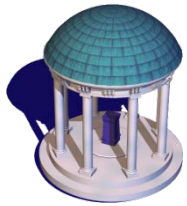
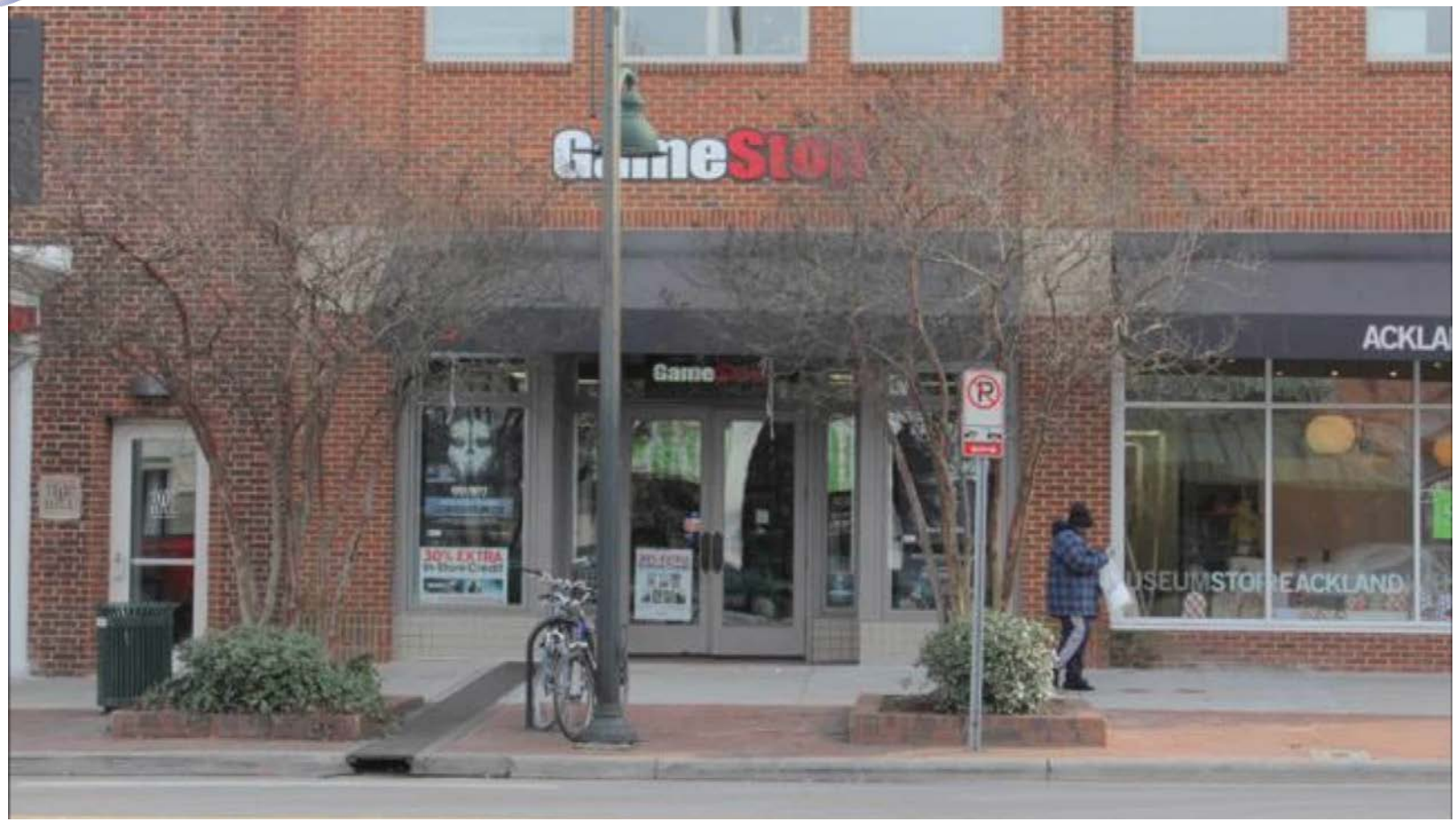


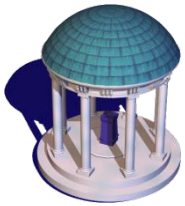
Joint Object Class Sequencing and Trajectory Triangulation (JOST)

Enliang Zheng, Ke Wang, Enrique Dunn, Jan-Michael Frahm

The University of North Carolina at Chapel Hill

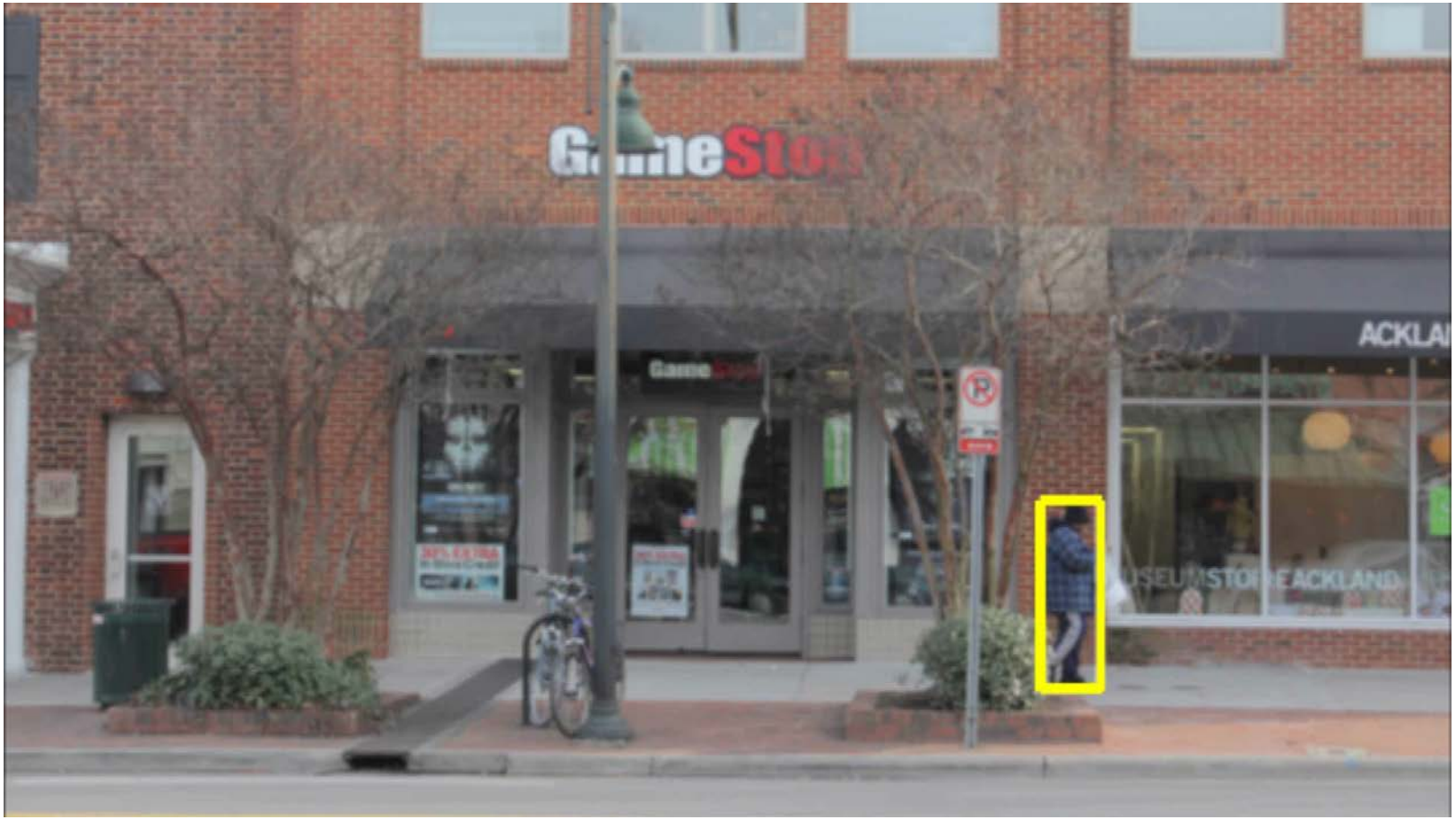
Unordered Images

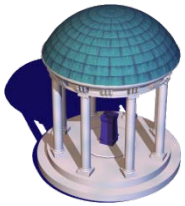




Static 3D Model

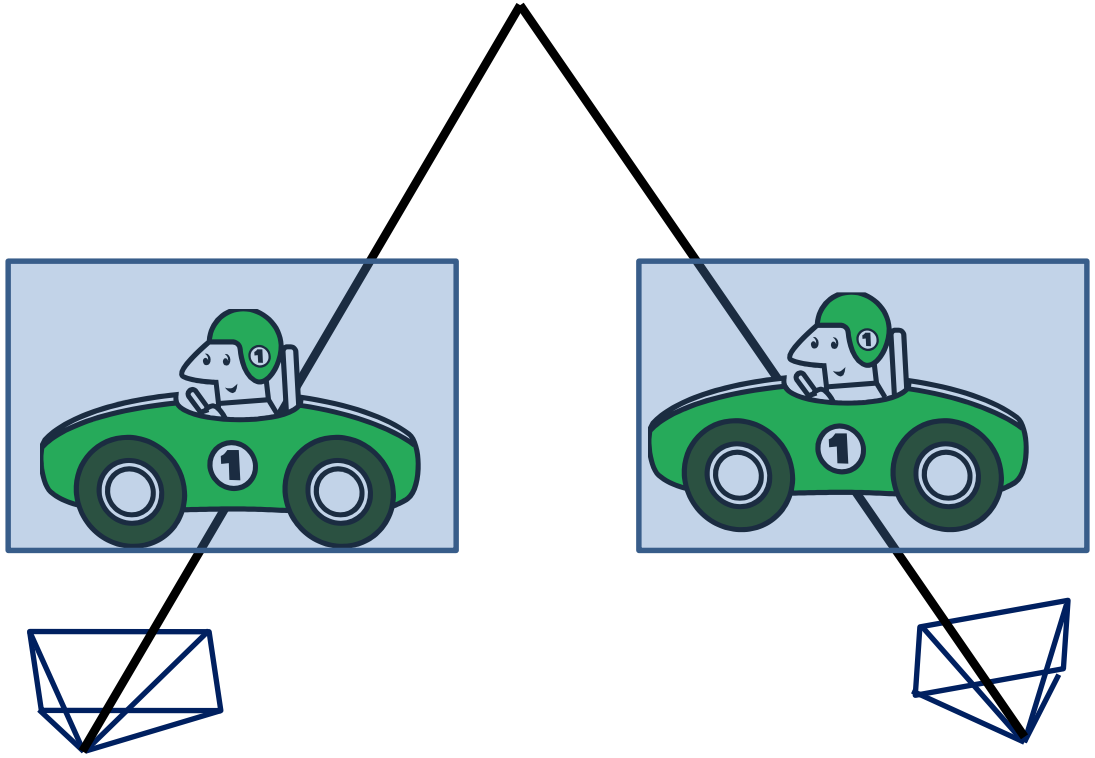
Dynamic Objects

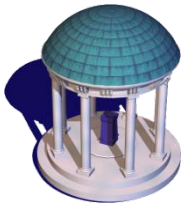




Goal

Reconstruct the 3D positions of the dynamic objects

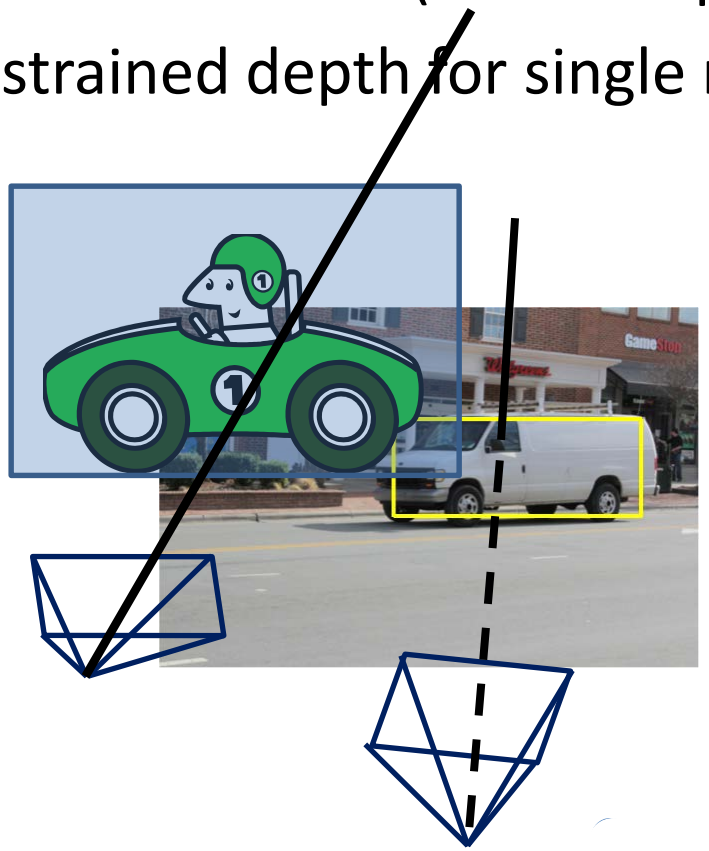


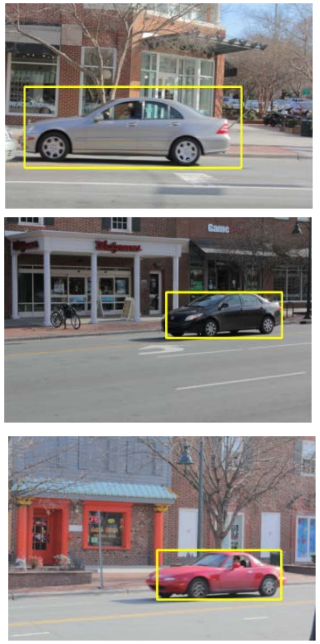


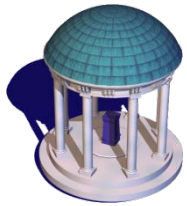
Goal

Reconstruct the 3D positions of the dynamic objects

- Challenges:
  - Single measurement (no correspondences)
  - Unconstrained depth for single measurement

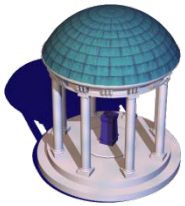






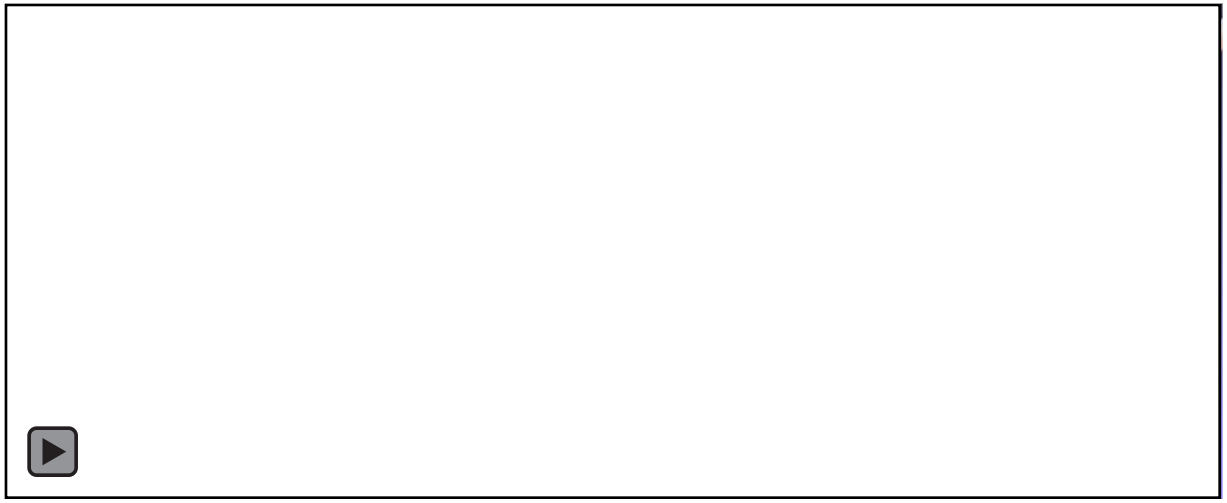
Insight

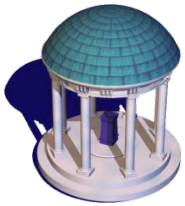
- Objects of the same class move in a common trajectory



Insight

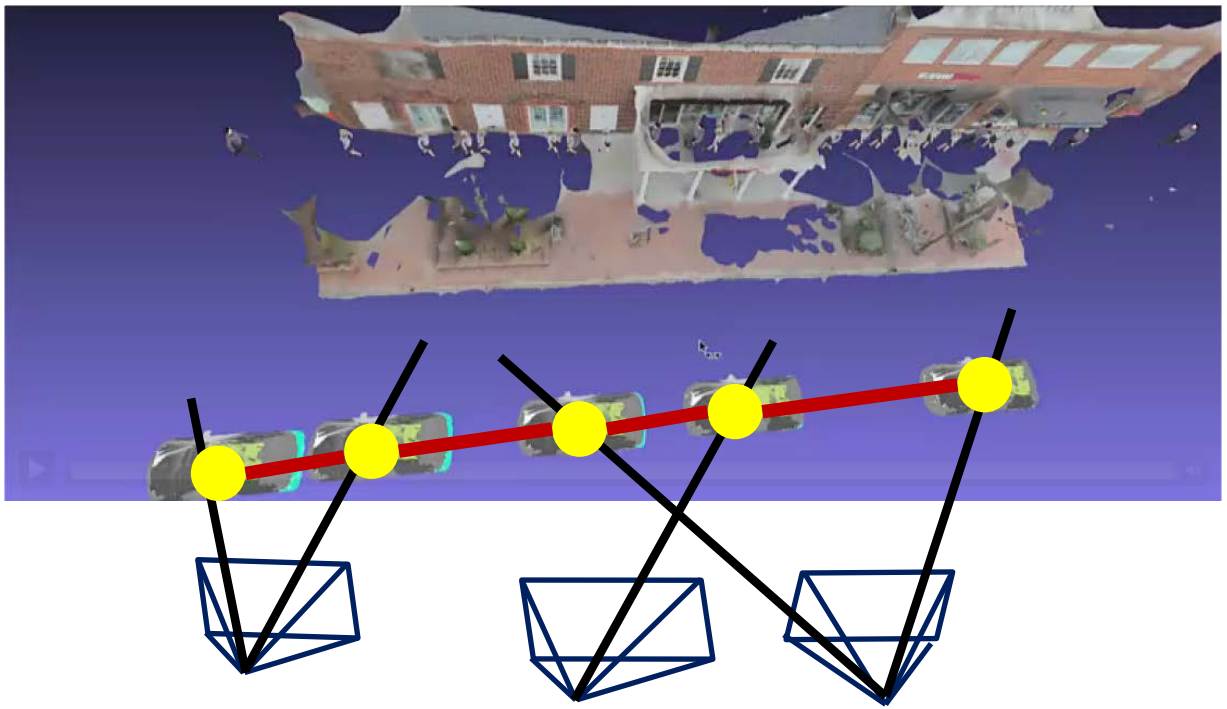
- Objects of the same class move in a common trajectory
- Trajectory: Pairwise connections of 3D positions

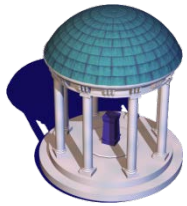




Insight

- Objects of the same class move in a common trajectory
- Trajectory: Pairwise connections of 3D positions
- Union of the observations reveals trajectory





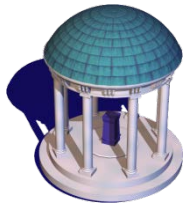
Approach

Can we use trajectory triangulation? [Park et al. ECCV 2010, Valmadre CVPR 2012]

No, there is no sequencing information

Can we use image sequencing methods? [Basha et al. ECCV 2012, ICCV 2013]

No, there are no correspondences



Approach

Can we use trajectory triangulation? [Park et al. EC

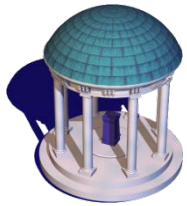
M *ation*

Can w s?

[Bash

No, there are no correspondences

Our solution:
Joint Object class Sequencing and trajectory Triangulation (JOST)

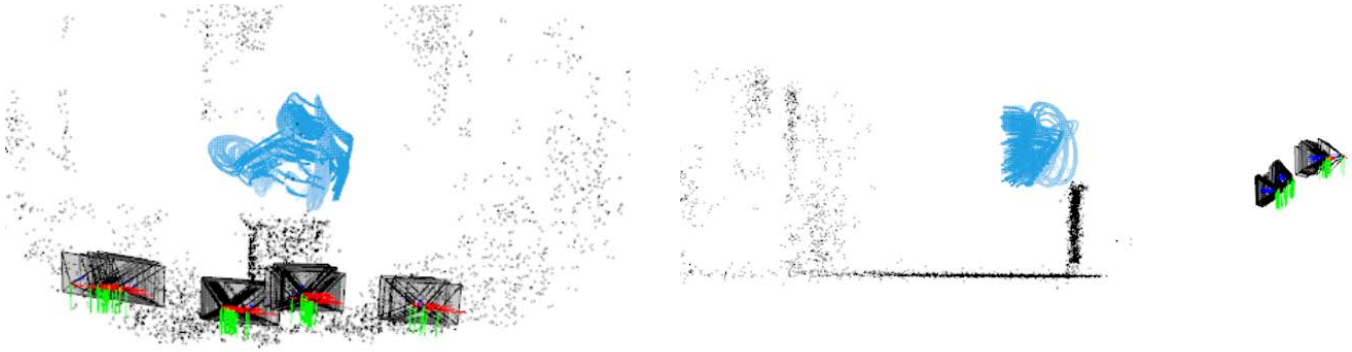


Overview

- JOST
- Related work
- JOST solver
- Results

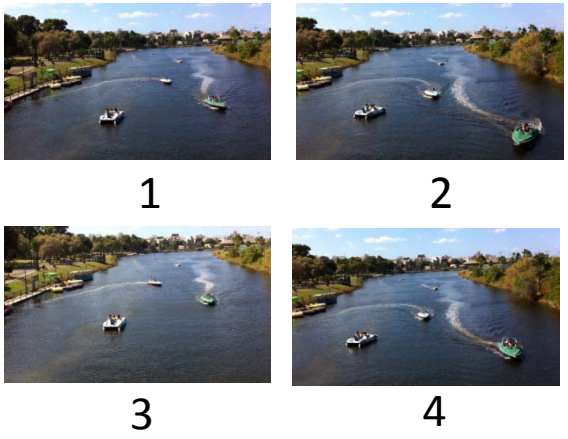
Related Work

- Trajectory triangulation given 2D points



Figures from Park et al.

- Photo sequencing: find the temporal order of images

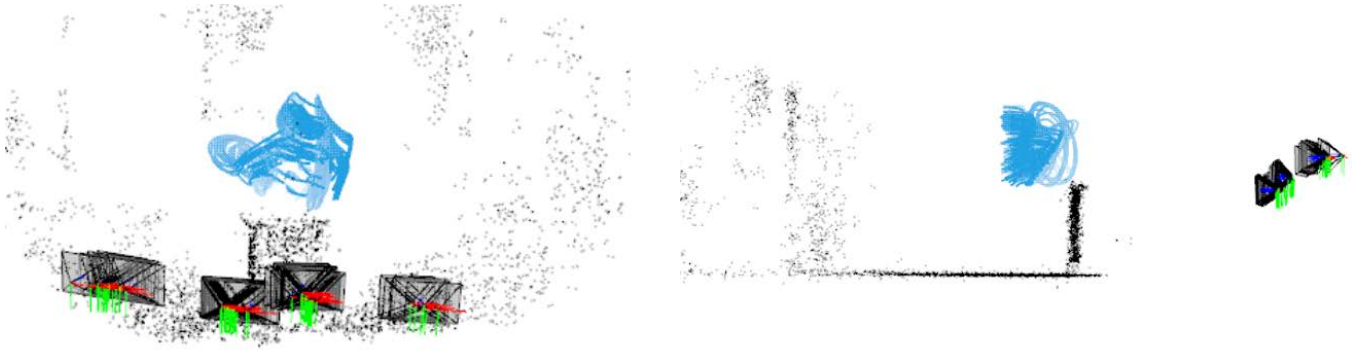


Order the images

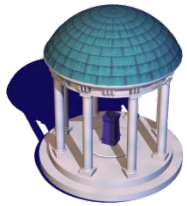
Figures from Basha et al.

Related Work

- Trajectory triangulation given temporal information
  - Park et al., ECCV 2010
    - Use K Discrete Cosine Transform (DCT) bases to approximately represent the trajectory



Figures from Park et al

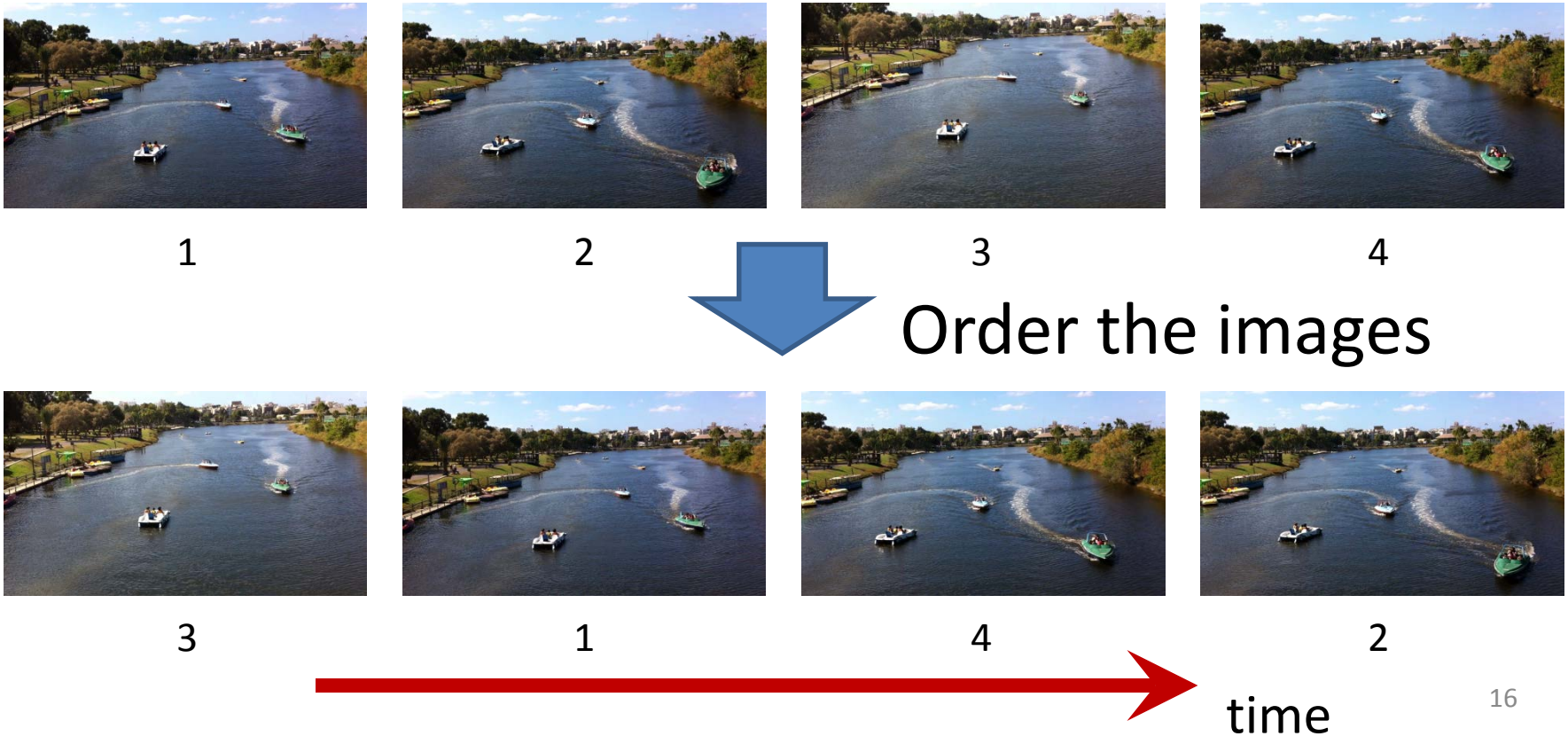


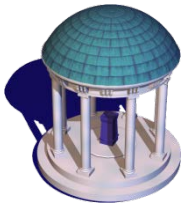
Related Work

- Trajectory triangulation given temporal information
  - Park et al., ECCV 2010
    - Use K Discrete Cosine Transform (DCT) bases to approximately represent the trajectory
  - Valmadre et al., CVPR2012
    - Minimize the trajectory's response to the high-pass filter
    - Advantage: eliminate the need to tune DCT bases size K

Related Work

- Photo sequencing: find the temporal order of images
  - Basha et al.
    - Two images taken from the same static camera (ECCV'12)
    - Temporal order of images in one camera is available (ICCV'13)

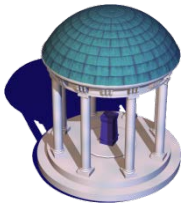




Input

Input images

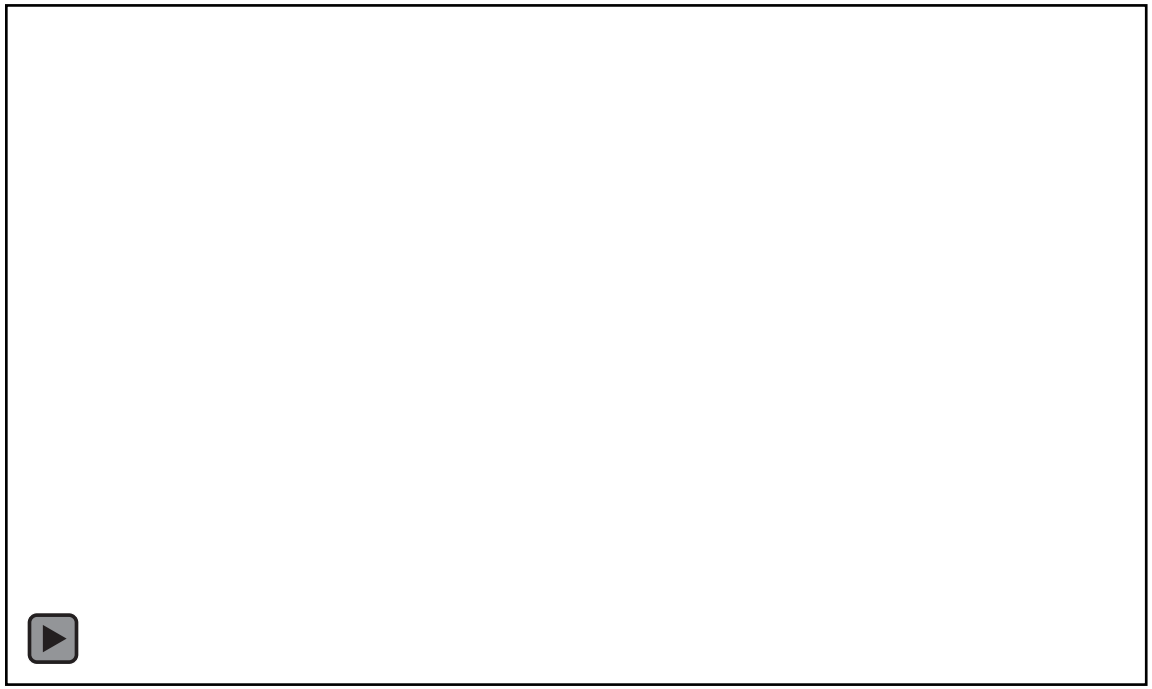
unordered images

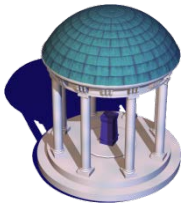


Structure from Motion

Input images

Structure From Motion

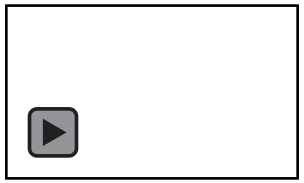




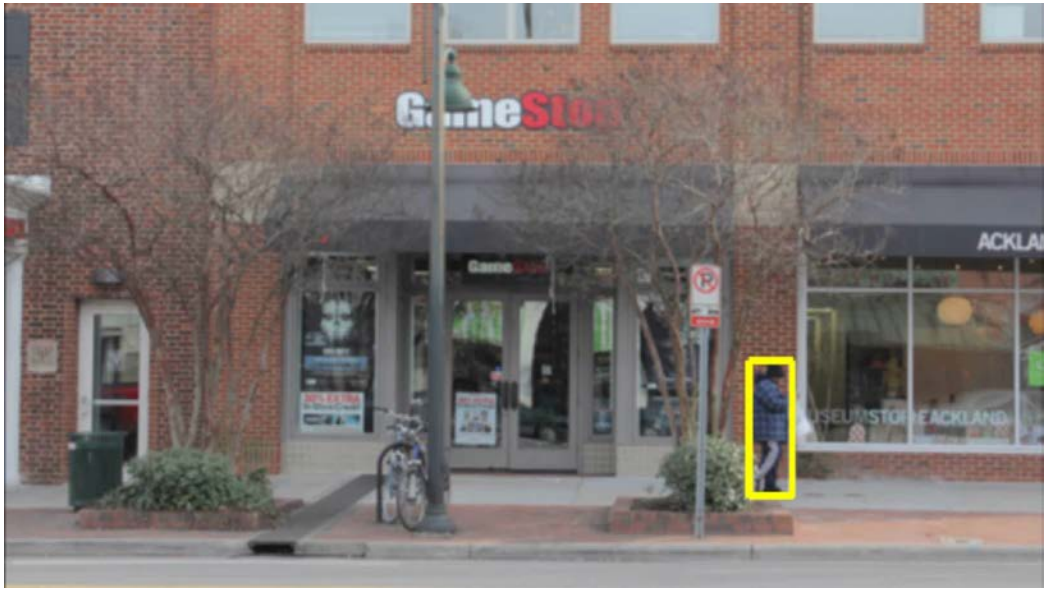
Object detection

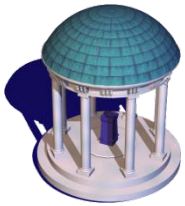
Input images

Structure From Motion



Object detection

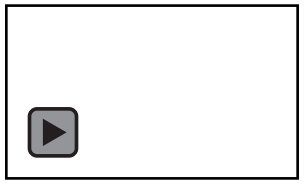




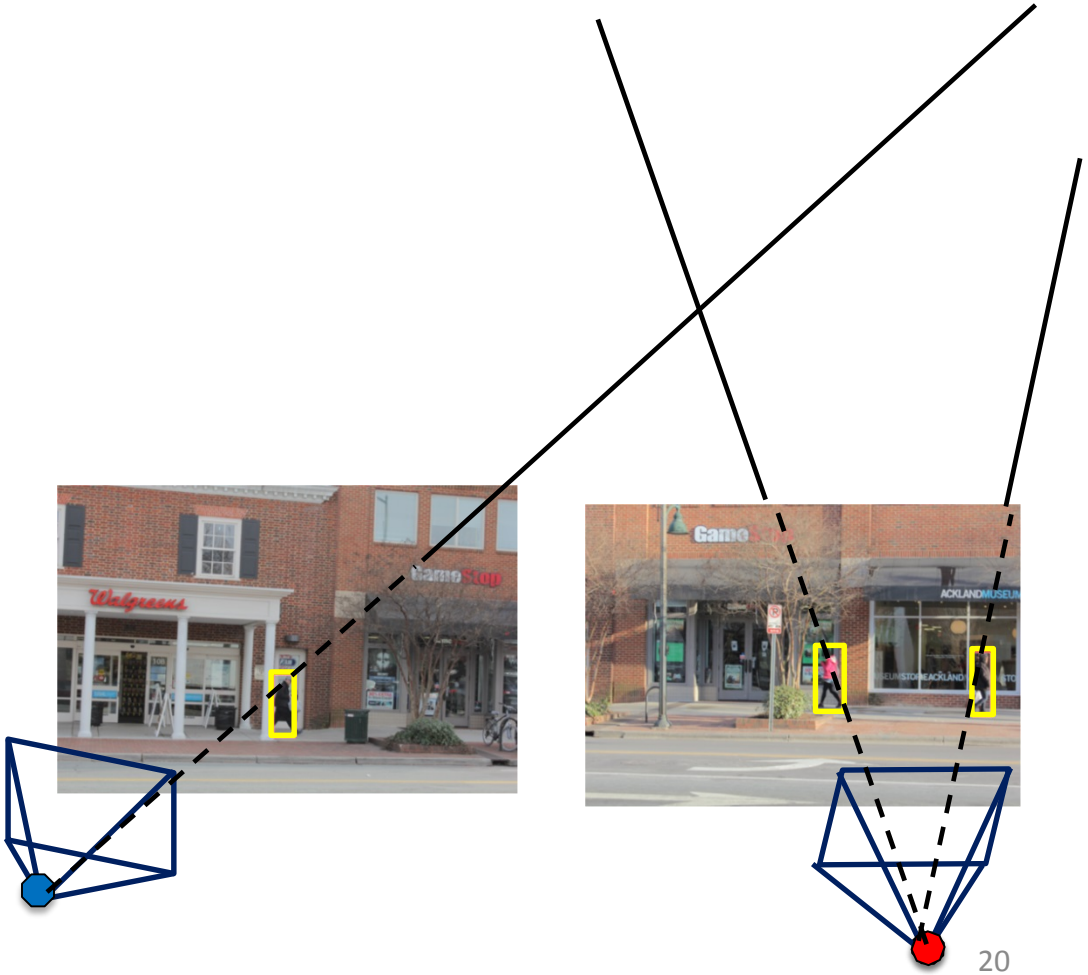
Viewing Ray Geometry

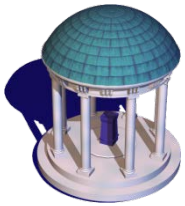
Input images

Structure From Motion



Object detection

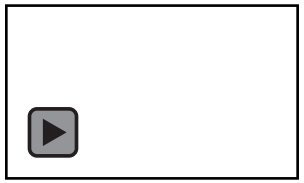




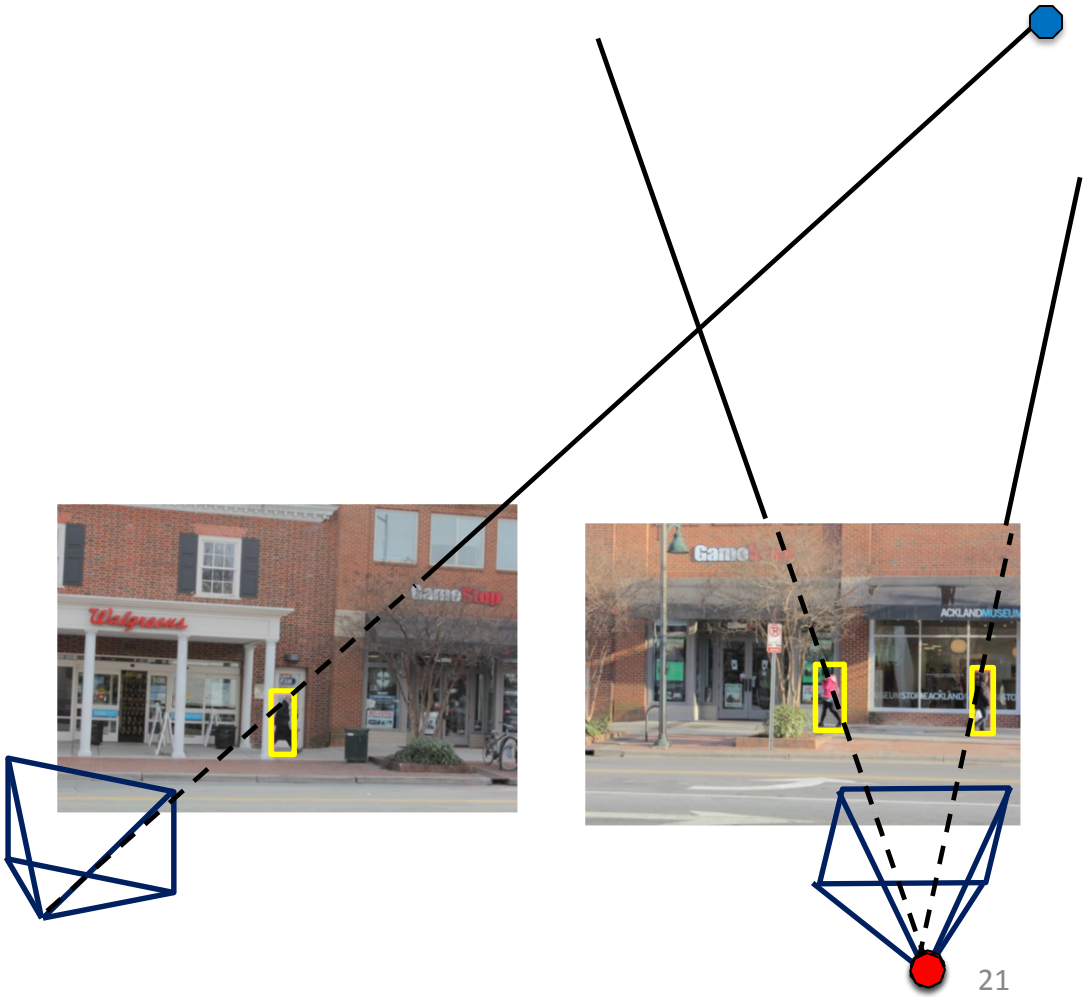
Viewing Ray Geometry

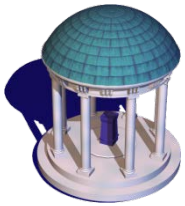
Input images

Structure From Motion



Object detection

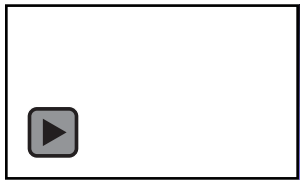




JOST Model Optimization

Input images

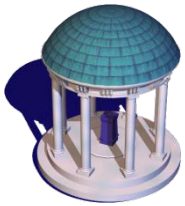
Structure From Motion



Object detection

JOST model optimization

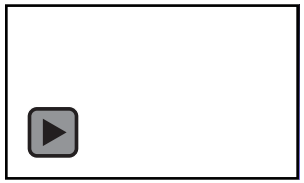
- Discrete Optimization
- Continuous Optimization



Output

Input images

Structure From Motion

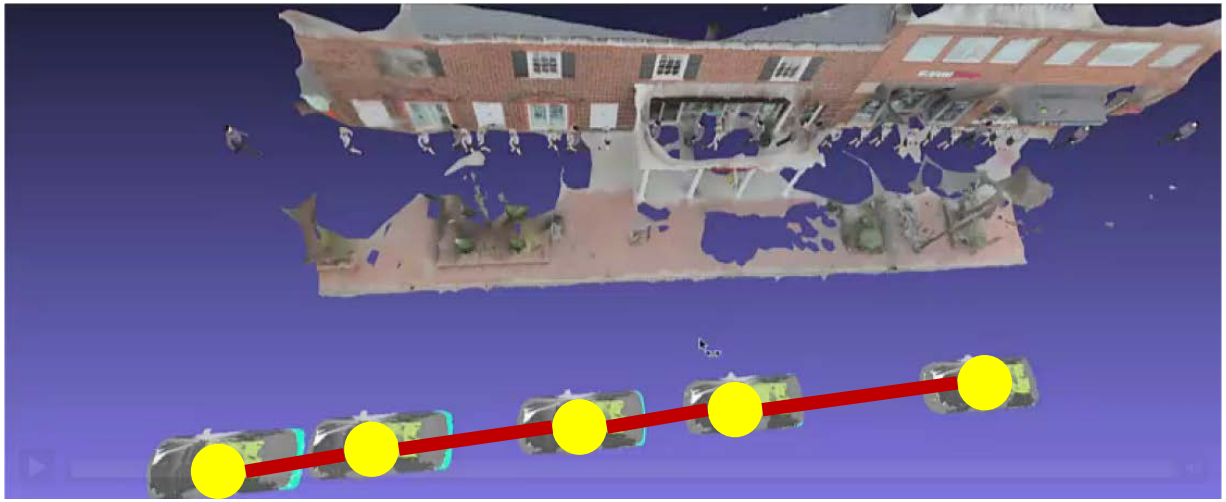


Object detection

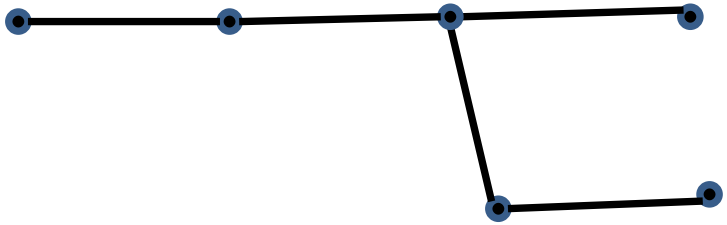
JOST model optimization

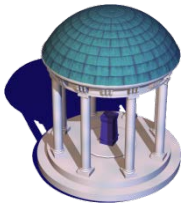
- Discrete Optimization
- Continuous Optimization

Trajectory Topology & Geometry



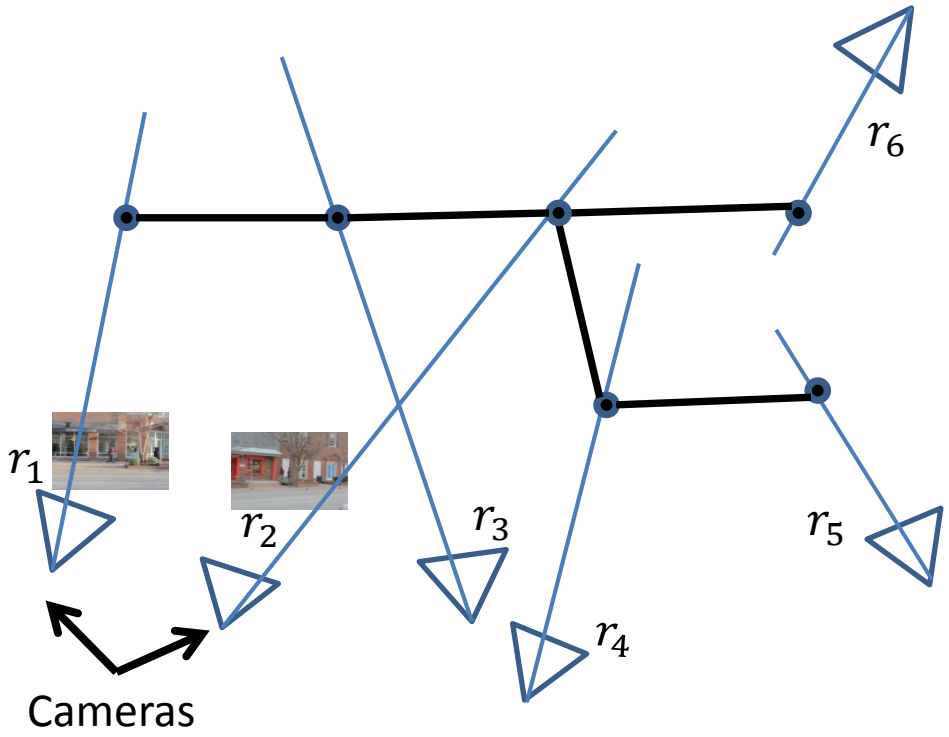
- Tree structure trajectory

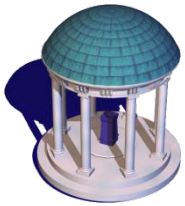




Sequencing

- Identify all pairwise viewing ray adjacencies (i.e. topology)

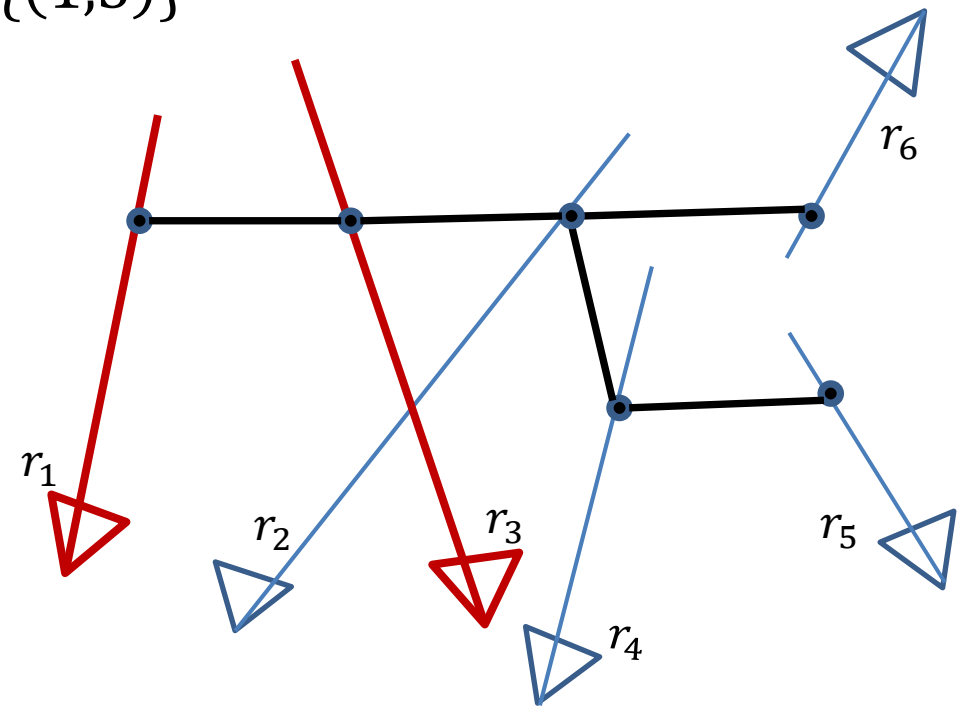


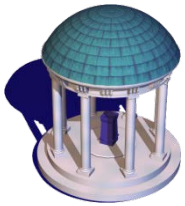


Sequencing

- Identify all pairwise viewing ray adjacencies (i.e. topology)

$P = \{(1,3)\}$

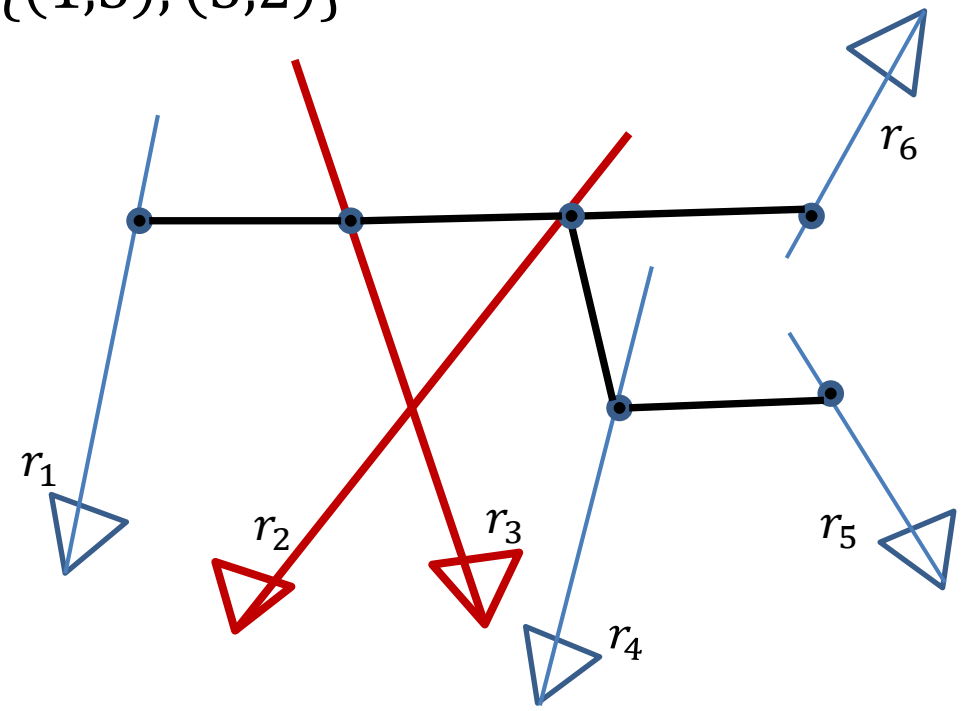


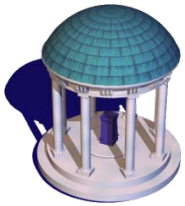


Sequencing

- Identify all pairwise viewing ray adjacencies (i.e. topology)

$$P = \{(1,3), (3,2)\}$$

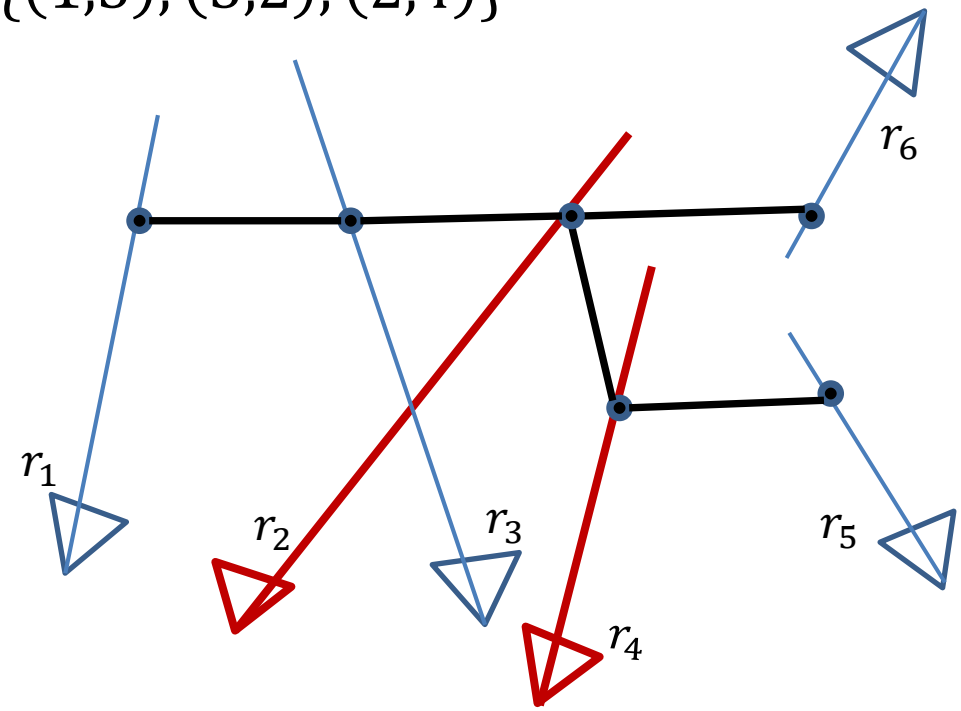


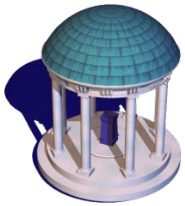


Sequencing

- Identify all pairwise viewing ray adjacencies (i.e. topology)

$$P = \{(1,3), (3,2), (2,4)\}$$

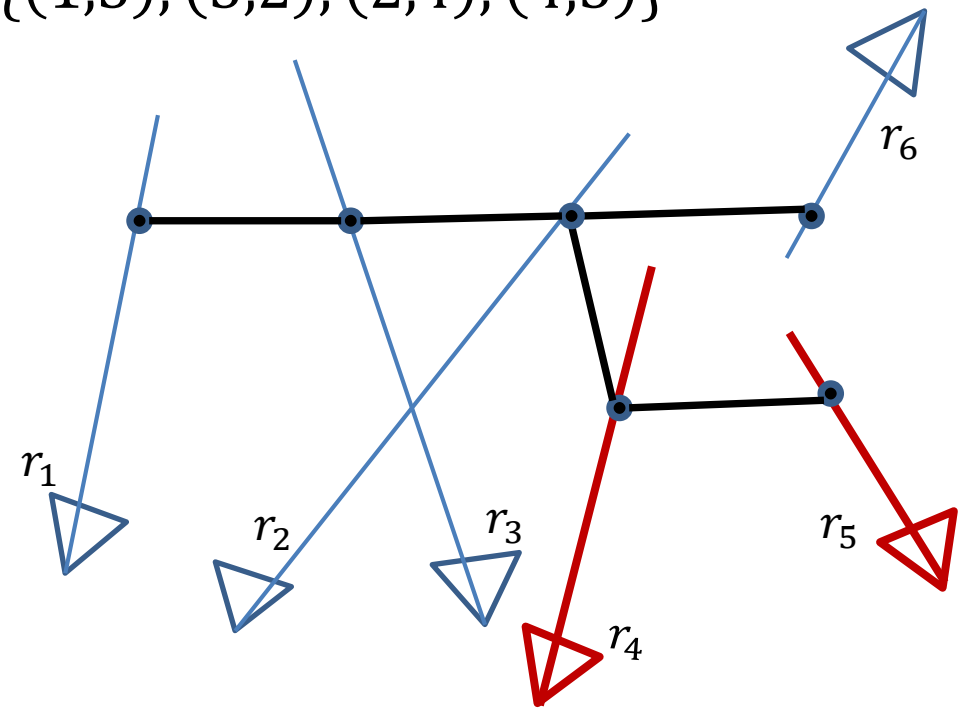


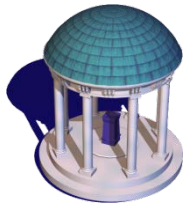


Sequencing

- Identify all pairwise viewing ray adjacencies (i.e. topology)

$$P = \{(1,3), (3,2), (2,4), (4,5)\}$$

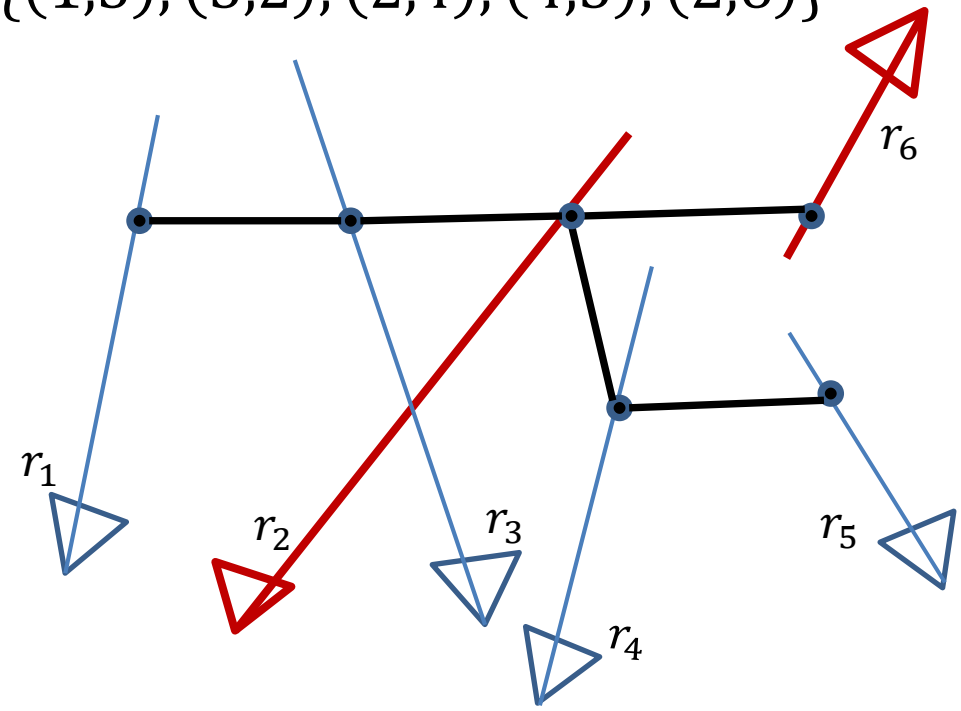


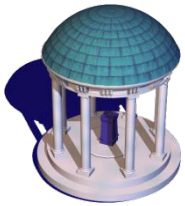


Sequencing

- Identify all pairwise viewing ray adjacencies (i.e. topology)

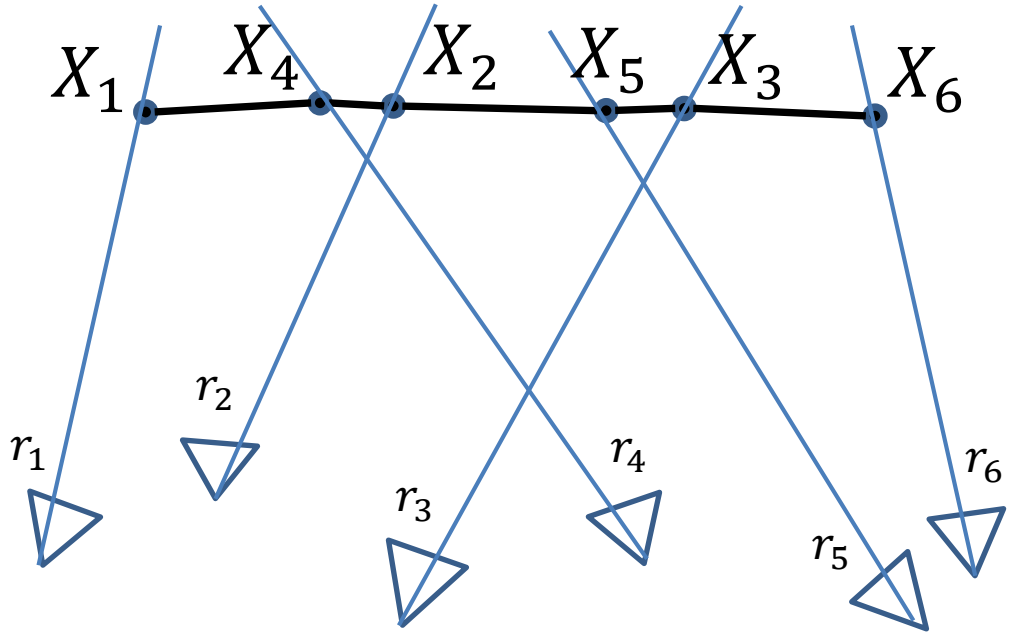
$$P = \{(1,3), (3,2), (2,4), (4,5), (2,6)\}$$





Trajectory(Chain-structured) Triangulation

- Trajectory triangulation by minimizing its response to the high pass filter (Valmadre et al. CVPR2012)

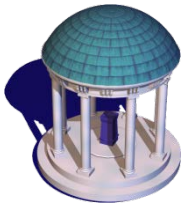


Chain structured trajectory

$$P = \{(1,4), (4,2), (2,5), (5,3), (3,6)\}$$

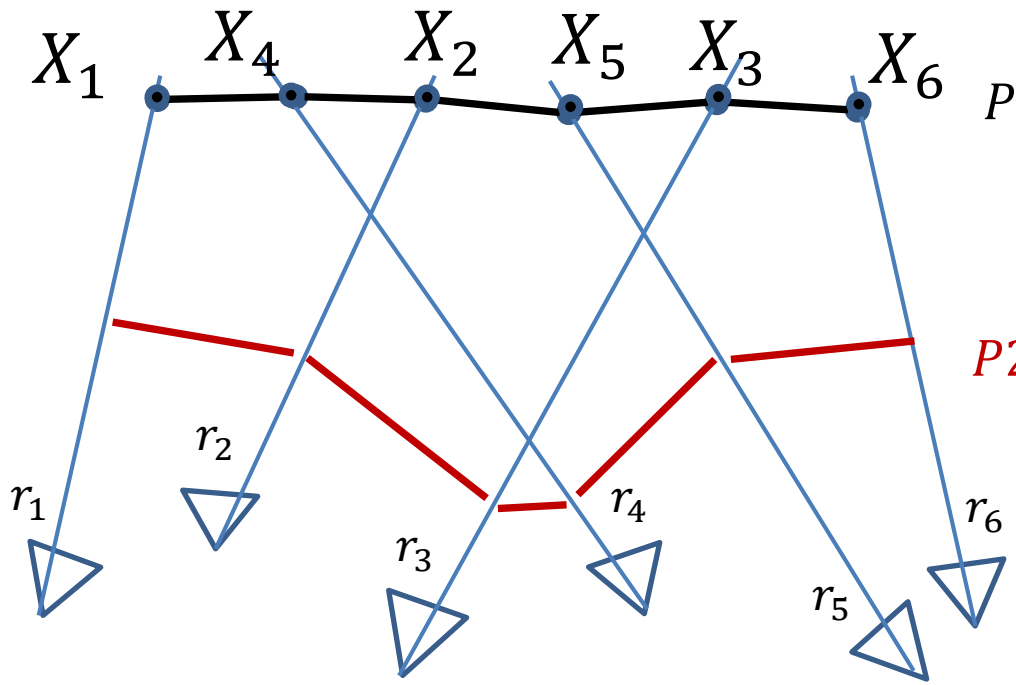
- If high pass filter is (-1, 1):

$$\min_{\{X_1, X_2 \ldots X_N\}} \sum_{(i,j)\in P} ||X_i - X_j||_2^2$$



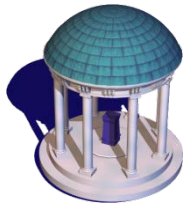
The Importance of Sequencing

$$\min_{\{X_1, X_2 \ldots X_N\}} \sum_{(i,j) \in P} ||X_i - X_j||_2^2$$



$P1 = \{(1,4), (4,2), (2,5), (5,3), (3,6)\}$

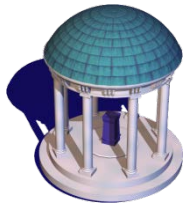
$P2 = \{(1,2), (2,3), (3,4), (4,5), (5,6)\}$



Trajectory(tree-structured) Triangulation

$$\min_{\{X_1, X_2 \ldots X_N\}} \sum_{(i,j)\in P} ||X_i - X_j||_2^2 ,$$

- Tree structured sequence P directly applies
- Sum of squared pairwise distances

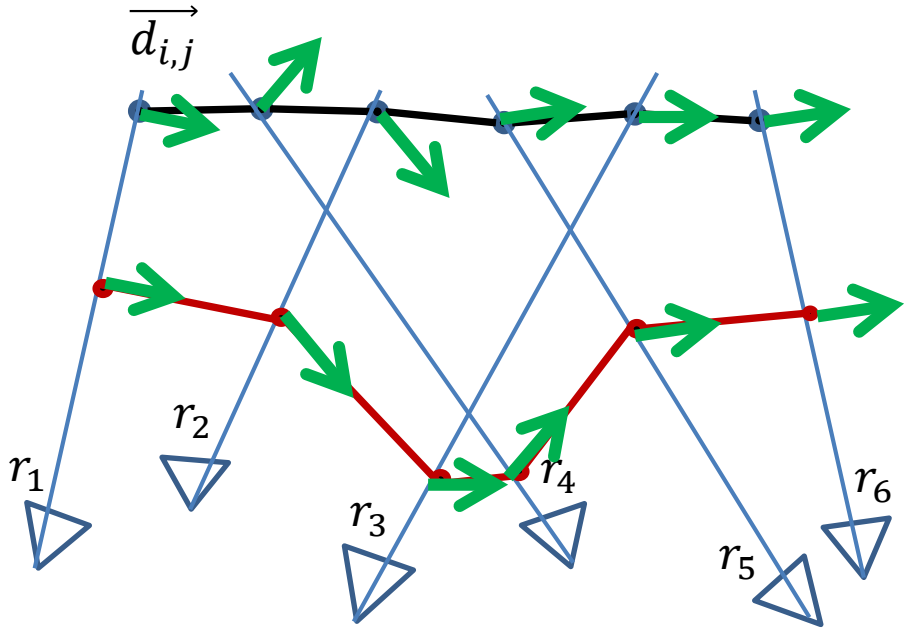


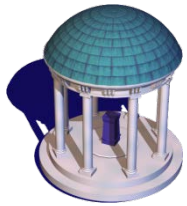
JOST Model Optimization

- If the adjacency is unknown: Optimize over both the 3D positions X and the sequencing

$$\min_{\{X_1, X_2 \ldots X_N\}, P} \sum_{(i,j) \in P} ||X_i - X_j||_2^2$$

- Enforcing motion vector constraint





JOST Model Optimization

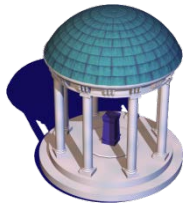
- If the adjacency is unknown: Optimize over both the 3D positions X and the sequencing

$$\min_{\{X_1, X_2 \dots X_N\}, P} \sum_{(i,j)\in P} ||X_i - X_j||_2^2$$

- Enforcing motion vector constraint

$$\min_{\{X_1, X_2 \dots X_N\}, P} \sum_{(i,j)\in P} \underbrace{||X_i - X_j||_2^2}_{\text{compactness}} + \underbrace{\lambda \varphi(X_i, X_j)}_{\text{fidelity}},$$

with $\varphi(X_i, X_j) = ||\overrightarrow{d_{i,j}} \times (X_i - X_j)||_2^2$



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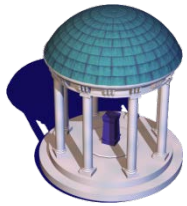
$$\min_{\{X_1, X_2 \ldots X_N\}, P} \sum_{(i,j)\in P} ||X_i - X_j||_2^2 + \lambda\varphi\left(X_i, X_j\right),$$

- Discrete-continuous optimization:



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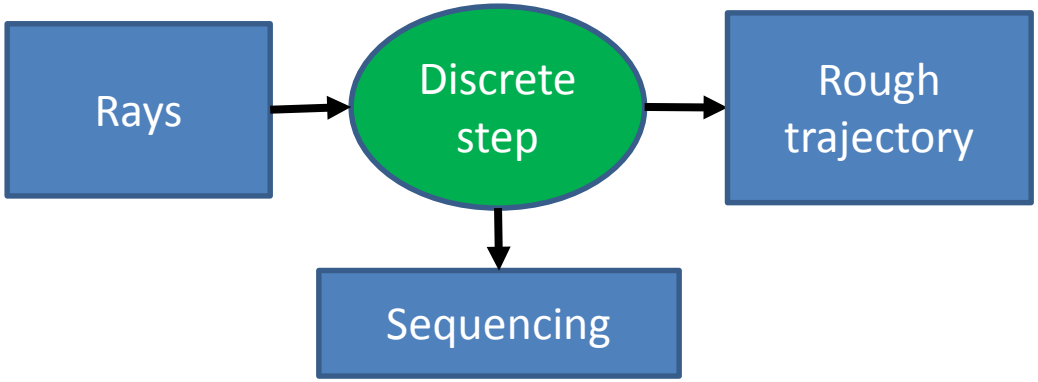

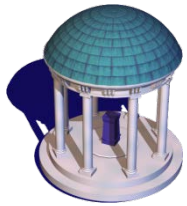

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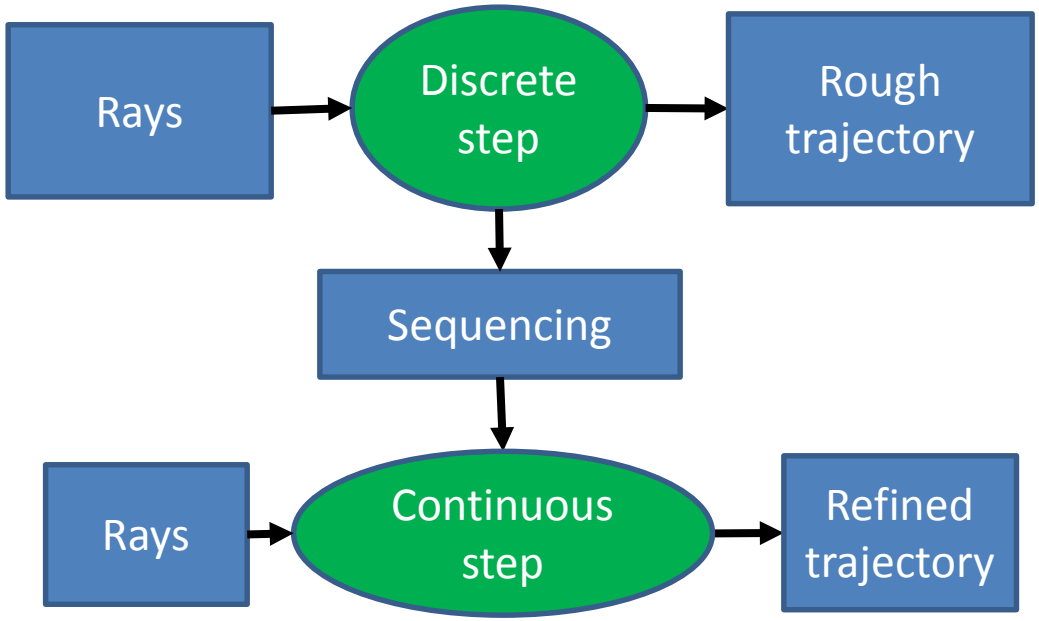

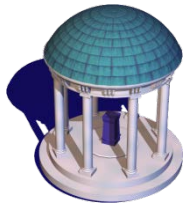

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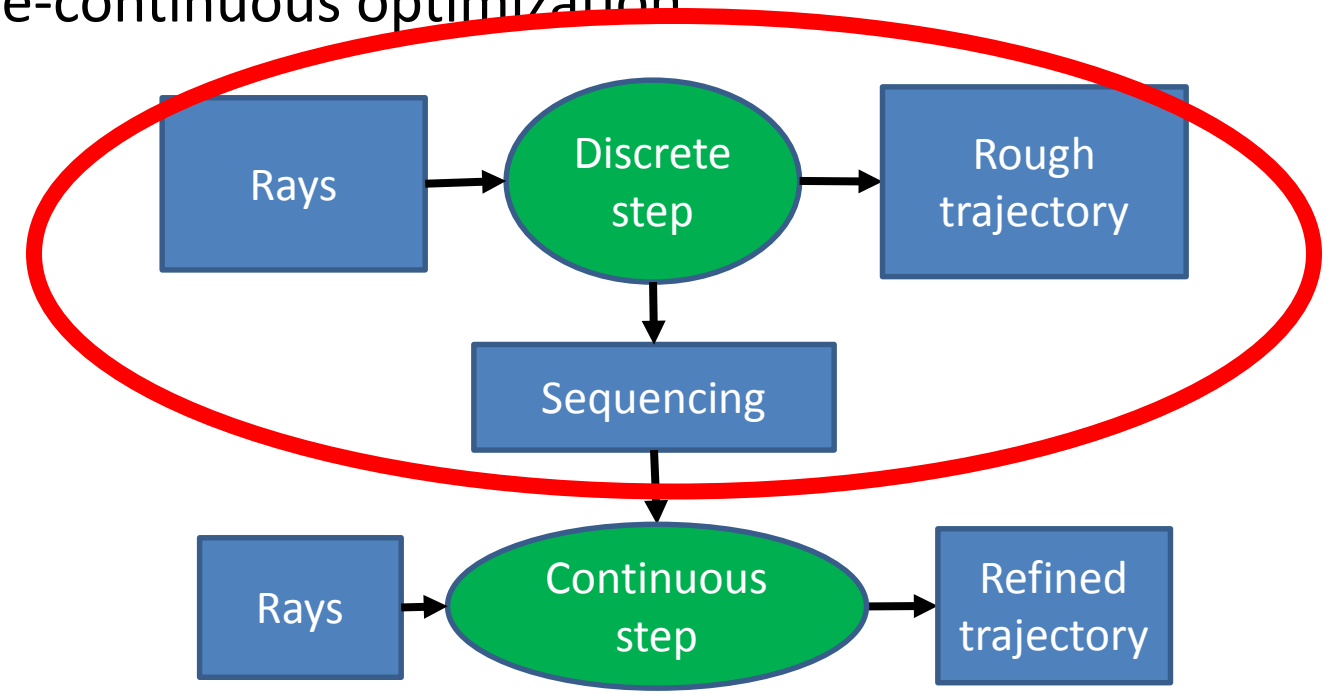
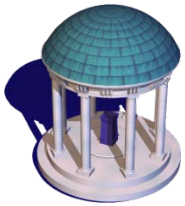
- Discrete-continuous optimization:

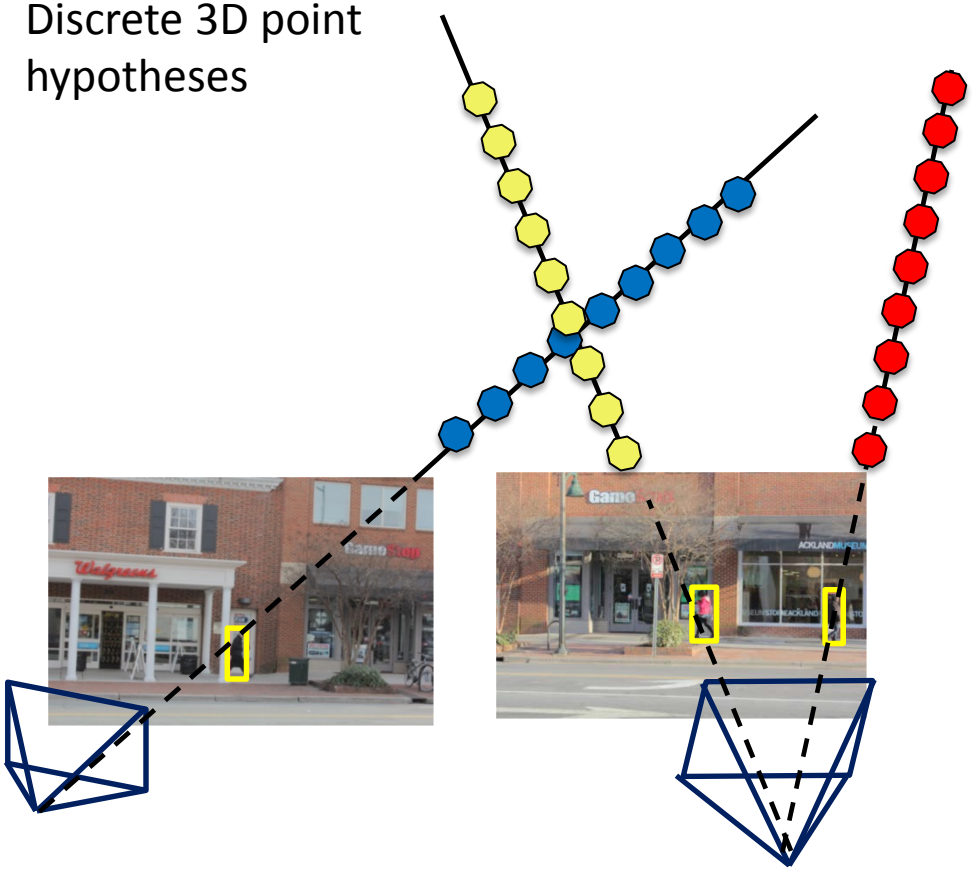




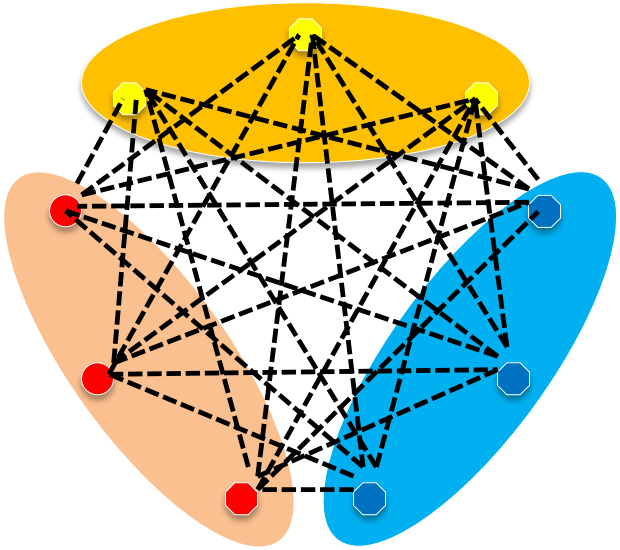
JOST Model Optimization

$$\underset{\{X_1, X_2 \ldots X_N\}, P}{\text{minimize}} \sum_{(i,j)\in P} \left|\left|X_i - X_j\right|\right|_2^2 + \lambda\varphi\left(X_i, X_j\right)$$

Discrete 3D point hypotheses

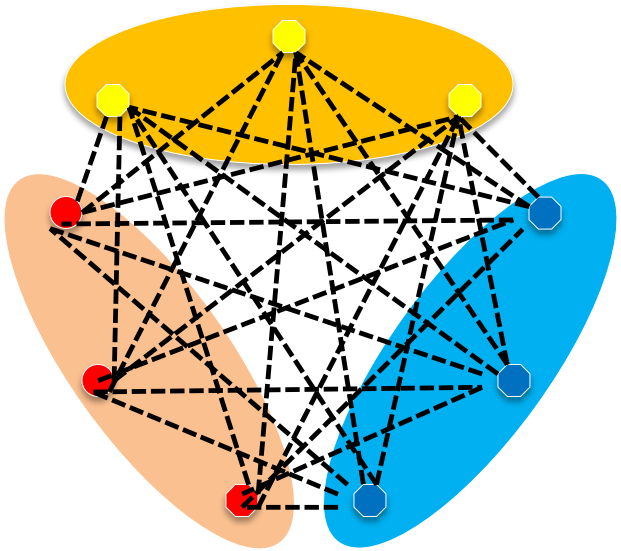


Edge cost

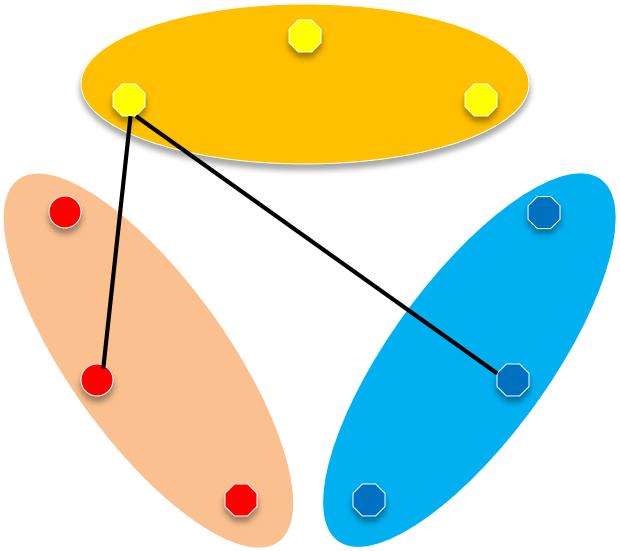


K-partite graph

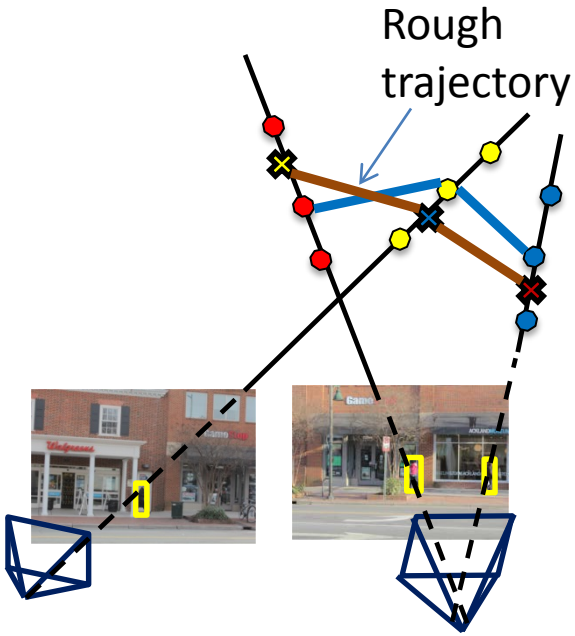
Generalized Minimum Spanning Tree(GMST)



K-partite graph



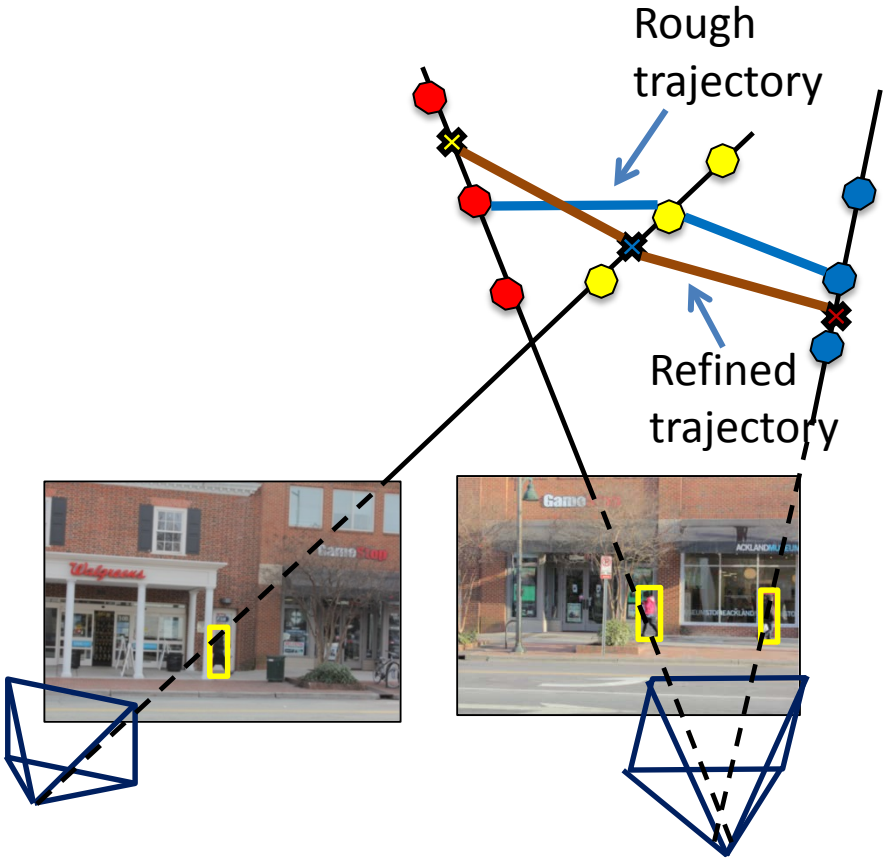
GMST



$$\underset{\{X_1,X_2\ldots X_N\},P}{\text{minimize}} \sum_{(i,j)\in P} ||X_i - X_j||_2^2 + \lambda\varphi(X_i, X_j)$$

- GMST is an NP hard problem

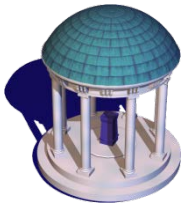
Trajectory Refinement



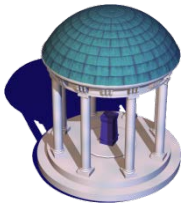
- Refinement:

$$\min_{\{X_1, X_2 \ldots X_N\}} \sum_{(i,j)\in P} ||X_i - X_j||_2^2 + \lambda\varphi(X_i, X_j),$$

with P being fixed.



Experiments (real data)



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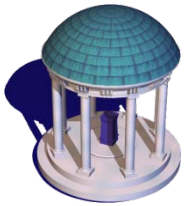
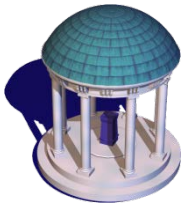
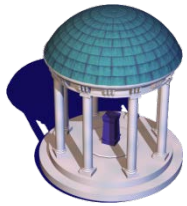


Contributions



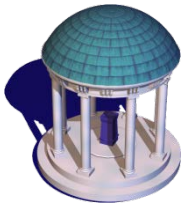
Contributions

- Introduce JOST



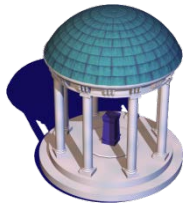
Contributions

- Introduce JOST
- Use object detections as general features



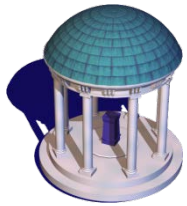
Contributions

- Introduce JOST
- Use object detections as general features
- Discrete-continuous solution



Contributions

- Introduce JOST
- Use object detections as general features
- Discrete-continuous solution
- Revisited reconstructability analysis



Thank you!

Questions?

This work is based upon work supported by the National Science Foundation under Grant No. IIS-1252921 and No. IIS-1349074