

The Distributed Camera

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Cornell University

Microsoft Faculty Summit
June 16, 2013

The Age of Exapixel Image Data



- Over a *trillion* photos available online
- Millions uploaded every hour
- Interconnected
- The Internet is becoming a **living visual record** of our world

Photos over time



1820's

1900

1990's

2000's

Early photography

Kodak Brownie

Digital cameras

Photo sharing



350 million photos
per day (Facebook)

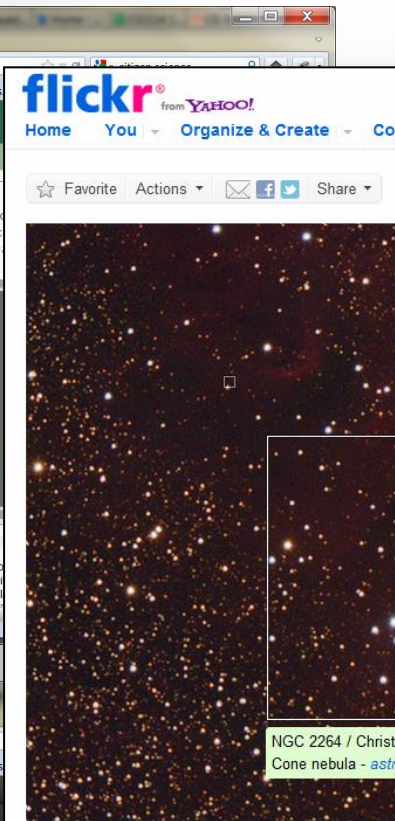
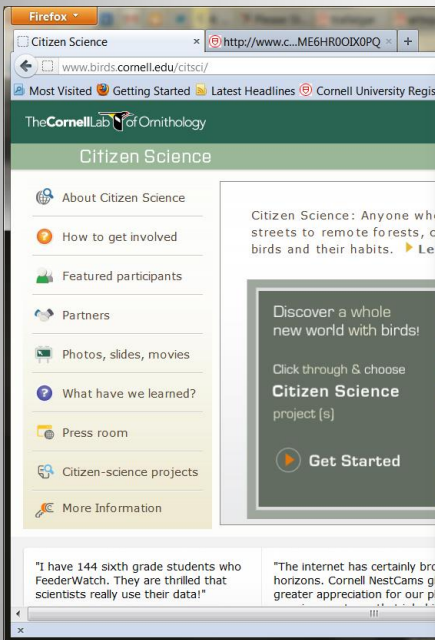
100 hours of video
per minute (YouTube)

“Every 2 minutes today we capture as many photos as the whole of humanity took in the 1800s.” [1000memories]

What can we do with all this data?



- Use images to understand the world
 - Changes in cities and environments over time
 - High-level behaviors, e.g. traffic patterns, pedestrian moments
 - Surprising events
 - Forensics – what happened, when?
- **Challenge:** data is extremely unstructured



NGC 2264 / Christmas Tree cluster

(reprocessed)

astronomy
 Hello, this is the blind astrometry solver. You
 (RA, Dec) center:(100.227235684, 9.938502)
 (RA, Dec) center (H:M:S, D:M:S):(06:40:54.4
 Orientation:146.00 deg E of N
 Pixel scale:3.17 arcsec/pixel
 Parity:Reverse ("Left-handed")
 Field size :72.02 x 52.33 arcminutes
 Your field contains:
 The star 15Mon
 NGC 2264 / Christmas Tree cluster / Cone n
[View in World Wide Telescope](#)

 If you would like to have other images solved

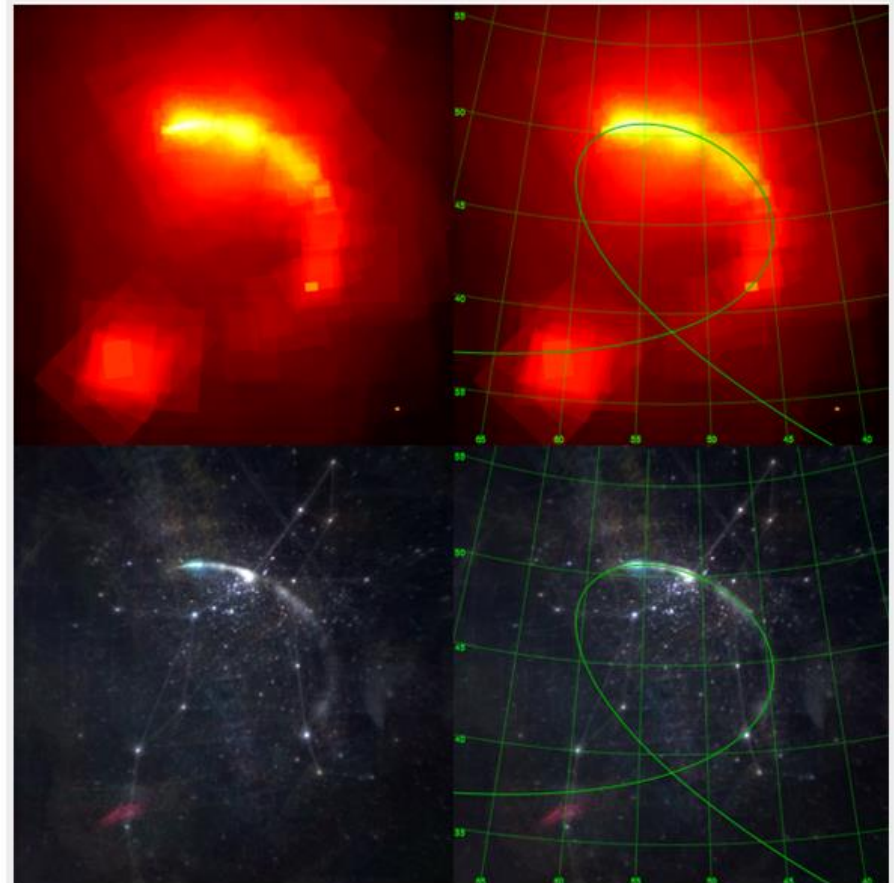


Astronomers Calculate Comet's Orbit Using Amateur Images From The Web

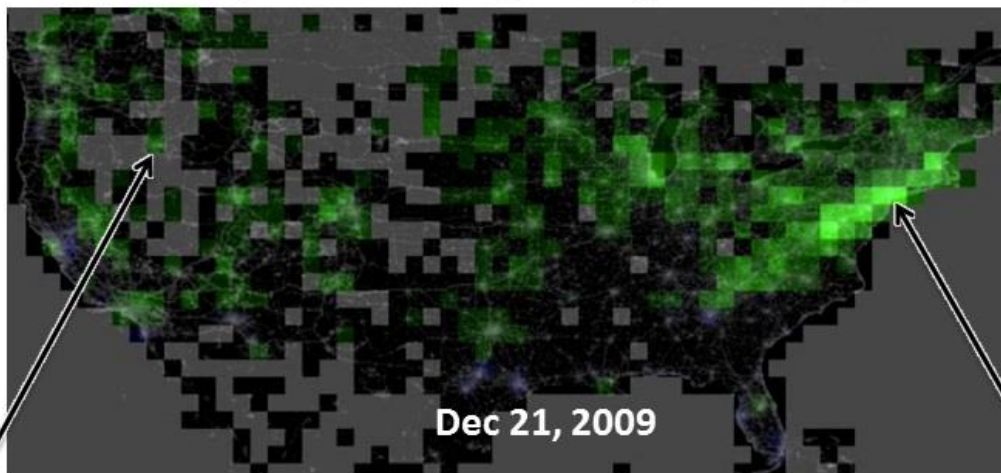
Amateur astrophotographs posted online represent a massive untapped resource. Now astronomers have worked out how to mine it

KFC 04/04/2011

5 COMMENTS



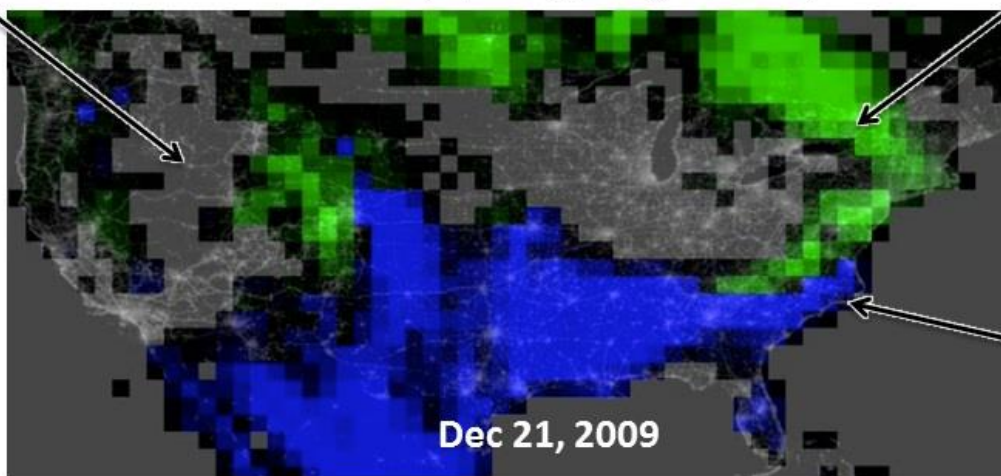
Map estimated by Flickr photo analysis



Missing data
(black/gray)

Snow cover
(green)

Satellite map (1 degree geo bins)

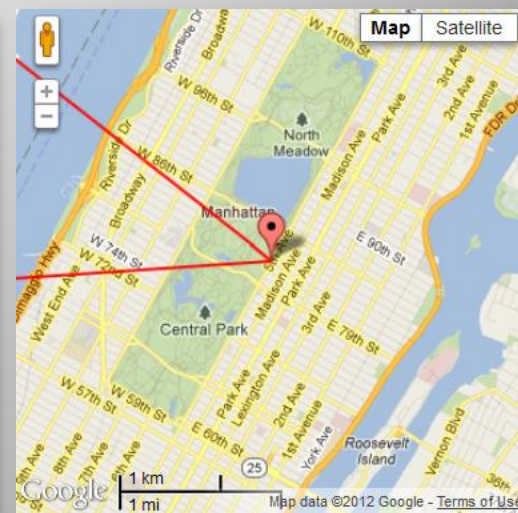


No snow cover
(blue)

Snow cover from Flickr photos

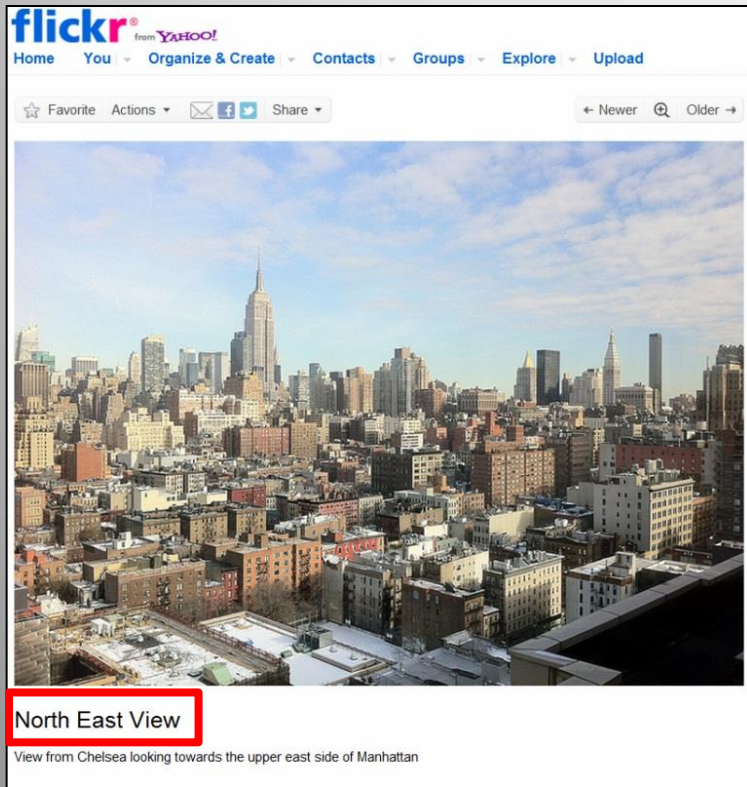
Calibrating the distributed camera

- For any photo on the web



- Where was it taken? In what direction?
- What time was it taken?
- What is visible in the image? Where?
- Our work: vision tools to provide basic calibration data

What about sensor data?



GPS Latitude	40 deg 44' 30.00" N
GPS Longitude	74 deg 0' 13.20" W
GPS Altitude Ref	Above Sea Level
GPS Altitude	10.3827476 m
GPS Time Stamp	17:53:26.86
GPS Img Direction Ref	True North
GPS Img Direction	171.3049327

- Provides a weak signal, but we want *pixel-accurate* localization

Location recognition



Image-based

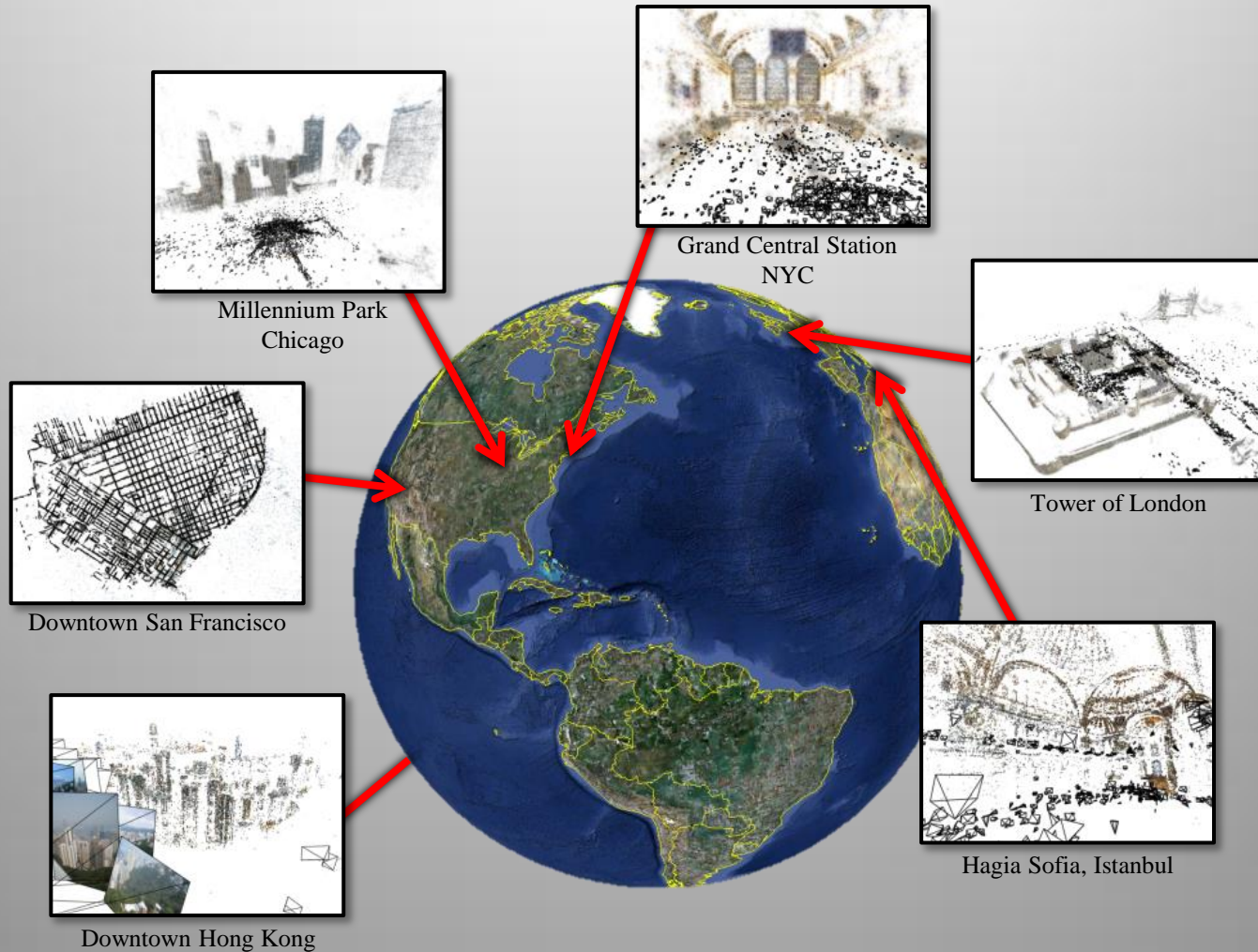
- [Schindler, Brown, Szeliski '06]
- [Hays & Efros '08]
- [Kalogerakis *et al.* '09]
- [Li, Crandall, Huttenlocher '09]
- [Knopp, Sivic, Pajdla, '10]



Geometry-based

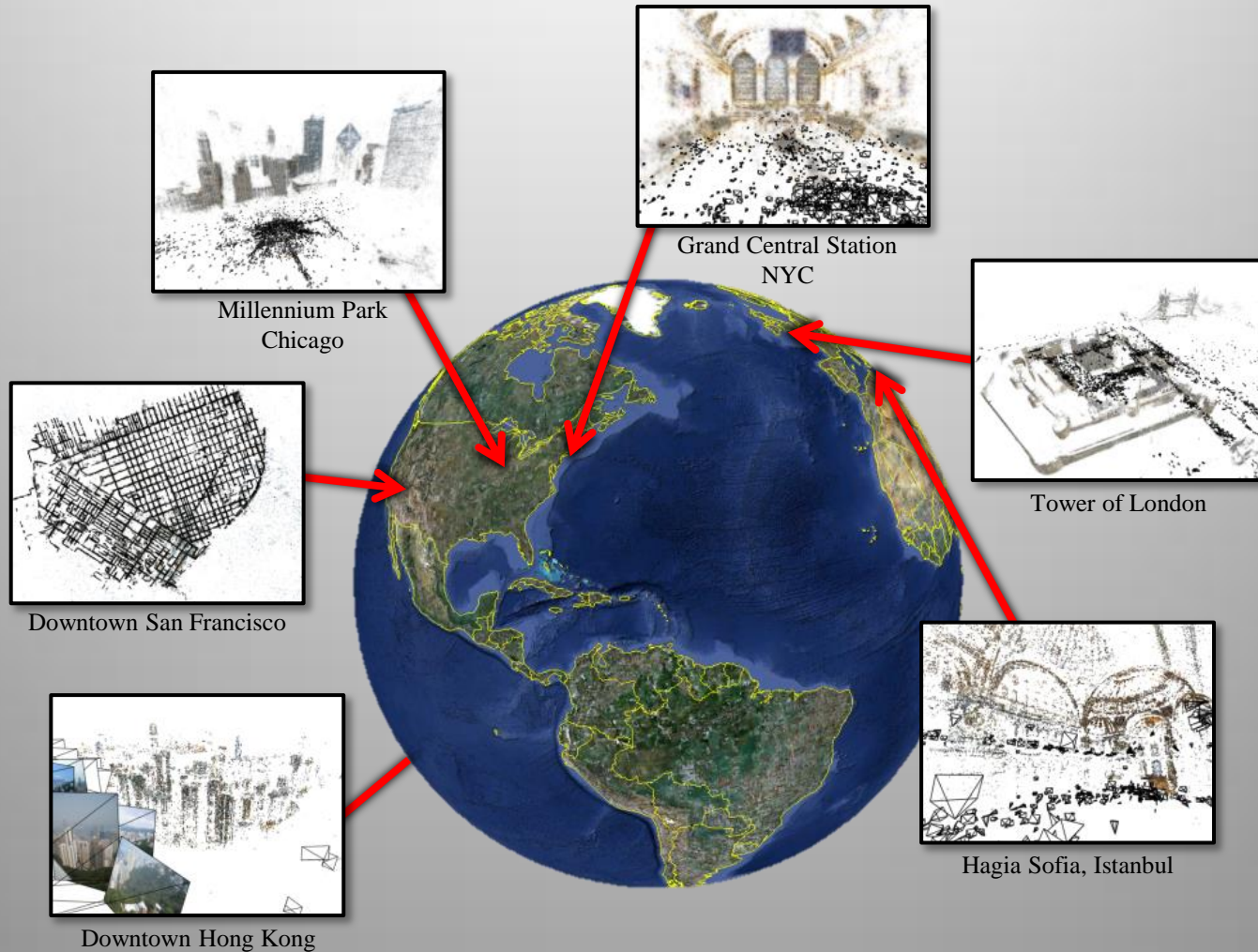
- [Li, *et al.* '10]
- [Sattler & Leibe '11]
- [Lim *et al.*, '11]
- [Li, Snavely, Huttenlocher, Fua '12]

A Database of 3D Geometry



Demo

A Database of 3D Geometry



Search

Photos Groups People

colosseum rome

SEARCH

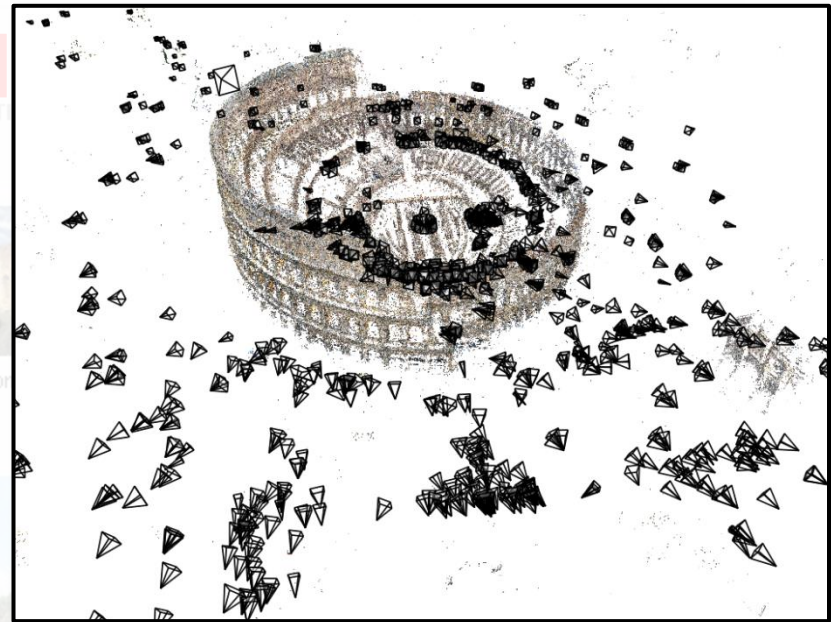
Advanced Search Search by Camera

Full text Tags only



sun and rome.

Show: Details +



From Jeremy...

From Jeremy...

From Jeremy...



From Jeremy...



From Jeremy...



From Jeremy...



From Jeremy...

www.florenceart.it

Colosseum Tickets

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www.TicketsPlus.com

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Save up to 75% on Italy hotels. Pay at check-in. No booking fees.

www.priceline-europe.com

Dubrovnik, Croatia





[*Building Rome in a Day*, Agarwal, Snavely, Simon, Seitz, Szeliski, ICCV 2009]



[Crandall, Backstrom, Huttenlocher, and Kleinberg. WWWo9]

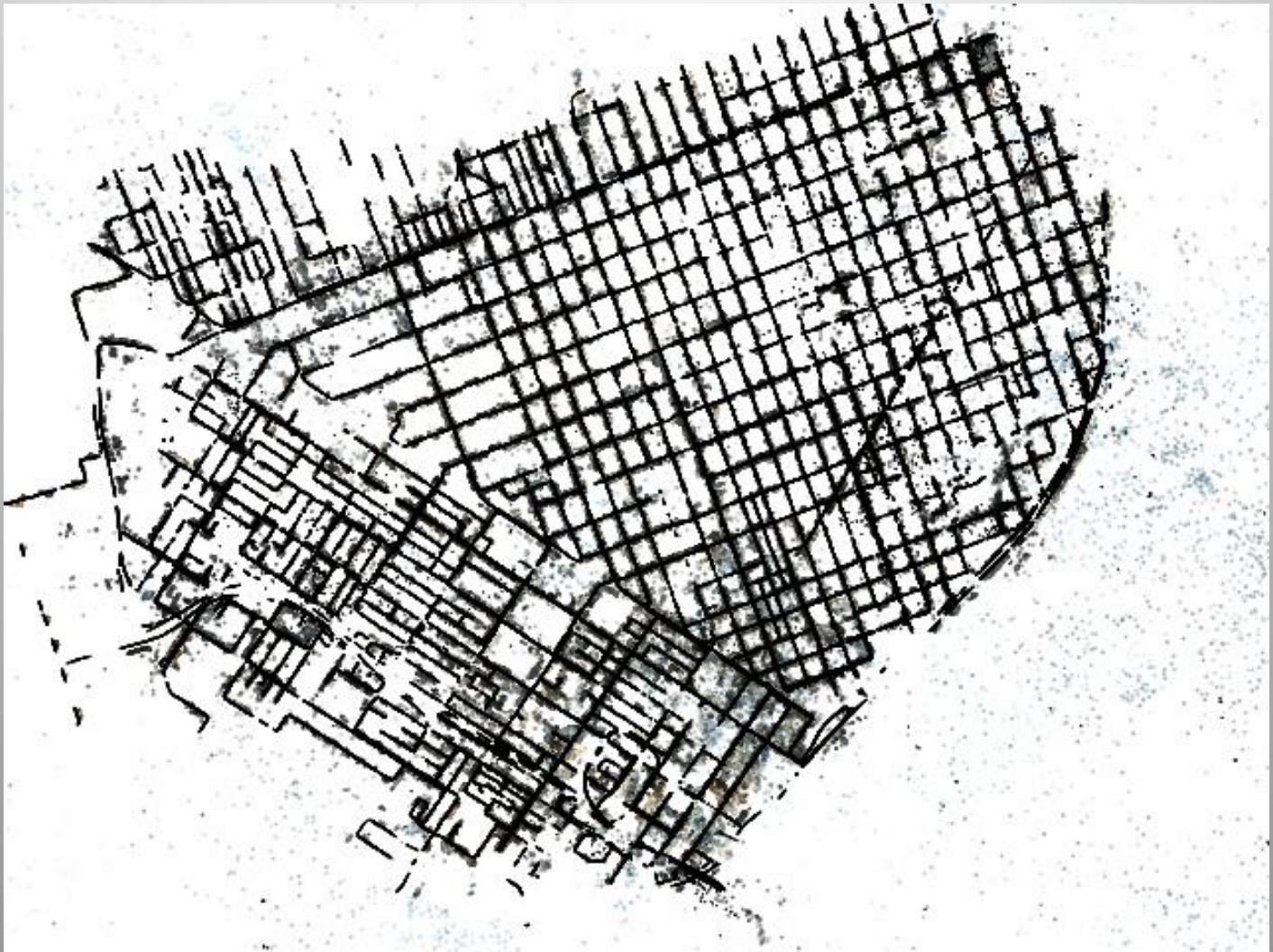
Status was last updated: 03/21/2012 08:55:50.

844 out of 10000 landmarks are processed (8.44%)

Landmark ID ¹	Tags (click to hide)	Cleaned ²	# components	Component 1	Component 2	Component 3
0000	paris eiffeltower eiffel toureiffel tower paris france					
0001	london trafalgarsquare trafalgar square london england uk		12	3951.0 (93.21%, 6380/6845)	1457.0 (87.62%, 92/105)	3613.0 (100.00%, 26/26)
0002	london londoneye eye thames london england uk		17	4771.0 (81.68%, 6102/7471)	4771.7 (80.69%, 163/202)	4771.6 (85.71%, 48/56)
0003	london bigben westminster england london uk		5	57.0 (86.67%, 4654/5370)	57.1 (88.33%, 106/120)	57.2 (89.66%, 26/29)
0004	paris cathedral notre dame notredame church france paris		49	1008.0 (7981/--)	1008.0.0 (7974/--)	1008.1 (2101/--)
0005	paris pyramid louvre museum paris france		68	508.1 (73.04%, 4273/5850)	508.6 (90.83%, 307/338)	508.12 (99.21%, 126/127)
0006	london tatemodern tate modern bridge thames london uk england		18	1076.0 (89.01%, 2851/3203)	1076.3 (73.54%, 164/223)	1076.4 (61.27%, 106/173)
0007	rome colosseum colosseo rome italy italia roma		8	33.0 (100.00%, 49/49)	120.0 (100.00%, 38/38)	67.0 (100.00%, 28/28)

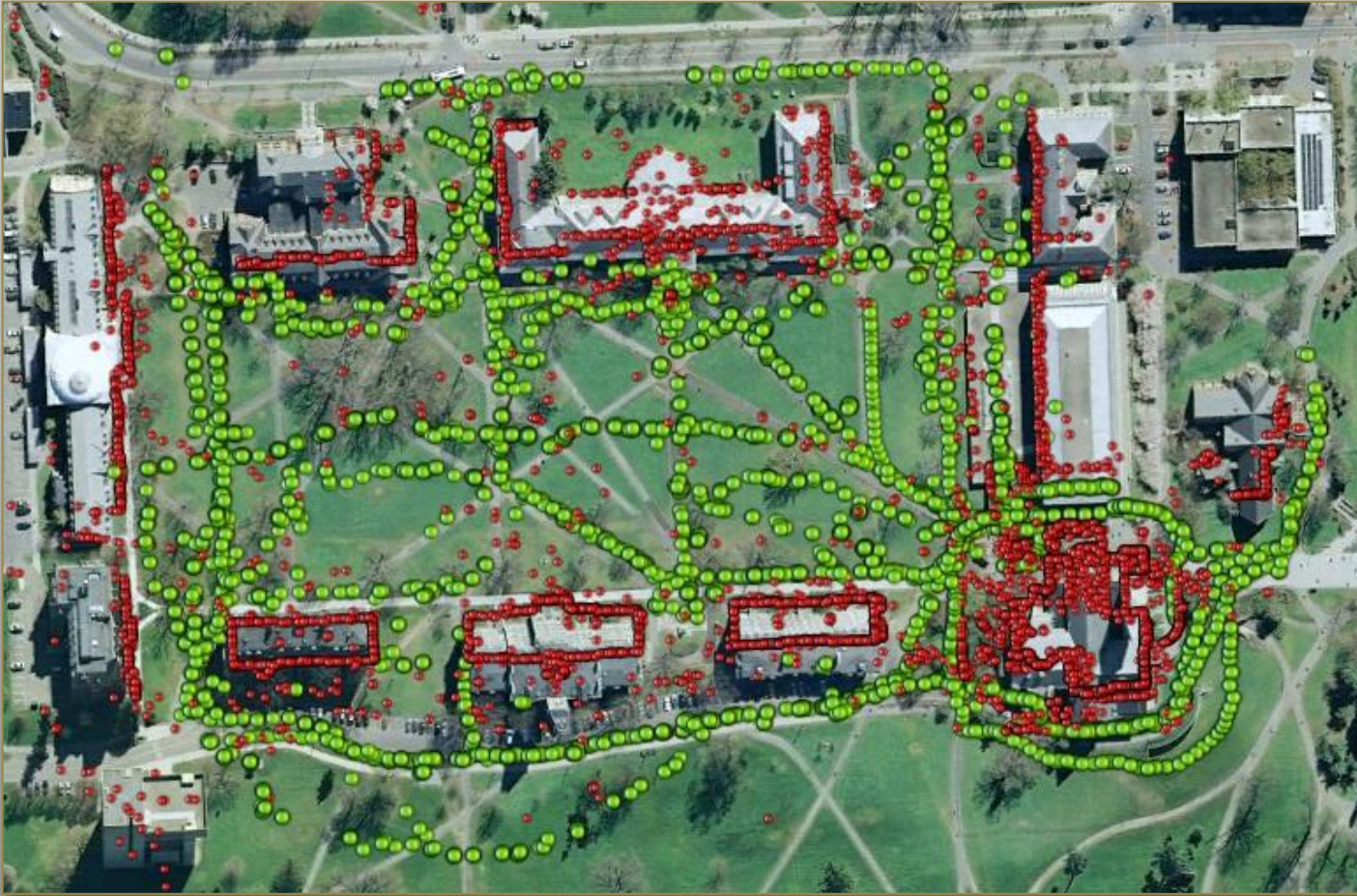
NAVTEQ SF Street View Dataset





Model of San Francisco

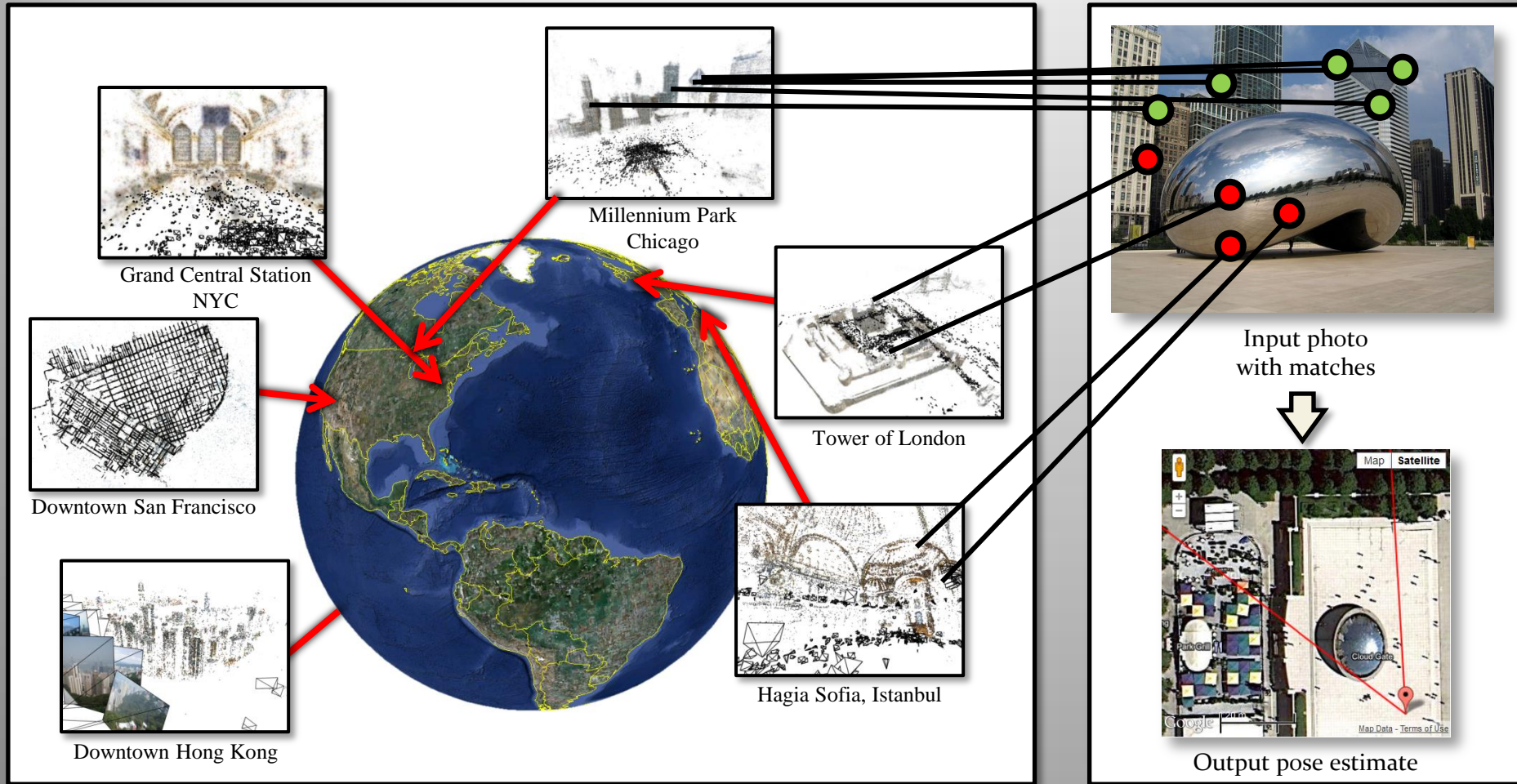
Automatic georeferencing



Where was this photo taken?



World-wide Pose Estimation



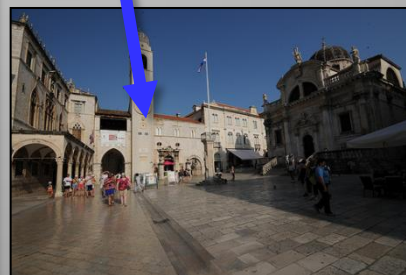
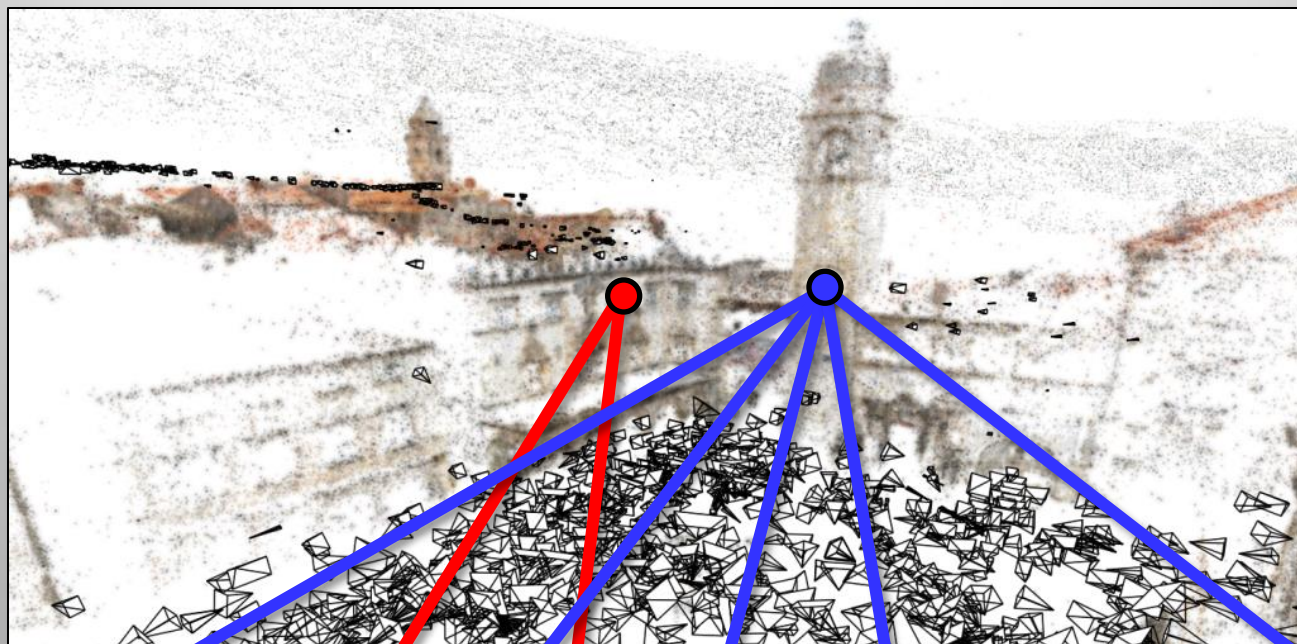
Matching becomes challenging as # of points grows very large

[Li, Snavely, Huttenlocher, Fua. ECCV 2012]

Very large search problem

- Largest model we've created:
 - About 500M 3D points
 - ... from several million images
- Each 3D point has 1 or more SIFT descriptors
 - We index these using standard kd-trees
- Finding good matches at this scale is challenging
 - We have to come up with new tricks

Not all 3D points are created equal...



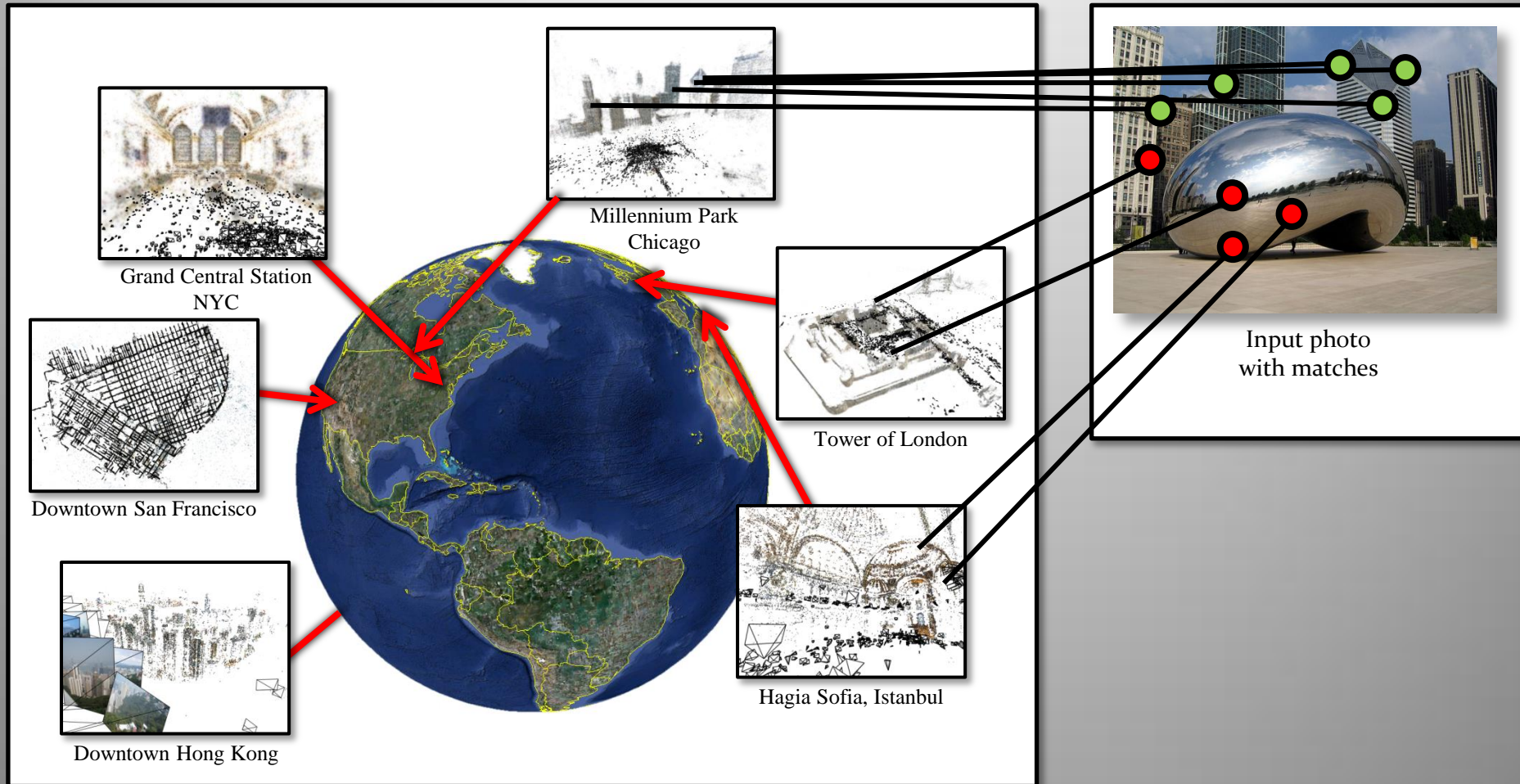
Point Co-occurrence



Examples of empirically frequently co-occurring triplets of points

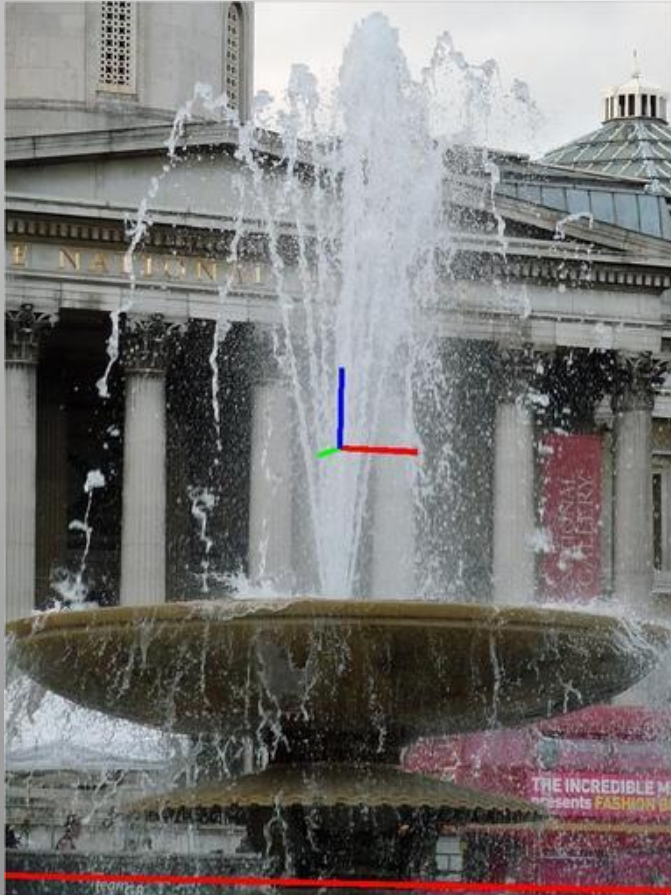
- We can use these rich statistics over point frequency and co-occurrence to make hypothesis testing much more efficient

Sampling based on co-occurrence

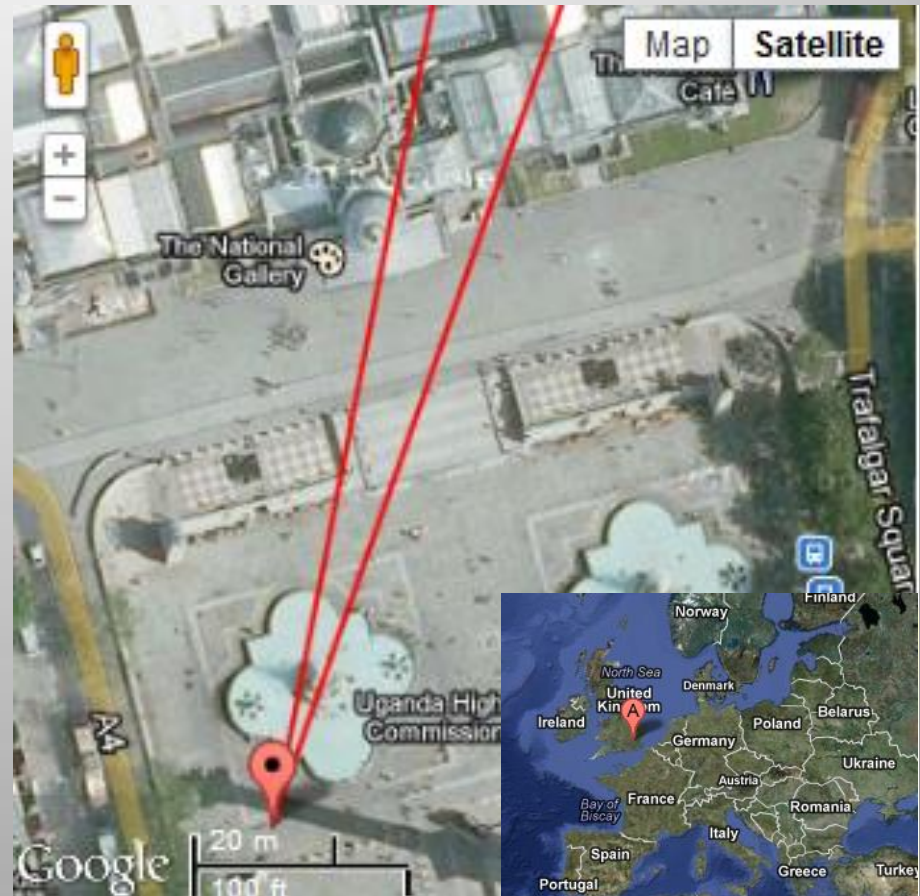


Example result

Input Photo

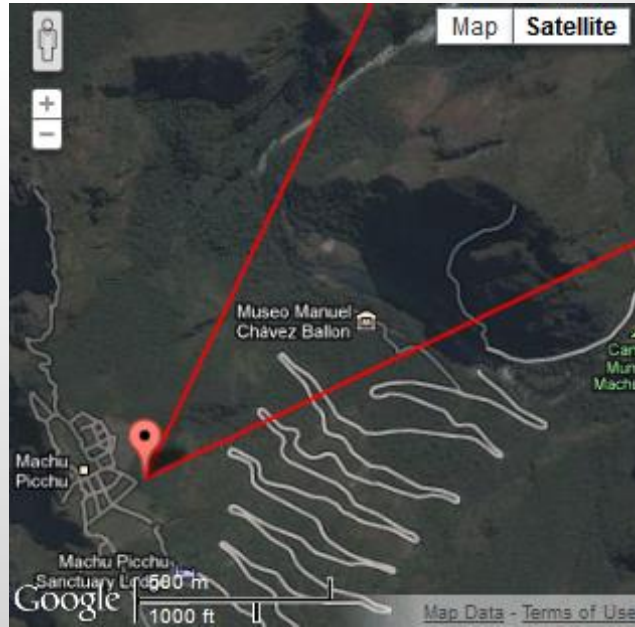
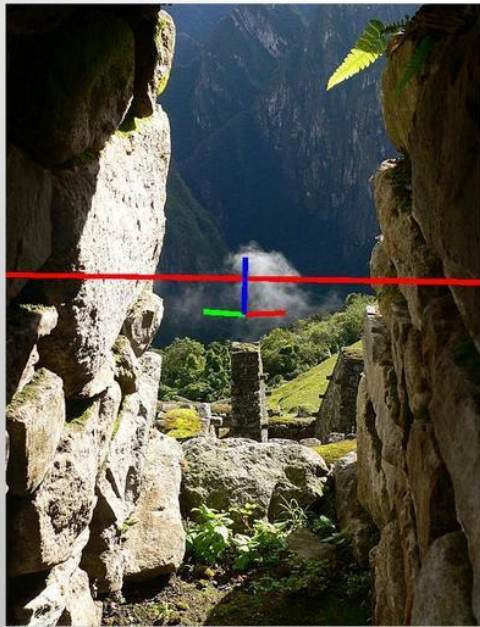


Estimated Camera Pose

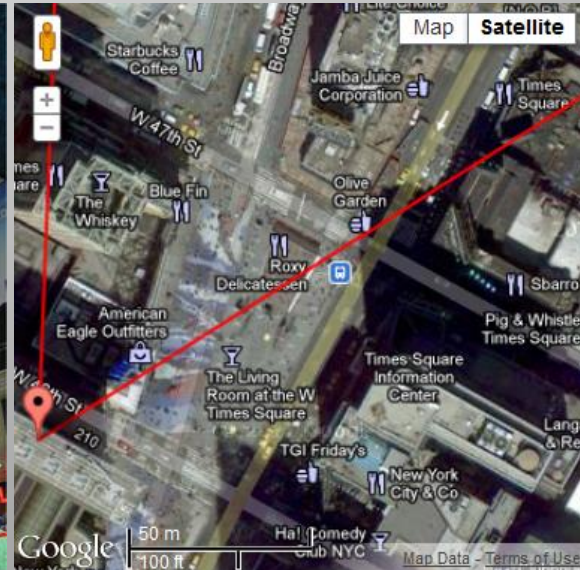


latitude: 51.5079 deg
longitude: -0.1283 deg
altitude: 0.718 m

zenith: 82.2991 deg
azimuth: -8.7291 deg
roll: -0.0391 deg
focalLength: 1610.01 px



Machu Picchu, Peru



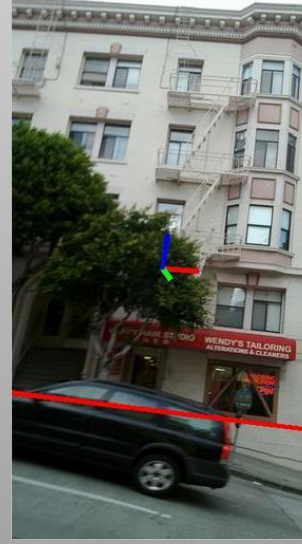
Times Square



Corner of Beach and Jones (San Francisco)

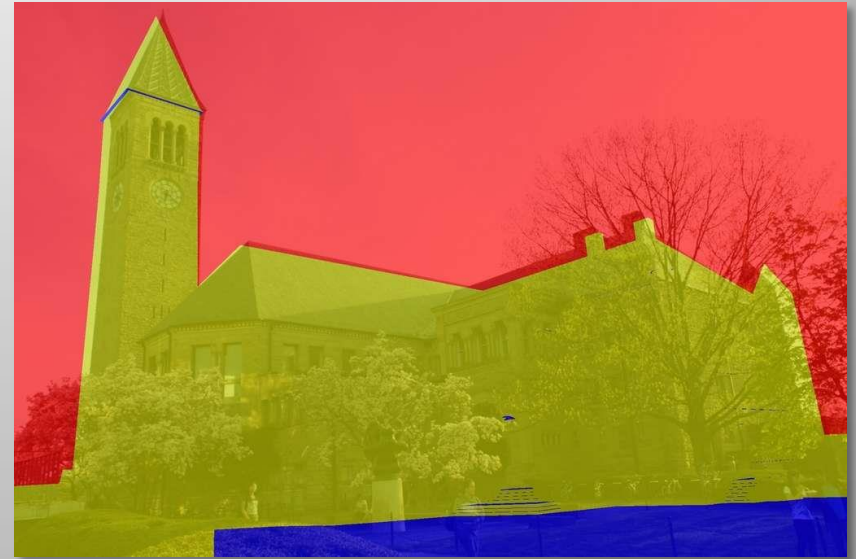


Sutter St.

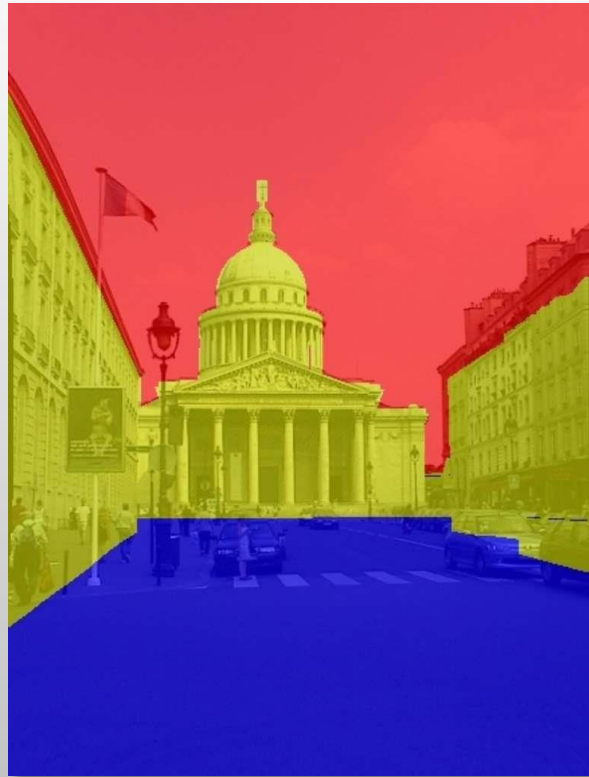


Pine St.

“Pixel-accurate” alignment



3D world model rendered from
estimated viewpoint



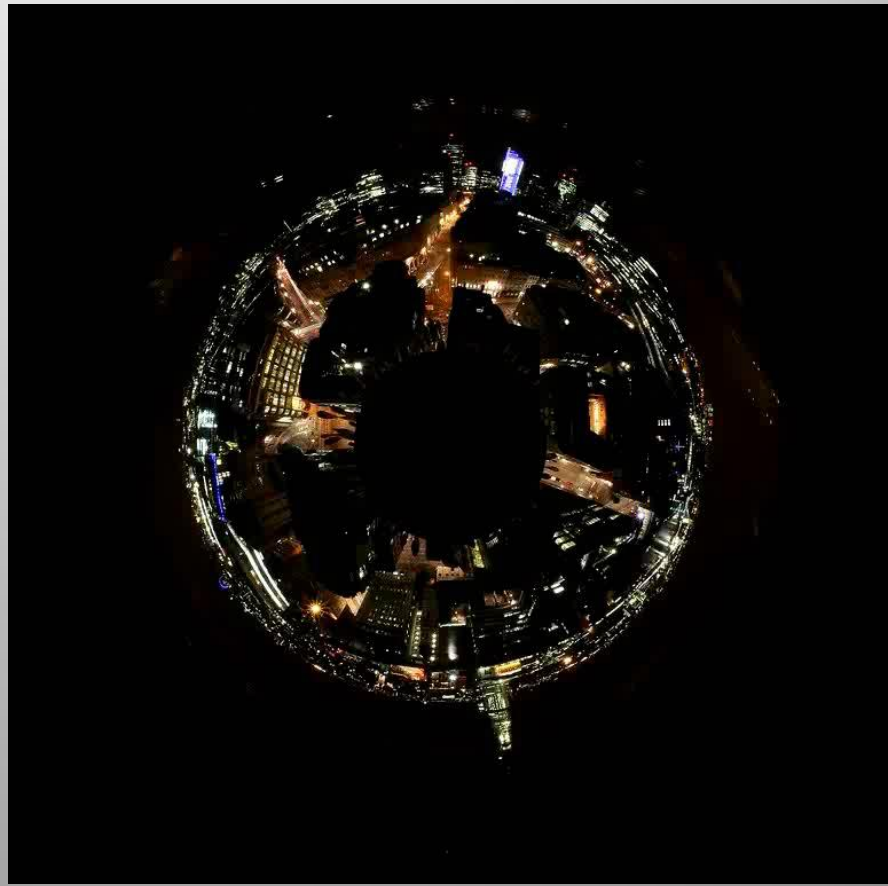
See also “Deep Photo,” Kopf *et al.* SIGGRAPH Asia 2008

What about time?

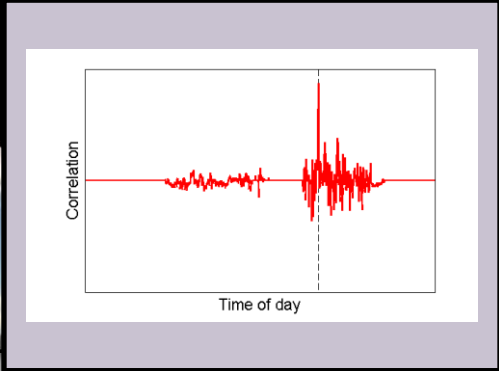
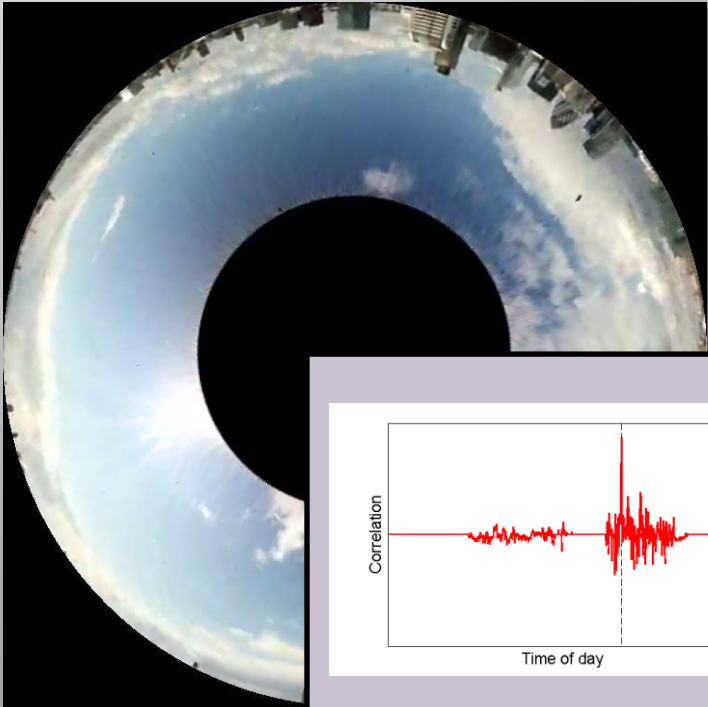
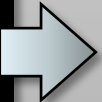
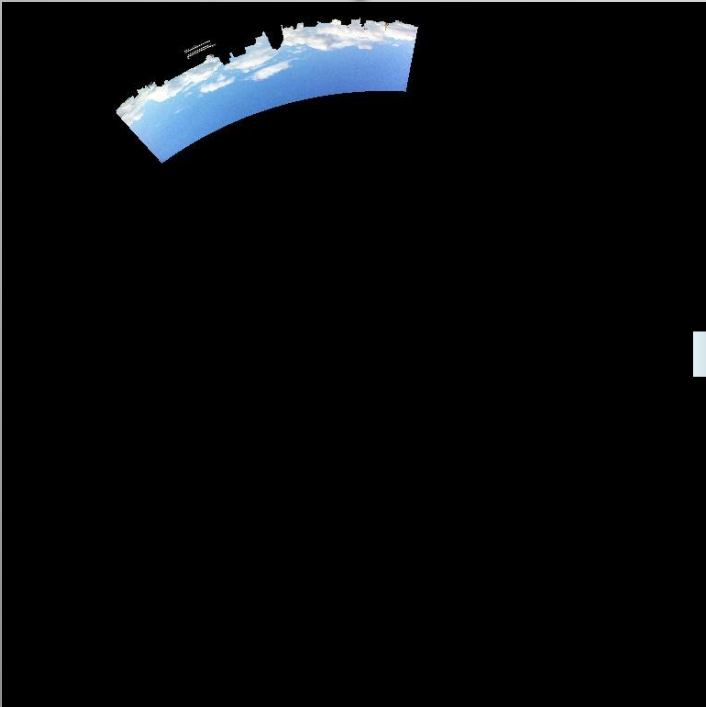
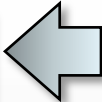




The Monument, London



[credit: Chris Meighs-Andrews]

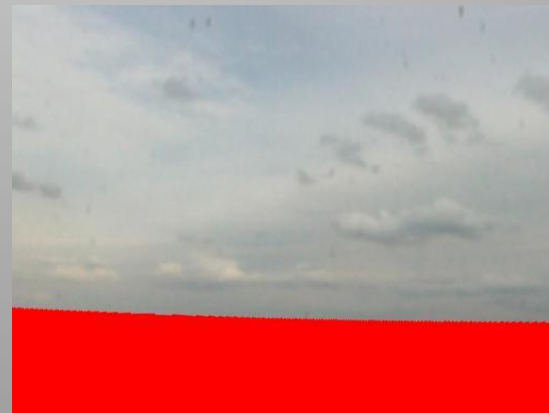
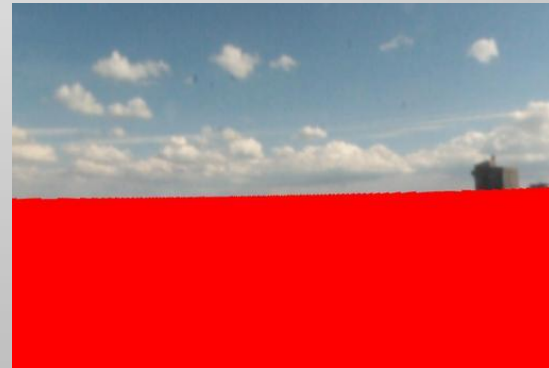




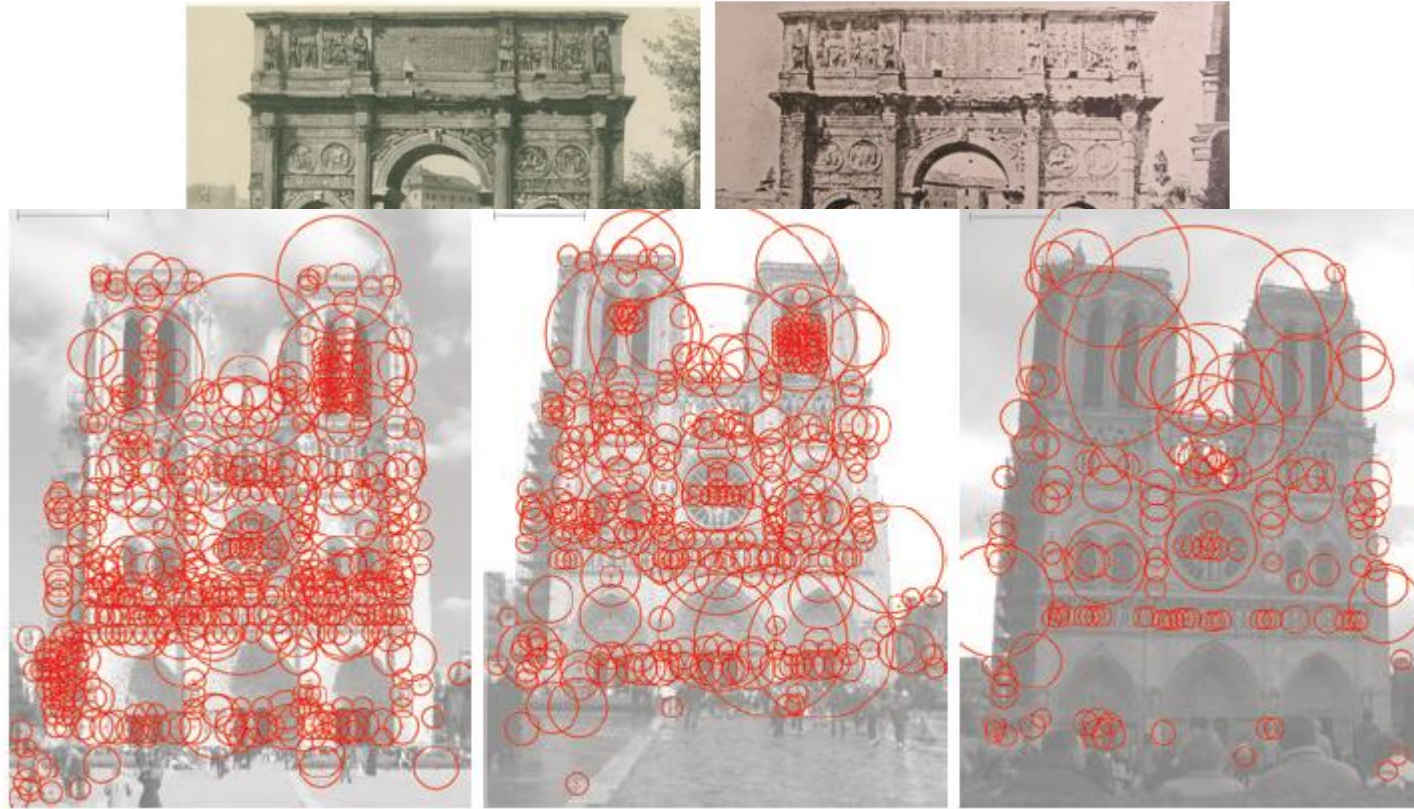
Input photo



Best matching webcam frame

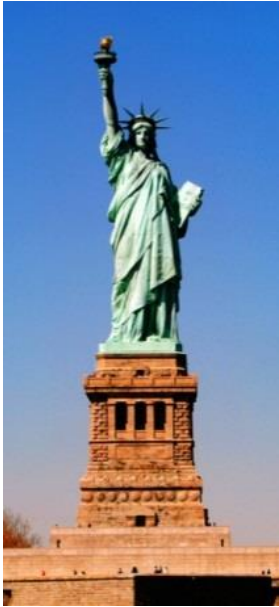


Matching features across time



Next steps

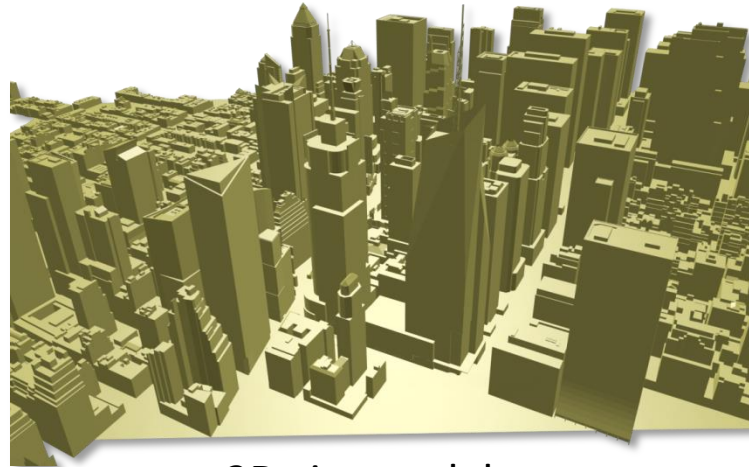
Scene appearance



Using geographic data



OpenStreetMap



3D city models

NOAA NATIONAL CLIMATIC DATA CENTER
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Quick Links

- Land-Based Station
 - Datasets
 - Find a Station
 - Station Metadata
 - Climate Data Online
 - Data Publications
- Satellite
- Radar
- Model
- Weather Balloon
- Marine / Ocean
- Paleoclimate
- Severe Weather

HOME > DATA ACCESS

Land-Based Station Data

Land-based (*in situ*) observations are collected from instruments sited at locations on every continent. They include temperature, dew point, relative humidity, precipitation, wind speed and direction, visibility, atmospheric pressure, and types of weather occurrences such as hail, fog, and thunder. NCDC provides a broad level of service associated with *in situ* observations. These include data collection, quality control, archive, and removal of biases associated with factors such as urbanization and changes in instrumentation through time. Data on sub-hourly, hourly, daily, monthly, annual, and multiyear timescales are available.

- Datasets and Products
 - Access NCDC's land-based datasets directly.
- Find a Station
 - Locate a station by using either a map tool or a location and data search tool.
- Station Metadata

Measuring instruments used for current observations and data reporting

Weather data

MAP LEGEND

- Makes all regular stops.
- SNOW route/Ruta para casos de nieve.
- TIME POINT/INTERMEDIAS: Street intersection used for time schedule reference point listed at the top of time columns to estimate bus arrival and trip times.
- TRANSFER POINT/LUGAR DE TRASBORDO: Route intersection for transferring to the connecting route or routes indicated.
- TIME POINT/TRANSFER POINT, INTERMEDIAS/LUGAR DE TRASBORDO.
- PARK & RIDE: Designated free parking area with direct bus service to major commercial centers.
- LANDMARK: A significant geographical reference point.

Northgate Transfer Center	16	68	347
University District	45	245	346
University District	41	303	555
University District	66	345	556
University District	67	346	

University District Transfer Point

University of Washington

Bus schedules

Relating geographic data to vision



- Which direction is north?
- What is the shape of the buildings?
- What was the weather like?
- Where are streets?
- What is the #51 bus schedule in Rome?

Goal: Integrate images into this ecosystem of geographic data

Understanding scenes over time



OpenSurfaces

Sean Bell, Paul Upchurch, Noah Snavely, Kavita Bala
Cornell University

Statistics

	Good	All
Labeled Scenes	25,357	91,876
Whitebalanced Photos	17,839	24,771
Segmentations	70,005	103,513
Planar Segmentations	36,482	70,005
Named Materials	56,625	68,761
Named Objects	31,697	42,203
Rectified Textures	16,829	22,219

Materials



Reflectances



Textures



<http://opensurfaces.cs.cornell.edu/>, SIGGRAPH 2013

Demo

Summary

- Massive image collections can help reveal information about our world
- We're taking steps toward organizing this massive data source
- Lots of interesting challenges

Acknowledgements

- Sean Bell
 - Daniel Cabrini Hauagge
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 - Andrew Owens
 - Chun-Po Wang
 - Kyle Wilson
-
- Yunpeng Li
 - Dan Huttenlocher
 - David Crandall
 - Kavita Bala

Thank you!

More information at

<http://www.cs.cornell.edu/~snave/>

