BBM 413
Fundamentals of Image Processing
Oct. 2, 2012

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Introduction
Instructor and Course Schedule

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• Lectures (BBM413): Tuesday, 13:00-15:45@D9
• Practicum (BBM415): Wednesday, 15:00-16:45@D9
• Office Hour: To be announced!
About BBM413-415

• An advanced level undergraduate course about the fundamentals of image processing.

• The aim of this course is to provide an introduction to students who wish to specialize in interrelated disciplines like image processing, computer vision and computational photography.

• The students will also be expected to gain hand-on experience via a set of programming assignments supplied in the complementary BBM 415 Image Processing Practicum.

• Hence, the students are strongly advised to register both BBM 413 and BBM 415 classes.
Communication

• The course webpage will be updated regularly throughout the semester with lecture notes, programming and reading assignments and important deadlines.
  http://web.cs.hacettepe.edu.tr/~erkut/bbm413.f12

• All other communications will be carried out through Piazza. Please enroll it by following the link
  https://piazza.com/hacettepe.edu.tr/fall2012/bbm413
Prerequisites

- Programming skills (C/C++, Matlab)
- Good math background (Calculus, Linear Algebra, Statistical Methods)
- Students are not expected to have any prior knowledge of image processing techniques.
Reading Material

• Lecture notes and handouts
• Papers and journal articles
Textbooks


Grading Policy

• BBM413 Fundamentals of Image Processing
  – Class participation, 5%
  – Written Assignments, 15%
  – Midterm Exam, 35%
  – Final Exam, 45%

• BBM415 Image Processing Practicum
  – 4 Programming Assignments
Programming Assignments

• Four assignments related to the topics covered in the class.

• Each assignment will involve implementing an algorithm, carrying out a set of experiments to evaluate it, and writing up a report on the experimental results.

• All assignments have to be done individually, unless stated otherwise.
Important Dates

• Programming Assignment 1 10 October 2012
• Programming Assignment 2 31 October 2012
• Programming Assignment 3 21 November 2012
• Programming Assignment 4 19 December 2012

• Midterm exam 20 November 2012
• Final exam To be announced later
Tentative Outline

• (1 week) Image formation and the digital camera
• (1 week) Color perception and color spaces
• (1 week) Point operations
• (1 week) Spatial filtering
• (1 week) Fourier Transform
• (1 week) Image pyramids and wavelets
• (1 week) Gradients, edges, contours
• (1 week) Image smoothing
• (2 weeks) Image segmentation
• (1 week) Advanced topics
Image Processing
What does it mean, to see?

• “The plain man’s answer (and Aristotle’s, too) would be, to know what is where by looking. In other words, vision is the process of discovering from images what is present in the world, and where it is.” David Marr, Vision, 1982

• Our brain is able to use an image as an input, and interpret it in terms of objects and scene structures.
What does Salvador Dali’s *Study for the Dream Sequence in Spellbound* (1945) say about our visual perception?

We see a two dimensional image

But, we perceive depth information.

- Light reflected on the retina
- Converging lines
- Shadows of the eye
Why does vision appear easy to humans?

• Our brains are specialized to do vision.
• Nearly half of the cortex in a human brain is devoted to doing vision (cf. motor control ~20-30%, language ~10-20%)

• “Vision has evolved to convert the ill-posed problems into solvable ones by adding premises: assumptions about how the world we evolved in is, on average, put together”
  Steven Pinker, How the Mind Works, 1997

• Gestalt Theory (Laws of Visual Perception),
  Max Wertheimer, 1912

Figures: Steven Pinker, How the Mind Works, 1997
Computer Vision

• “Vision is a process that produces from images of the external world a description that is useful to the viewer and not cluttered with irrelevant information”
  ~David Marr

• The goal of Computer Vision:
  To develop artificial machine vision systems that make inferences related to the scene being viewed through the images acquired with digital cameras.
THE SUMMER VISION PROJECT

Seymour Papert

The summer vision project is an attempt to use our summer workers effectively in the construction of a significant part of a visual system. The particular task was chosen partly because it can be segmented into sub-problems which will allow individuals to work independently and yet participate in the construction of a system complex enough to be a real landmark in the development of "pattern recognition".
Origins of computer vision


Slide credit: S. Lazebnik
Marr’s observation: Studying vision at 3 levels

• Vision as an information processing task [David Marr, 1982]

• Three levels of understanding:
  1. Computational theory
     – What is computed? Why it is computed?
  2. Representation and Algorithm
     – How it is computed?
     – Input, Output, Transformation
  3. Physical Realization
     – Hardware
Visual Modules and the Information Flow

- Visual perception as a data-driven, bottom-up process (traditional view since D. Marr)
- Unidirectional information flow
- Simple low-level cues $\Rightarrow$ Complex abstract perceptual units
Visual Modules and the Information Flow

• Vision modules can be categorized into three groups according to their functionality:
  – Low-level vision: filtering out irrelevant image data
  – Mid-level vision: grouping pixels or boundary fragments together
  – High-level vision: complex cognitive processes
Fundamentals of Image Processing

- What is a digital image, how it is formed?
- How images are represented in computers?
- Why we process images?
- How we process images?
Image Formation

Three Dimensional World ▶ Two Dimensional Image Space

• What is measured in an image location?
  - brightness
  - color

viewpoint
illumination conditions
local geometry
local material properties

Figures: Francis Crick, The Astonishing Hypothesis, 1995
• Discretization
  – in image space - sampling
  – In image brightness - quantization

Image Representation

- **Digital image:** 2D discrete function $f$
- **Pixel:** Smallest element of an image $f(x,y)$

Figure: M. J. Black
Image Representation

- **Digital image**: 2D discrete function $f$
- **Pixel**: Smallest element of an image $f(x,y)$

Figure: M. J. Black
Human Eye

- Two types of receptor cells in retina:
  - Cone Receptor cells: 6-7 million → function in bright light, color sensitive, fine detail
  - Rod receptor cells: 75-150 million → function in dim light, color insensitive, coarse detail
- A recent discovery: Photosensitive retinal ganglion cells → sensitive to blue light

Hierarchy of Visual Areas

- There are many different neural connections between different visual areas.

Felleman & van Essen, 1991 (on the right)
Visual Modules and the Information Flow

- Vision modules can be categorized into three groups according to their functionality:
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Subject matter of this course
Sample Problems

- Edge Detection
- Image Denoising
- Image Smoothing
- Image Segmentation
- Image Registration
- Image Inpainting
- Image Retargeting
- ...

**Image Filtering**

- Filtering out the irrelevant information

\[ f(x) = u(x) + n(x) \]

- Image denoising, image sharpening, image smoothing, image deblurring, etc.
- Edge detection
Edge Detection

- Edges: abrupt changes in the intensity
  - Uniformity of intensity or color
- Edges to object boundaries

Canny edge detector
Image Filtering

- **Difficulty:** Some of the irrelevant image information have characteristics similar to those of important image features
Image Smoothing - A Little Bit of History

• Gaussian Filtering / linear diffusion
  – the most widely used method

\[ \frac{\partial u}{\partial t} = \nabla \cdot (\nabla u) = \nabla^2 u \]

• mid 80’s – unified formulations
  – methods that combine smoothing and edge detection
  – Geman & Geman’84, Blake & Zisserman’87,
    Mumford & Shah’89, Perona & Malik’90
Image Denoising

- Images are corrupted with 70% salt-and-pepper noise

What do these examples demonstrate?

Noisy input  |  Recovered image  |  Original image

R. H. Chan, C.-W. Ho, and M. Nikolova, Salt-and-Pepper Noise Removal by Median-Type Noise Detectors and Detail-Preserving Regularization. IEEE TIP 2005
Non-local Means Denoising

Figure 1. Scheme of NL-means strategy. Similar pixel neighborhoods give a large weight, $w(p,q1)$ and $w(p,q2)$, while much different neighborhoods give a small weight $w(p,q3)$.

Preserve fine image details and texture during denoising

A. Buades, B. Coll, J. M. Morel, A non-local algorithm for image denoising, CVPR, 2005
Context-Guided Filtering

• Use local image context to steer filtering

Preserve main image structures during filtering

E. Erdem and S. Tari, Mumford-Shah Regularizer with Contextual Feedback, JMIIV, 2009
Image Smoothing

L. Xu, C. Lu, Y. Xu, J. Jia, Image Smoothing via L0 Gradient Minimization, SIGGRAPH ASIA 2011
Image Segmentation

• Partition an image into meaningful regions that are likely to correspond to objects exist in the image

Grouping of pixels according to what criteria?

high-level object specific knowledge matters!

Figures: A. Erdem
Image Segmentation

- Boundary-based segmentation
- Region-based segmentation
- Unified formulations
Snakes

- Curve Evolution - parametric curve formulation
Snakes

- Curve Evolution - parametric curve formulation

Non-rigid, deformable objects can change their shape over time, e.g. lips, hands…

M. Kass, A. Witkin, and D. Terzopoulos, Snakes: Active Contour Models, IJCV, 1988
Normalized Cuts

- A graph-theoretic formulation for segmentation

Normalized Cuts
From contours to regions

- **State-of-the-art:** \textit{gPb-owt-ucm} segmentation algorithm

From contours to regions

- **State-of-the-art:** gPb-owt-ucm segmentation algorithm

Prior-Shape Guided Segmentation

- Incorporate prior shape information into the segmentation process

E. Erdem, S. Tari, and L. Vese, Segmentation Using The Edge Strength Function as a Shape Prior within a Local Deformation Model, ICIP 2009
Registration

• Estimate a transformation function between
  – two images
  – two point sets
  – two shapes
  – ...
Registration

Fig. 5. Experiments on deformation. Each column represent one example. From left to right, increasing degree of deformation. Top row: warped template. Second row: template and target (same as the warped template). Third row: ICP results. Bottom row: RPM results.

H. Chui and A. Rangarajan, A new point matching algorithm for non-rigid registration, CVIU, 2003
Image Registration

Fig. 2. An example of a geodesic between images (original images taken from the Olivetti face database). The three intermediate images are generated by the optimization algorithm.

A tumor progressively appearing on a brain

Tumor: Reference image, registered target and deformation

What do these examples demonstrate?

Since 1699, when French explorers landed at the great bend of the Mississippi River and celebrated the first Mardi Gras in North America, New Orleans has brewed a fascinating melange of cultures. It was French, then Spanish, then French again, then sold to the United States. Through all these years, and even into the 1900s, others arrived from everywhere: Acadians (Cajuns), Africans, indige-
Image Retargetting

- automatically resize an image to arbitrary aspect ratios while preserving important image features

How we define the importance?

S. Avidan and A. Shamir, Seam Carving for Content-Aware Image Resizing, SIGGRAPH, 2007
Image retargeting by Seam Carving with different importance maps

Input  Seam Carving  GBVS  sigLab  sigRGB  our map

Fig. S.6: Some example results from the ReTargetMe data set.