Panoramic Imaging and Cinematic VR

Gordon Wetzstein
Stanford University

EE 267 Virtual Reality

Lecture 15

stanford.edu/class/ee267/

Overview

- overview
- panoramic imaging
- stereo / omnistereo panoramas
- camera rigs

Jaunt VR

Jaunt VR

Lytro

Google

Nokia

Facebook

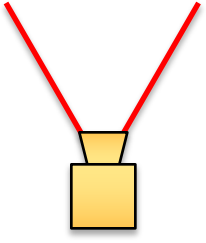
Red

Samsung

Panorama v Stereo Movie v Stereo Panorama

Panorama

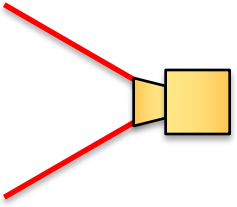
mono & head rotation



Panorama v Stereo Movie v Stereo Panorama

Panorama

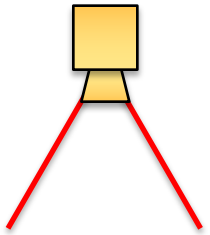
mono & head rotation



Panorama v Stereo Movie v Stereo Panorama

Panorama

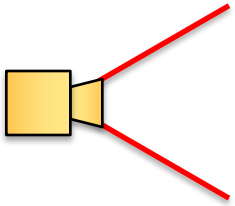
mono & head rotation



Panorama v Stereo Movie v Stereo Panorama

Panorama

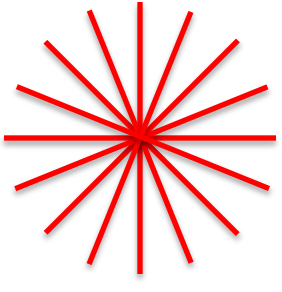
mono & head rotation



Panorama v Stereo Movie v Stereo Panorama

Panorama

mono & head rotation

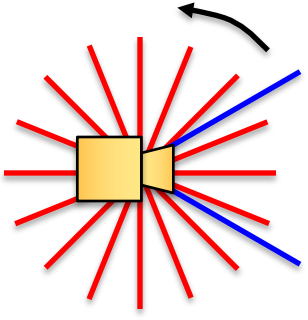


1 center of projection!

Panorama v Stereo Movie v Stereo Panorama

Panorama

mono & head rotation



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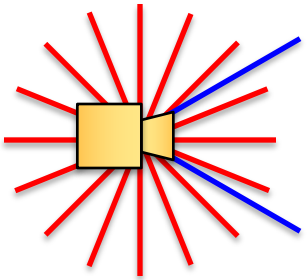
Panorama v Stereo Movie v Stereo Panorama

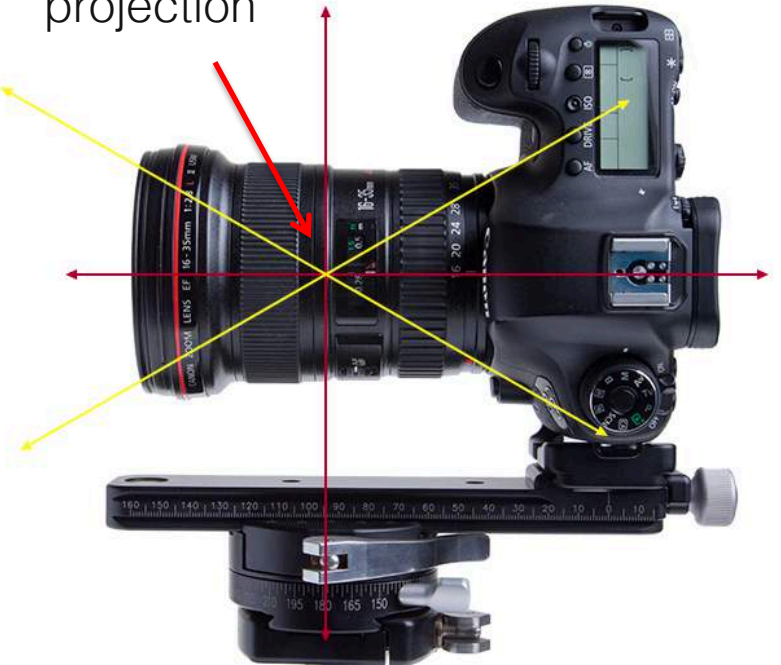
Panorama

mono & head rotation



1 center of projection!

center of projection



Panoramas

Slides from Marc Levoy's excellent CS 178 course

Stitching images together to make a mosaic

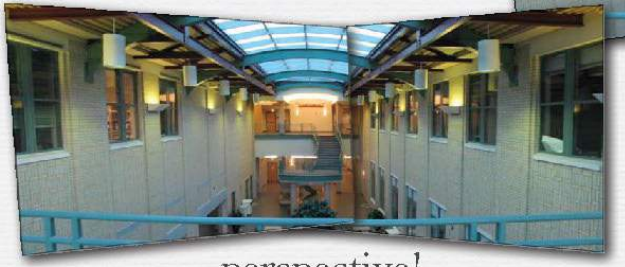
Panoramas

Slides from Marc Levoy's excellent CS 178 course

What kind of transformation do we need?

translation?

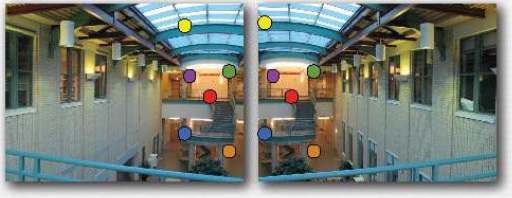
rotation?



perspective!

Slides from Marc Levoy's excellent CS 178 course

Stitching images together to make a mosaic



- step 1: find corresponding features in a pair of image
- step 2: compute perspective from 2nd to 1st image
- step 3: warp 2nd image so it overlays 1st image
- step 4: blend images where they overlap one another
- repeat for 3rd image and mosaic of first two, etc.

Panoramas

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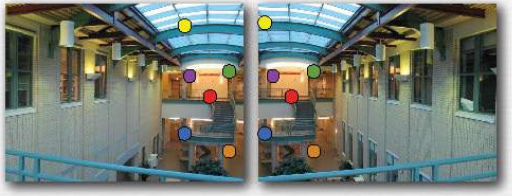
Stitching images together to make a mosaic



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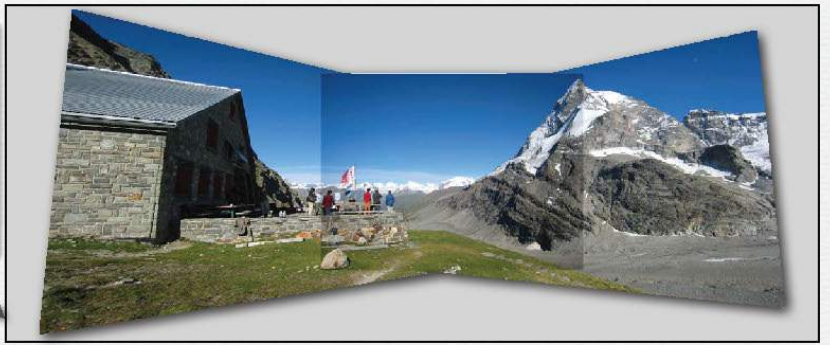
take CS 131, EE 368, EE 367!

Panoramas

Slides from Marc Levoy's excellent CS 178 course

Example: the Matterhorn

common picture plane of mosaic image



perspective projection

Panoramas

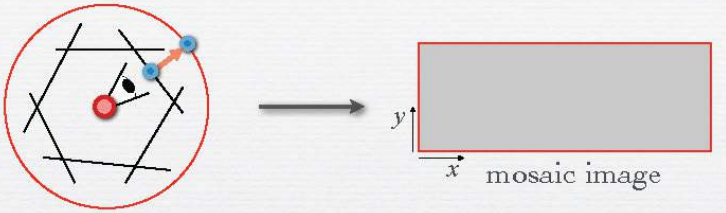
Slides from Marc Levoy's excellent CS 178 course

Using 4 shots instead of 3

Slides from Marc Levoy's excellent CS 178 course

Cylindrical panoramas

- even works for 360° panorama



- project each image onto a cylinder
- a cylindrical image can be stored as a rectangular image

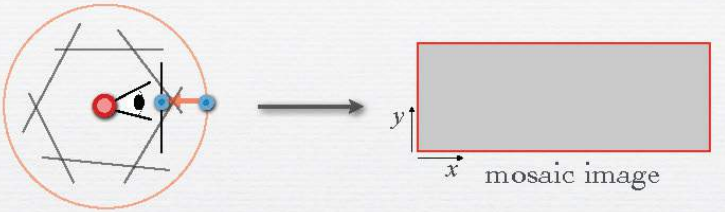
Slides from Marc Levoy's excellent CS 178 course

Cylindrical panoramas

(FLASH DEMO)

http://graphics.stanford.edu/courses/cs178/applets/projection.html

- even works for 360° panorama



- project each image onto a cylinder
- a cylindrical image can be stored as a rectangular image
- to view without distortion, reproject part of the cylinder onto a picture plane representing the display screen
  - if your FOV is narrow, this view won't be too distorted

Panoramas

Slides from Marc Levoy's excellent CS 178 course

Back to the Matterhorn

cylindrical projection

Panoramas

Slides from Marc Levoy's excellent CS 178 course

Back to the Matterhorn

surface of cylinder

blended

Slides from Marc Levoy's excellent CS 178 course

Spherical panoramas

- projections are to a sphere instead of a cylinder
- can't store as rectangular image without extreme stretching

Panoramas

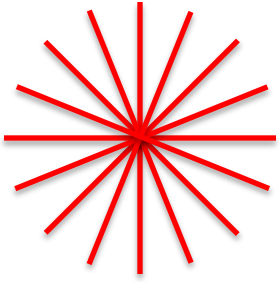
- see CS 178 and EE 368 course material for more detail

- now common in every image processing software and cellphone

Panorama v Stereo Movie v Stereo Panorama

Panorama

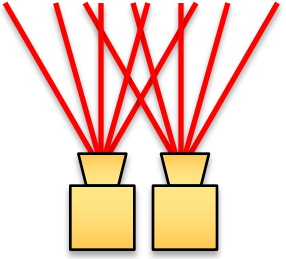
mono & head rotation



1 center of projection!

Stereo

stereo & no head rotation



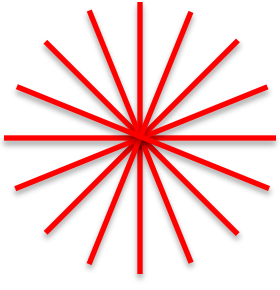
Stereo Panorama

stereo & head rotation

Panorama v Stereo Movie v Stereo Panorama

Panorama

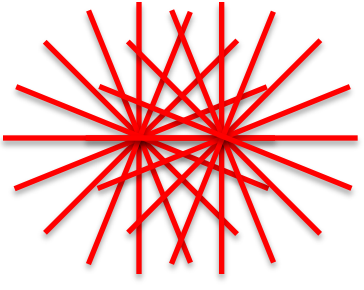
mono & head rotation



1 center of projection!

Stereo

stereo & no head rotation



2 centers of projection!

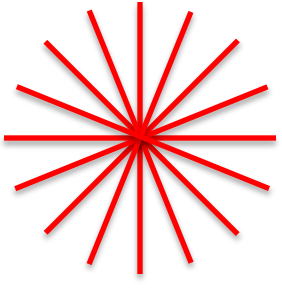
Stereo Panorama

stereo & head rotation

Panorama v Stereo Movie v Stereo Panorama

Panorama

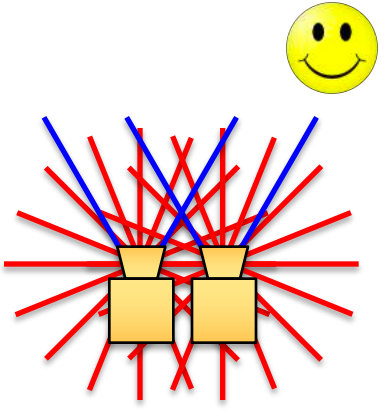
mono & head rotation



1 center of projection!

Stereo

stereo & no head rotation



2 centers of projection!

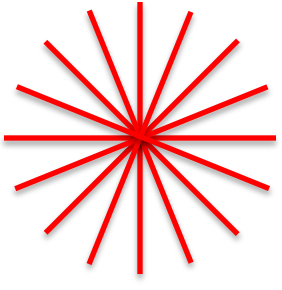
Stereo Panorama

stereo & head rotation

Panorama v Stereo Movie v Stereo Panorama

Panorama

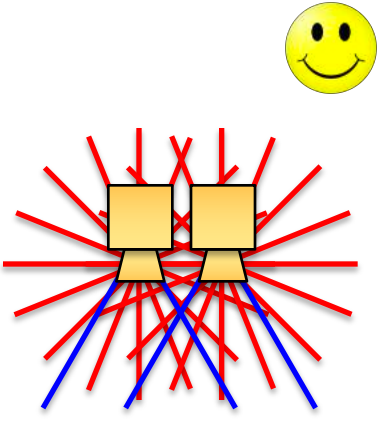
mono & head rotation



1 center of projection!

Stereo

stereo & no head rotation



2 centers of projection!

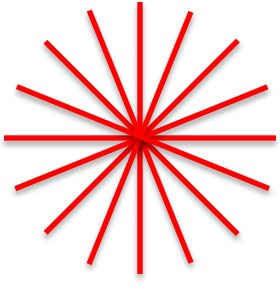
Stereo Panorama

stereo & head rotation

Panorama v Stereo Movie v Stereo Panorama

Panorama

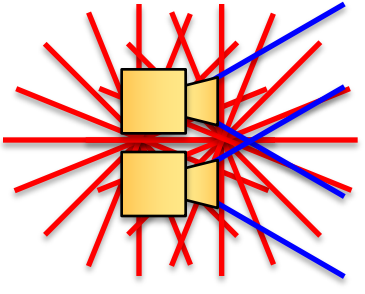
mono & head rotation



1 center of projection!

Stereo

stereo & no head rotation



2 centers of projection!

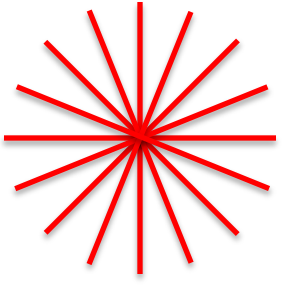
Stereo Panorama

stereo & head rotation

Panorama v Stereo Movie v Stereo Panorama

Panorama

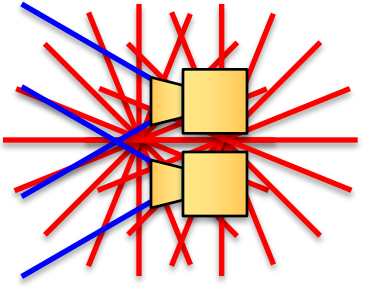
mono & head rotation



1 center of projection!

Stereo

stereo & no head rotation



2 centers of projection!

Stereo Panorama

stereo & head rotation

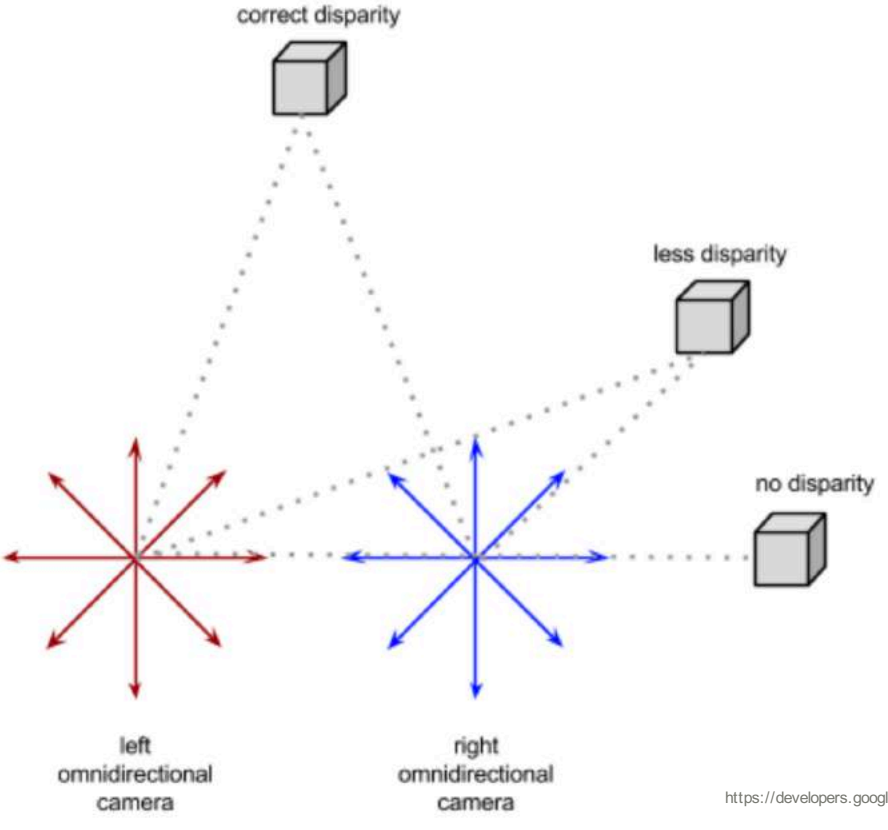
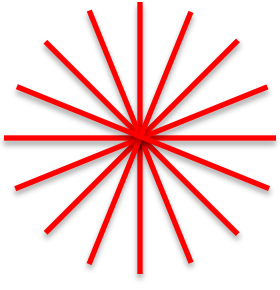


Image from Google Jump
https://developers.google.com/vr/jump/rendering-ods-content.pdf

Panorama v Stereo Movie v Stereo Panorama

Panorama

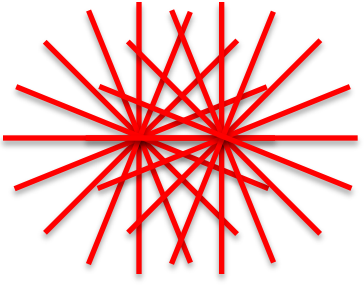
mono & head rotation



1 center of projection!

Stereo

stereo & no head rotation

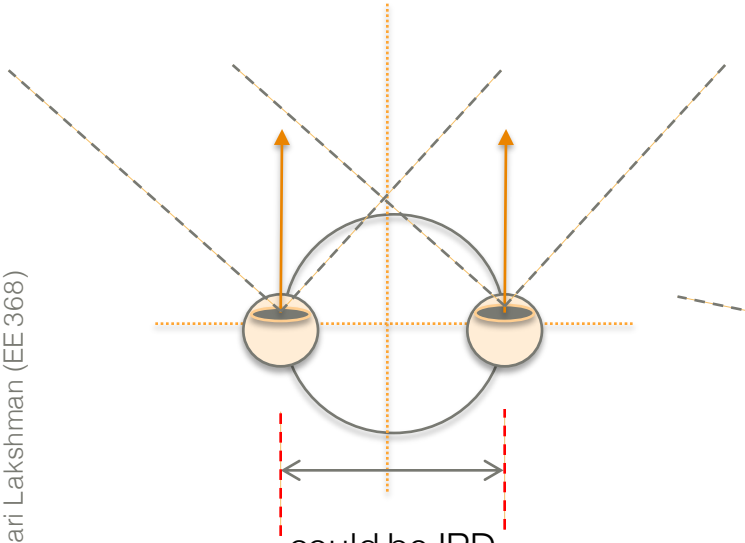


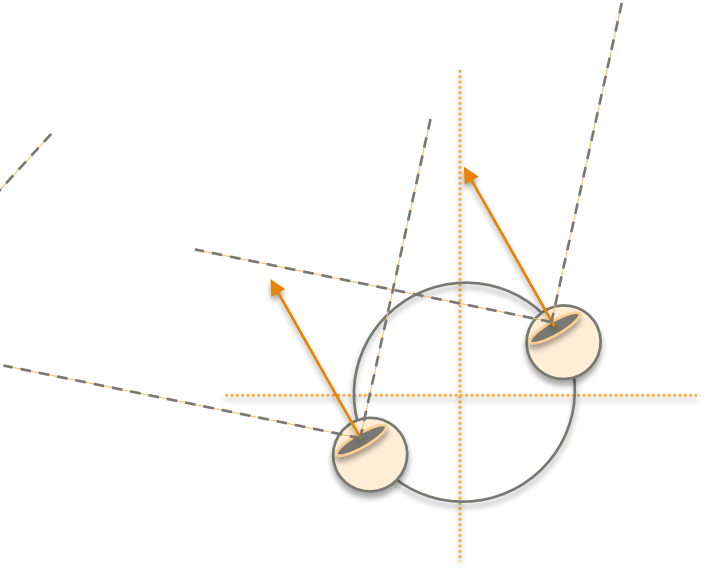
2 centers of projection!

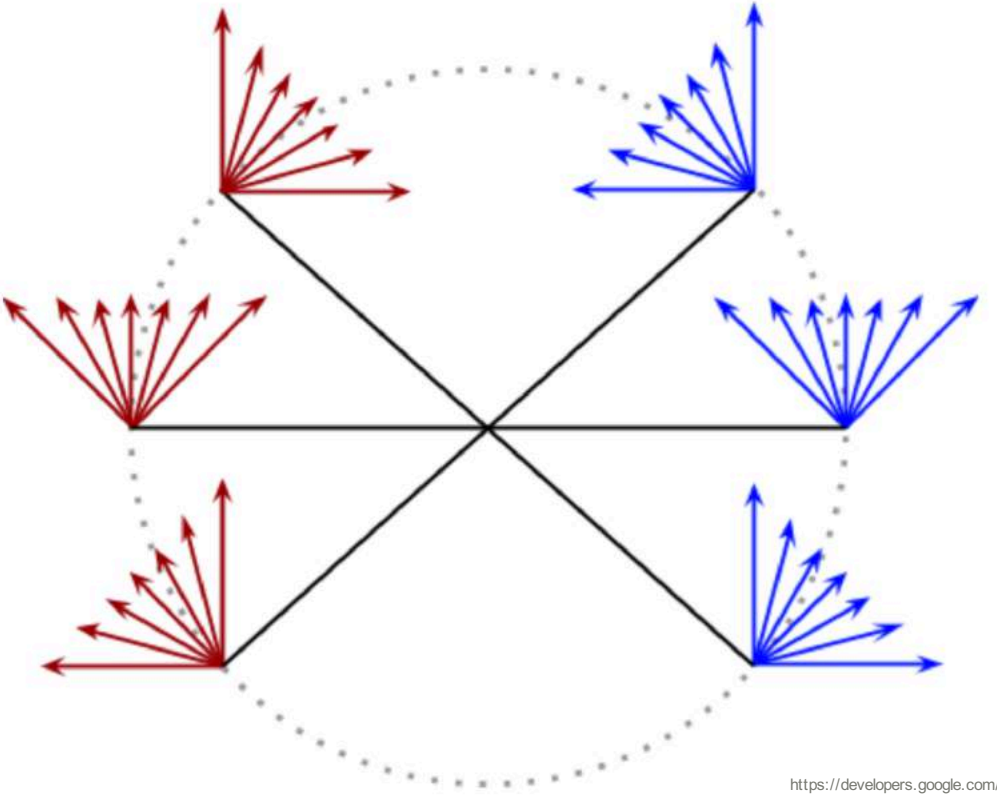
Stereo Panorama

stereo & head rotation

Head Rotation







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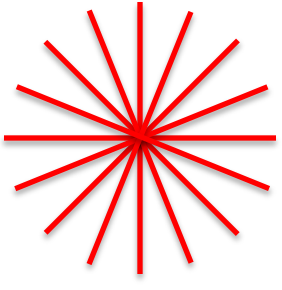
Panorama v Stereo Movie v Stereo Panorama

Panorama

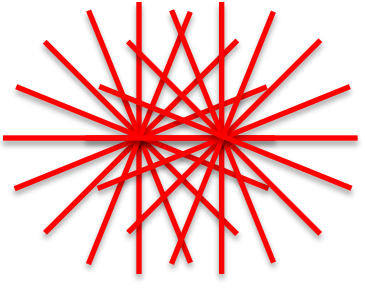
mono & head rotation



1 center of projection!

Stereo

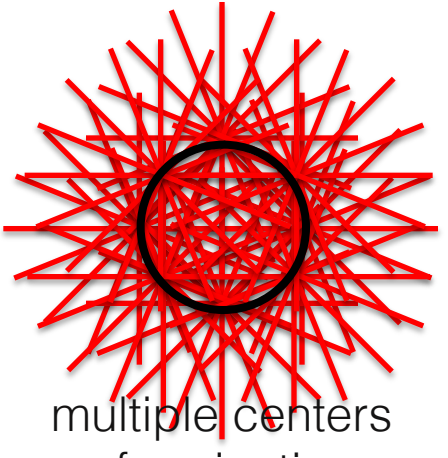
stereo & no head rotation



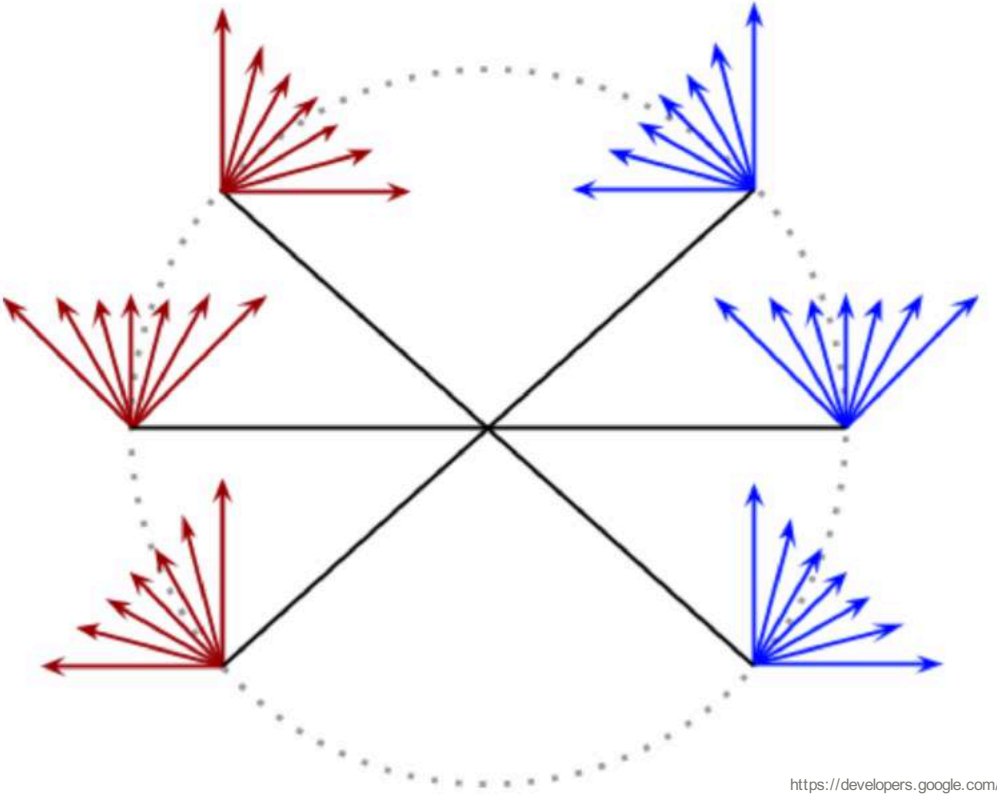
2 centers of projection!

Stereo Panorama

stereo & head rotation



multiple centers of projection



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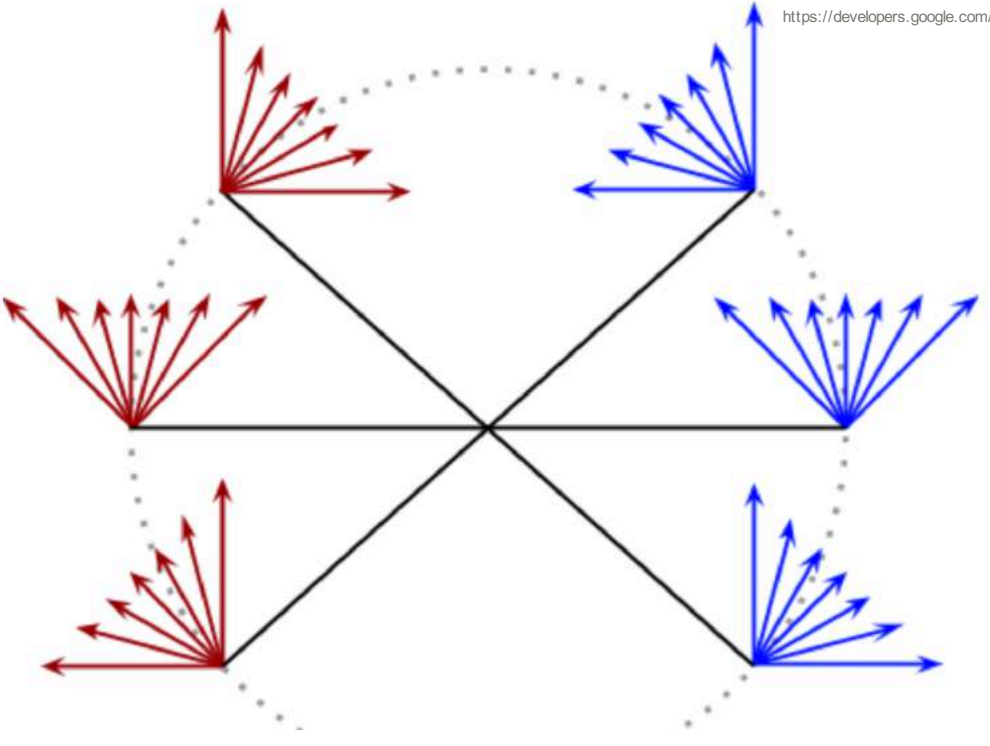
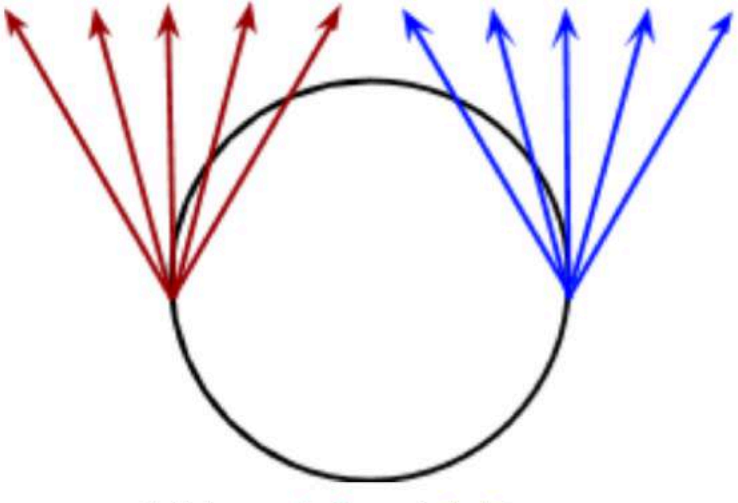


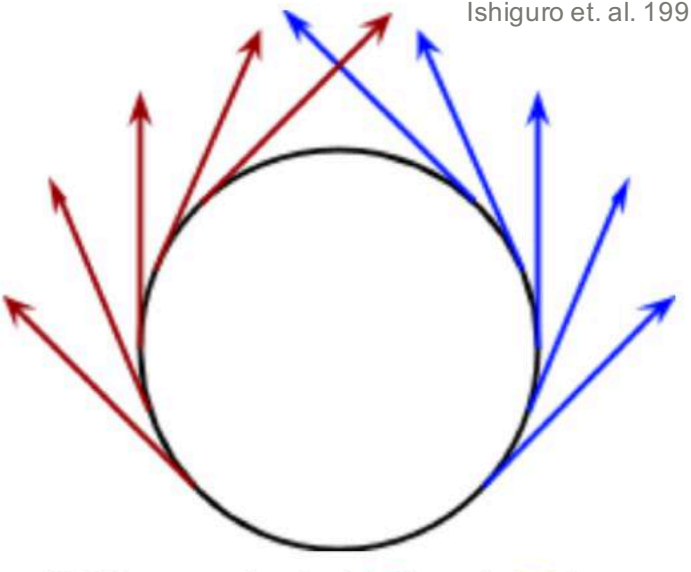
Store image pair for each direction → Problem: Too much data!!!

Omni-directional Stereo (ODS) Approximation

Peleg et. al 2001
Ishiguro et. al. 1990



full-frame **left** and **right** eyes



ODS-approximated **left** and **right** eyes

Image from Google Jump
https://developers.google.com/vr/jump/rendering-ods-content.pdf

Omni-directional Stereo (ODS) Approximation

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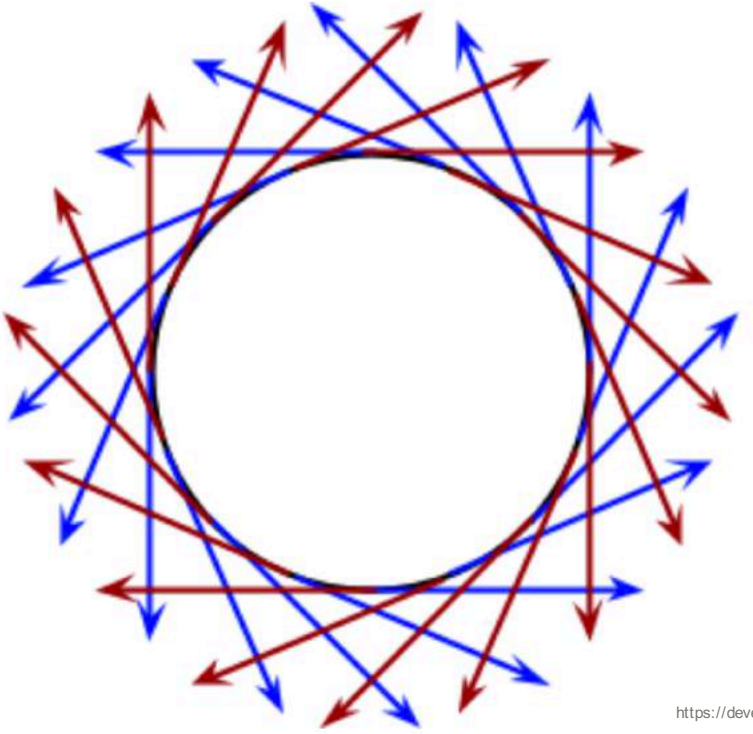

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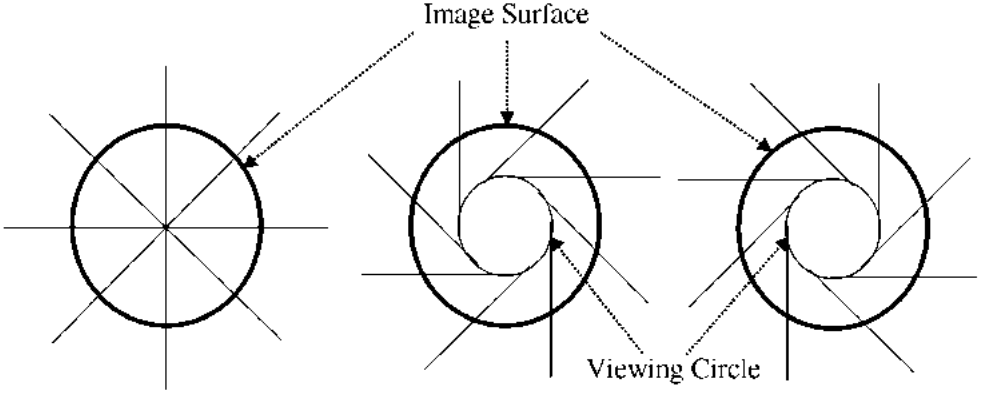
Comparison: Mono and Stereo Panoramas

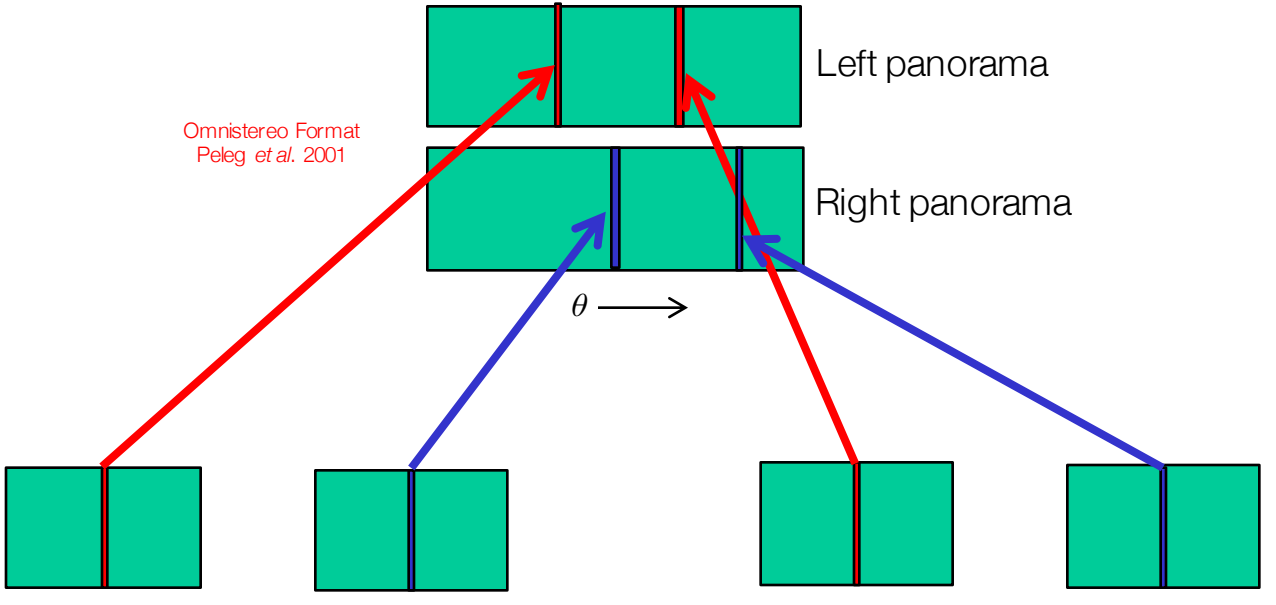


Central,
a.k.a. Mono

Omnistereo,
Multiperspective

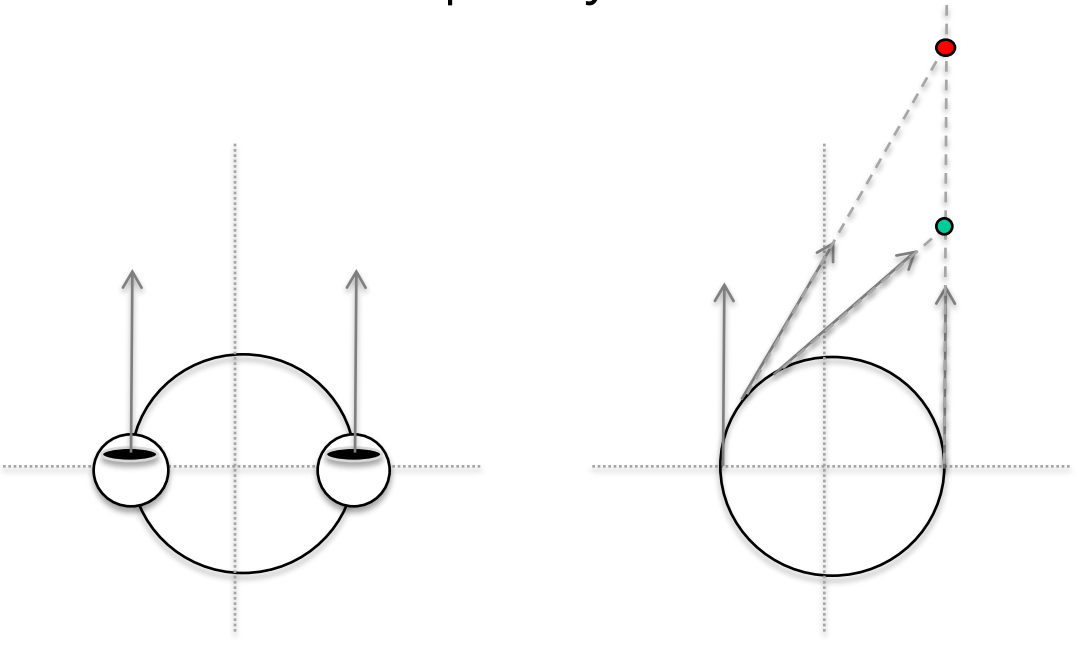
Peleg et al. 2001

Omnistereo Panoramas



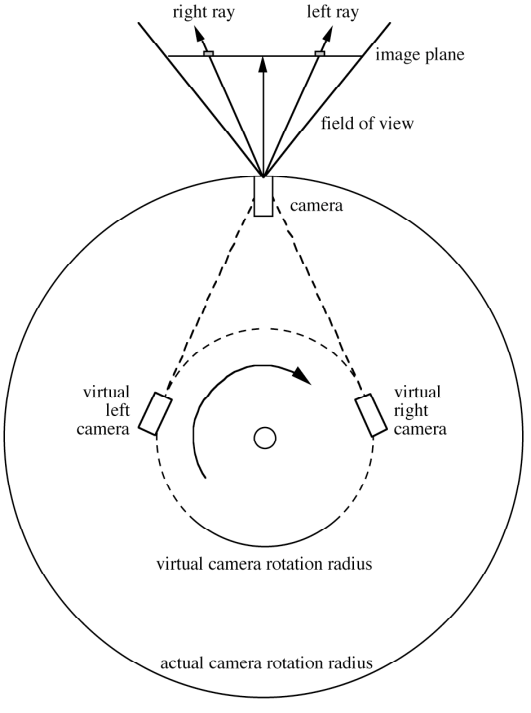
side by Hari Lakshman (EE 368)

Zero Disparity Distance



To control zero disparity distance: circularly shift left pano relative to right pano

Capture using Single Camera



Peleg et al. 2001

side by Hari Lakshman (EE 368)

CAMERA 1

Image from Google Jump
https://developers.google.com/vr/jump/rendering-ods-content.pdf

Panorama v Stereo Movie v Stereo Panorama

Panorama

mono & head rotation

Ricoh Theta

Stereo

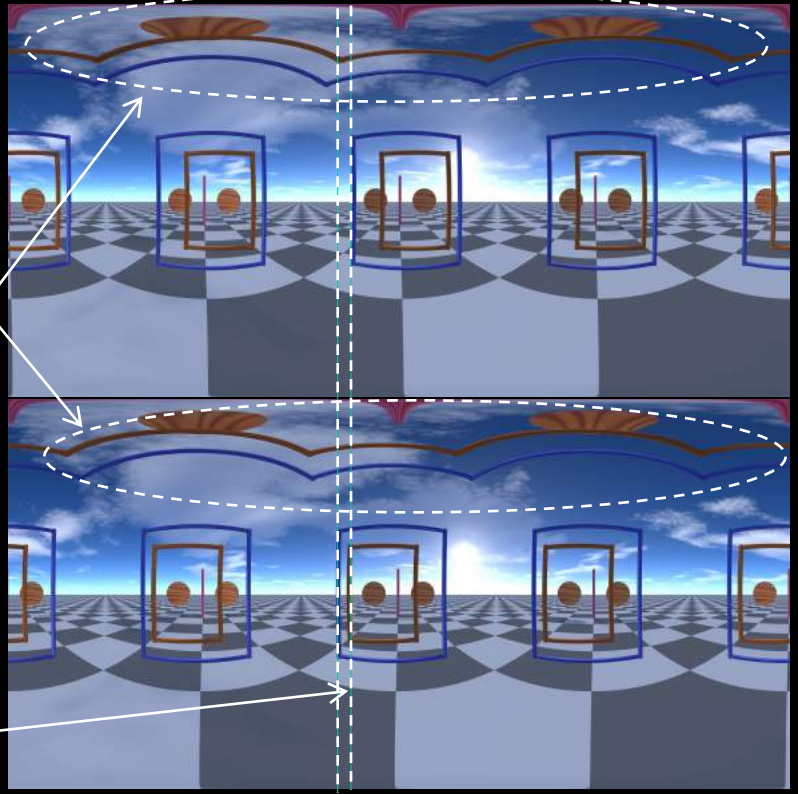
stereo & no head rotation

Stereo Panorama

stereo & head rotation

horizontal-only parallax

Omnistereo example



Left panorama

Sphere-to-plane distortions

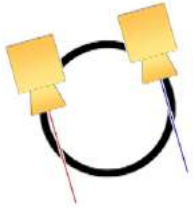
Right panorama

Disparity

Multiperspective Projection

Jingyi Yu

Omnidirectional Stereo



Left Eye

Right Eye

widely used by YouTube VR, Google Daydream, Facebook, ...

Existing VR Cameras

Recorded Videos ~ 17 Gb/sec

Facebook's Surround 360

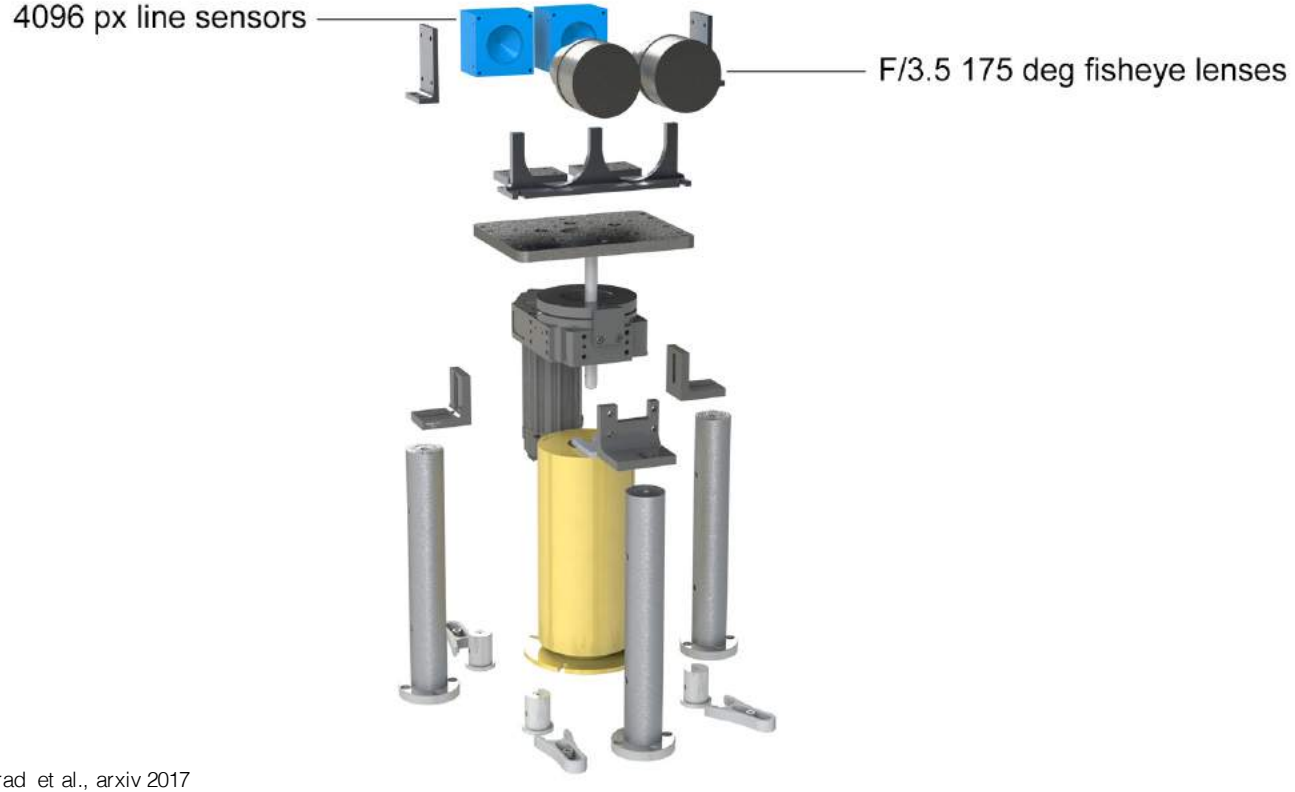
RAW Data: 17 Gb/sec

Compute time: days to weeks on conventional computer,
minutes to hours on data center

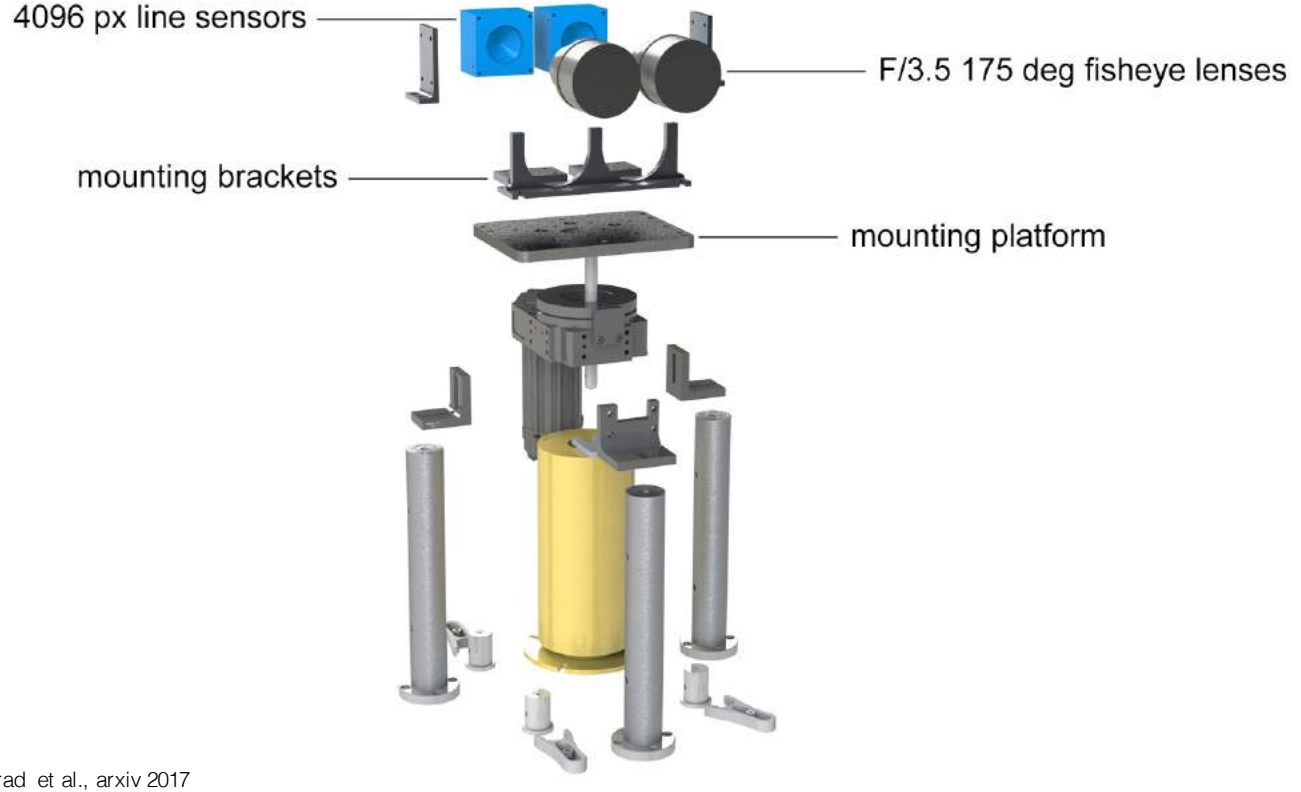
Facebook's Surround 360

RAW Data: 17 Gb/sec

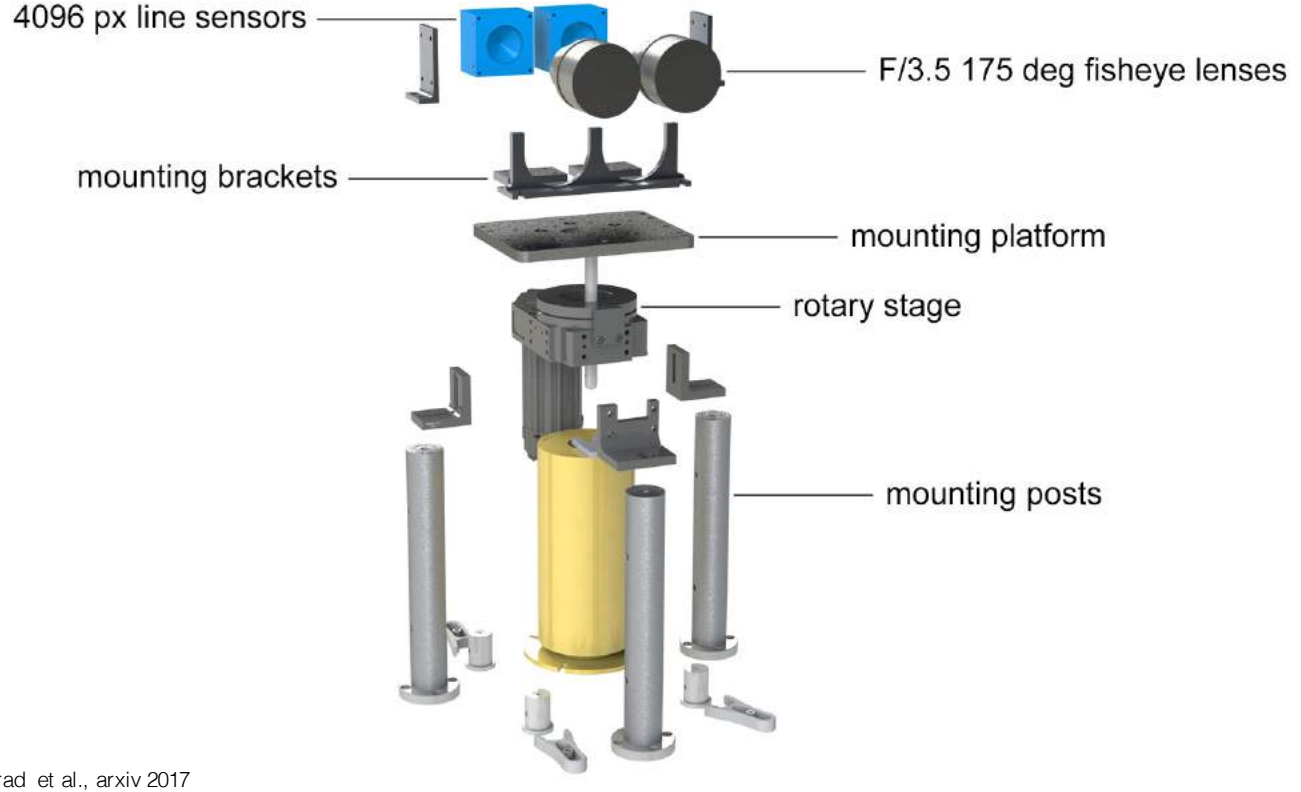
Compute time: days to weeks on conventional computer,
minutes to hours on data center



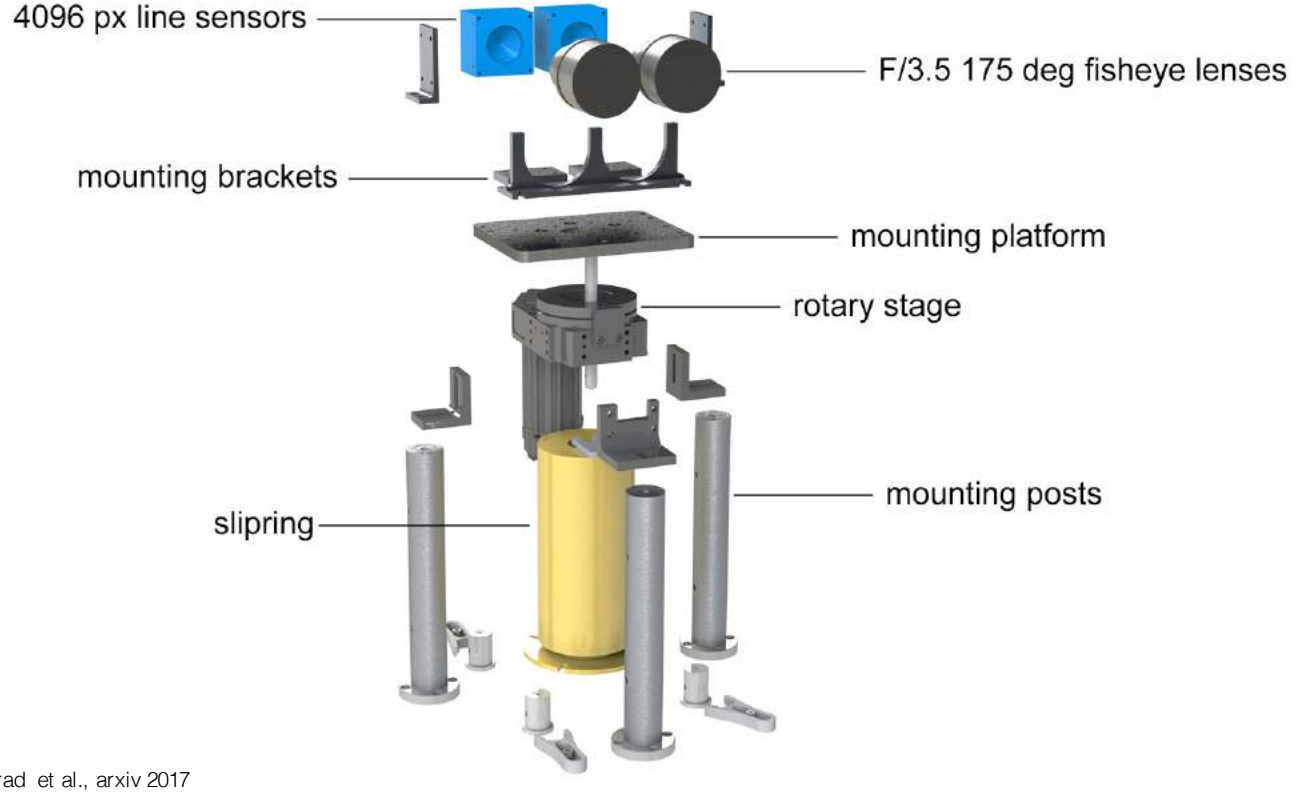
Konrad et al., arxiv 2017



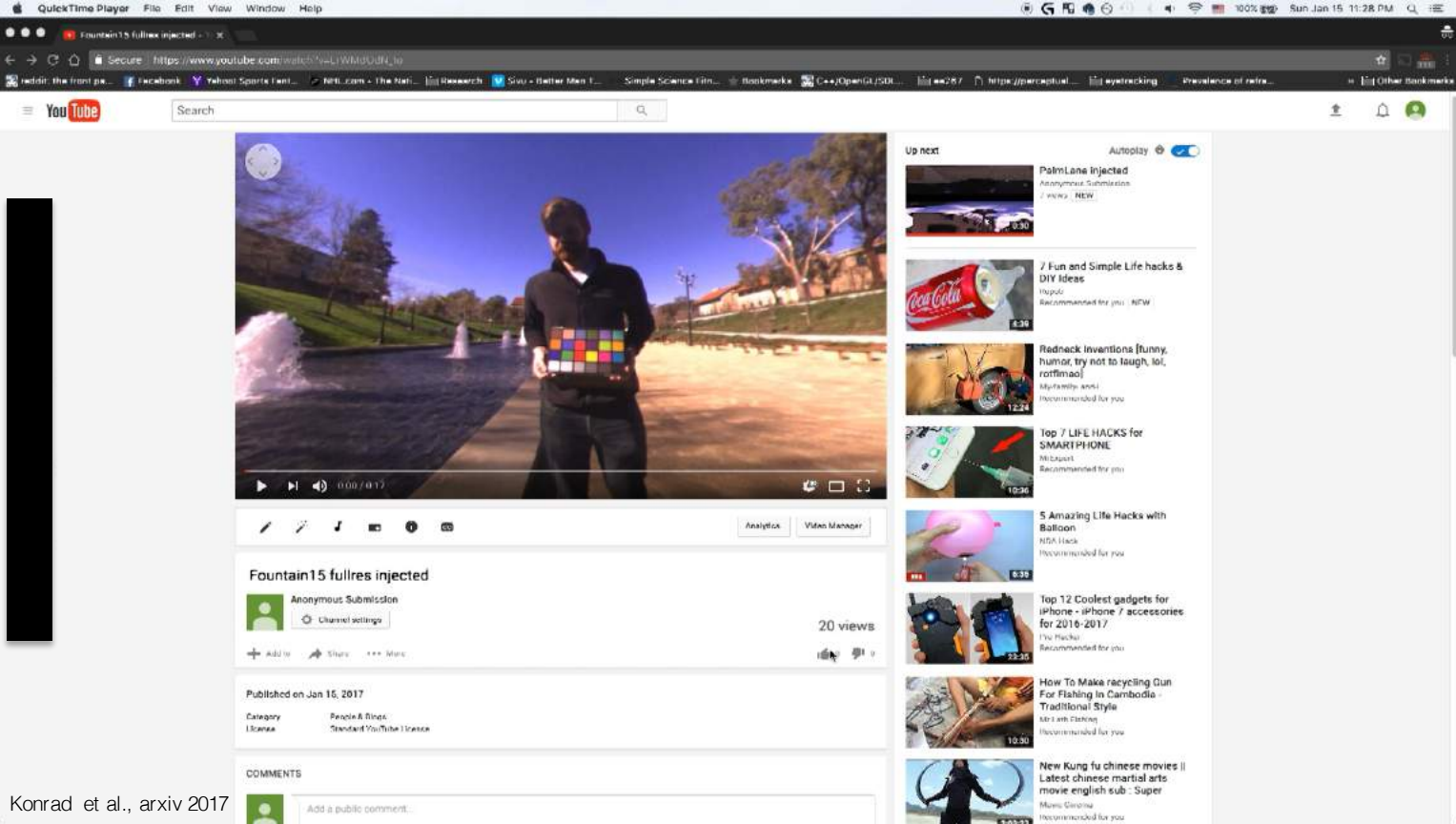
Konrad et al., arxiv 2017



Konrad et al., arxiv 2017



Konrad et al., arxiv 2017



Konrad et al., arxiv 2017

Additional Information

- M. Brown, D. Lowe “Automatic Panoramic Image Stitching using Invariant Features”, IJCV 2007
- autostitch: http://matthewalunbrown.com/autostitch/autostitch.html
- S. Peleg, M. Ben-Ezra, Y. Pritch “Omnistereo: Panoramic Stereo Imaging” IEEE PAMI 2001