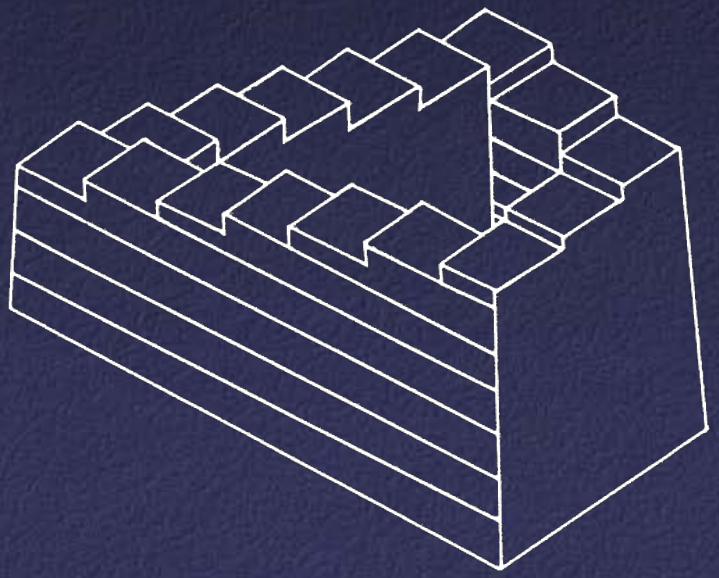
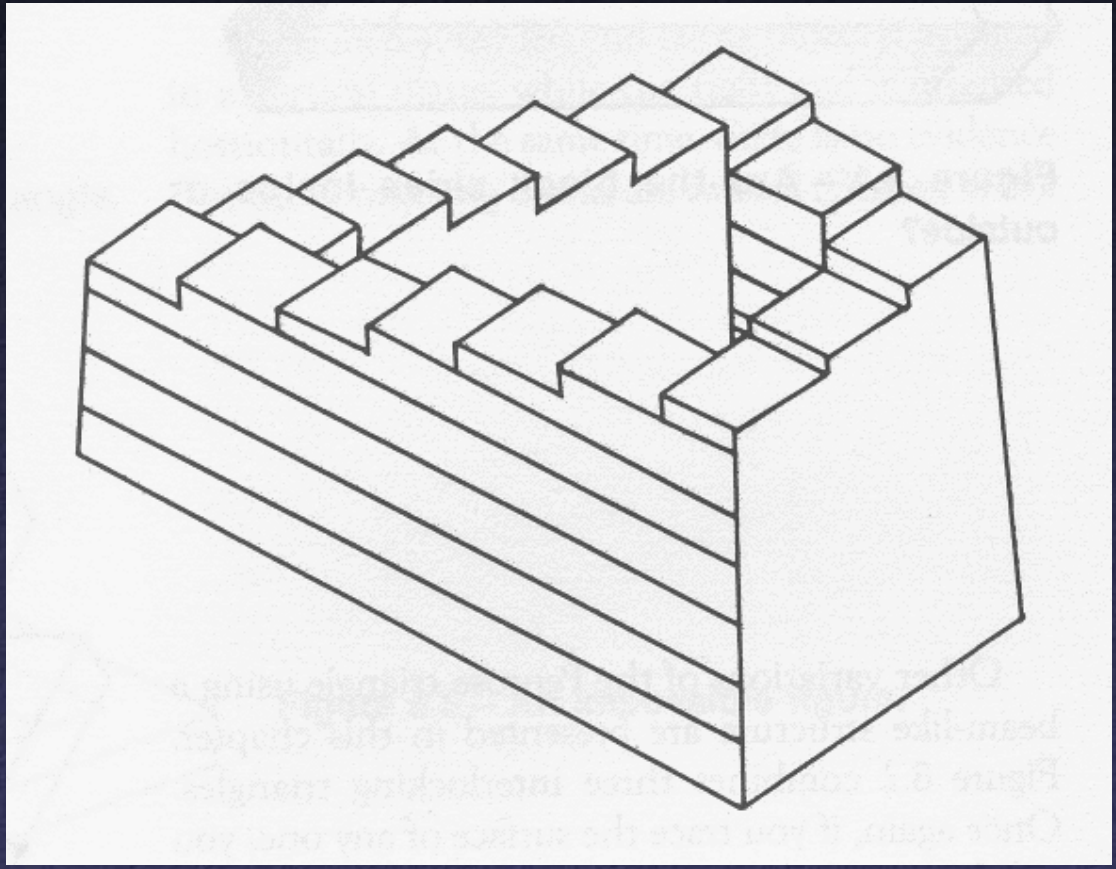
3D Vision



3D Perception: Illusions



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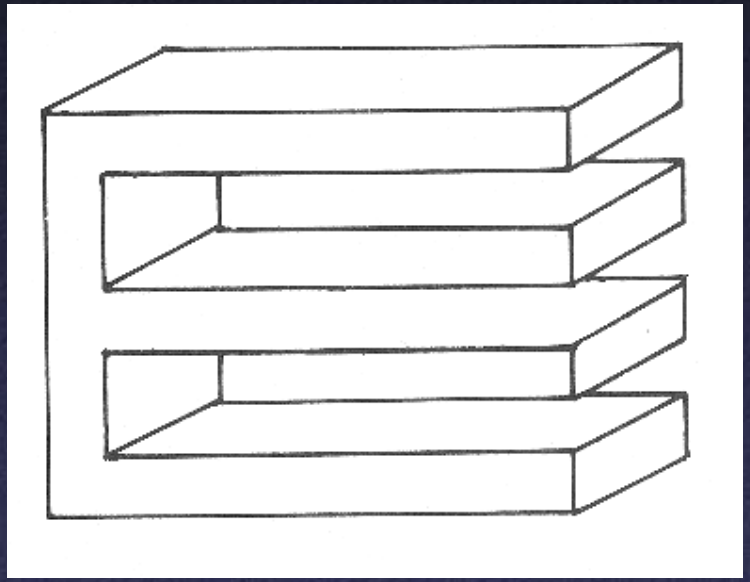
3D Perception: Illusions



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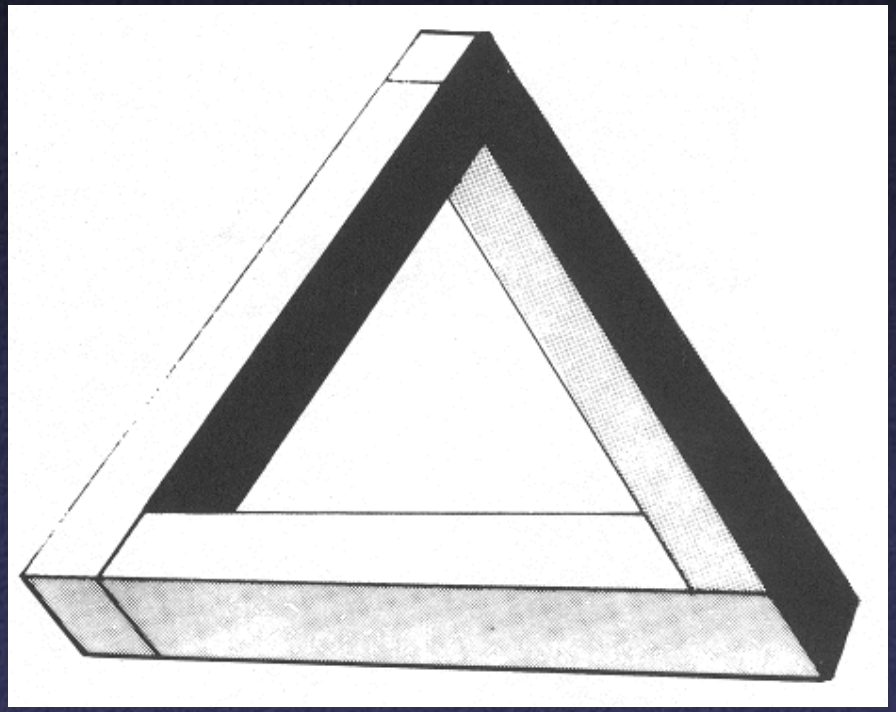
3D Perception: Illusions



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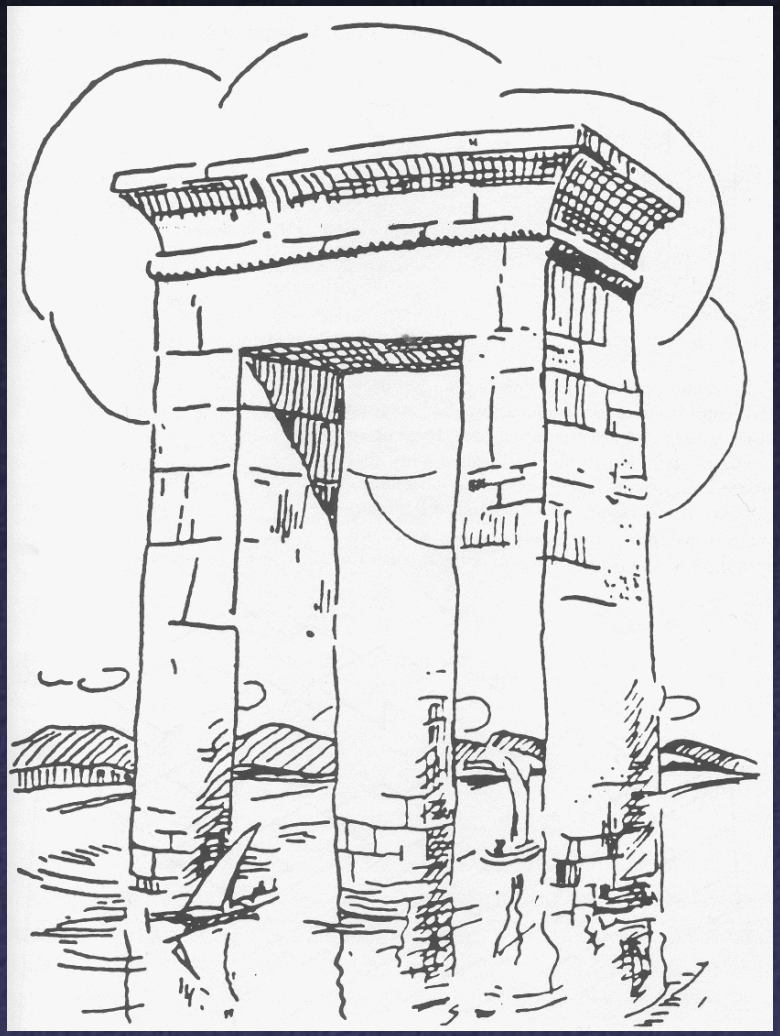
3D Perception: Illusions



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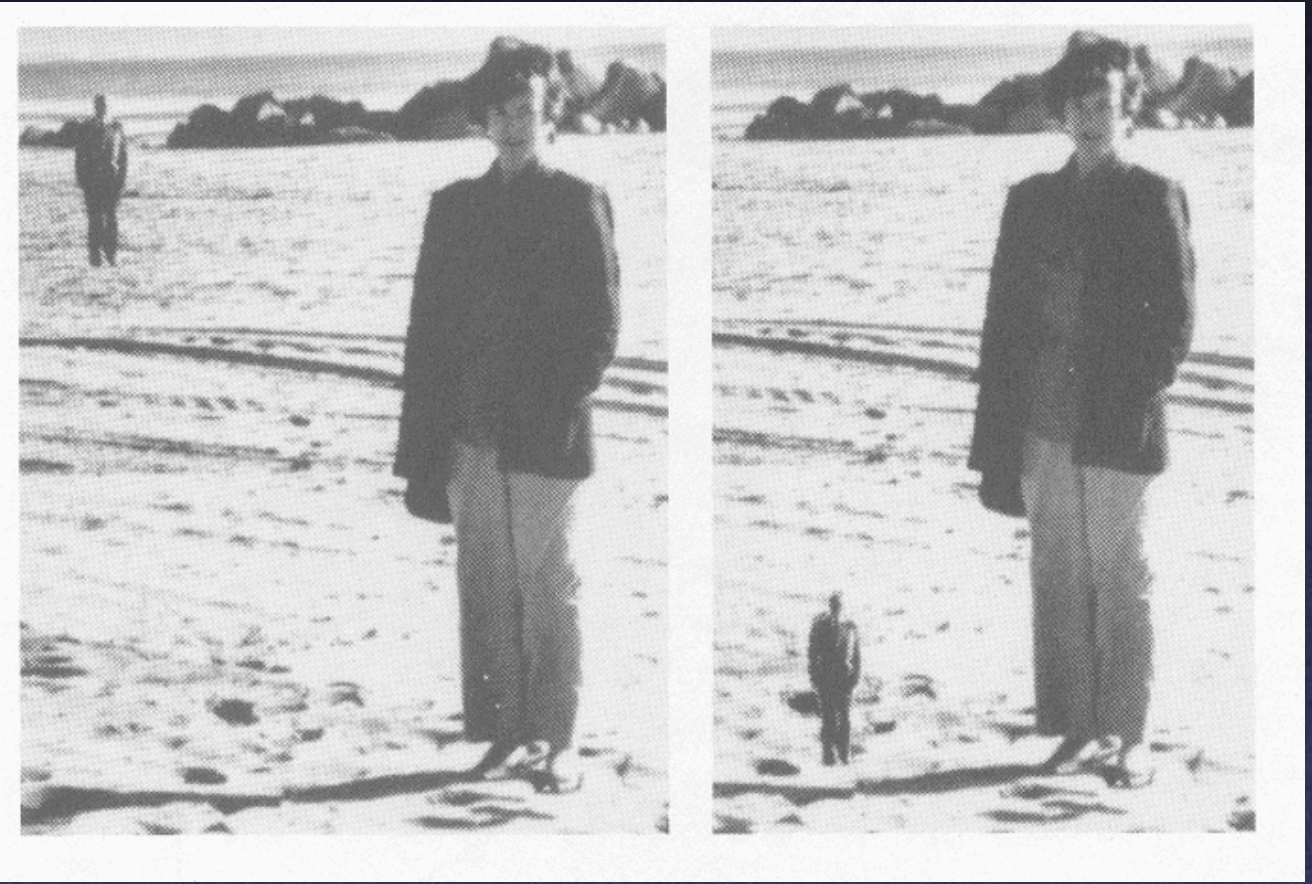

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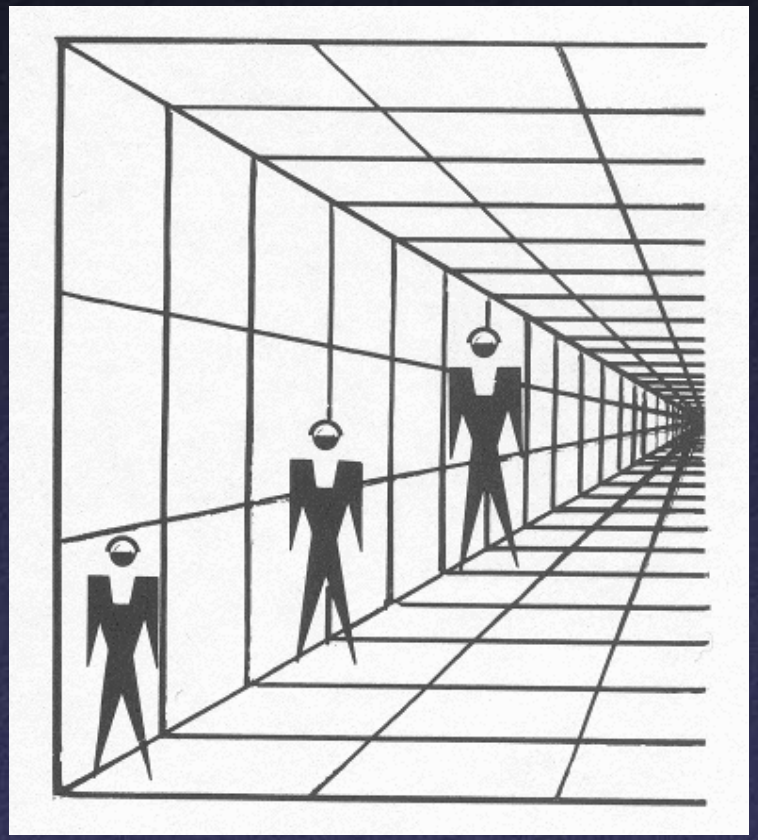

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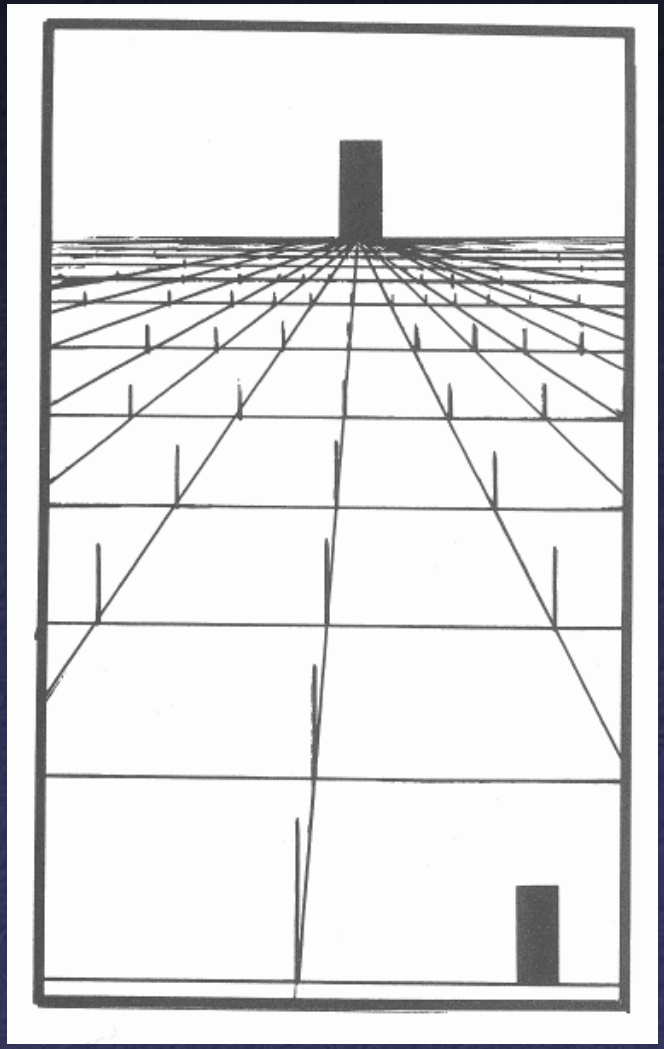

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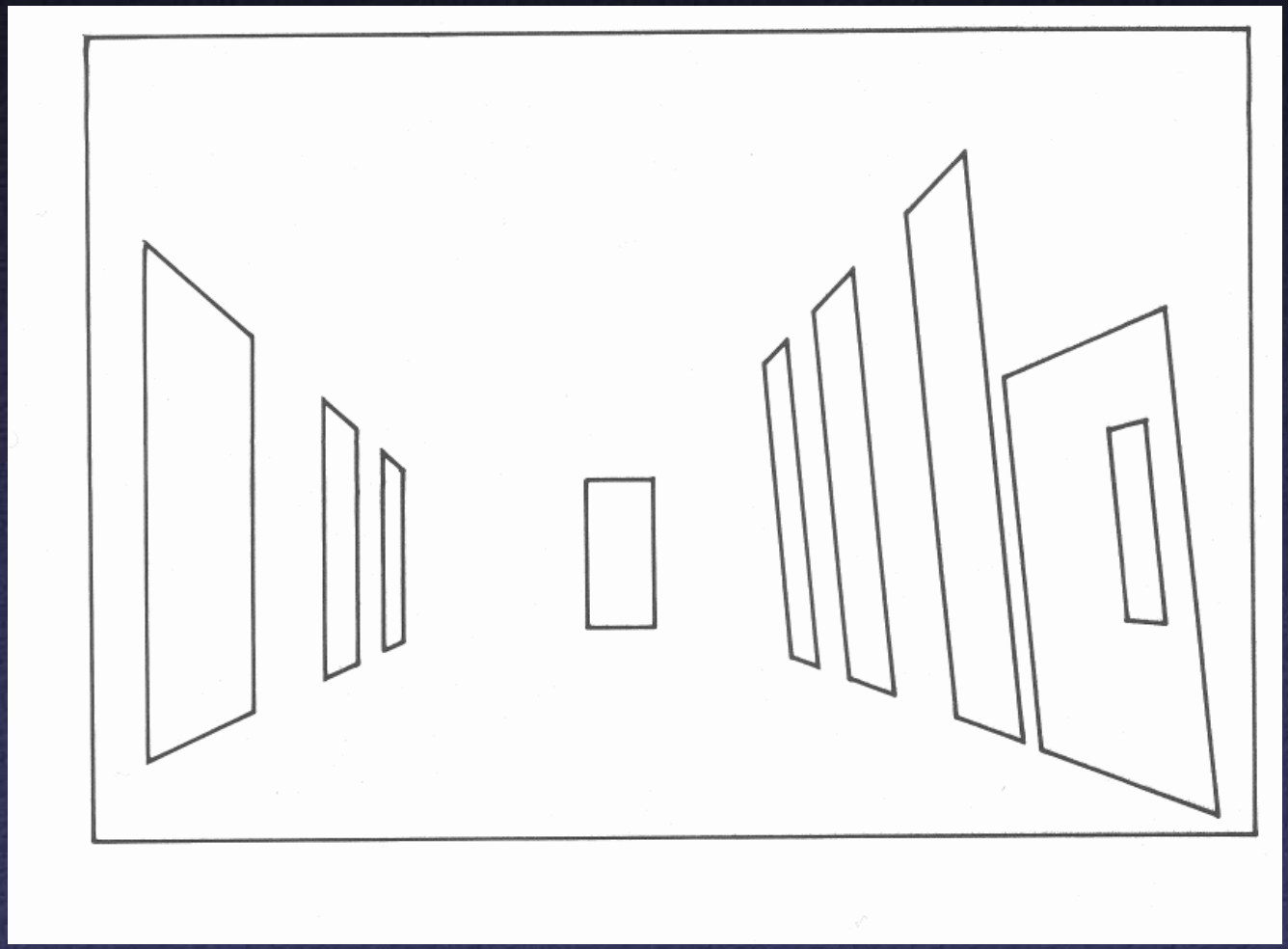

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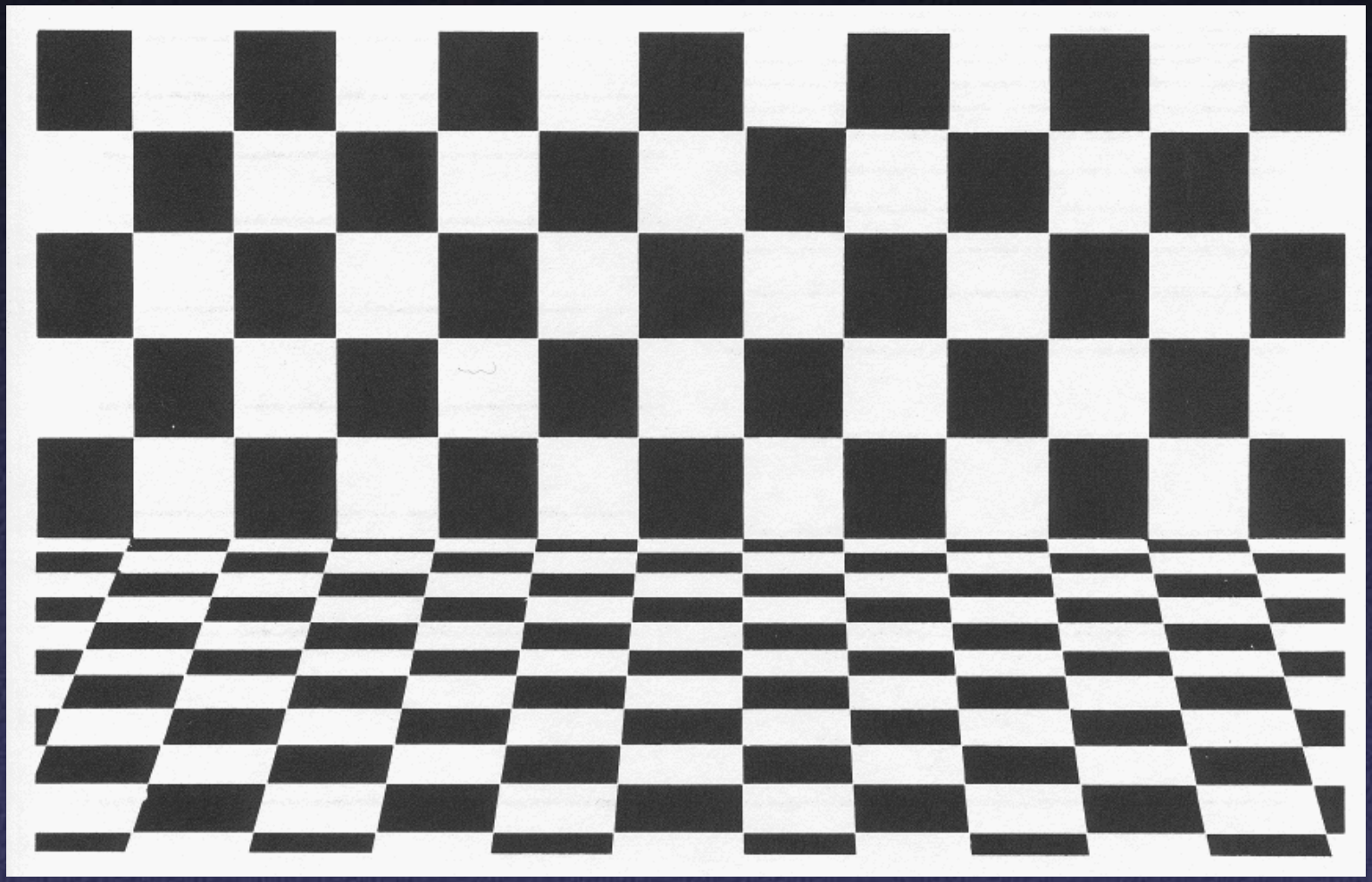

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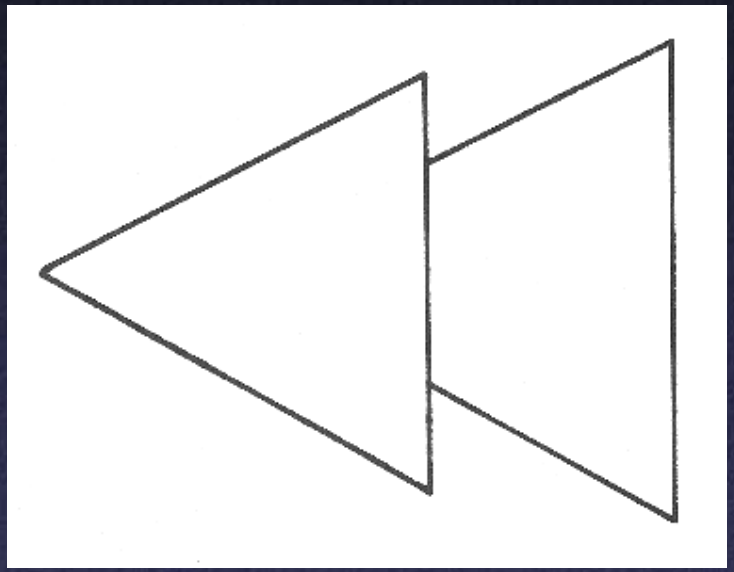
3D Perception: Illusions



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3D Perception: Conclusions

- Perspective is assumed
- Relative depth ordering
- Occlusion is important
- Local consistency

3D Perception: Stereo

- Experiments show that absolute depth estimation not very accurate
  - Low "relief" judged to be deeper than it is
- Relative depth estimation very accurate
  - Can judge which object is closer for stereo disparities of a few seconds of arc

3D Computer Vision

- Accurate (or not) shape reconstruction
- Some things easier to understand on 3D models than in 2D:
  - Occlusion
  - Variation with lighting (shading)
  - Variation with viewpoint
- As a result, some problems become easier:
  - Segmentation
  - Recognition

3D Data Types

- Point Data
- Volumetric Data
- Surface Data

3D Data Types: Point Data

- "Point clouds"
- Advantage: simplest data type
- Disadvantage: no information on adjacency / connectivity

3D Data Types: Volumetric Data

- Regularly-spaced grid in (x,y,z): “voxels”
- For each grid cell, store
  - Occupancy (binary: occupied / empty)
  - Density
  - Other properties
- Popular in medical imaging
  - CAT scans
  - MRI

3D Data Types: Volumetric Data

- Advantages:
  - Can represent inside of object
  - Uniform sampling: simpler algorithms
- Disadvantages:
  - Lots of data
  - Wastes space if only storing a surface
  - Most “vision” sensors / algorithms return point or surface data

3D Data Types: Surface Data

- Polyhedral
  - Piecewise planar
  - Polygons connected together
  - Most popular: “triangle meshes”
- Smooth
  - Higher-order (quadratic, cubic, etc.) curves
  - Bézier patches, splines, NURBS, subdivision surfaces, etc.

3D Data Types: Surface Data

- Advantages:
  - Usually corresponds to what we see
  - Usually returned by vision sensors / algorithms
- Disadvantages:
  - How to find “surface” for translucent objects?
  - Parameterization often non-uniform
  - Non-topology-preserving algorithms difficult

3D Data Types: Surface Data

- Implicit surfaces (cf. parametric)
  - Zero set of a 3D function
  - Usually regularly sampled (voxel grid)
- Advantage: easy to write algorithms that change topology
- Disadvantage: wasted space, time

2½-D Data

- Image: stores an intensity / color along each of a set of regularly-spaced rays in space
- Range image: stores a depth along each of a set of regularly-spaced rays in space
- Not a complete 3D description: does not store objects occluded (from some viewpoint)
- View-dependent scene description

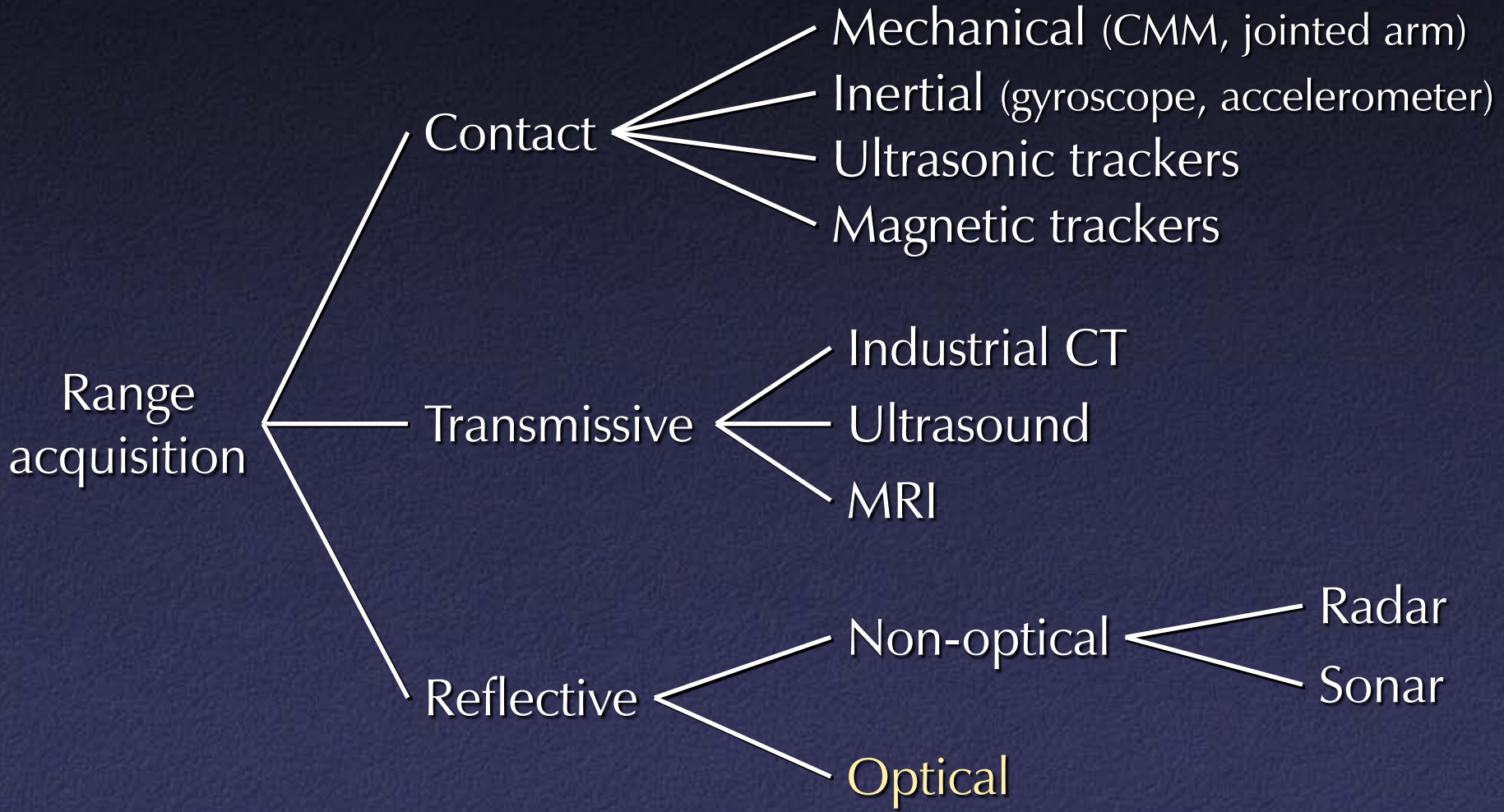
2½-D Data

- This is what most sensors / algorithms really return
- Advantages
  - Uniform parameterization
  - Adjacency / connectivity information
- Disadvantages
  - Does not represent entire object
  - View dependent

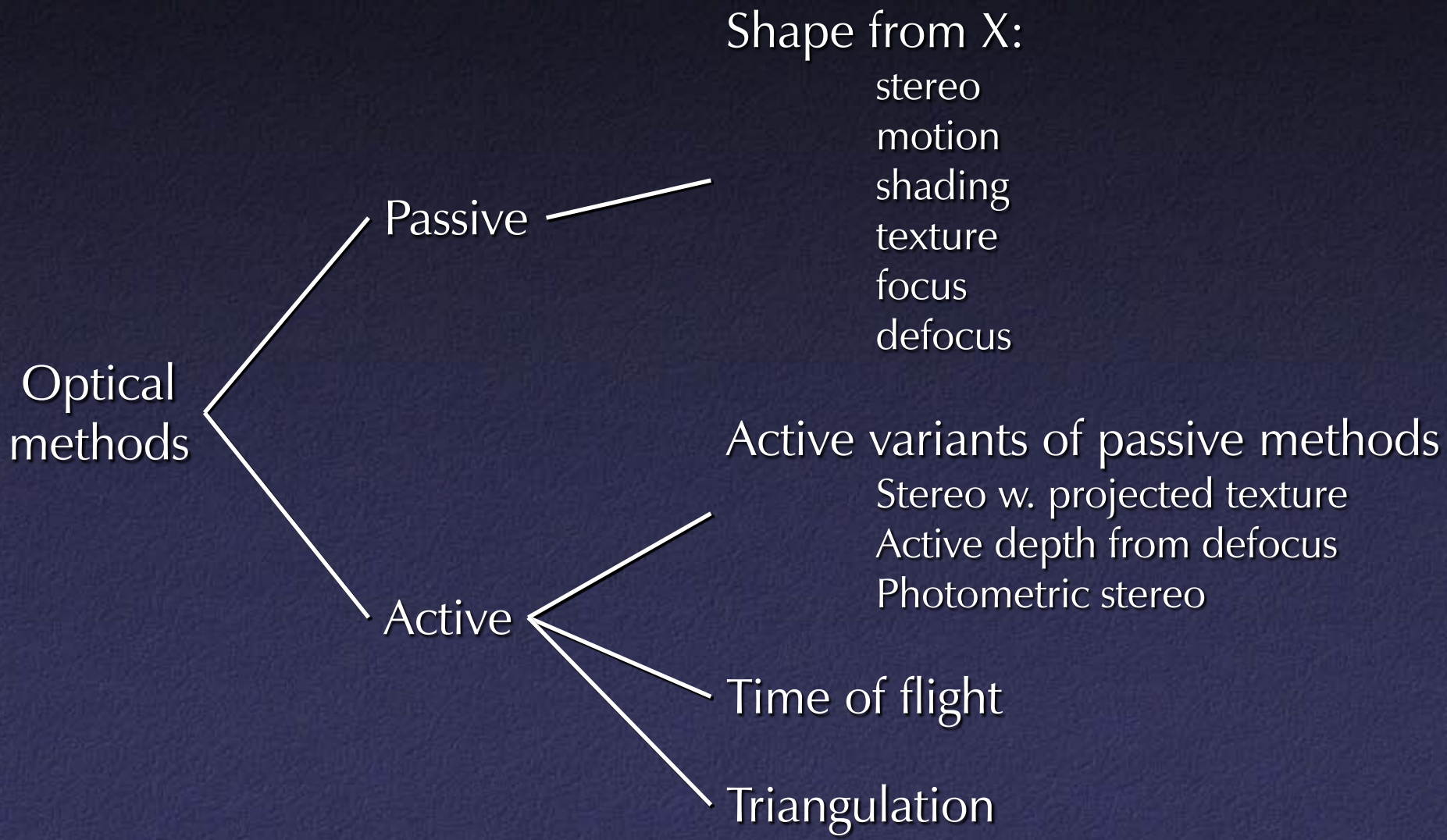
2½-D Data

- Range images
- Range surfaces
- Depth images
- Depth maps
- Height fields
- 2½-D images
- Surface profiles
- *xyz* maps
- …

Range Acquisition Taxonomy



Range Acquisition Taxonomy

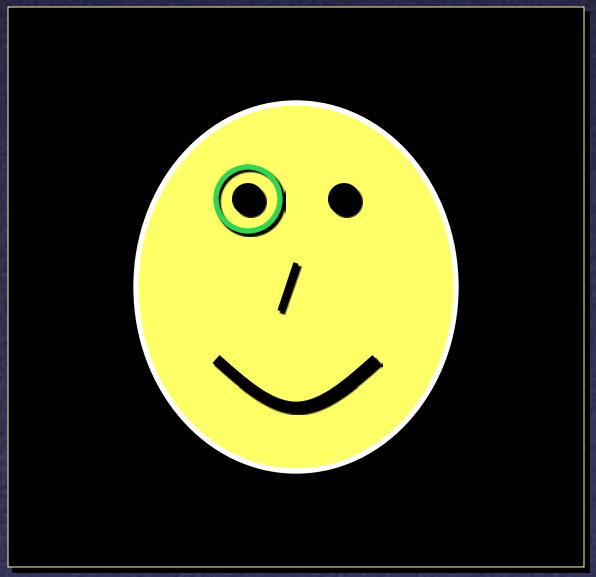


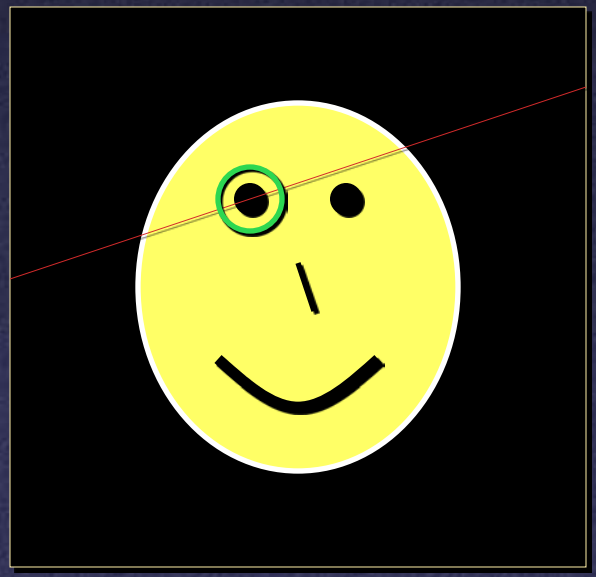
Optical Range Acquisition Methods

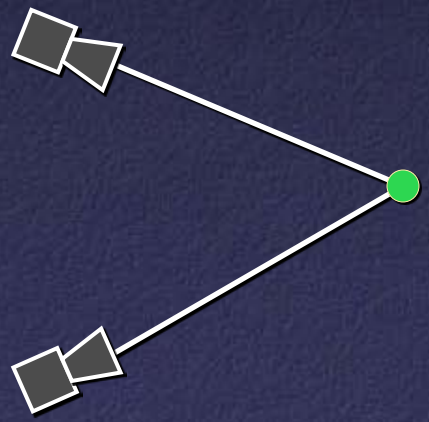
- Advantages:
  - Non-contact
  - Safe
  - Usually inexpensive
  - Usually fast
- Disadvantages:
  - Sensitive to transparency
  - Confused by specularity and interreflection
  - Texture (helps some methods, hurts others)

Stereo

- Find feature in one image, search along epipolar line in other image for correspondence







Stereo

- Advantages:
  - Passive
  - Cheap hardware (2 cameras)
  - Easy to accommodate motion
  - Intuitive analogue to human vision
- Disadvantages:
  - Only acquire good data at “features”
  - Sparse, relatively noisy data (correspondence is hard)
  - Bad around silhouettes
  - Confused by non-diffuse surfaces
- Variant: multibaseline stereo to reduce ambiguity

Shape from Motion

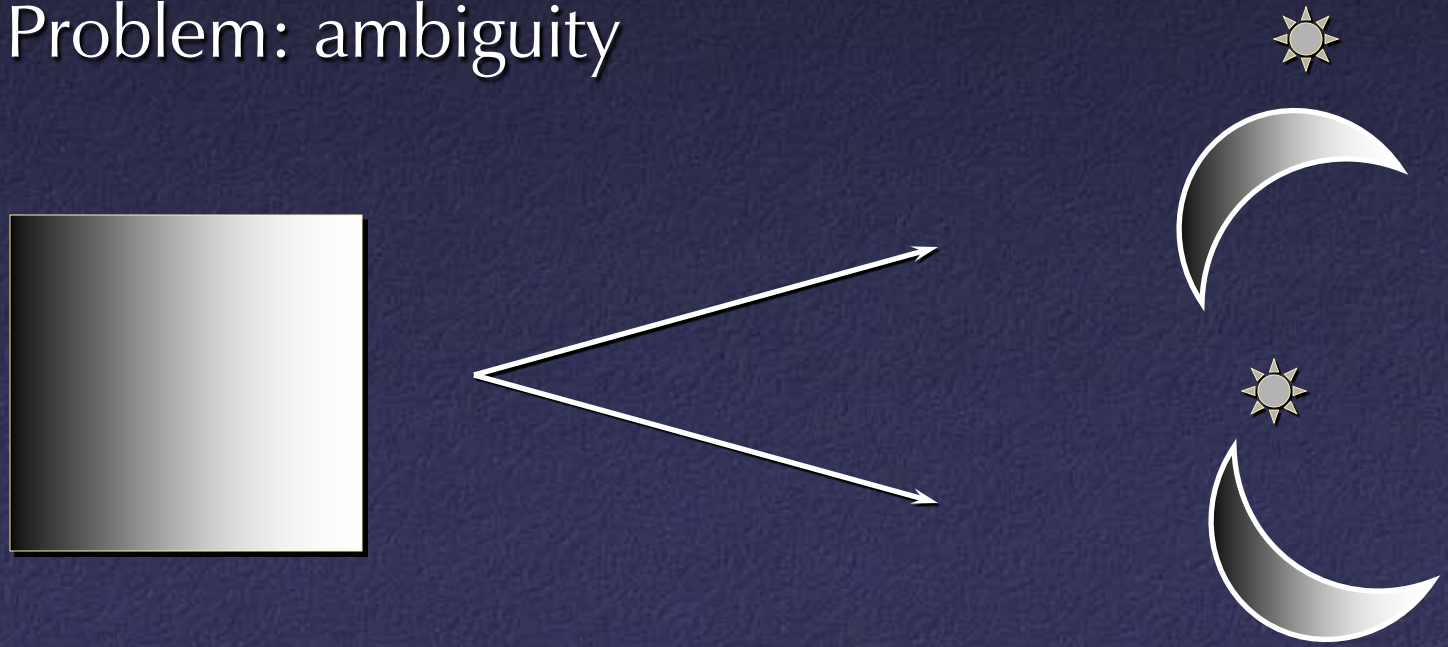
- "Limiting case" of multibaseline stereo
- Track a feature in a video sequence
- For n frames and f features, have $2 \cdot n \cdot f$ knowns, $6 \cdot n + 3 \cdot f$ unknowns

Shape from Motion

- Advantages:
  - Feature tracking easier than correspondence in far-away views
  - Mathematically more stable (large baseline)
- Disadvantages:
  - Does not accommodate object motion
  - Still problems in areas of low texture, in non-diffuse regions, and around silhouettes

Shape from Shading

- Given: image of surface with known, constant reflectance under known point light
- Estimate normals, integrate to find surface
- Problem: ambiguity

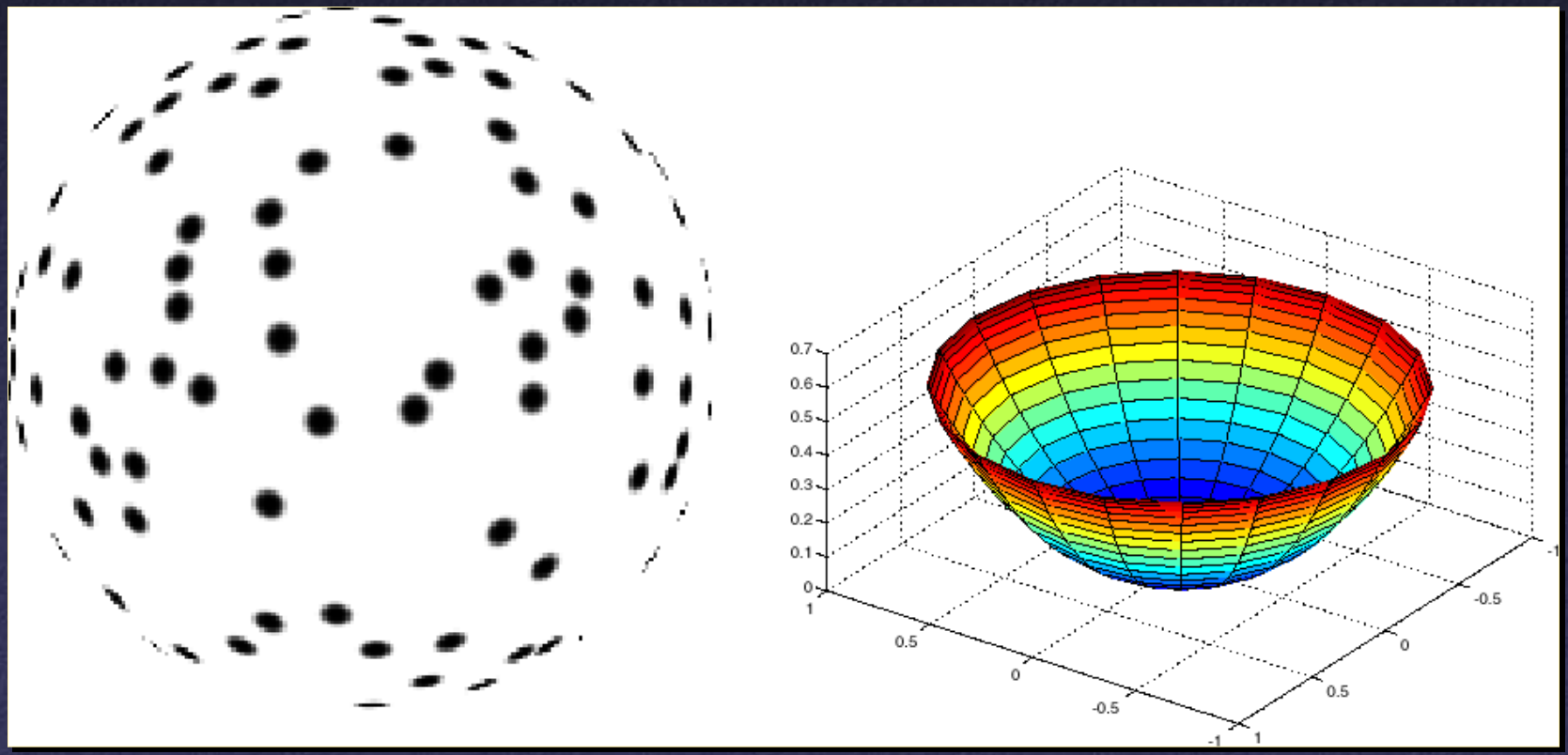


Shape from Shading

- Advantages:
  - Single image
  - No correspondences
  - Analogue in human vision
- Disadvantages:
  - Mathematically unstable
  - Can't have texture
- "Photometric stereo" (active method) more practical than passive version

Shape from Texture

- Mathematically similar to shape from shading, but uses stretch and shrink of a (regular) texture



Shape from Texture

- Analogue to human vision
- Same disadvantages as shape from shading

Shape from Focus and Defocus

- Shape from focus: at which focus setting is a given image region sharpest?
- Shape from defocus: how out-of-focus is each image region?
- Passive versions rarely used
- Active depth from defocus can be made practical

Active Optical Methods

- Advantages:
  - Usually can get dense data
  - Usually much more robust and accurate than passive techniques
- Disadvantages:
  - Introduces light into scene (distracting, etc.)
  - Not motivated by human vision

Terminology

- Range acquisition, shape acquisition, rangefinding, range scanning, 3D scanning
- Alignment, registration
- Surface reconstruction, 3D scan merging, scan integration, surface extraction
- 3D model acquisition

Related Fields

- Computer Vision
  - Passive range sensing
  - Rarely construct complete, accurate models
  - Application: recognition
- Metrology
  - Main goal: absolute accuracy
  - High precision, provable errors more important than scanning speed, complete coverage
  - Applications: industrial inspection, quality control, as-built models

Related Fields

- Computer Graphics
  - Often want complete model
  - Low noise, geometrically consistent model more important than absolute accuracy
  - Application: animated CG characters