Multi-View Geometry and Computational Photography Using Non-Classical Cameras

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Welcome

Course WebPage :
http://www.umiacs.umd.edu/~aagrawal/ECCV12Tutorial/index.html

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Goals of this Tutorial

- Focus on understanding concepts in non-classical cameras
- Thinking beyond pixels in ray-space
  - Central, Axial, Non-central, 4D Lightfield,
- Capture: New ways of sampling the visual world
  - Mirrors, Refractors
- Modeling: How to practically use these cameras
  - Calibration, pose/motion estimation, analytical forward projection
- Synthesis: 3D Reconstruction, refocusing, view interpolation
  - GPUs for speed up

Schedule

9:15 Introduction and Geometry of Rays

9:45 Modeling Non-Classical Cameras

10:30 Break

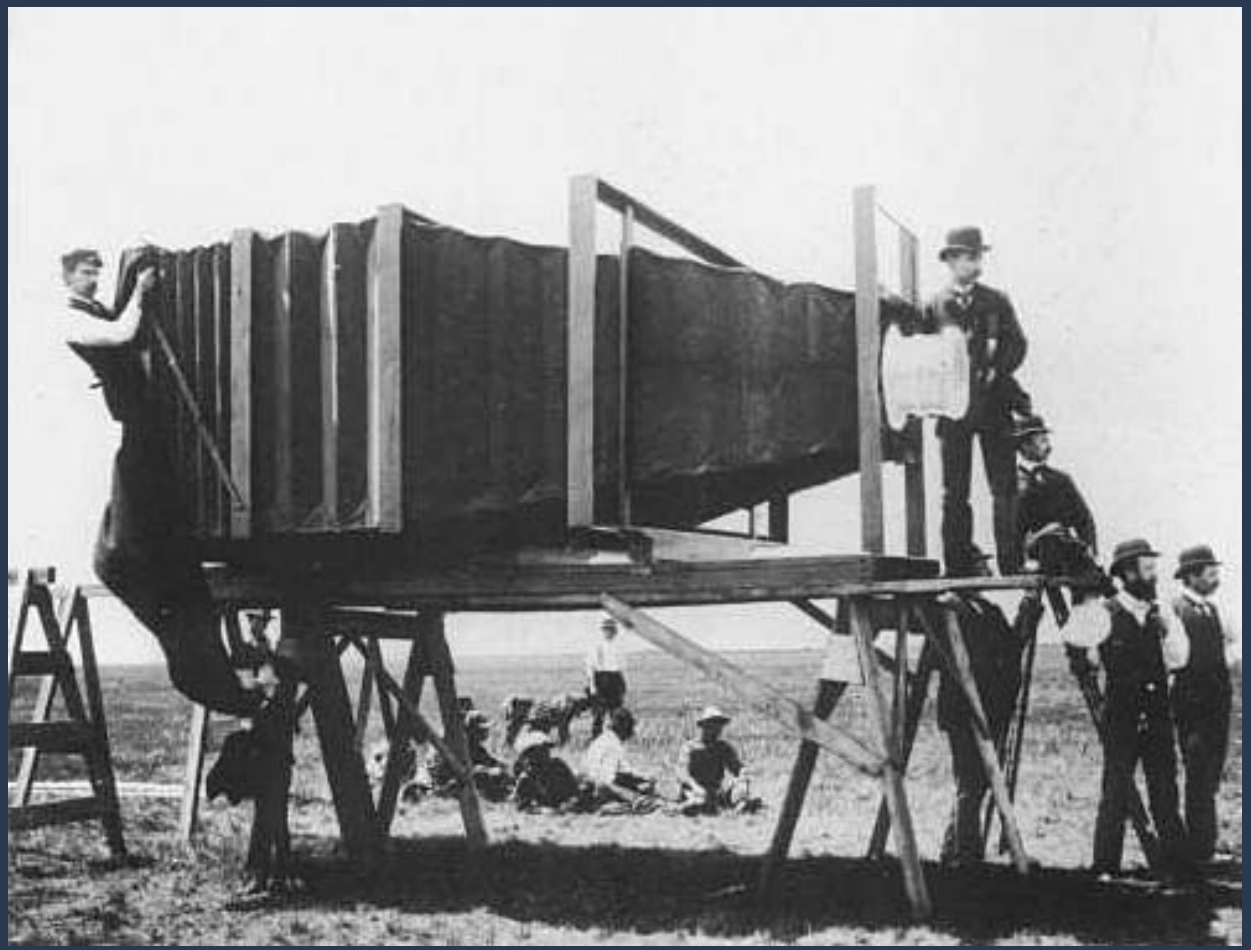
10:45 Calibration and Multi-View-Geometry

11:30 Break

11:45 Synthesis/Reconstruction

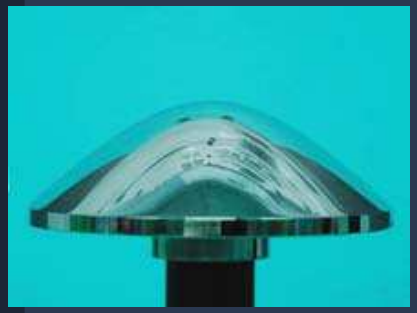
12:30 Future Directions and Discussions

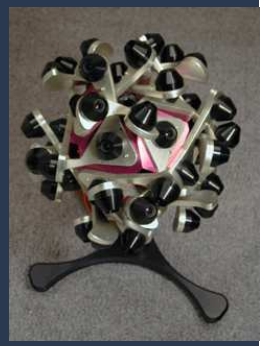
Conventional Camera



Introduction

There exist lots of camera designs:





Introduction

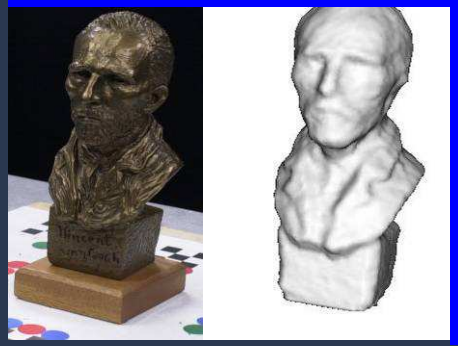
Some applications:

Automatic Vehicle Navigation

Aerial Mosaics

3D Video Conferencing

Shape Computation



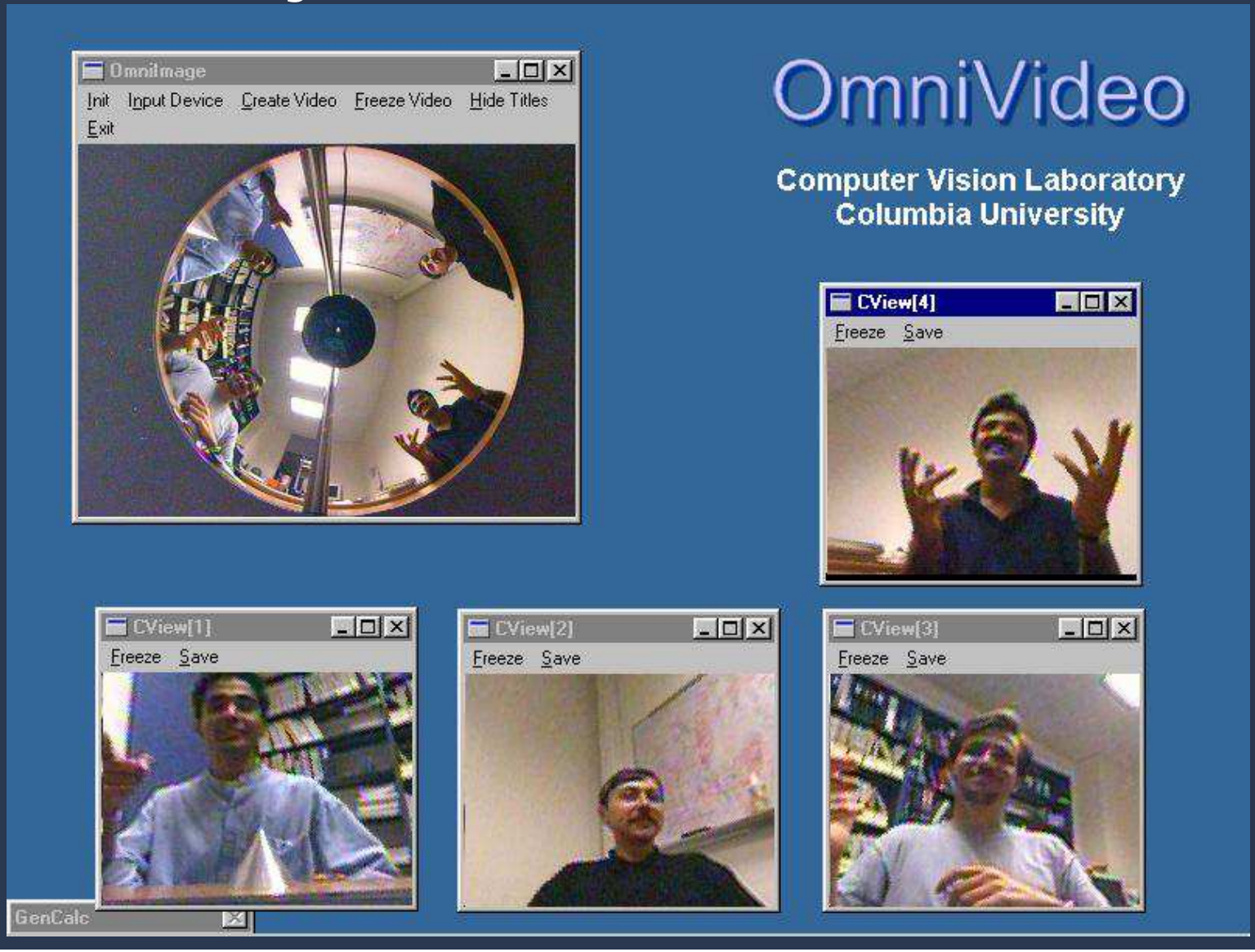
Surveillance

Panoramic Imaging

- Many applications require/benefit from a specific type of imaging system
- Work underlying this tutorial started by considering omnidirectional systems (large field of view)

Introduction

Videoconferencing:



Introduction

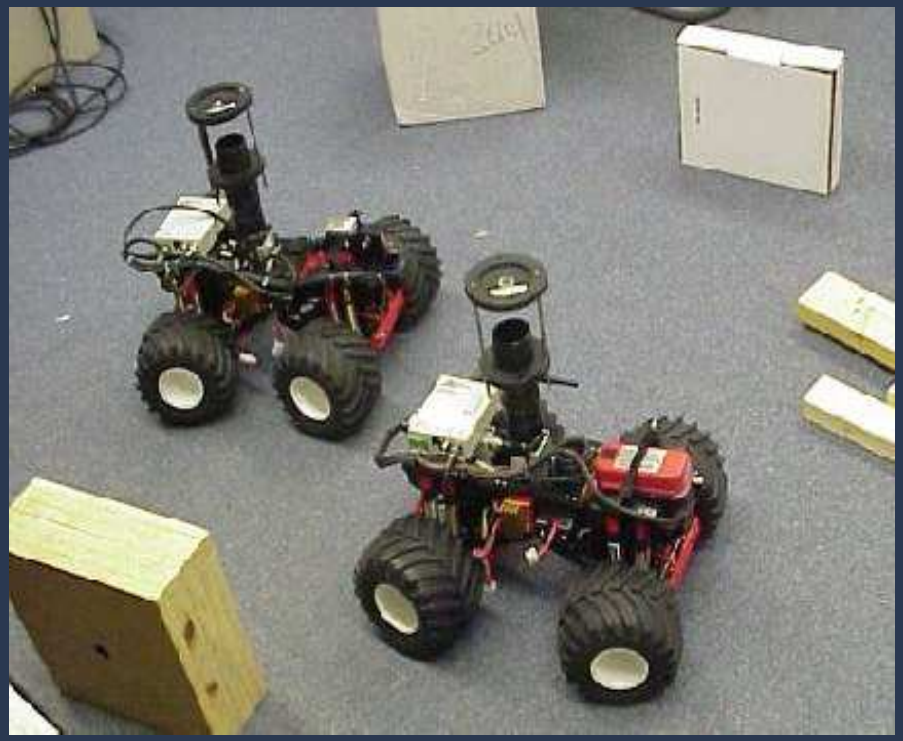
Surveillance:

Introduction

Surveillance:

Introduction

Robot navigation (including obstacle avoidance):



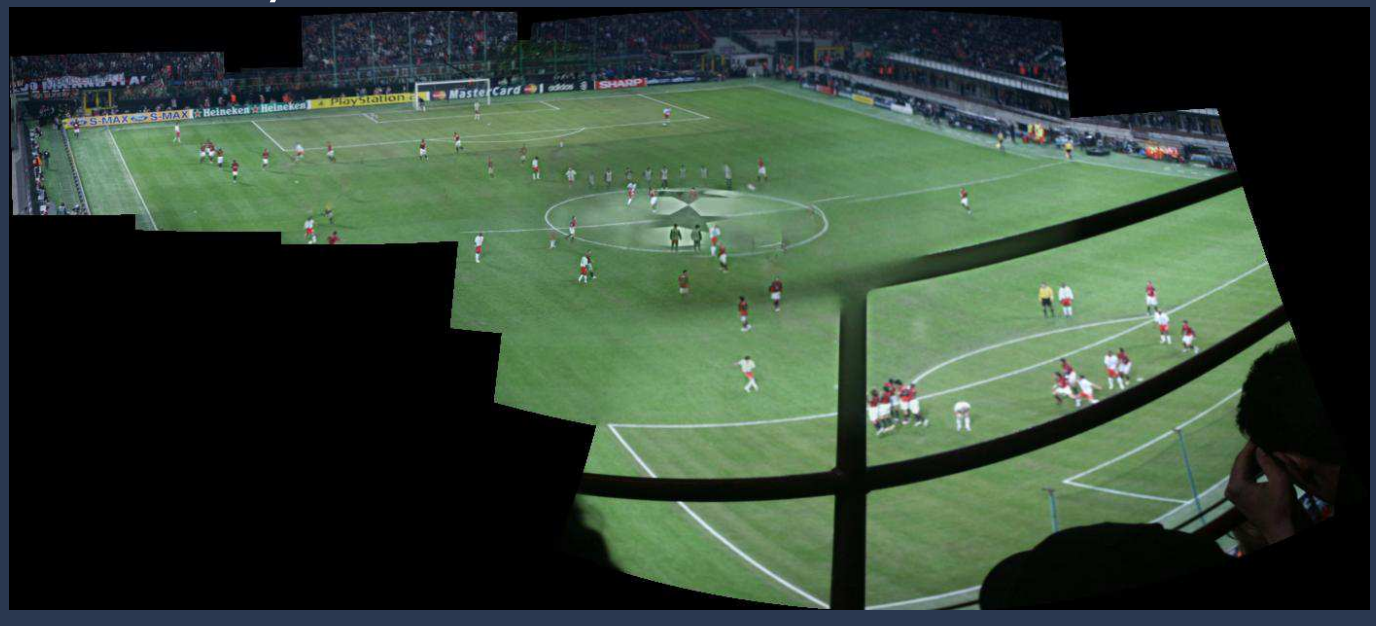
Taylor et al. – GRASP

Santos Victor et al. – ISR/IST

Introduction

Panoramic imaging, here mosaicing:

Problematic for dynamic scenes:



Introduction

Panoramic imaging with omnidirectional cameras:

Fisheye

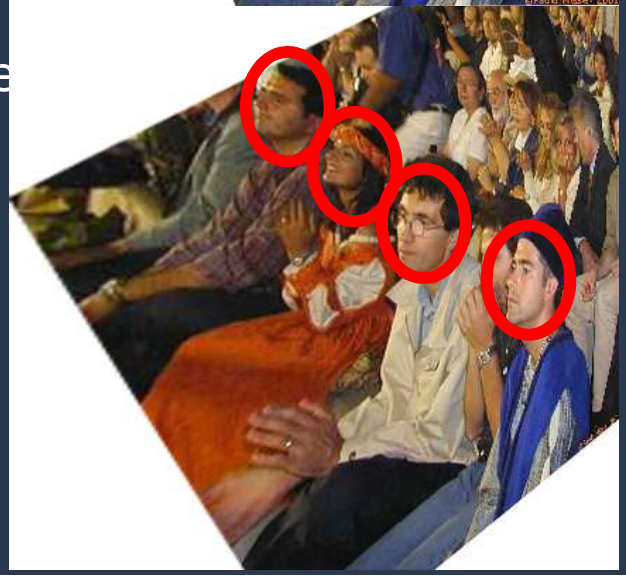
Catadioptric

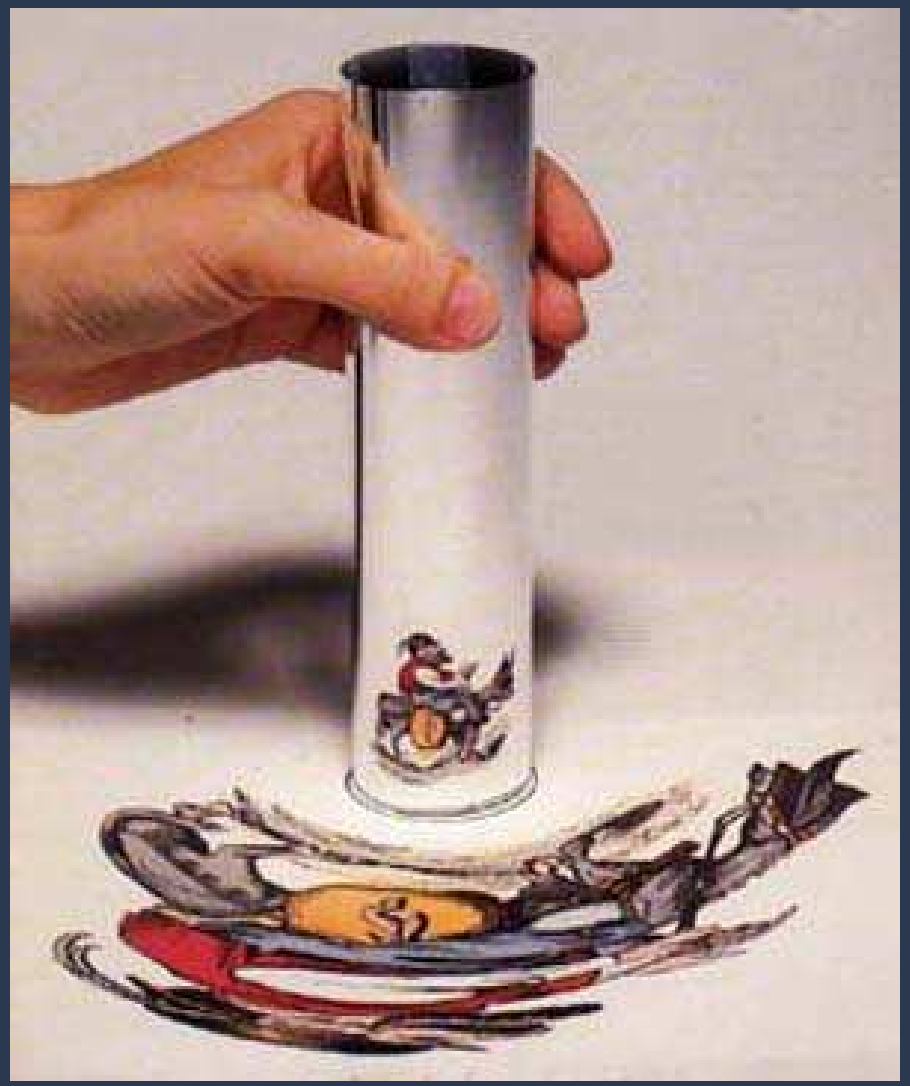
Introduction

Design of tailor-made imaging systems:

Usual:

De





Introduction

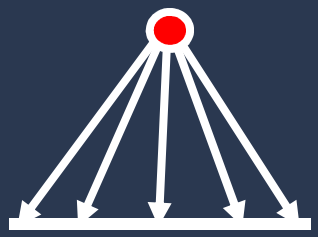
Design of tailor-made imaging systems:

By Julian Beever

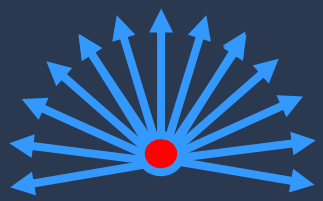
Introduction

Different cameras "sample light rays" in different ways:

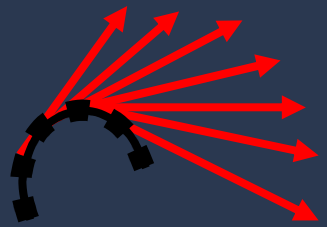
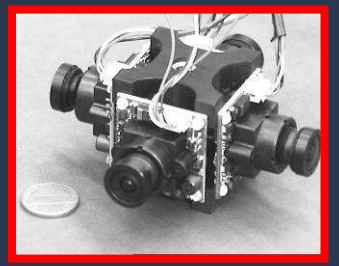
Perspective cameras:



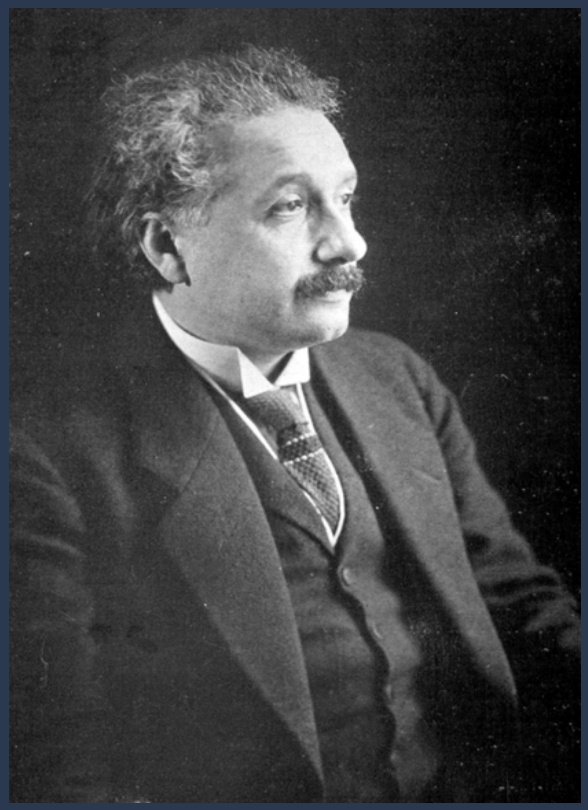
Single viewpoint cameras:



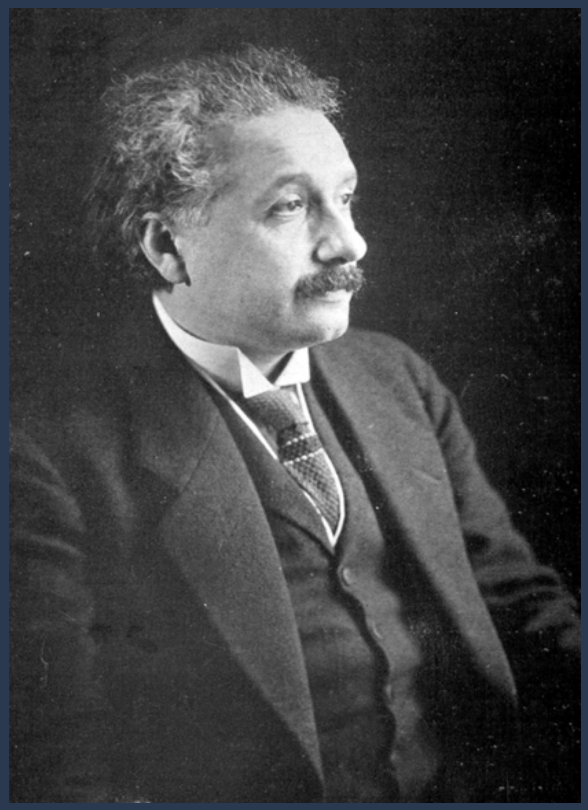
Non-single viewpoint cameras:

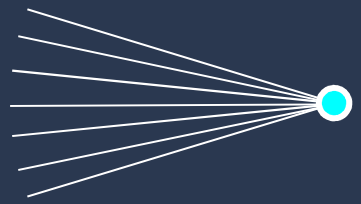



Can you see any similarity between the two images?



Both the images sample the same set of light-rays!
In this talk, ray space is more important than pixels.



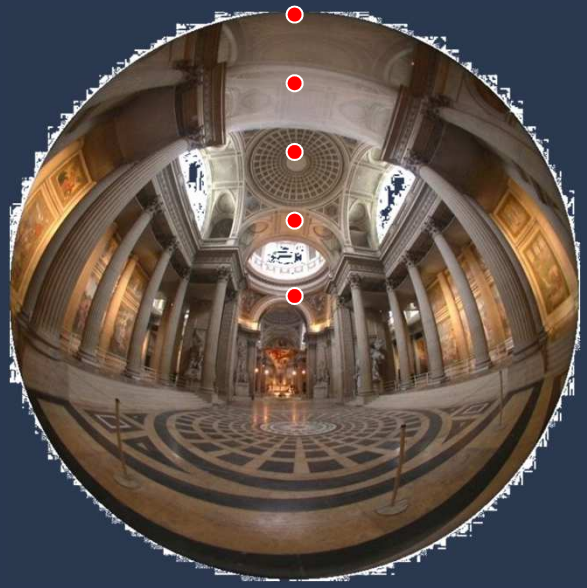


Both set of rays obey pinhole geometry

Imaging Models

Single viewpoint cameras:

- Fisheyes
  - several models have been proposed (ad hoc or derived from actual lens designs)
  - e.g. equi-angular model (existence of distortion center and optical axis such that distance of image point to distortion center is proportional to angle between projection ray and optical axis)

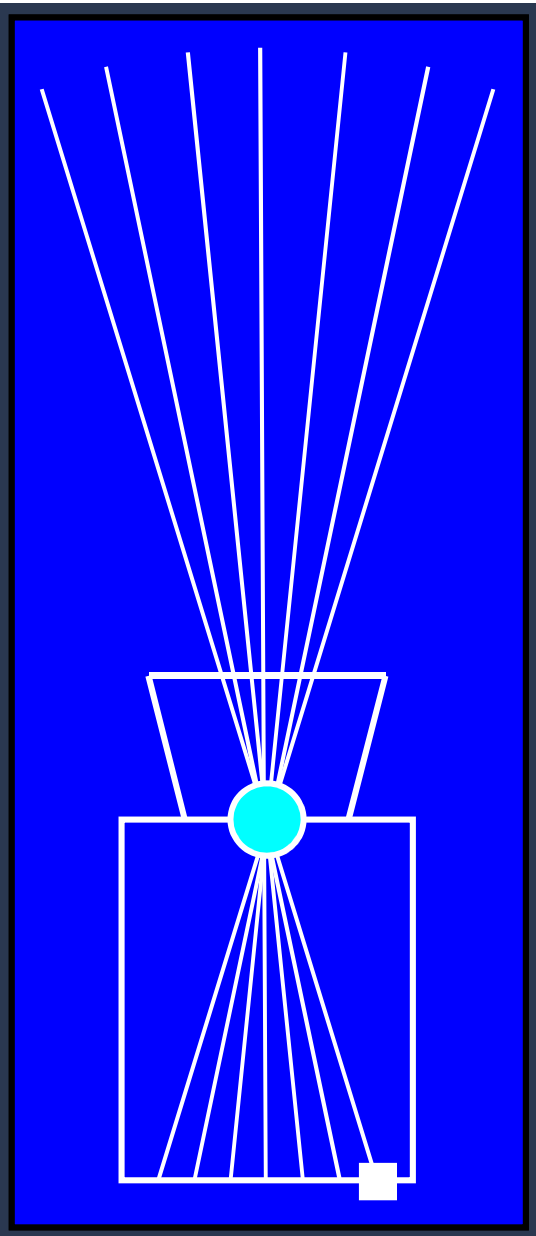


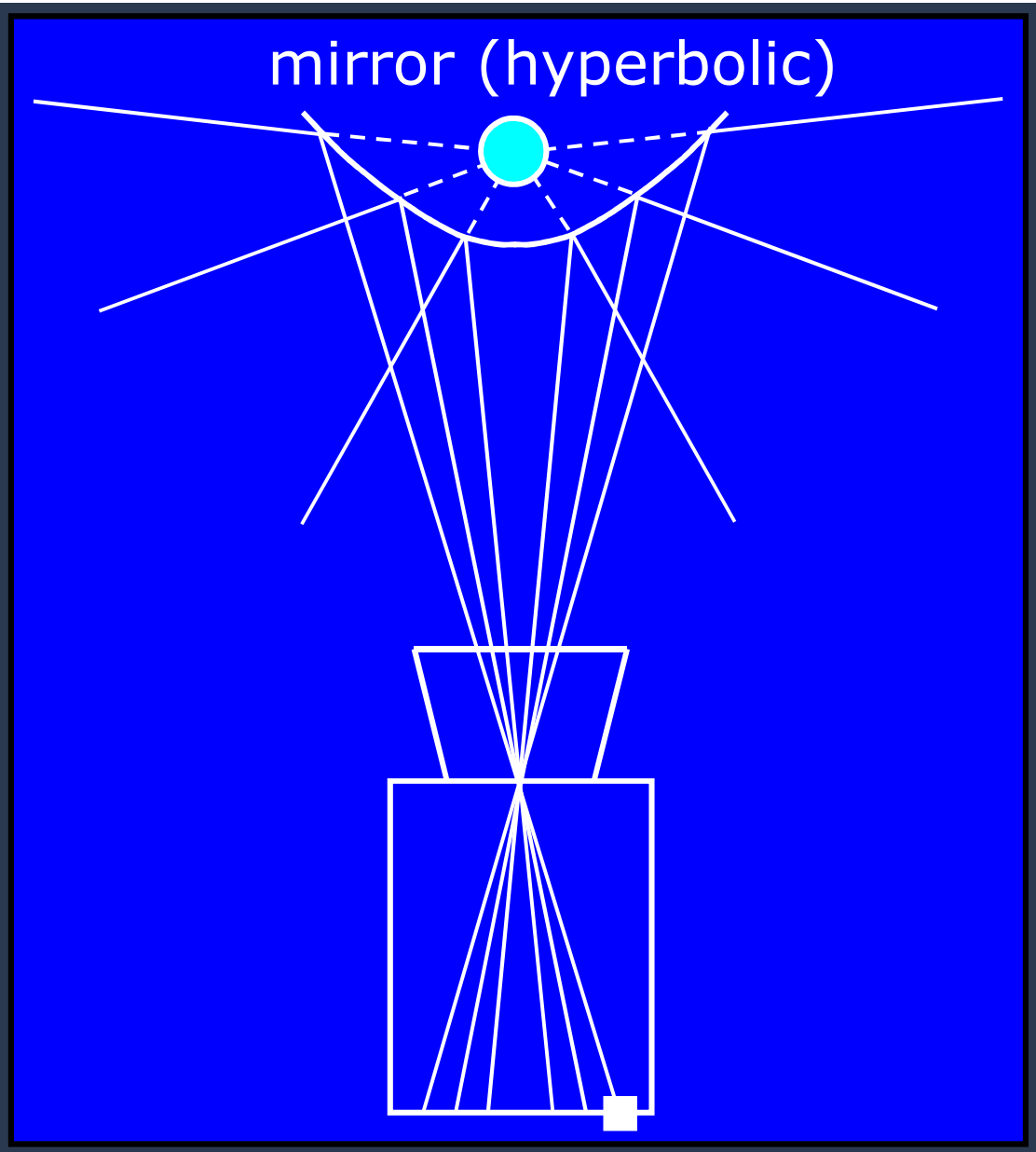
Imaging Models

Catadioptric systems (camera + mirror):

- Knowledge of mirror shape and position relative to camera, together with camera's interior orientation, allows to perform back-projection

Imaging Models





Imaging Models

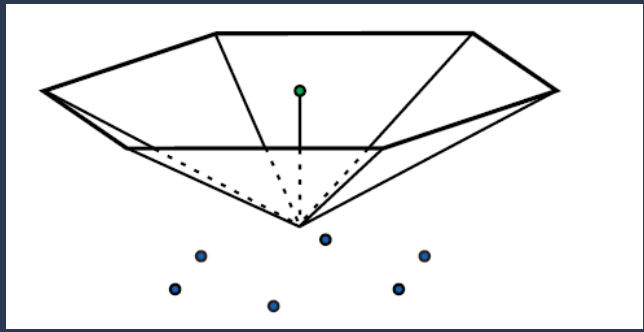
Single viewpoint cameras:

- Central catadioptric system using **multiple** planar mirrors and cameras (so-called Nalwa pyramid)

  - perspective camera + planar mirror
    ≡ perspective camera with effective optical center on the other side of the plane

  - Nalwa pyramid: assemble pairs (camera, mirror) such that effective optical centers coincide

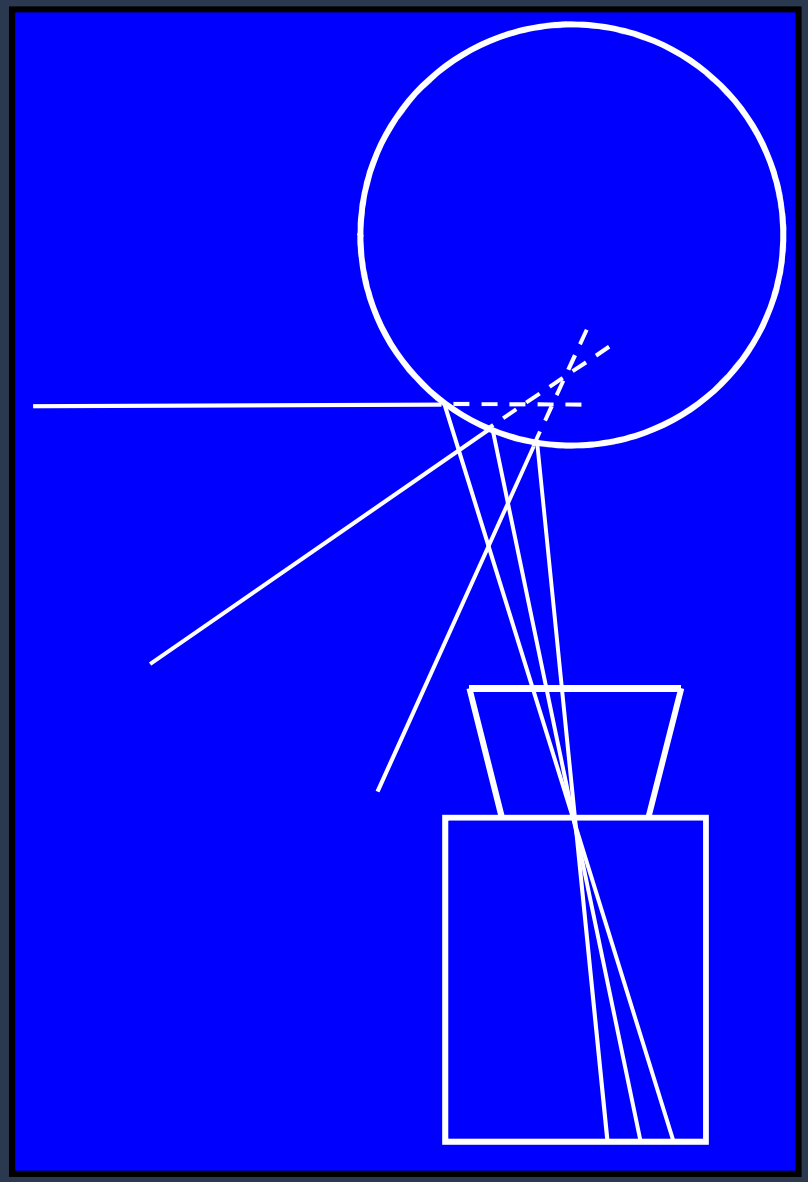
→ possibility to construct a high-resolution panoramic image



Imaging Models

Non-single viewpoint cameras:

- **Non-central** catadioptric systems
  - spheres, cones or any non-quadric mirrors give non-central system: projection rays do not intersect in a single point
  - calibration approaches have been developed for individual systems
  - example:
    - mirror that leads to equi-angular imaging model

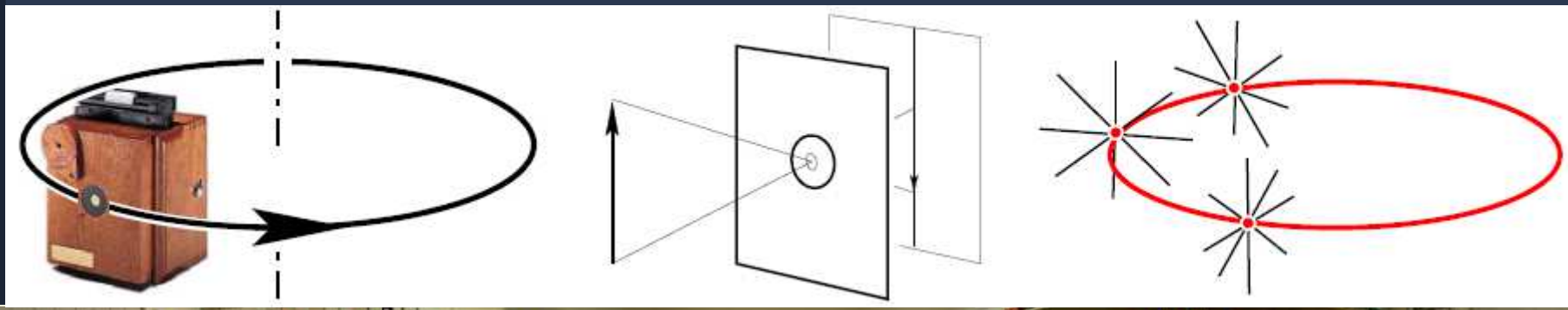


Imaging Models

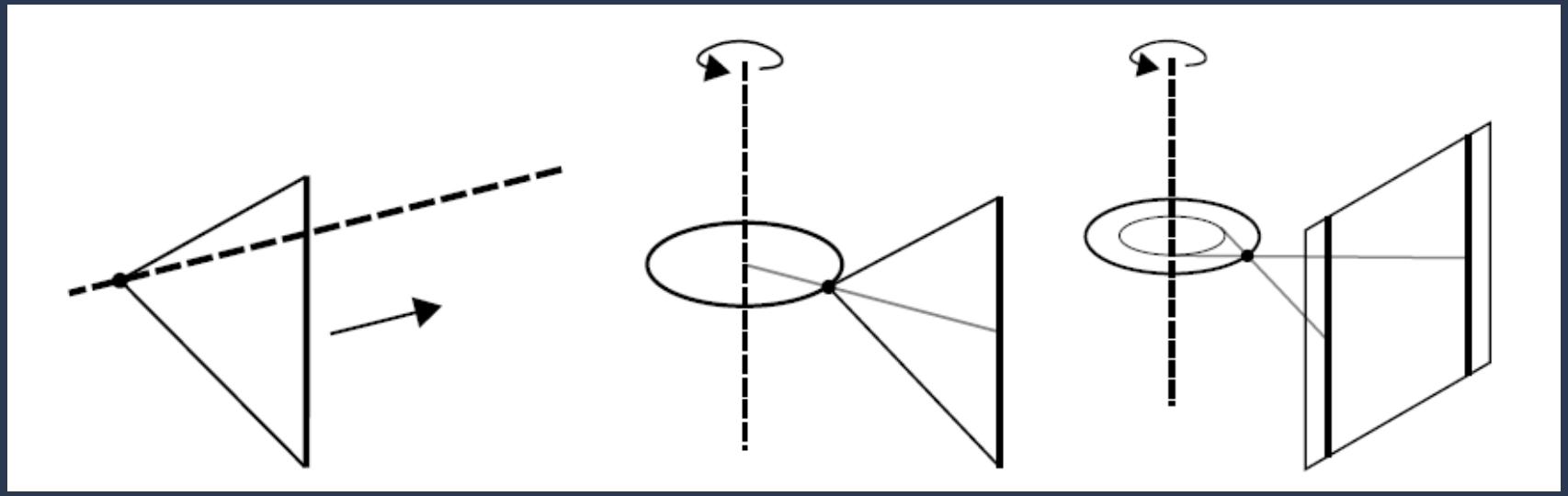
Other non-single viewpoint cameras:

- Pushbroom cameras
  - Moving linear camera acquires 1D images that are stitched together to a 2D image (motion is usually a lateral translation)

- So-called non-central mosaics
  - Acquired by a camera rotating about an axis not containing the optical center (from each image, take one or several columns of pixels and stitch them all together)



Geometry of Non-Central Slit Imaging



Linear Pushbroom acquisition

Circular non-central panaroma

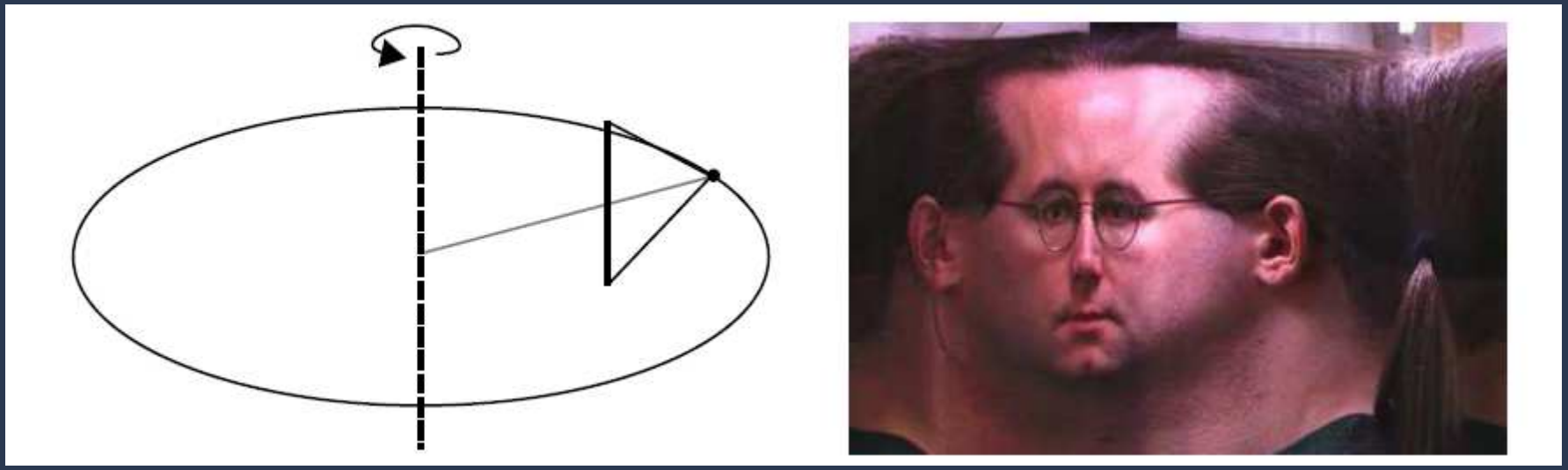
Dual slit principle to generate stereo panaroma

[Sturm et al. Camera Models and Fundamental Concepts Used in Geometric Computer Vision, 2011]

Imaging Models

Other non-single viewpoint cameras:

- So-called multi-perspective images
  - Acquired like a non-central mosaic but with camera looking inwards

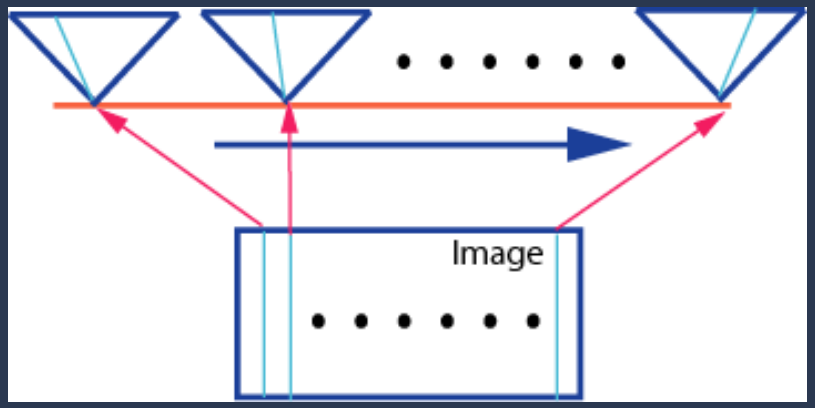


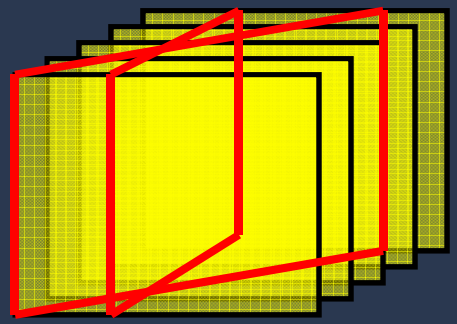
Cyclograph generation using inward looking cameras

Example of cyclograph, courtesy of Steve Seitz

Multiperspective Cameras

- Pushbroom and Cross-slits
  - [Zheng & Tsuji ’92], [Gupta & Hartley ‘94, ’97]
  - [Seitz ’02], [Pajdla ‘02], [Zomet et al ’03]





Multiperspective Images

[Cubism]

[M.C. Escher]

[Rademacher & Bishop '98]

- Images that depict more than can be seen from any single viewpoint, yet remain interpretable

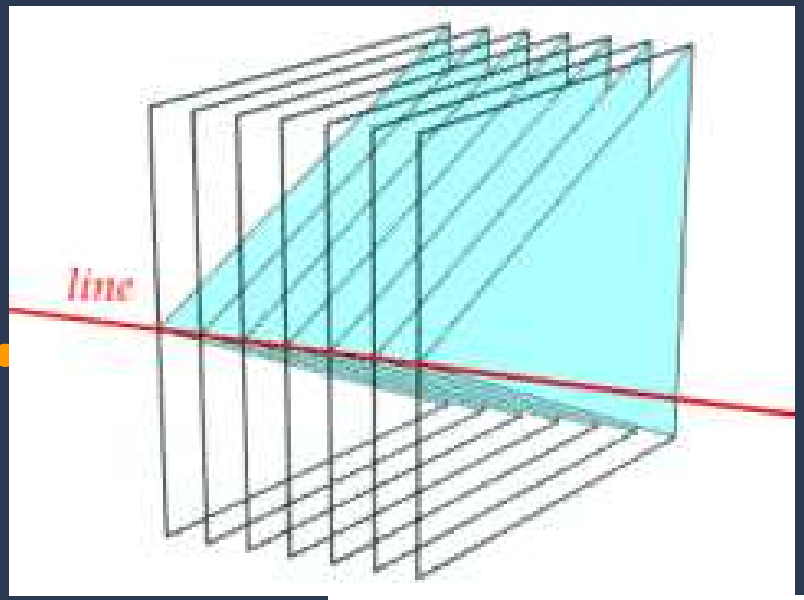
Multiperspective Panoramas

Disney's 1940 film *Pinocchio*

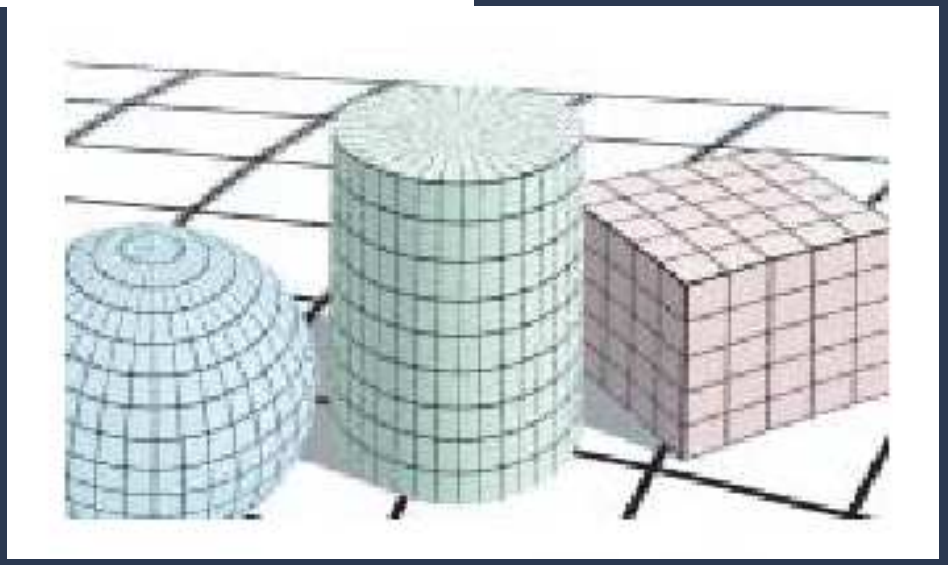
Applications: cel-animation

Computer Generated: [Wood et al., '97]

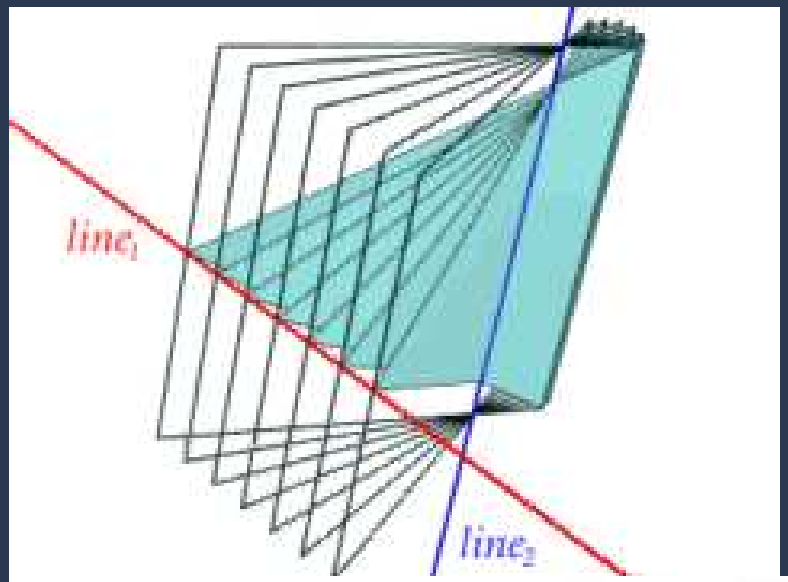
Linear Pushbroom Cameras



[Gupta & Hartley ‘94, ’97]

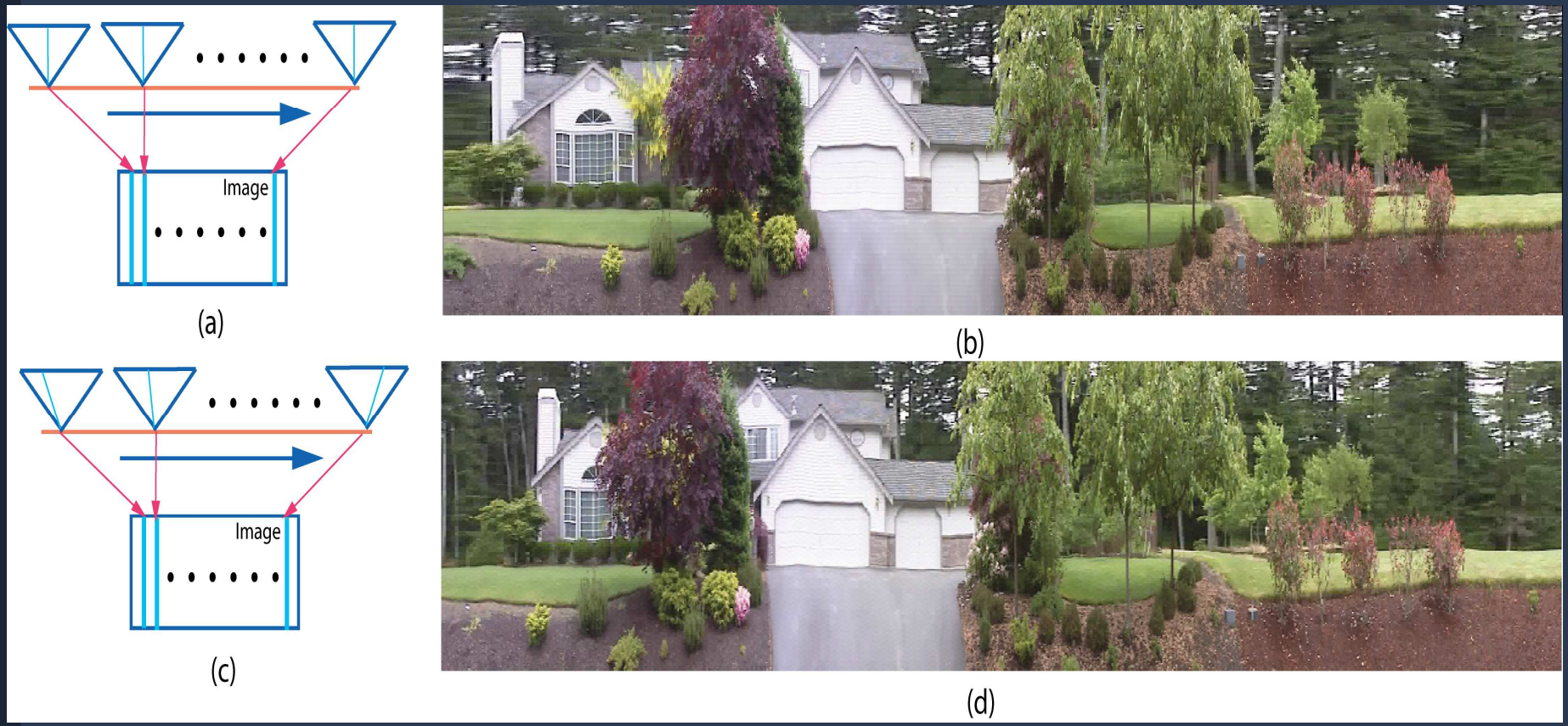


Cross-slit Camera



[Zomet, Feldman, Peleg, & Weinshall ’03]

Column Stitching



Courtesy of Steve Seitz

Construction by a Strip Camera

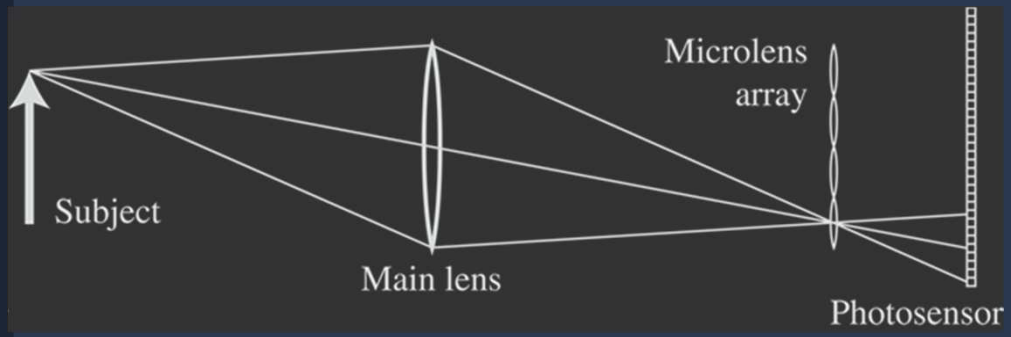
Piecing together different GLCs

Román et al. '04

Photomontage

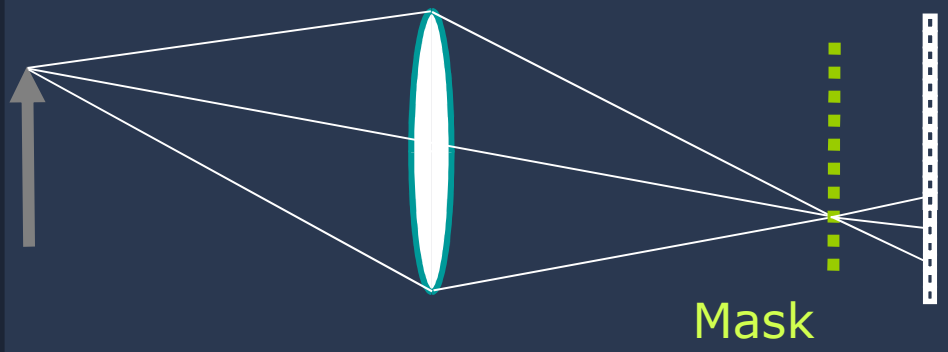
Agarwala et al. '06

Single Shot Light Field Cameras



Adelson and Wang, 1992, Ng et al. 2005

Using Lenslets, Ng et al. 2005



Veeraraghavan et al. 2007

Using Mask

Light Field Cameras

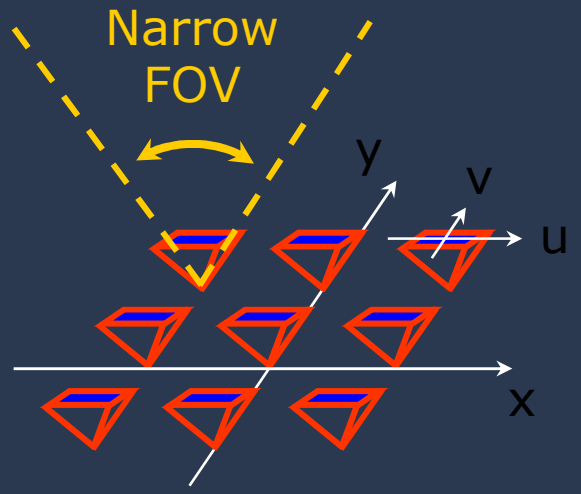
- Camera arrays / Hand-held light field cameras
  - Represented by a set of perspective cameras
  - Typically capture narrow field of view (FOV) light fields

[Wilburn et al. 05]

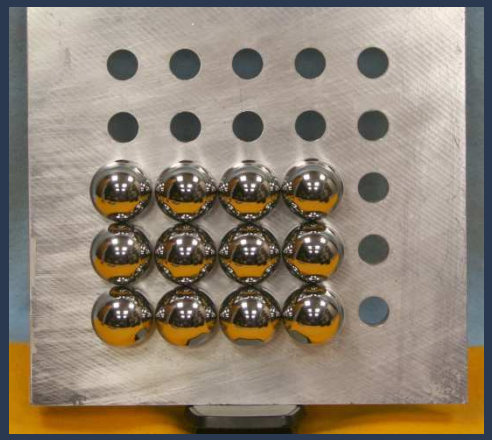
[Ng et al. 05]

[Georgiev et al. 06]

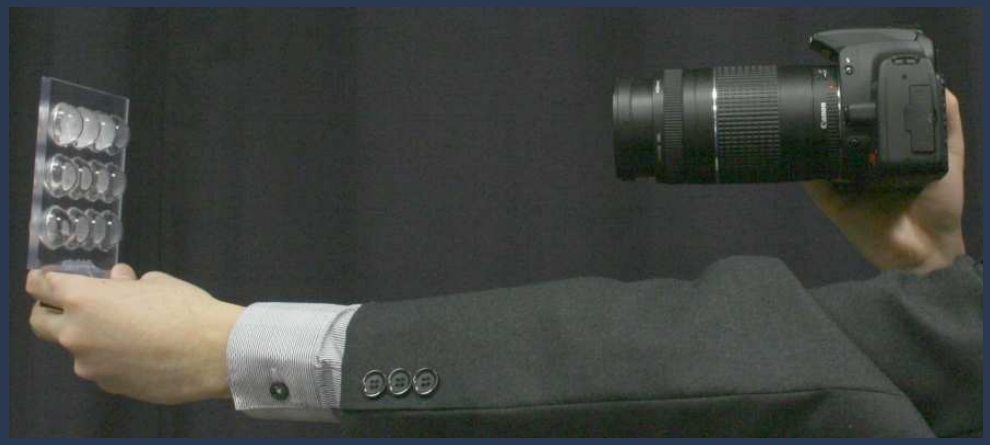
[Veeraraghavan et al. 07]



Wide FOV Light Field !



Spherical Mirror Array



Refractive Sphere Array

Applications: 3D Reconstruction

[Courtesy of Shree Nayar]

Capturing 3D Texture

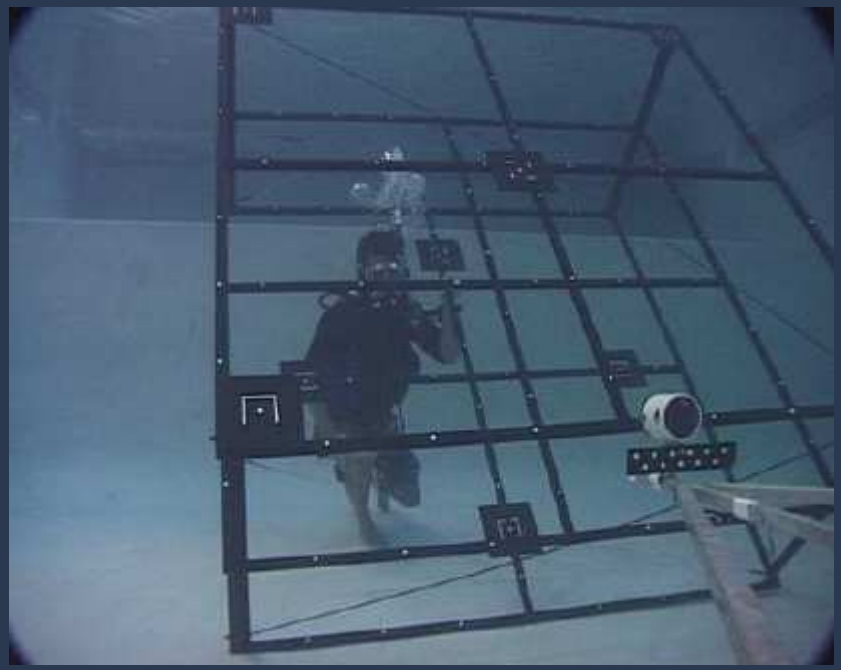
Bark Bread

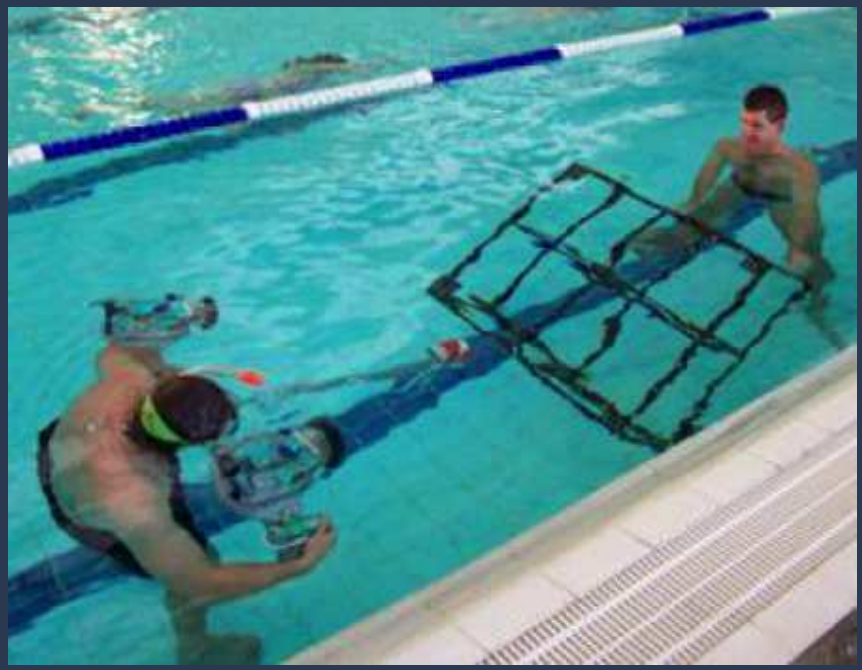
Imaging with Refractions

Imaging through refractions

- Not the same as pinhole imaging
- Pinhole model (central approximation) is not valid

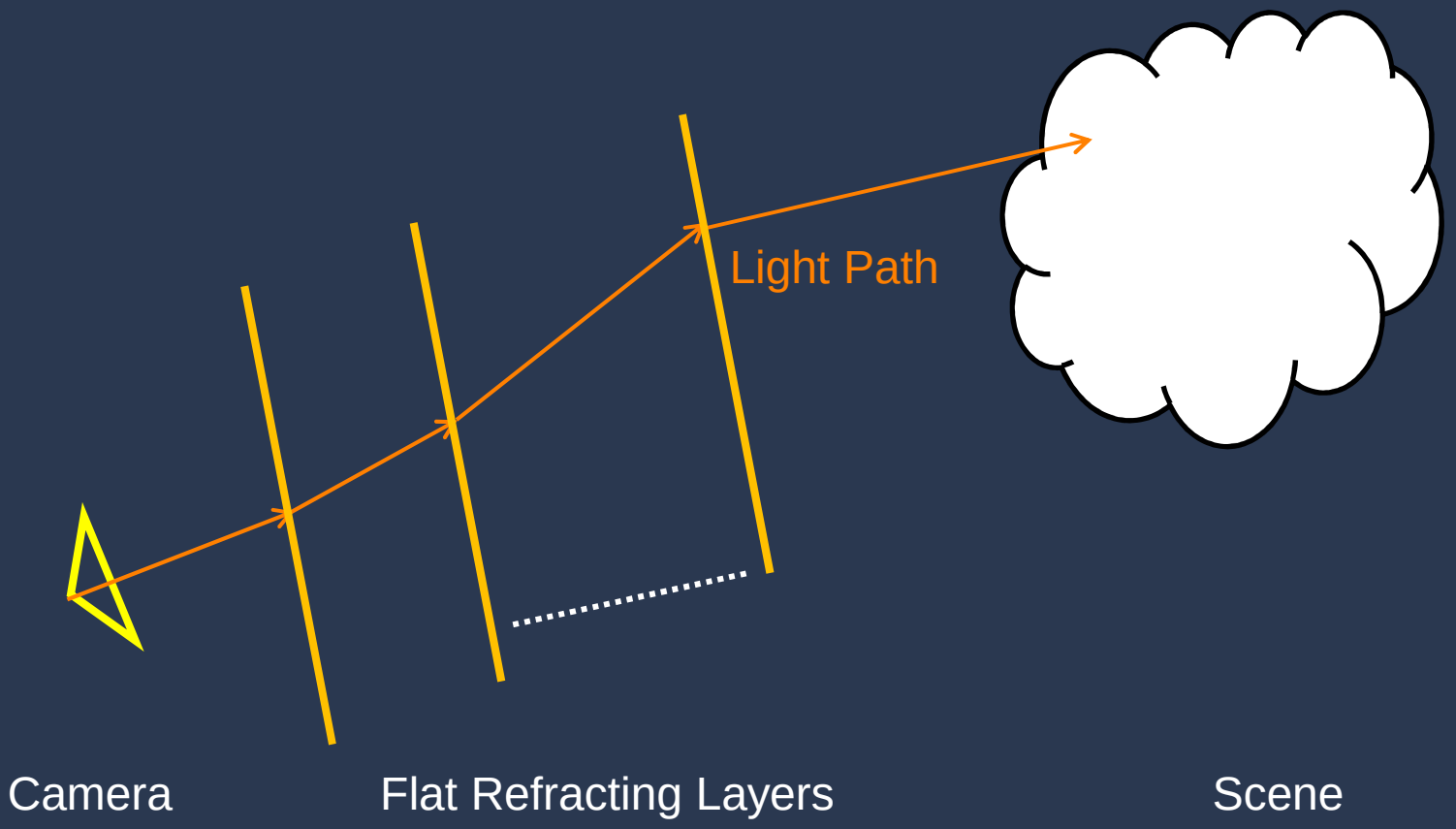
Calibration





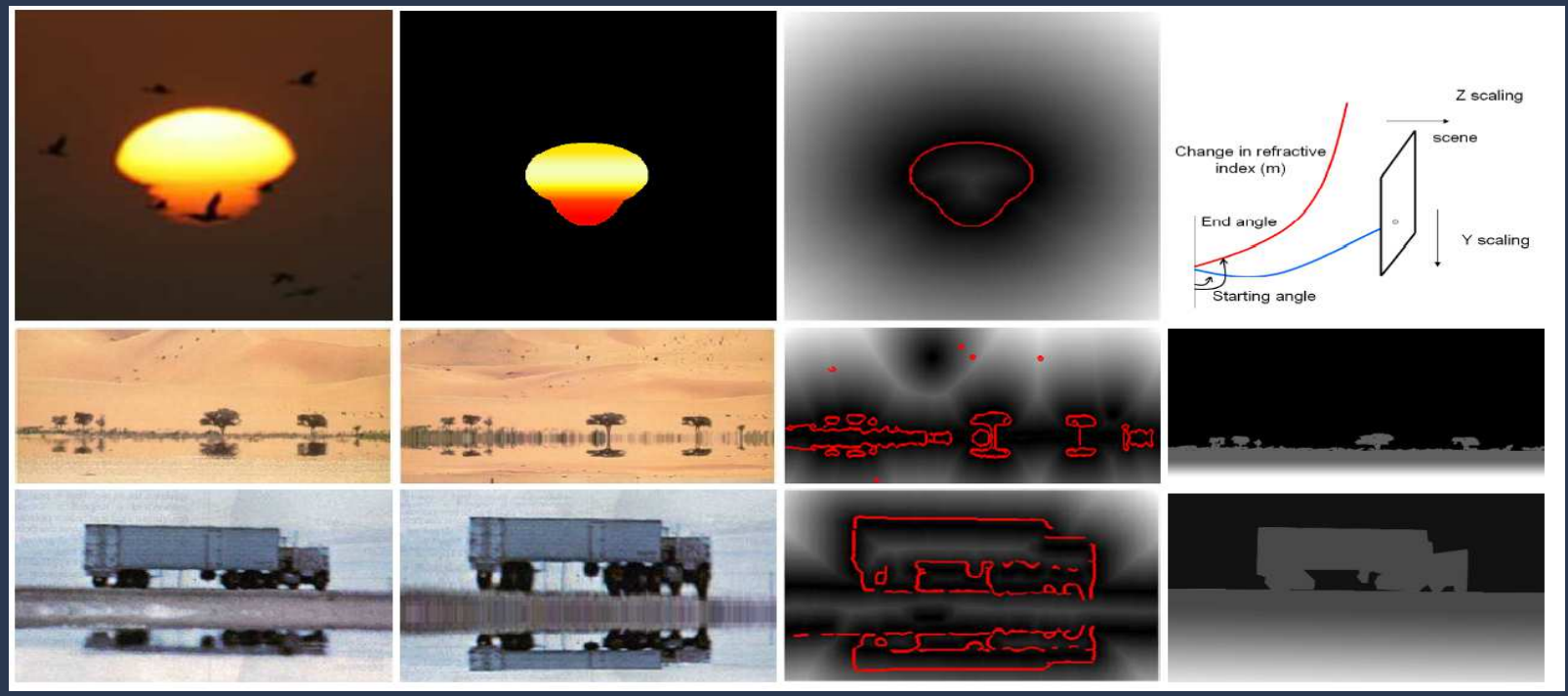
Source: Shortis et al. SPIE 2007

Multi-Layer Flat Refractive Systems



[Agrawal et al. CVPR 2012]

Modeling Mirages using Light-Paths



Real images of Mirages

Synthesized images of mirages

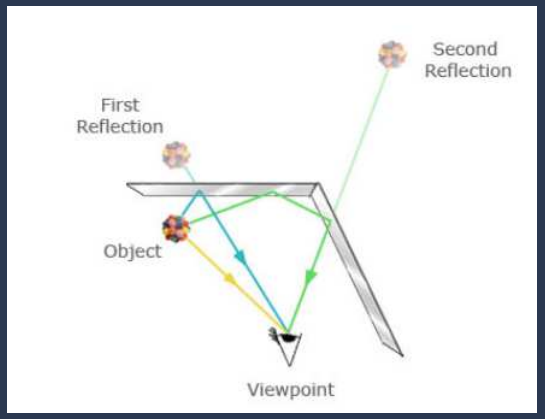
Chamfer Matching

Estimation of planes in the scene

[Ramalingam et al. CVPR 2011]

Toward Light-Paths

An Icosahedron (20 faces)



Every object appears in many places

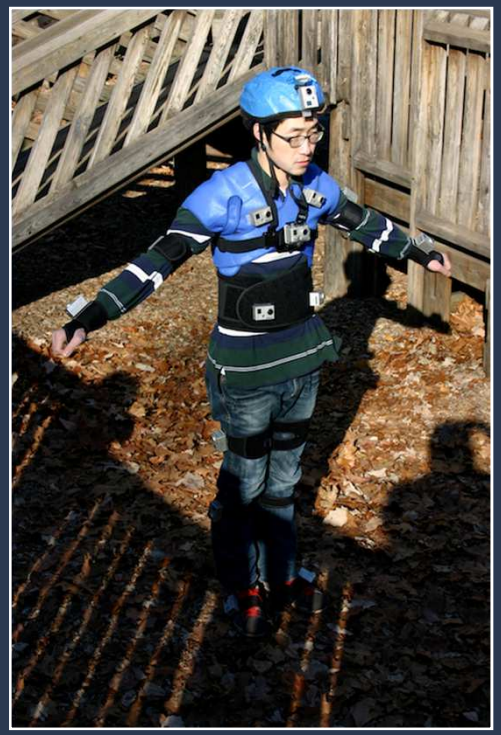
- Make your favorite kaleidoscope and place some known 3D object inside it.
- From the image, can you find the location of the object?

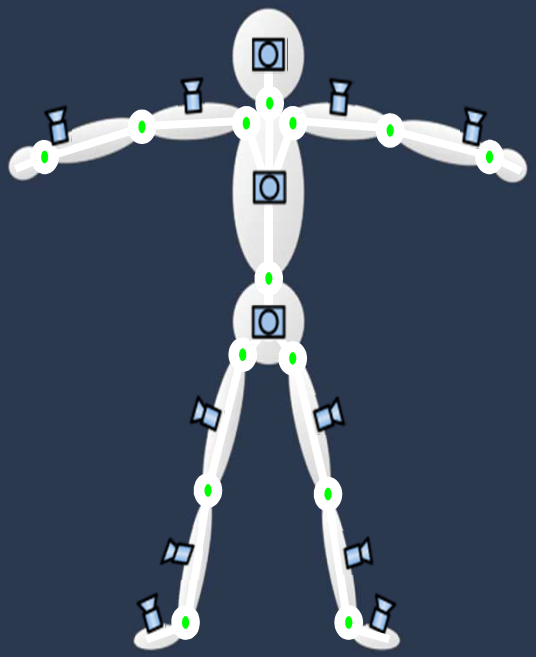
Toward Light-Paths

If Bruce Lee knows the locations of all the mirrors, can he spot his opponent more accurately without breaking the mirrors?

[Movie: Enter the dragon]

Motion Capture using Omni-directional Cameras





Outdoor capture

Global motion

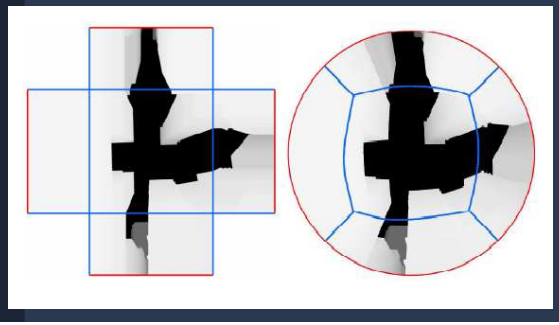
3D structure of environment

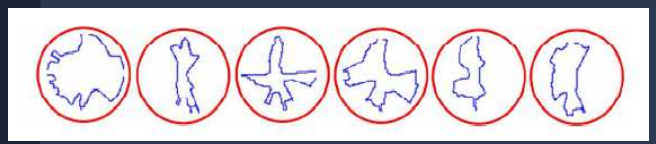
[Shiratori et al. SIGGRAPH 2011]

Applications: SKYLINE2GPS

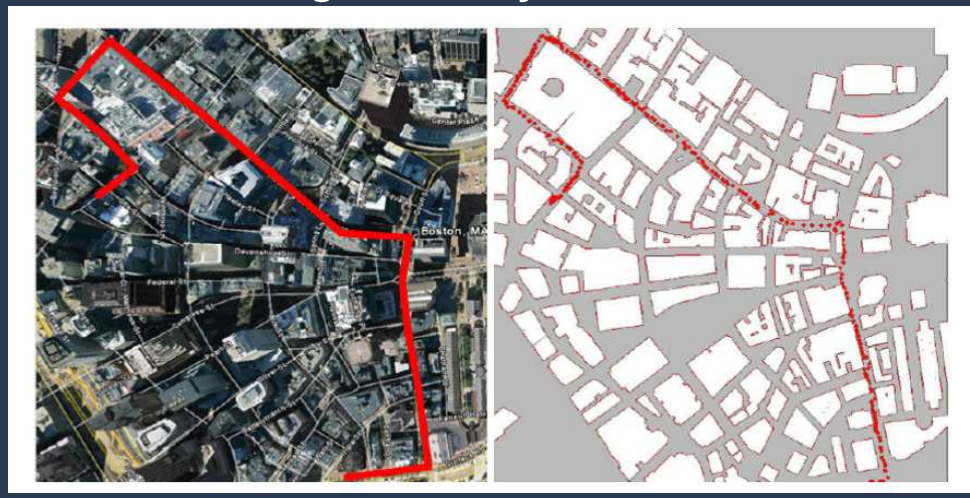
Real Images of Skylines

The location in 3D model where the fisheye image was synthesized.



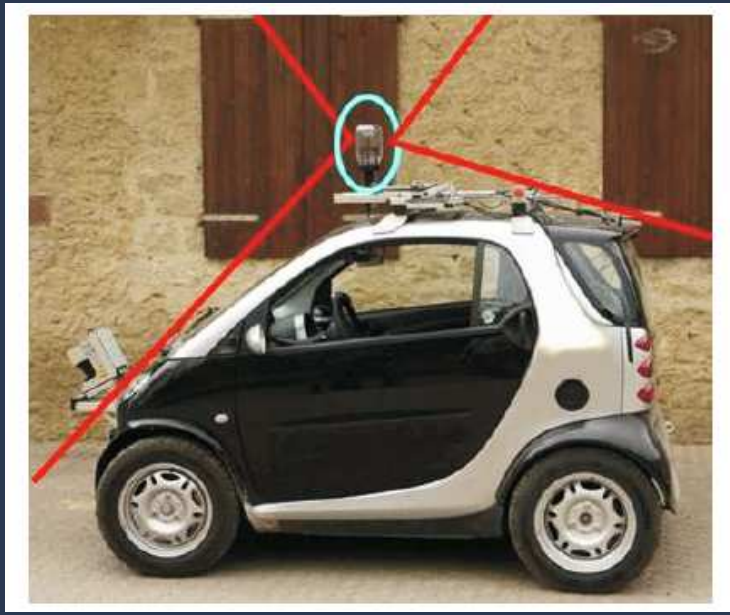


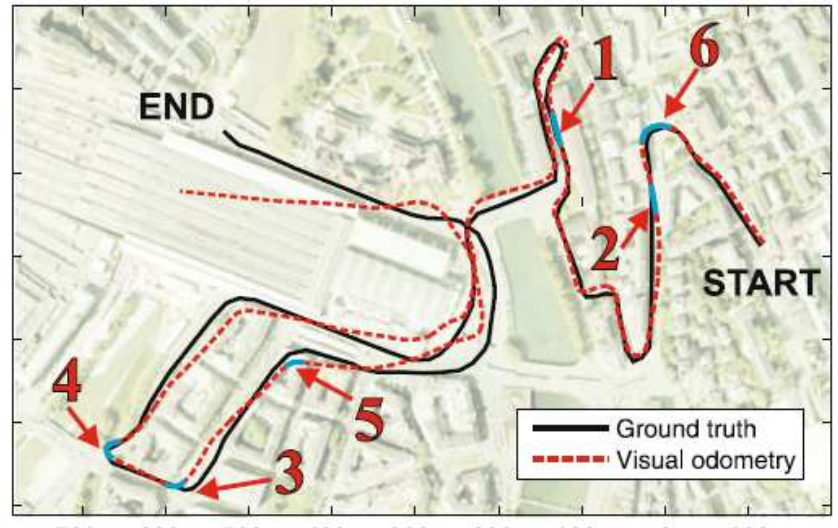
Sample skylines at different locations



Geo-trajectory by matching skylines [Ramalingam et al. IROS 2010]

1-Point SLAM





[Scaramuzza et al. IJCV 2011]

Non-Classical Camera Calibration

Several calibration algorithms and softwares exist for calibration non-classical cameras.

- Scaramuzza's Toolbox
- Christopher Mei's Toolbox
- Tardif et al. plumbline calibration algorithm
- Devernay's calibration Algorithm (Straight lines must be straight)
- Agrawal et al. Underwater Calibration algorithm
- Geyer and Daniilidis Unifying Camera Model
- Ramalingam and Sturm's Generic Calibration Algorithm

Non-Classical Geometric Algorithms

- Agrawal et al. Forward projection algorithms
- Nister et al., Ramalingam et al., Chen et a. Generic pose estimation algorithms
- Stewanius and Nister, Minimal generalized motion estimation algorithms
- Hondong Li’s Generalized motion estimation