

# De-ghosting for Gigapixel Snapshot Processing



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# Outline

## 1 Introduction

## 2 De-ghosting

- Pipeline
- Alignment
- Fusion
- Illustrations

## 3 Recap

## 4 Acknowledgments

# Example Multi-Camera Systems

- Higher-end performance through lower-end cameras

System	Overlap ratio	Purpose	Ref.
Stanford Multi-Camera Array (mode 1)	~ 90%	high frame-rate video; synthetic aperture	1
Stanford Multi-Camera Array (mode 2)	~ 50%	high resolution eFOV	1
AWARE-2	~ 10%	high resolution eFOV	2,3
ARGUS-IS	~ 5%	high resolution eFOV	4
<i>Single-camera sweep over stationary scene</i>	variable	high resolution eFOV	5



<sup>1</sup> B. Wilburn *et al.* *ACM Transactions on Graphics* 24:3, 2005.

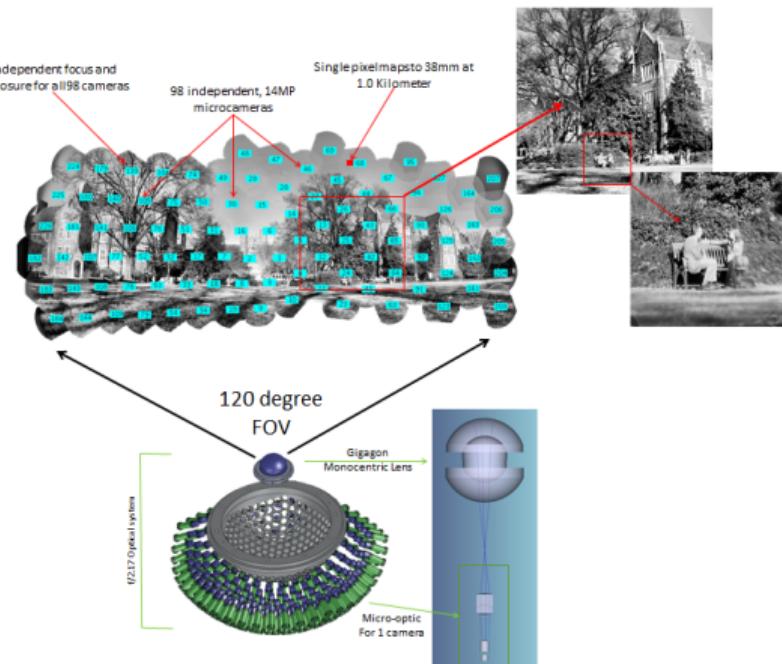
<sup>3</sup> F.R. Golish *et al.* *Optics Express* 20:20, 2012.

<sup>5</sup> J. Kopf *et al.* *ACM Transactions on Graphics* 26:3, 2007.

<sup>2</sup> D.J. Brady *et al.* *Nature* 486:7403, 2012.

<sup>4</sup> B. Leininger *et al.* *SPIE* 6981, 2008.

# AWARE-2 Prototype: 2 Gigapixels, 120° FOV



- Independent focus & exposure
- Gigapixel-resolution snapshots
- Complex configuration on a hemisphere

D.J. Brady *et al.* *Nature* 486:7403, 2012.  
D.R. Golish *et al.* *Optics Express* 20:20, 2012.  
E.J. Tremblay *et al.* *Applied Optics* 51:20, 2012.

AWARE-2 image acquisition outline. Image taken from <http://www.mosaic.disp.duke.edu/AWARE/index.html>.

# Gigapixel Imaging Applications

- Survey, query and monitoring of:
  - urban and suburban development<sup>1</sup>
  - wild-life habitats<sup>2</sup>
  - archaeological sites<sup>3</sup>
- Exploration and dynamics of celestial bodies<sup>4</sup>
- Recognition<sup>5</sup>
- Surveillance<sup>6</sup>

<sup>1</sup> M.A. Smith. *Fine International Conference on Gigapixel Imaging for Science*, 2010.

<sup>2</sup> M.H. Nichols et al. *Rangeland Ecology & Management* 62, 2009.

<sup>3</sup> M. Seidl and C. Breiteneder. *VAST*, 2011.

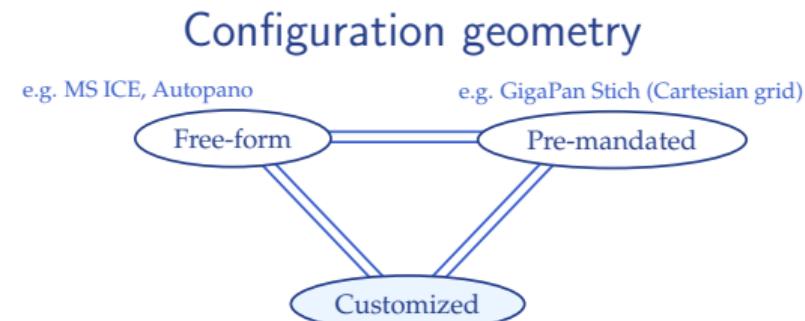
<sup>4</sup> A. McEwen et al. *Journal of Geophysical Research: Planets* 115, 2007.

<sup>5</sup> L. Gueguen et al. *IGARSS*, 2011.

<sup>6</sup> B. Leinenen et al. *SPIE* 6981, 2008.

# Stitching Software

- GigaPan Stitch<sup>1</sup>
  - Autopano Giga<sup>2</sup>
  - Microsoft ICE<sup>3</sup>
  - Autostitch<sup>4</sup>
  - Panorama Tools<sup>5</sup>
  - Fiji<sup>6</sup>
  - ...
- 
- Challenged by complex, sparse geometry & small, noisy overlap



<sup>1</sup> [gigapan.com/](http://gigapan.com/)

<sup>3</sup> [research.microsoft.com/en-us/UM/redmond/groups/IVM/ICE/](http://research.microsoft.com/en-us/UM/redmond/groups/IVM/ICE/)

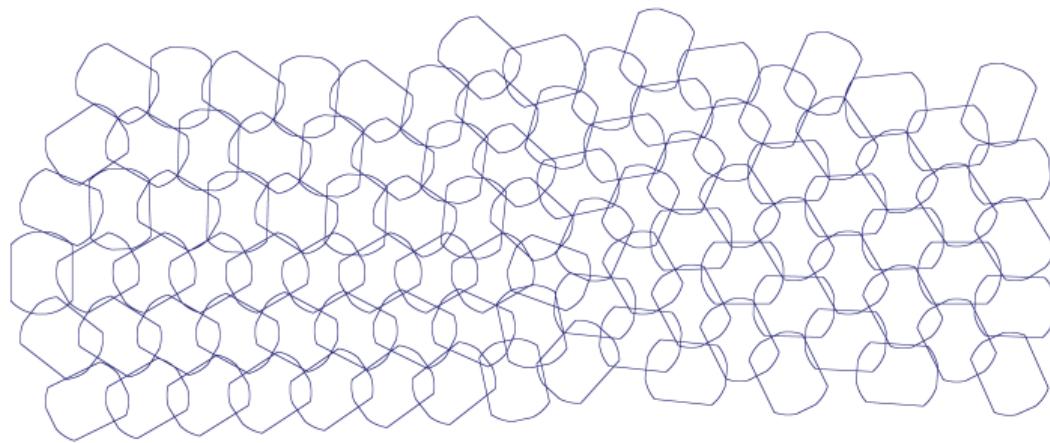
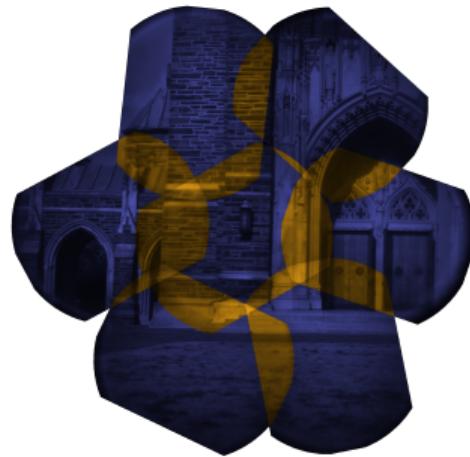
<sup>5</sup> [panotools.sourceforge.net/](http://panotools.sourceforge.net/)

<sup>2</sup> [autopano.net/](http://autopano.net/)

<sup>4</sup> [www.cs.bath.ac.uk/brown/autostitch/autostitch.html](http://www.cs.bath.ac.uk/brown/autostitch/autostitch.html)

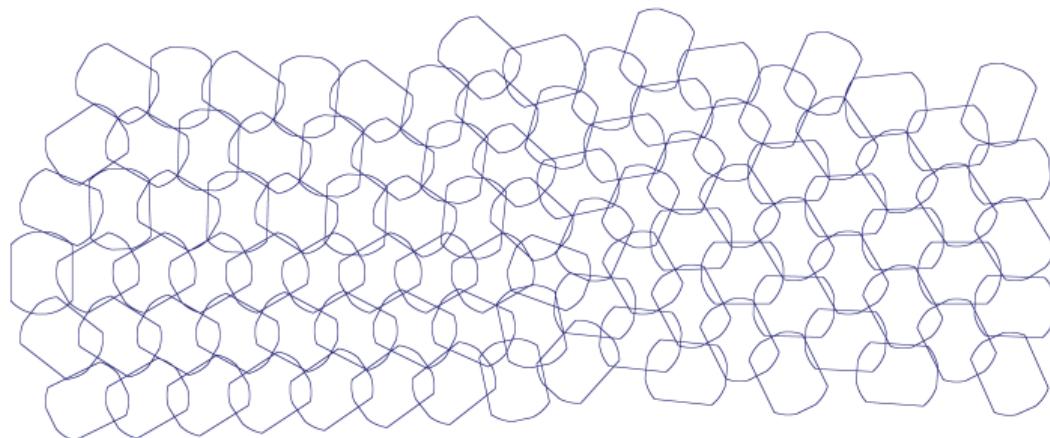
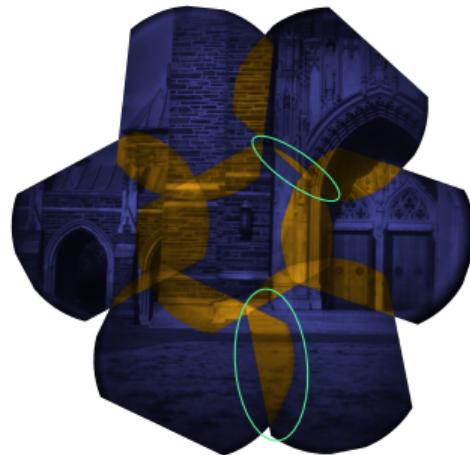
<sup>6</sup> <http://fiji.sc/>

# FoV Overlap: Small, Sparse, Noisy



Note: AWARE-10 is coming out; see M. Gehm's talk

# FoV Overlap: Small, Sparse, Noisy



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# Ghosting & De-ghosting

Ghosted image



De-ghosted using our pipeline



Both results from the AWARE-2 (monochrome) dataset     (*AWARE-10 produces color images*)

# Ghost Sources

- Static/systematic:
  - Deviations from design during manufacturing
  - Displacement in array mounting
  
- Transient/scene-dependent:
  - Variable camera viewpoints
  - Independent camera parameters & settings

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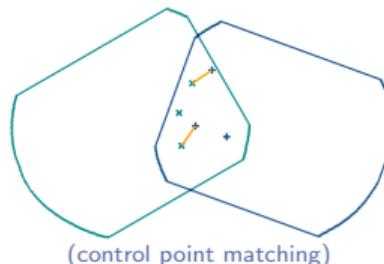
- Pipeline
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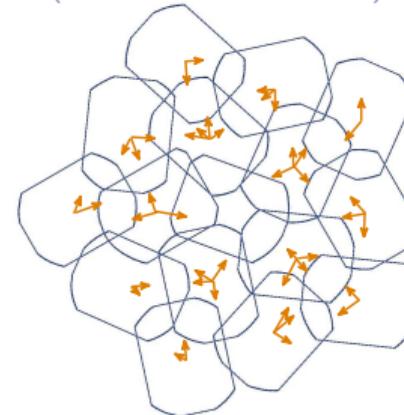
# De-ghosting: 3 Key Steps

## ■ Pairwise registration

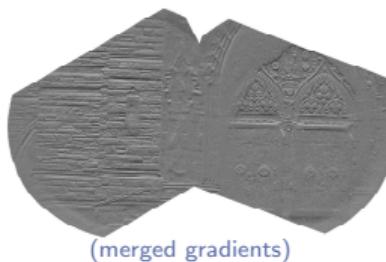


## ■ Global bundle adjustment among multiple images

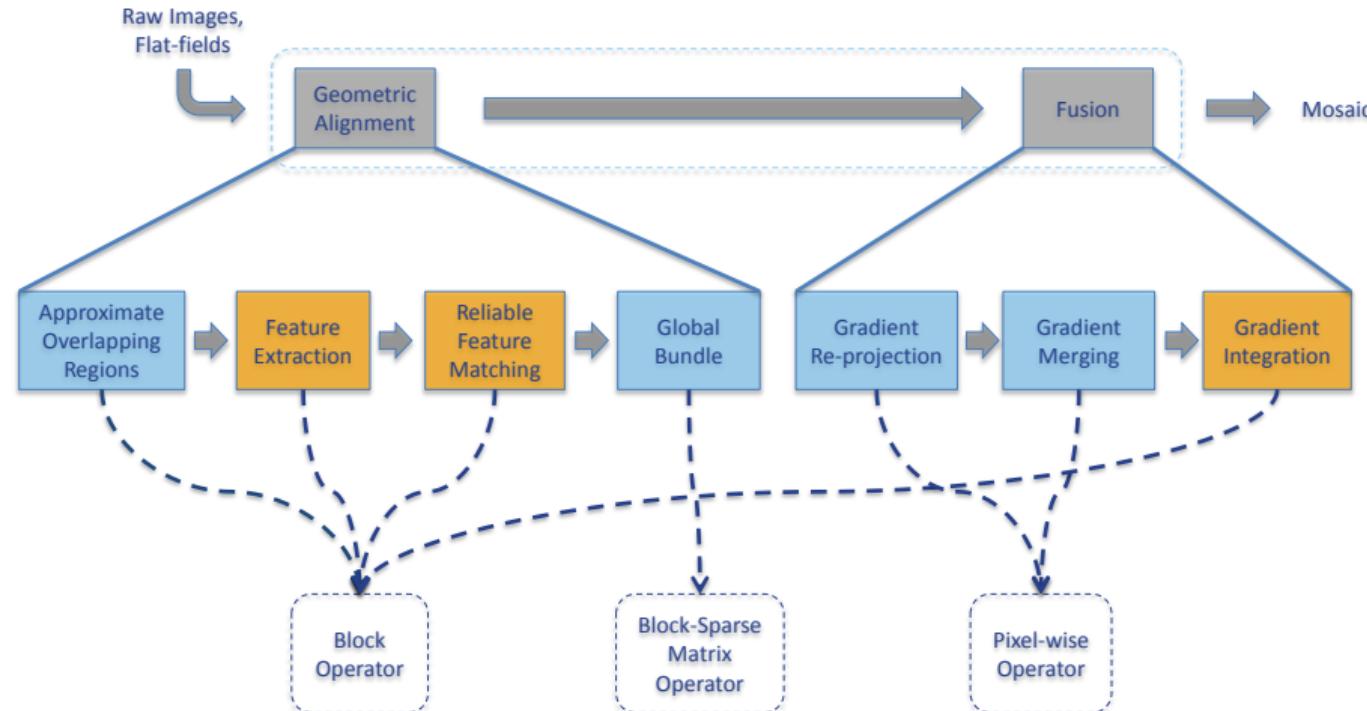
(simultaneous transformations)



## ■ Gradient-domain blending



# De-ghosting Pipeline



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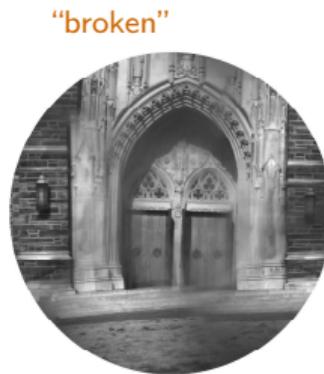
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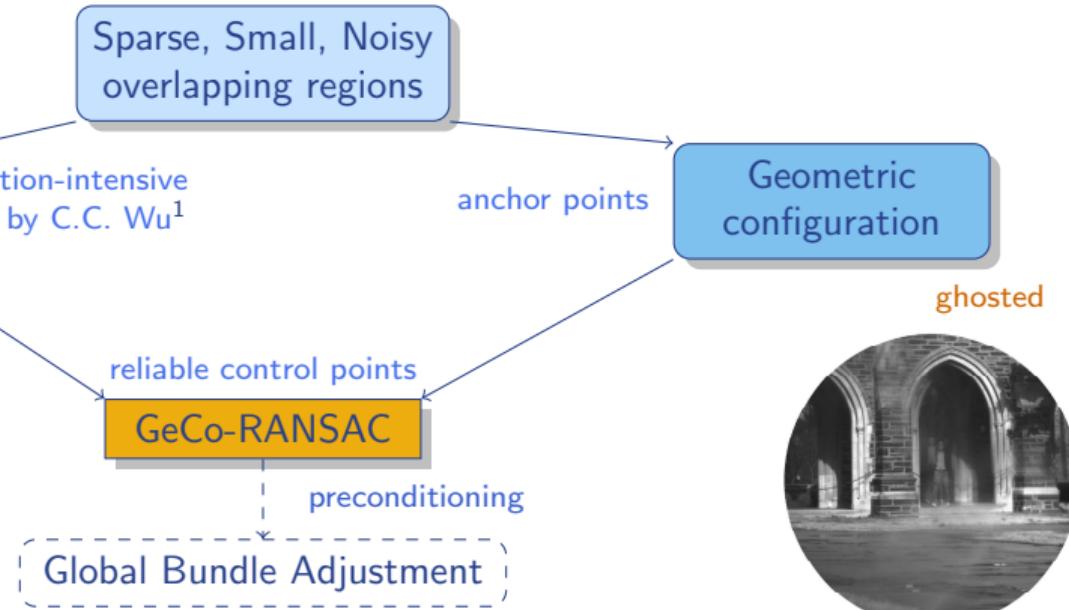
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# Pairwise Registration

**Speed-up by  
algorithm & GPU:  
>1000x!**



<sup>1</sup> <http://cs.unc.edu/~ccwu/siftgpu>



## Bundle Adjustment

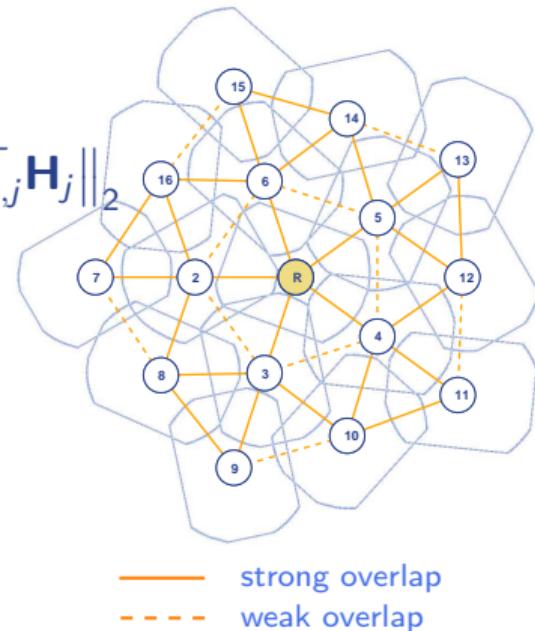
- #### ■ Adhere to geometric configuration

$$(\text{variational form 1}) \quad \min_{\{\mathbf{H}_i\}} \sum_{I_i \cap I_j \neq \emptyset} \sum_{\mathbf{x}_k \in \mathcal{M}_{ij}}$$

(variational form 2)  $\min_{\mathbf{H}} \|\mathbf{W}\mathbf{E}_x\mathbf{H}\|_2$

- Fix a reference frame  $R$ :

(normal/Laplace equation)  $\mathbf{L}_{\bar{R}} \mathbf{H}_{\bar{R}} = \mathbf{B}_R$



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# Gradient Re-projection

- Place & compute gradients on the mosaic canvas
  - Pack images into non-overlapping sets
- Custom CUDA kernels
  - Transformation back-projection; interpolation
  - Binary image erosion to remove spurious gradient border
- **Speed-up by packing & GPU: 40x**

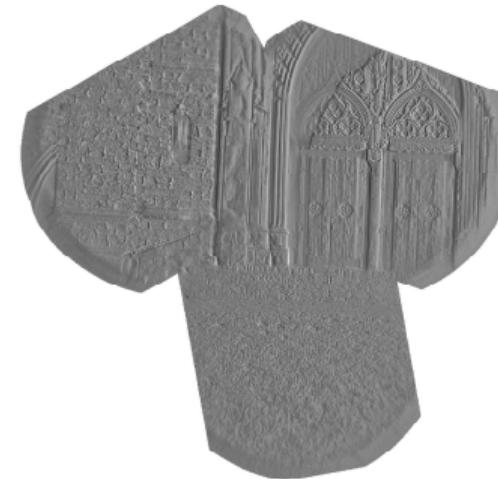
# Gradient-domain Blending

- Maintains high-frequency information
- Smooths intensity seams
- Invariant to camera sensor bias
- Computation-intensive integration

$$\nabla \mathbf{I}(\mathbf{x}) = \sum_{\mathbf{x} \in I_i} w_i(\mathbf{x}) \nabla \mathbf{I}_i(\mathbf{x})$$

$$\mathbf{I} = G * \text{div}(\nabla \mathbf{I})$$

- Green's function ( $G$ ) is approximated via a convolution pyramid.<sup>1</sup>
- **Speed-up by algorithm, memory streaming, GPU: 30x**



<sup>1</sup> Z. Farbman et al. ACM Transactions on Graphics 30, 2011.

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# Illustrations I



# Illustrations II



# Illustrations III



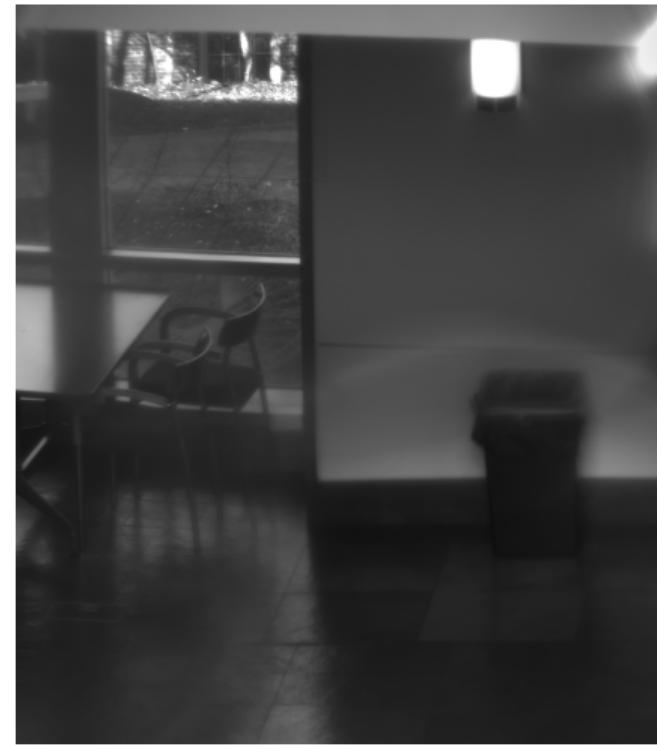
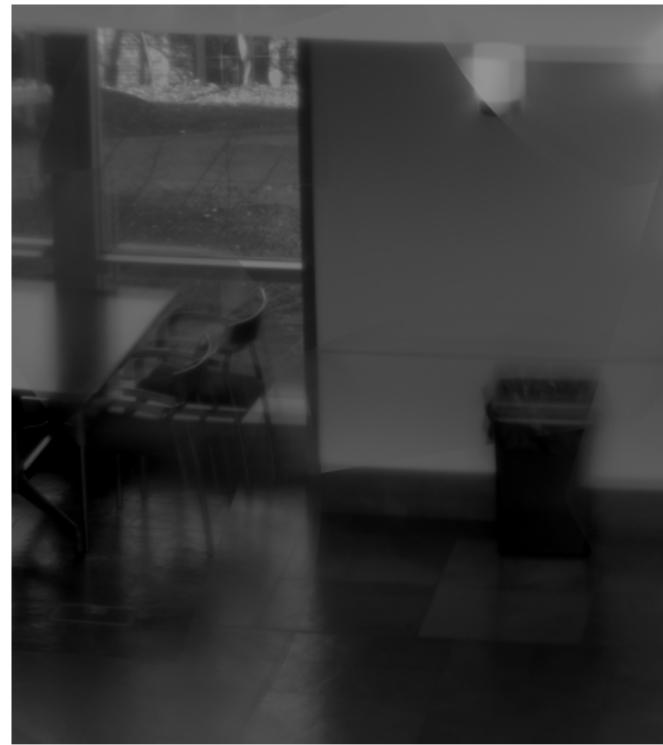
# Illustrations IV



# Illustrations V



# Illustrations VI



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# Recap

- Unconventional projective layout:
  - Sparse, Small and Noisy overlaps among multiple FoVs
- Combine static spatial/geometric knowledge and scene-dependent parameters & features
- Computation-intensive steps enabled by GPU
- Potential other applications include:
  - Sparse and adaptive sampling in video data
  - Individual tracking among a crowd

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# Acknowledgments I



# Acknowledgments II

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- National Science Foundation (CCF), USA
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# Thank you!

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