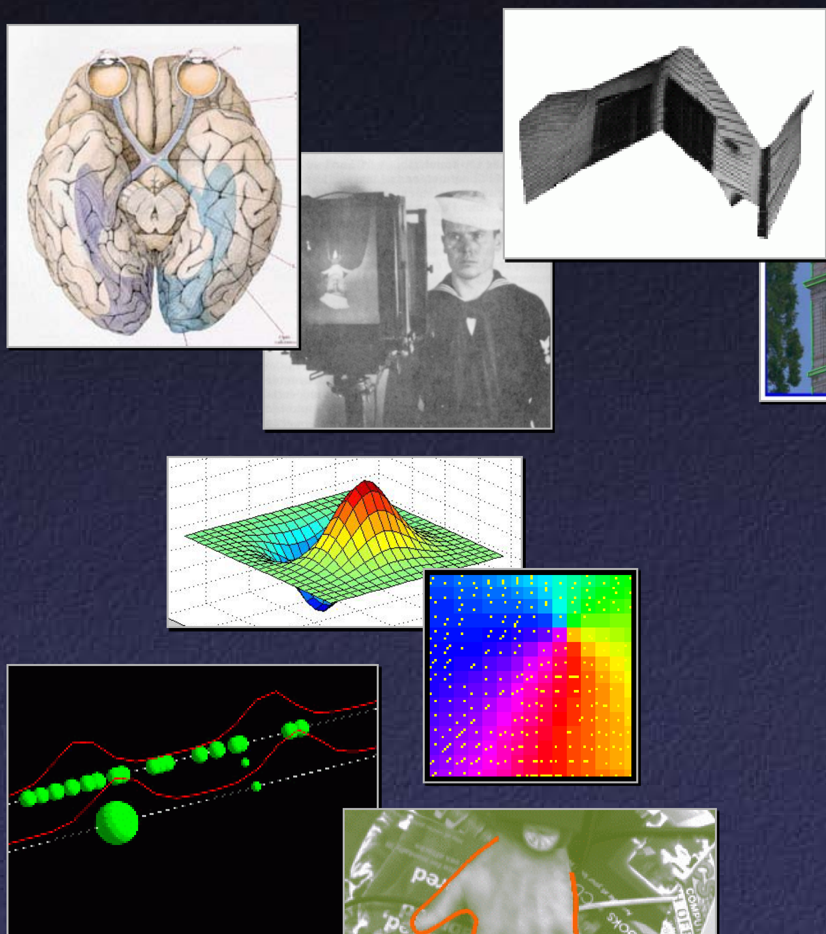
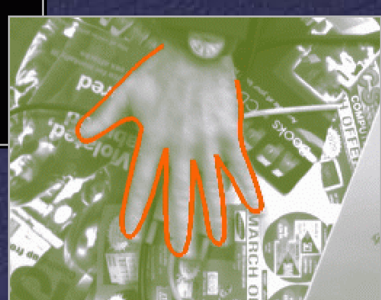
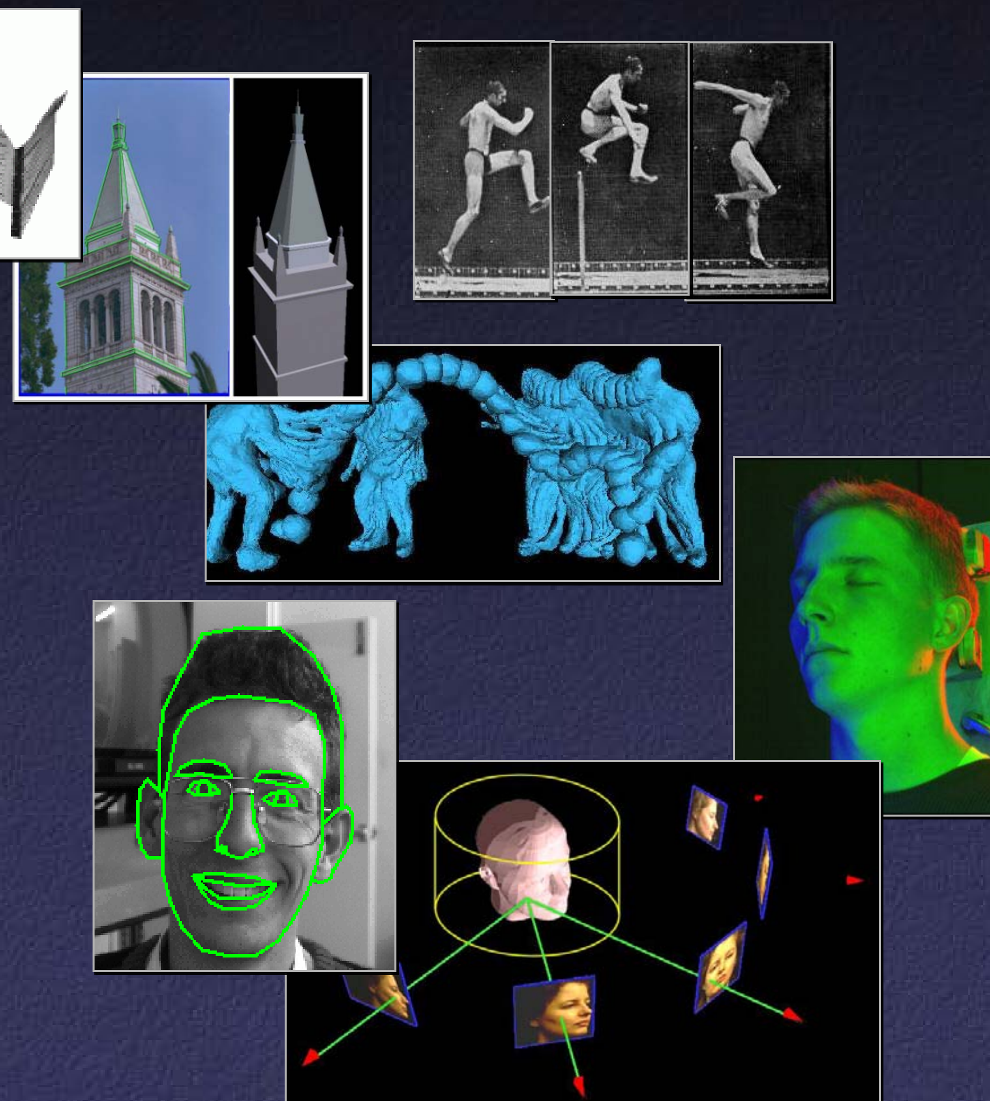
COS 429: Computer Vision







Thanks to Chris Bregler

COS 429: Computer Vision

- Instructor: Szymon Rusinkiewicz

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- Course web page

http://www.cs.princeton.edu/courses/archive/fall09/cos429/

What is Computer Vision?

- Input: images or video
- Output: description of the world
- But also: measuring, classifying, interpreting visual information

Low-Level or “Early” Vision

“There’s an edge!”

- Considers local properties of an image

Mid-Level Vision

- Grouping and segmentation

“There’s an object and a background!”

High-Level Vision

"It's a chair!"

- Recognition
- Classification

Big Question #1: Who Cares?

- Applications of computer vision
  - In AI: vision serves as the “input stage”
  - In medicine: understanding human vision
  - In engineering: creating models of the world

Consumer Applications

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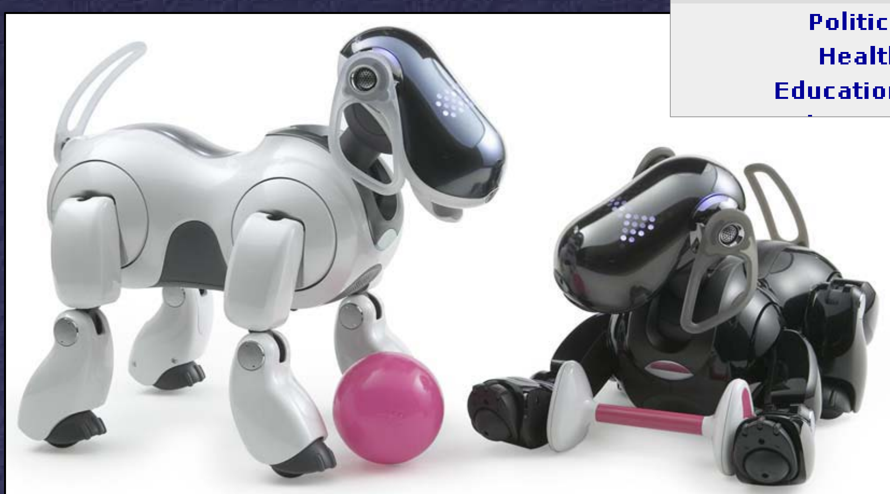
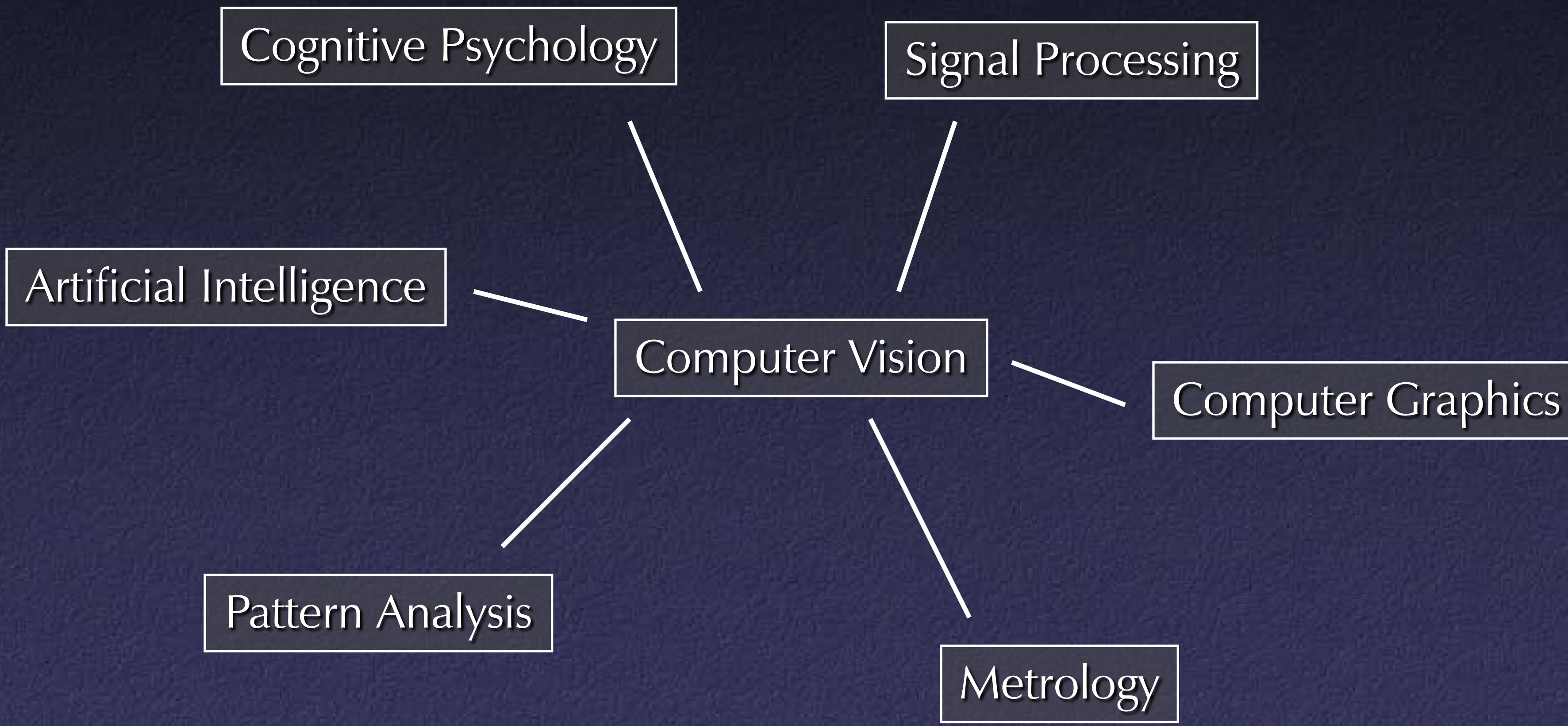
Face-hunting cameras boost Nikon

Japanese camera maker Nikon has tripled its profits on the back of strong sales of digital cameras that automatically focus on human faces.

Face recognition cameras like the Coolpix L1 are popular



Vision and Other Fields



Big Question #2: Does It Work?

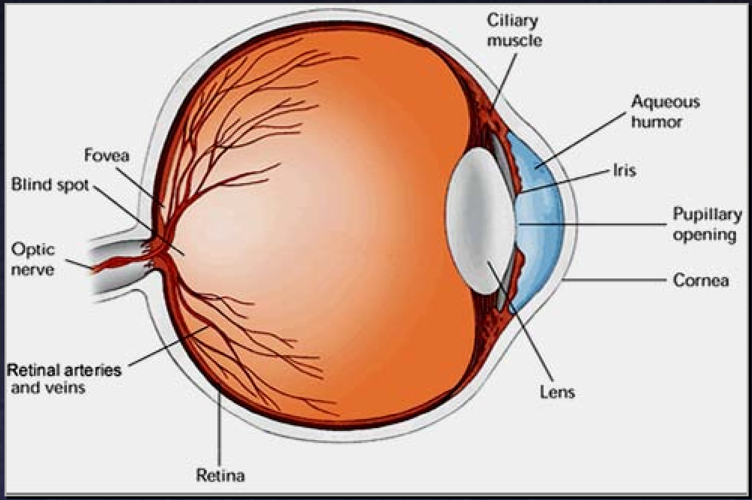
- Situation much the same as AI:
  - Some fundamental algorithms
  - Large collection of hacks / heuristics
  - Continuous progress: more success than you might think!
- Vision is hard!
  - Especially at high level, physiology unknown
  - Requires integrating many different methods
  - Requires reasoning and understanding: "AI completeness"

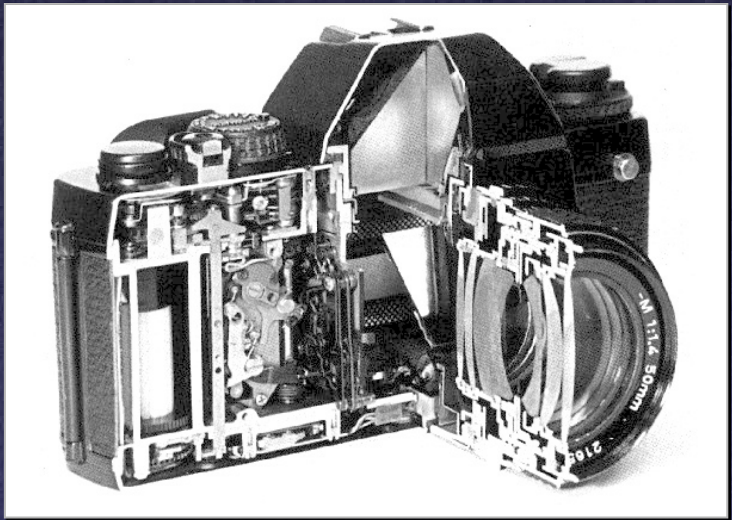
Computer and Human Vision

- Emulating effects of human vision
- Understanding physiology of human vision
- Analogues of human vision at
  low, mid, and high levels

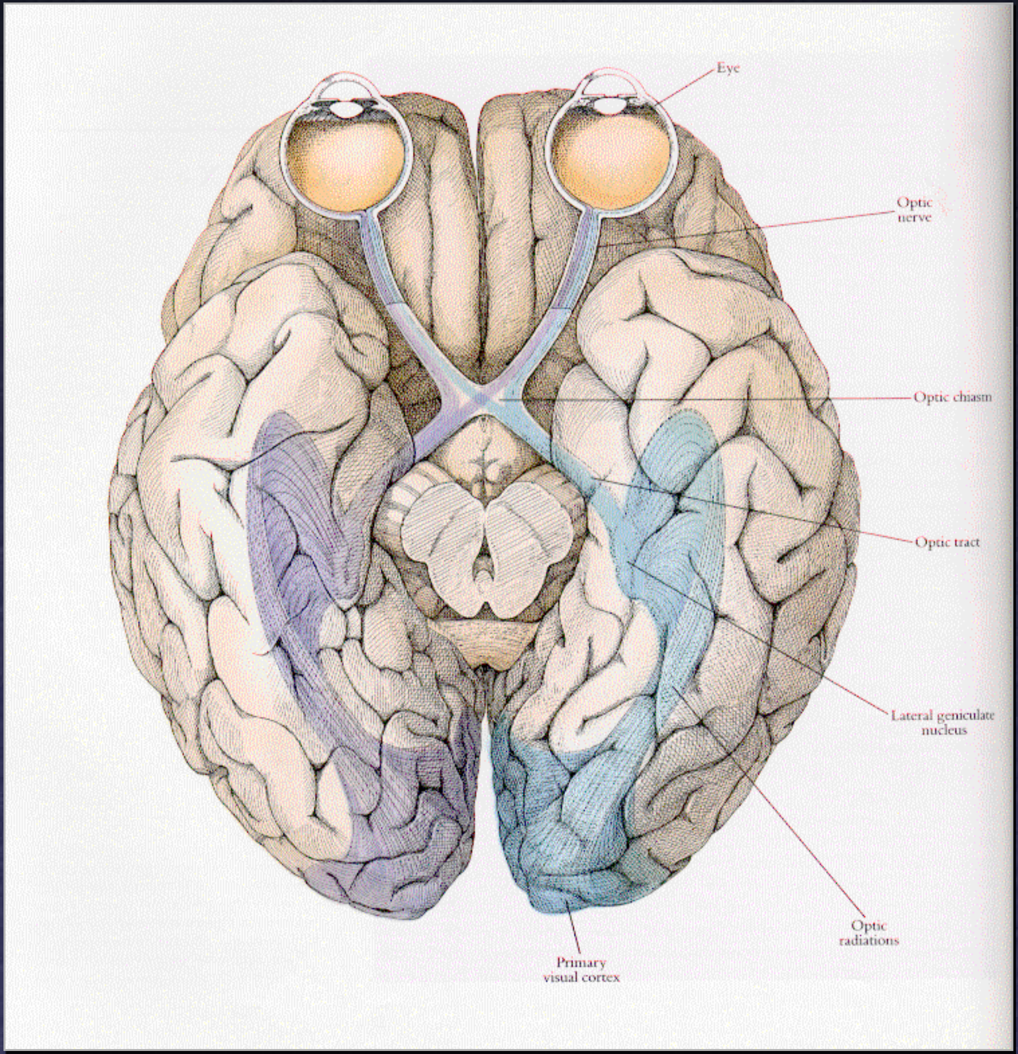
Image Formation

- Human: lens forms image on retina, sensors (rods and cones) respond to light
- Computer: lens system forms image, sensors (CCD, CMOS) respond to light





Low-Level Vision



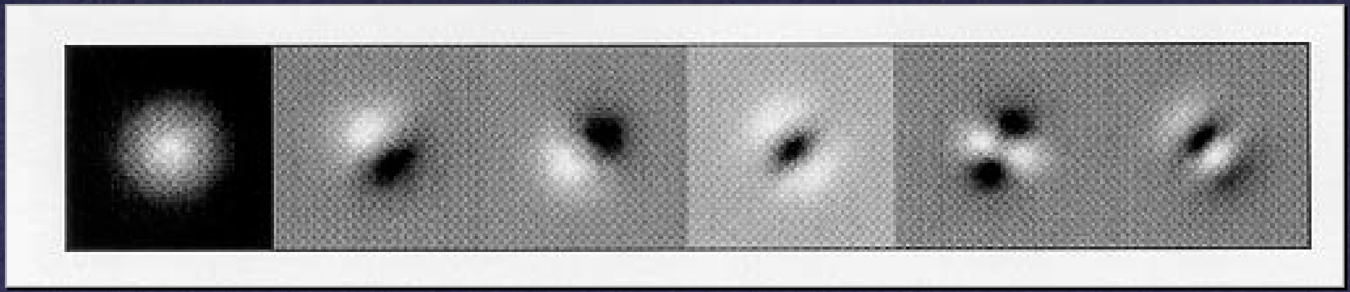
Hubel

Low-Level Vision

- Retinal ganglion cells
- Lateral Geniculate Nucleus – visual adaptation?
- Primary Visual Cortex
  - Simple cells: orientational sensitivity
  - Complex cells: directional sensitivity
- Further processing
  - Temporal cortex: what is the object?
  - Parietal cortex: where is the object? How do I get it?

Low-Level Vision

- Net effect: low-level human vision can be (partially) modeled as a set of *multiresolution, oriented* filters



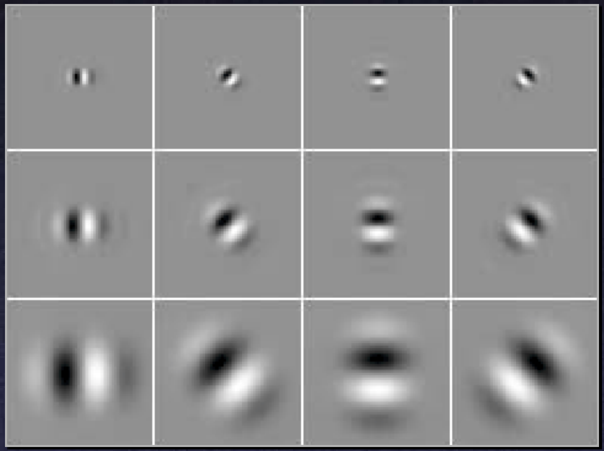
Low-Level Depth Cues

- Focus
- Vergence
- Stereo
- Not as important as popularly believed

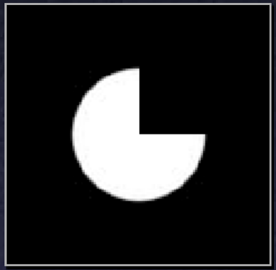
Low-Level Computer Vision

- Filters and filter banks
  - Implemented via convolution
  - Detection of edges, corners, and other local features
  - Can include multiple orientations
  - Can include multiple scales: “filter pyramids”
- Applications
  - First stage of segmentation
  - Texture recognition / classification
  - Texture synthesis

Texture Analysis / Synthesis



Multiresolution
Oriented
Filter Bank



Original
Image

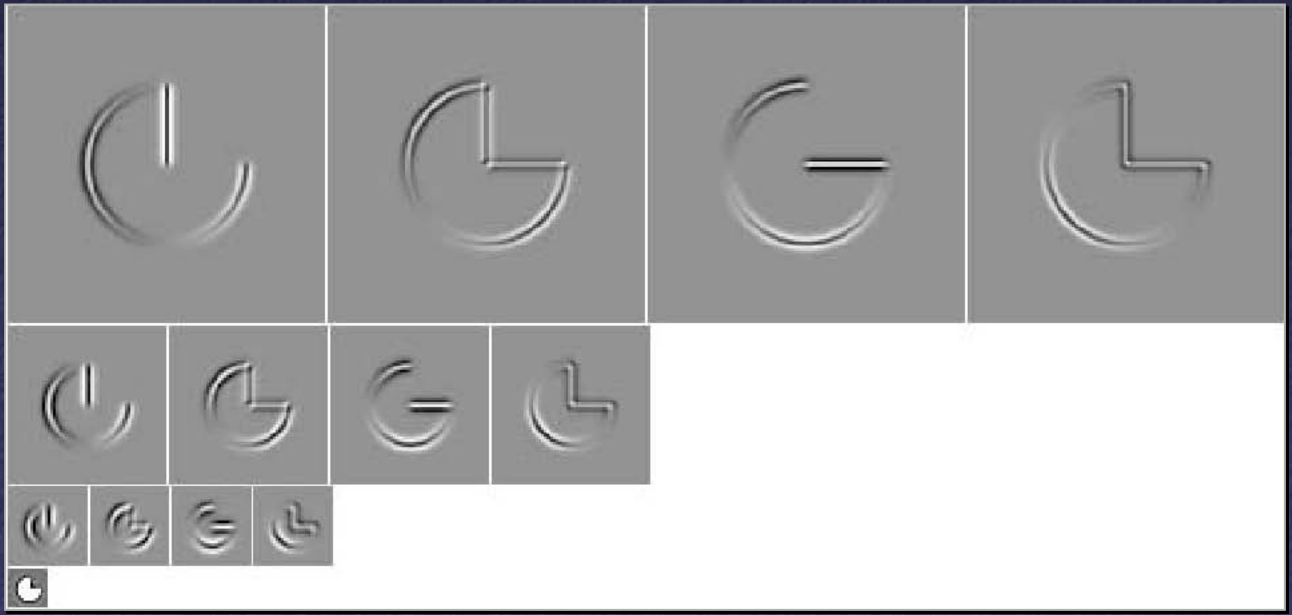
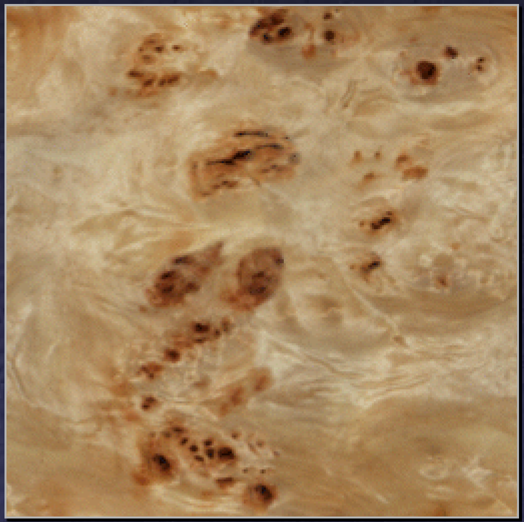


Image
Pyramid

Texture Analysis / Synthesis



Original
Texture

Synthesized
Texture

[Heeger and Bergen]

Low-Level Computer Vision

- Optical flow
  - Detecting frame-to-frame motion
  - Local operator: gradients over space and time
- Applications
  - First stage of tracking

Optical Flow

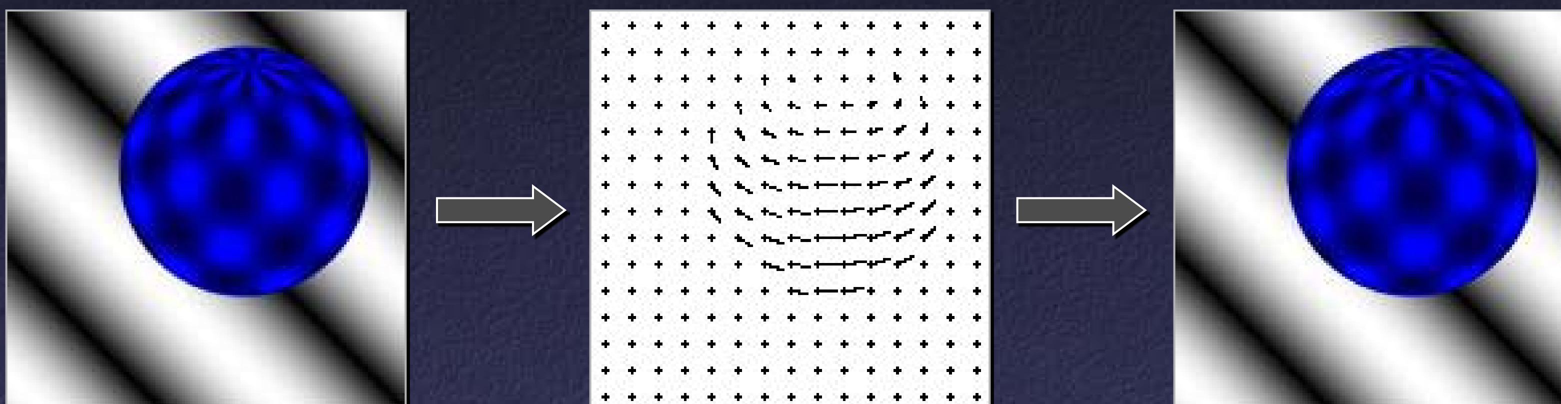


Image #1

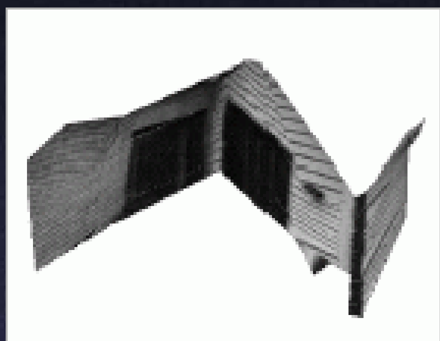
Optical Flow Field

Image #2

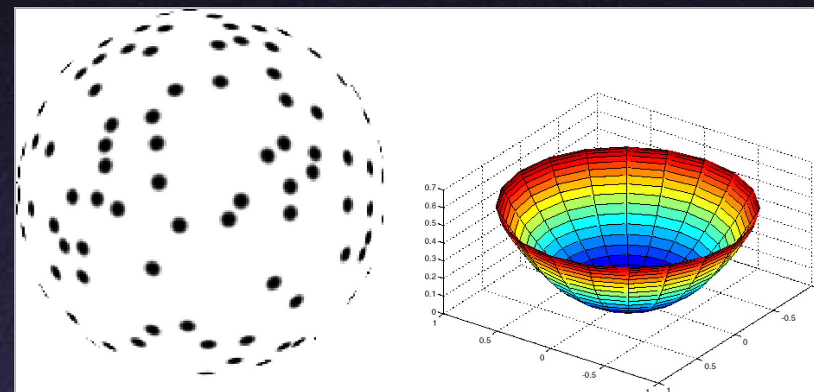
Low-Level Computer Vision

- Shape from X
  - Stereo
  - Motion
  - Shading
  - Texture foreshortening

3D Reconstruction

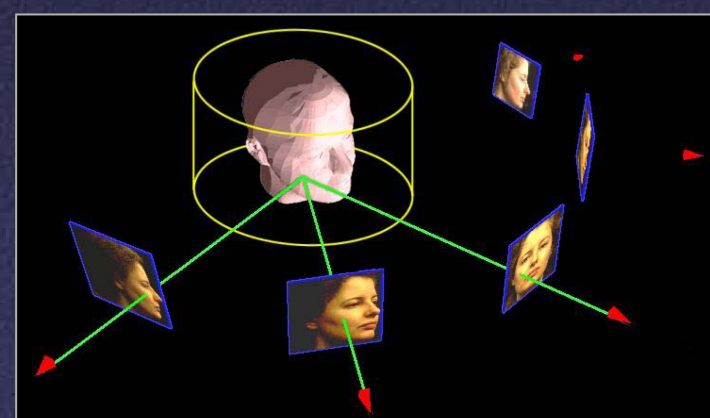


Tomasi+Kanade



Forsyth et al.

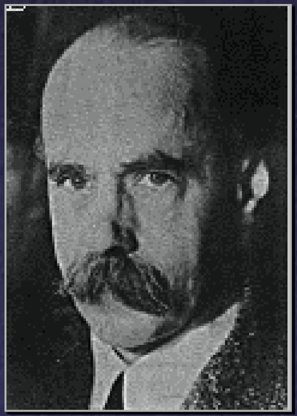
Debevec,Taylor,Malik



Phigin et al.

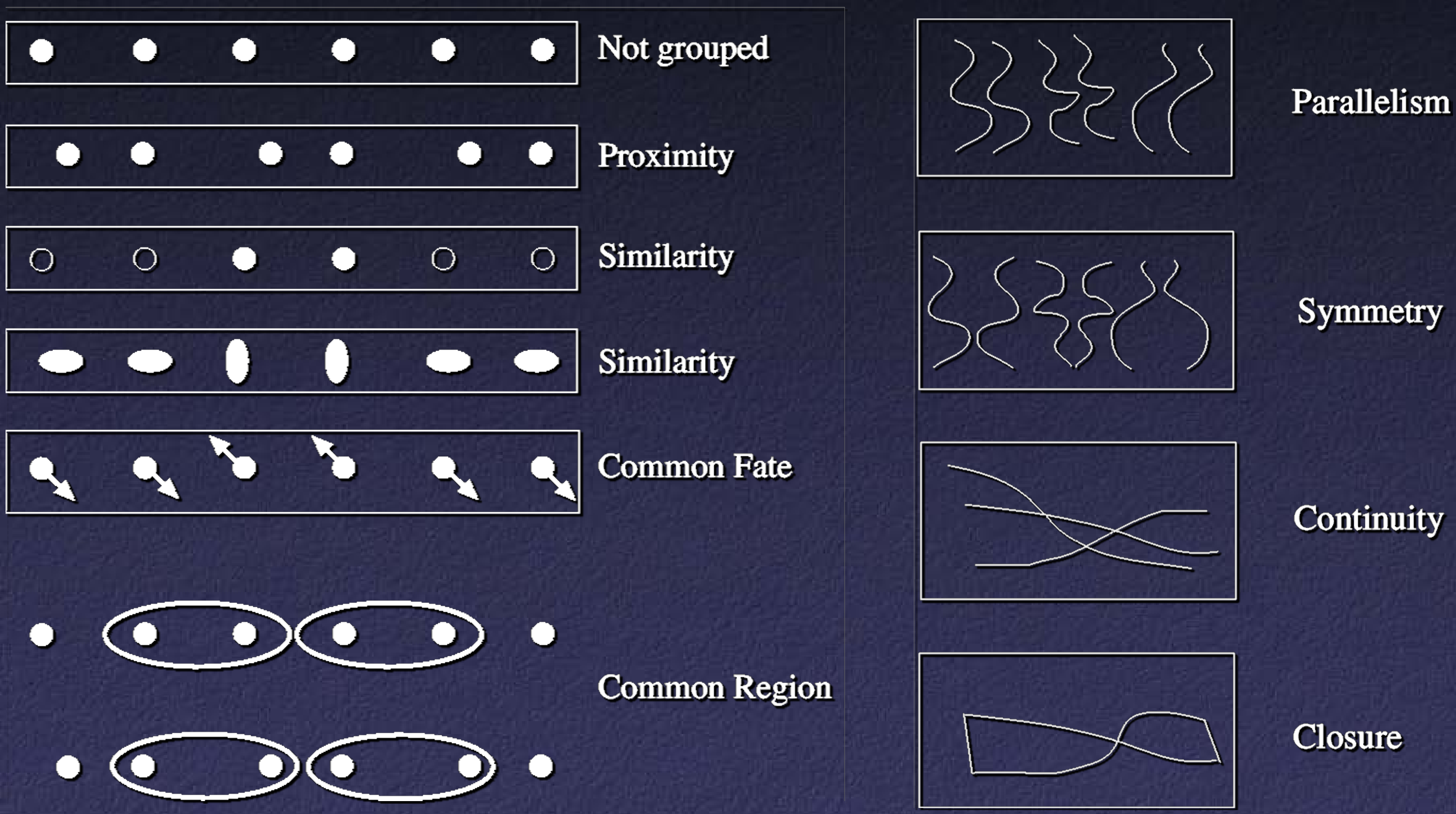
Mid-Level Vision

- Physiology unclear, but recent experiments with FMRI
- Observations by Gestalt psychologists
  - Proximity
  - Similarity
  - Common fate
  - Common region
  - Parallelism
  - Closure
  - Symmetry
  - Continuity
  - Familiar configuration

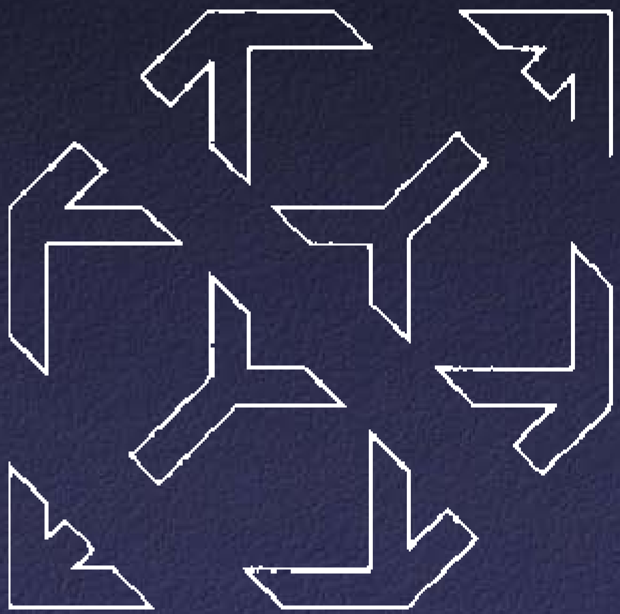


Wertheimer

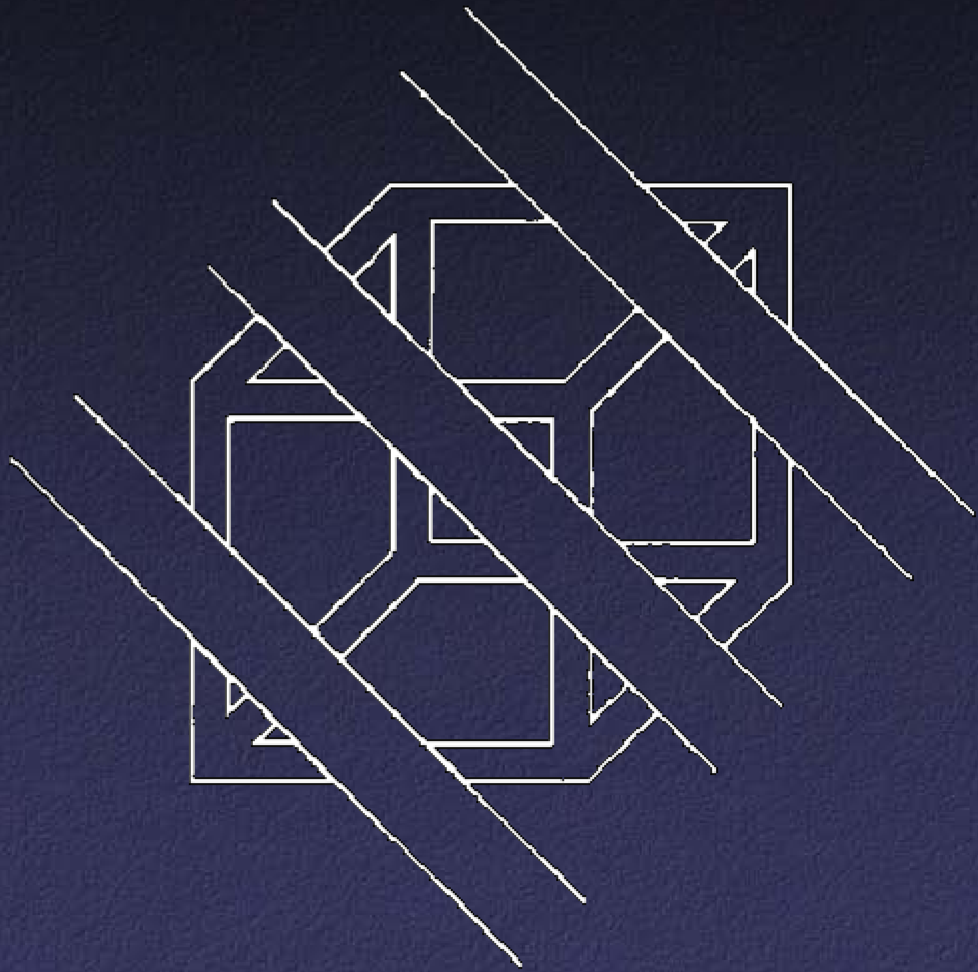
Grouping Cues



Grouping Cues



Grouping Cues



Grouping Cues

Mid-Level Computer Vision

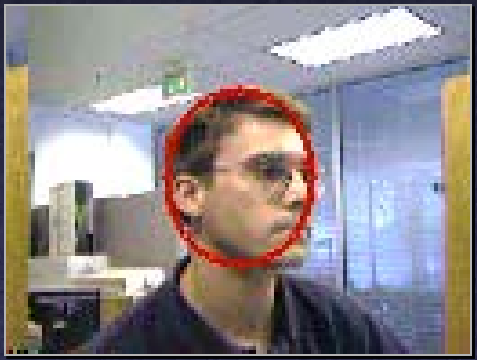
- Techniques
  - Clustering based on similarity
  - Limited work on other principles
- Applications
  - Segmentation / grouping
  - Tracking

Snakes: Active Contours

Contour Evolution for
Segmenting an Artery

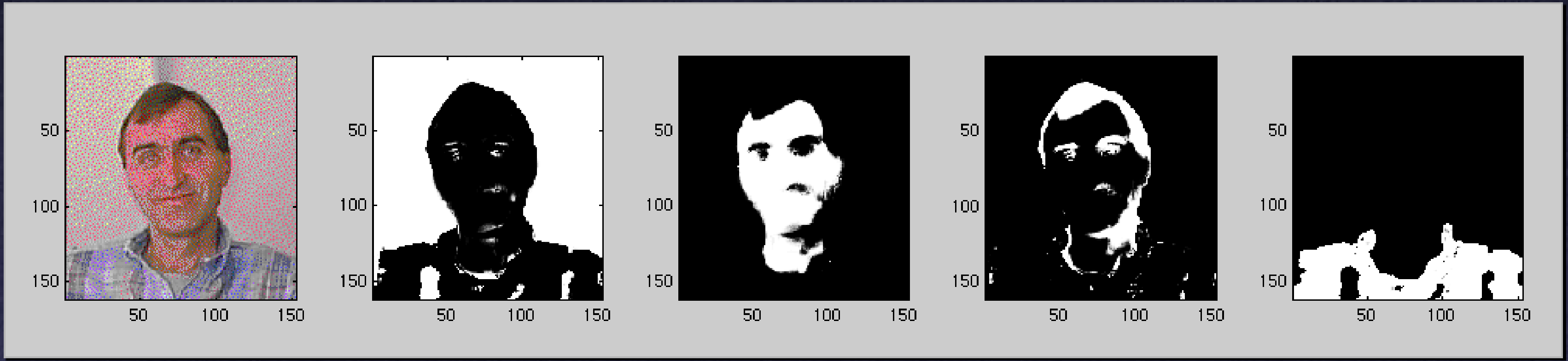
Histograms





[Birchfeld]

Expectation Maximization (EM)



Color Segmentation

Bayesian Methods

- Prior probability
  - Expected distribution of models
- Conditional probability P(A|B)
  - Probability of observation A given model B

Bayesian Methods

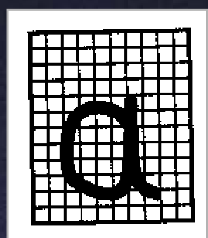
- Prior probability
  - Expected distribution of models
- Conditional probability P(A|B)
  - Probability of observation A given model B
- Bayes's Rule

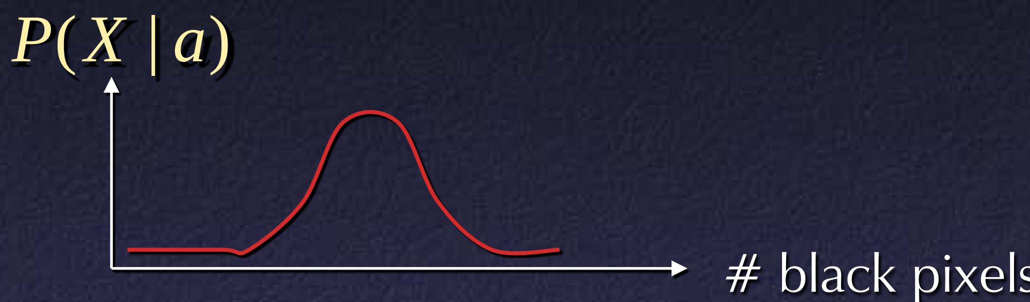
$$P(B|A) = P(A|B) \cdot P(B) \,/\, P(A)$$

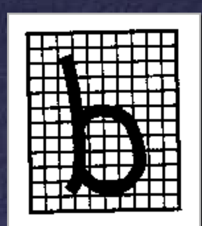
  - Probability of model B given observation A

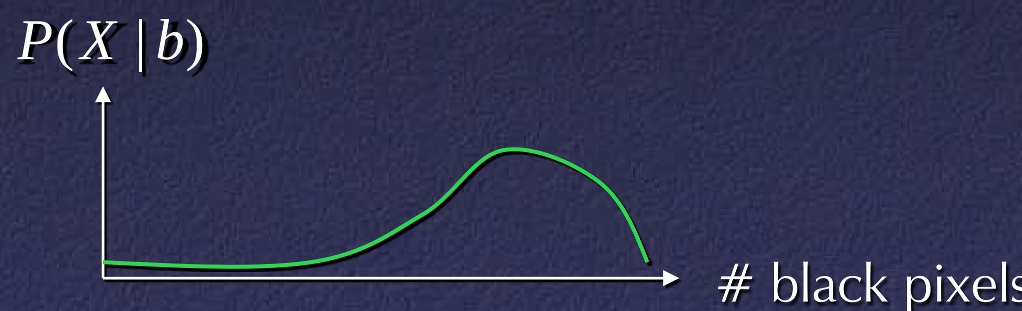
Thomas Bayes
(c. 1702-1761)

Bayesian Methods









High-Level Vision

- Human mechanisms: ???

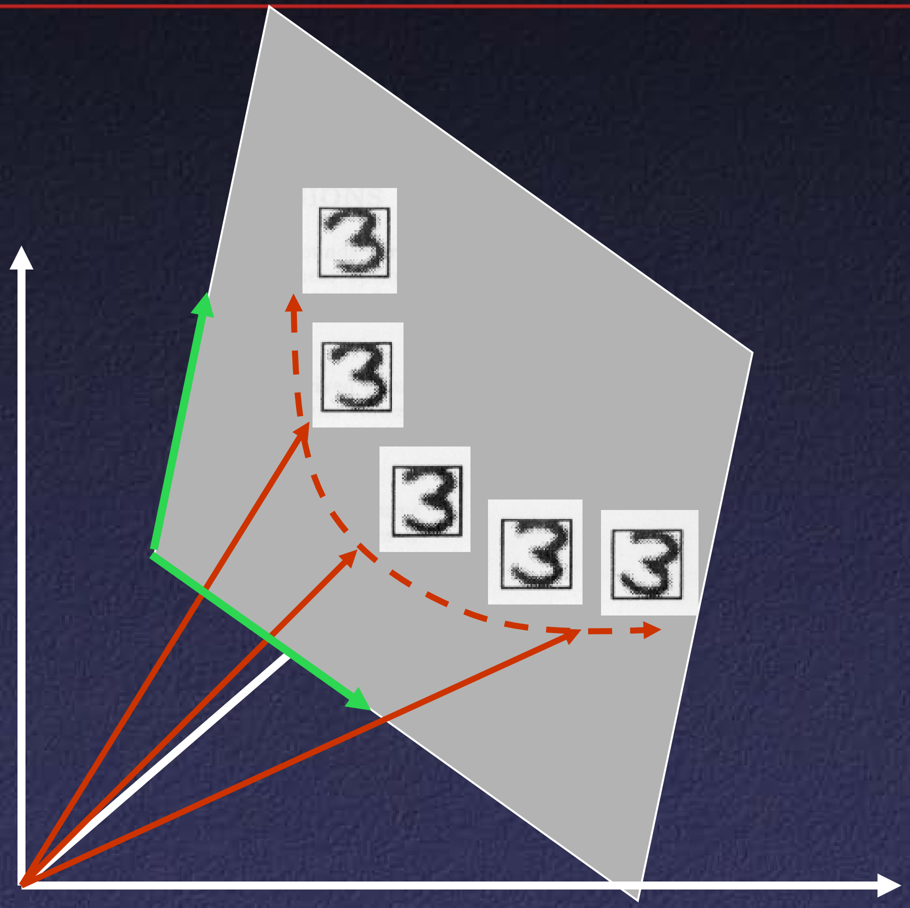
High-Level Vision

- Computational mechanisms
  - Bayesian networks
  - Templates
  - Linear subspace methods
  - Kinematic models

Template-Based Methods

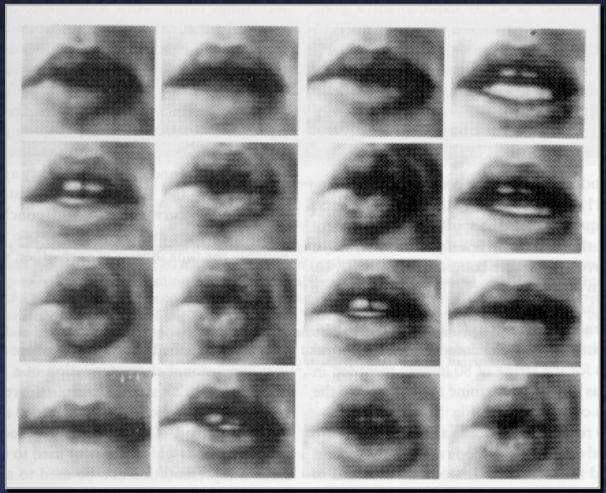
Cootes et al.

Linear Subspaces



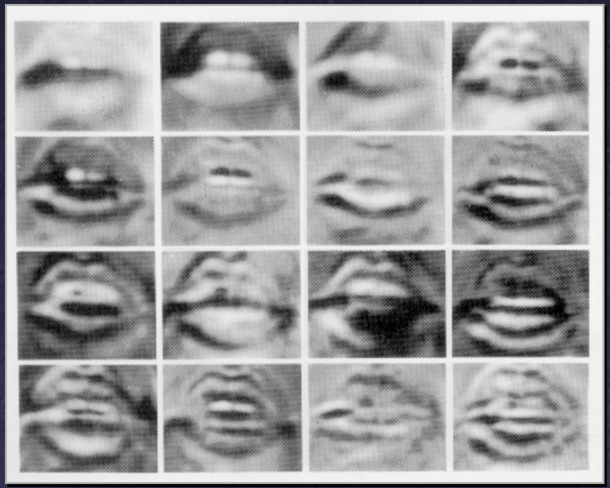
Principal Components Analysis (PCA)

Data



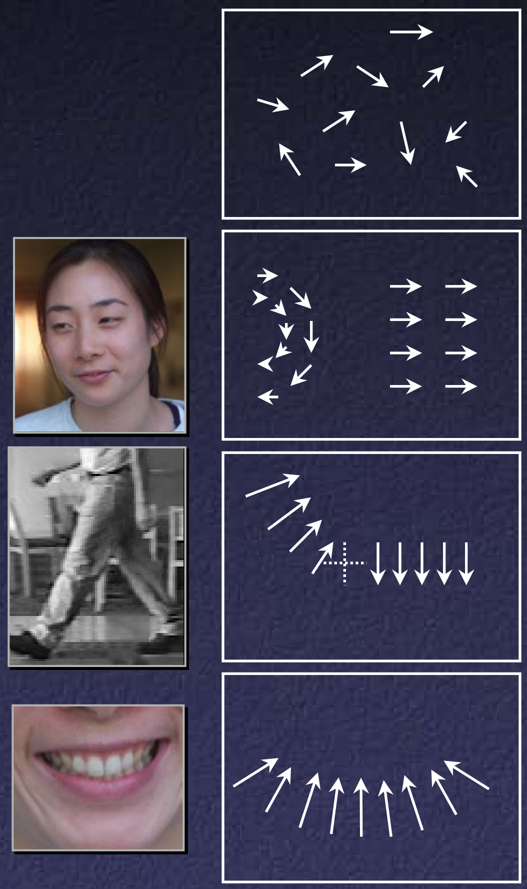
PCA

New Basis Vectors



Kirby et al.

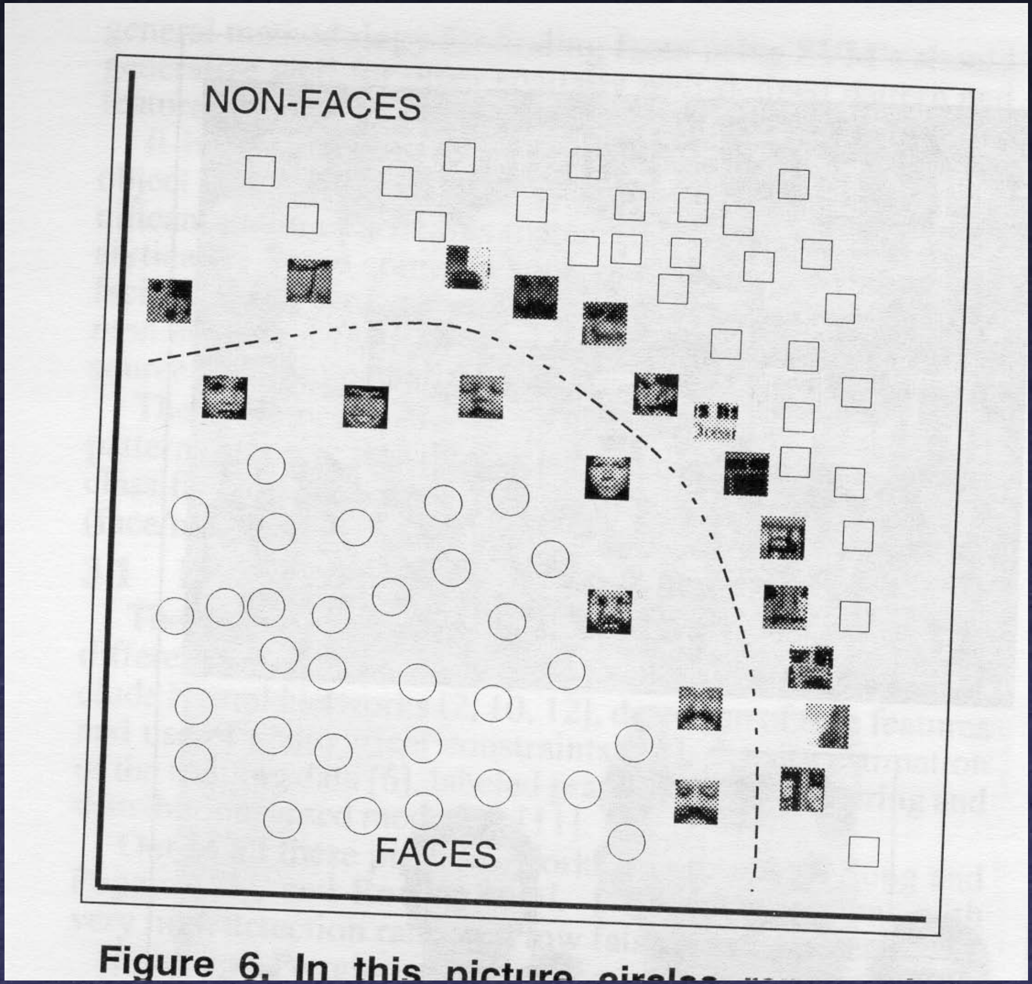
Kinematic Models



- Optical Flow/Feature tracking: no constraints
- Layered Motion: rigid constraints
- Articulated: kinematic chain constraints
- Nonrigid: implicit / learned constraints

Real-world Applications

Osuna et al:



Real-world Applications

Osuna et al:

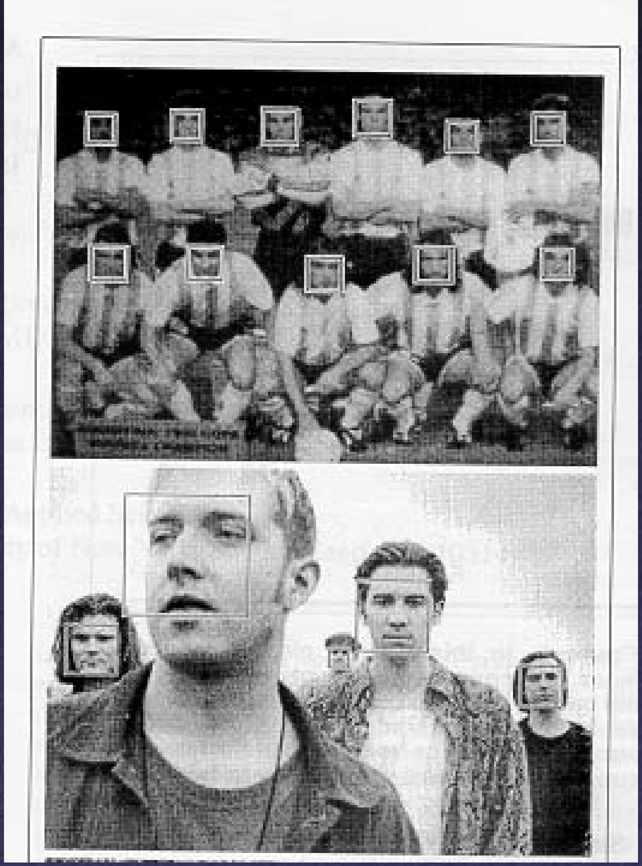


Figure 5. Results from our Face Detection system

Course Outline

- Image formation and capture
- Filtering and feature detection
- Motion estimation
- Segmentation and clustering
- Recognition and classification
- 3D shape acquisition

3D Scanning

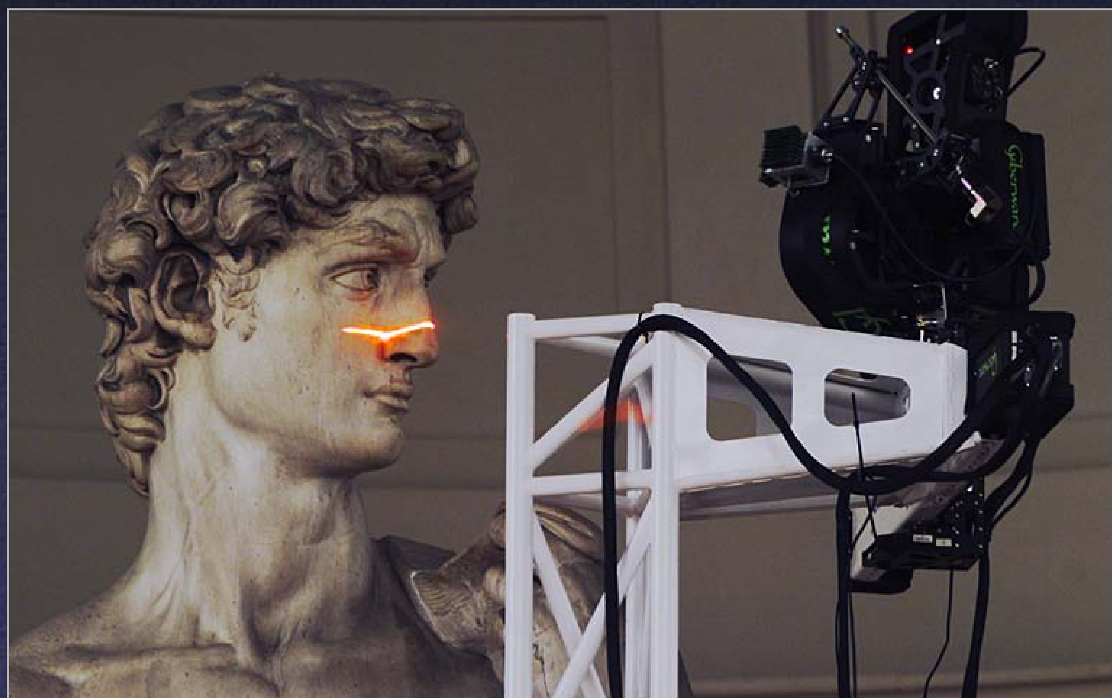
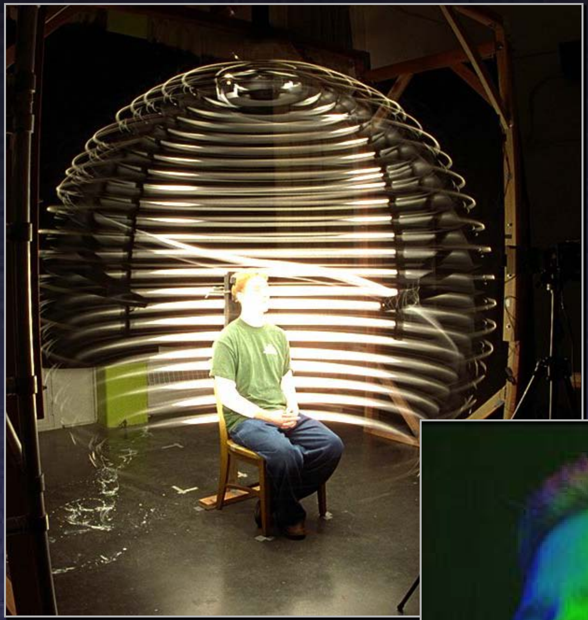
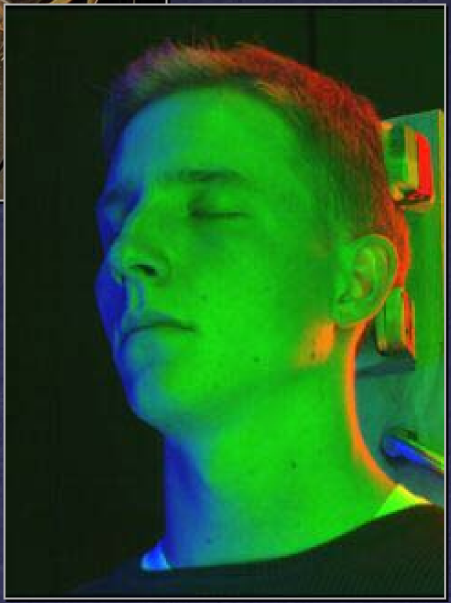


Image-Based Modeling and Rendering





Debevec et al.

Manex

Reassembling the Thera Wall Paintings

- Shattered by earthquakes, volcanic eruption

Reassembling the Frescoes

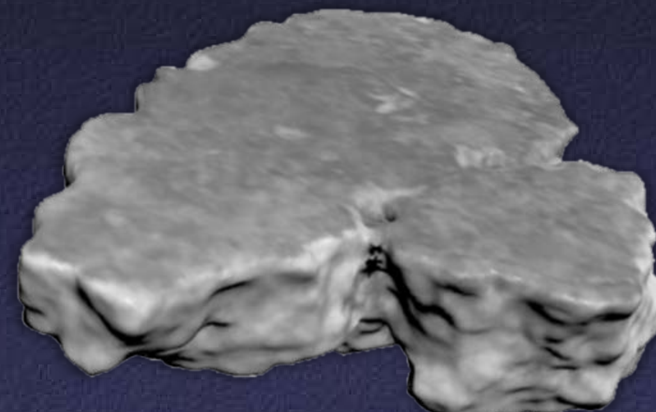
Example Fragments

More Fragments…

Even More Fragments…

And Still More Fragments

3-D Acquisition



Matching Results

Course Mechanics

- 70%: 4 written / programming assignments
  - Individual: all submitted work must be your own
  - 3 free late days
- 30%: Final project
  - Small groups – 2-3 people
  - Presentation / demo in January
  - Writeup due on Dean's date

Course Mechanics

- Recommended book:
  Introductory Techniques for 3-D Computer Vision
  Emanuele Trucco and Alessandro Verri

- Assigned papers / other readings

MATLAB

- Some of the assignments use MATLAB

- School of Engineering is running a short course, Monday Sep 21 – Tuesday Sep 22
- We'll also do a precept next week

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