Introduction

Computer Vision I
CSE 252A
Lecture 1

What is Computer Vision?

- Trucco and Verri (Text): Computing properties of the 3-D world from one or more digital images
- Sockman and Shapiro: To make useful decisions about real physical objects and scenes based on sensed images
- Ballard and Brown: The construction of explicit, meaningful description of physical objects from images.
- Forsyth and Ponce: Extracting descriptions of the world from pictures or sequences of pictures”

Why is this hard?

What is in this image?
1. A hand holding a man?
2. A hand holding a mirrored sphere?
3. An Escher drawing?

- Interpretations are ambiguous
- The forward problem (graphics) is well-posed
- The “inverse problem” (vision) is not

We all make mistakes

“640K ought to be enough for anybody.” – Bill Gates, 1981

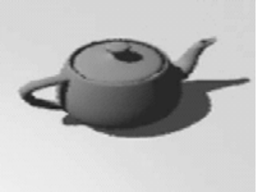
“…” – Marvin Minsky

What do you see?

Changing viewpoint

Moving light source

Deforming shape



What was happening

Changing viewpoint

Moving light source

✓Deforming shape

Should Computer Vision follow from our understanding of Human Vision?

Yes & No

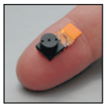
1. Who would ever be crazy enough to even try creating machine vision?
2. Human vision “works”, and copying is easier than creating.
3. Secondary benefit – in trying to mimic human vision, we learn about it.

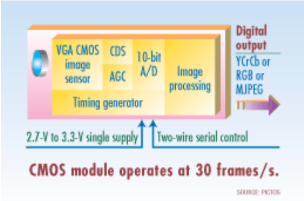
1. Why limit oneself to human vision when there is even greater diversity in biological vision
2. Why limit oneself to biological when there may be greater diversity in sensing mechanism?
3. Biological vision systems evolved to provide functions for “specific” tasks and “specific” environments. These may differ for machine systems
4. Implementation – hardware is different, and synthetic vision systems may use different techniques/methodologies that are more appropriate to computational mechanisms

The Near Future: Ubiquitous Vision

[Written two years ago, seemed a bit far fetched]

- Five years from now, digital cameras will cost 1 cent (sensor cost).
- Digital video will be a widely available commodity component embedded in cell phones, PDA’s, doorbells, bridges, security systems, cars, etc.
- 99.9% of digitized video won’t be seen by a person.
- That doesn’t mean that only 0.1% is important!





CMOS module operates at 30 frames/s.

SOURCE: PICTOS

Applications: touching your life

- Football
- Movies
- Surveillance
- HCI – hand gestures
- Aids to the blind
- Face recognition & Biometrics
- Road monitoring
- Industrial inspection
- Homeland security
- Robotic control
- Autonomous driving
- Space: planetary exploration, docking
- Medicine – pathology, surgery, diagnosis
- Microscopy
- Military
- Remote Sensing
- Digital photography

Some Vision Problems

- Segmentation
  - Breaking images and video into meaningful pieces
- Reconstructing the 3D world
  - from multiple views
  - from shading
  - from structural models
- Recognition
  - What are the objects in a scene?
  - What is happening in a video?
- Video
  - Understand movement and change in image sequence.
  - Tracking objects

Related Fields

- Image Processing
- Computer Graphics
- Pattern Recognition
- Perception
- Robotics
- AI

Image Interpretation - Cues

- Variation in appearance in multiple views
  - stereo
  - motion
- Shading & highlights
- Shadows
- Contours
- Texture
- Blur
- Geometric constraints
- Prior knowledge

Computer Vision: Fiction or Fact

Biometrics segment

Shading and lighting

Shading as a result of differences in lighting is

1. A source of information
2. An annoyance

Illumination Variability
An annoyance

"The variations between the images of the same face due to illumination and viewing direction are almost always larger than image variations due to change in face identity."
-- Moses, Adini, Ullman, ECCV '94

How do we understand shading

(An idealization of "engineering" research)

1. Construct a model of the domain (usually mathematical, based on physics).
2. Prove properties of that model to better understand the model and opportunities of using it.
3. Develop algorithms to solve a problem that is correct under the model.
4. Implement & evaluate it.
5. Question assumptions of the model & start all over again.

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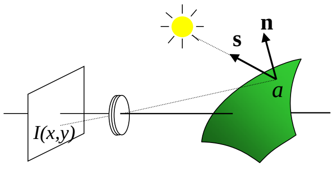
1. Image Formation



At image location *(x,y)* the intensity of a pixel *I(x,y)* is

$$I(x,y) = a(x,y)\,\mathbf{n}(x,y) \bullet \mathbf{s}$$

where

- *a(x,y)* is the albedo of the surface projecting to *(x,y).*
- **n***(x,y)* is the unit surface normal.
- **s** is the direction and strength of the light source.

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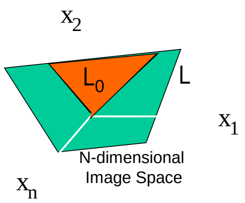
2. A property:
3-D Linear subspace

The set of images of a Lambertian surface with no shadowing is a subset of 3-D linear subspace.

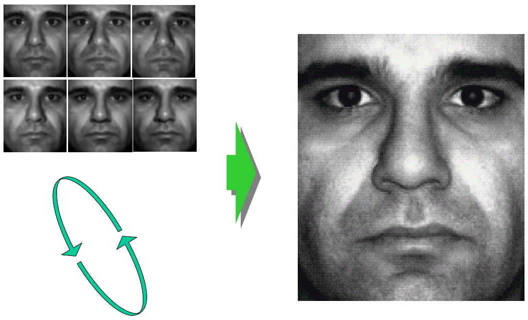
[Moses 93], [Nayar, Murase 96], [Shashua 97]

$L = \{\mathbf{x} \mid \mathbf{x} = B\mathbf{s},\ \forall \mathbf{s} \in R^3\}$

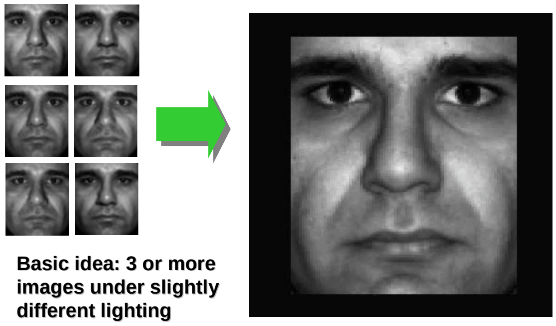
where B is a *n* by 3 matrix whose rows are product of the surface normal and Lambertian albedo



3,4 : An implemented algorithm: Relighting


Single Light Source

3,4: An implemented algorithm Photometric Stereo


Basic idea: 3 or more images under slightly different lighting

5. Question Assumpions

- Many objects are not Lambertian (specular, complex reflectance functions).

The course

- Part 1: The Physics of Imaging
- Part 2: Early Vision
- Part 3: Reconstruction
- Part 4: Recognition

Part I of Course: The Physics of Imaging

- How images are formed
  - Cameras
    - What a camera does
    - How to tell where the camera was located
  - Light
    - How to measure light
    - What light does at surfaces
    - How the brightness values we see in cameras are determined
  - Color
    - The underlying mechanisms of color
    - How to describe it and measure it

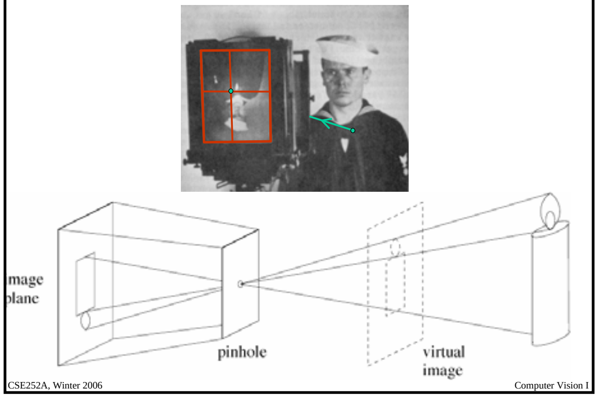
Cameras, lenses, and sensors


Figure 1.16 The first photograph on record, *la table servie*, obtained by Nicéphore Niepce in 1822. *Collection Harlinge–Viollet.*

•Pinhole cameras
•Lenses
•Projection models
•Geometric camera parameters

From Computer Vision, Forsyth and Ponce, Prentice-Hall, 2002.

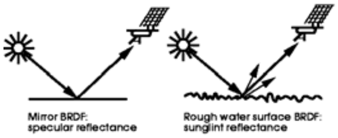
A real camera … and its model



Lighting & Photometry

- How does measurement relate to light energy?

- Sensor response
- Light sources
- Reflectance



Color

Part II: Early Vision in One Image

- Representing small patches of image
  - For three reasons
    - We wish to establish correspondence between (say) points in different images, so we need to describe the neighborhood of the points
    - Sharp changes are important in practice --- known as “edges”
    - Representing texture by giving some statistics of the different kinds of small patch present in the texture.
      - Tigers have lots of bars, few spots
      - Leopards are the other way

Segmentation

- Which image components “belong together”?
- Belong together ≅ lie on the same object
- Cues
  - similar color
  - similar texture
  - not separated by contour
  - form a suggestive shape when assembled

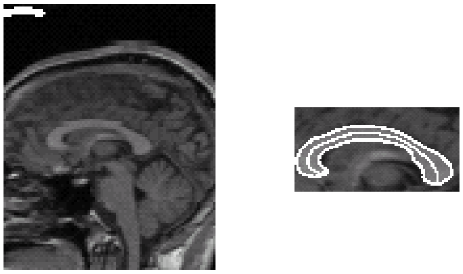
Boundary Detection

http://www.robots.ox.ac.uk/~vdg/dynamics.html

Boundary Detection: Local cues

Gradients

Boundary Detection



Finding the Corpus Callosum

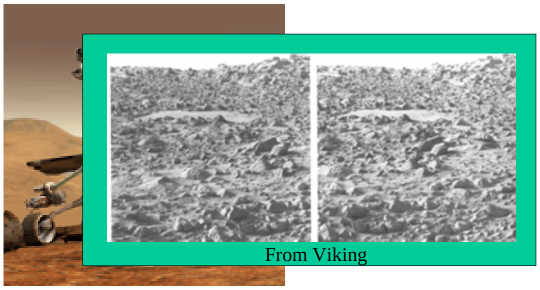
(G. Hamarneh, T. McInerney, D. Terzopoulos)

Part 3: Reconstruction from Multiple Images

- Photometric Stereo
  - – What we know about the world from lighting changes.
- The geometry of multiple views
- Stereopsis
  - – What we know about the world from having 2 eyes
- Structure from motion
  - – What we know about the world from having many eyes
    - or, more commonly, our eyes moving.

Mars Rover

Spirit



From Viking

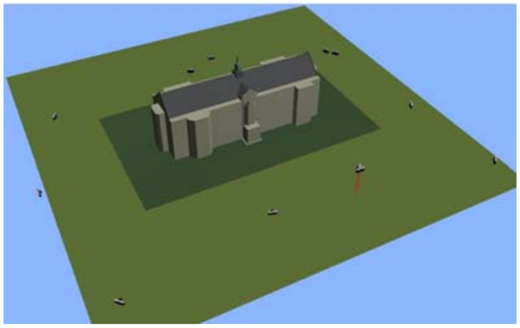
Façade (Debevec, Taylor and Malik, 1996)
Reconstruction from multiple views, constraints, rendering

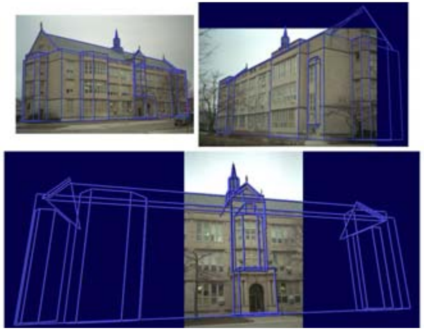
Architectural modeling:
- photogrammetry;
- view-dependent texture mapping;
- model-based stereopsis.

Reprinted from “Modeling and Rendering Architecture from Photographs: A Hybrid Geometry- and Image-Based Approach,” By P. Debevec, C.J. Taylor, and J. Malik, Proc. SIGGRAPH (1996).

Images with marked features

Resulting model & Camera Positions





Recovered model edges reprojected through recovered camera positions into the three original images

UNI High Movie

Façade

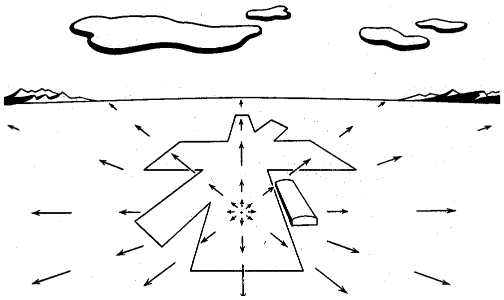
- The Camponile Movie

Video-Motion Analysis

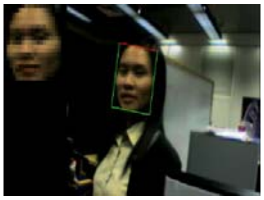
- Where “things” are moving in image – segmentation.
- Determining observer motion (egomotion)
- Determining scene structure
- Tracking objects
- Understanding activities & actions

Forward Translation & Focus of Expansion

[Gibson, 1950]



Visual Tracking



Main Challenges

1. 3-D Pose Variation
2. Occlusion of the target
3. Illumination variation
4. Camera jitter
5. Expression variation

etc.

[Ho, Lee, Kriegman]

Visual Tracking

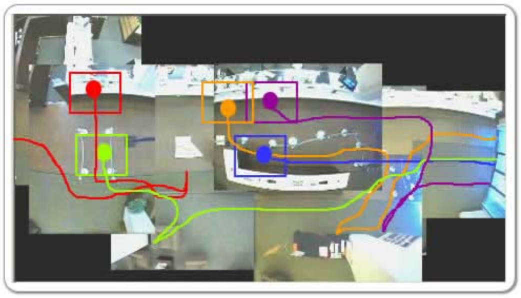
- State: usually a finite number of parameters (a vector) that characterizes the "state" (e.g., location, size, pose, deformation of thing being tracked.
- Dynamics: How does the state change over time? How is that changed constrained?
- Representation: How do you represent the thing being tracked
- Prediction: Given the state at time *t-1*, what is an estimate of the state at time *t*?
- Correction: Given the predicted state at time *t*, and a measurement at time *t*, update the state.

Tracking

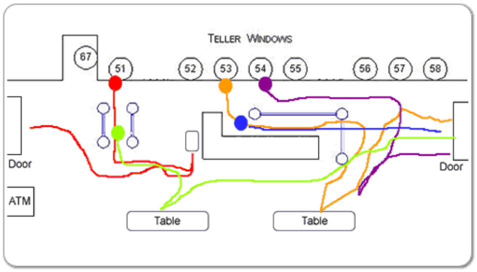
(www.brickstream.com)

Tracking

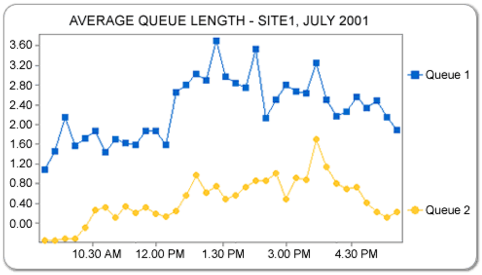
Tracking



Tracking



Tracking



Part 4: Recognition

Given a database of objects and an image determine what, if any of the objects are present in the image.

Recognition Challenges

- Within-class variability
  - Different objects within the class have different shapes or different material characteristics
  - Deformable
  - Articulated
  - Compositional
- Pose variability:
  - 2-D Image transformation (translation, rotation, scale)
  - 3-D Pose Variability (perspective, orthographic projection)
- Lighting
  - Direction (multiple sources & type)
  - Color
  - Shadows
- Occlusion – partial
- Clutter in background -> false positives

Object Recognition Issues:

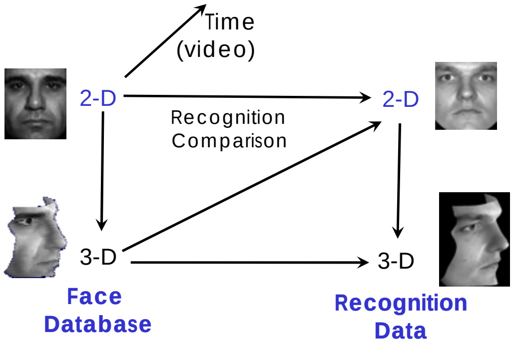
- How general is the problem?
  - 2D vs. 3D
  - range of viewing conditions
  - available context
  - segmentation cues
- What sort of data is best suited to the problem?
  - Whole images
  - Local 2D features (color, texture,
  - 3D (range) data
- What information do we have in the database?
  - Collection of images?
  - 3-D models?
  - Learned representation?
  - Learned classifiers?
- How many objects are involved?
  - small: brute force search
  - large: ??

Recognition Example: Face Detection: Classify face vs. non-face

Why is Face Recognition Hard?

Many faces of Madona

Face Recognition: 2-D and 3-D



Time (video)

2-D

2-D

Recognition Comparison

3-D

3-D

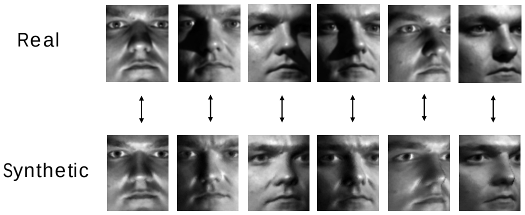
Face Database

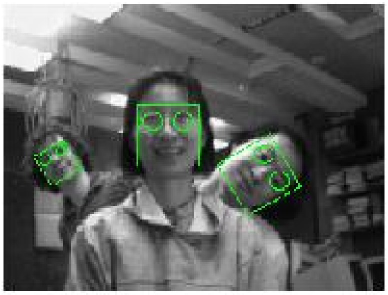
Recognition Data

Yale Face Database B

64 Lighting Conditions
9 Poses
=> 576 Images per Person

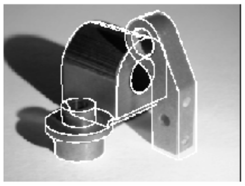
Real vs. Synthetic





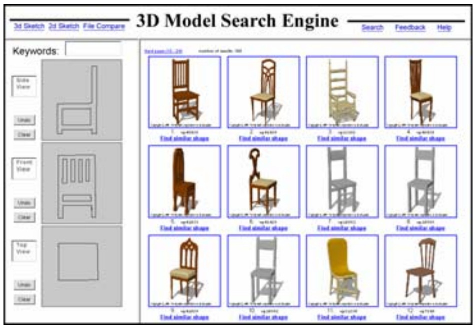
http://www.ri.cmu.edu/projects/project_271.html

Model-Based Vision



- Given 3-D models of each object
- Detect image features (often edges, line segments, conic sections)
- Establish correspondence between model &image features
- Estimate pose
- Consistency of projected model with image.

Object Classes: Chairs



(Funkhauser, Min, Kazhdan, Chen, Halderman, Dobkin, Jacobs)

Scene Interpretation

“The Swing”
Fragonard, 1766