

# Coupled Structure-from-Motion and Symmetry Detection for Urban Facades

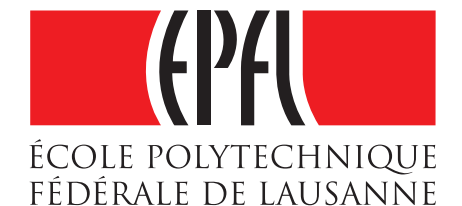
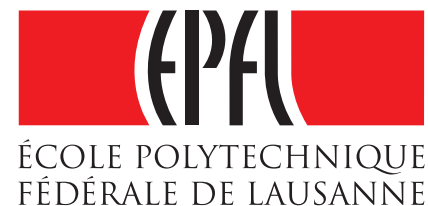


Duygu Ceylan

Niloy J. Mitra

Youyi Zheng

Mark Pauly



# 3D Reconstruction of Urban Scenes



# 3D Reconstruction of Urban Scenes

*CityEngine*



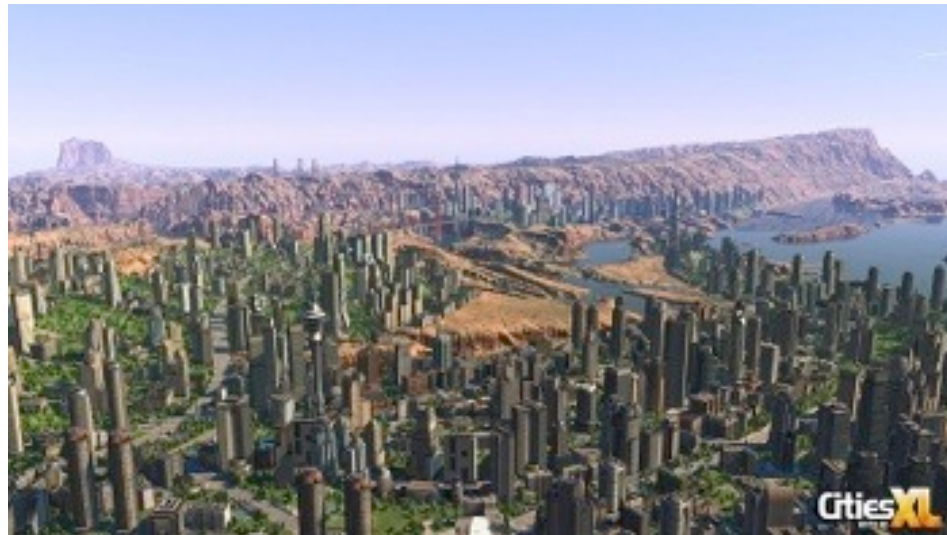
urban design

# 3D Reconstruction of Urban Scenes

*CityEngine*



urban design



content creation



# 3D Reconstruction of Urban Scenes

*CityEngine*

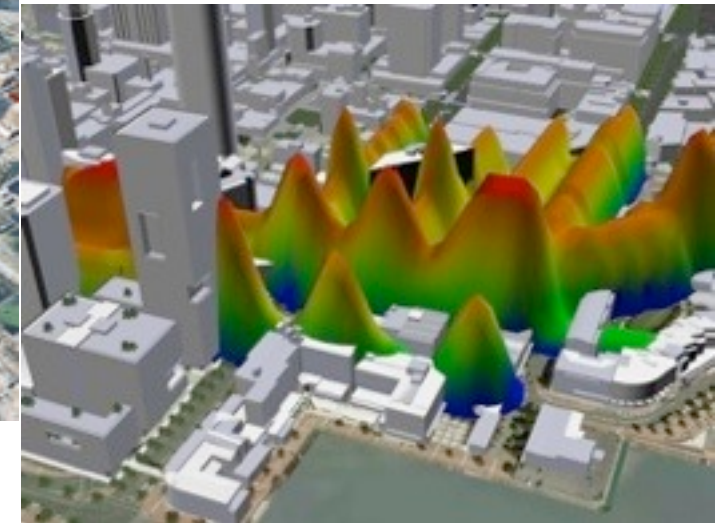


urban design

*CubeCities*



*NextSpace*



data visualization



content creation



# 3D Reconstruction of Urban Scenes

*CityEngine*

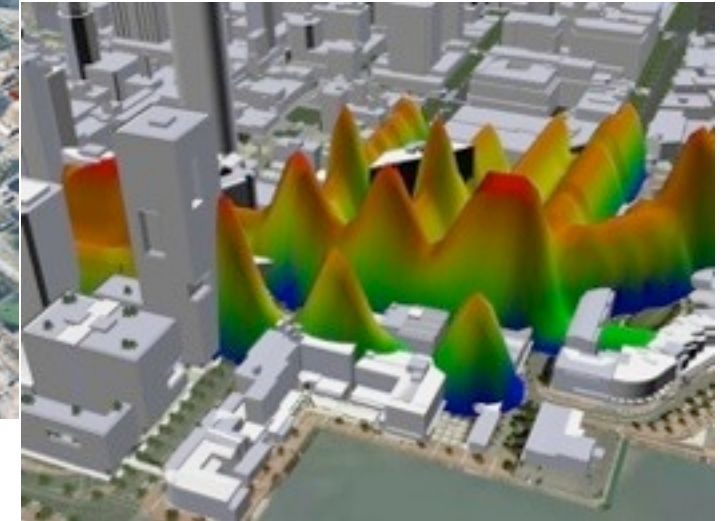


urban design

*CubeCities*



*NextSpace*



data visualization

Google Maps



content creation



mapping and navigation



# 3D Reconstruction of Urban Scenes

*CityEngine*

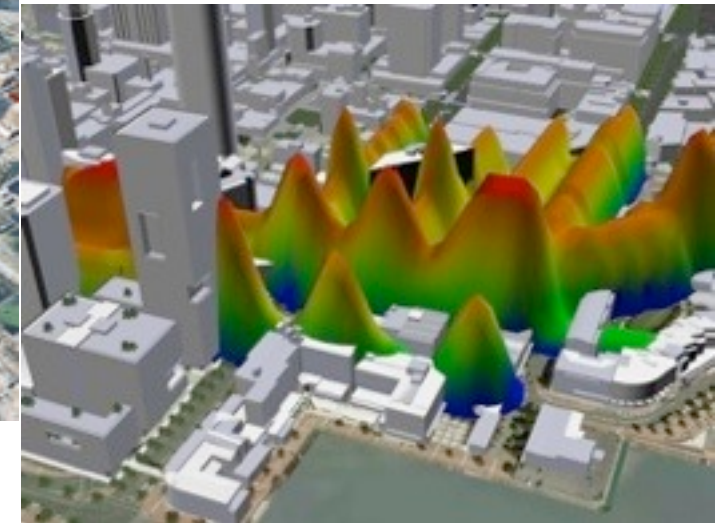


urban design

*CubeCities*

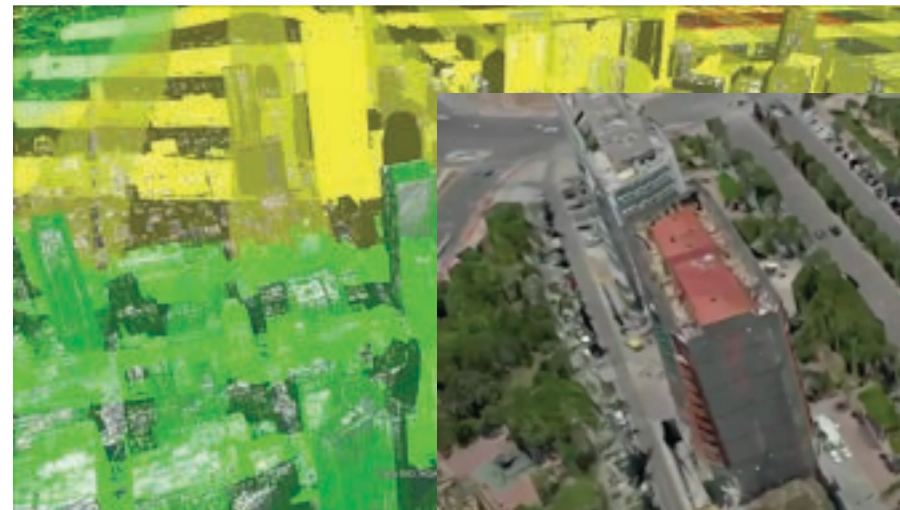


*NextSpace*



data visualization

Google Maps



Microsoft Bing Maps



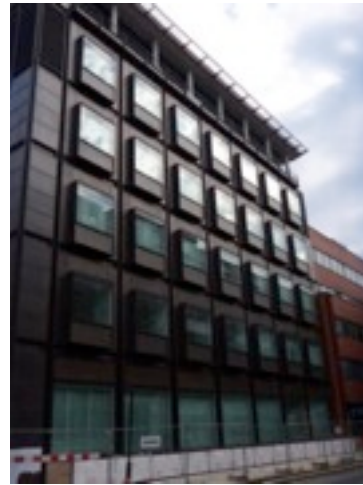
mapping and navigation



content creation



# Image-based Reconstruction



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# Image-based Reconstruction

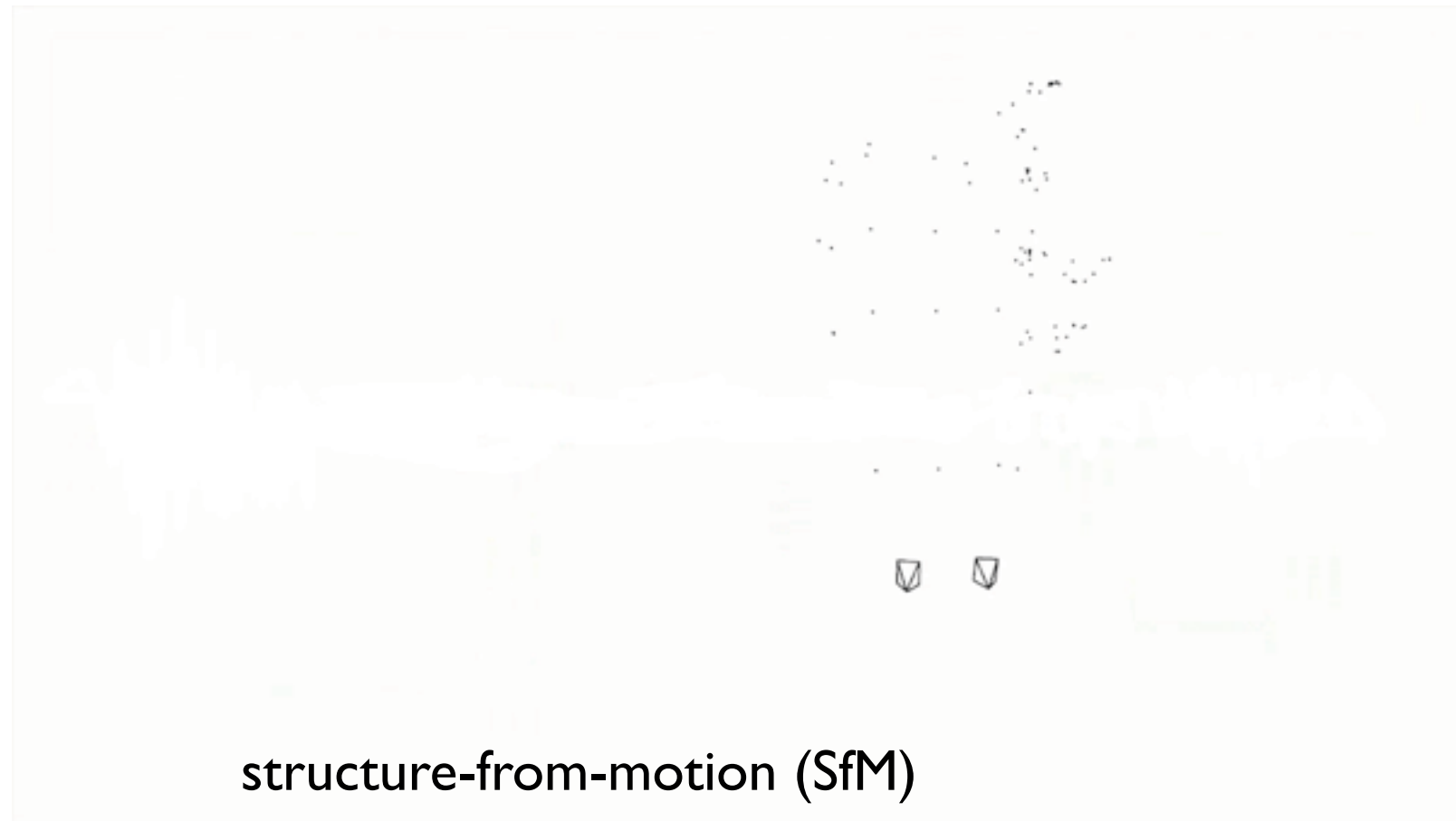


correspondence search

# Image-based Reconstruction



correspondence search

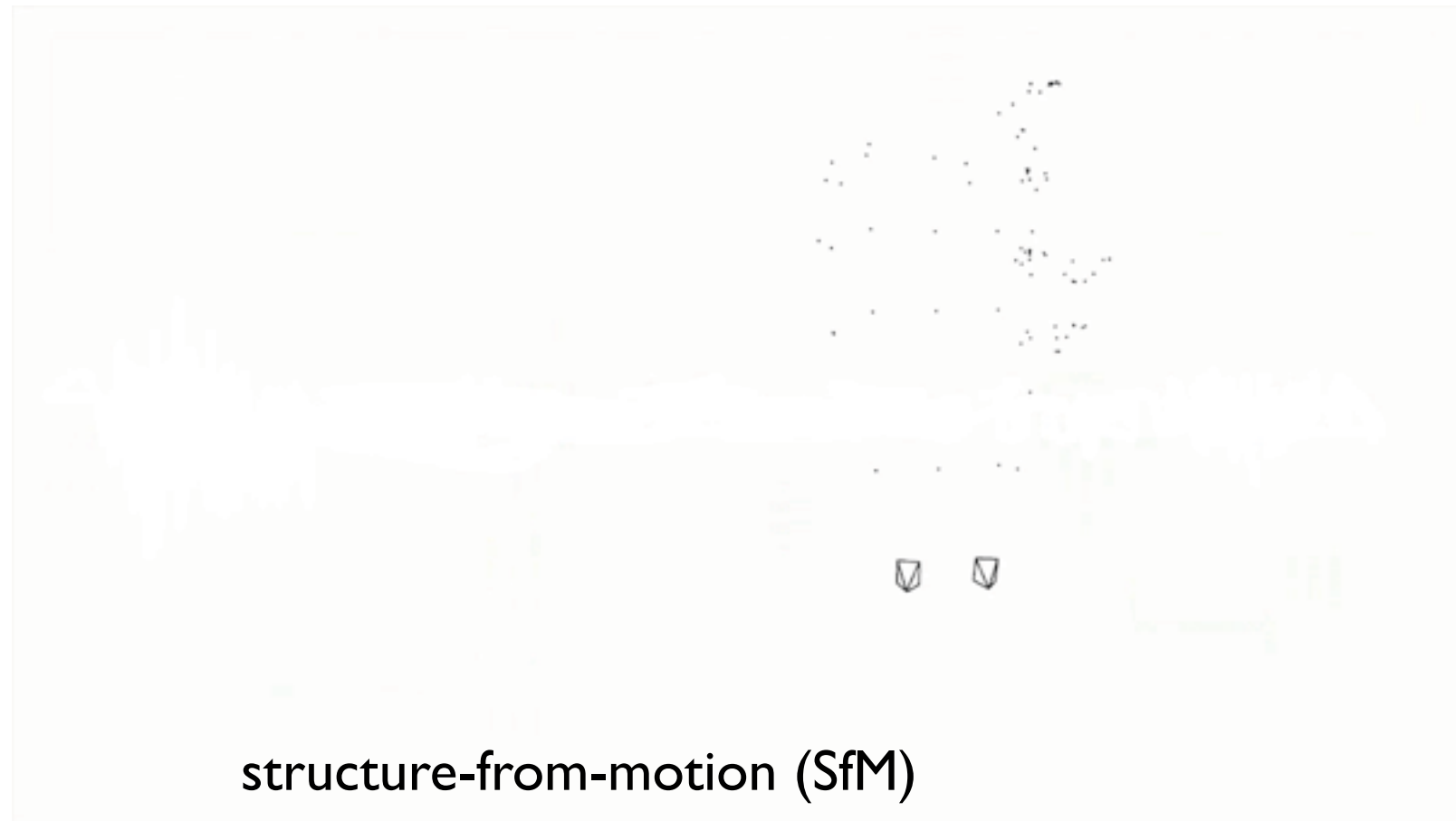


structure-from-motion (SfM)

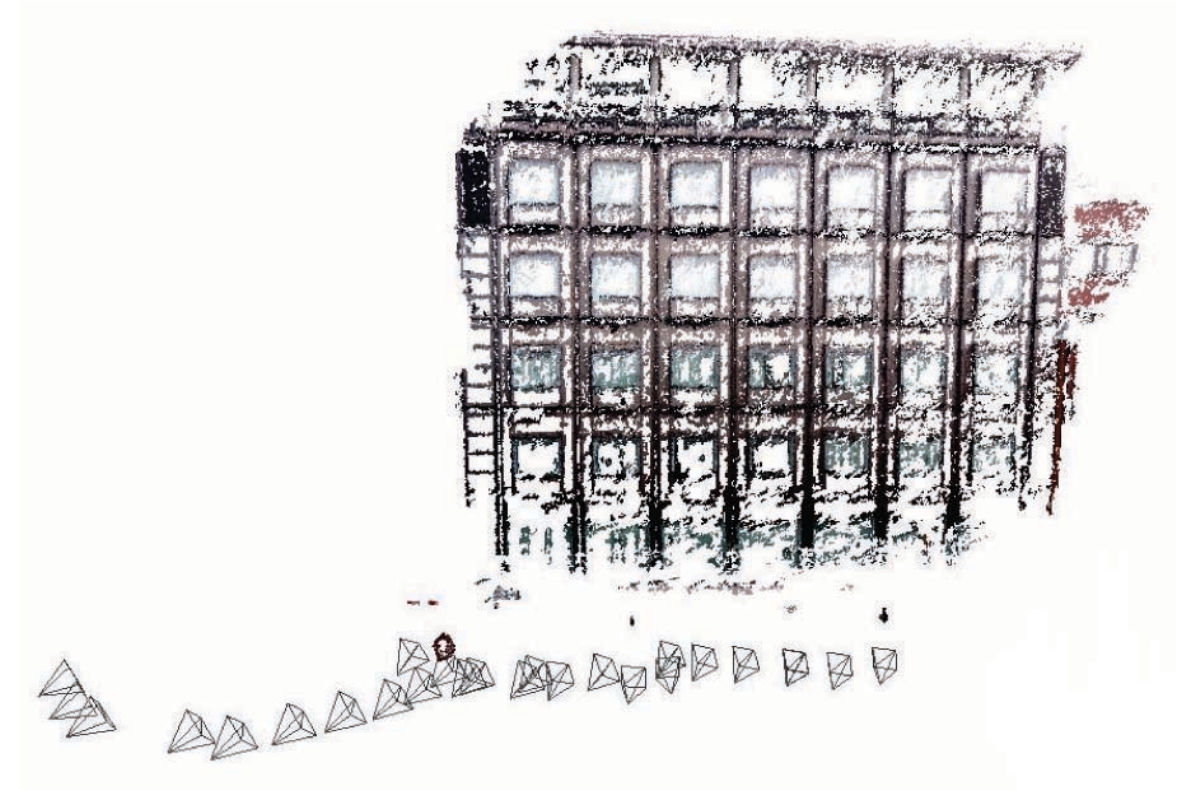
# Image-based Reconstruction



correspondence search



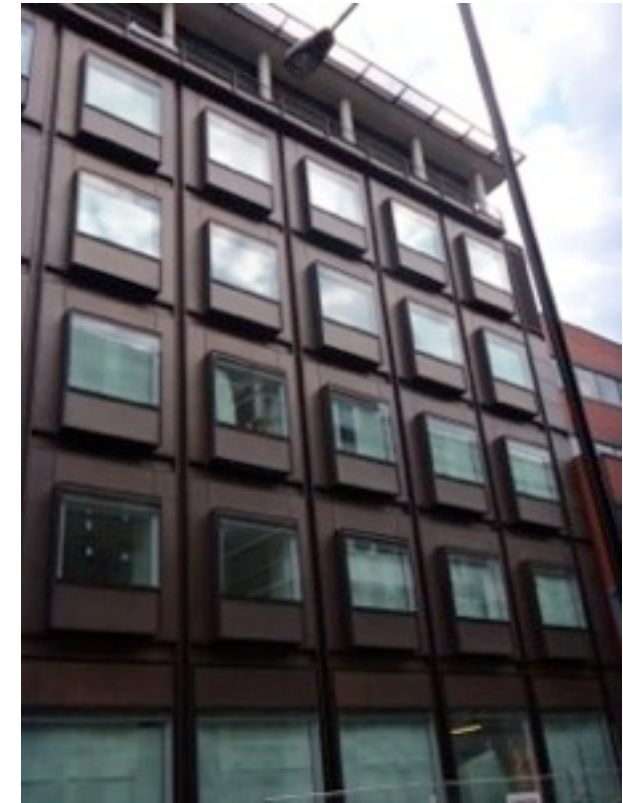
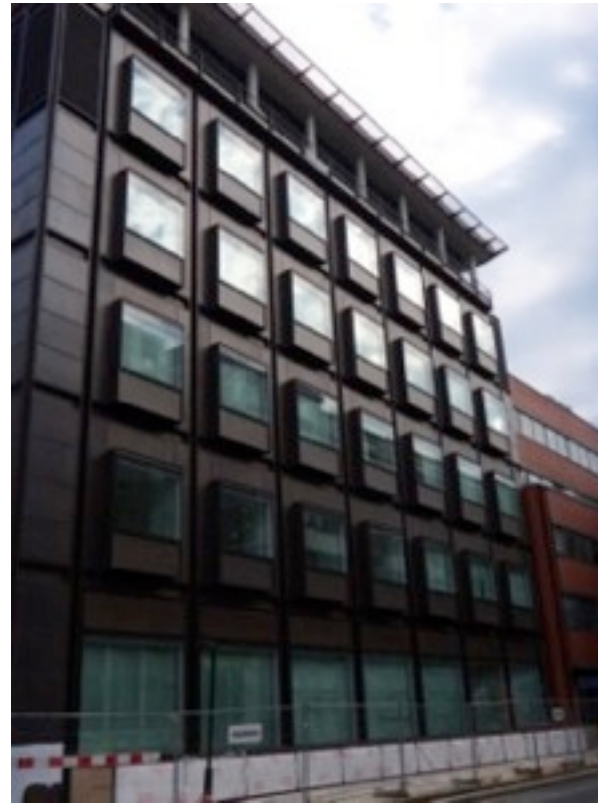
structure-from-motion (SfM)



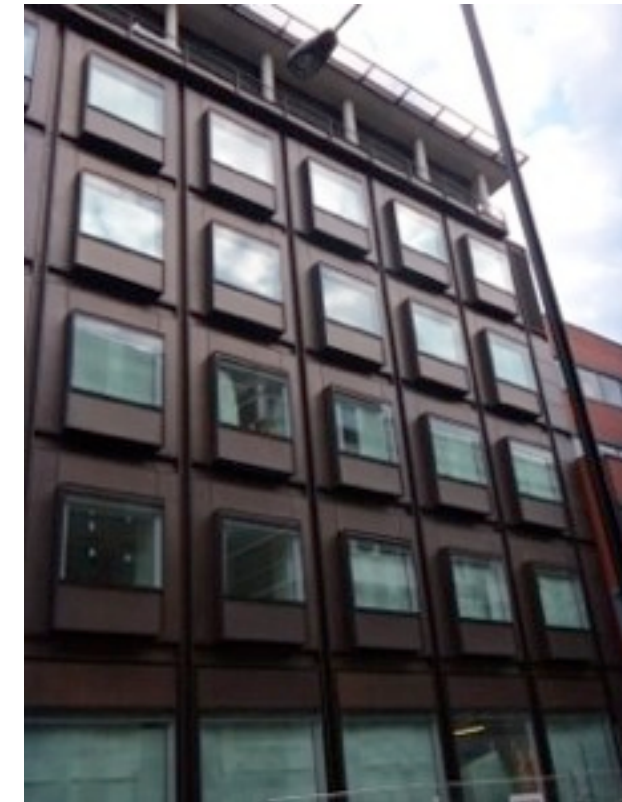
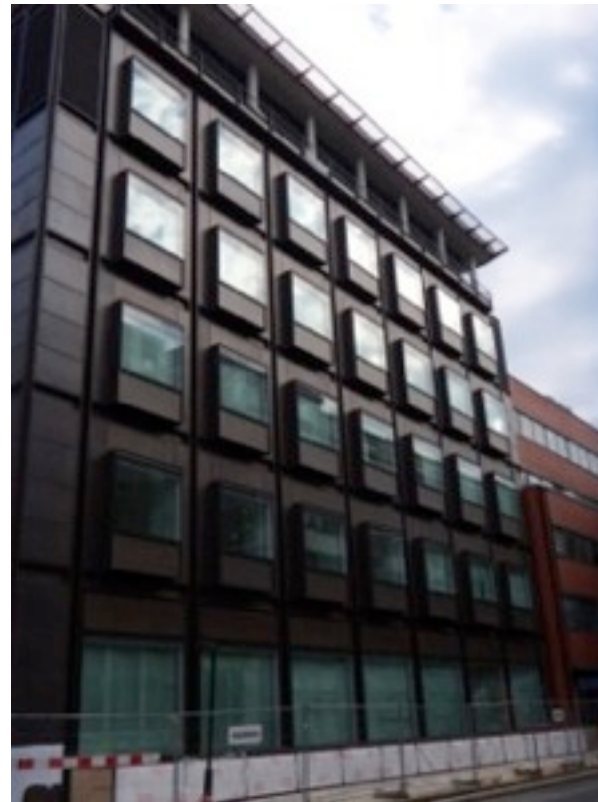
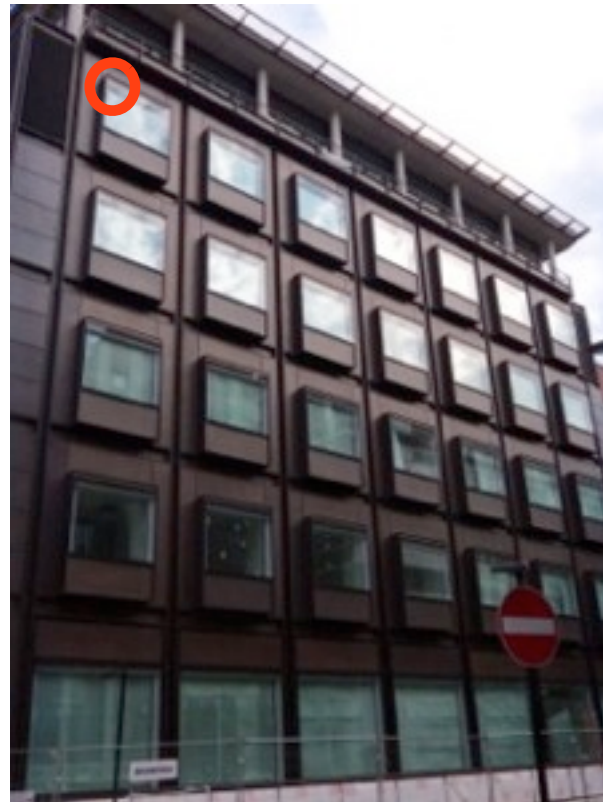
dense reconstruction (PMVS)



# Correspondence Problem



# Correspondence Problem





# Correspondence Problem





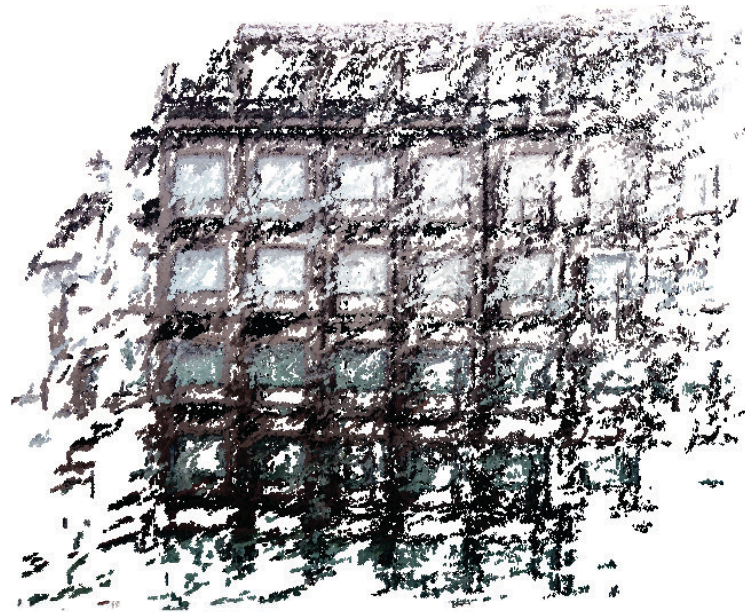
# Correspondence Problem



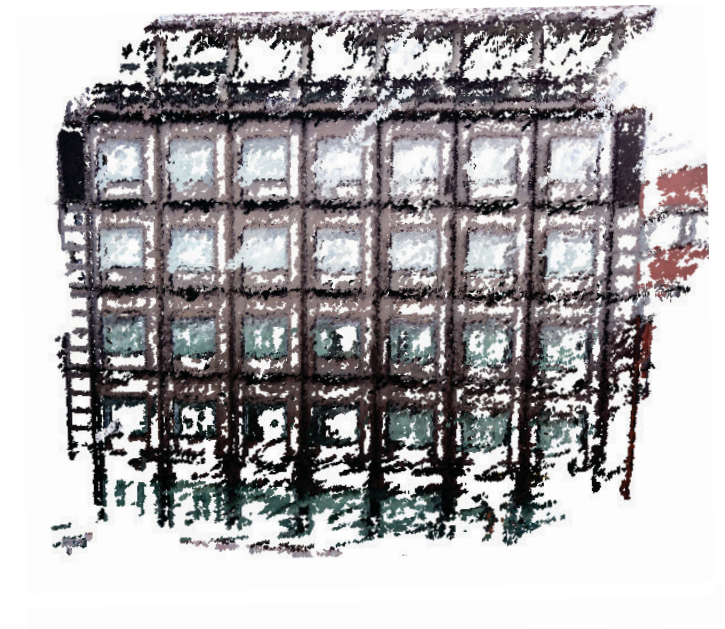
# Artifact Types

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standard output (Bundler + PMVS)



desired output (ours + PMVS)

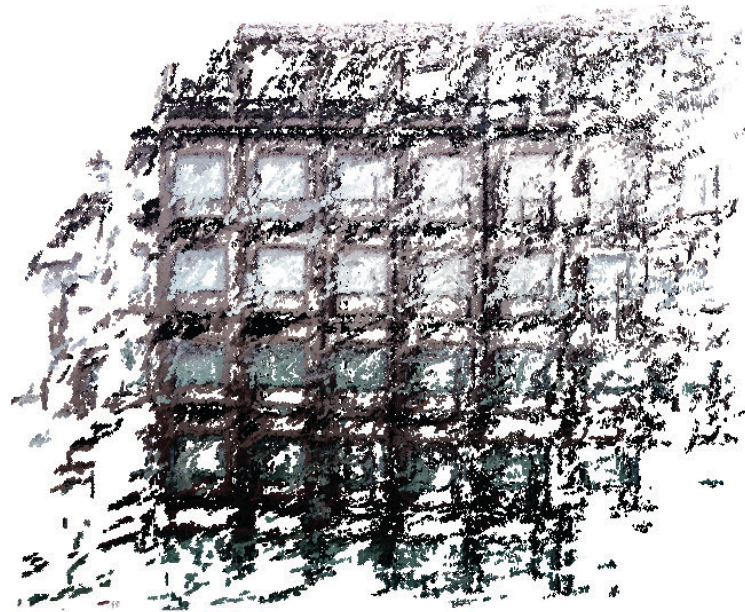


poor/noisy output

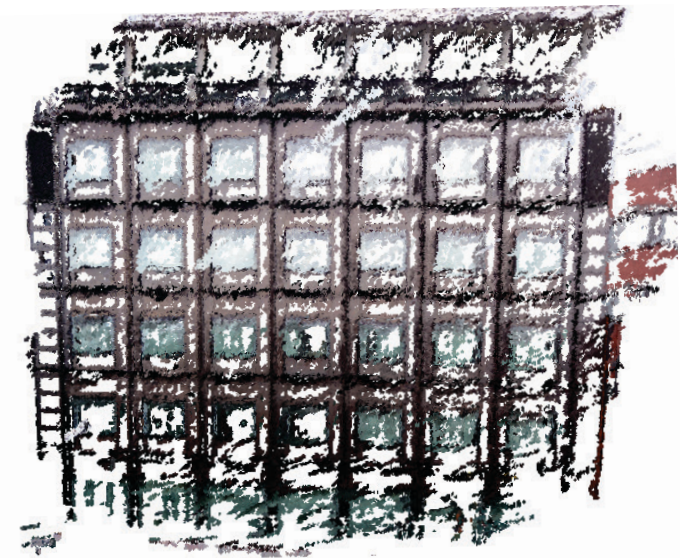


# Artifact Types

standard output (Bundler + PMVS)



desired output (ours + PMVS)



poor/noisy output



incorrect number of repeating elements

# Related Work



# Related Work

internet images:



*Bundler (Snavely et al. '2006)*



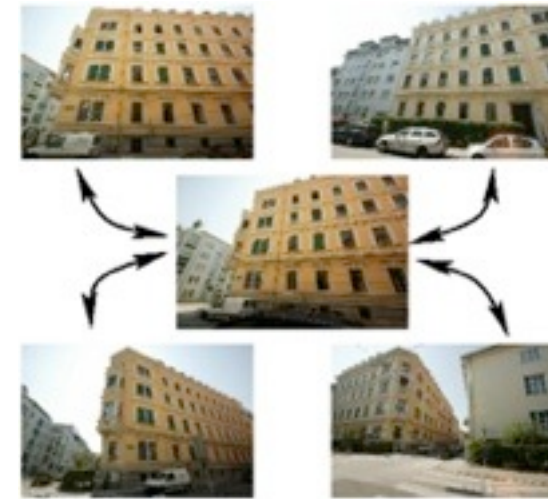
# Related Work

internet images:



*Bundler (Snavely et al. '2006)*

global relations:



*Zach et al. '2010*

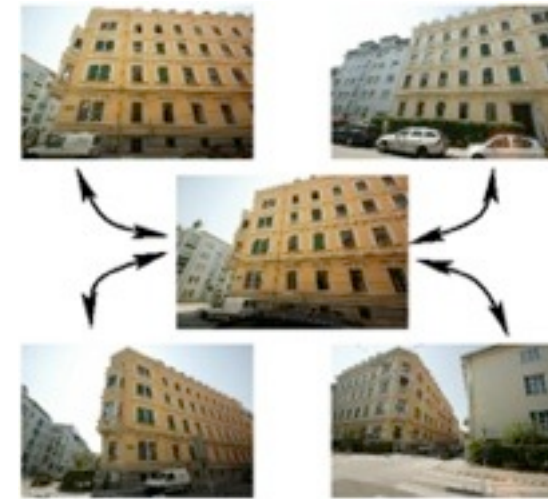
# Related Work

internet images:

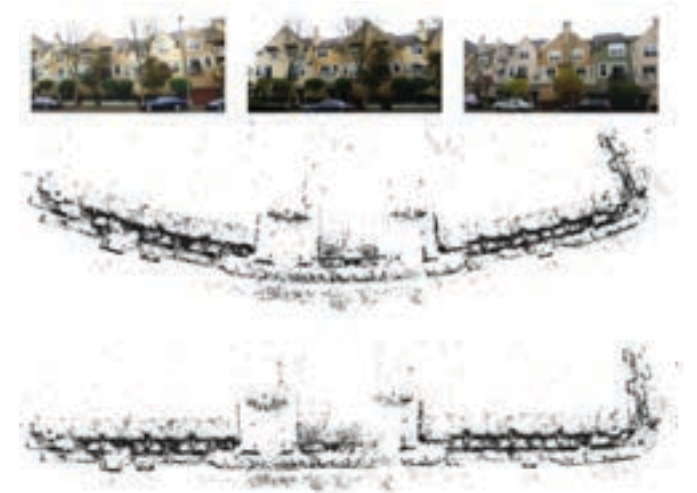


*Bundler (Snavely et al. '2006)*

global relations:



*Zach et al. '2010*



*Cohen et al. '2012*

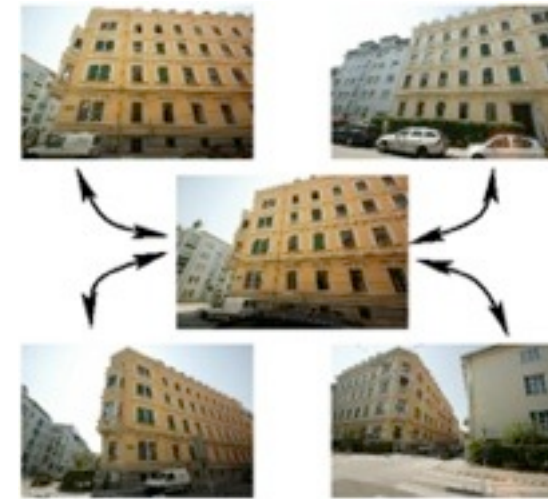
# Related Work

internet images:

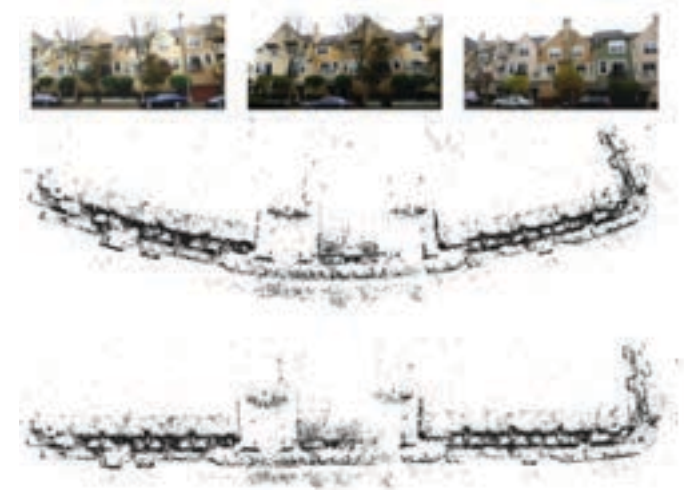


*Bundler (Snavely et al. '2006)*

global relations:

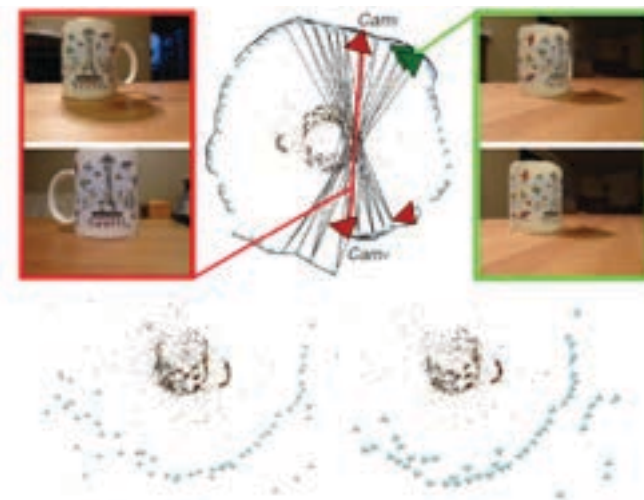


*Zach et al. '2010*



*Cohen et al. '2012*

duplicate structures:



*Jiang et al. '2012*



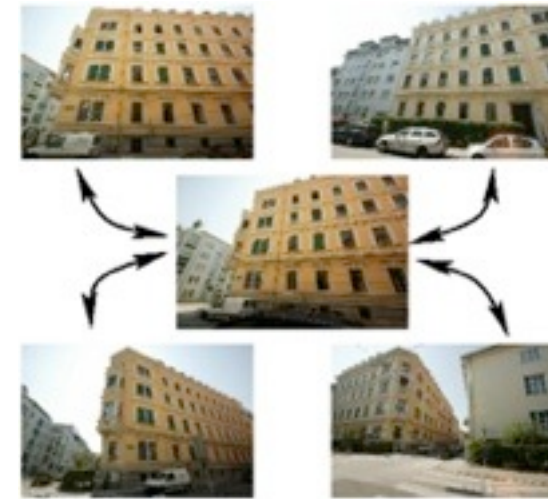
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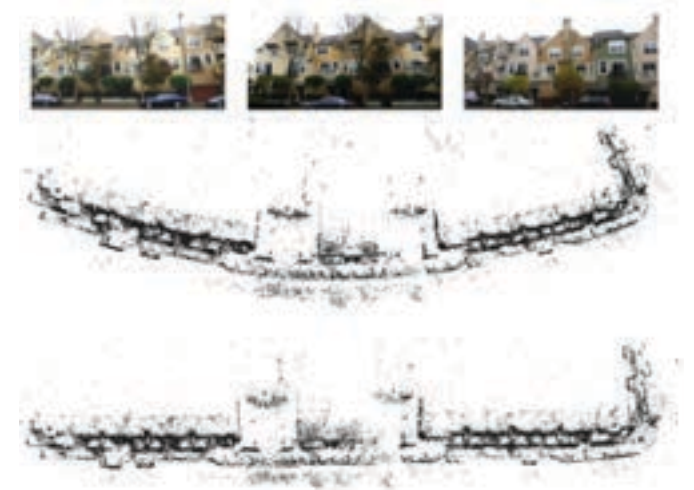


*Bundler (Snavely et al. '2006)*

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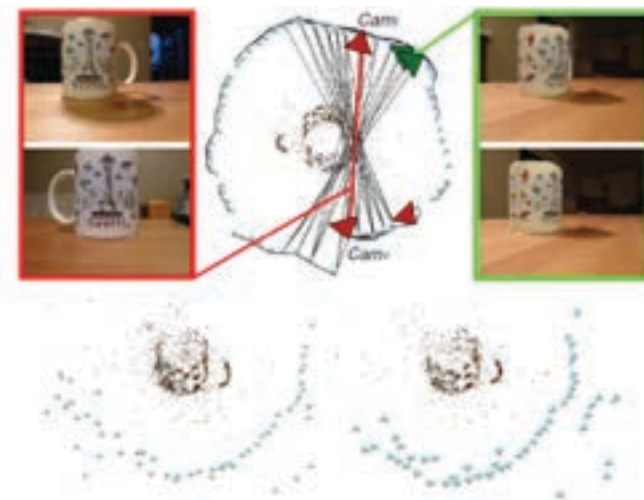


*Zach et al. '2010*

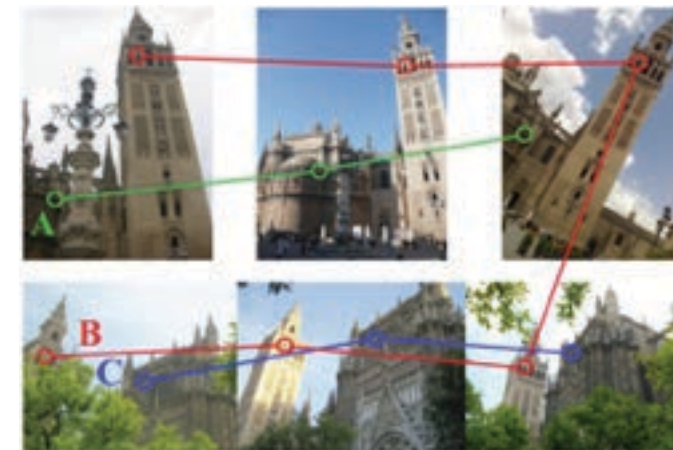


*Cohen et al. '2012*

duplicate structures:



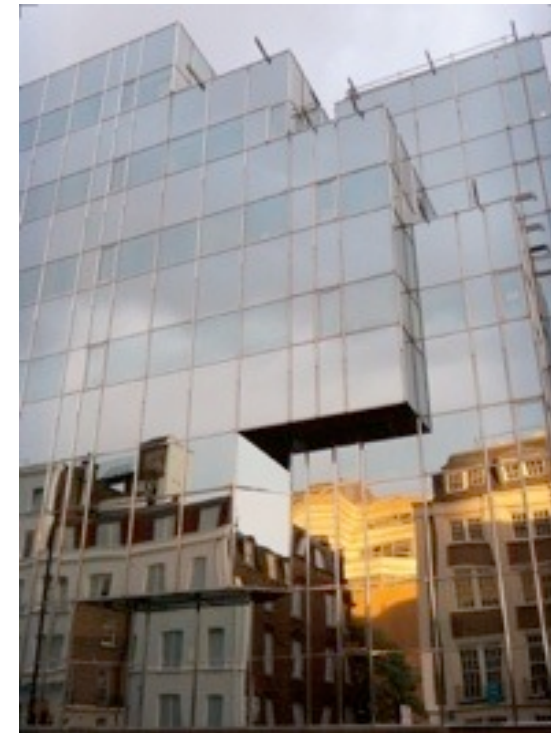
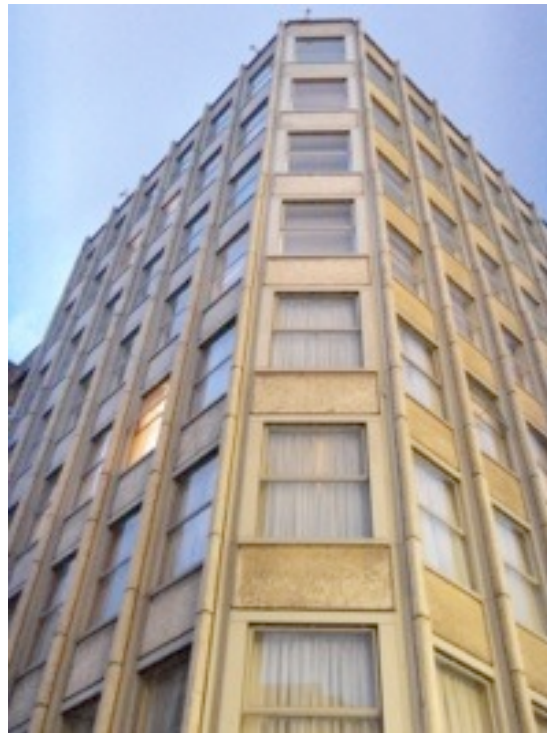
*Jiang et al. '2012*



*Wilson et al. '2013*

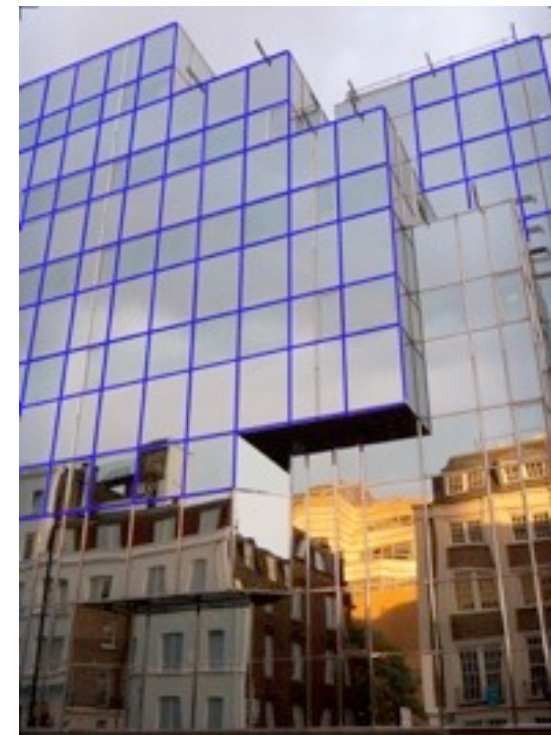
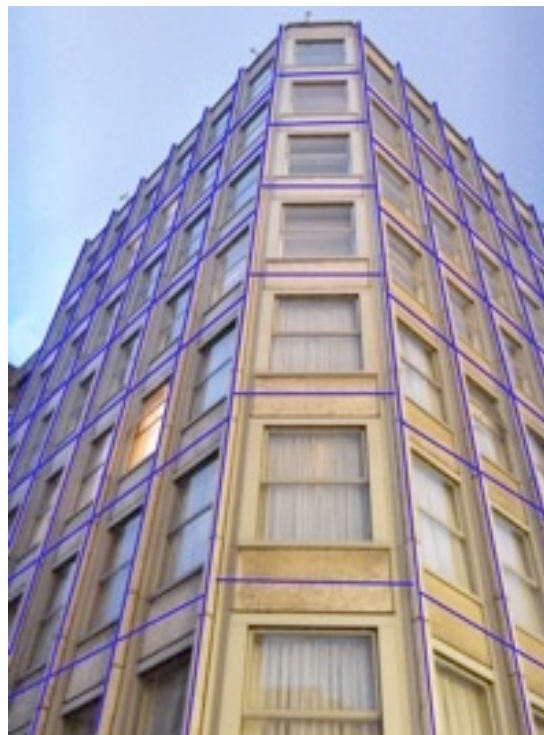


# Main Observation: Joint Detection & SfM



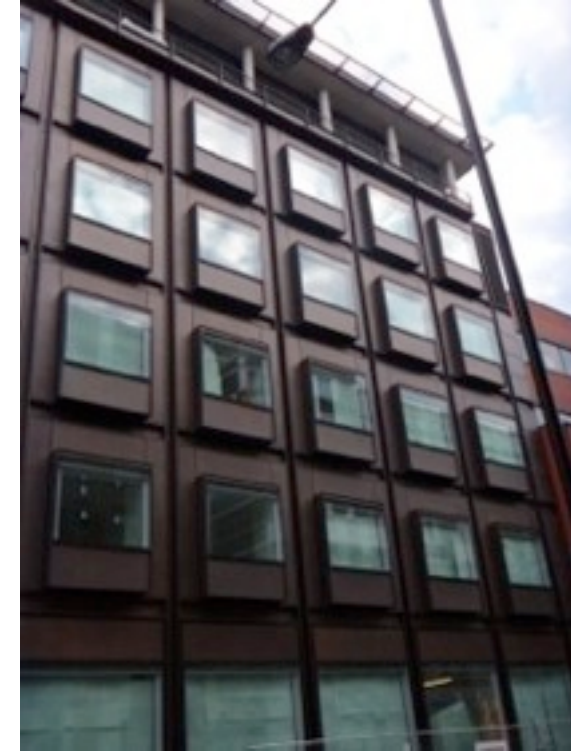
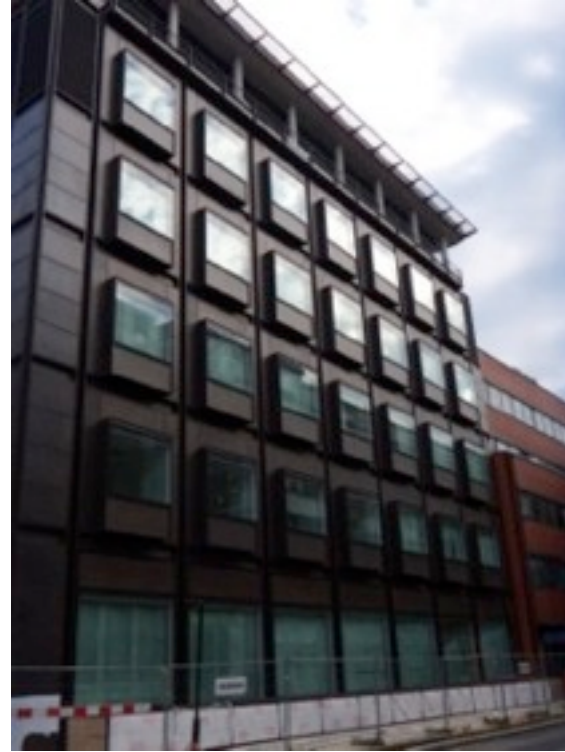


# Main Observation: Joint Detection & SfM





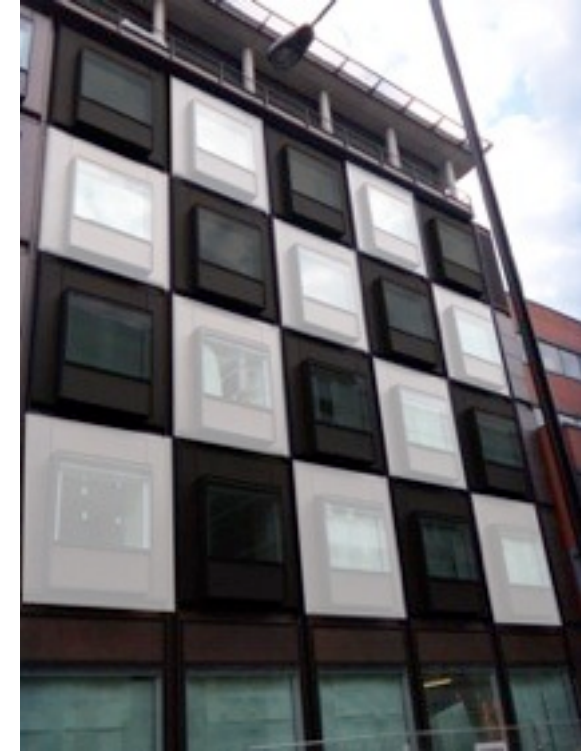
# ‘Grid’ Matching



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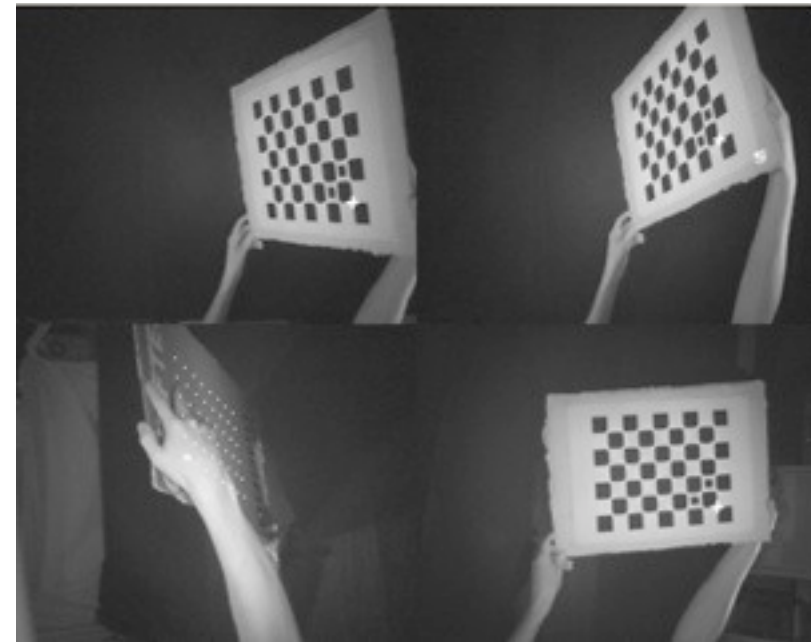
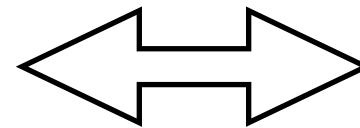
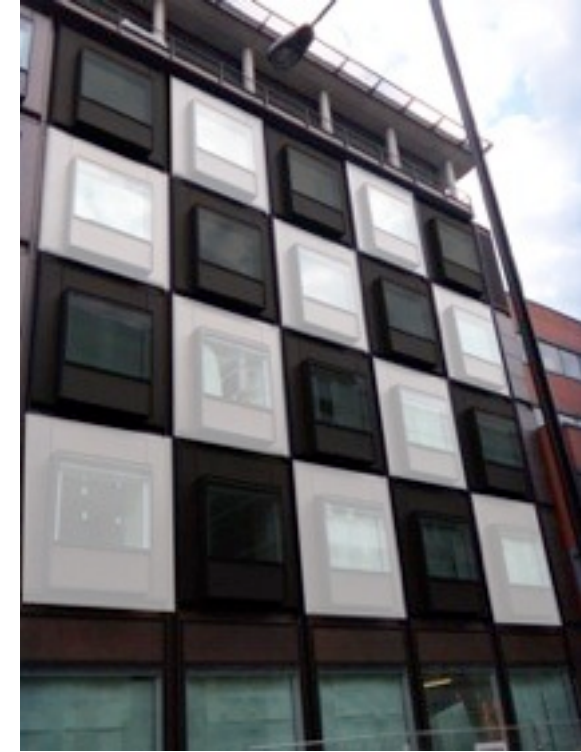


# ‘Grid’ Matching

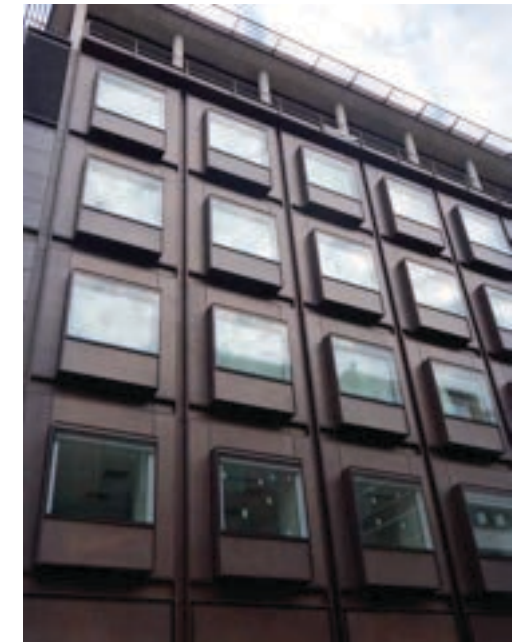
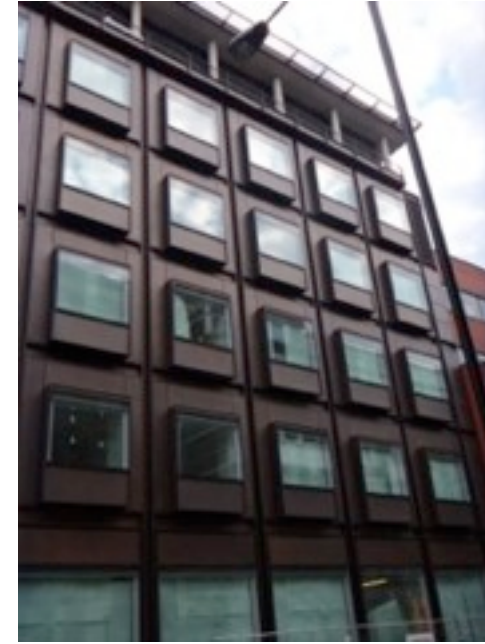




# ‘Grid’ Matching

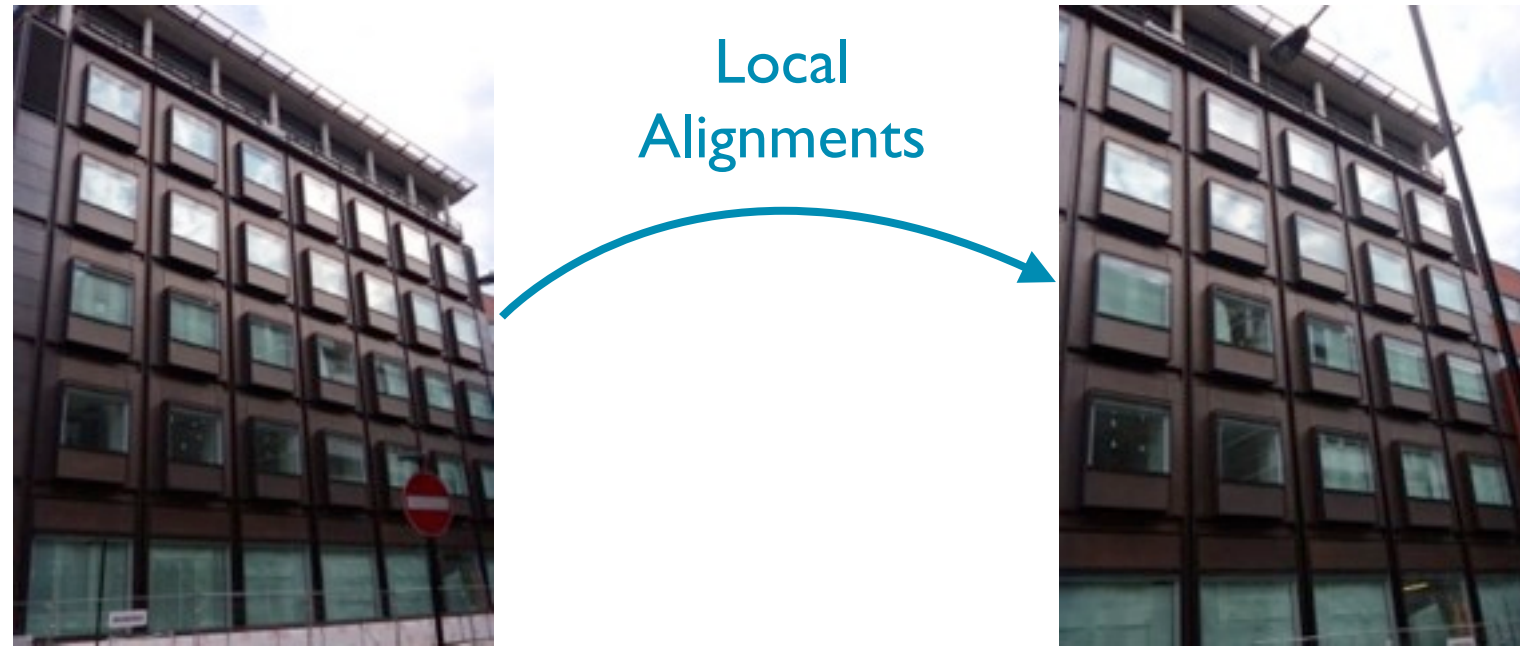


# Local & Global Alignment





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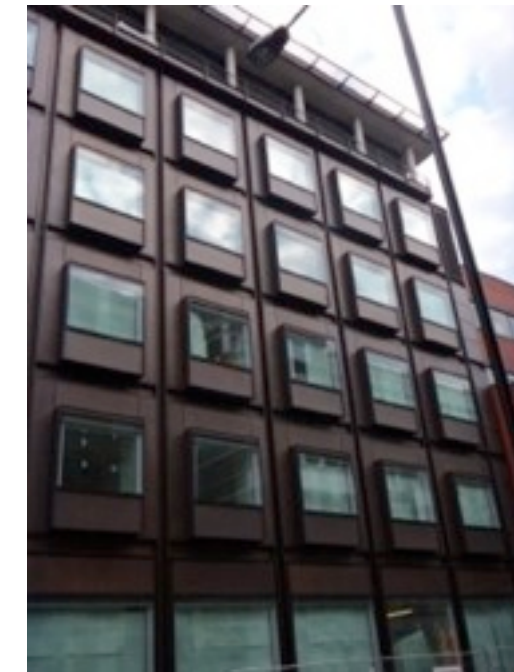
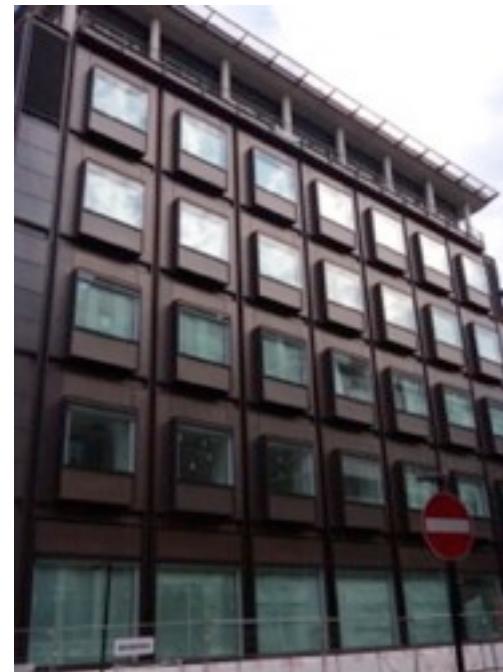
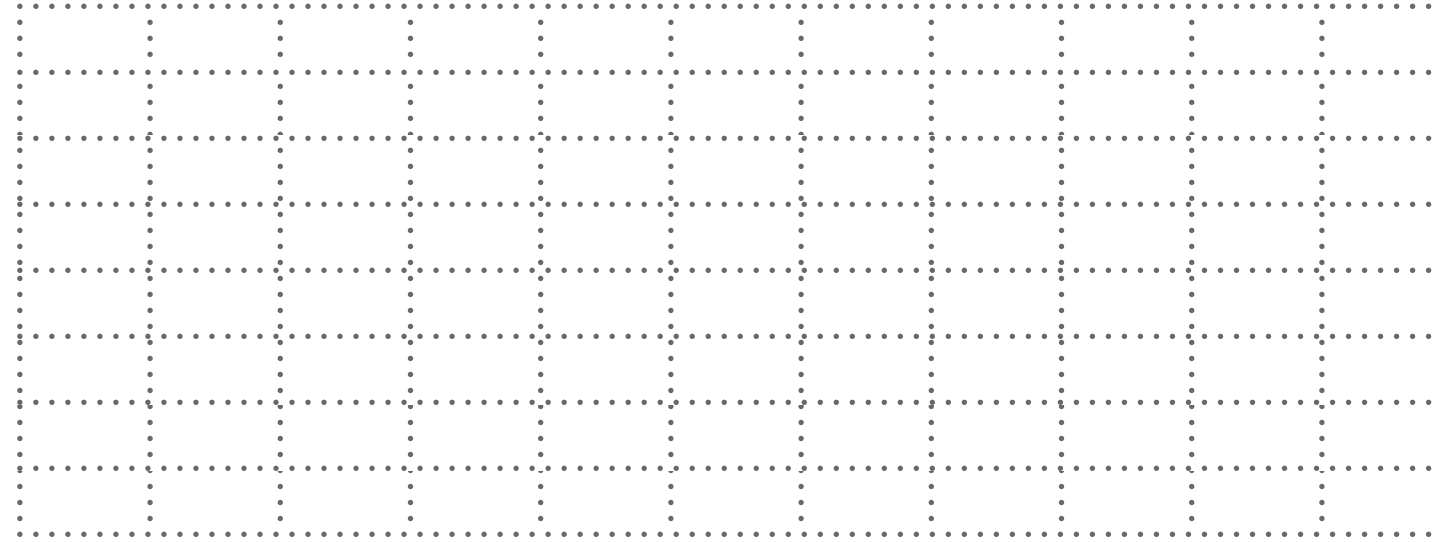
# Local & Global Alignment





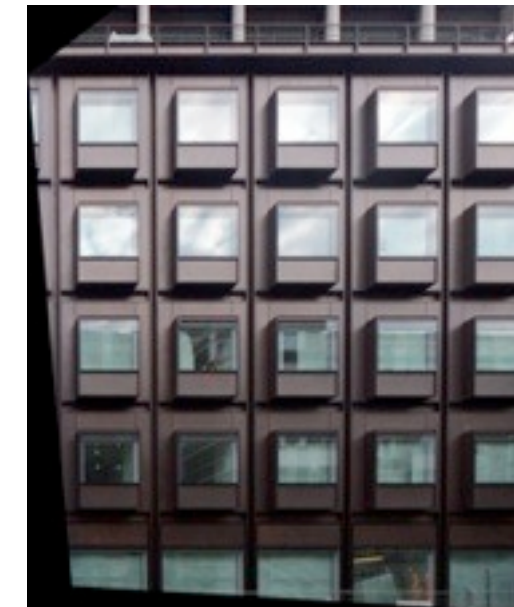
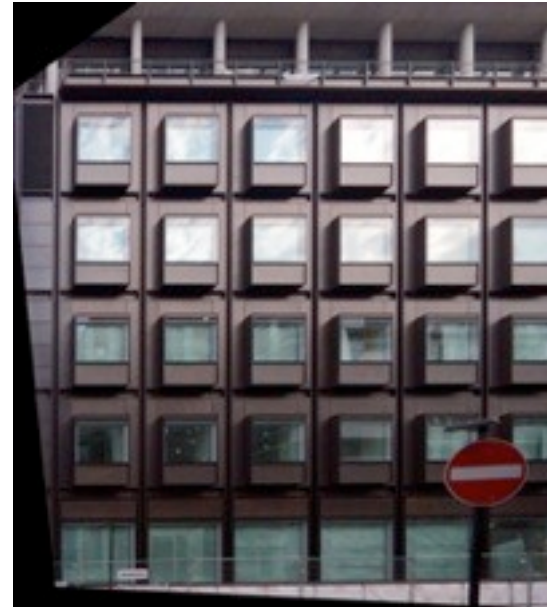
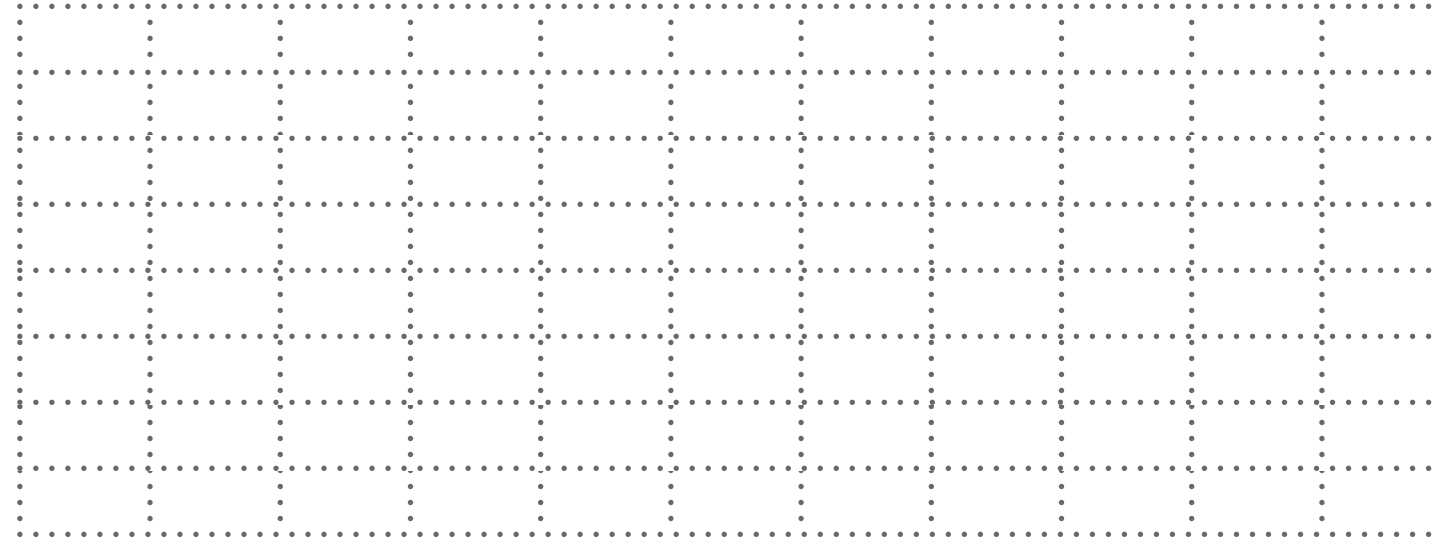
# Global Grid Alignment

*unknown*  
global grid



# Global Grid Alignment

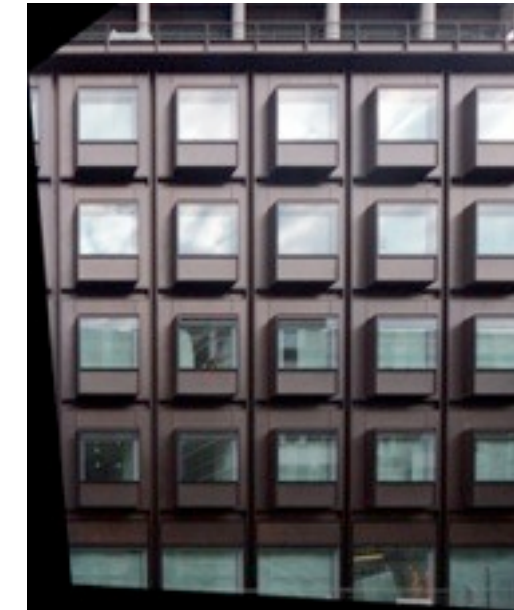
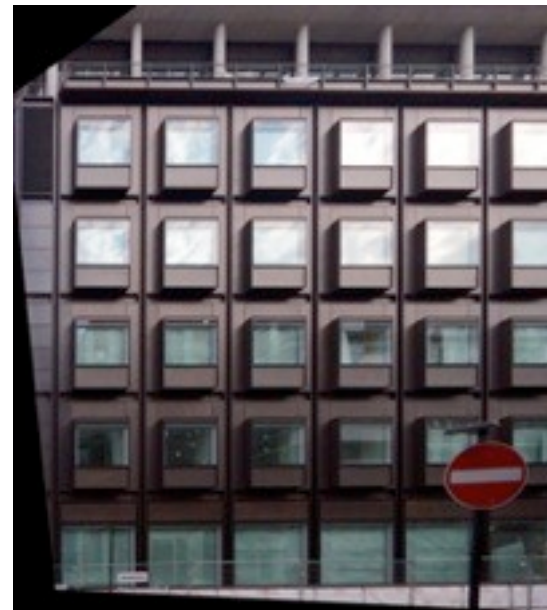
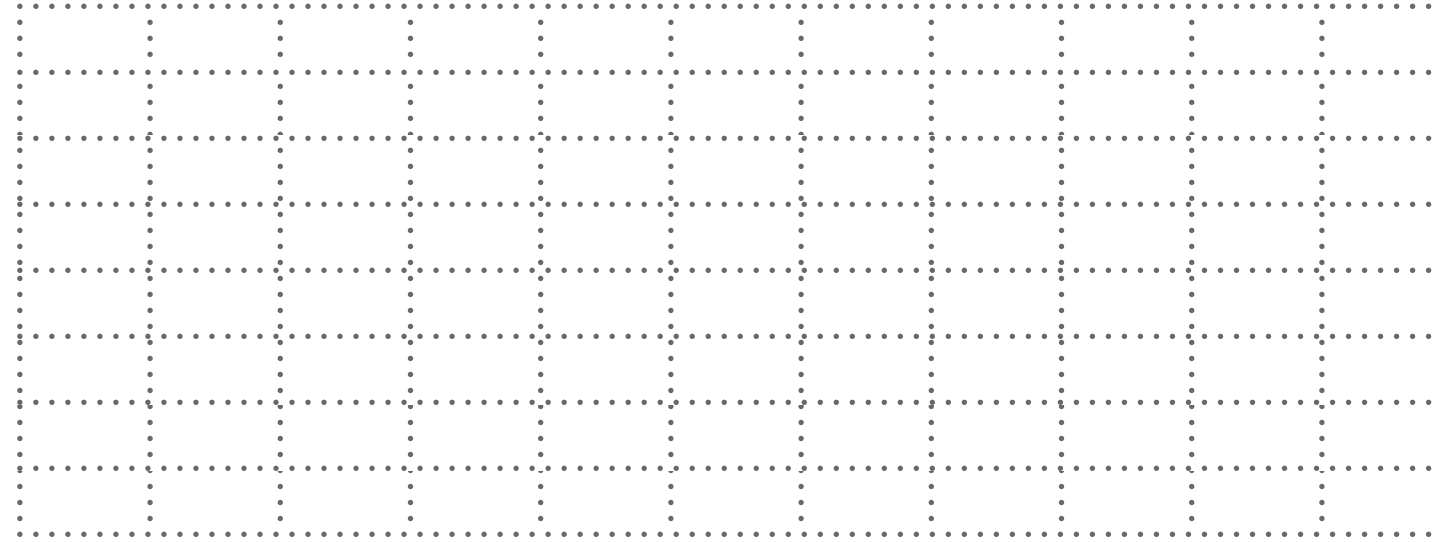
*unknown*  
global grid





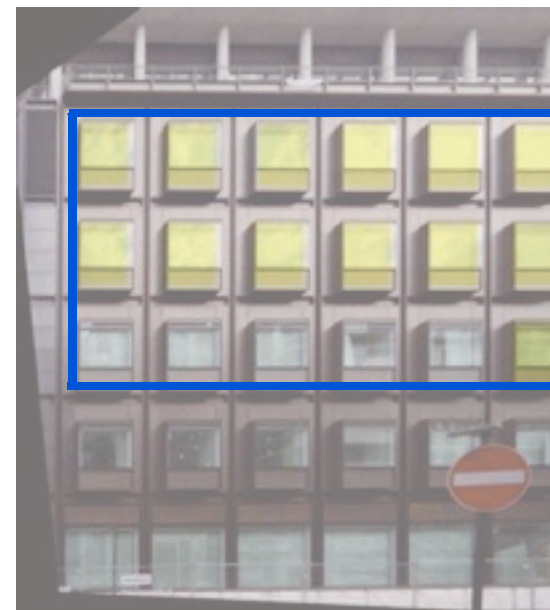
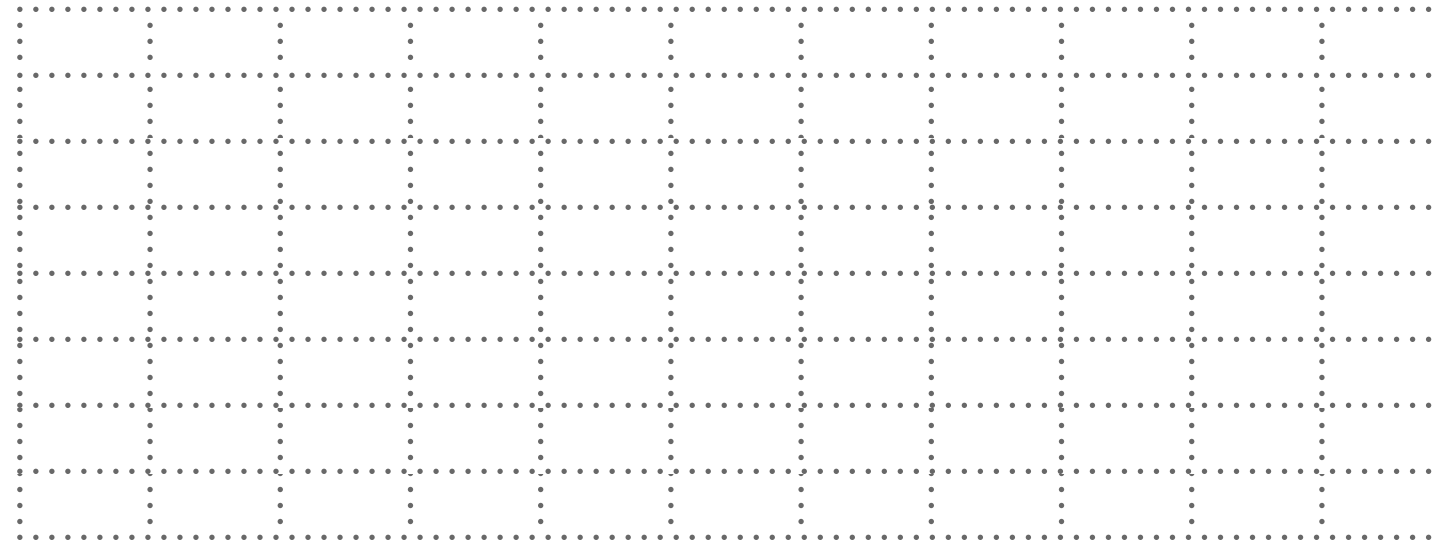
# Global Grid Alignment

*unknown*  
global grid



# Global Grid Alignment

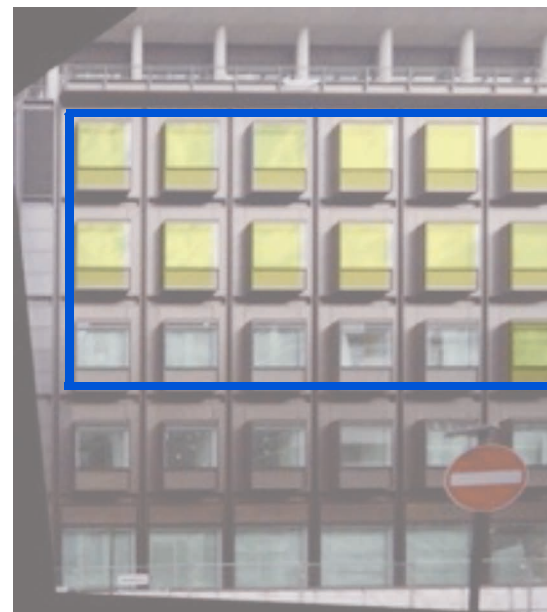
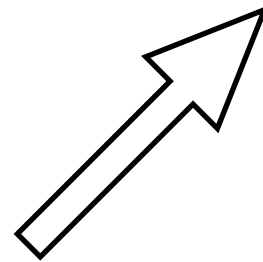
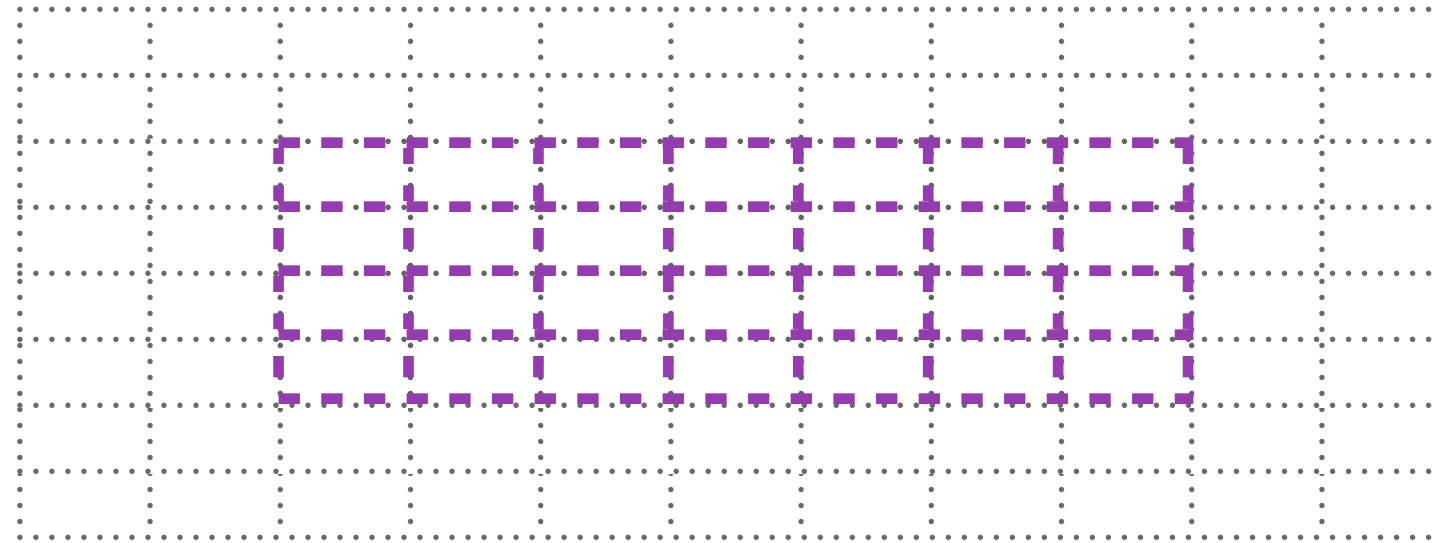
*unknown*  
global grid





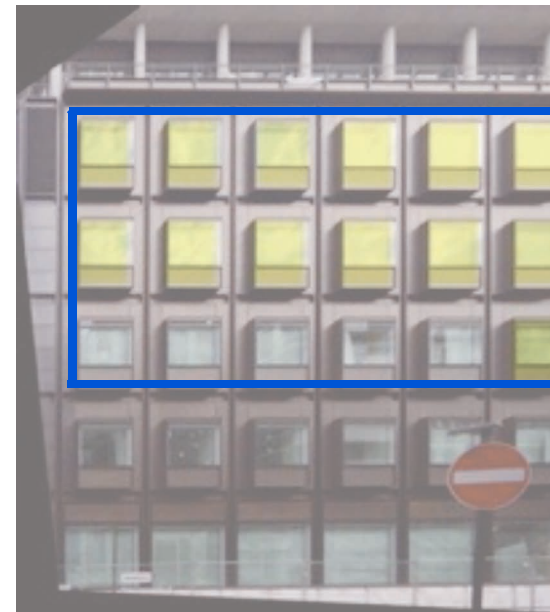
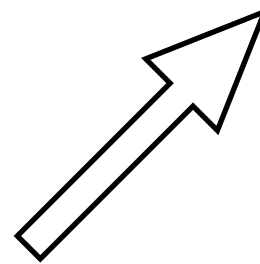
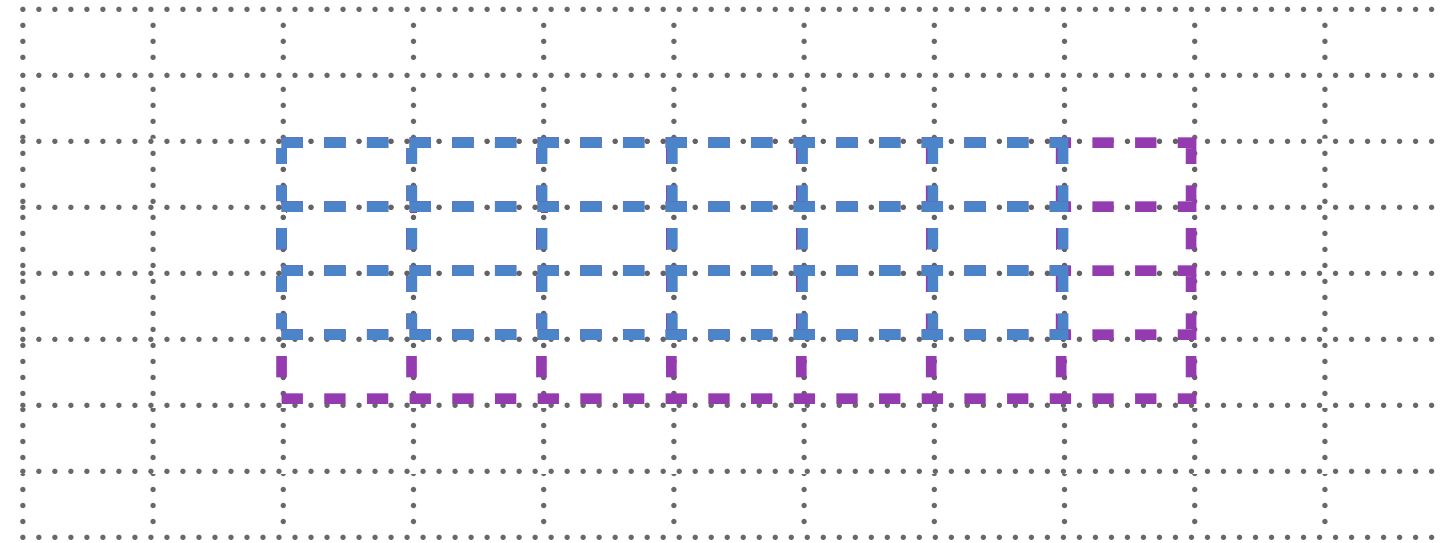
# Global Grid Alignment

*unknown  
global grid*



# Global Grid Alignment

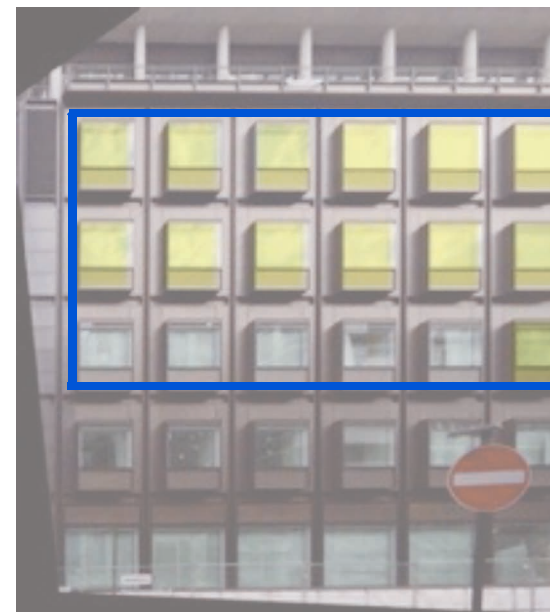
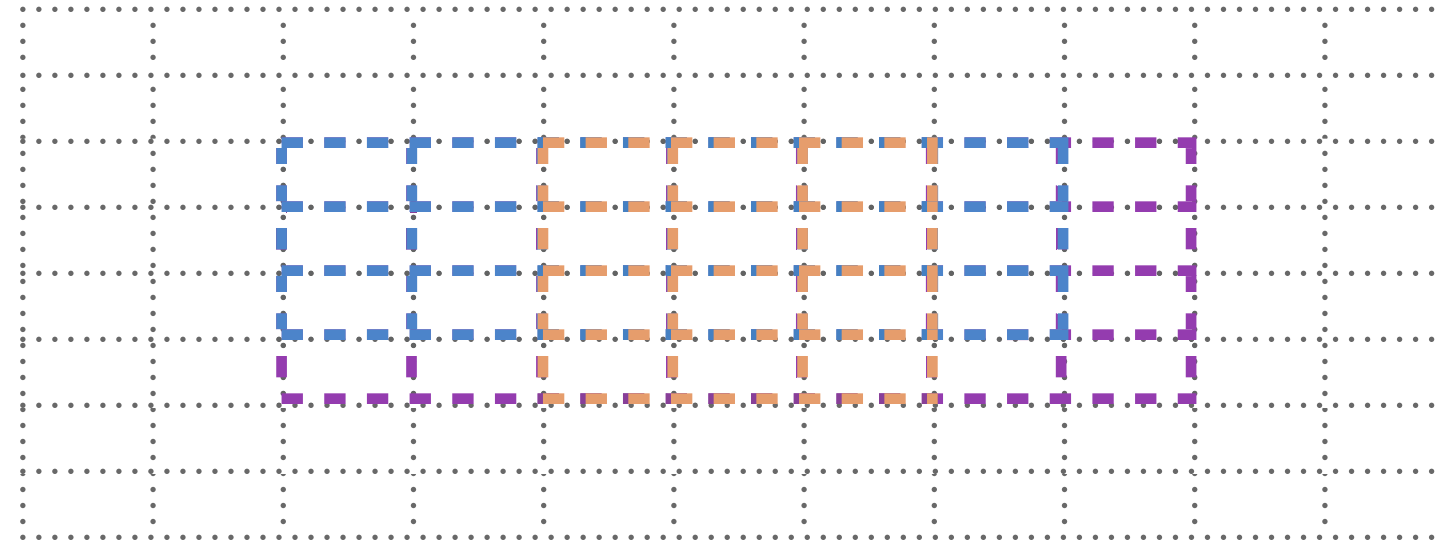
*unknown  
global grid*





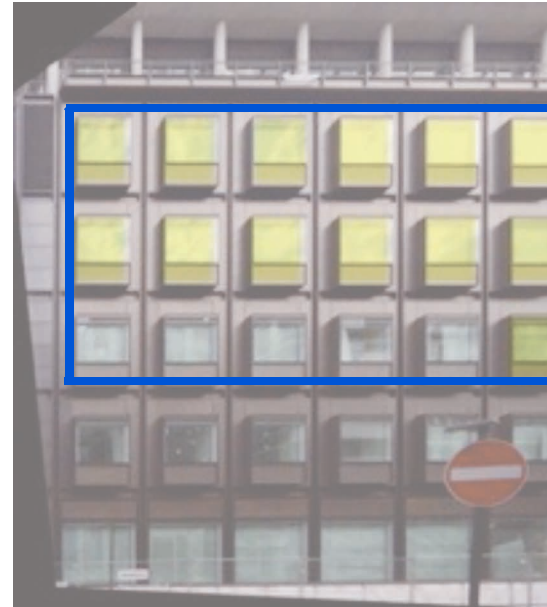
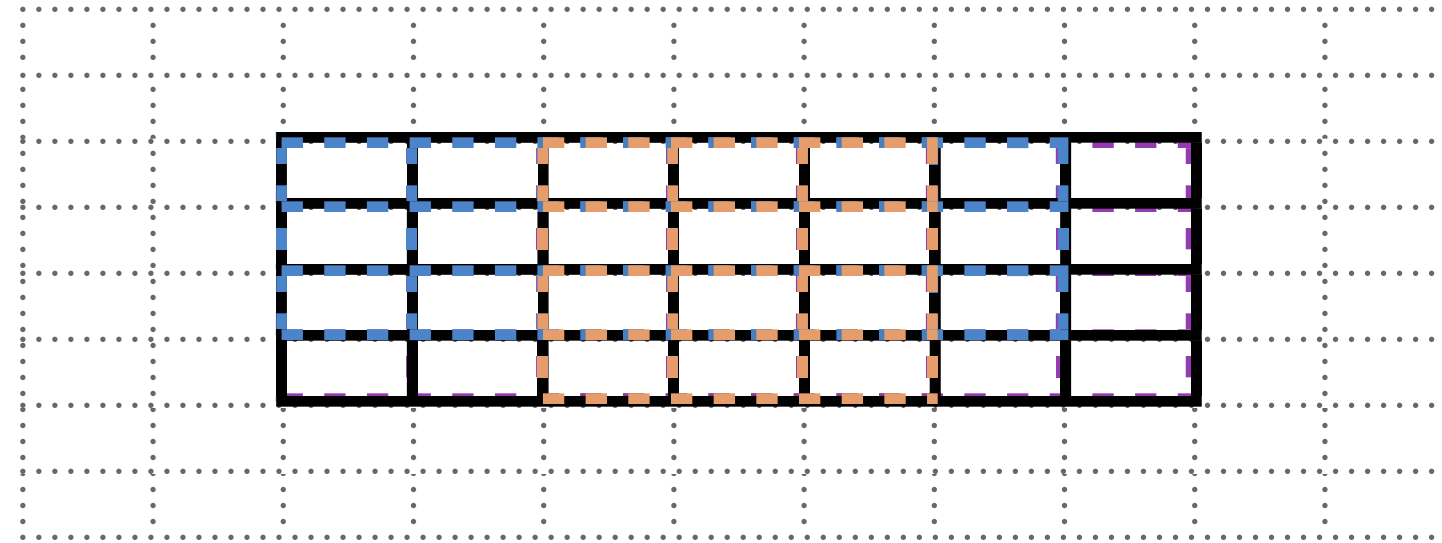
# Global Grid Alignment

*unknown  
global grid*



# Global Grid Alignment

*unknown  
global grid*





# Local Alignment



original image pair

# Local Alignment



original image pair



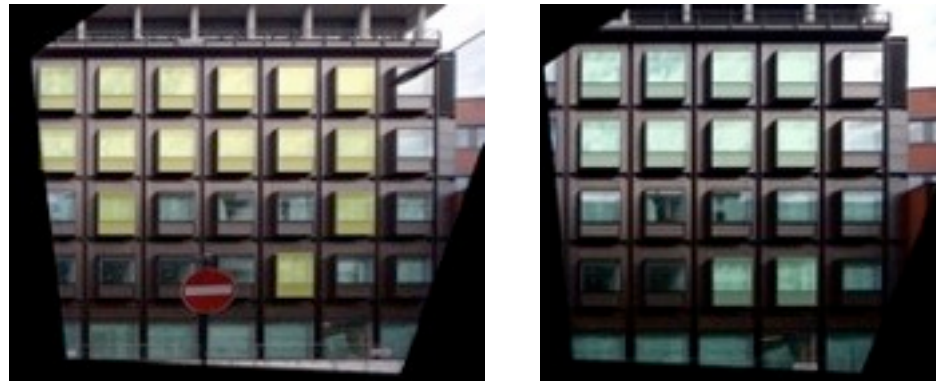
detected 2D grids



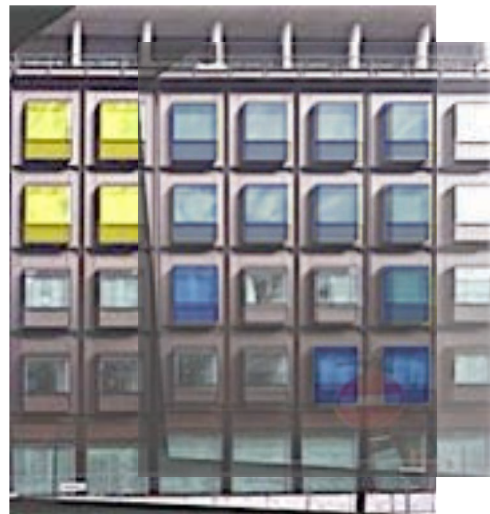
# Local Alignment



original image pair



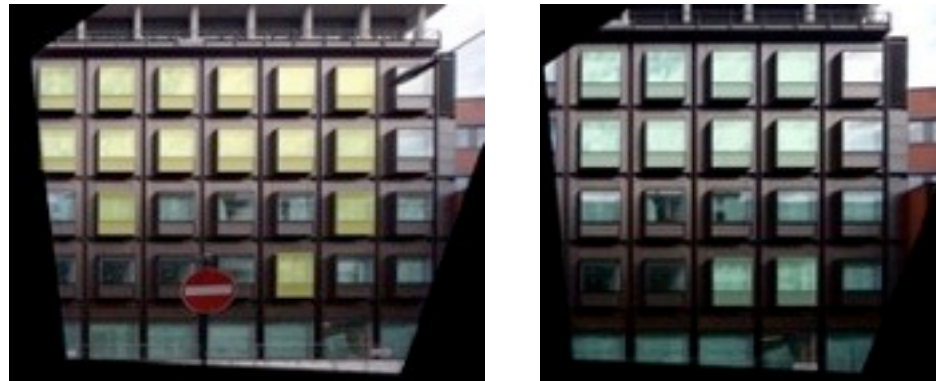
detected 2D grids



# Local Alignment



original image pair



detected 2D grids



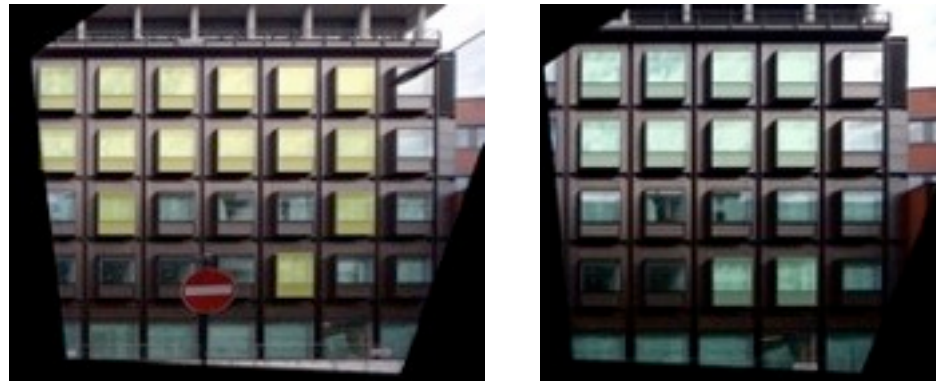
alignment ~ shifts in rows/columns



# Local Alignment



original image pair



detected 2D grids



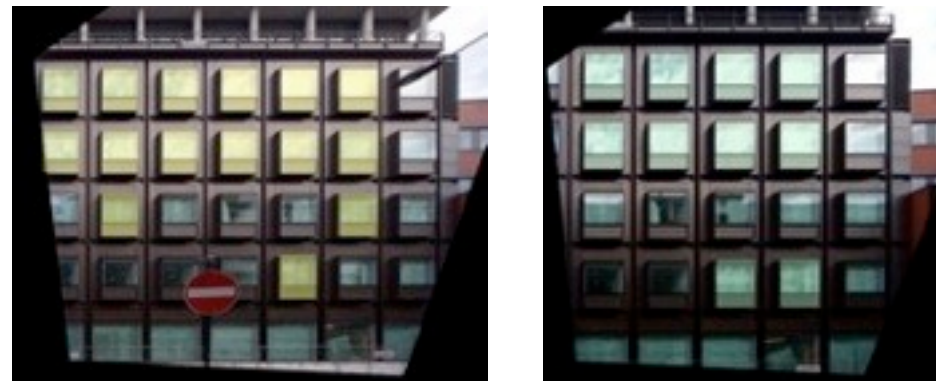
alignment ~ shifts in rows/columns



# Local Alignment



original image pair



detected 2D grids



alignment ~ shifts in rows/columns



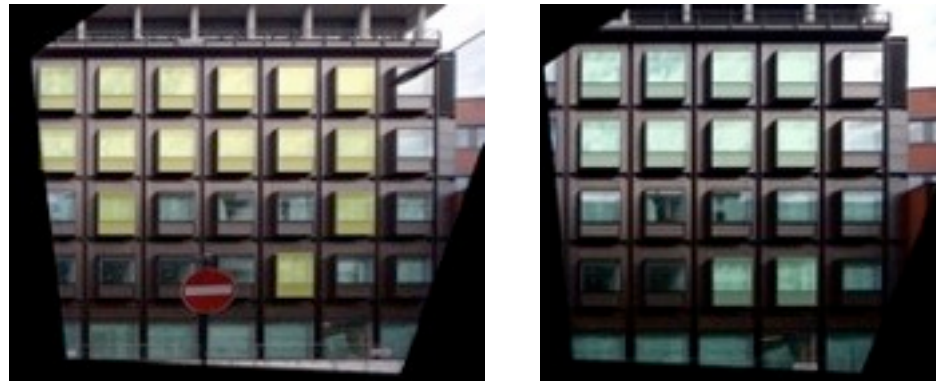
20 supporting feature matches



# Local Alignment



original image pair



detected 2D grids



alignment ~ shifts in rows/columns



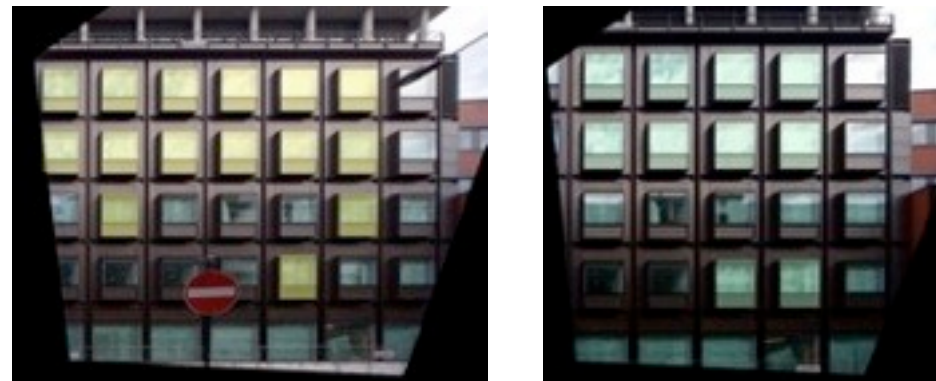
51 supporting feature matches



# Local Alignment



original image pair



detected 2D grids



alignment ~ shifts in rows/columns



51 supporting feature matches

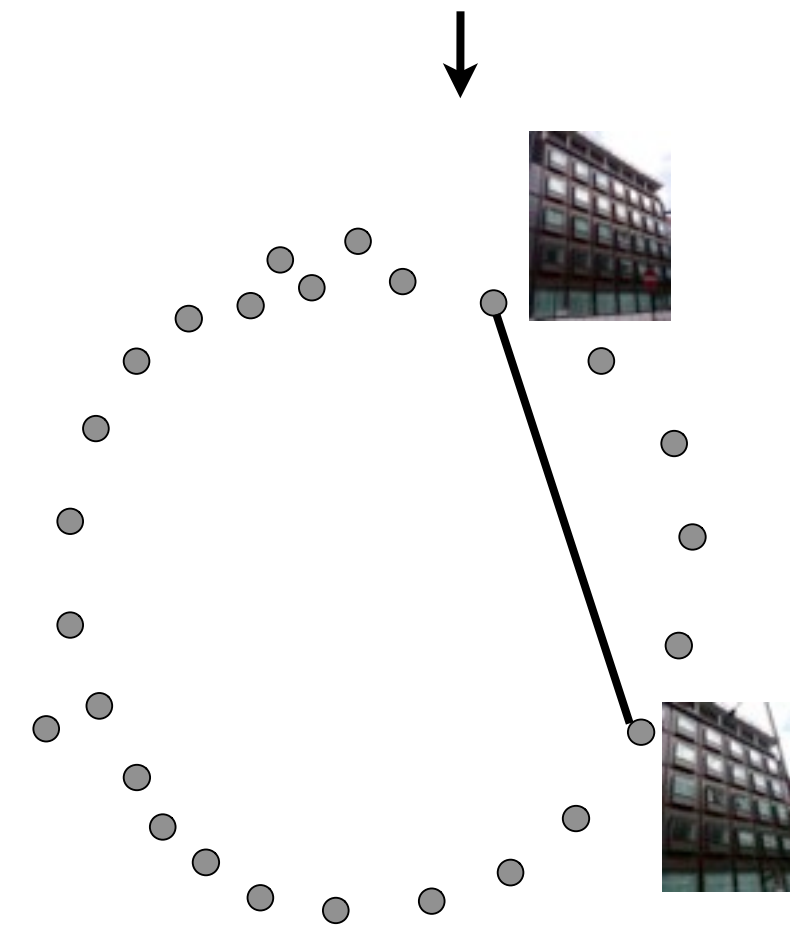


image matching graph

# Global Alignment

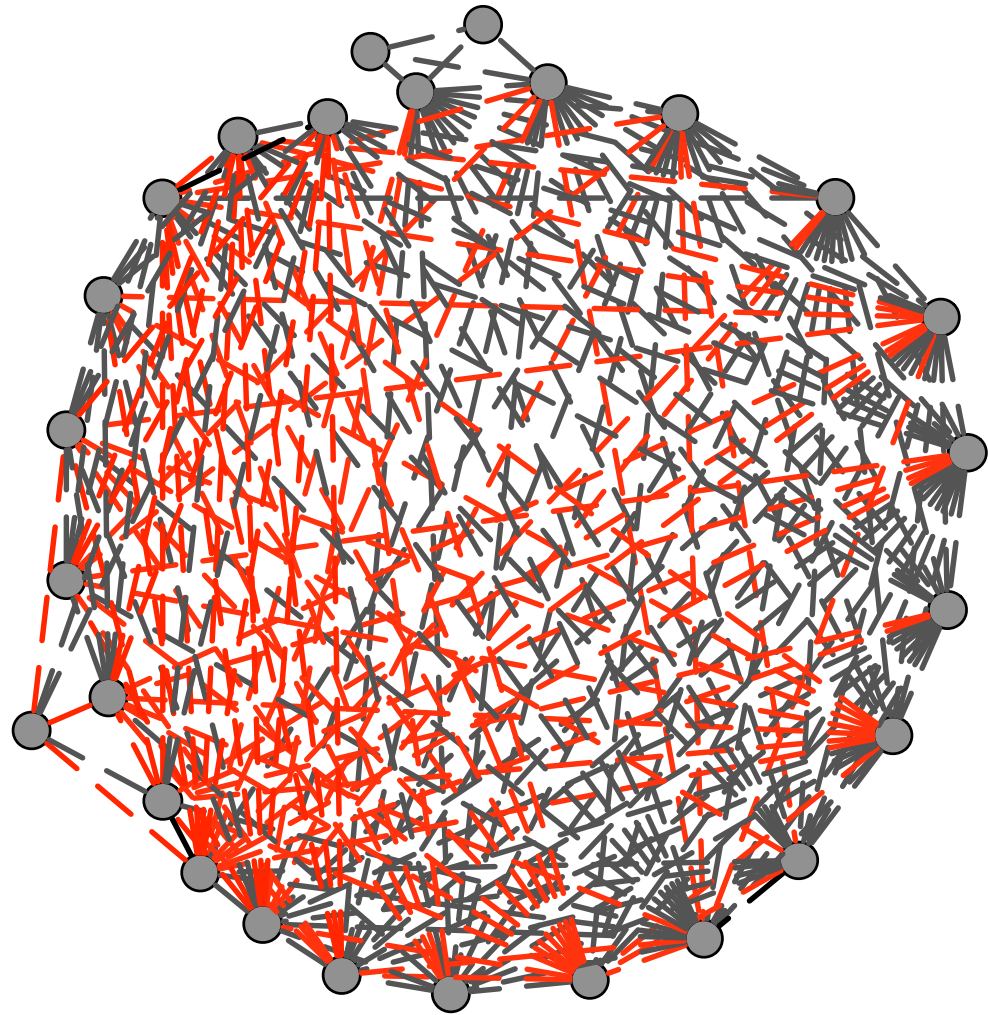


image matching graph



# Global Alignment

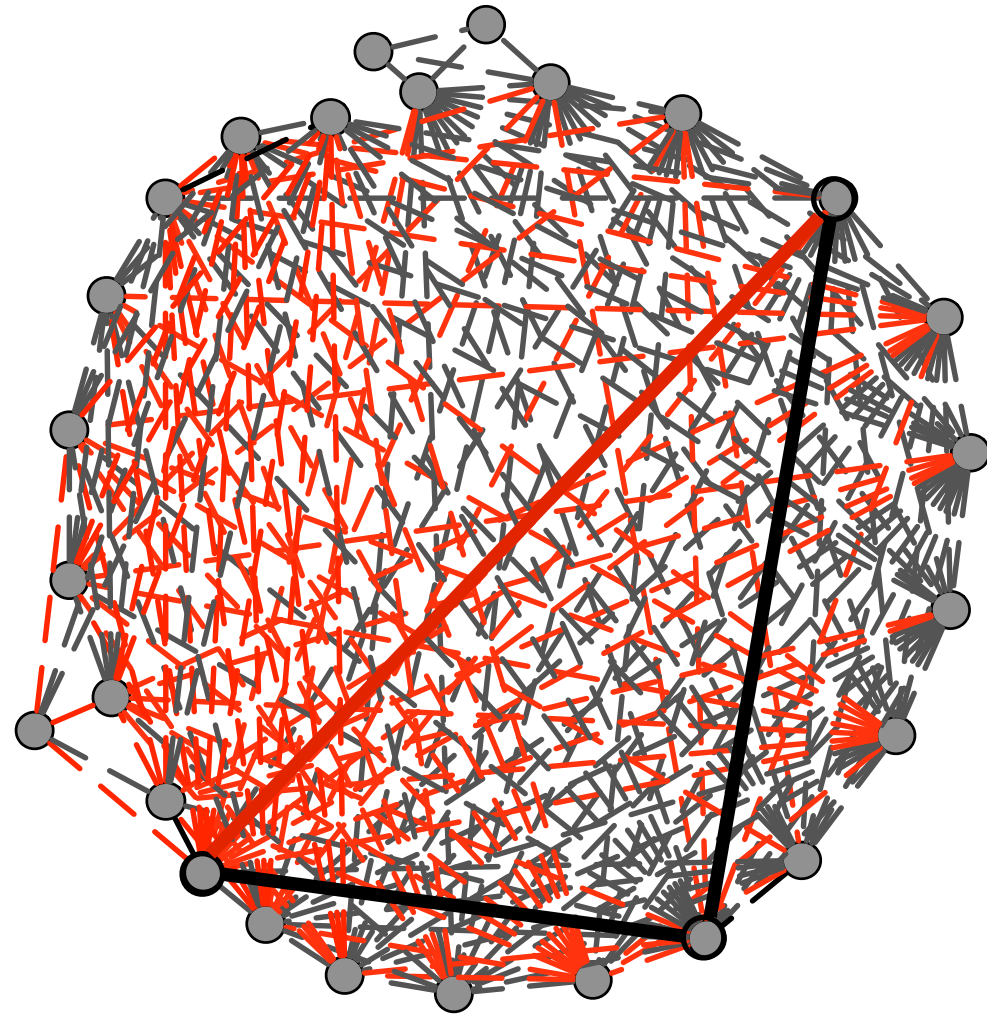
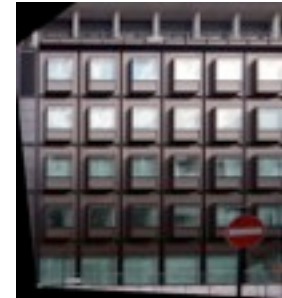


image matching graph

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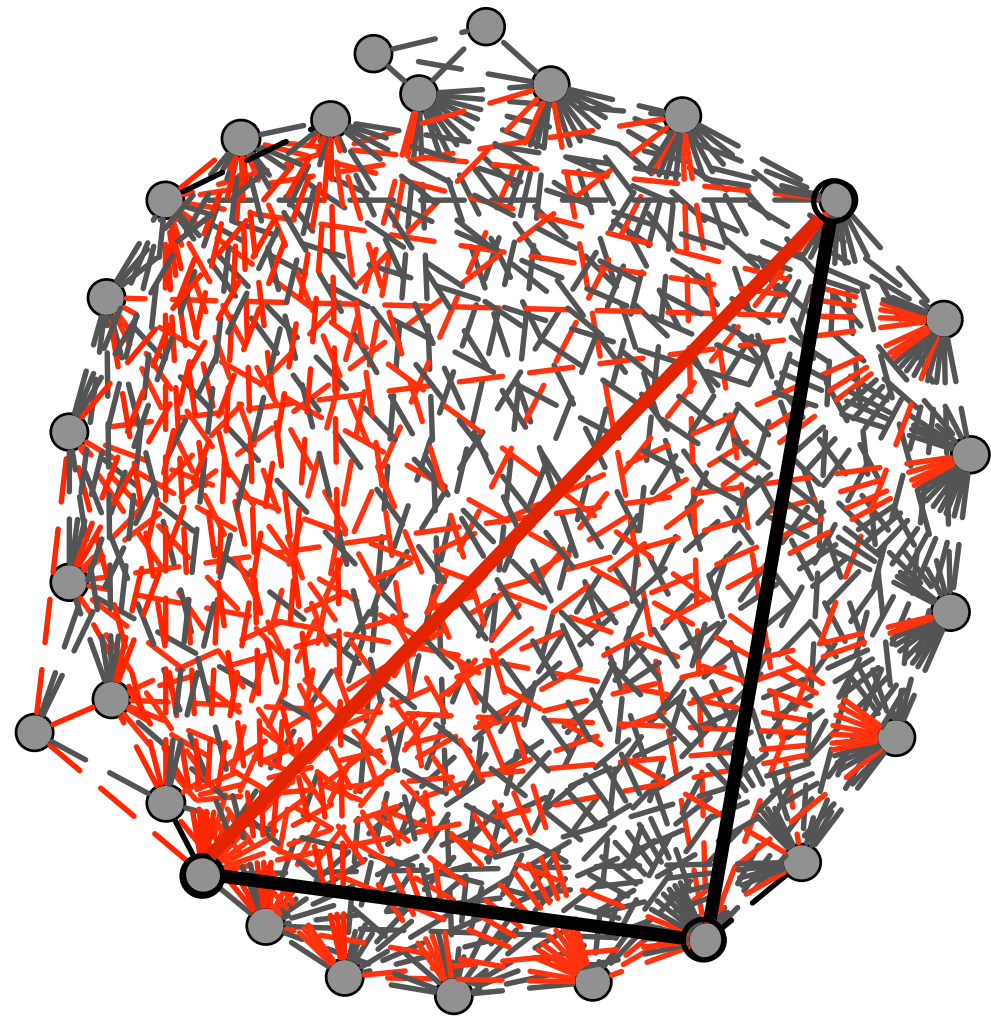
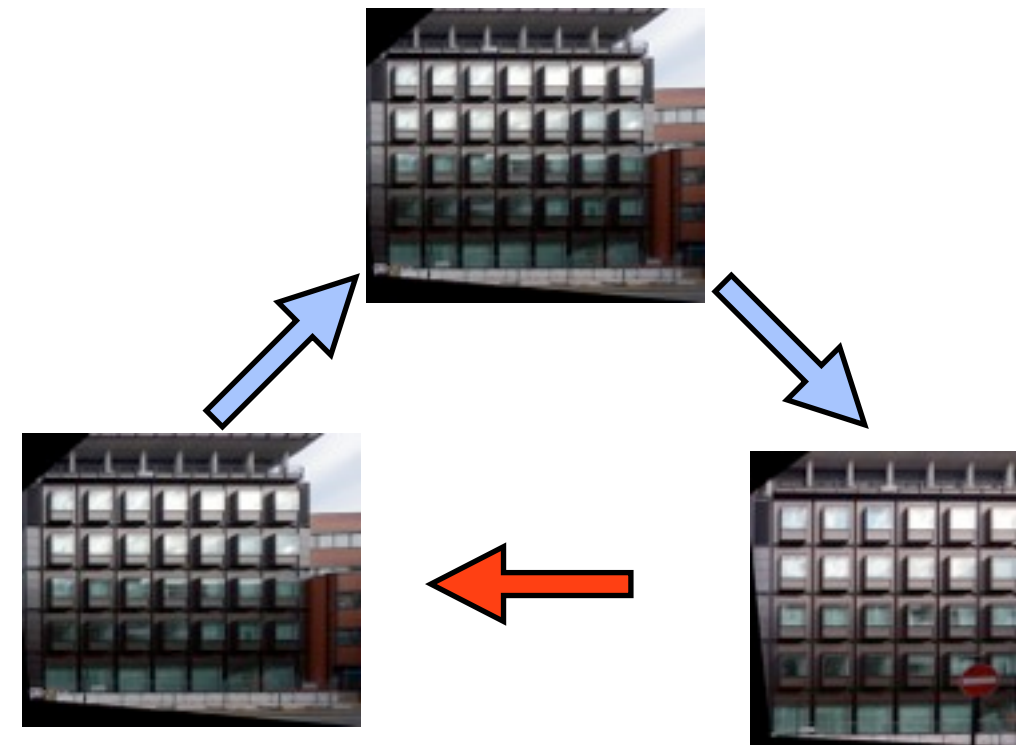


image matching graph



total shift in rows/columns  $\stackrel{?}{=} 0$

# Global Alignment

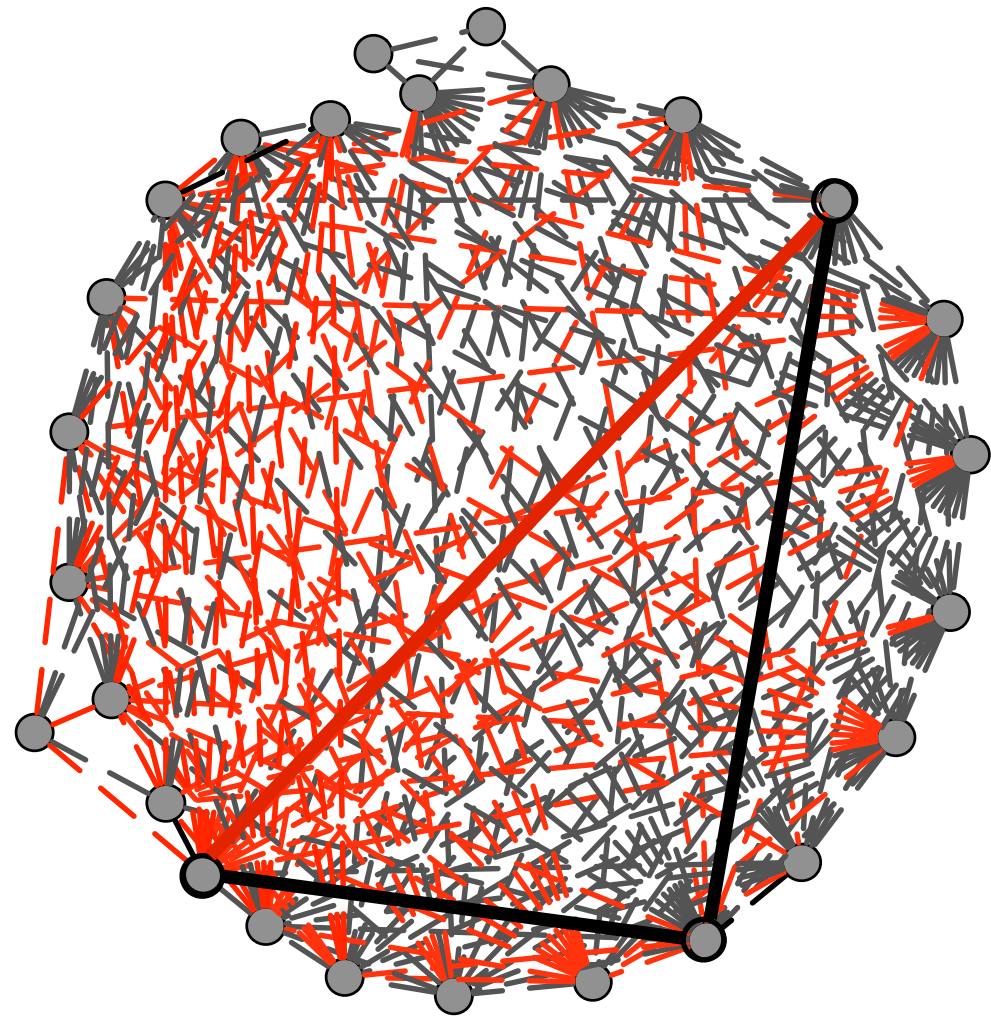
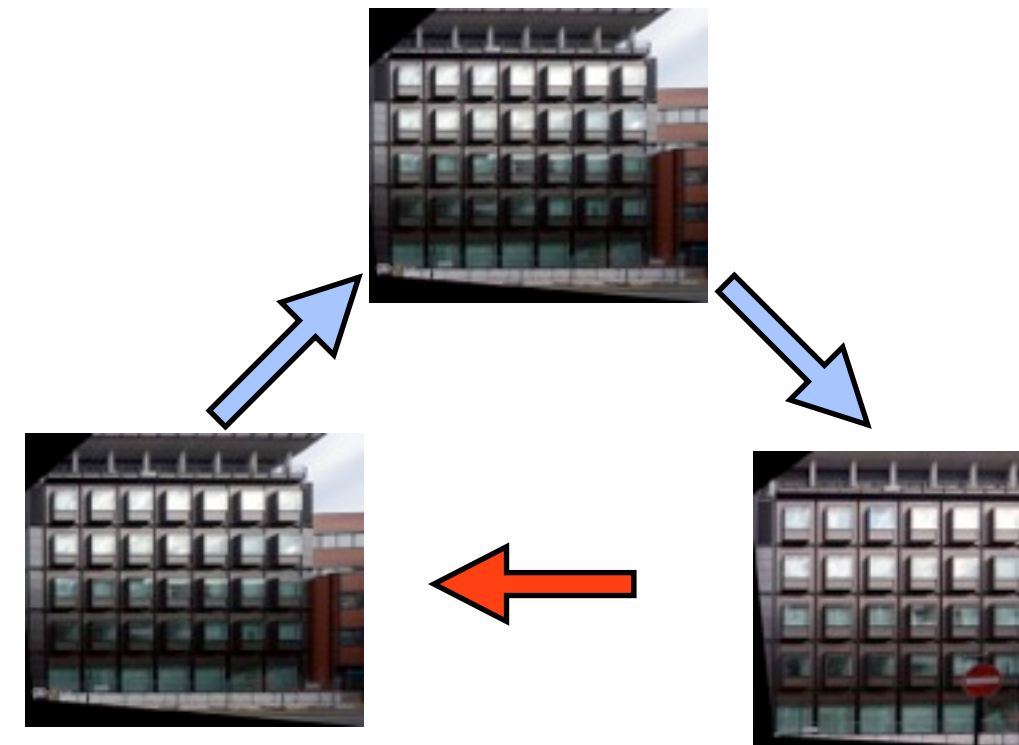


image matching graph



total shift in rows/columns  $\stackrel{?}{=} 0$   
**inconsistent loop  $L_i$**



# Global Alignment

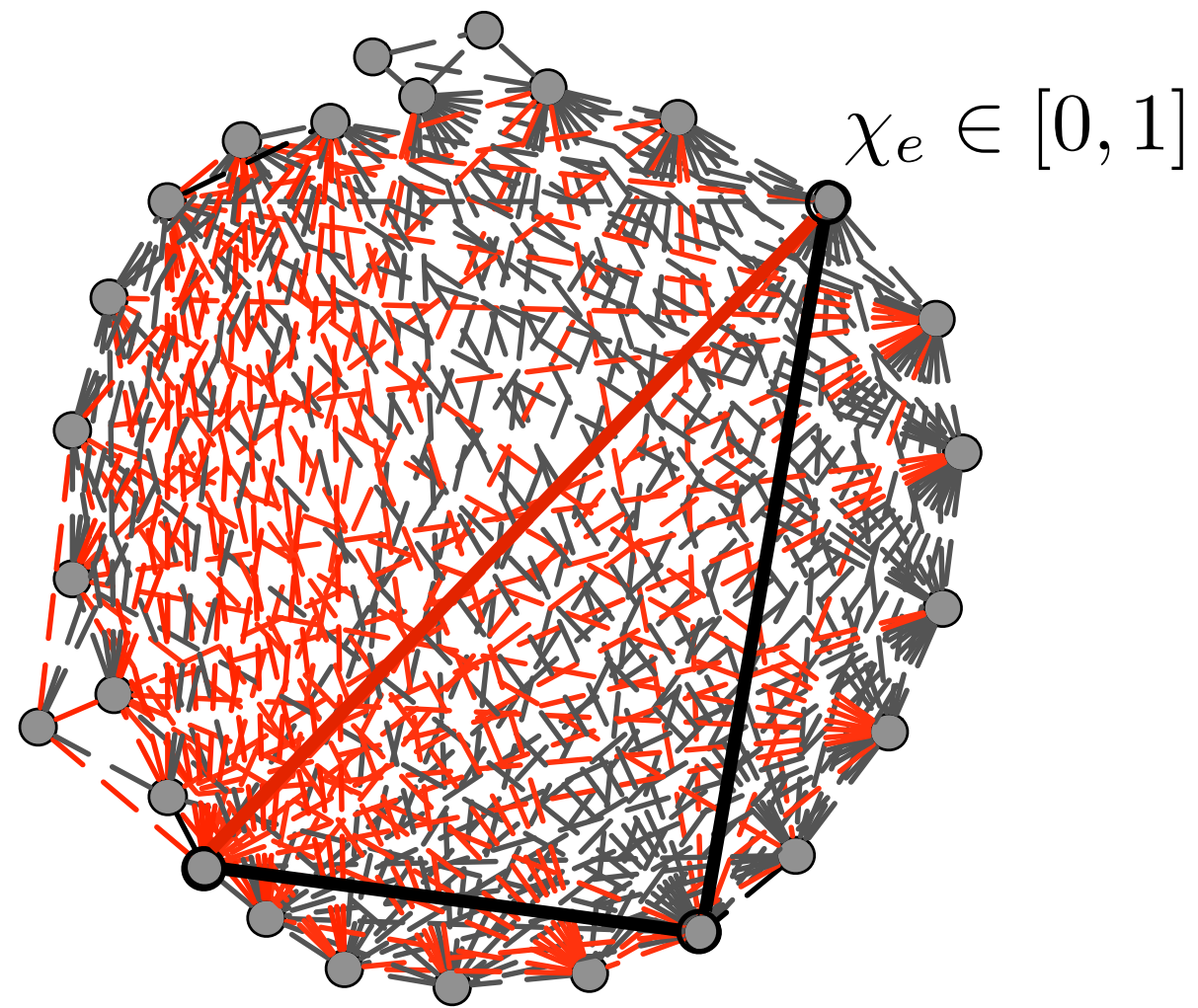
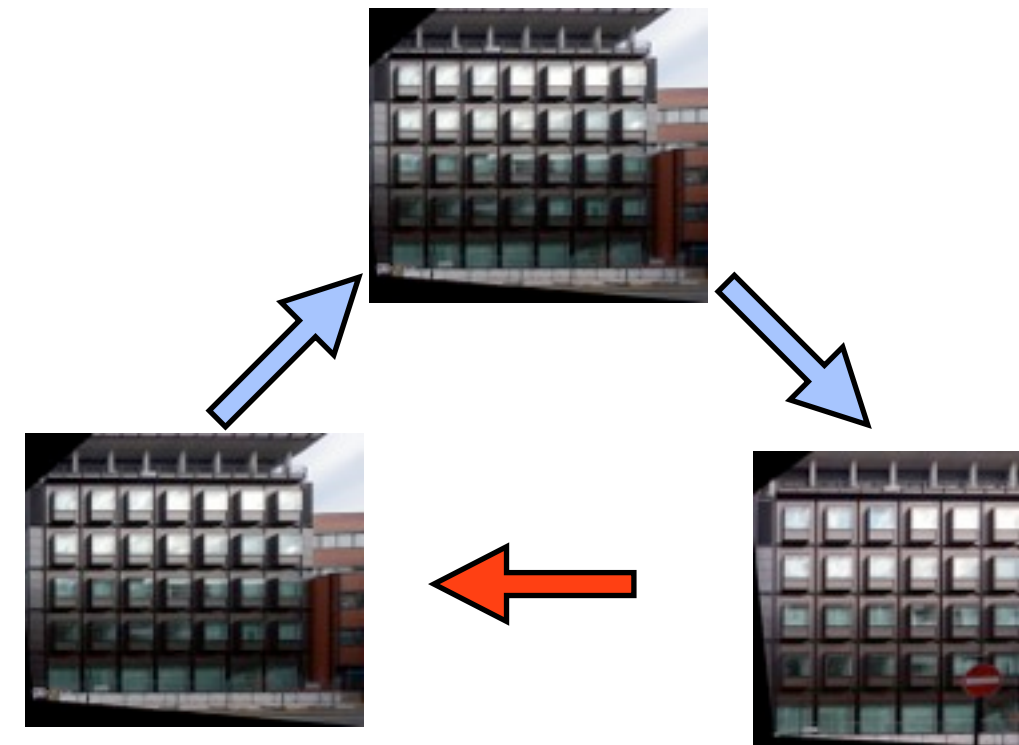


image matching graph



total shift in rows/columns  $\stackrel{?}{=} 0$   
**inconsistent loop  $L_i$**

# Global Alignment

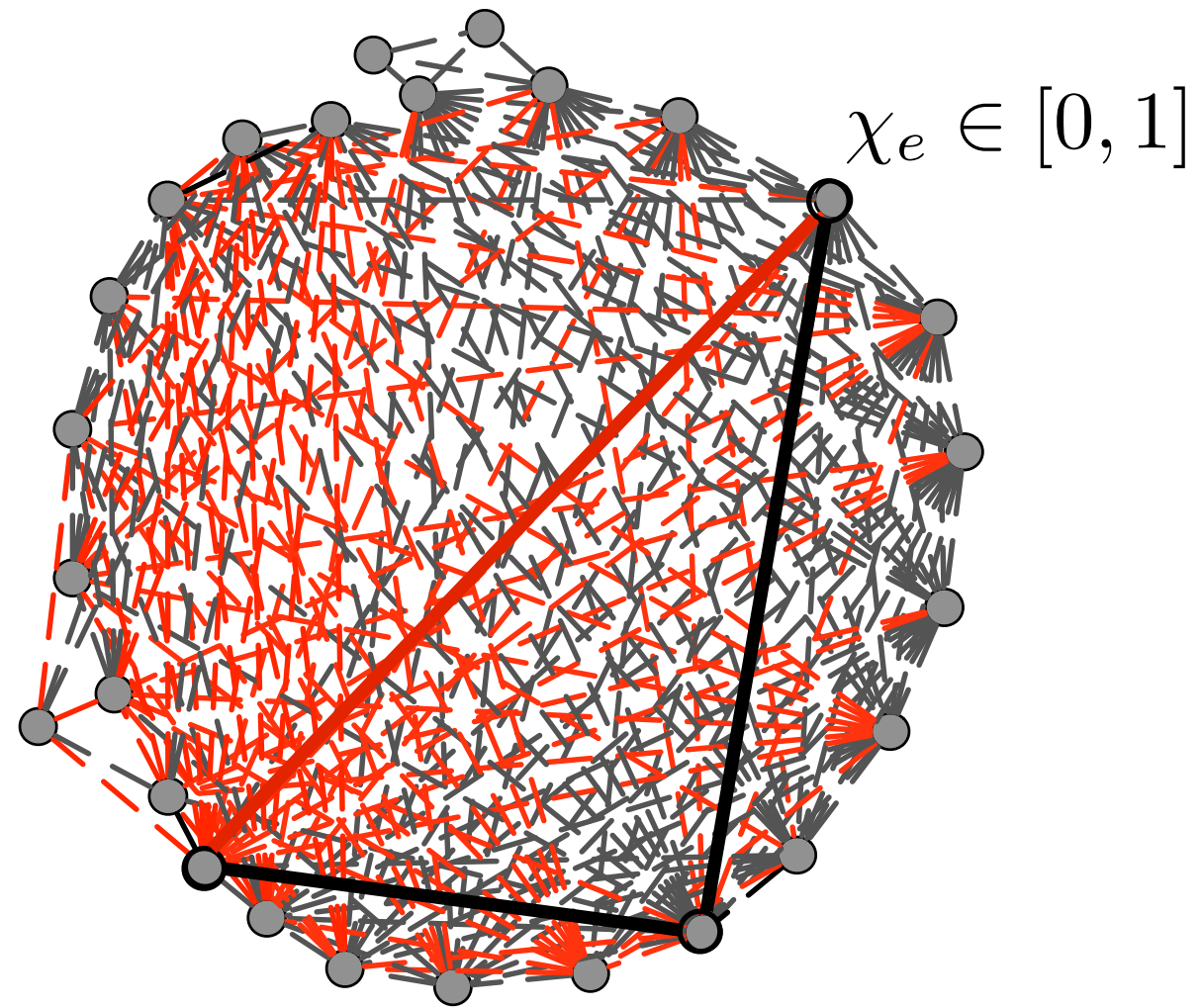
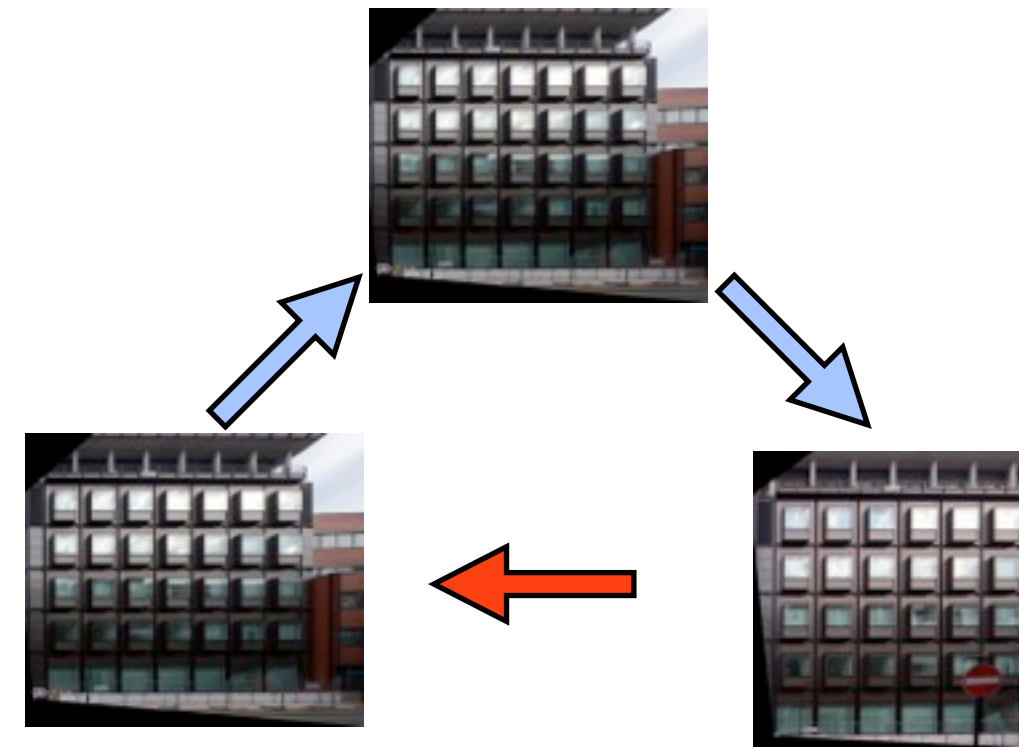


image matching graph



total shift in rows/columns  $\stackrel{?}{=} 0$

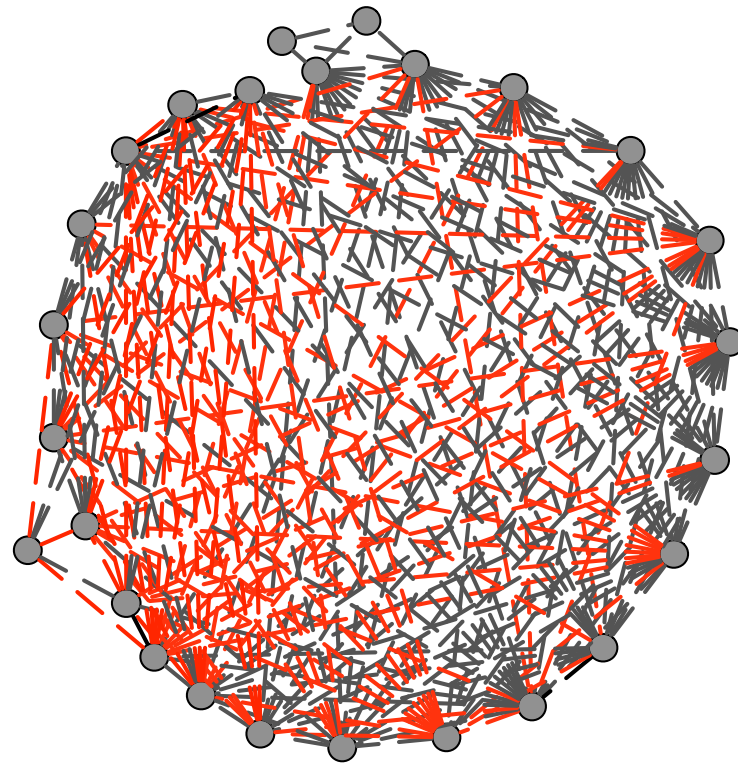
**inconsistent loop  $L_i$**

$$\min_{\{\chi_e\}} \sum_{e \in E} w_e \chi_e$$

subject to  $\sum_{e \in L_i} \chi_e \geq 1$

*linear programming (CVX)*

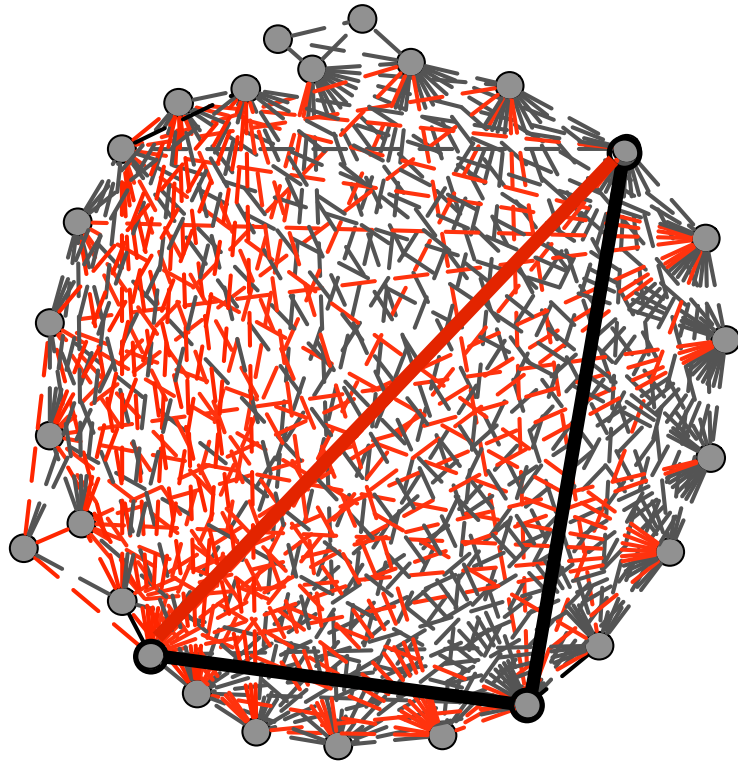
# Global Alignment



initial graph



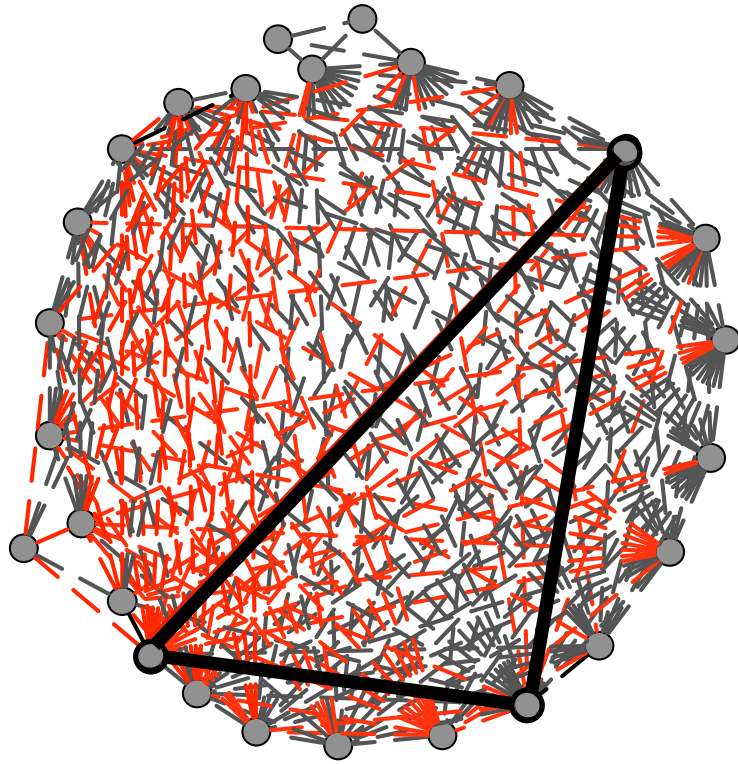
# Global Alignment



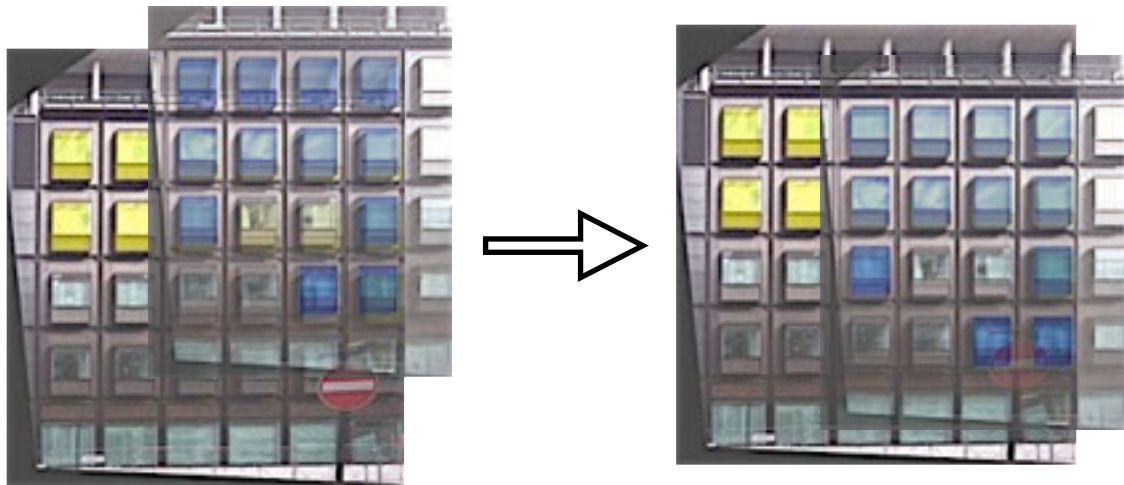
initial graph



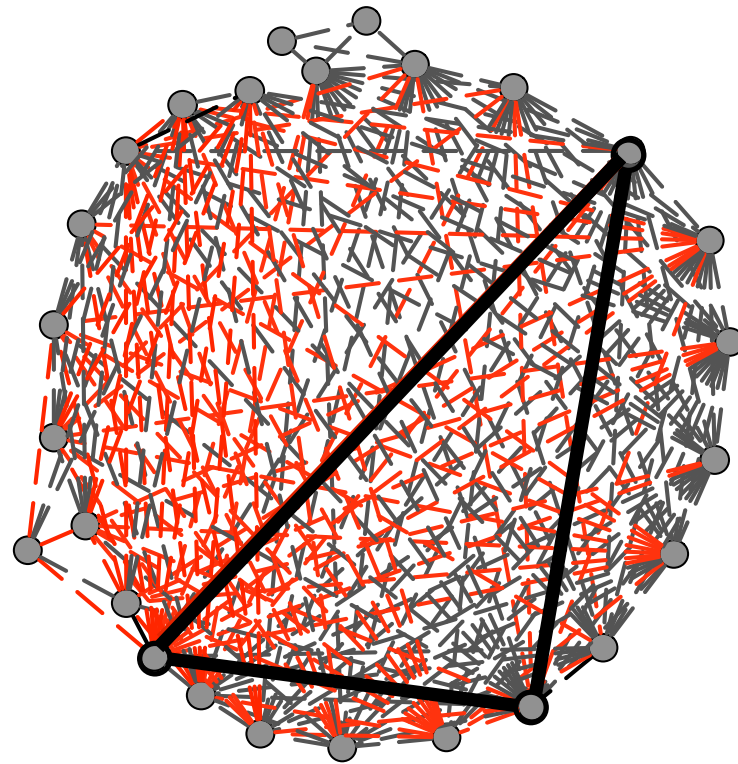
# Global Alignment



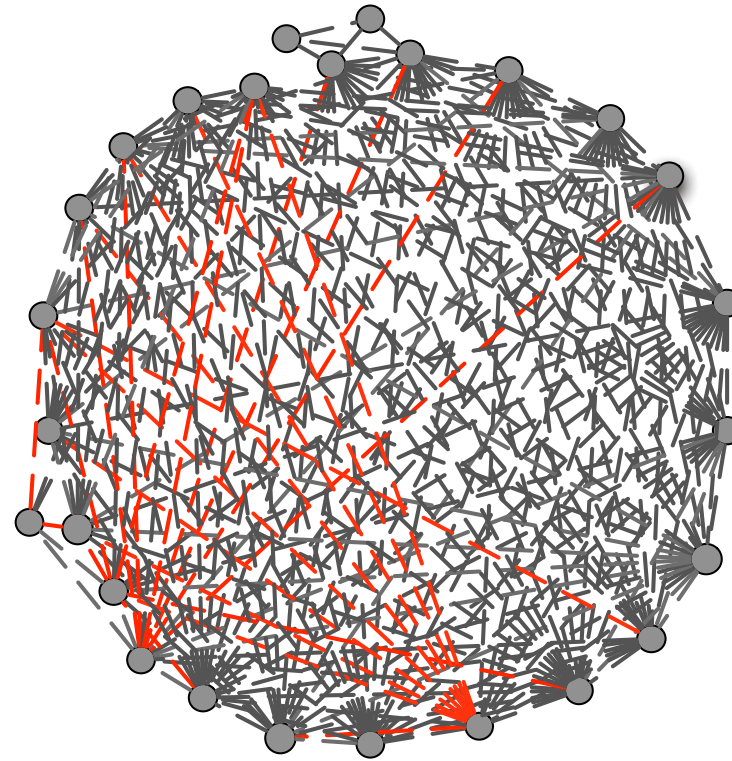
initial graph



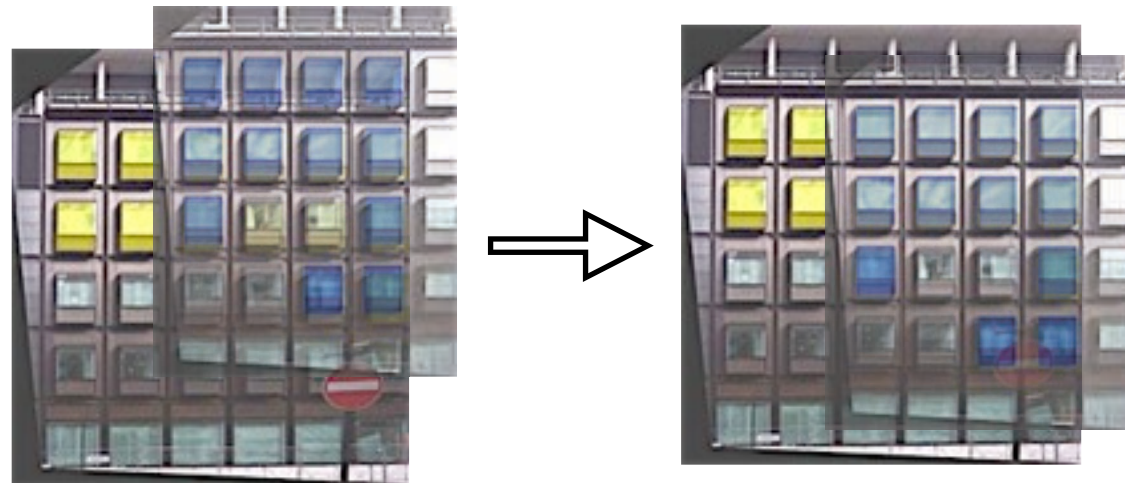
# Global Alignment



initial graph

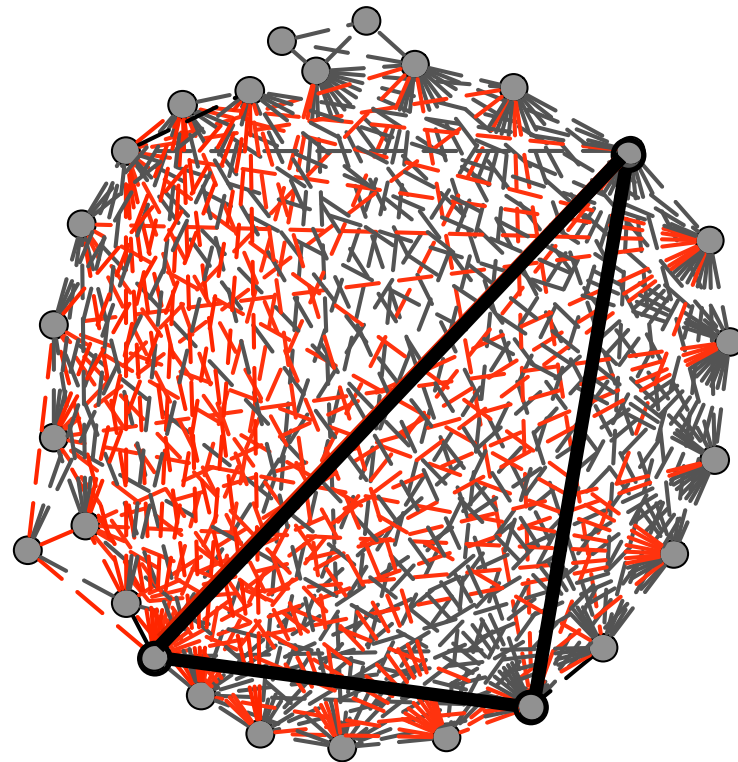


iteration 3

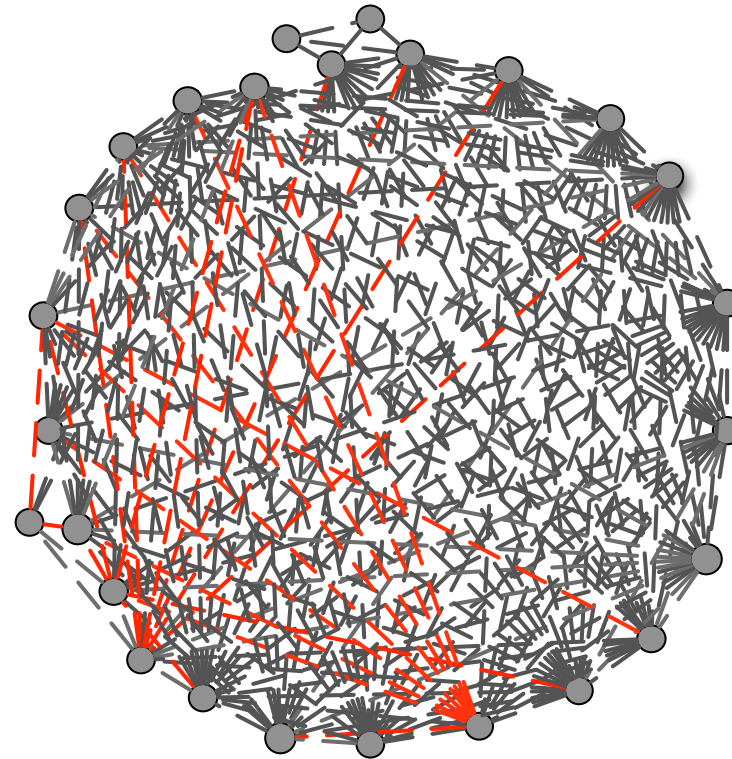




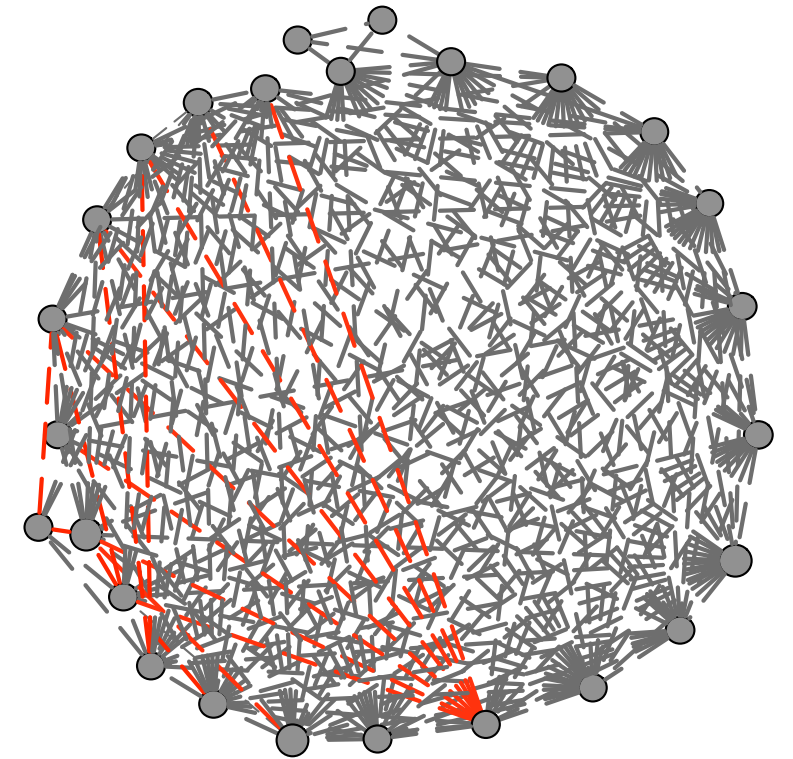
# Global Alignment



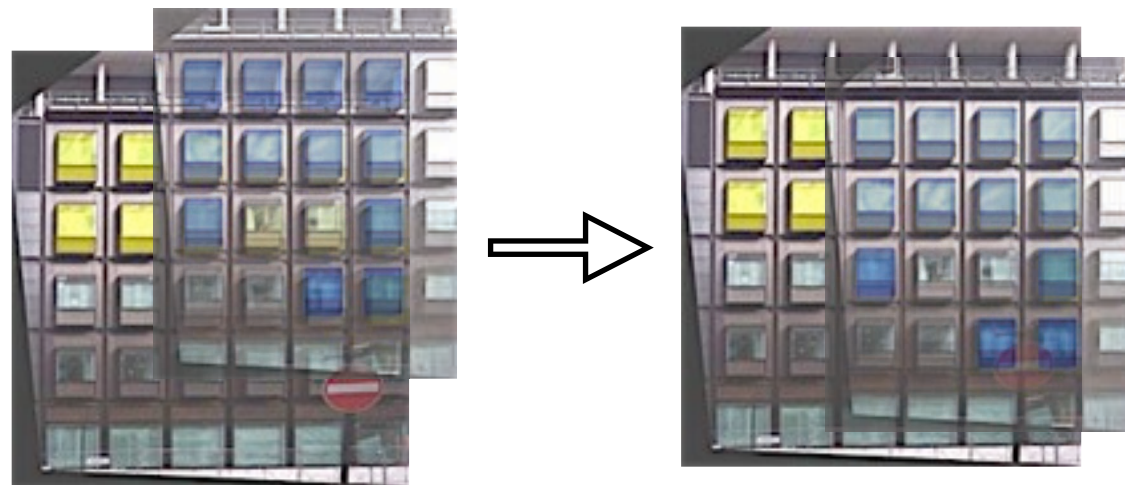
initial graph



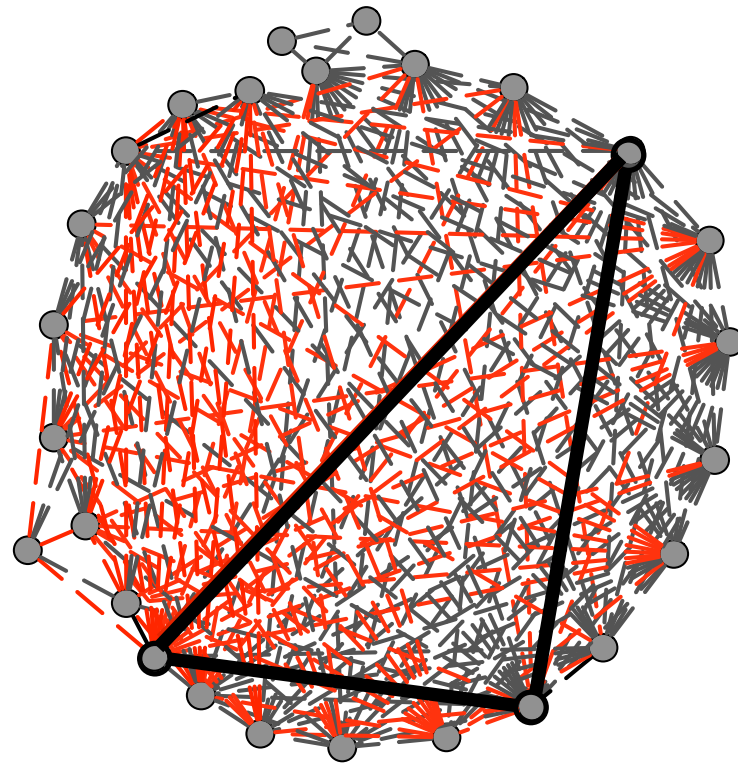
iteration 3



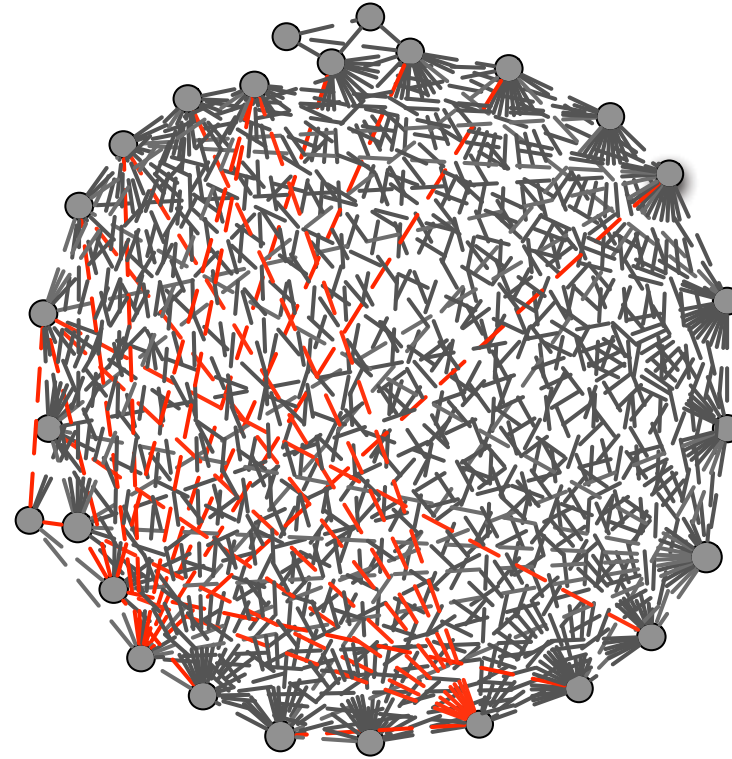
iteration 6  
(final iteration)



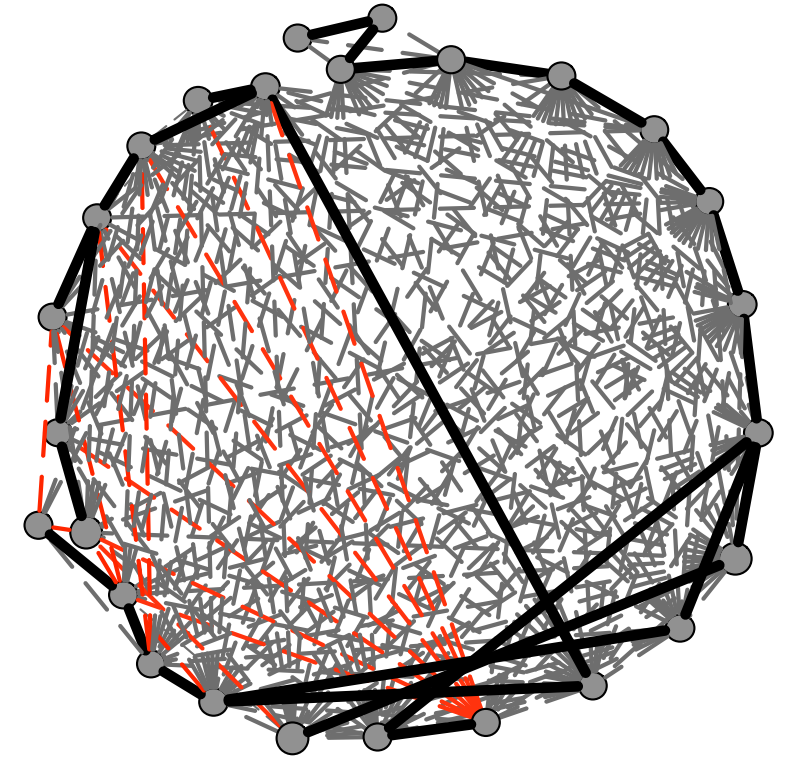
# Global Alignment



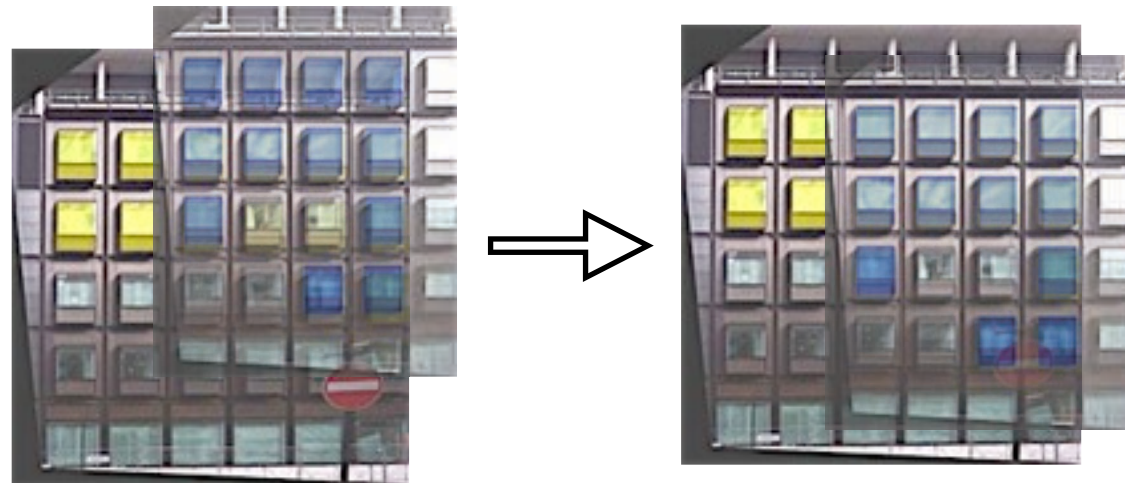
initial graph



iteration 3

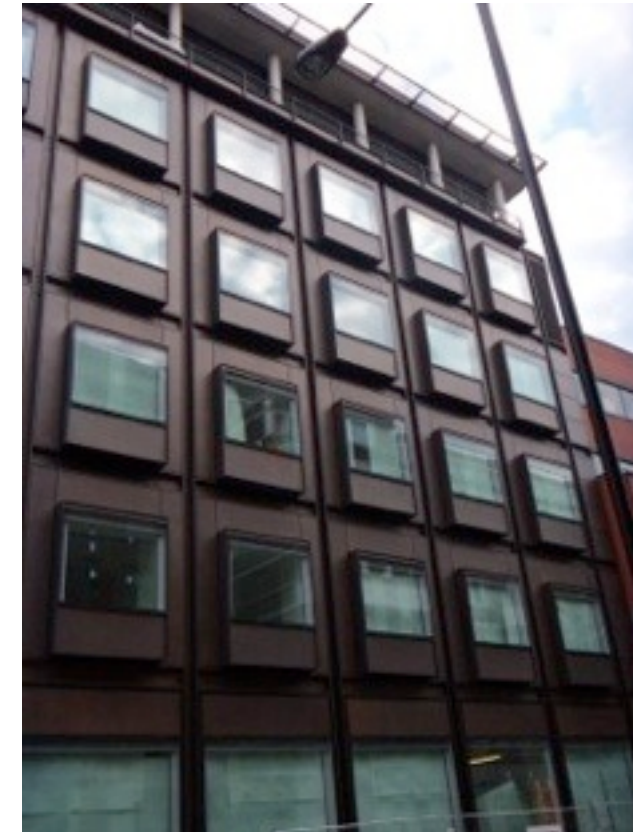


iteration 6  
(final iteration)





# Symmetry-Aware Bundle Adjustment

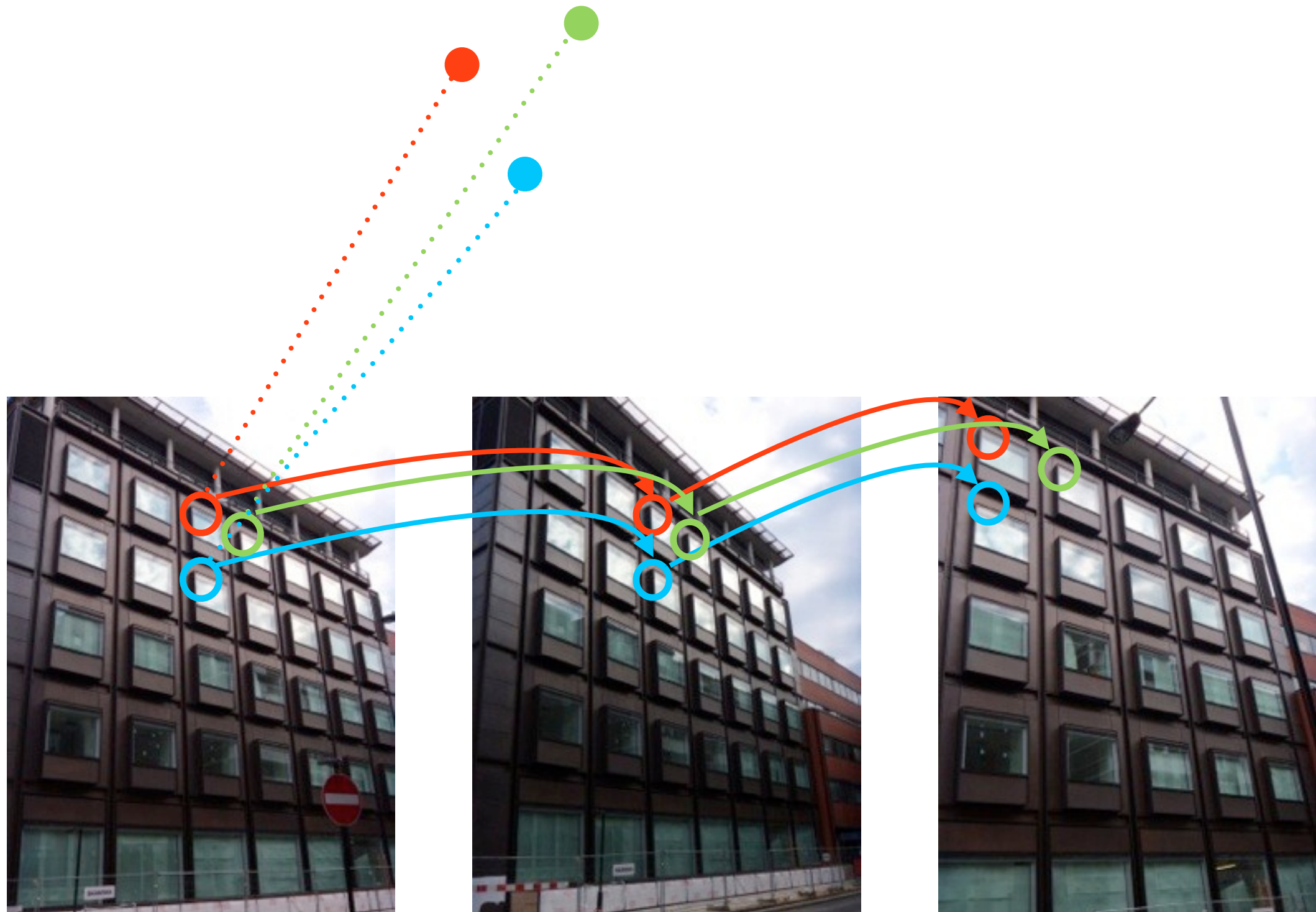




# Symmetry-Aware Bundle Adjustment

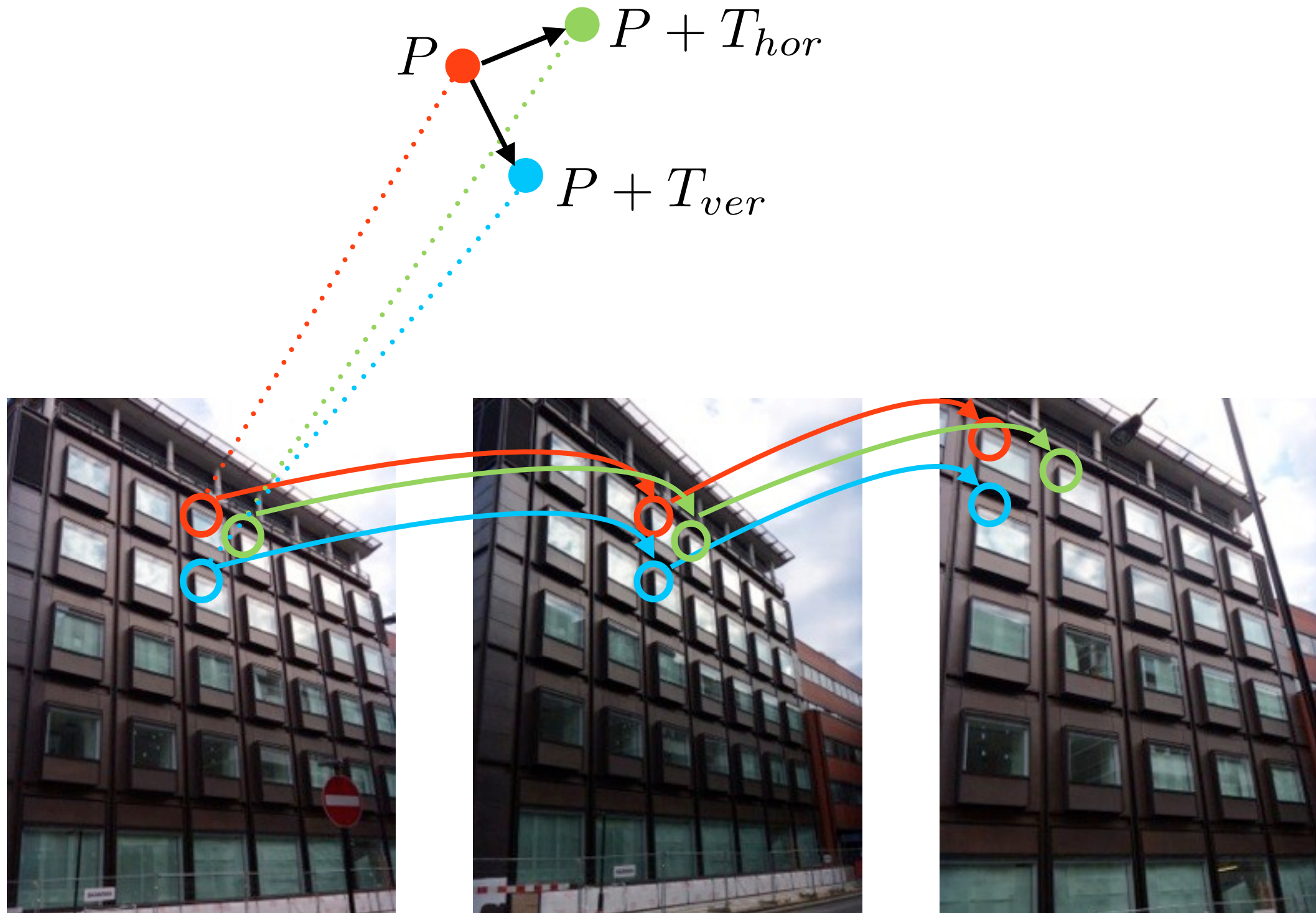


# Symmetry-Aware Bundle Adjustment





# Symmetry-Aware Bundle Adjustment





# Results



input images

# Results



input images



Bundler + PMVS



Symmetry-aware SFM + PMVS

# Results



input images



Bundler + PMVS



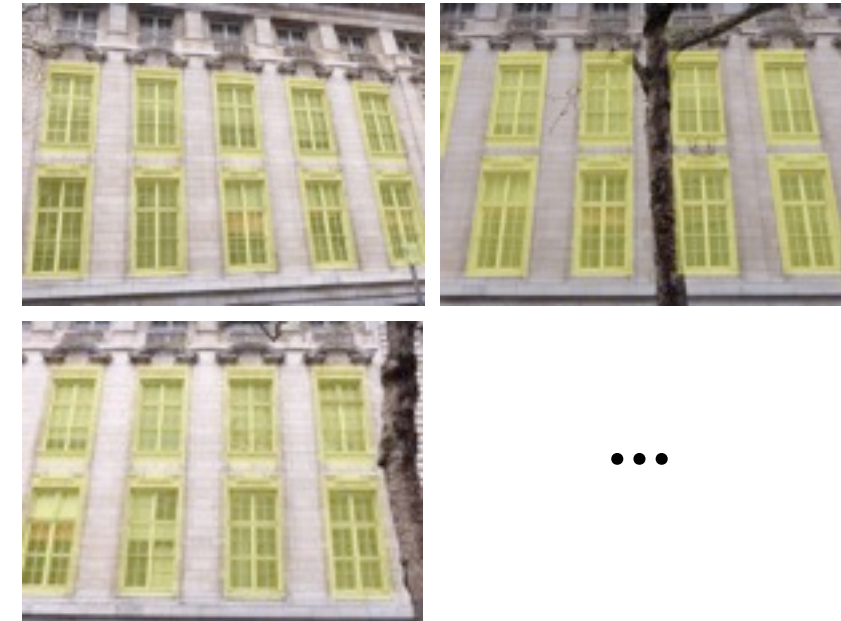
Symmetry-aware SFM + PMVS



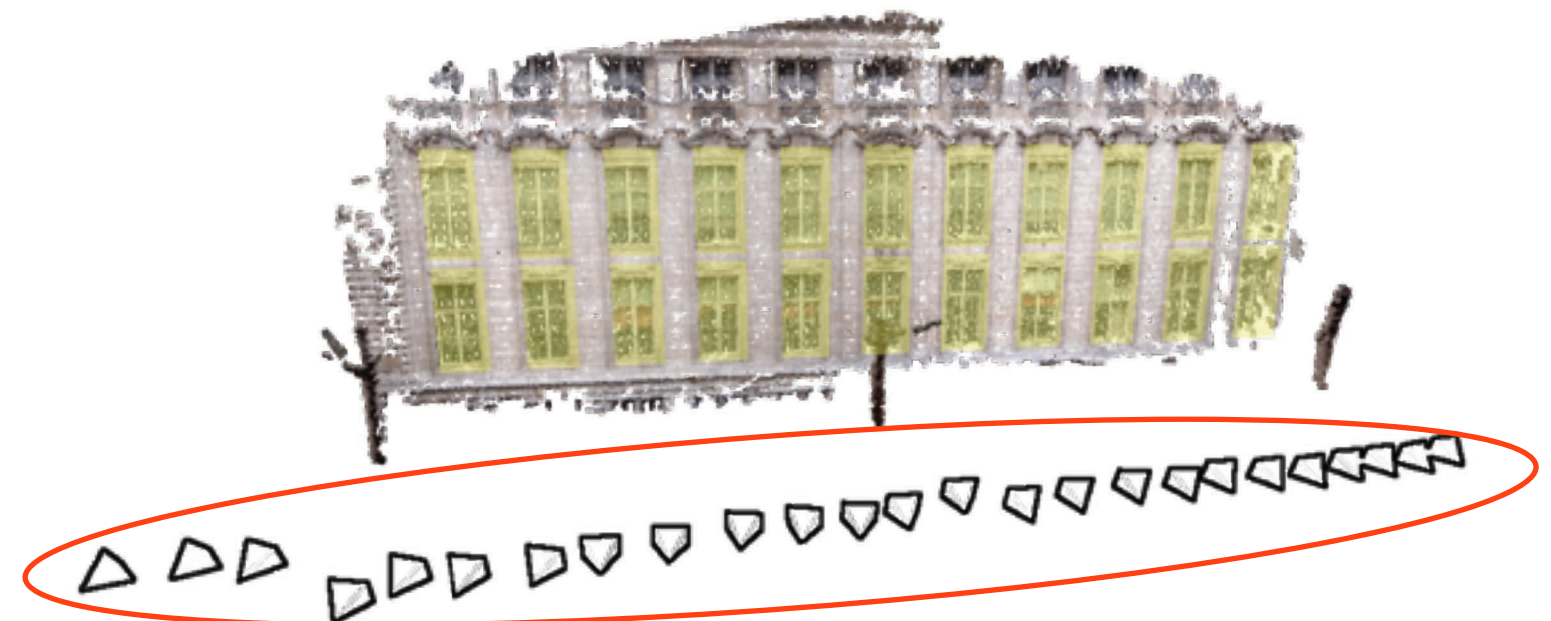
# Results



input images



Bundler + PMVS



Symmetry-aware SFM + PMVS

# Results



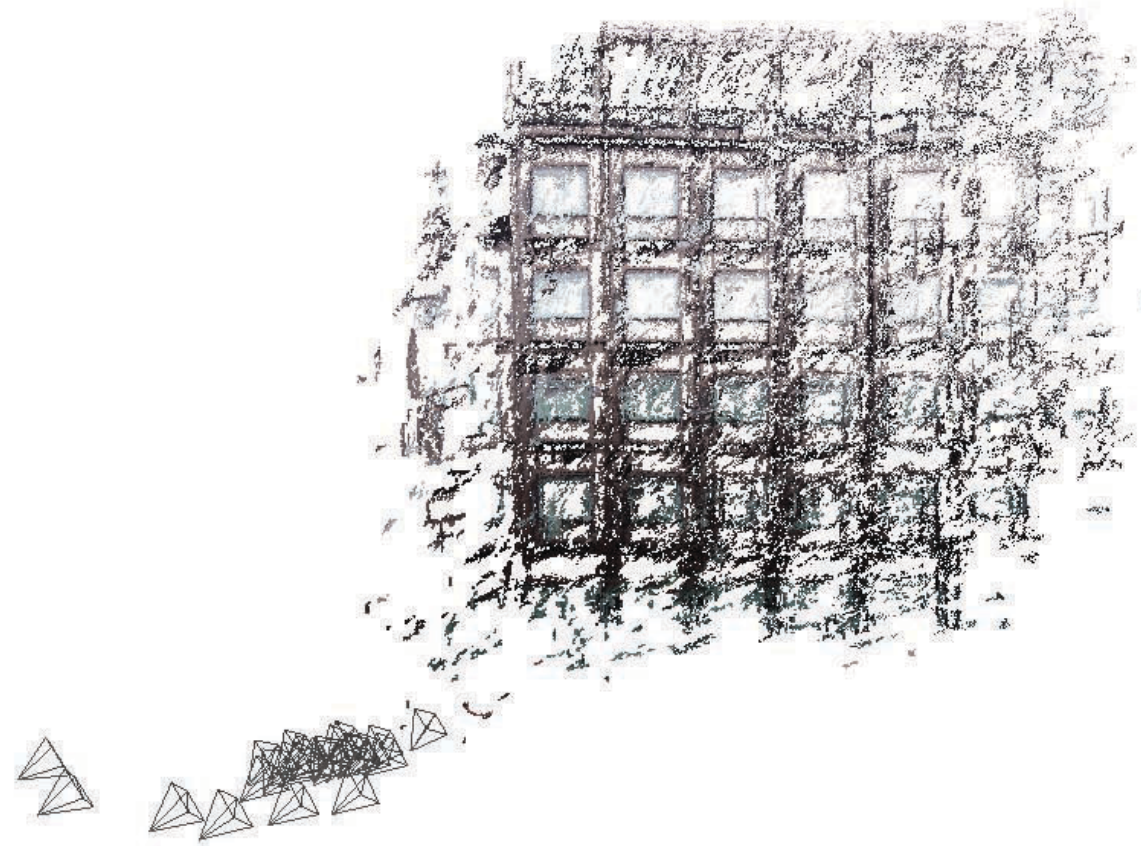
input images



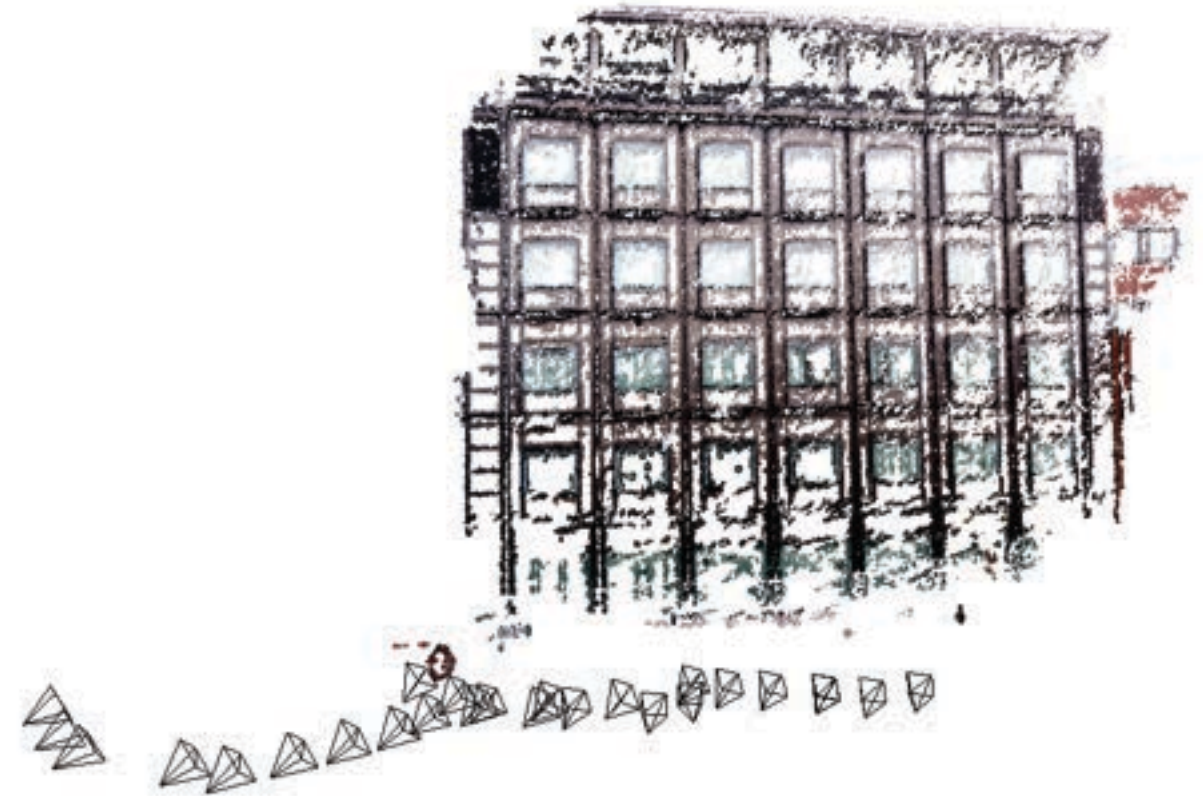
# Results



input images



Bundler + PMVS



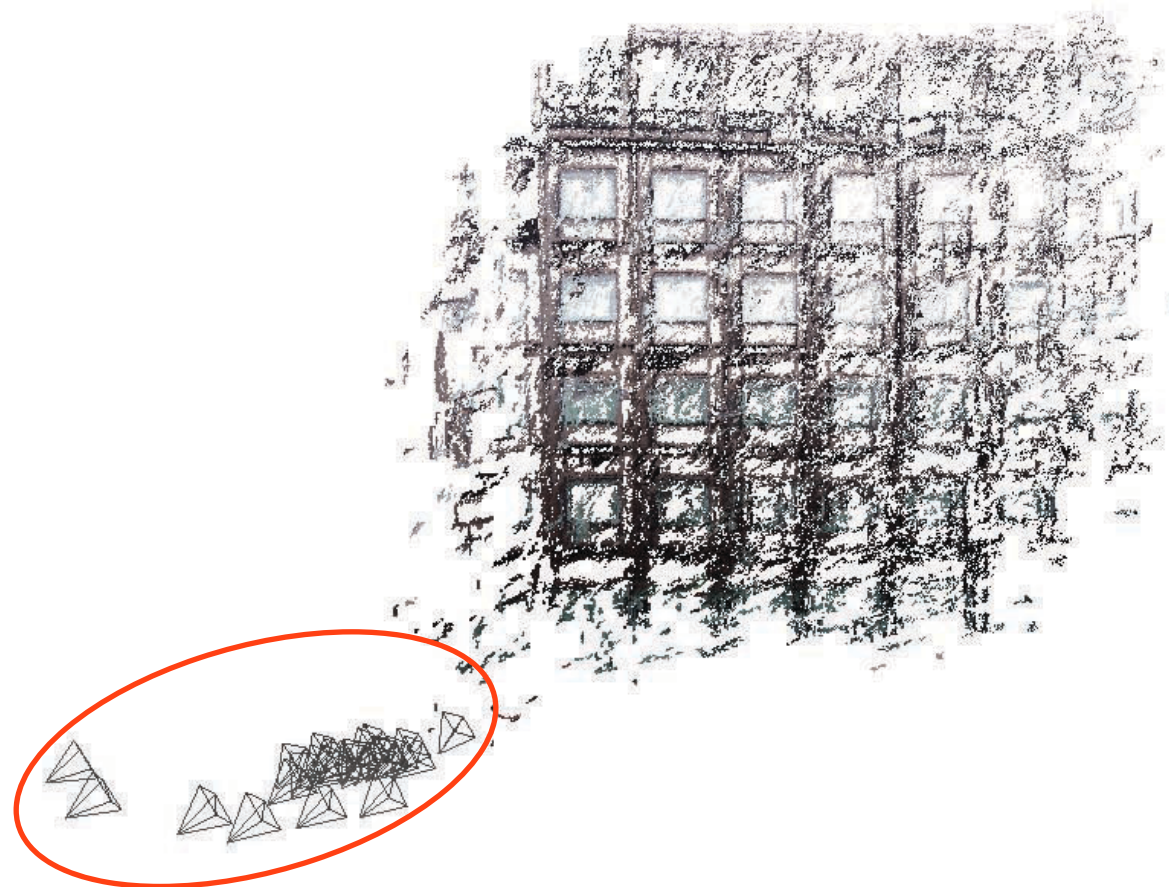
Symmetry-aware SFM + PMVS



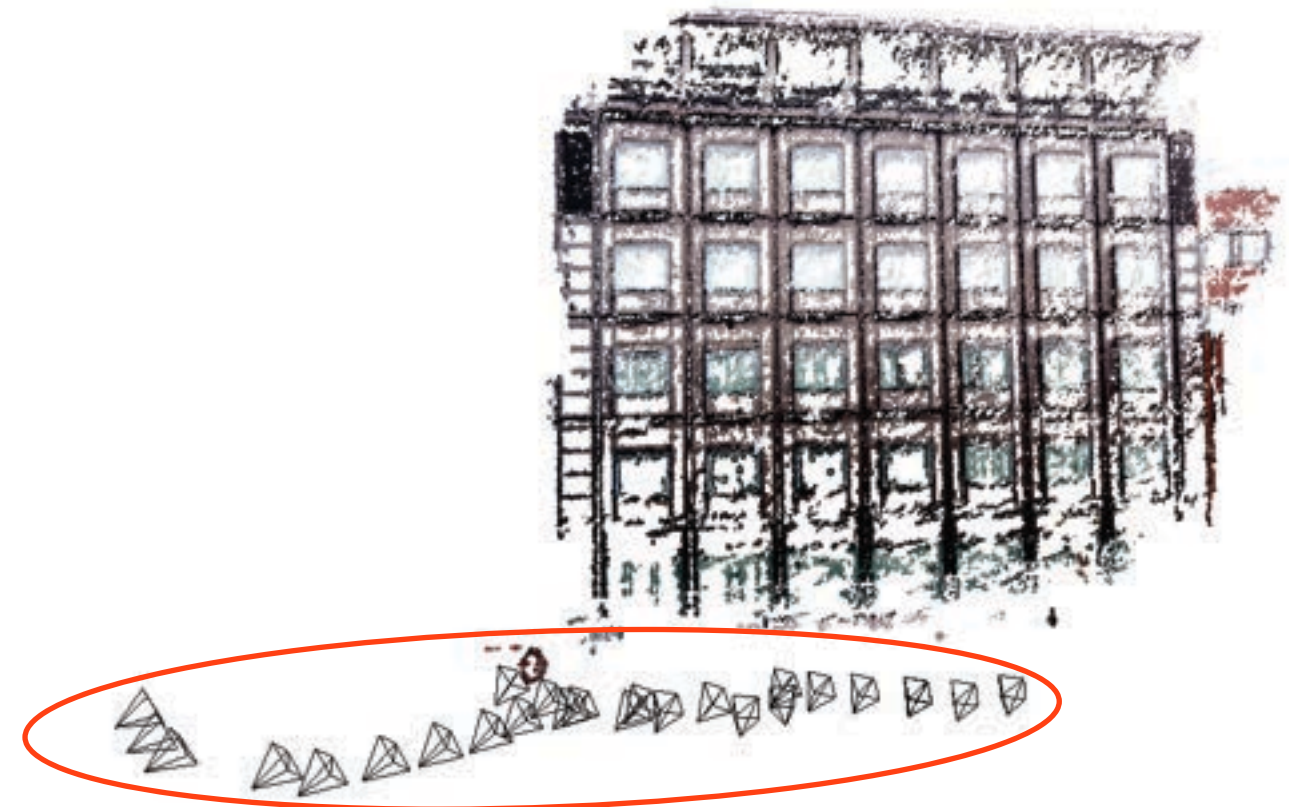
# Results



input images



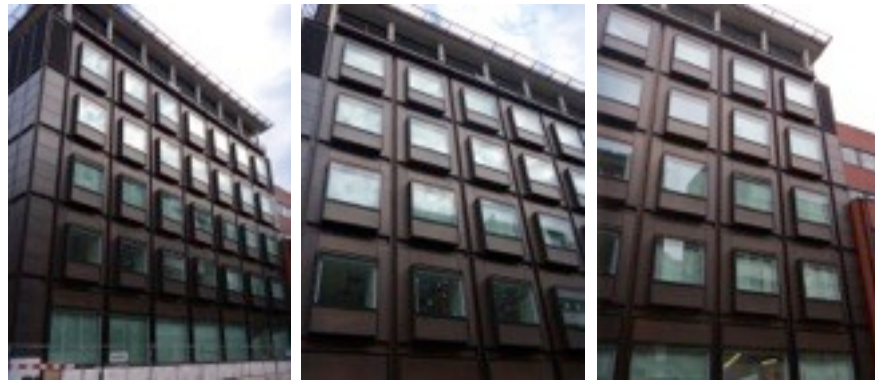
Bundler + PMVS



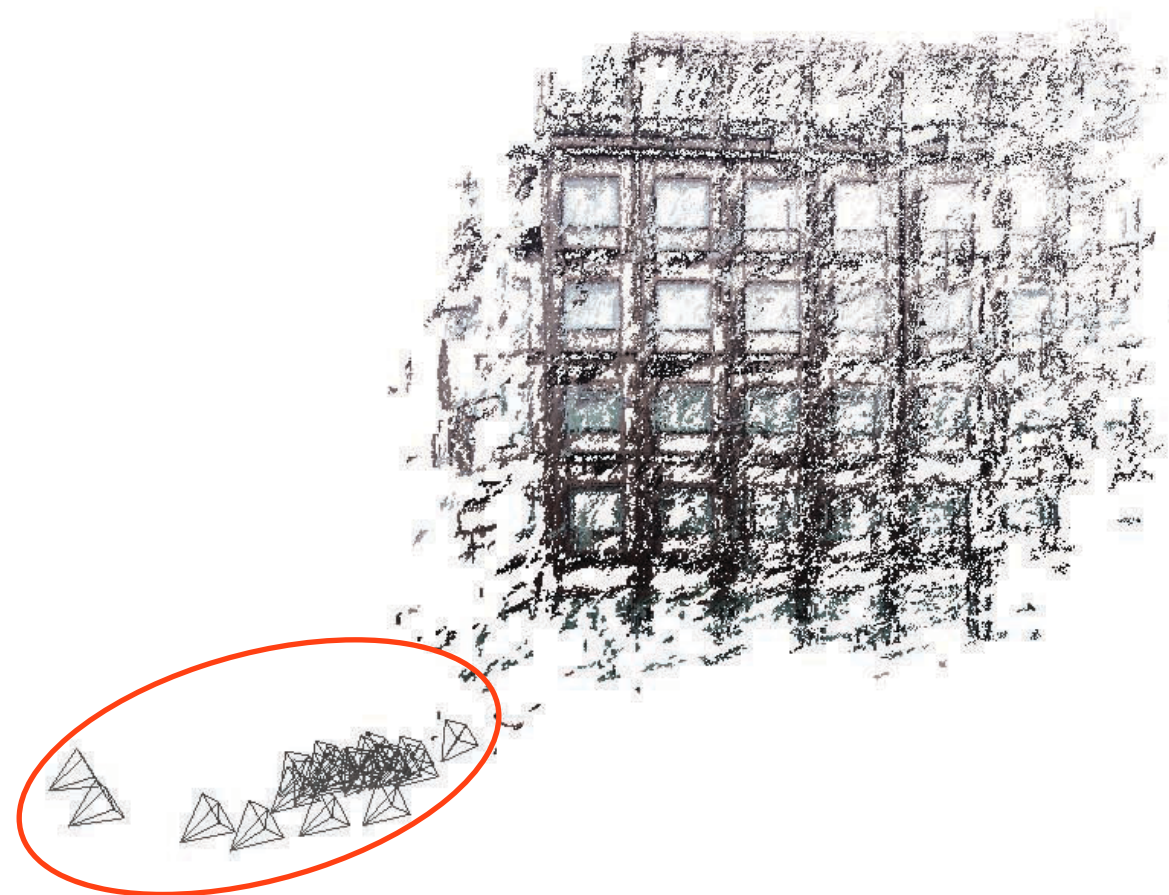
Symmetry-aware SFM + PMVS



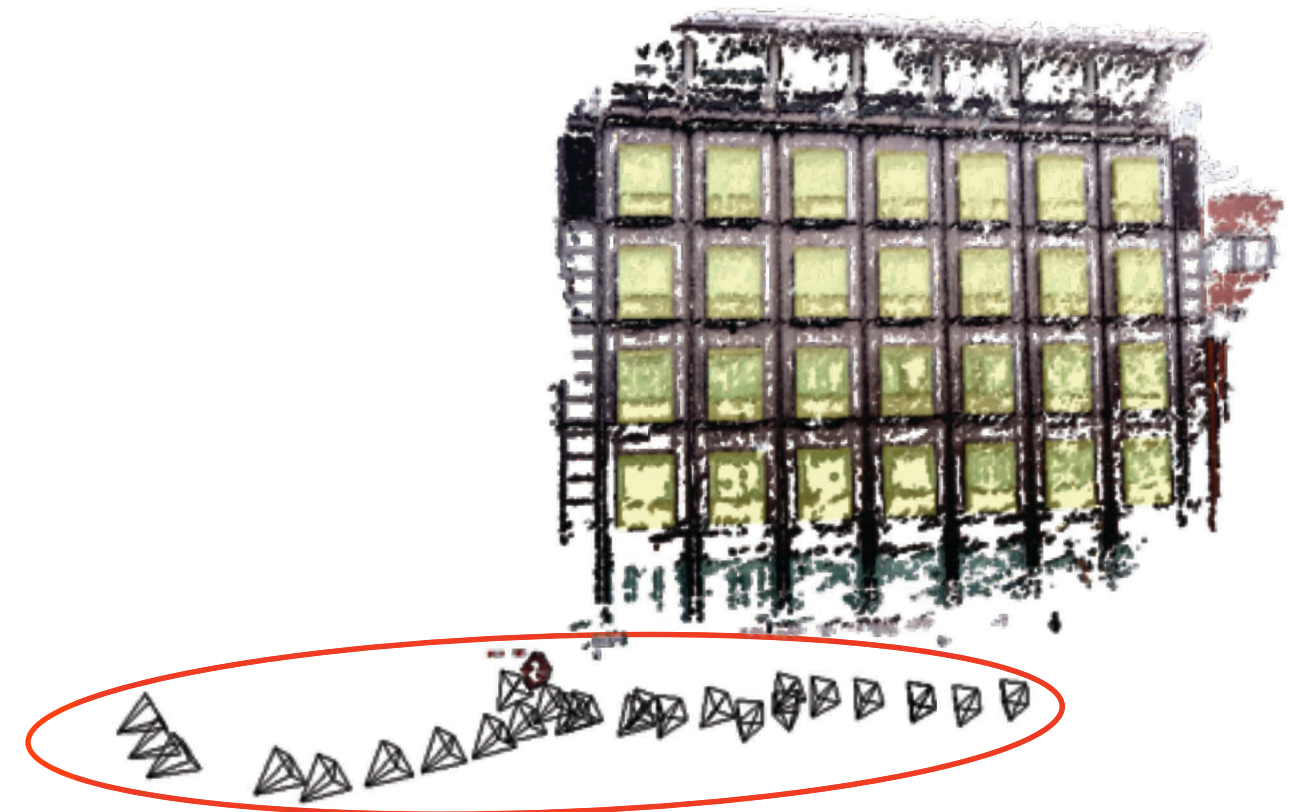
# Results



input images



Bundler + PMVS



Symmetry-aware SFM + PMVS

# Comparisons



...

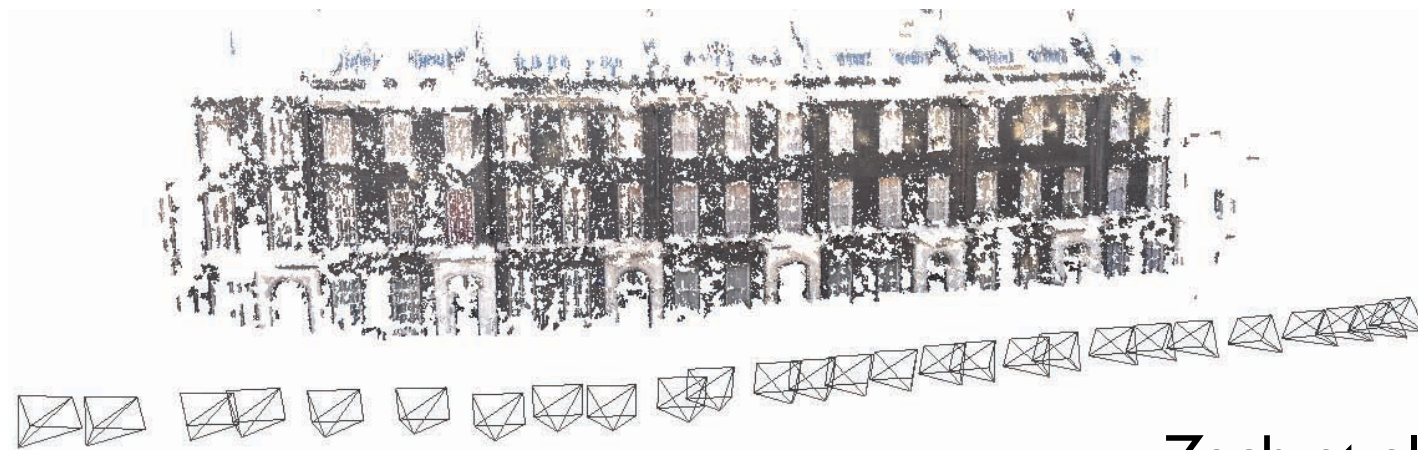
input images



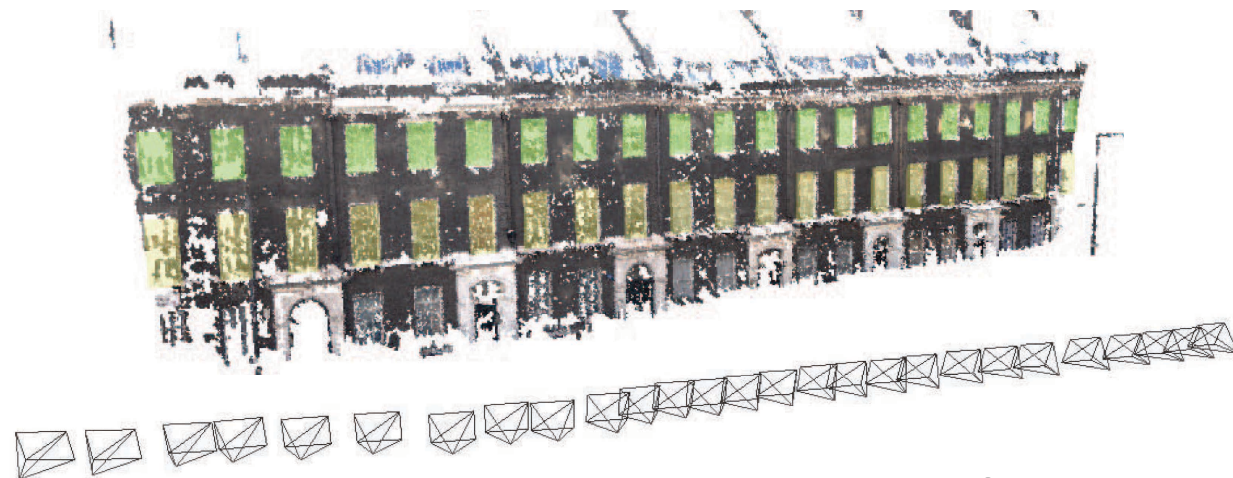
# Comparisons



input images



Zach et al. '2010 + PMVS



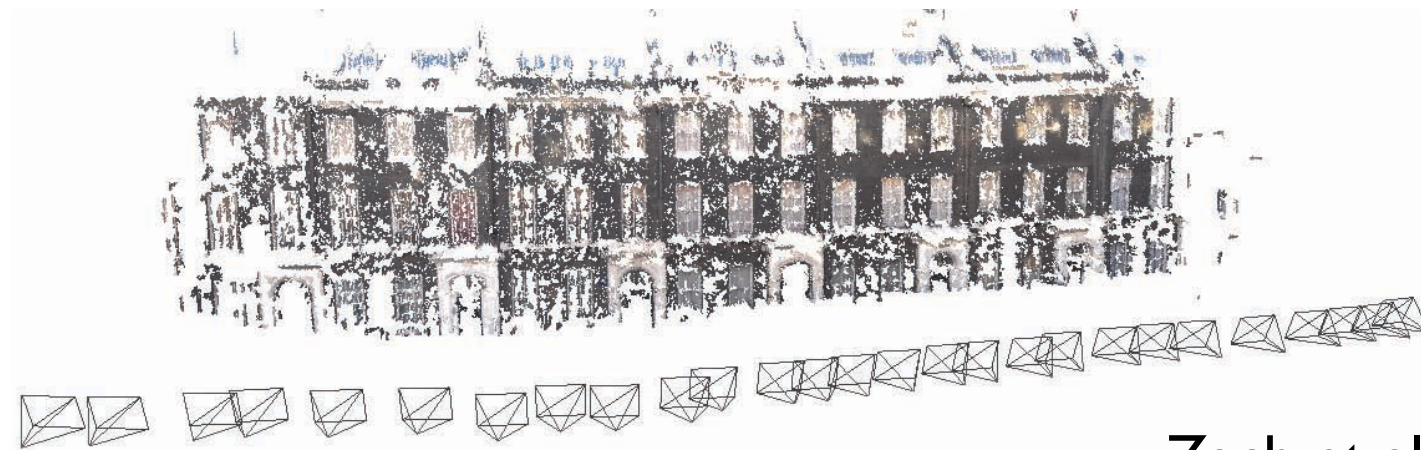
Symmetry-aware SFM + PMVS



# Comparisons



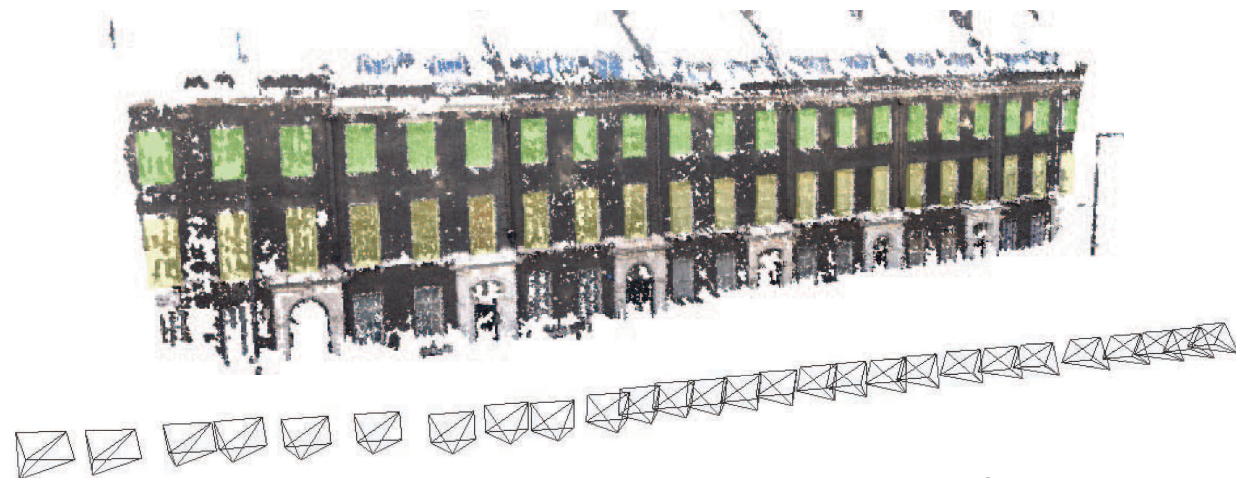
input images



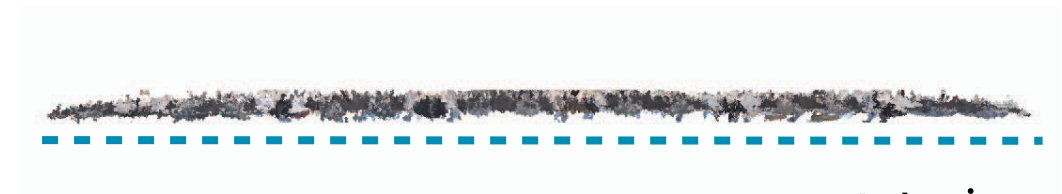
Zach et al. '2010 + PMVS



*top view*

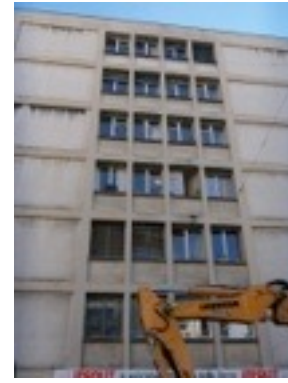
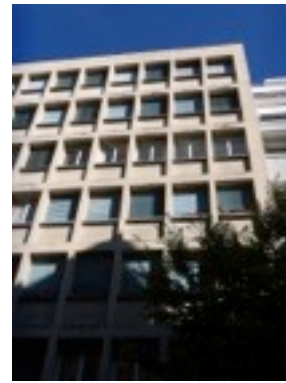


Symmetry-aware SFM + PMVS



*top view*

# Comparisons

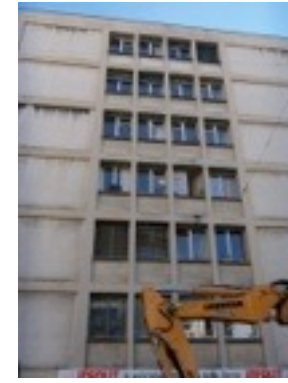
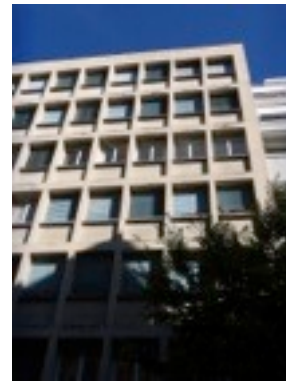
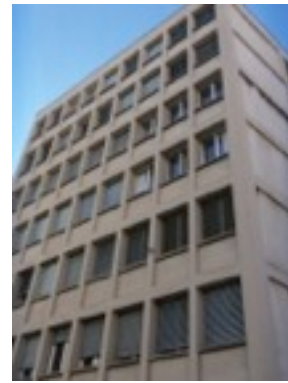


...

input images

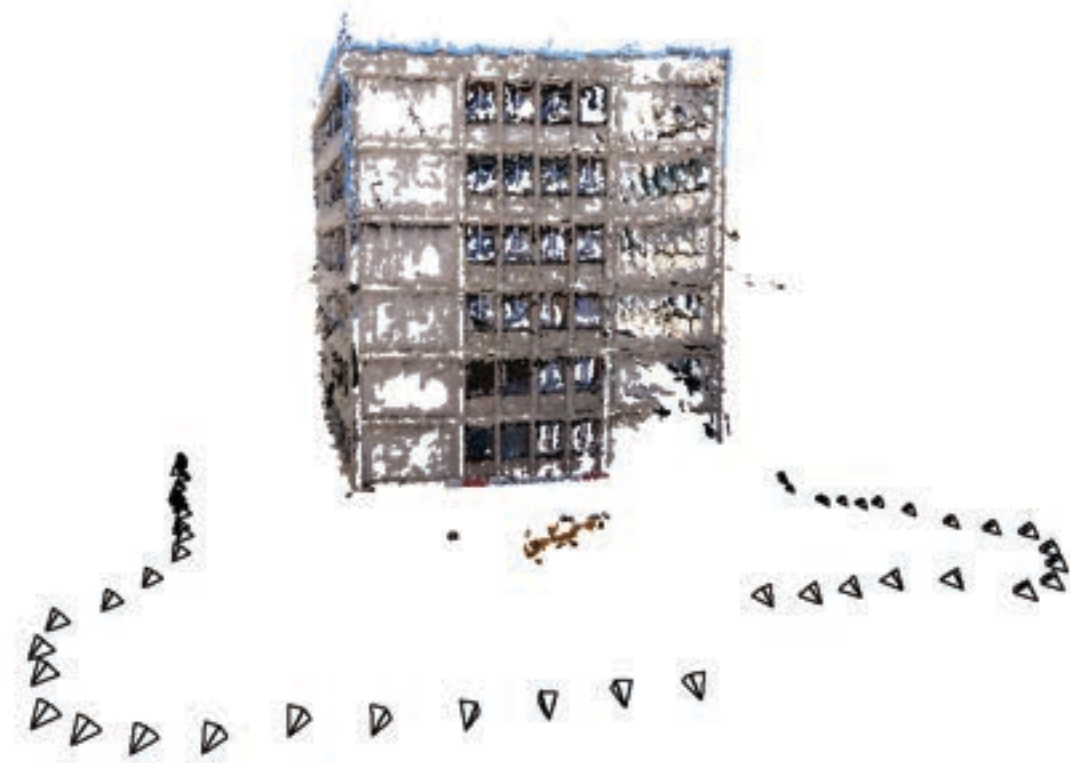


# Comparisons

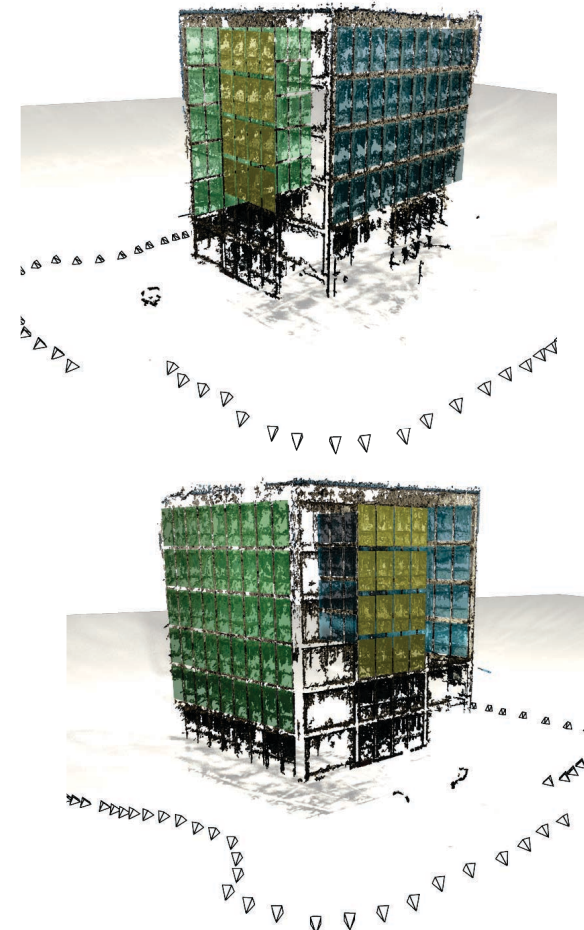


...

input images

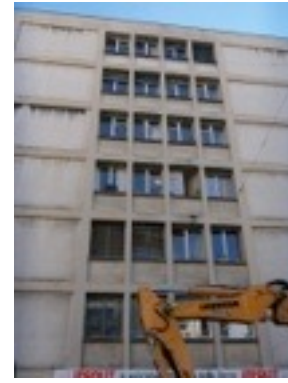
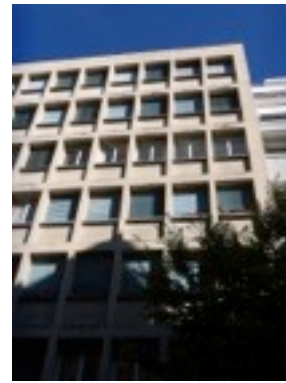


Jiang et al.'2012 + PMVS



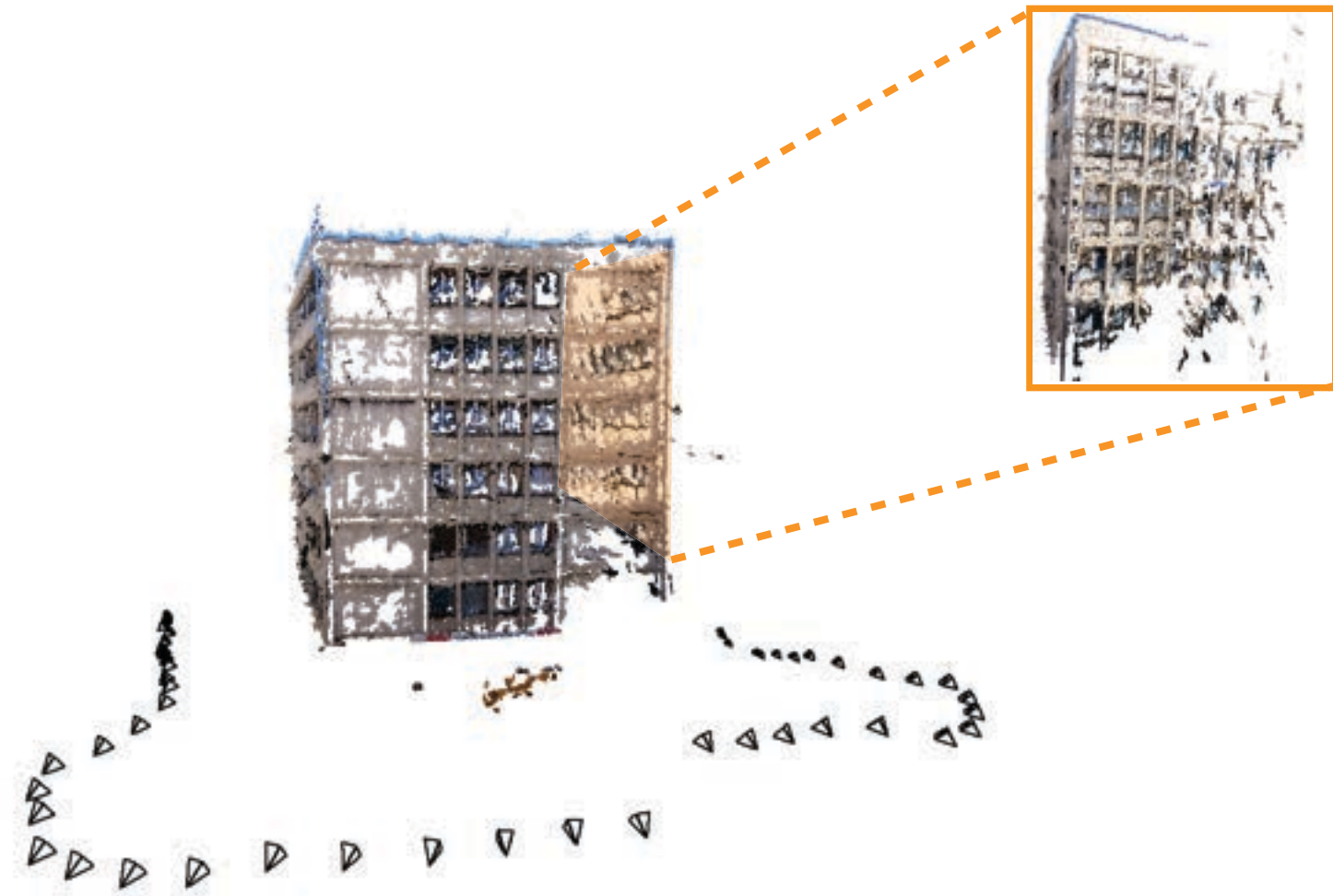
Symmetry-aware SFM + PMVS

# Comparisons

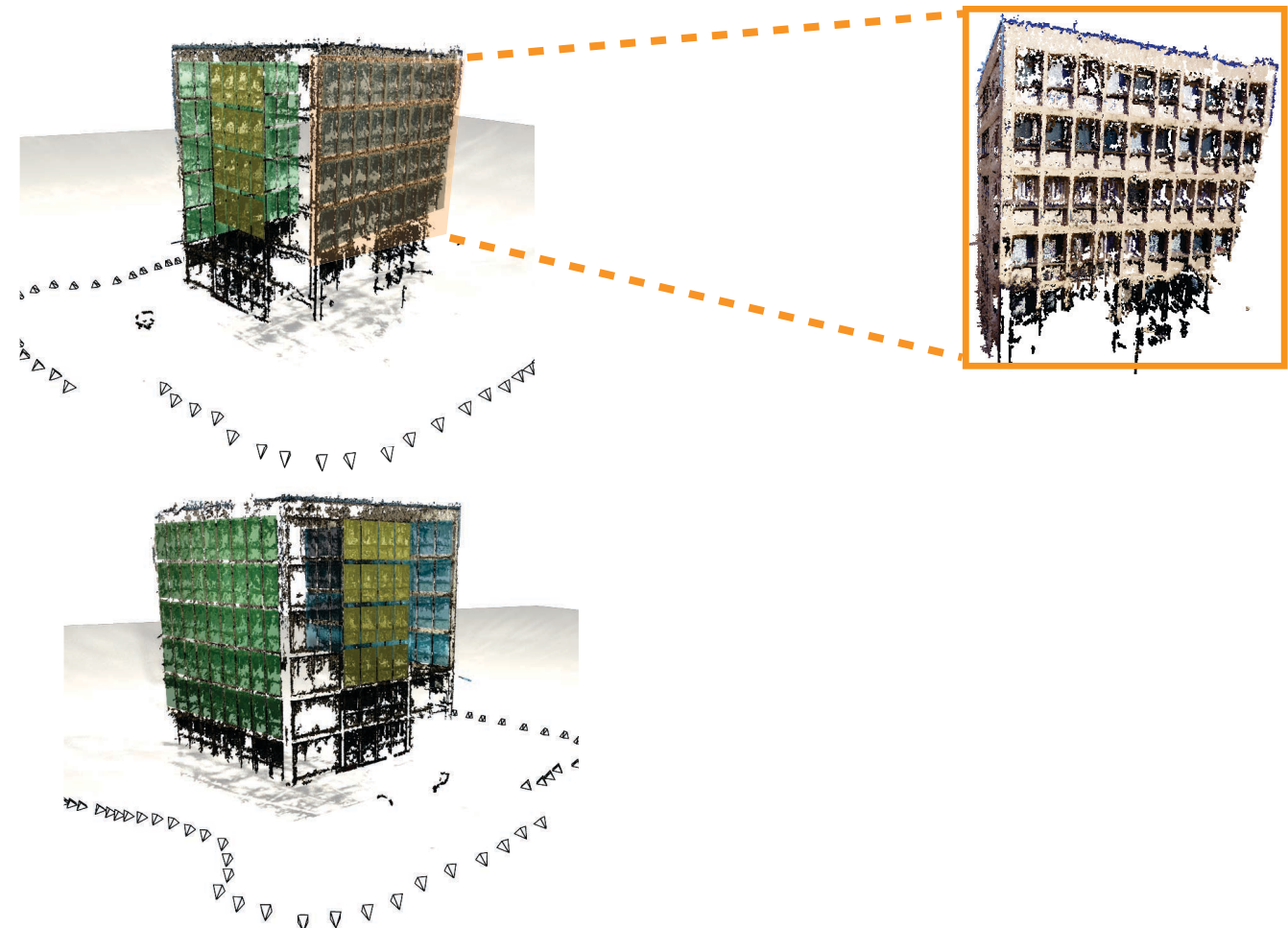


...

input images



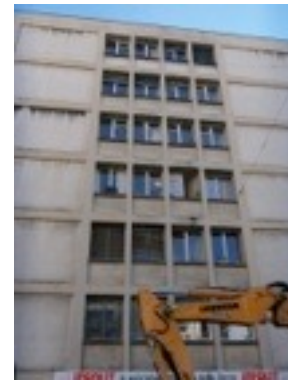
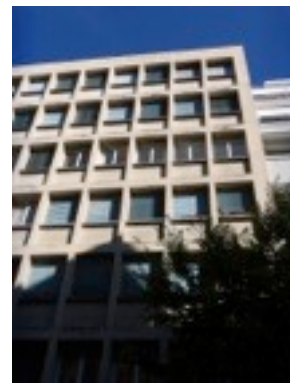
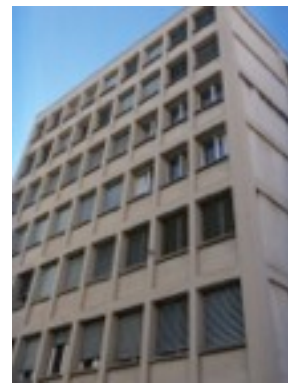
Jiang et al.'2012 + PMVS



Symmetry-aware SFM + PMVS

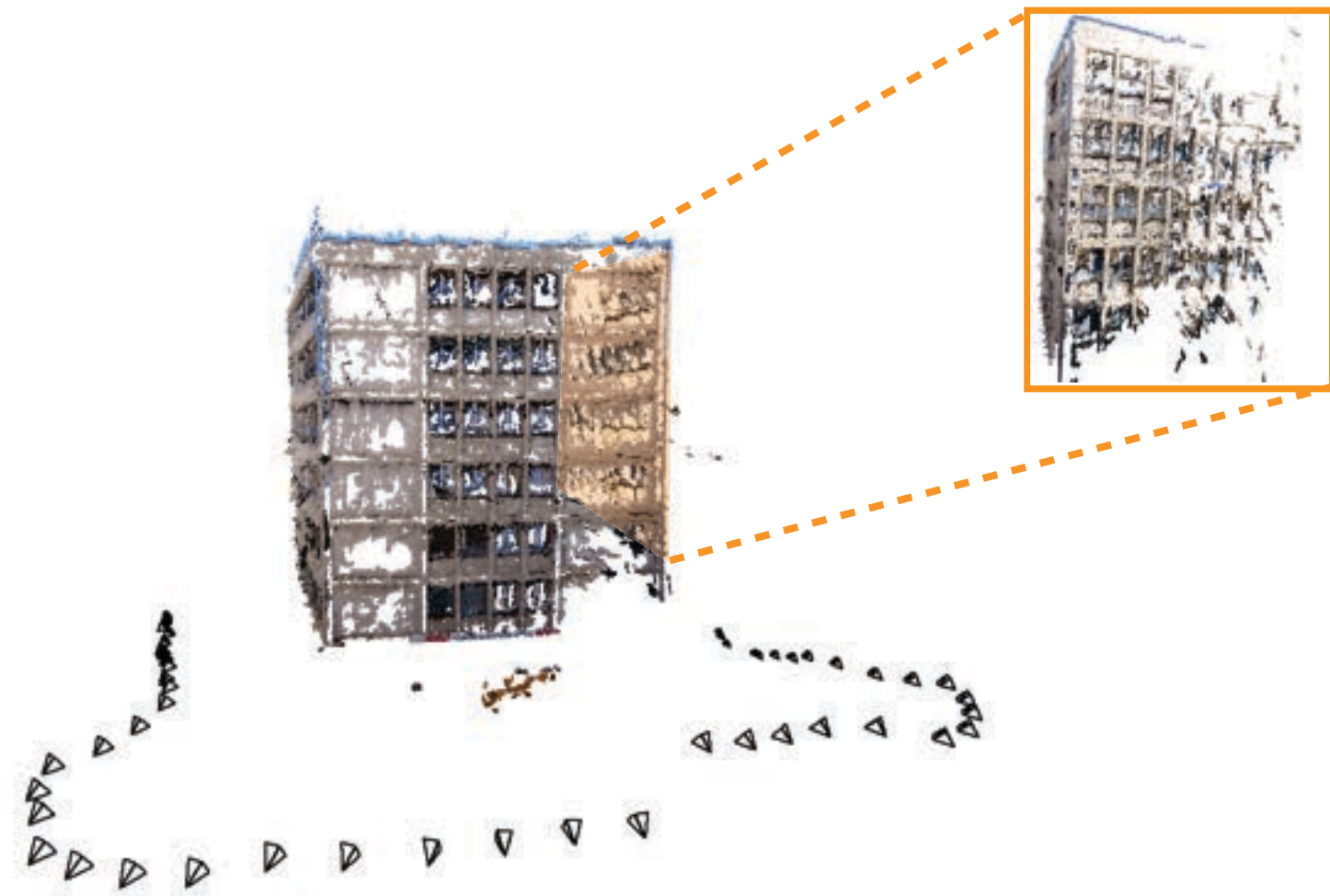


# Comparisons

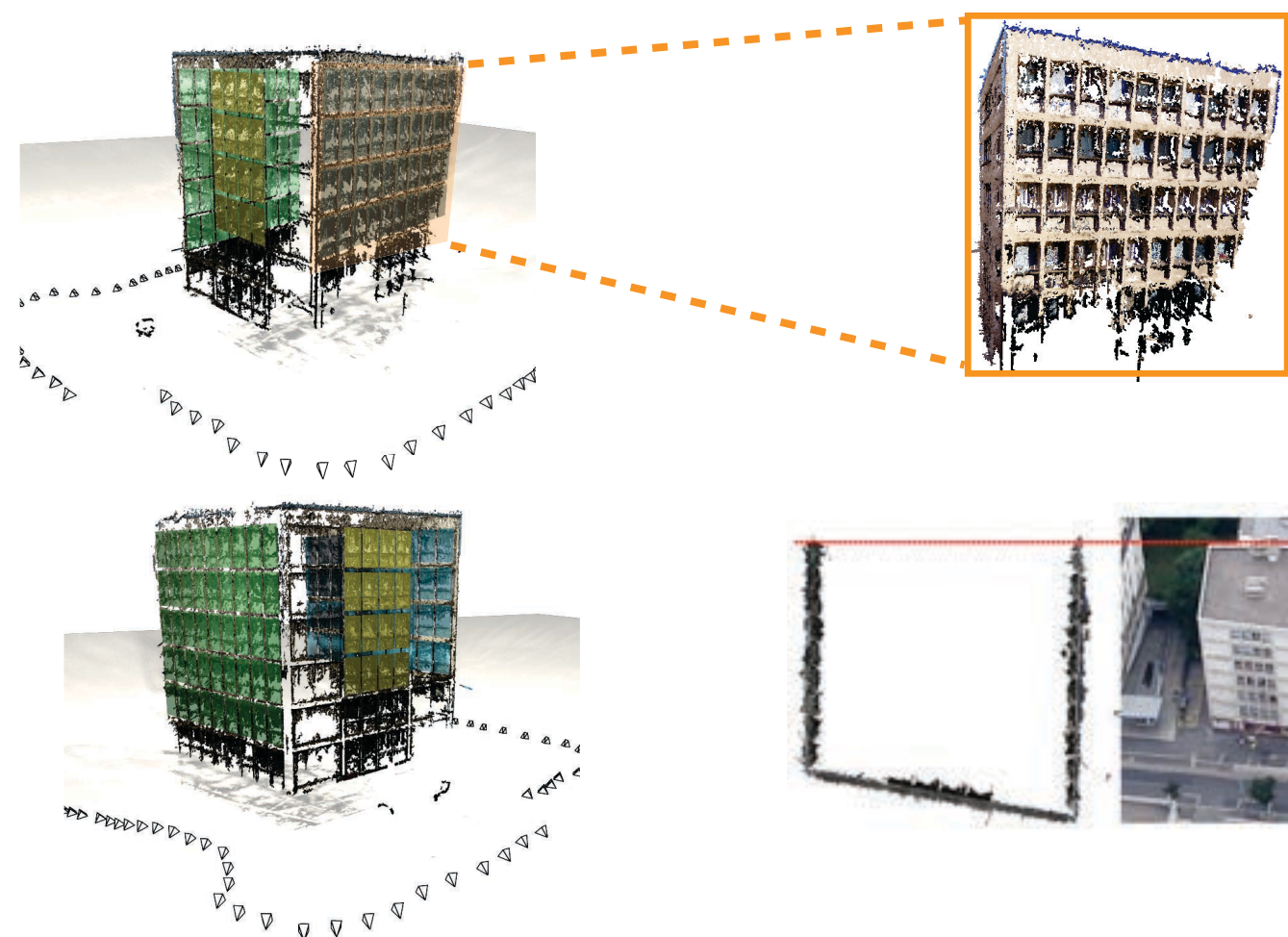


...

input images



Jiang et al.'2012 + PMVS



top view

Symmetry-aware SFM + PMVS



# Applications: Image Editing

image 1



image 2



original images  
(7-by-4 grid)

edit-1  
(9-by-5 grid)

edit-2  
(5-by-3 grid)

# Applications: Occlusion Removal



image 1



image 2



image 3





# Summary



...



input images

# Summary



...



input images



...



partial 2D grids



# Summary



...



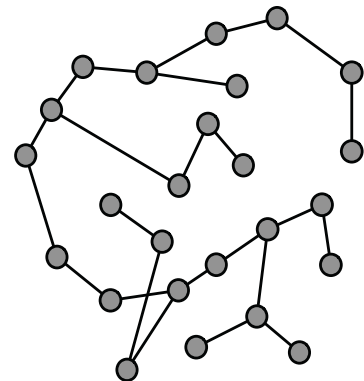
input images



...



partial 2D grids



global optimization

# Summary



...



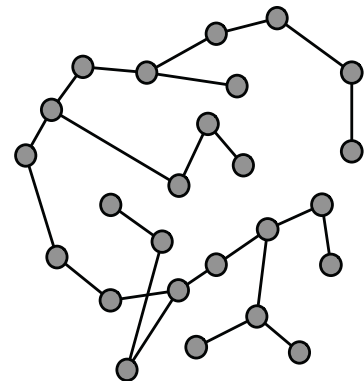
input images



...



partial 2D grids



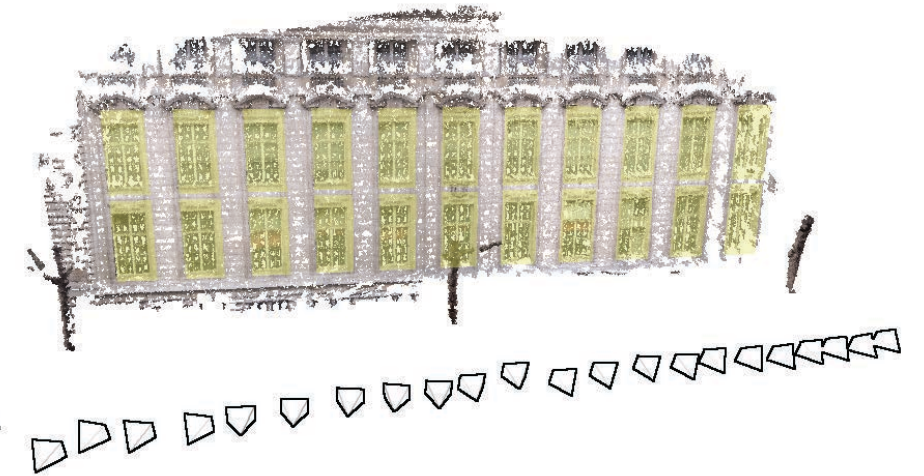
global optimization



...



complete 2D symmetry information



camera parameters + 3D symmetry information





# Limitations & Future Work



insufficient discriminating features

# Limitations & Future Work



insufficient discriminating features



our method



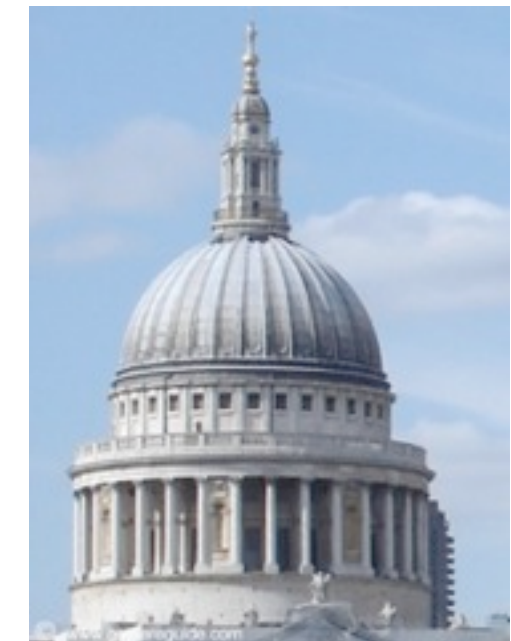
Bundler



# Limitations & Future Work



insufficient discriminating features



irregular/rotational symmetries



our method



Bundler

# Acknowledgements

Noah Snavely

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Nianjuan Jiang

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Sawsan AlHalawani

Qixing Huang

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Visionair Project Grant

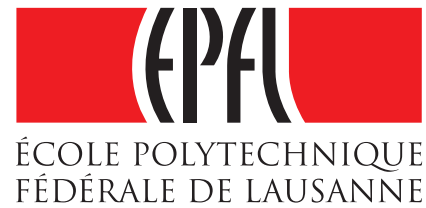
Marie Curie CIG

UCL Impact Award



# Coupled Structure-from-Motion and Symmetry Detection for Urban Facades

Duygu Ceylan



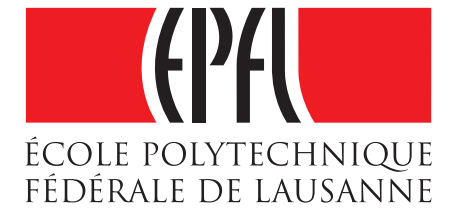
Niloy J. Mitra



Youyi Zheng



Mark Pauly



<http://www.duygu-ceylan.com/duygu-ceylan/symmCalib.html>

