What is Computer Vision?

SS 2013

Dr. Elli Angelopoulou

Pattern Recognition Lab (Computer Science 5)

University of Erlangen-Nuremberg

Overview

- Administrative information
- A short journey through

  Computer Vision
- Computer Vision in practice

Computer Vision (CV)

- Lecture
  - Mon 12:15 – 13:30 (02.133-113)
  - Wed 12:15 – 13:30 (02.133-113)
  - Elli Angelopoulou
  - elli@i5.cs.fau.de

- Exercises
  - Mon 10:15 – 11:45 (09.150-113)
  - Mon 14:15 – 15:45 (09.150-113)
  - Sven Haase
  - sven.haase@cs.fau.de

- Exercises
  - Provide additional details on the material given in class
  - Give you an opportunity to gain experience by programming some of the algorithms described in class
  - Offer you additional insight by solving problems related to the theory presented in class

Computer Vision - Exams

Certificates

- Oral exam at the end of the semester
- Graded certificate *(benoteter Schein)* or exam through *meinCampus*
  - 5 ECTS - 30 min. oral exam on lecture **and** exercises
  - 7.5 ECTS - 30 min. oral exam on lecture **and** exercises **and** a programming project
- Pass/Fail certificate *(unbenoteter Schein)*
  - 5 ECTS - 30 min. oral exam on lecture **and** exercises

Additional Material for CV

- When applicable, printed slides for Summer Semester 2013 will be made available through the web.
- You are still expected to take notes yourself.
- Slides and notes do not replace the textbooks (see next slide).
- Most of the slides can be understood only with the additional explanation provided during the lecture and through the use of additional material from textbooks.
- Slides from the Summer Semester 2012 are available at http://www5.cs.fau.de/lectures/ss-12/computer-vision-cv/

CV Reading Material:

- Recommended Textbooks:

[1] E. Trucco, A. Verri. Introductory Techniques fo 3-D Computer Vision. Prentice Hall, Upper Saddle River, New Jersey, USA

[2] D. A. Forsyth, J. Ponce. Computer Vision - A Modern Approach. (2nd ed) Prentice Hall, Upper Saddle River, New Jersey, USA

Introduction

- The goal of this presentation is to give a brief introduction and overview of the field of
  - Computer Vision
- An atypical computer science discipline
- Multidisciplinary
  - Programming
  - Algorithms
  - Geometry
  - Optics

Outline

- Definition
- Brief History
- Applications
- The importance of shape (geometry) and optics
- Brief overview of widely used computer vision techniques. Most of these topics we will cover in during the course of the semester.

What is Computer Vision?

- **Computer vision** involves the automatic deduction of the *structure* and the *properties* of a possibly dynamic three-dimensional world from either a single or multiple two-dimensional images of the world.

```
Example

Input: Image on the left

Output:

1 windmill: 3 stories tall, 4 blades
(1 hidden), conical roof;

5 people: 3 male, 2 female;

1 mill stone;

1 stone wall
```

How it all started

- The term Computer (Machine, Robot) Vision was first introduced as a special topic in Artificial Intelligence.
- First attempts: Tracing boundaries of polygonal objects.
- Revolutionary work by David Marr around 1975 at the Massachusetts Institute of Technology.
- First use of a pair of cameras for mimicking biological eyes in the 1960s.

Computer Vision

- Computer Vision evolved as a stand-alone field around the late 1970s
- Vision moved beyond "biological imitation" when it started being applied in factory automation as a robotic sensor (term Robot Vision started appearing)
- Different schools of thought:
  - Physics and math oriented
  - Statistical analysis
  - Neural networks
  - Heuristic approaches

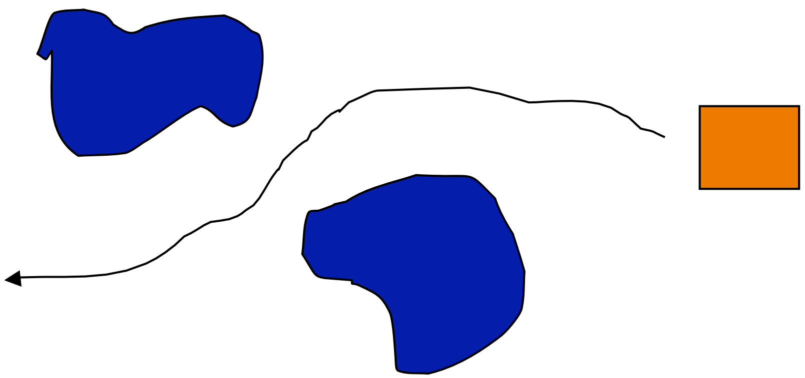
LME

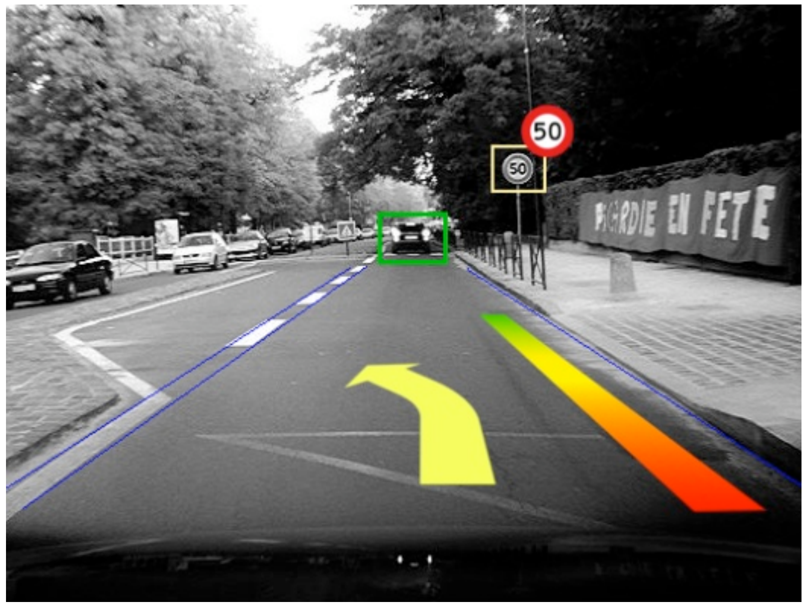
Applications

- Navigation (autonomous vehicles)
- Factory automation (assembly and packaging)
- Tele-presence (Telemedicine, virtual presence in museums, athletic events, like a basketball game)
- Object recognition (Automatic Target Recognition)
- Object tracking (surveillance)
- Human detection and identification (security and surveillance)
- Motion analysis (weather forecasting)
- Image retrieval (database or web-page search)

The Role of Computer Vision

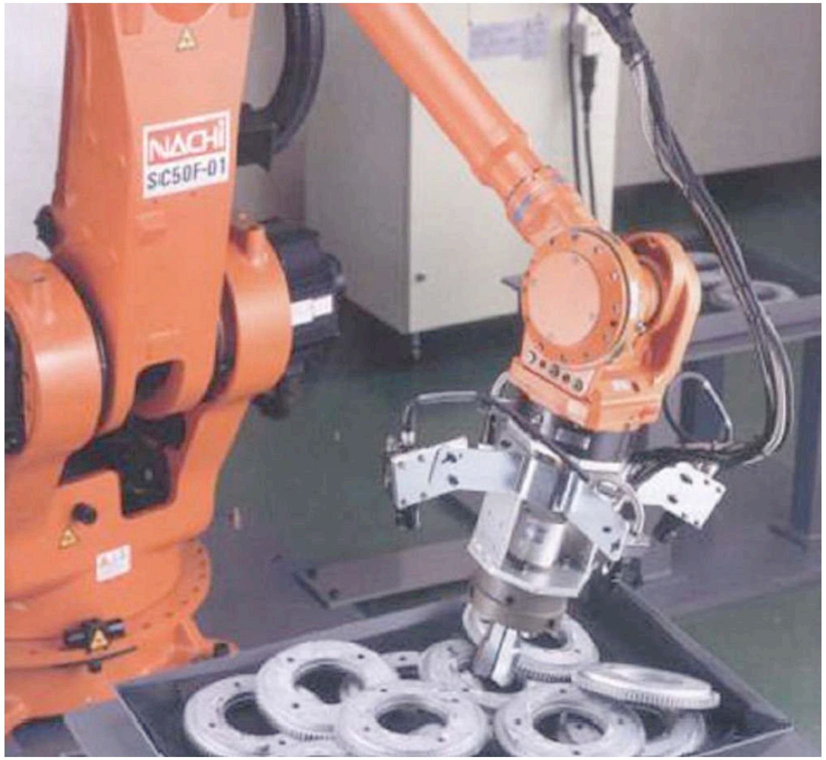
- Navigation
  - Compute distance to the various obstacles
  - Compute path that guarantees shortest safe path
  - Identify different types of objects in its path (people, cars, roadsigns, etc.)





The Role of Computer Vision

- Factory Automation
  - Identify object to be manipulated
  - Compute its shape, color or other properties
  - Quality assessment
  - Compute shortest and safest trajectory of robotic grasping arm



The Role of Computer Vision

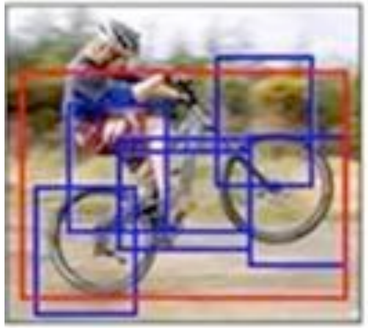
- Tele-presence
  - Compute the dimensions, shape and location of each object in the different locations.
  - Merge the scenes in one virtual scene that is geometrically correct (proper locations, not overlapping)
  - Merge the scenes in one virtual scene that is optically correct (shadows, inter-reflections, same background, consistent lighting)

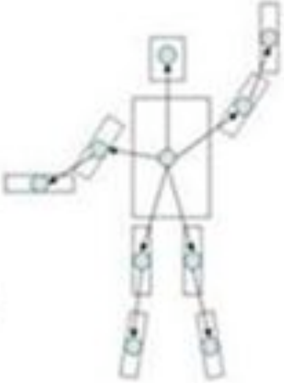
The Role of Computer Vision

- Object Recognition (initial work focused a lot on Automatic Target Recognition -ATR)
  - Compute dimensions of objects
  - Classify objects as possible targets
  - Compute location of each possible target and/or trajectory to it.

Original Scene

Nominated Targets Based



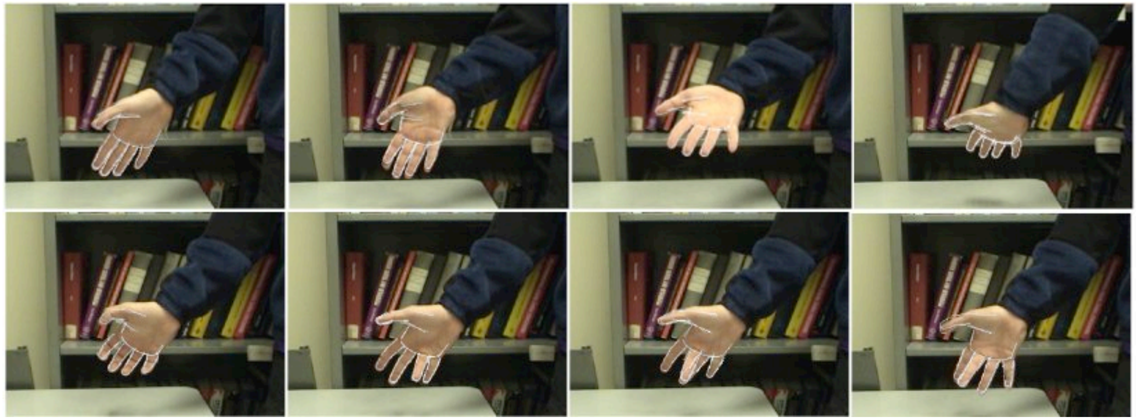


From the CFP of the *ECCV Workshop on Parts and Attributes* 2010

The Role of Computer Vision

In a sequence of images taken over a period of time

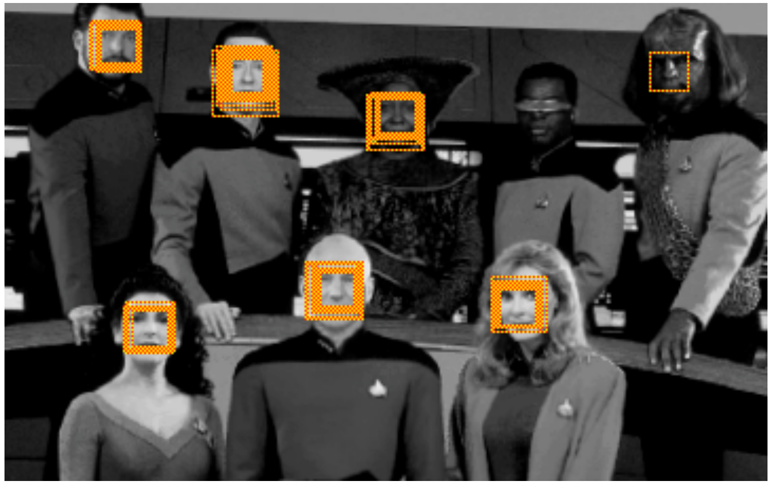
- Object Tracking
  - Identify the object of interest
  - Compute its location at each time instance *t*.
- Motion Analysis
  - Identify which objects are moving in the scene
  - Compute their velocity



"Visual Hand Tracking Using Occlusion Compensated Message Passing" by Erik B. Sudderth, Michael I. Mandel, William T. Freeman and Alan S. Willsky.

The Role of Computer Vision

- Human Detection and Identification
  - Compute the location of faces in a cluttered scene
  - Identify a specific individual under varying conditions



Bottom Line

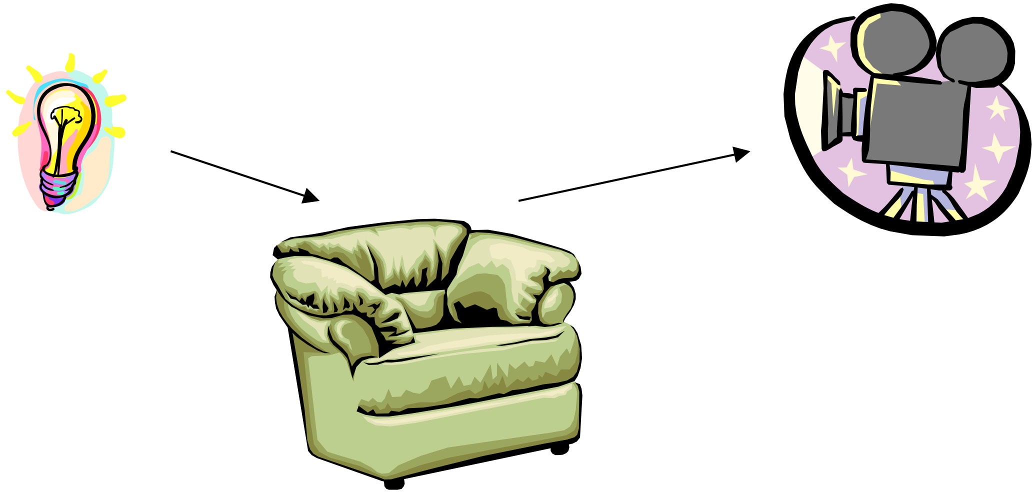
- The majority of applications involve the (ideally robust) computation of a quantitative description of the objects in the captured scene.
- Quantitative description
  - geometry (shape) of objects in the scene
  - material, color or other properties of the objects in the scene
  - persistence in measurements independent of viewing conditions
- Reverse engineer the process that caused the image to be formed.
- Semantic gap
  - go beyond quantitative analysis
  - extract more abstract descriptions (chair, table, painting, upset person, lost/forgotten item)

Computer Vision Warning

- Diverse applications
- Need for
  - Quantitative description
  - Higher level (more abstract) representation
- Large variety of sometimes disconnected algorithms
- Common underlying principles
- Strive for rigor through mathematics, physics and the use of accurate models
- But... imaging is under-constrained (too many variables, too few images, many environmental unknowns)
- Beware of imperfect solutions.

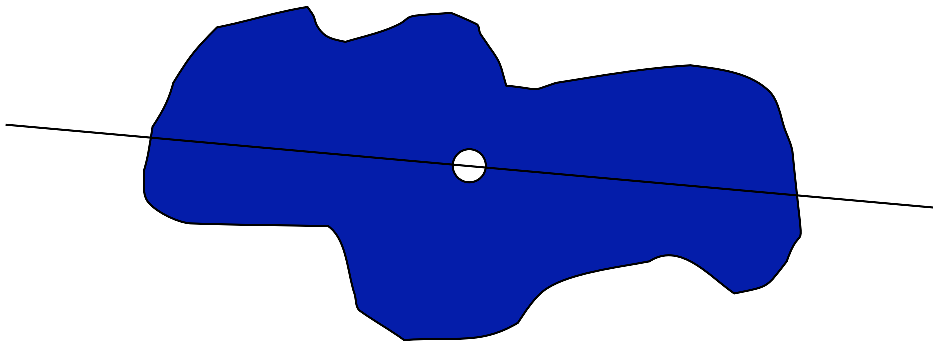
Image Formation

- There are three major components that determine the appearance of an image
  - Geometry
  - Optical properties of the materials in the scene
  - Illumination conditions



Basic Shape Analysis

- The center of black and white silhouettes can be easily computed using moment analysis
  - 0th order moment → size
  - 1st order moment → center of mass
  - 2nd order moments → orientation information

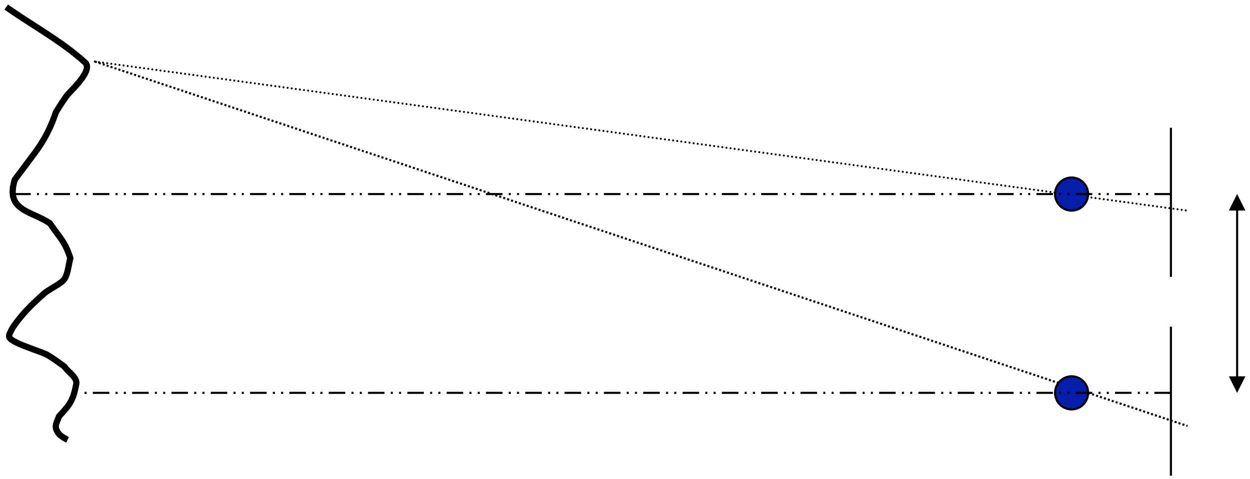


Extraction of Silhouettes

- Edge detection
- Biological evidence that animals perform some form of differentiation on the images
- Further analysis is done on 2.5 D sketch: 2D image formed on retina + edge information (Marr)

Depth Computation

- Binocular (poly-ocular stereo)
- The “shifting” of the scene between the 2 images provides the depth information



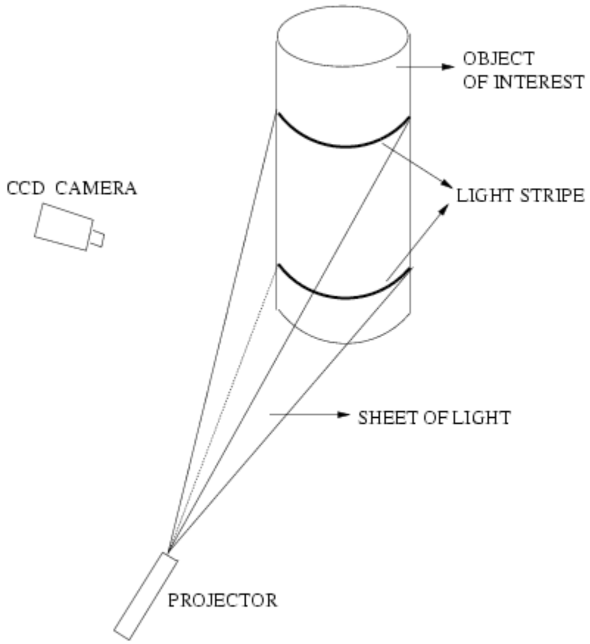
- What if there are not enough uniquely identifiable points?

Shape from Shading

- Shading provides shape clues (disk versus sphere)
- In the 1970s it was proved by Horn that the shape of a surface can be extracted from a single image, if we know how the surface is illuminated.
- Main idea:
  - The variations in shading of a single-colored object are caused by changes in the geometry of the object.
  - You are given the relationship between the shape of the object and the shading variations
  - A camera captures these shading variations
  - Extract the geometry

Shape Analysis: Structured Light

- Project a light beam of known geometry (e.g. a collection of thin vertical stripes) onto a scene
- Take a picture of the scene illuminated by the structured light
- The shape of the objects on the scene distorts the light pattern. Use that distortion to deduce the shape of the object



Motion Analysis

- Main idea: Track features as they move from one frame to the next
- A basic technique:
  - Extract edges at each frame of the movie
  - Compute the motion of these edges in the 2D frames
  - Relate 2D motion in image with 3D motion
- What happens if the scene changes abruptly? (lights are turned off)
- Does the shadow of moving clouds get interpreted as motion, when there shouldn't be any?

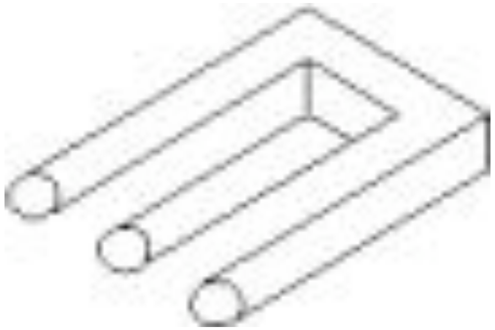
Shape Analysis

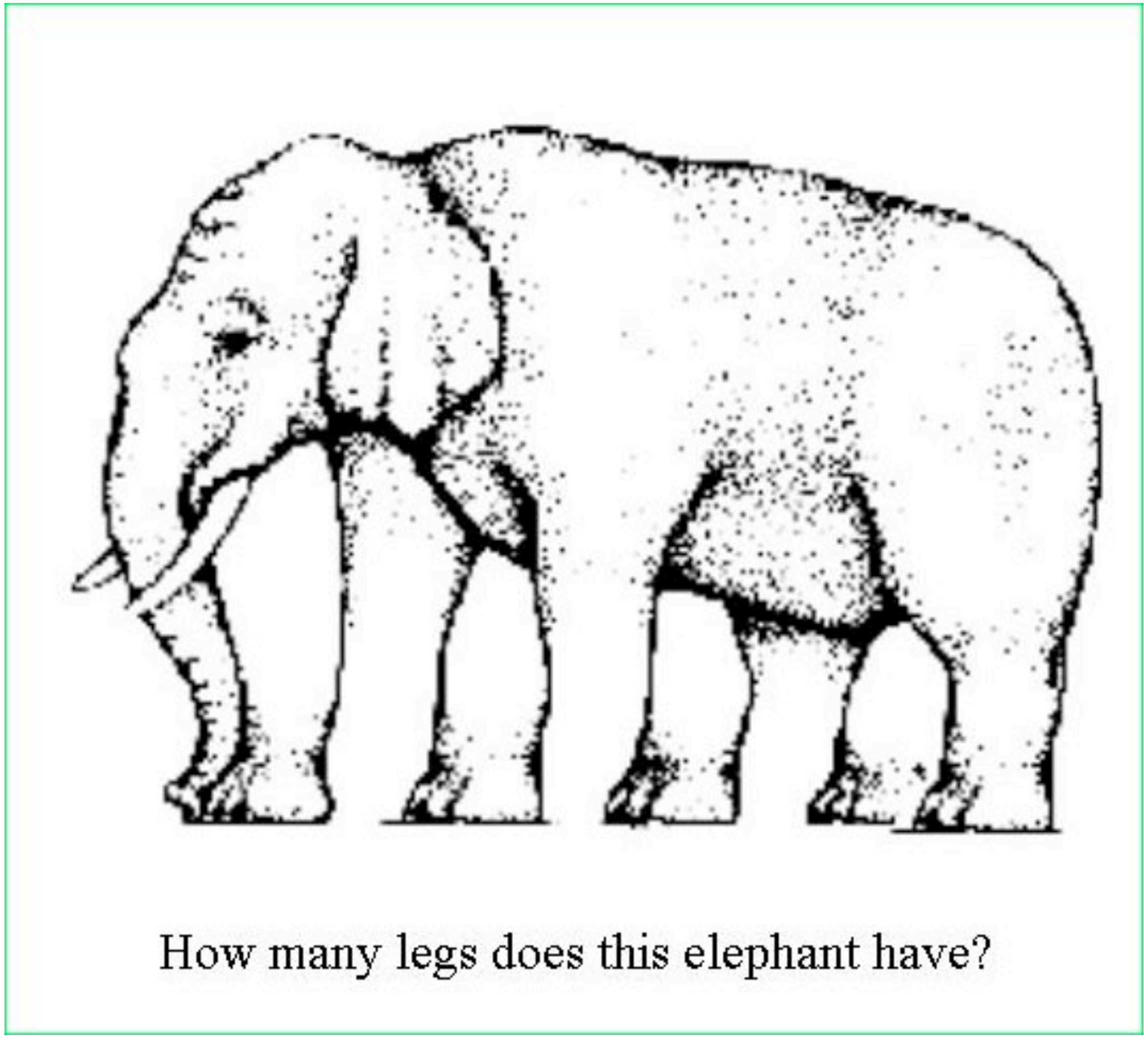
- Extract invariant shape descriptors that can be used in object recognition
- Ideally descriptors should be succinct to facilitate information transmission
- Example: Curvature information

Challenges – Computer Vision

- Why is computer vision so difficult:
  - Ambiguities
  - Implicit knowledge
  - Prior information
  - Technical problems (noise, limited data, encoding...)

Implicit Knowledge

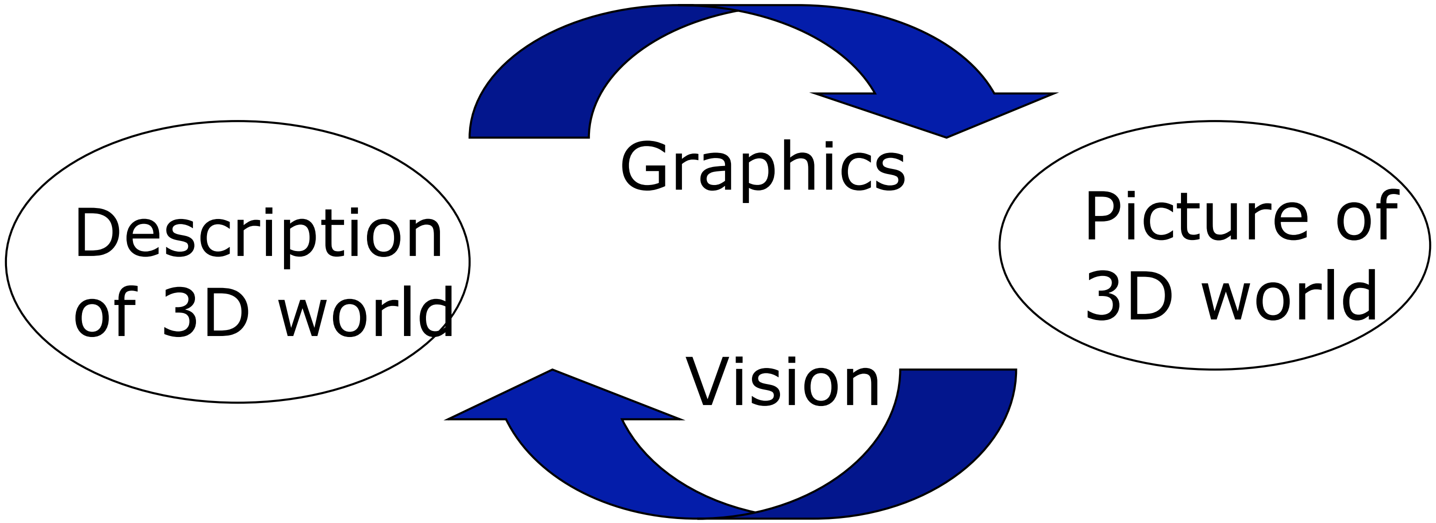




Computer Vision vs. Image Processing

- Image processing typically deals with the early processing stages.
- Conversion of sensed light into an image file
- Noise removal
- Image enhancement
- Image compression
- Typically, the input is an image and the output is also an image
- Treats the input as a signal

Computer Vision vs. Computer Graphics

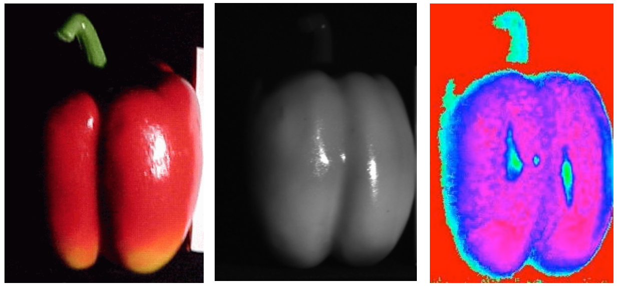


Shared Tools: underlying theory (optics, geometry)
algorithms

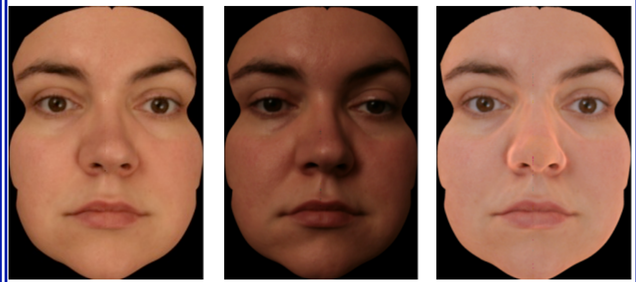
Computer Vision vs. Medical Imaging

- Medical Imaging was originally part of Computer Vision
- Different imaging modalities with very distinct image formation processes.
- More constrained set of objects that appear in medical images (easier to use prior knowledge).
- High demands in accuracy.

Computer Vision - Research Projects



Reflectance analysis



Skin reflectance

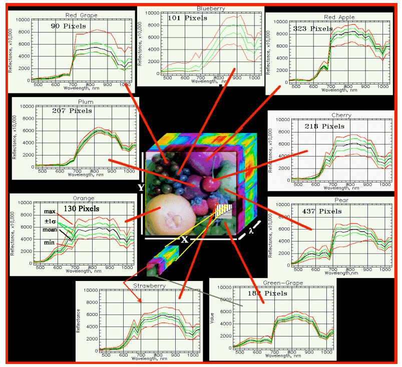
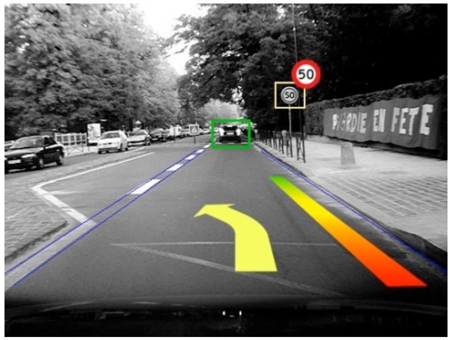


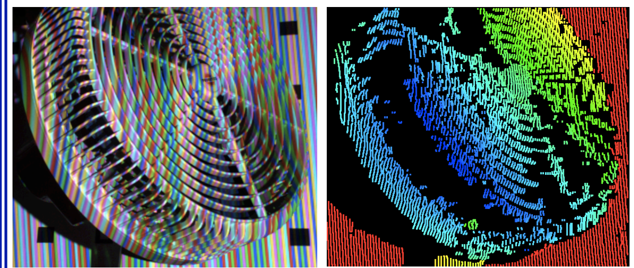
Image courtesy of Dr. Nahum Gat, OKSI, Inc.

Multispectral imaging

Image forensics



Context-aware navigation



3D Reconstruction

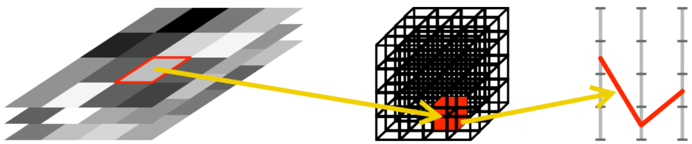
Exploit Color Information: Improved Skin Detection

- Color information depends on:
  - Object color
  - Scene geometry
  - Illumination conditions in the scene
  - Camera (e.g. sensor sensitivities, image gamma)
- Common approach in physics-based color vision:
  Find a reflectance model and color space to extract desired scene properties.

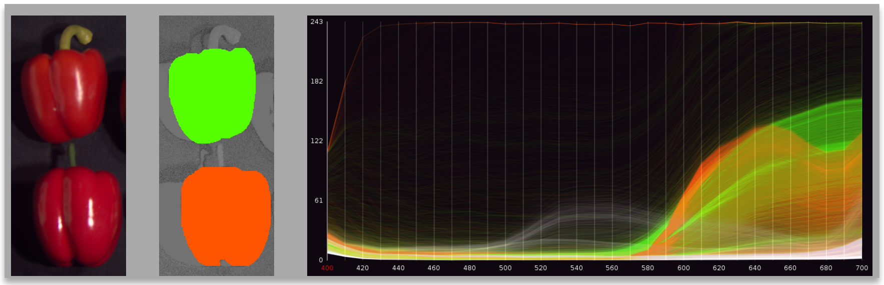
Multispectral Imaging

Novel Visualization

Parallel coordinates visualize spectral distribution



- real-time representation of full image data
- instant connection of topology, spectrum
- interactive step-by-step data exploration



sRGB labels spectral distribution

 http://**gerbil.sf.net/**

Segmentation & Clustering

- Supervised segmentation with **Power watershed**
- Superpixel-accelerated **Fast Adaptive Mean Shift** clustering

Dimensionality Reduction

Self-organizing Maps employed for

- false-color visualization
- edge detection
- supervised segmentation

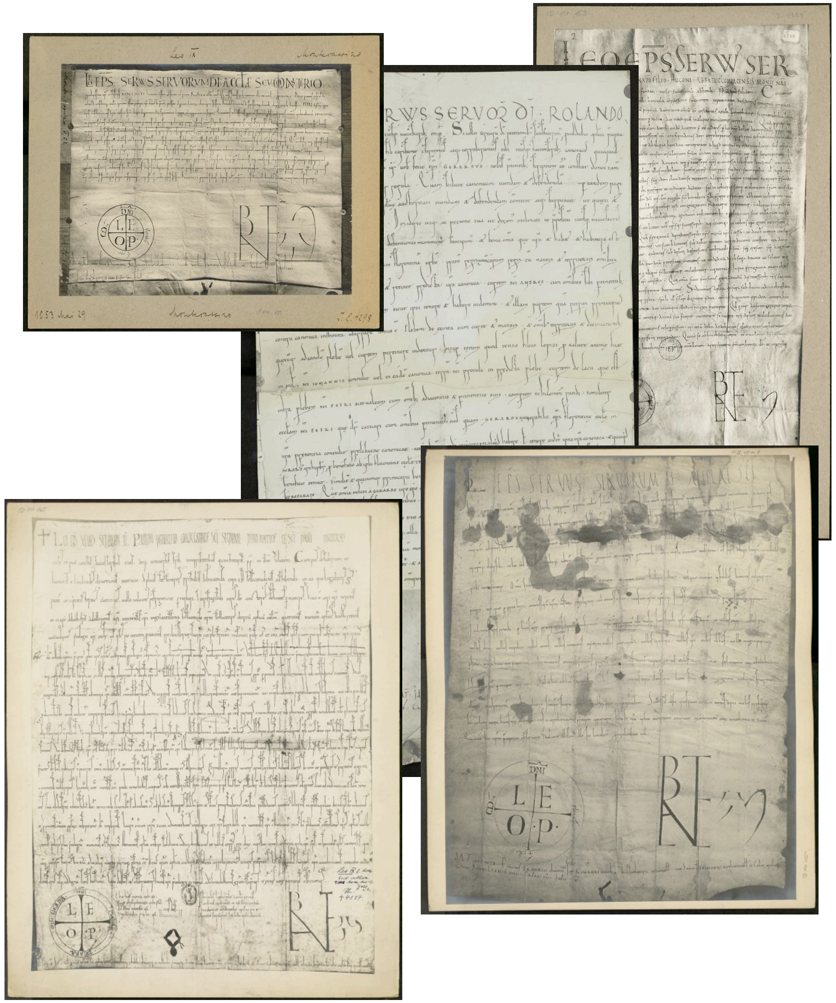
Image Forgery Detection

Beirut 2006 by Adnan Hajj, published by Reuters (close-up)

Original image, published by Reuters later

Historical Document Analysis

- Joint work with the History-(FAU) and Paleography-department (LMU)
- Papal Charters:
  - 11th - 12th century
  - About 30 pontificates
  - Currently digitalizing ca. 1500 documents (≈850 photographs + ≈650 sketches)
- Goals:
  - Analysis of the layout & writing
  - Analysis of the temporal changes
  - Scribe identification



Solar Irradiance Forecasts

Challenge: Production of solar power plants influenced by changes in irradiation

Approach:

1. Monitor the sky
2. Detect clouds
3. Estimate the cloud motion
4. Forecast cloud motion
5. Establish irradiance forecast

Summary

- Computer Vision is a multidisciplinary field.
- Many diverse topics.
- In order to be able to apply oneself in computer vision one must have an understanding of:
  - Image formation process
  - Basic image processing methods
  - Information that can be extracted from single images
  - Combination of information from multiple images
  - Implementation of algorithms (real time issues, accuracy issues etc.)
- Upon completion of the class, one should:
  - Have a good understanding of the aforementioned topics
  - Be able to formally argue about the effectiveness a computer vision system, and implement and test a prototype.

DARPA Grand Challenge

- A prize competition for driverless (autonomous) cars organized by DARPA (Defense Advanced Research Project Agency), the research oprganization of the USA Department of Defense.

- „DARPA Grand Challenge" of 2004 – Mojave Desert, CA, 240km
  - No competitor of the 21 participants finished the race
  - CMU won for completing the longest distance 11.78km

- „DARPA Grand Challenge" of 2005 – Mojave Desert, CA, 212km on a wider road with fewer curves
  - 5 out of the 23 (22%) participants finished the race
  - 22 out of the 23 participants surpassed the 11.78km distance.
  - 1st place: Stanford's „Stanley" (VW Touareg) after 6:54hrs of driving
  - 2nd place: CMU's „Sandstorm" at 7:05hrs
  - 3rd place: CMU's „Highlander" at 7:14hrs

DARPA Grand Challenge

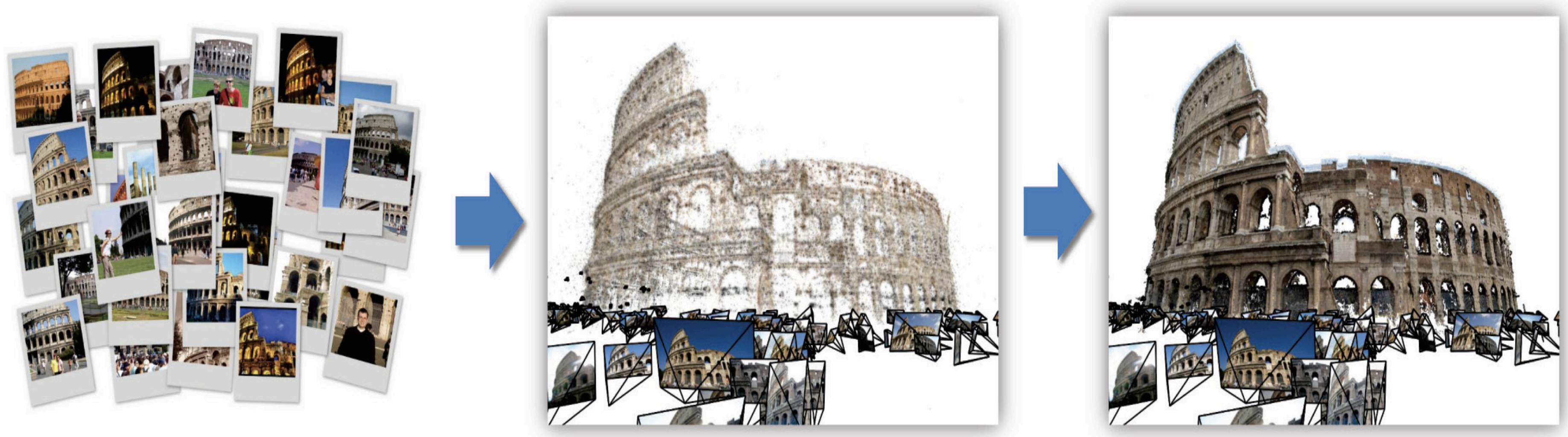
DARPA Grand Challenge Bloopers

DARP Urban Challenge Event

- Goal: Autonomous driving in an city setup
- Course:
  - 96km to be completed in less than 6hrs
  - Obey all traffic regulations
  - Handle obstacles and other cars on the road
  - Merge into traffic
- Day of Final Event: November 3, 2007
- Results:
  - 35 participants, 11 passed to the finals
  - 6 out of 11 finalists (55% of finalists, 17% of participants) completed the course
  - 1st place: CMU (Chevy Tahoe) after 4:10hrs of driving
  - 2nd place: Stanford (Volkswagen Passat) at 4:29hrs
  - 3rd place: Virginia Tech at 4:36hrs
  - Followed by MIT, UPenn and Cornell

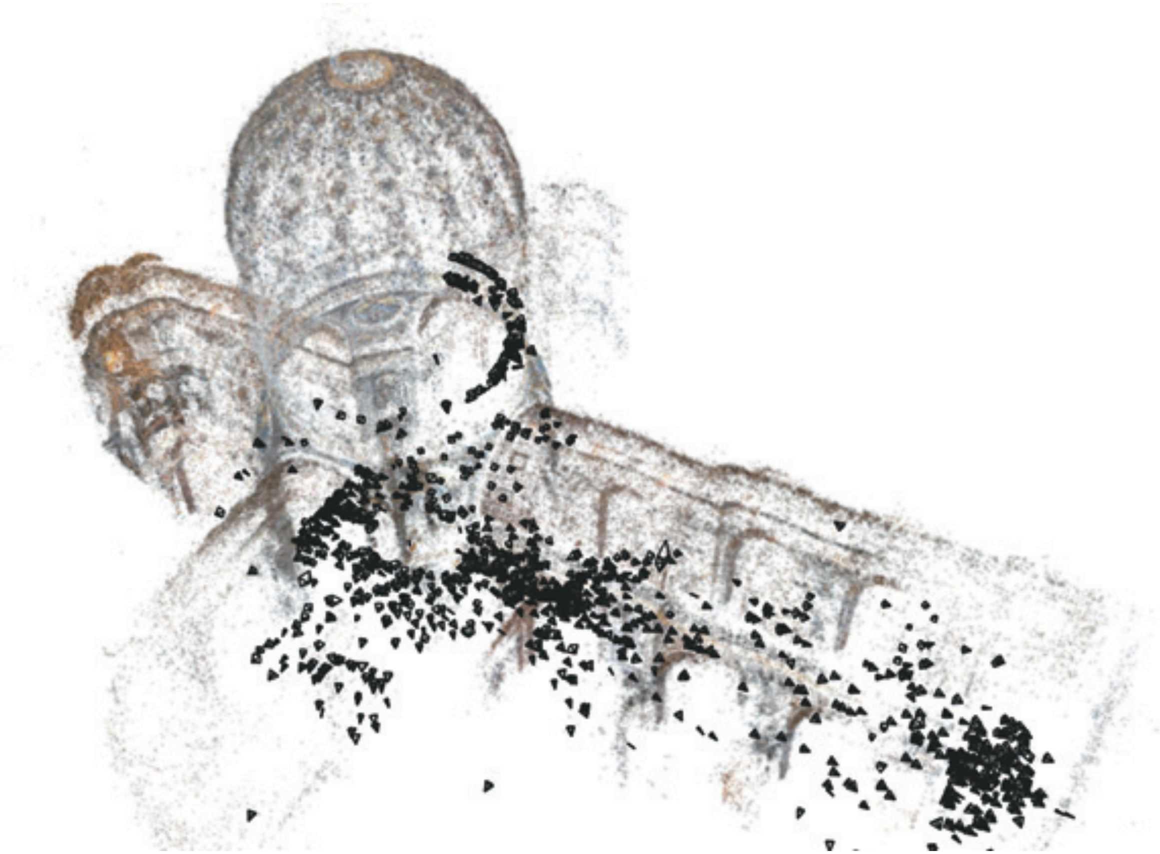
DARPA Urban Challenge Event

Reconstruction from Web Pictures



- It is part of the Community Photo Collections project at the University of Washington GRAIL Lab.
- Related prior work includes:
  - Photo Tourism (http://phototour.cs.washington.edu/)
  - Skeletal Sets (http://www.cs.washington.edu/homes/snavely/projects/skeletalset/)
  - Photosynth (http://photosynth.net/)

St. Peter’s Reconstruction



St. Peter’s Basilica – 1,294 photos

- Reconstructing Rome (150,000 pictures) took 26 hrs (18hrs for matching 8hrs for reconstruction) using 496 processors .

Dense St. Peter's Basilica Reconstruction

Dense St. Peter’s Basilica Reconstruction

Dense Reconstruction of San Marco Plaza

Dense Reconstruction of San Marco Plaza