

**Image-Based Rendering**  
CSE 274, Lecture 6: Photo Tourism (and Façade)  
Ravi Ramamoorthi  
<http://www.cs.ucsd.edu/~ravir>



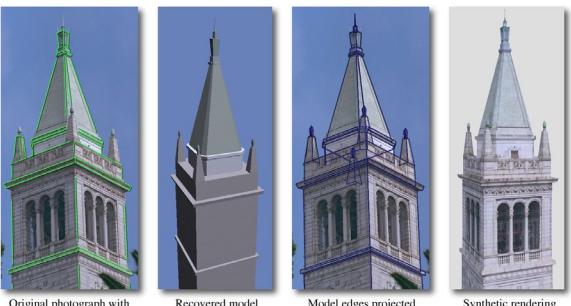
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## Motivation

- Today IBR models whole urban world (think of Streetview with 3D modeling, NeRFs)
- Remains important topic for sparse views
  - Actively working on WRIVA project
- Briefly trace two key developments
  - Façade system (Debevec et al. 96)
  - [Not covered: ] Teller ~00: Automated Model Capture in Extended Urban Environments
  - **Photo Tourism (Snavely et al. 06)**

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Modeling and Rendering Architecture from Photographs  
Debevec, Taylor, and Malik 1996



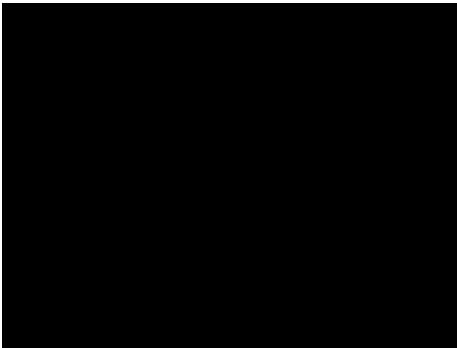
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## FACADE

- Photogrammetric Modeling
  - Interactively recover 3D models and camera positions from photographs for simple structures
- View-Dependent Texture Mapping (3D model and set of photos into renderings)
- Model-Based Stereo refines geometric model
- Video: <https://youtu.be/F-L5qnTZEFG>

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**Campanile Movie (SIGGRAPH 97 ET)**



For audio, play off [debevec-campanile.mov](#)

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Jon Gaeta sees a direct line from the impactful implementation of the Wachowskis' vision in *The Matrix* built on the research from Paul Debevec's team to today's volumetric captures, virtual production, holographic and ML NeRF concepts, and so many other derivatives of reality - captured from the real world. While the film was about simulating reality for Neo, the VFX crew built the Wachowskis' cyberpunk world by sampling and then providing a fresh and original perspective.



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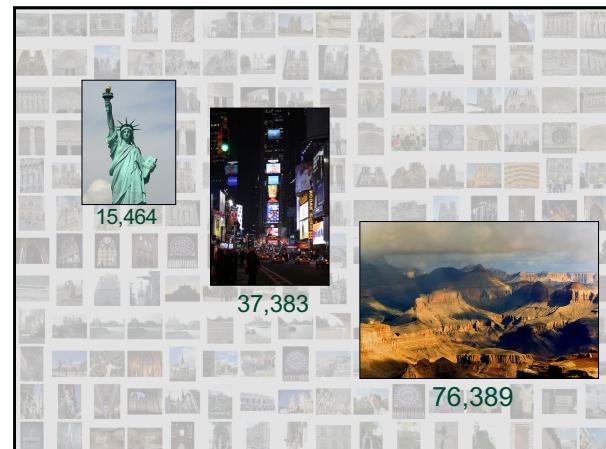
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**Photo Tourism:**  
Exploring Photo Collections in 3D

Noah Snavely  
Steven M. Seitz  
*University of Washington*  
Richard Szeliski  
*Microsoft Research*

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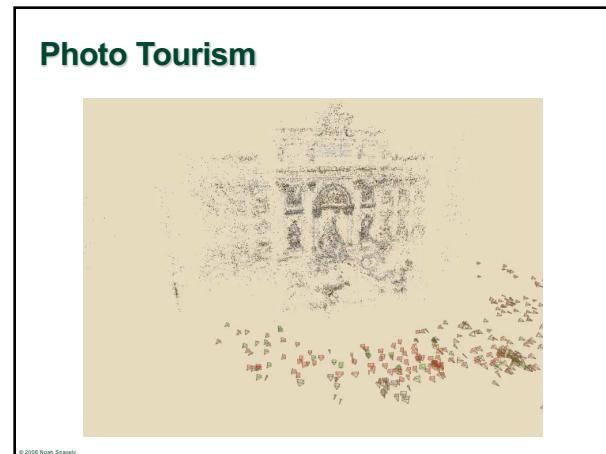
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Creative Commons / Attribution-NonCommercial-NoDerivs License  
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**Photo Tourism overview**

Input photographs → Scene reconstruction → Photo Explorer

Relative camera positions and orientations  
Point cloud  
Sparse correspondence

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**Related work**

- Image-based modeling

Debevec, *et al.*  
SIGGRAPH 1996

Schaffalitzky and Zisserman  
ECCV 2002

Brown and Lowe  
3DIM 2005

- Image-based rendering

Photorealistic IBR:  
Levoy and Hanrahan, SIGGRAPH 1996  
Gortler, *et al.*, SIGGRAPH 1996  
Seitz and Dyer, SIGGRAPH 1996  
Aliaga, *et al.*, SIGGRAPH 2001  
and many others

Aspen Movie Map  
Lippman, *et al.*, 1978

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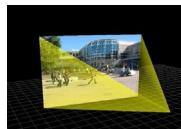
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## Related work

- Image browsing



Toyama, et al,  
Int. Conf. Multimedia, 2003



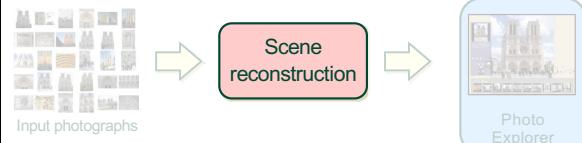
McCurdy and Griswold  
Mobicys 2003



Sivic and Zisserman  
ICCV 2003

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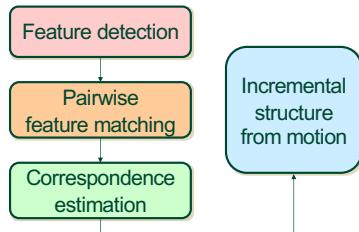
## Photo Tourism overview



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## Scene reconstruction

- Automatically estimate
  - position, orientation, and focal length of cameras
  - 3D positions of feature points

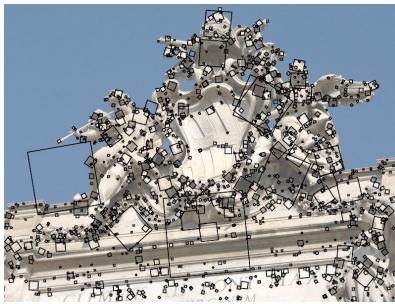


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## Feature detection

Detect features using SIFT [Lowe, IJCV 2004]



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## Feature detection

Detect features using SIFT [Lowe, IJCV 2004]



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## Feature detection

Detect features using SIFT [Lowe, IJCV 2004]

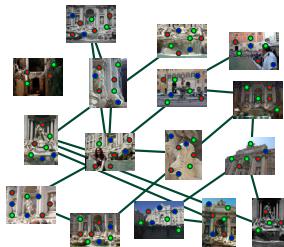


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## Feature matching

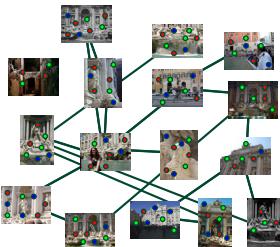
Match features between each pair of images



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## Feature matching

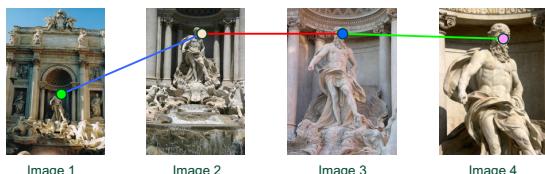
Refine matching using RANSAC [Fischler & Bolles 1987] to estimate fundamental matrices between pairs



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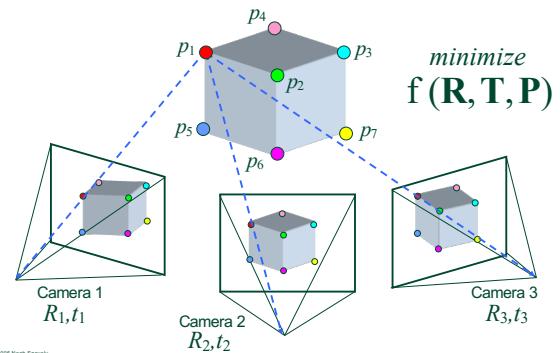
## Correspondence estimation

- Link up pairwise matches to form connected components of matches across several images



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## Structure from motion



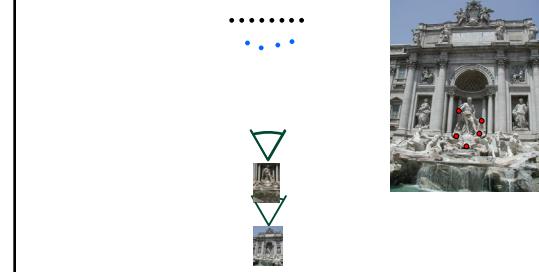
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## Incremental structure from motion



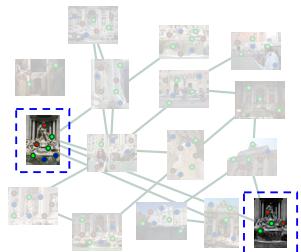
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## Incremental structure from motion



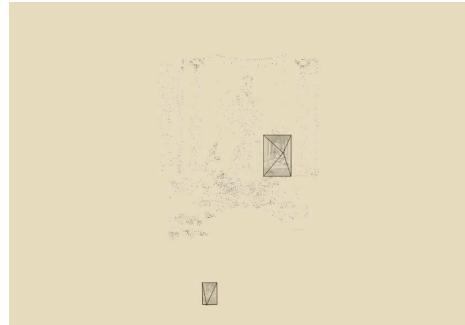
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### Incremental structure from motion



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### Incremental structure from motion



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### Reconstruction performance

- For photo sets from the Internet, 20% to 75% of the photos were registered
- Most unregistered photos belonged to different connected components



- Running time: < 1 hour for 80 photos  
> 1 week for 2600 photo

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### Photo Tourism overview



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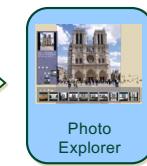


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## Photo Tourism overview



Scene reconstruction



- Navigation
- Rendering
- Annotations

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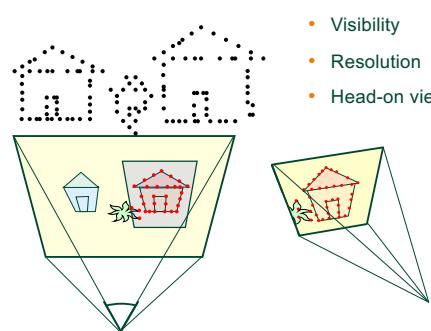
## Object-based browsing



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## Object-based browsing

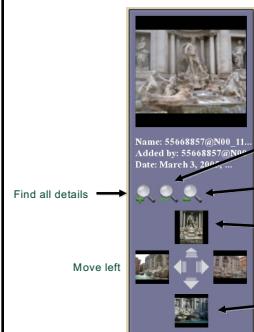


- Visibility
- Resolution
- Head-on view

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## Relation-based browsing



Name: 55608857@N00\_11  
Added by: 55608857@N00  
Date: March 3, 2006

Find all similar images

Find all details

Find all zoom outs

Zoom in

Move left

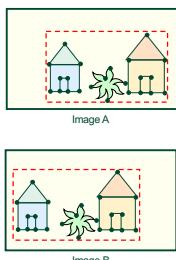
Move right

Zoom out

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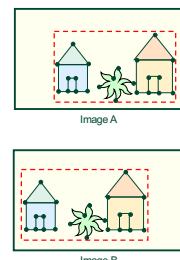
## Relation-based browsing



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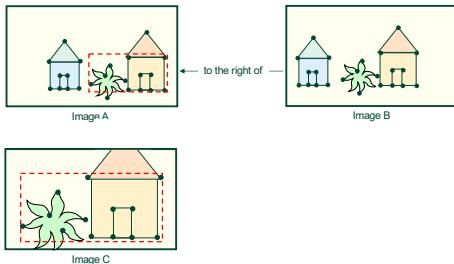
## Relation-based browsing



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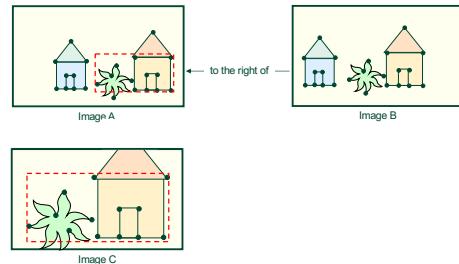
## Relation-based browsing



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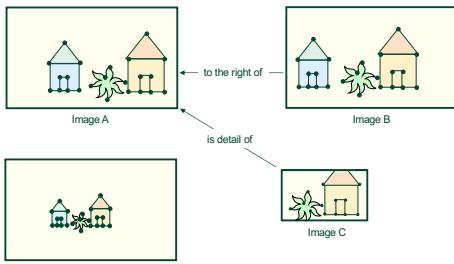
## Relation-based browsing



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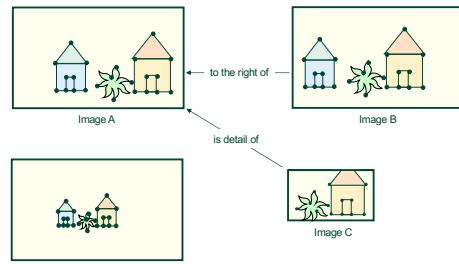
## Relation-based browsing



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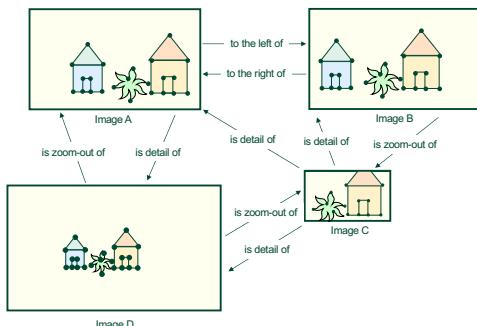
## Relation-based browsing



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## Relation-based browsing



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## Overhead map



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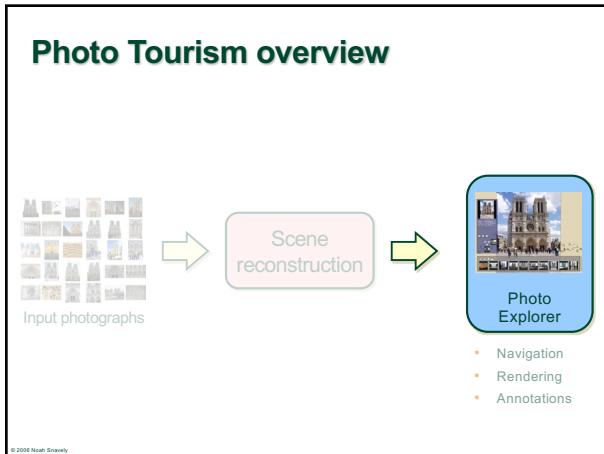
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### Prague Old Town Square



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### Photo Tourism overview



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### Rendering



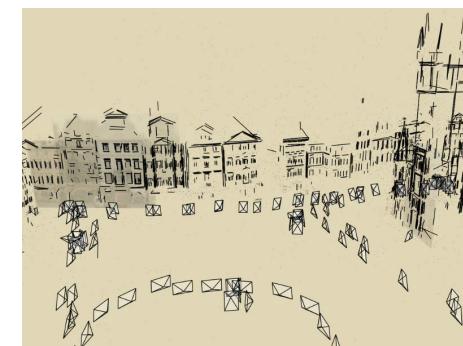
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### Rendering



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### Rendering



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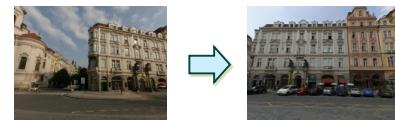
## Rendering transitions



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## Rendering transitions



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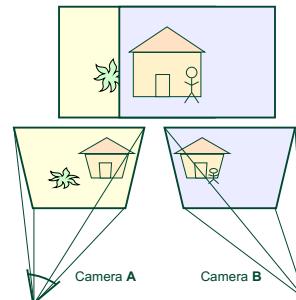
## Rendering transitions



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## Rendering transitions



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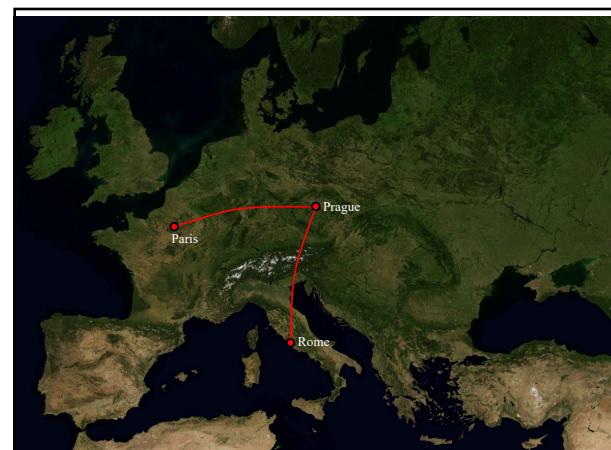
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## Photo Tourism overview



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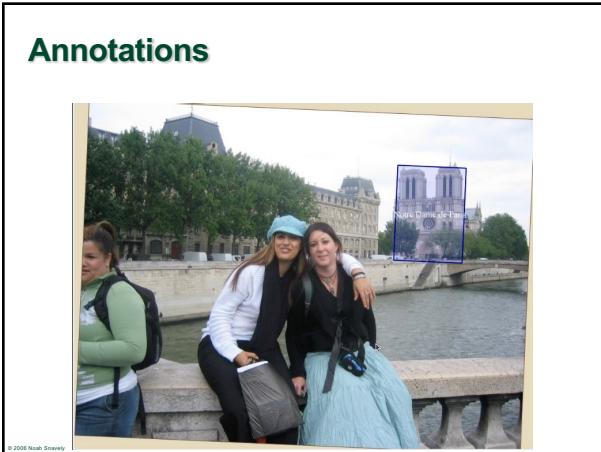
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**Annotations**

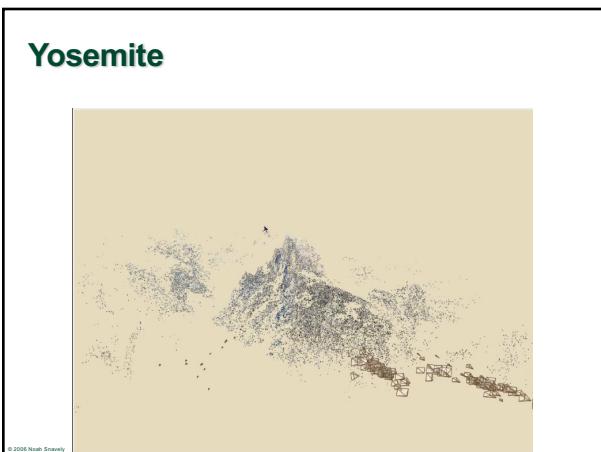
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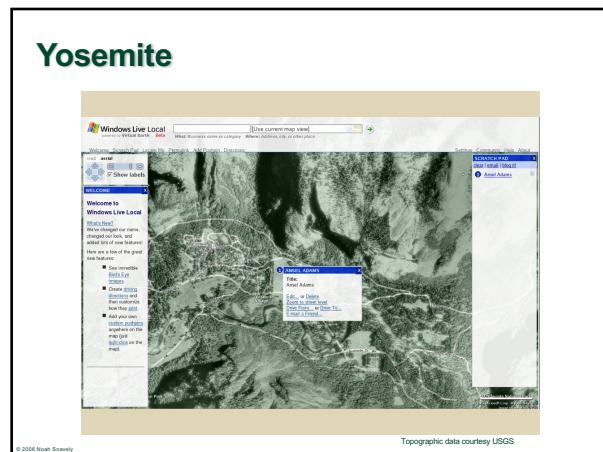
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## Contributions

- Automated system for registering photo collections in 3D for interactive exploration
- Structure from motion algorithm demonstrated on hundreds of photos from the Internet
- Photo exploration system combining new image-based rendering and photo navigation techniques

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## Limitations / Future work

- Not all photos can be reliably matched



- Structure from motion scalability

→ More efficient (sparse) algorithms

- Plane-based transitions lack parallax



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## Limitations / Future work



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## Limitations / Future work

- Not all photos can be reliably matched
  - Better feature detection / matching
  - Integrating GPS & other localization info.
- Structure from motion scalability
  - More efficient (sparse) algorithms
- Plane-based transitions lack parallax
  - Richer transitions
- Photo explorer scalability...

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## Future work

- Photo explorer scalability
  - Design client-server architecture for streaming images and geometry at required resolution
  - Scale to *all* of the world's photos (and videos...)
  - Photosynth project at Microsoft Live Labs (live demo)

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## Acknowledgements

- National Science Foundation
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- The many people who allowed use of their photos
- UW GRAIL Lab
- MSR Interactive Visual Media Lab
- Kevin Chiu and Andy Hou for writing the Java applet

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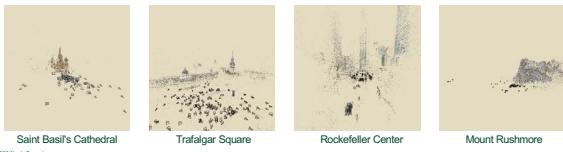
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## Conclusion

Indexing everyone's photos provides a new way to share and experience our world

To find out more:

- <http://phototour.cs.washington.edu>
- <http://research.microsoft.com/IVM/PhotoTourism>
- <http://labs.live.com/photosynth>
- Exhibition booth #2619



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## Today: NeRFs for Landscapes



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Instant NeRF (@jonstephens85 on Twitter); slide courtesy Thomas Müller

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## NeRFs in StreetView



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