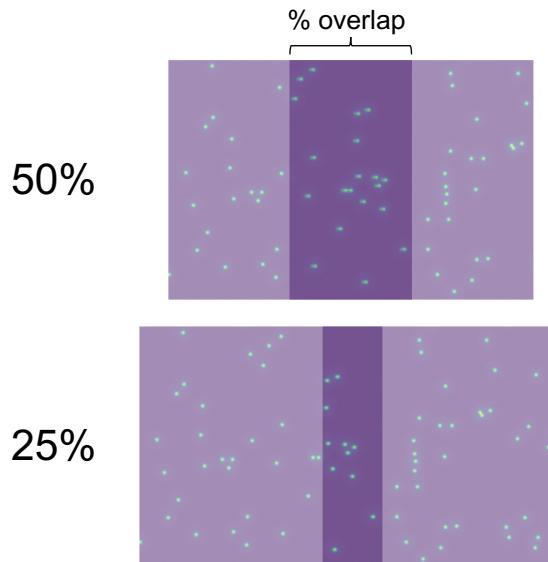


# Methods – Dataset

## Synthetic particle images

- Access to ground truth.
- Standardized dataset.<sup>1</sup>
- Widely used.<sup>2</sup>

**Investigate:** Percent image overlap



Dataset #1

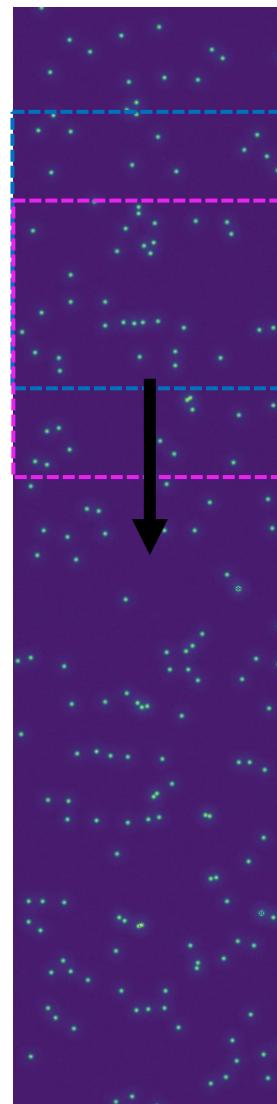
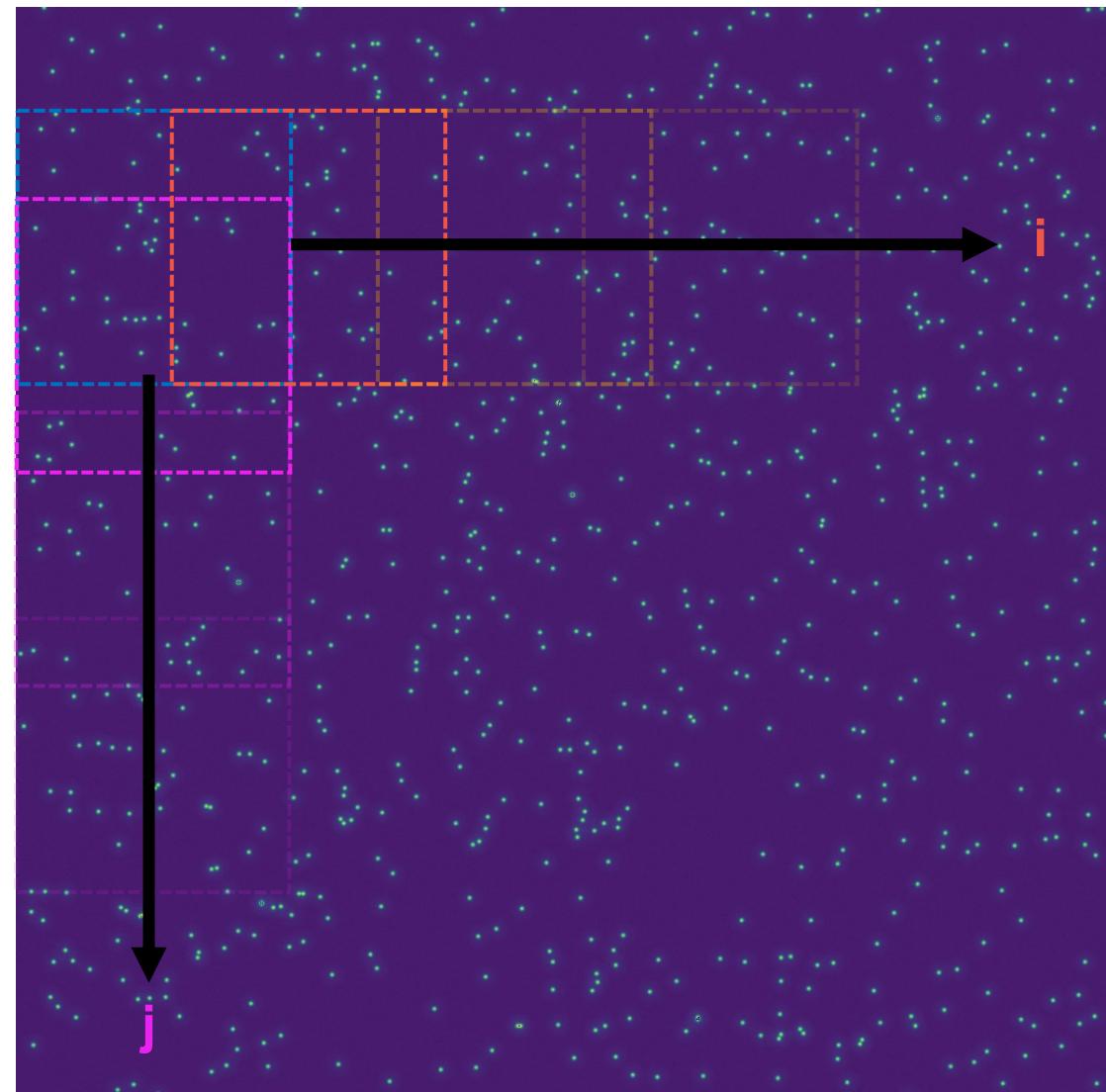


Image for 1D stitching

Dataset #2



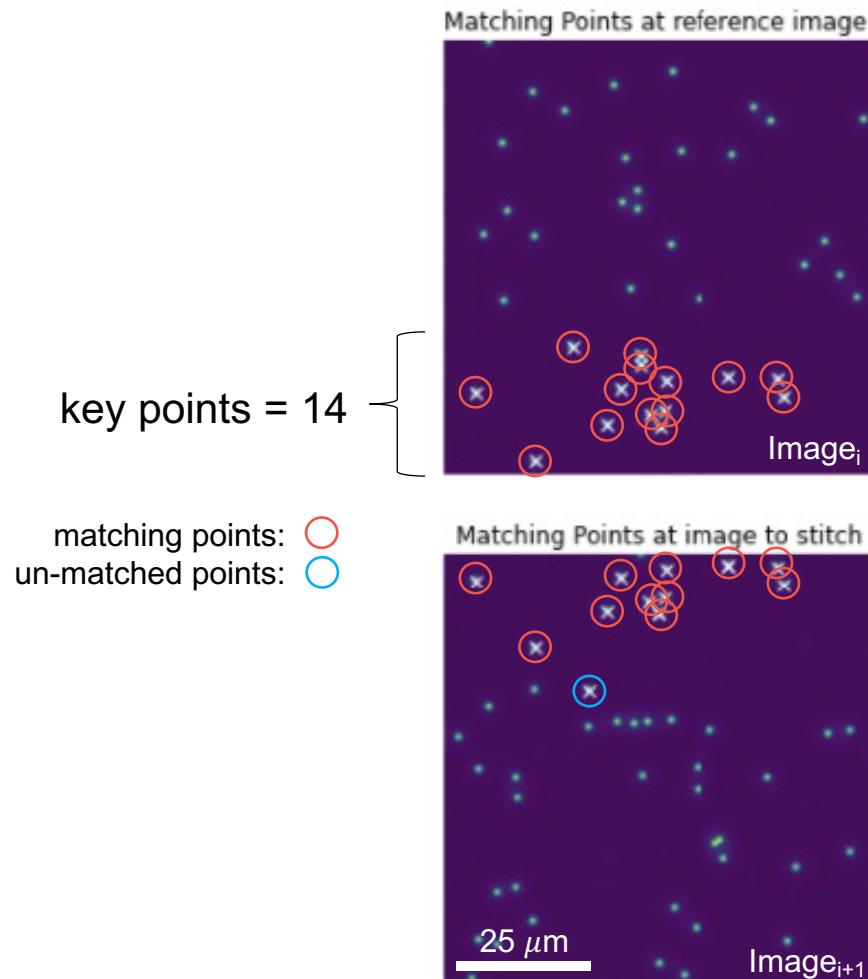
Widefield image for 2D stitching

# Methods – Image Stitching

1. Feature Detection
  - Laplacian of Gaussian (LoG)
  - Difference of Gaussian (DoG)
  - Determinant of Hessian (DoH)
2. Keypoint Preselection
  - Common approaches
  - Our algorithm
3. Keypoint Matching
  - SSD minimization
4. Image Stitching
5. Post-processing Bundle Adjustment

## 2. Keypoint Selection

### (1) Manually define # of key points



Common approaches:

- RANSAC
- Least Median of Squares (LMS)

In our algorithm:

- Challenge: Keypoints look very similar
- Sort the keypoints based on y-position
- Choose a few keypoints from upper
- Choose a few keypoints from lower
- Feature matching (SSD Minimization)

# 3. Keypoint Matching – SSD Minimization

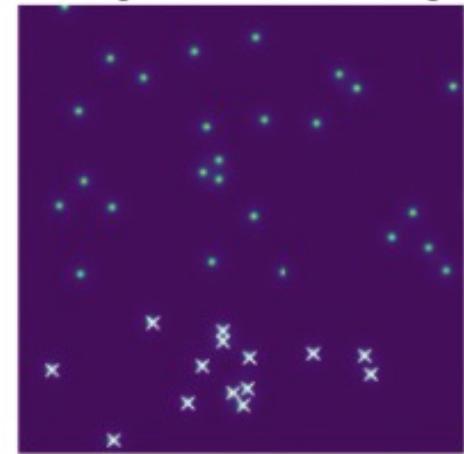
```
def match_locations(img0, img1, coords0, coords1, radius=5, sigma=3):
    """Match image locations using SSD minimization.

    Areas from `img0` are matched with areas from `img1`. These areas
    are defined as patches located around pixels with Gaussian
    weights.
```

Routine:

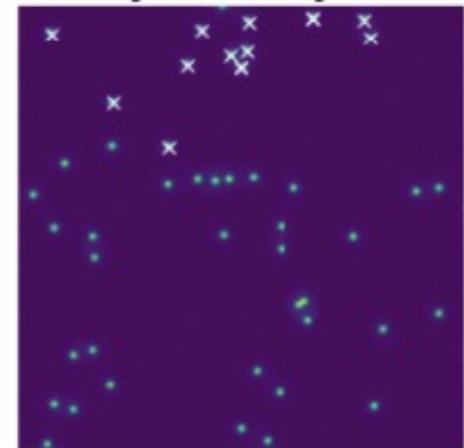
1. For key point<sub>1</sub> in image<sub>i</sub> (img0)
  1. Find the nearest key point in image<sub>i+1</sub> (img1)
  2. Calculate the pixel-wise “distance”:
    1. Evaluate the Gaussian-weighted sum of squared difference over a pixel neighborhood (e.g. 11x11 pixels)
  3. Return the pixel with the smallest distance.
2. Repeat for all key points<sub>1...N</sub>

Matching Points at reference image



image<sub>i</sub>  
(img0)

Matching Points at image to stitch



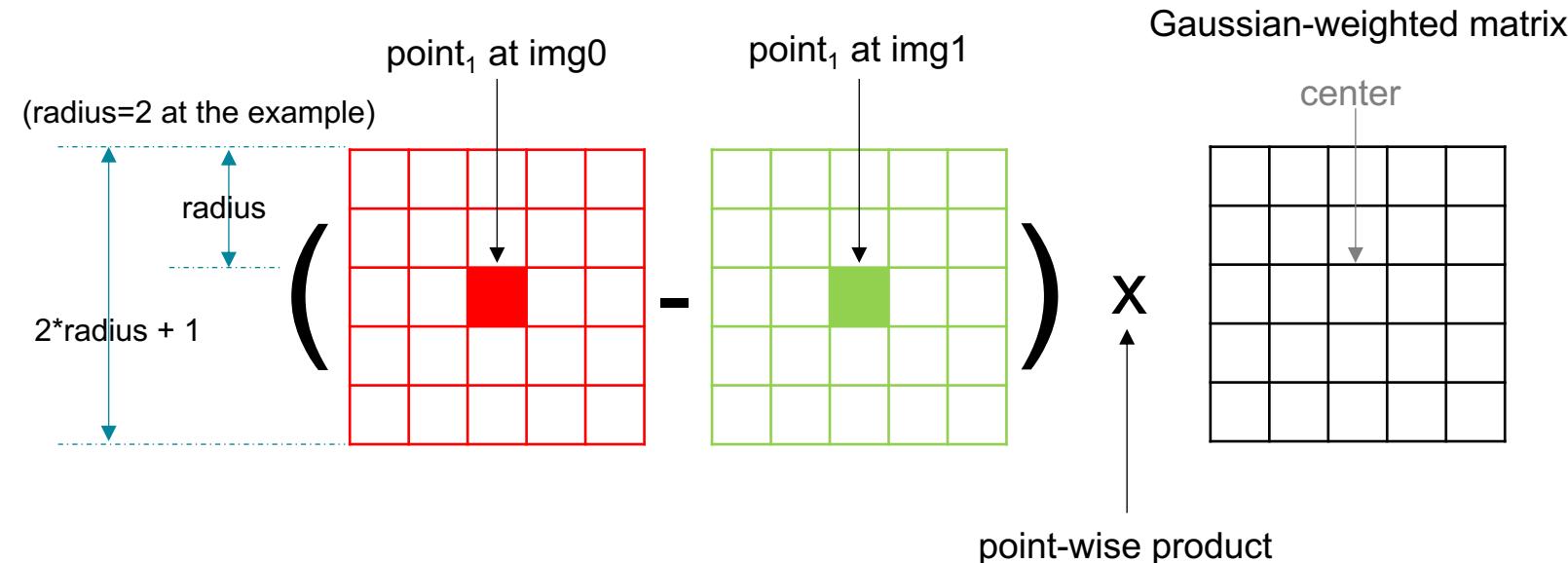
image<sub>i+1</sub>  
(img1)

# 3. Keypoint Matching – SSD Minimization

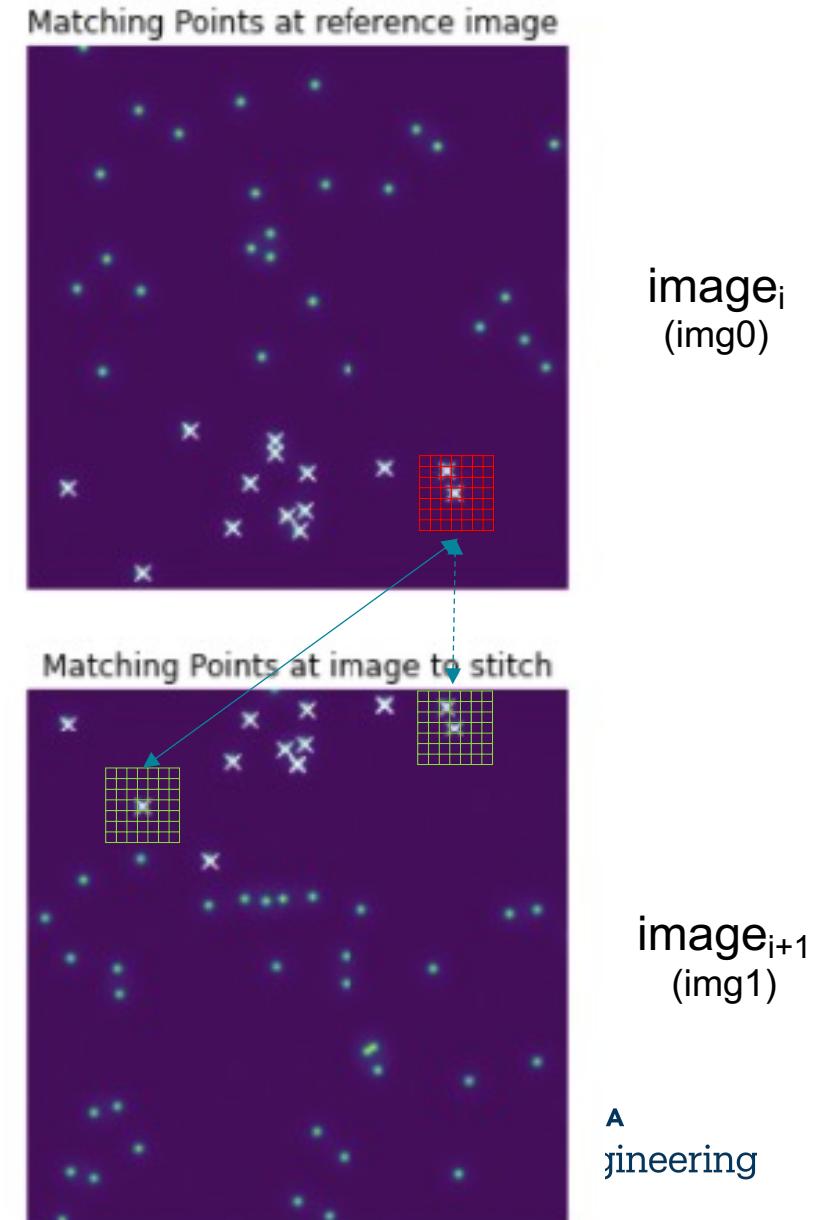
```
def match_locations(img0, img1, coords0, coords1, radius=5, sigma=3):  
    """Match image locations using SSD minimization.
```

Areas from `img0` are matched with areas from `img1`. These areas are defined as patches located around pixels with Gaussian weights.

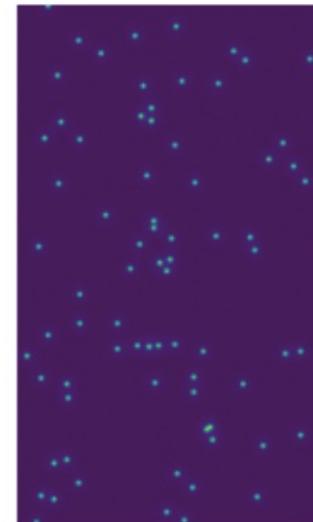
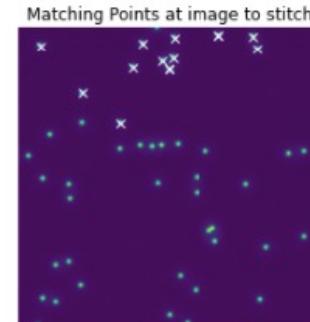
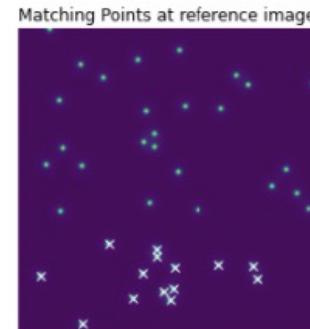
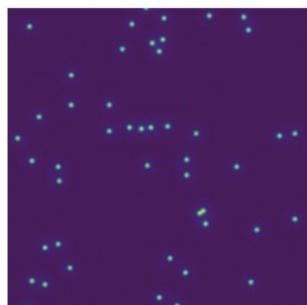
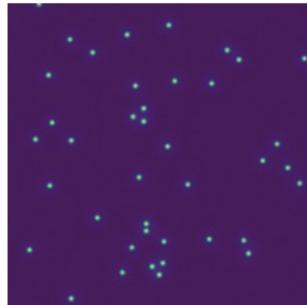
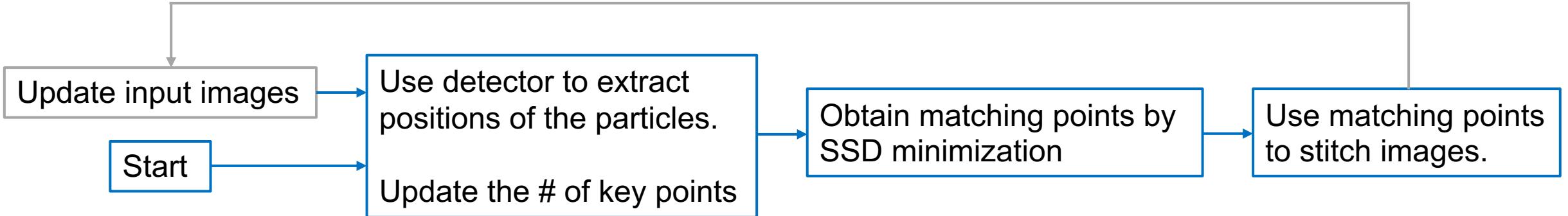
## 1<sup>st</sup> step: compute diff matrix



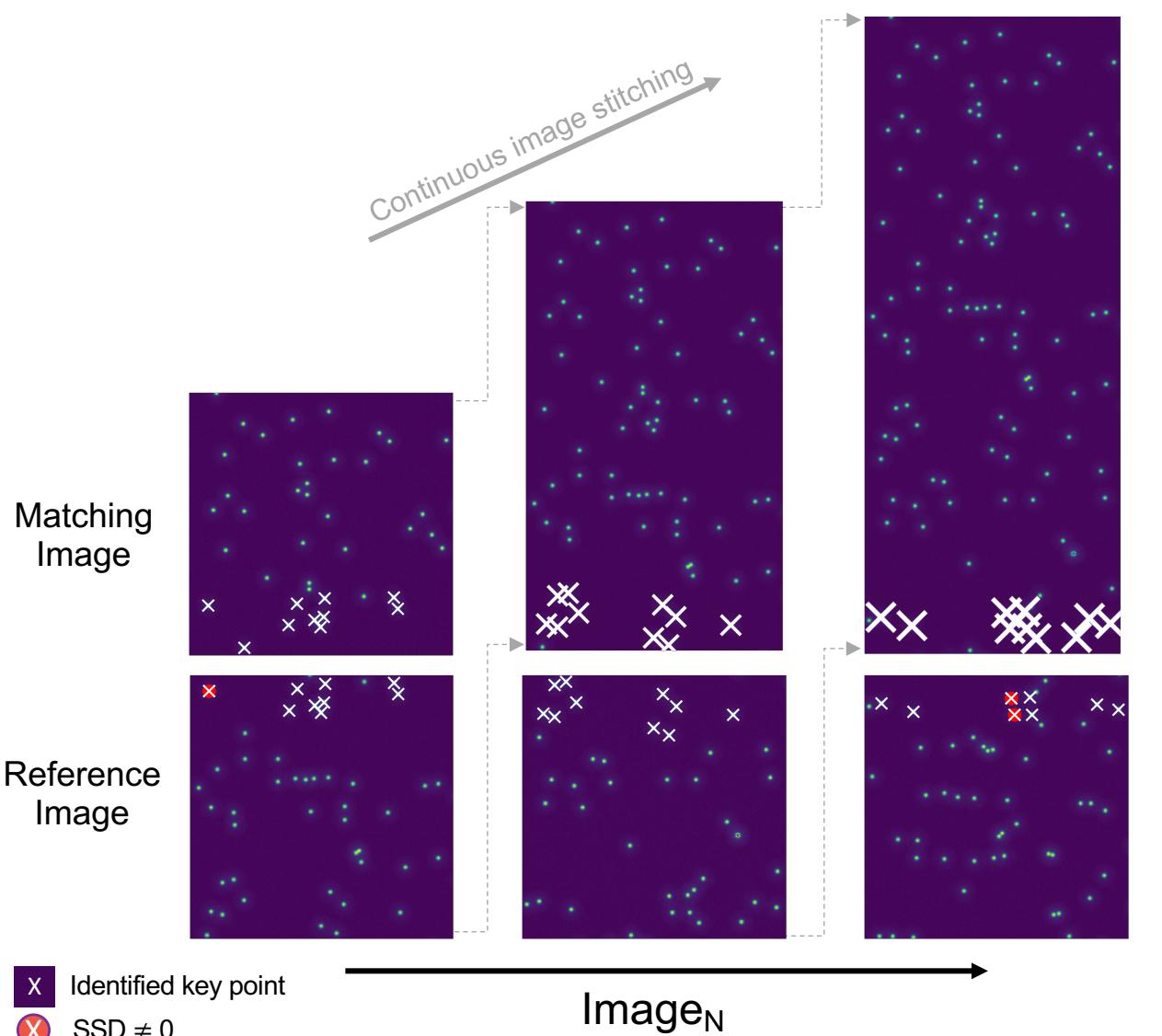
## 2<sup>nd</sup> step: compute sum of elements in diff matrix



# Algorithm Mechanism

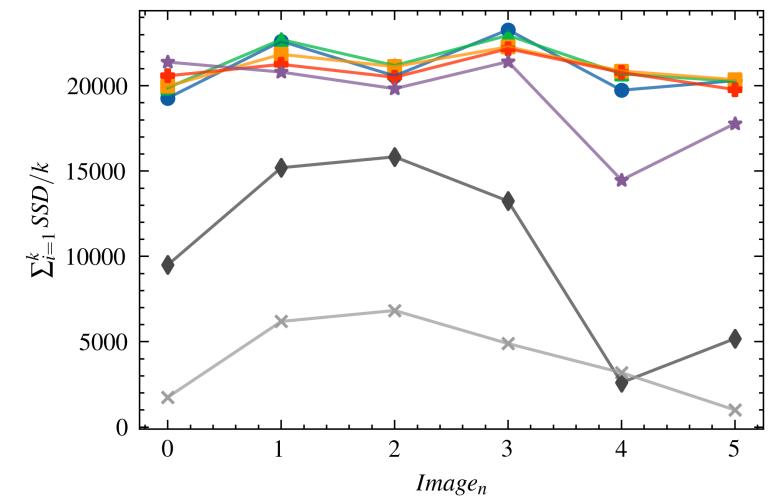
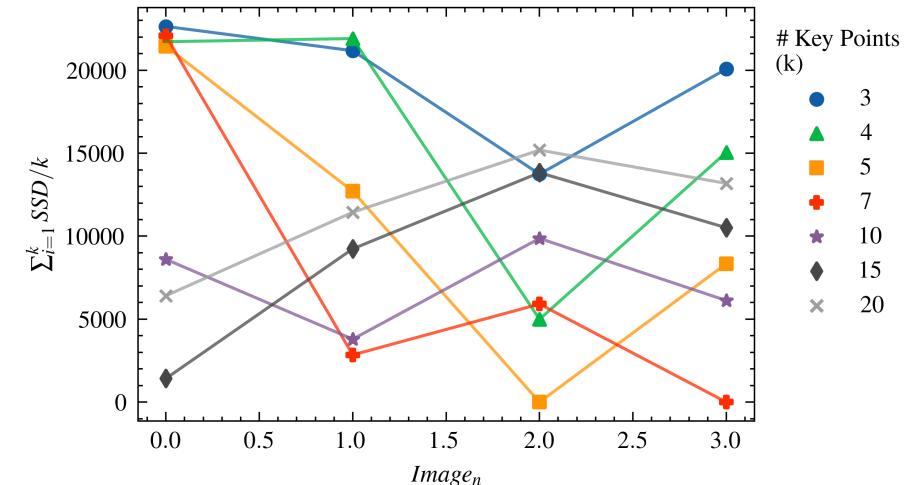


# Results – Number of Key Points



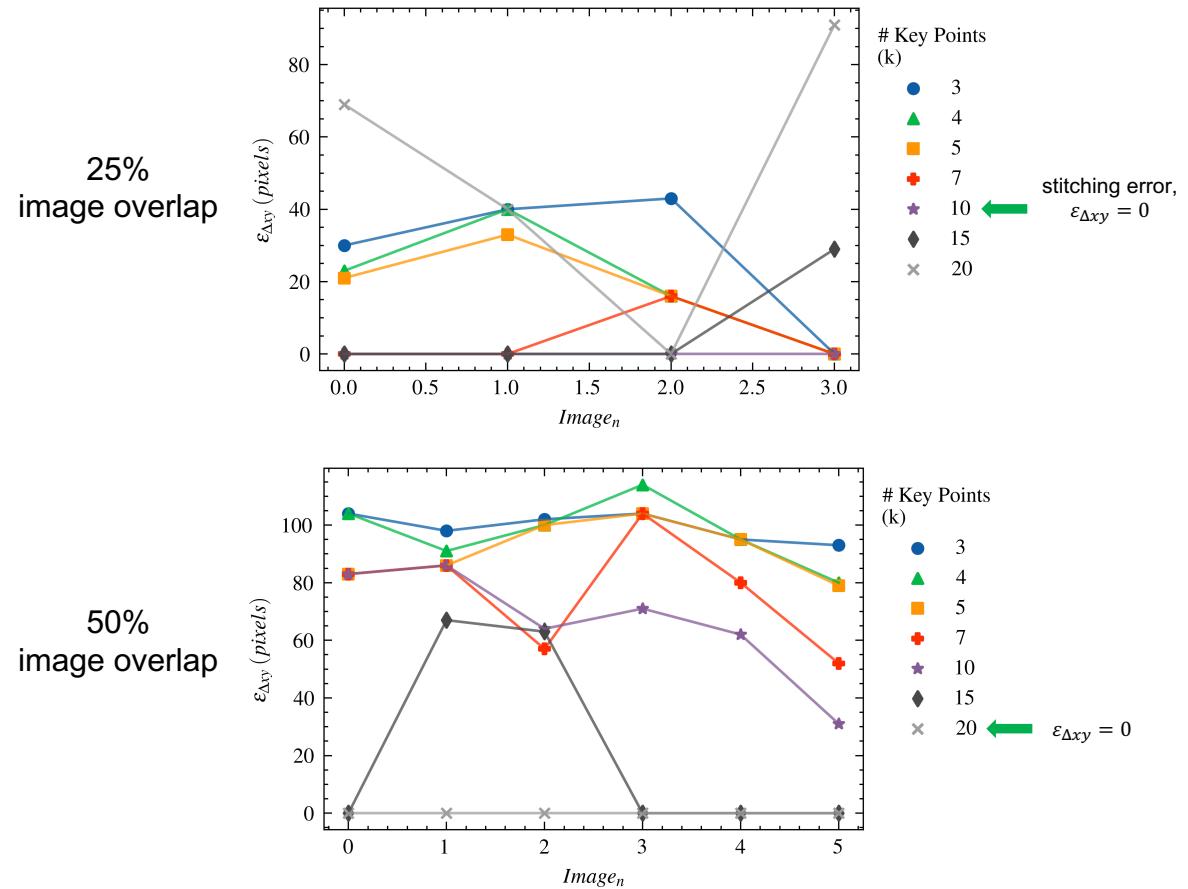
25%  
image overlap

50%  
image overlap

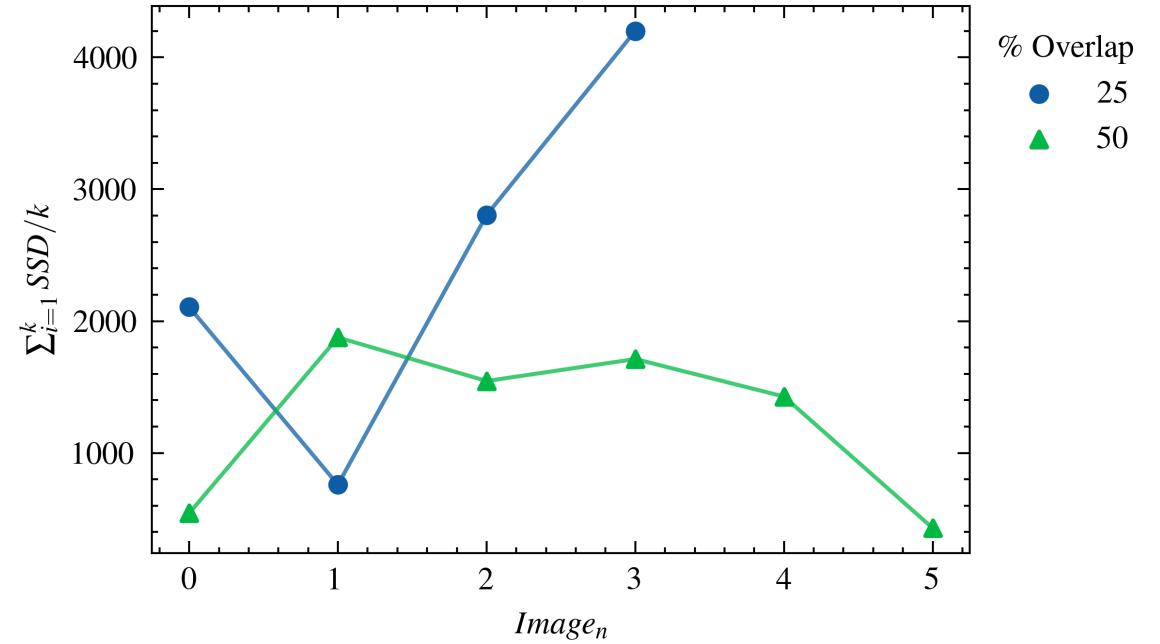


# Results – Percent Image Overlap

1. Identified two “best” stitching implementations.



2. Evaluated super widefield 2D stitching accuracy for 25% and 50% image overlap.



# Conclusion

## Key Takeaways:

- Evaluating pointwise matching accuracy is *not necessarily indicative* of image stitching accuracy.

→ Example: 25% overlap with DoH with 10 key points had lower matching accuracy but perfect stitching accuracy.

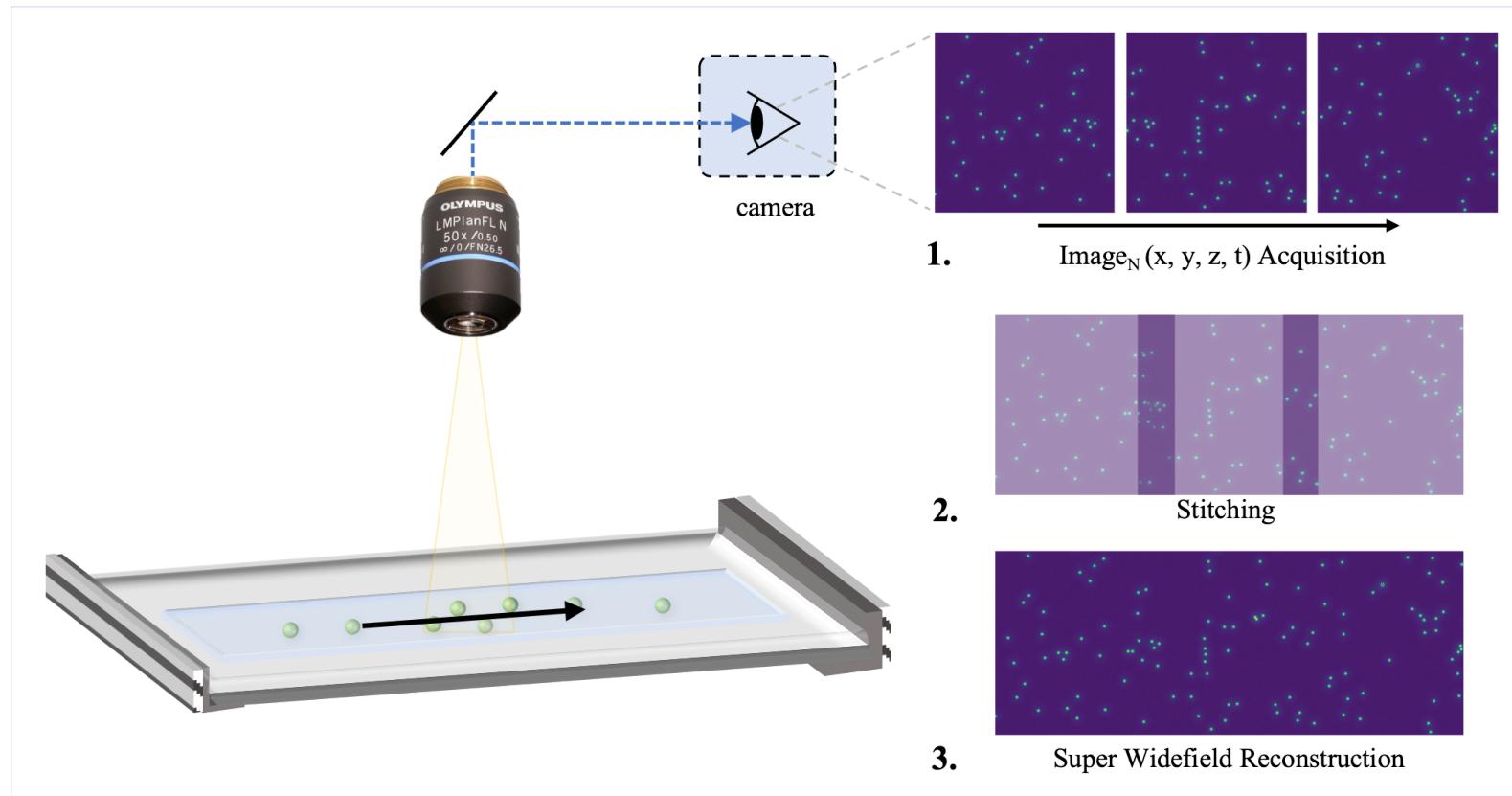
- Increasing the # of key points *generally* increases accuracy.

→ Example: 25% overlap with DoH with 10 key points.

- Increasing the image overlap *generally* increases the accuracy.

→ But perfect stitching was demonstrated at 25% overlap.

→ Enables faster scanning of super widefield area.



# Thank you!

## Questions?

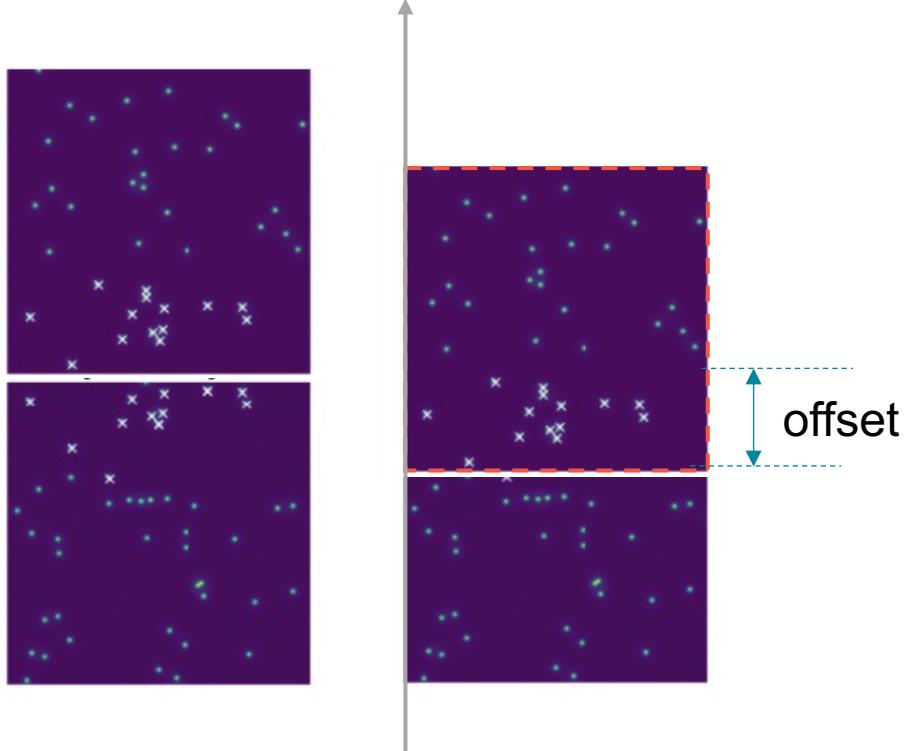
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**College of Engineering**

# Supplementary Information

# Outline

1. Introduction + Background
  - microscopes are limited by field-of-view
2. Solution
  - stitching images together to capture a widefield
3. Methods
  1. Feature Detection
    - 1. Difference of Gaussian (DoG), Determinant of Hessian (DoH), Corner Harris
  2. Keypoint Preselection
    - 1. Manual Input
  3. Matching
    - 1. Custom Gaussian Weighted SSD
  4. Stitching
  5. Post-processing Bundle Adjustment
4. Results and Discussion
  - 1. Number of Key Points
  - 2. Percent Image Overlap
5. Conclusion

# Stitching Function Principle



$$\widehat{\text{offset}} = \operatorname{argmin}_{\text{offset}} \sum_{\substack{\text{matching point } i \\ \text{at img0}}} \sum_{\substack{\text{matching point } j \\ \text{at img1}}} \text{distance}(P_i, P_j)$$

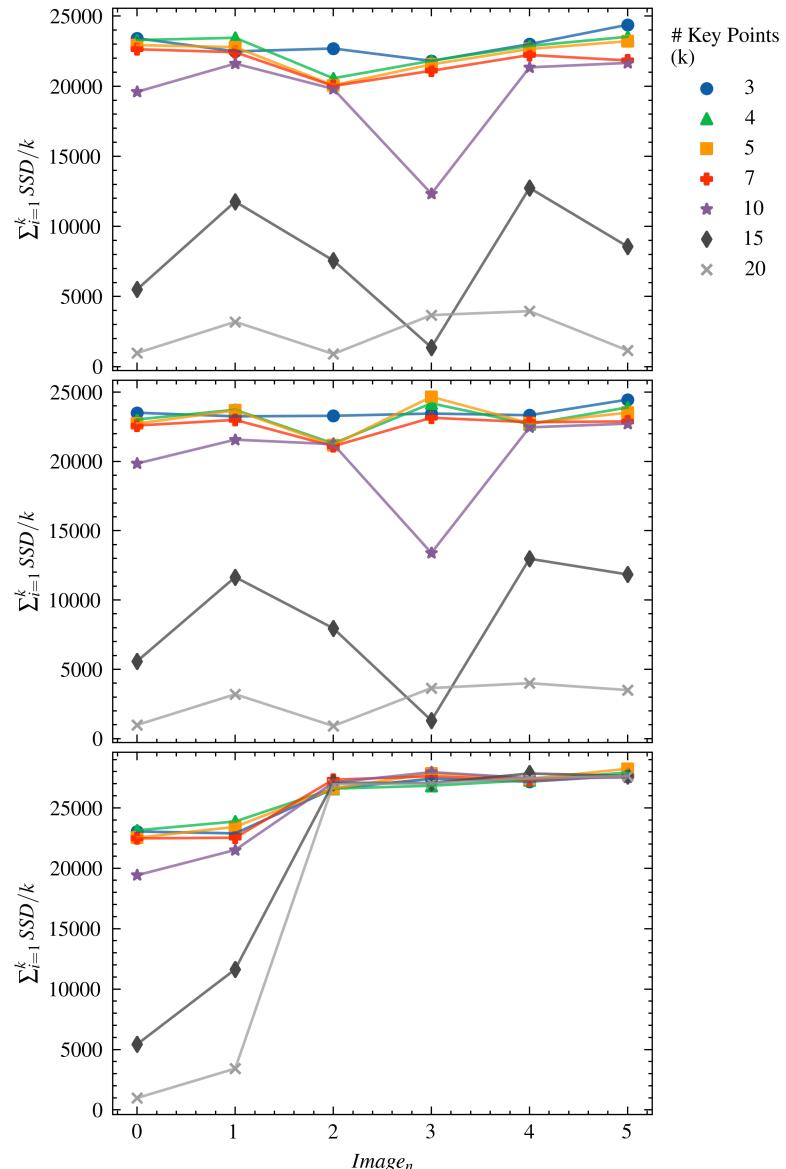
In this example, offset increases from 0 to 256.

# Feature Detection Method

Difference of Gaussians  
(DoG)

Harris Corner Detector

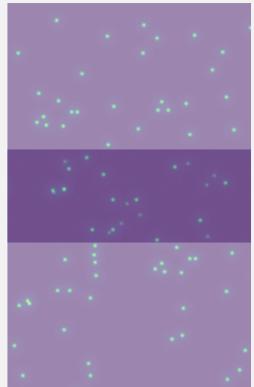
Determinant of Hessian  
(DoH)



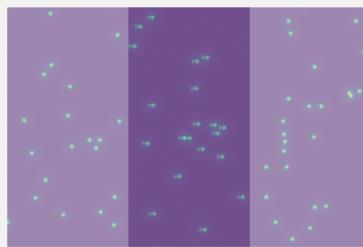
# Future Directions

## Present Work

**Vertical**



**Horizontal**



## Future Work

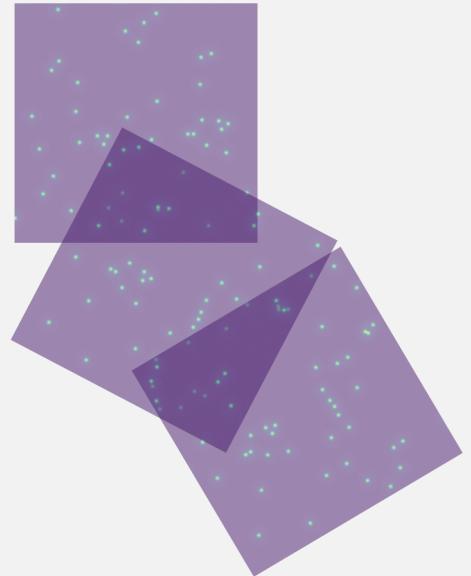
**Arbitrary 2D**

$(x, y)$



**Arbitrary 3D**

$(x, y, \theta)$



# Evaluation Metrics

Metric	Variable Name	Description
Ground Truth	true_image_length	The ground truth image length.
	true_image_width	The ground truth image width.
	true_percent_overlap	The percent overlap of the synthetically generated images.
	true_shift	The pixel shift described by the true percent overlap.
Inputs	input_direction	The direction of the image stitching (e.g., horizontal or vertical)
	input_detector	The key point detector (e.g., Difference of Gaussians)
	input_num_keypoints	The number of key points used for image stitching.
	input_min_distance	The minimum distance (in pixels) allowable for some key point detectors.
Outputs	image_number	The image number along a stitching path where 0 is the first image.
	num_keypoints_detected	The number of key points detected in the image.
	num_keypoints_matching	The number of key points used for image stitchings (dependent on detection).
	sum_ssd	The sum of the sum squared difference over all matching points between two images.
	calc_shift	The calculated shift to stitch two images together.
	calc_diff	A quantitative metric of the image stitching error (note: not used for evaluation).
	calc_image_length	The reconstructed image length.
	calc_image_width	The reconstructed image width.