Acquisition and manipulation of dense image-based data

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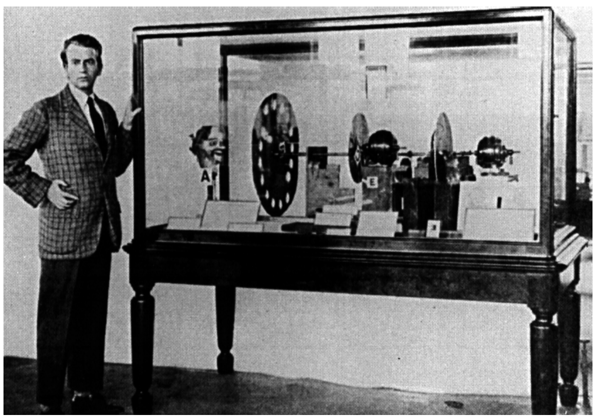
Stanford University

- input technologies
  - range + color
  - light fields
  - BRDFs
- algorithms
  - compression of light fields
  - shape from light fields
  - hierarchical light fields
  - spatially varying BRDFs

A lesson from history

The <u>key</u> innovation in television was the camera



Baird's Nipkow disk system

Zworykin's kinescope

Input technologies

- devices
  - laser triangulation scanners
  - time-of-flight scanner
  - spherical light field & BRDF gantry
  - real-time light field camera
  - handheld BRDF meter
  - structured-light range scanner
  - planar-motion light field gantry

- people

Kari Pulli	Brian Curless
Szymon Rusinkiewicz	David Koller
Li-Wei He	Olaf Hall-Holt
Dennis Zoran	Bennett Wilburn

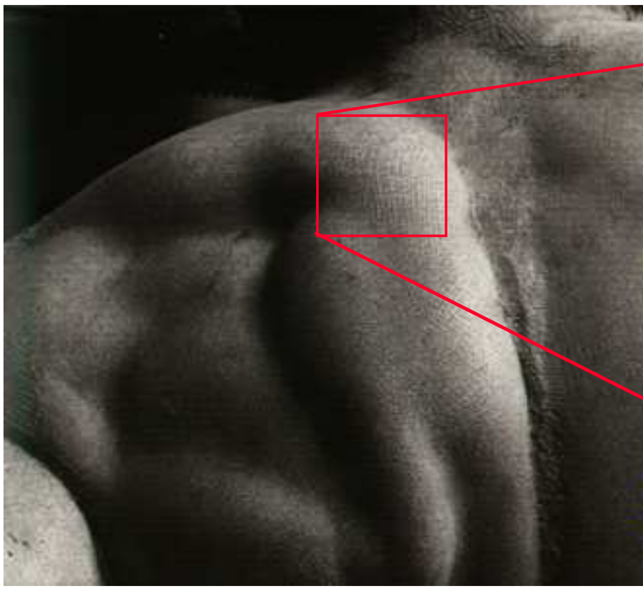
- companies

Cyberware	Faro
Cyra	3D Scanners

Laser triangulation scanner for Michelangelo's statues

- 1m standoff
- range + color
- 0.25mm resolution
- large reach without moving the gantry

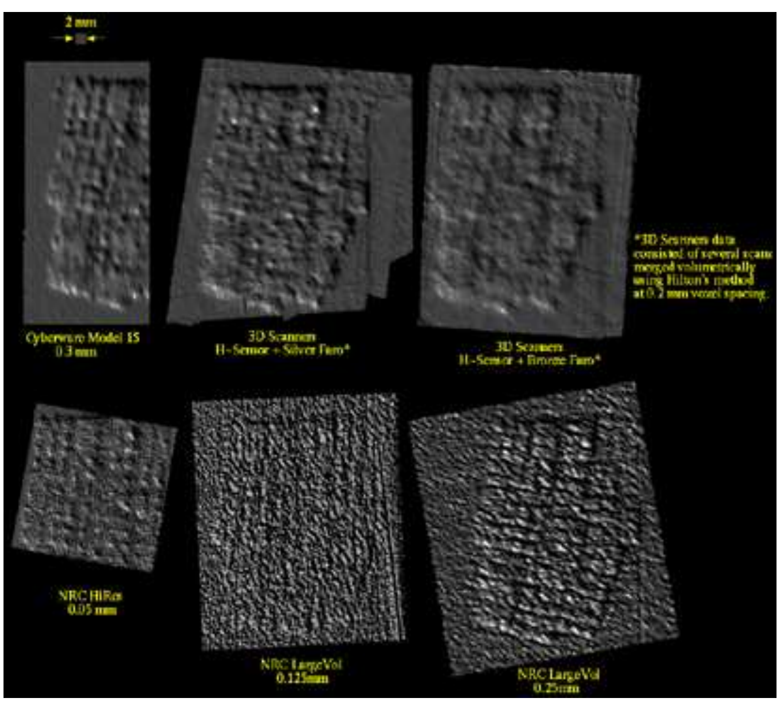
Capturing Michelangelo's chisel marks



“Day”, from the Medici Chapel

⊢ 2mm

bushing chisel marks



3D models from several triangulation scanners

Alternative triangulation scanner for statues

A Faro digitizing arm in use

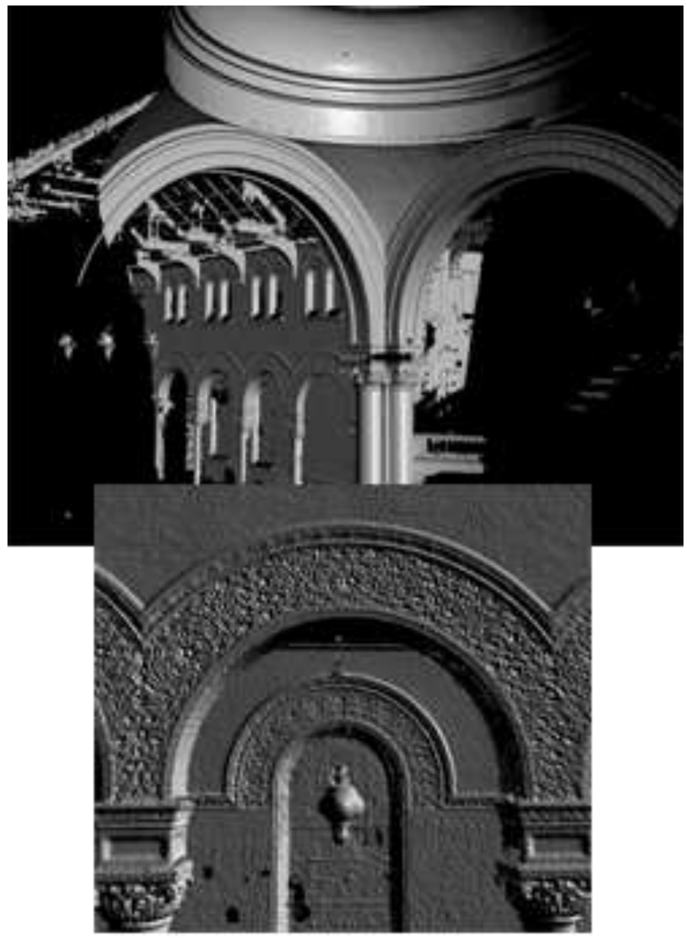
A 3Dscanners Modelmaker in use

The scanning head of the Modelmaker

– color + range
– 0.25mm resolution
– small footprint for “tight spots”
– large reach without moving the tripod

Time-of-flight laser scanner for architectural settings

Cyrax scanner



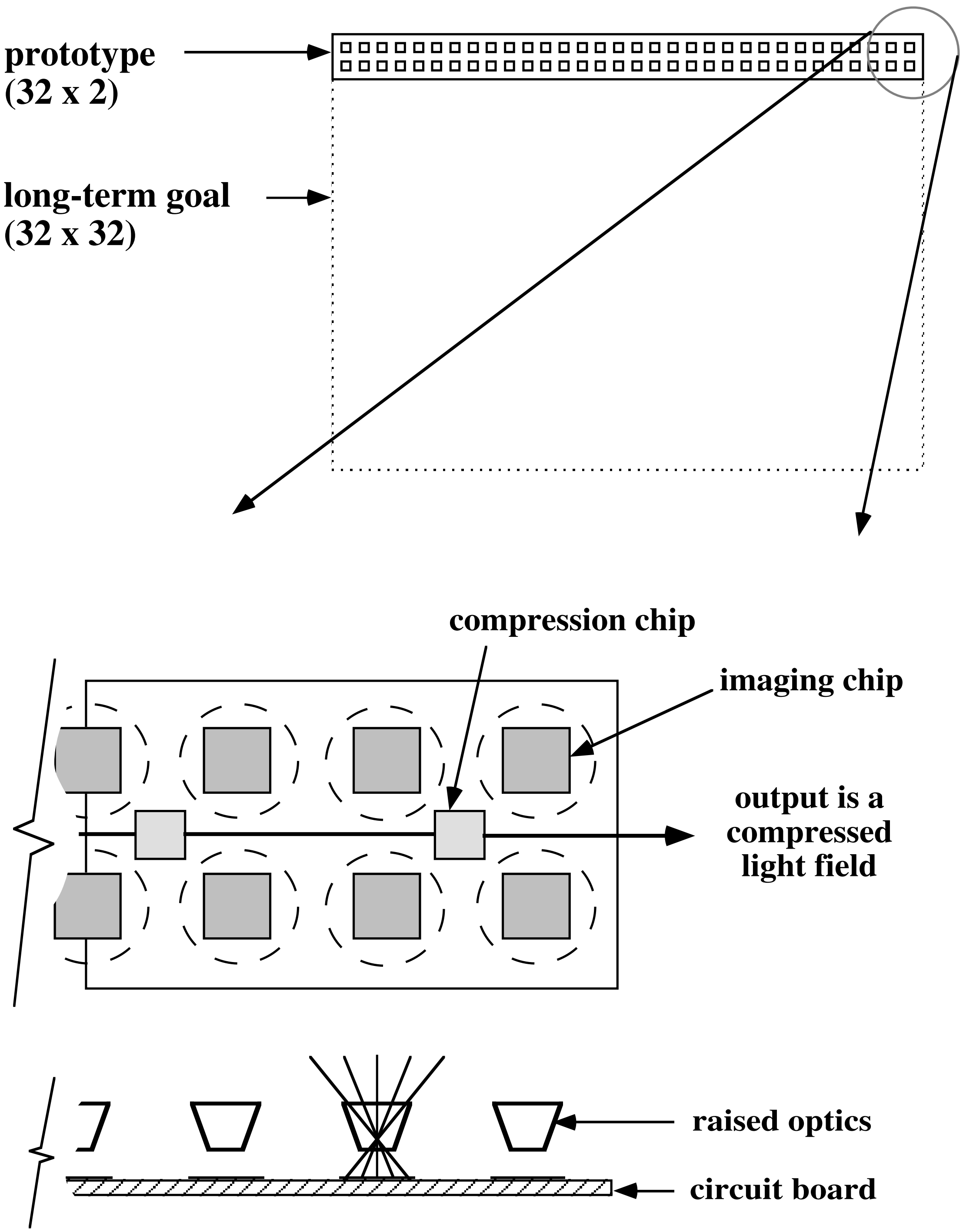
partial 3D model of Stanford's Memorial Church

– range + color
– 4mm resolution
– 100m maximum range

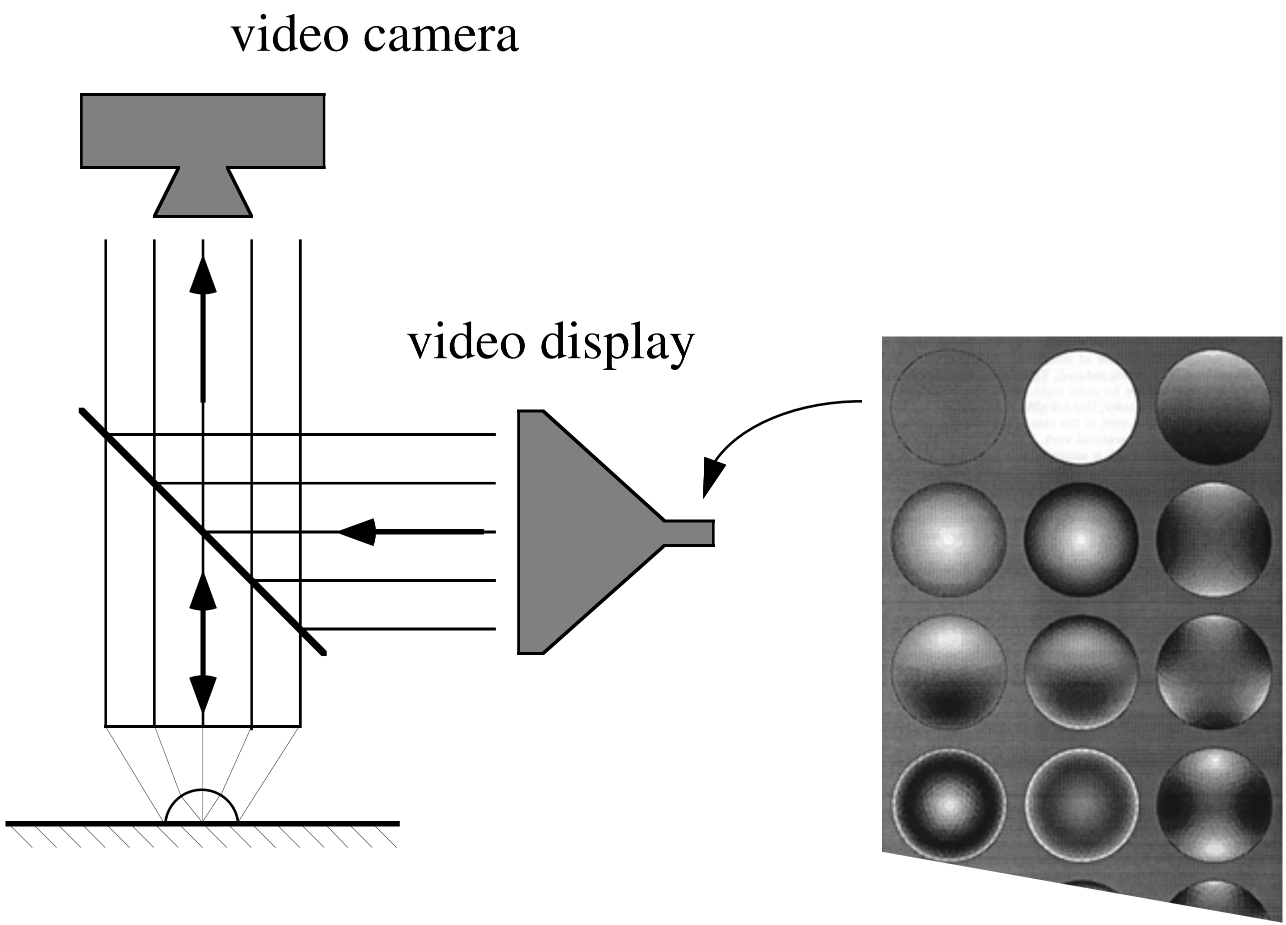
Spherical 4-DOF gantry for light fields and BRDFs

– 0.03 degree positioning error (1mm)
– 0.01 degree aiming error (1 pixel)
– can acquire video while in motion

Real-time light field camera



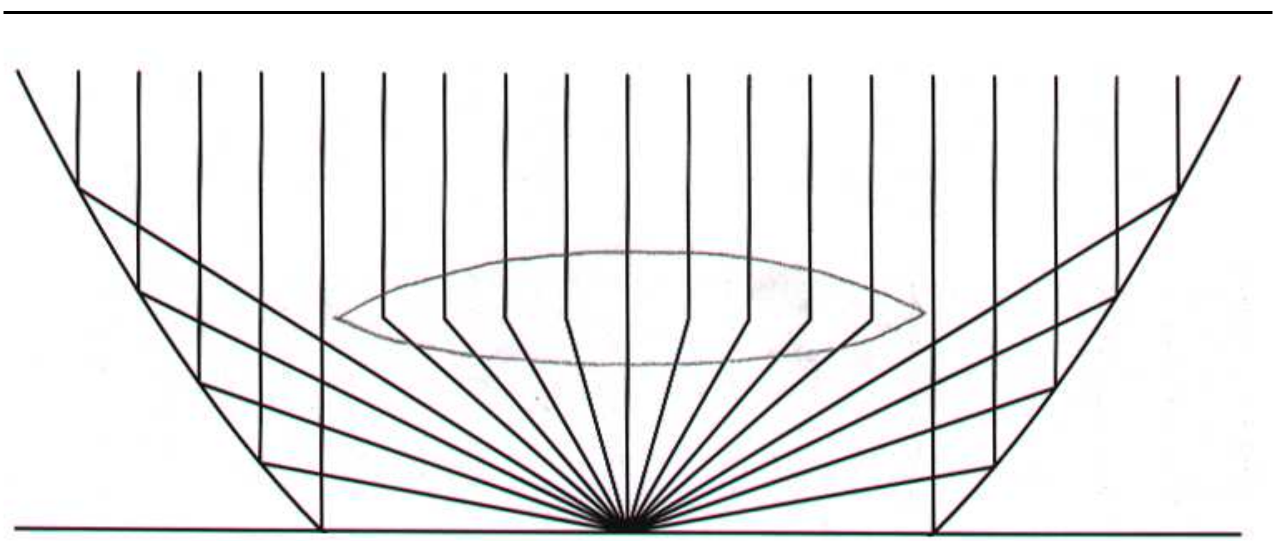
Handheld BRDF meter



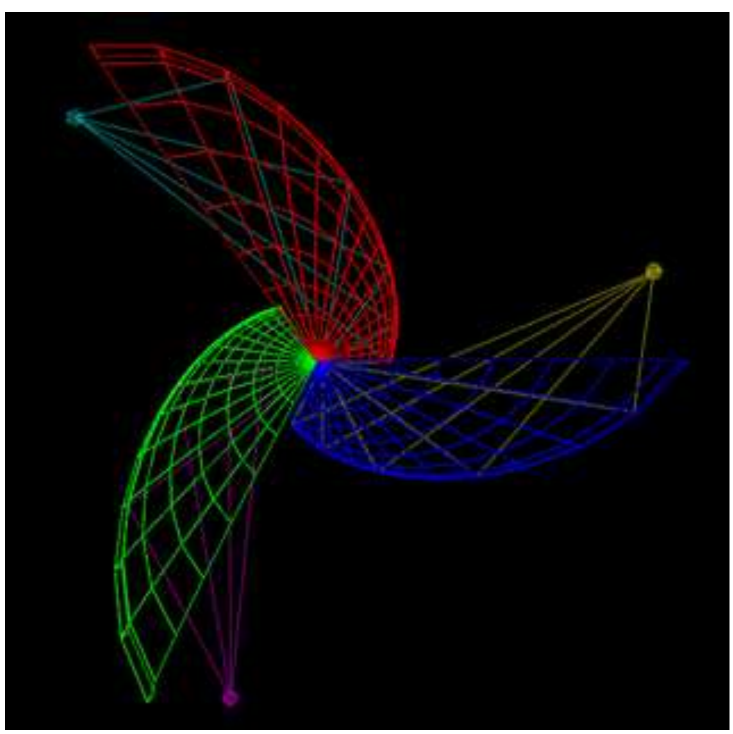
(from Koenderink)

– dual imaging (illumination & sensing)
– no moving parts
– illumination is a sequence of basis functions

Inward-looking hemispherical optics



a solution using catadioptrics



a solution using three ellipsoidal mirrors

Other devices

- planar-motion light field gantry for outward-looking light fields
- real-time structured-light range scanner for telepresence

Algorithms for light fields

- compression of light fields
- shape from light fields
- hierarchical light fields
- spatially varying BRDFs

Compression of light fields

(Lucas Pereira, Ben Zhu)

- LFs are big
  - 256 x 128 views x 512^2 pixels = 25 GB
- hard to beat custom-codebook VQ!
  - 150:1 with few artifacts
- motion estimation $\rightarrow$ 3x improvement
  - similar to MPEG's improvement over JPEG
  - 256 x 128 views x 512^2 pixels / 500:1 = 50MB
- SFLF $\rightarrow$ 3D model $\rightarrow$ view interpolation

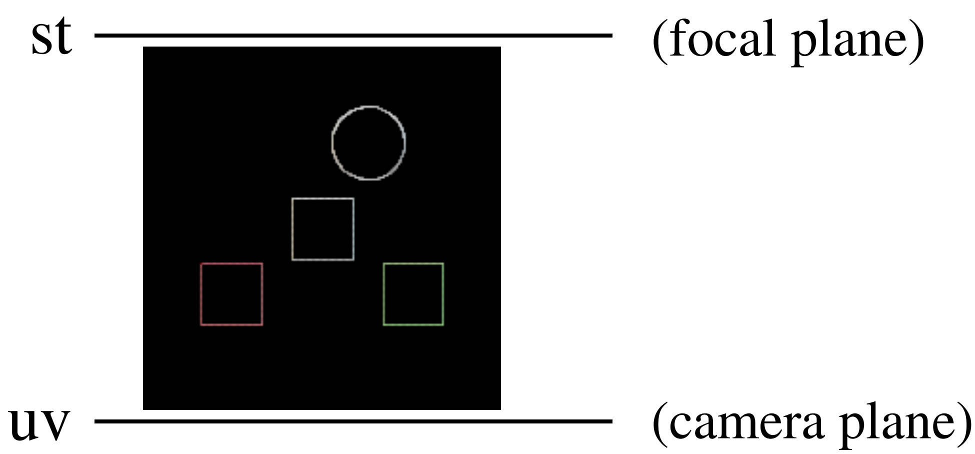
Shape from light fields

(Marc Levoy, Li-Yi Wei)

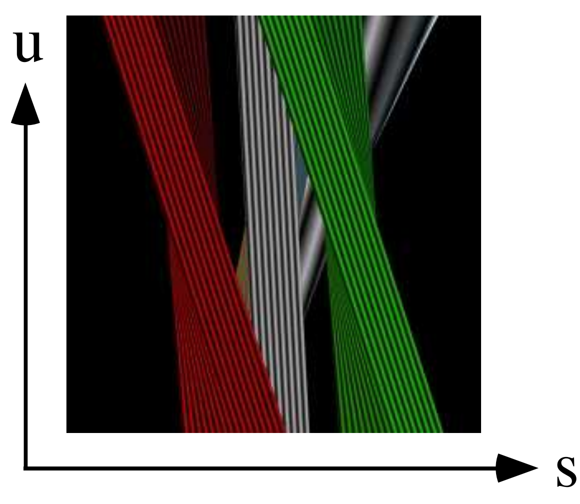
- properties of flatland light fields
- vision algorithms for light fields
- filtered backprojection
- algebraic reconstruction
- the looming field
- the vector light field

Flatland light fields

- flatland scene

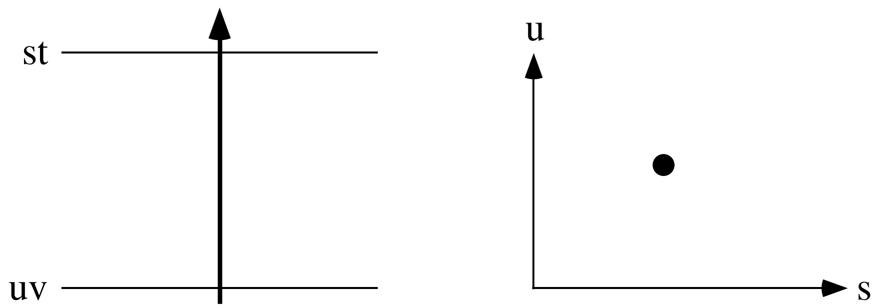


- flatland light field (a.k.a. epipolar image)

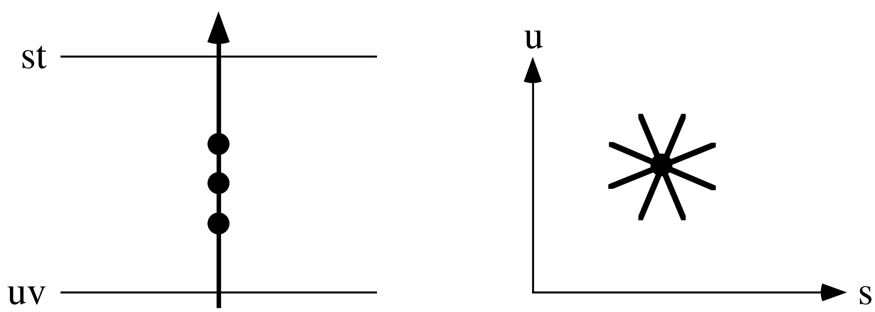


The epipolar image as a line space representation

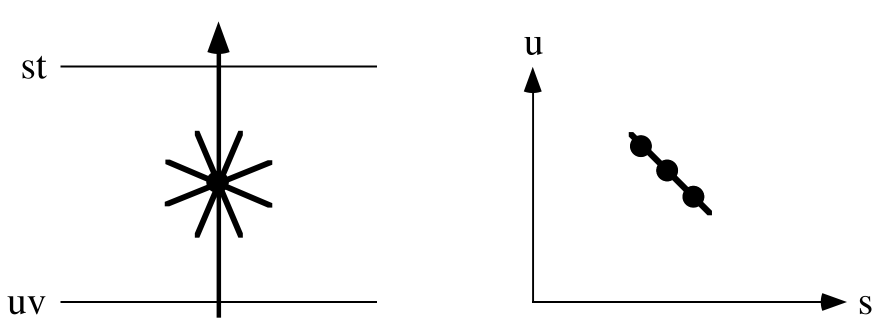
- a line



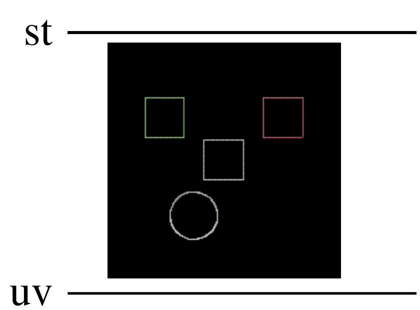
- points on a line



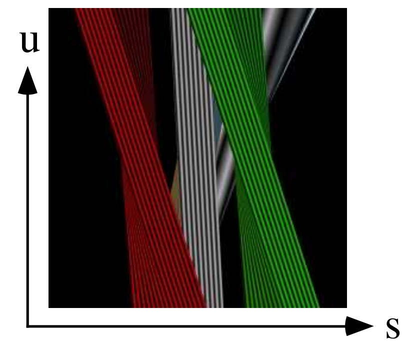
- lines through a point



Vision algorithms considered in line space

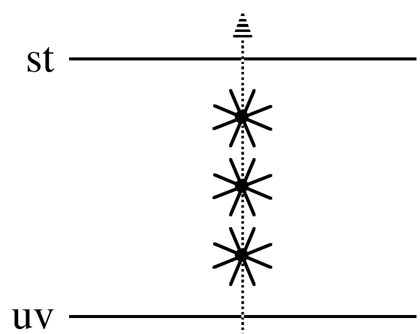


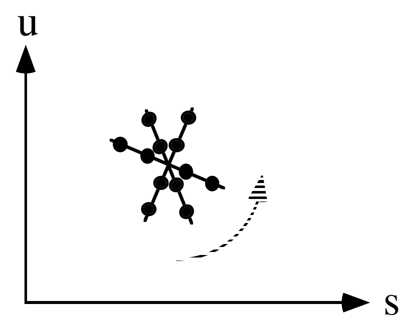
scene



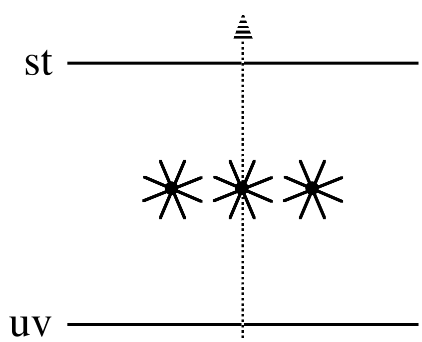
light field

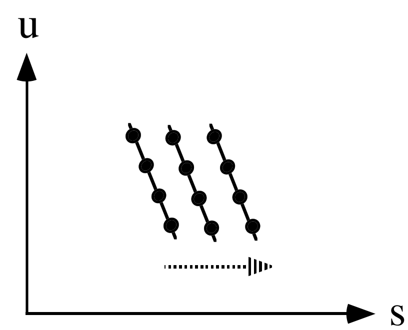
- shape from stereo



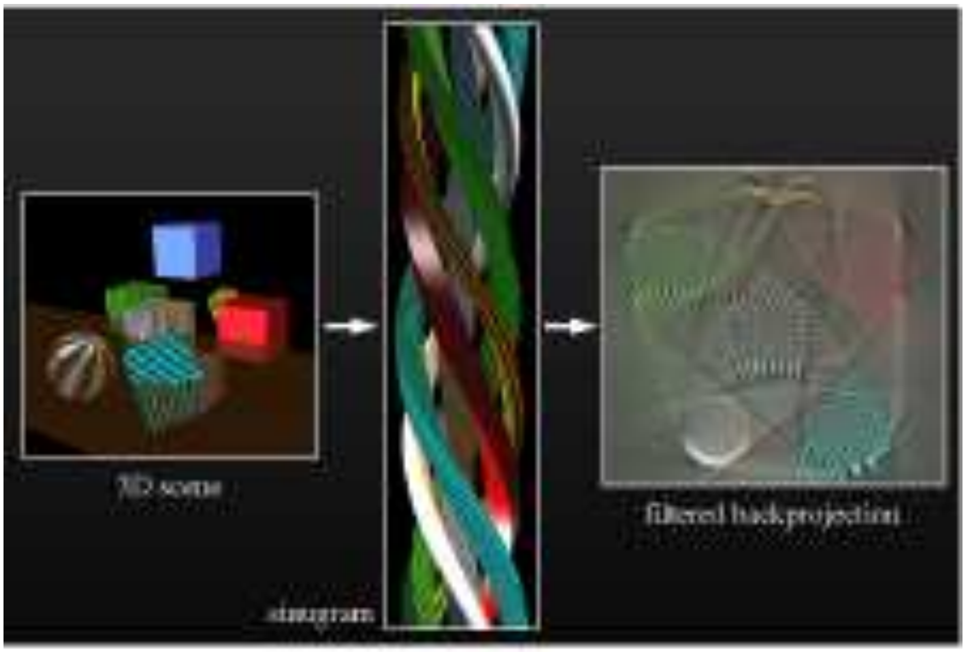


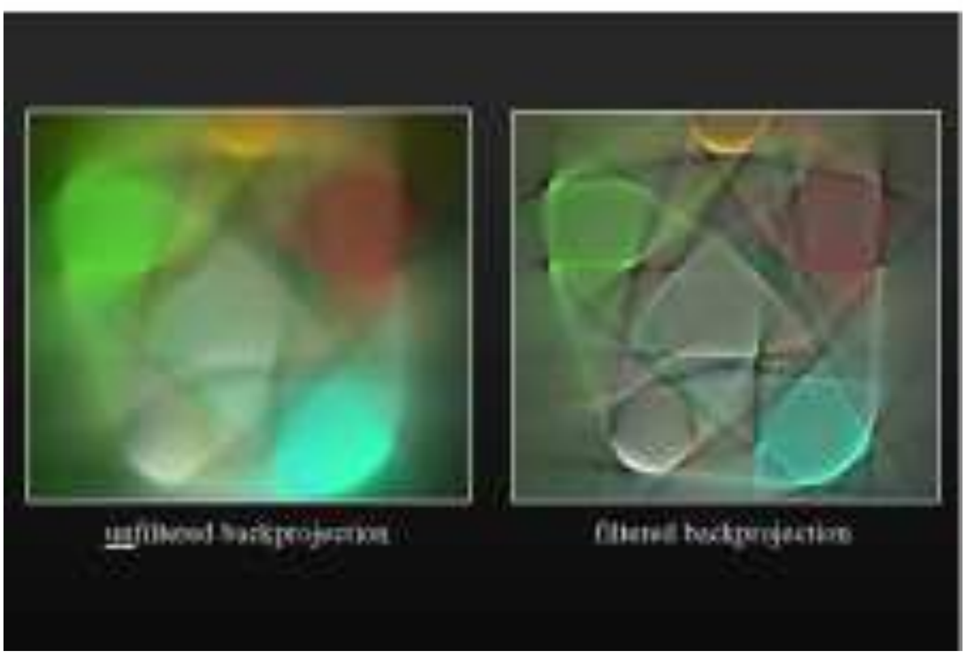
- shape from focus

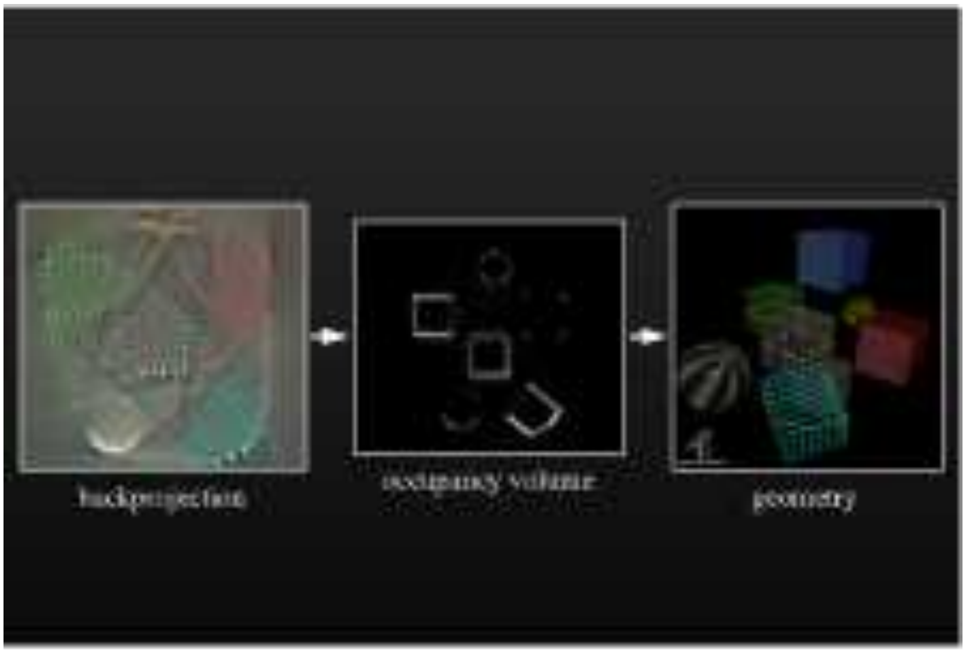


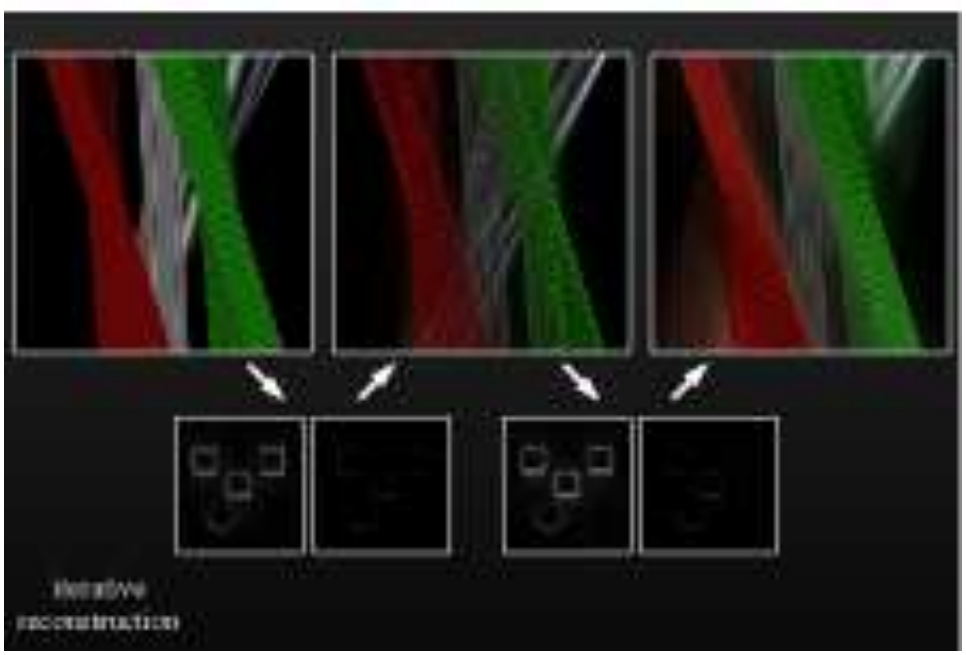


Shape from light fields using filtered backprojection

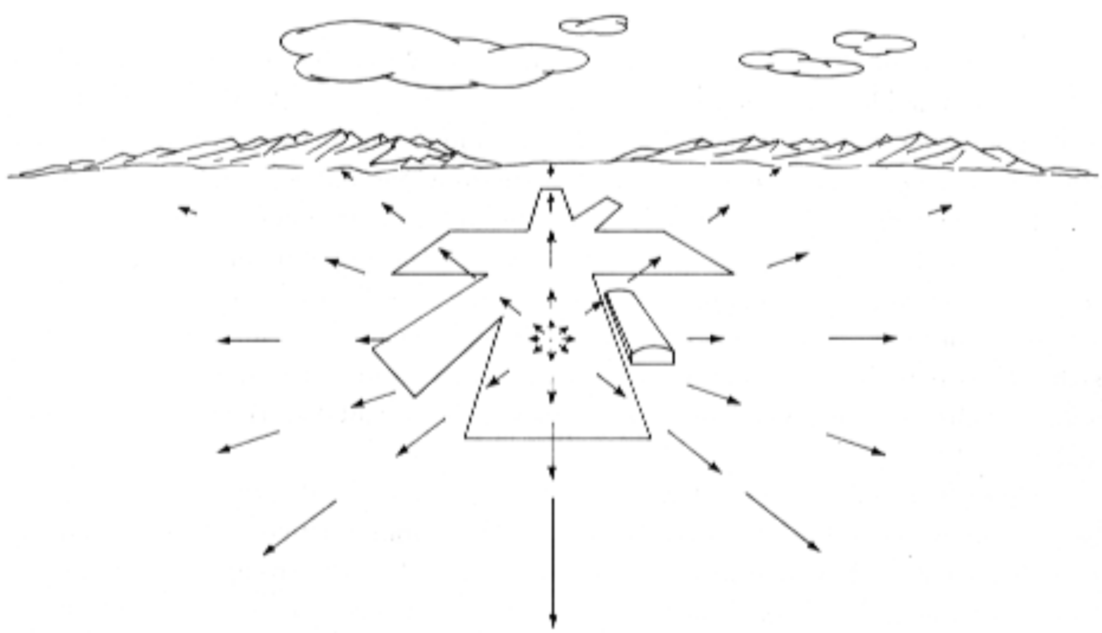





backprojection
occupancy volume
geometry


iterative
reconstruction

The looming field



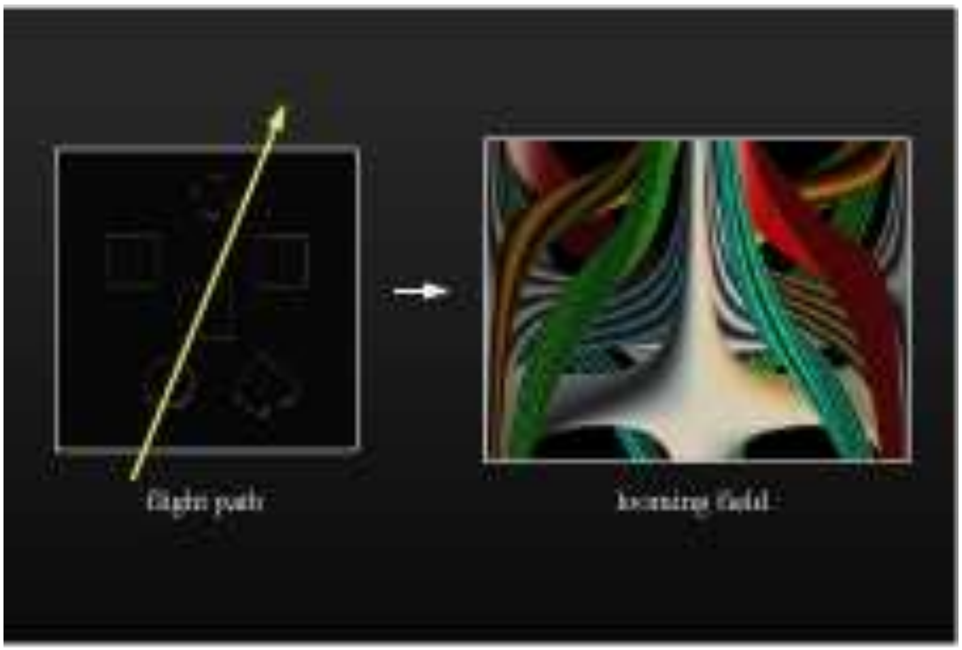
(from Gibson)

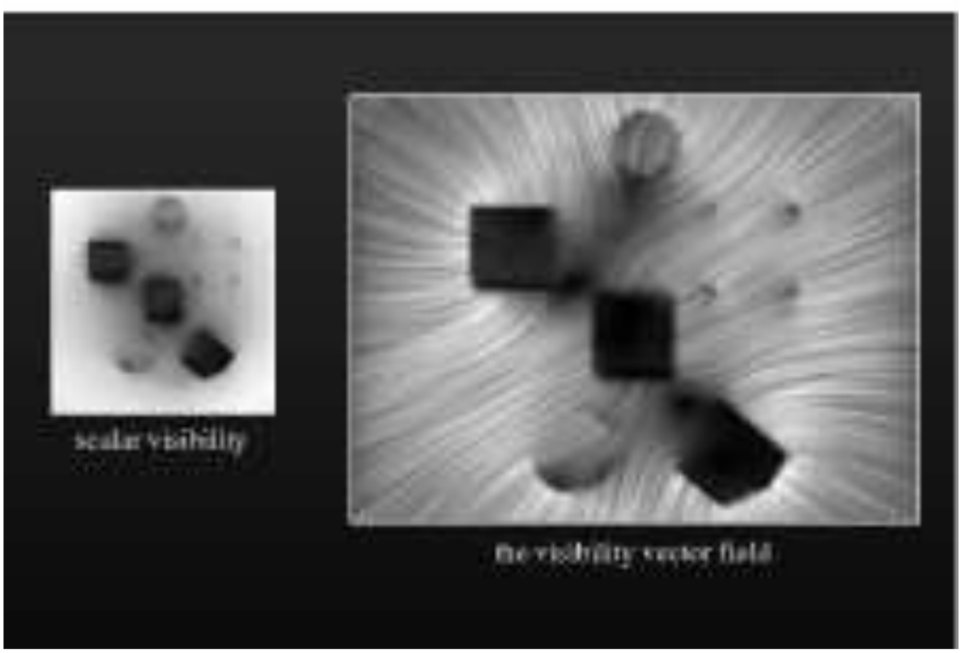
The vector light field

$$\Phi(\boldsymbol{x}) = \int_{\boldsymbol{S}^2} \omega \; L(\boldsymbol{x}, \omega) \; d\omega$$

- amplitude gives irradiance at point *x*
- direction tells which way to orient a surface for maximum brightness
- the “visibility vector field”

Other light field representations





Other algorithmic work

- hierarchical light fields

  (Cindy Chen, Pat Hanrahan)

  – partition scene into disjoint cells
  – links between cells are light fields
  – hierarchicy of cells, links, light fields
  – # of links is linear in # of cells

- spatially varying BRDFs

  (Szymon Rusinkiewicz)

  – scanning protocol
  – change of variables
  – separable BRDFs
  – texture analysis / synthesis

Is computer graphics in crisis?

- four stages of scientific revolution
  1. normal science - “paradigm”
  2. anomaly
  3. crisis
  4. resolution
- characteristics of a crisis
  - attempts to fit anomolous results to existing theory
  - regression to pre-paradigmatic science
  - loosening of the rules for research
  - emergence of new theories
  - confusion about goals

“The proponents of competing paradigms will often disagree about the list of problems that any candidate for paradigm must resolve.”

- Thomas S. Kuhn,
The Structure of Scientific Revolutions

Sponsors

- National Science Foundation
- Advanced Research Projects Agency
- Center for Integrated Systems
- Interval Research Corporation
- Paul W. Allen Foundation for the Arts