BBM 413
Fundamentals of Image Processing

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Introduction

Today

• Introduction
  – About the class
  – Organization of this course

• What is image processing?
  – What does it mean, to see?
  – Vision as a computational problem
  – Sample image processing problems and applications

About this course

• This course is an advanced level undergraduate course about the fundamentals of image processing.

• Requirements
  – Programming skills (C/C++, Matlab)
  – Good math background (Calculus, Linear Algebra, Statistical Methods)
  – Little or no prior knowledge of image processing techniques

• BBM 415 Introduction to Programming Practicum
  – The students will gain hand-on experience via a set of programming assignments.
About this course (cont’d.)

• **Goals of the course:**
  – to provide an introduction to students who wish to specialize in interrelated disciplines like image processing, computer vision and computational photography

• **Skills to develop:**
  – a foundational understanding and knowledge of concepts that underlie image processing

• **What is image processing?**
  – What does image processing deal with?
  – Computational analysis of low and mid-level vision

Textbooks and Reference Material


• Lecture notes and handouts
• Papers and journal articles

BBM 413-415 Team

- **Instructor**
  - Erkut ERDEM
  - erkut@cs.hacettepe.edu.tr
  - Office: 114

- **TA**
  - Levent KARACAN
  - karacan@cs.hacettepe.edu.tr
  - Office: Vision Lab

  Office hours: to be announced!

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.f14](http://web.cs.hacettepe.edu.tr/~erkut/bbm413.f14)
Getting Help

• Office hours
  – See webpage for the schedule

• BBM 415 Image Processing Practicum
  – Course related recitations, practice with example codes, etc.

• Communication
  – Announcements and course related discussions through piazza
    https://piazza.com/hacettepe.edu.tr/fall2014/bbm413

Course work and grading

• Reading assignments (12%)
  – Reading research papers and preparing their summaries

• Quizzes (16%)
  – Pop-up quizzes during class

• Midterm exam (32%)
  – Closed book and notes
  – In class on November 29th

• Final exam (40%)
  – Closed book and notes
  – To be scheduled by Registrar

Course Overview

– Introduction (0.5 week)
– What is image processing? (0.5 week)
– Image formation and the digital camera (1 week)
– Color perception and color spaces (1 week)
– Point operations (1 week)
– Spatial filtering (1 week)
– Frequency Domain Techniques (2 weeks)
– Image pyramids and wavelets (1 week)
– Gradients, edges, contours (1 week)
– Image segmentation (2 weeks)
– Image smoothing (1 week)
– Advanced topics (1 week)

BBM 415 Image Processing Practicum

• Programming assignments (PAs)
  – Five programming assignments throughout the semester.
  – Each assignment has a well-defined goal such as solving a specific problem.
  – You must work alone or a group of two on all assignments stated unless otherwise.

• Important Dates (Tentative)
  – PA 1: October 2nd
  – PA 2: October 16th
  – PA 3: October 30th
  – PA 4: November 20th
  – PA 5: December 11th
Policies

• **Work groups**
  – You must work alone or a group of two on all assignments stated unless otherwise

• **Submission**
  – Assignments due at 23:59 on Friday evenings
  – Electronic submissions (no exceptions!)

• **Lateness penalties**
  – Get penalized **10% per day**
  – No late submission later than **3 days after due date**

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• **What is image processing?**
  – What does it mean, to see?
  – Vision as a computational problem
  – Sample image processing problems

**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

- converging lines
- shadows of the eye
- light reflected on the retina

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

Why does vision appear easy to humans?

- “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.

Computer Vision

- “Things that are easy for us are difficult for computers and vice versa” ~ Marvin Minsky
Origins of computer vision


Slide credit: S. Lazebnik

Vision: a very difficult computational problem, at several levels of understanding

- 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

Reading Assignment #1

- Due on 10th of October.
- Submit a brief 1-2 pages summary (in English) electronically.
- Use LaTeX to prepare your reports in pdf file format.
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 ➔ Complex abstract perceptual units

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

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

Figures: Francis Crick, The Astonishing Hypothesis, 1995
Image Formation

- Discretization
  - in image space - sampling
  - in image brightness - quantization


Image Representation

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


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


The raster image (pixel matrix)

```
0.92 0.93 0.94 0.97 0.62 0.37 0.85 0.97 0.93 0.92 0.99
0.95 0.89 0.82 0.89 0.56 0.31 0.75 0.92 0.81 0.95 0.91
0.89 0.72 0.51 0.55 0.51 0.42 0.57 0.41 0.49 0.91 0.92
0.96 0.95 0.88 0.94 0.56 0.46 0.91 0.87 0.90 0.97 0.95
0.71 0.81 0.81 0.87 0.57 0.37 0.80 0.88 0.89 0.79 0.85
0.49 0.62 0.60 0.58 0.50 0.60 0.58 0.50 0.61 0.45 0.33
0.86 0.84 0.74 0.58 0.51 0.39 0.73 0.92 0.91 0.49 0.74
0.96 0.67 0.54 0.85 0.48 0.37 0.88 0.90 0.94 0.82 0.93
0.69 0.49 0.56 0.66 0.43 0.42 0.77 0.73 0.71 0.90 0.99
0.79 0.73 0.90 0.67 0.33 0.61 0.69 0.69 0.79 0.73 0.93
0.91 0.94 0.89 0.49 0.41 0.78 0.78 0.77 0.89 0.99 0.93
```

Figure: M. J. Black
Hierarchy of Visual Areas

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

Figures: Nikos K. Logothetis, Vision: A Window on Consciousness, SciAm, Nov 1999F (on the left)
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:
  - Low-level vision: filtering out irrelevant image data
  - Mid-level vision: grouping pixels or boundary fragments together
  - High-level vision: complex cognitive processes

Subject matter of this course

Image Filtering

- Instagram
  - A photo-sharing and social networking service
  - Built-in vintage filters

@ Wikimedia Commons

Image Filtering

- Filtering out the irrelevant information
  \[ f(x) = u(x) + n(x) \]

- Image denoising, image sharpening, image smoothing, image deblurring, etc.
- Edge detection
- Required for many other image manipulation tasks
**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](image)

**Image Smoothing - A Little Bit of History**

- Gaussian Filtering / linear diffusion \( \frac{\partial u}{\partial t} = \nabla \cdot (\nabla u) = \nabla^2 u \)
  - the most widely used method

- 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

![Image Denoising](image)

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

**Edge Detection**

![Canby edge detector](image)
**Non-local Means Denoising**

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

**Context-Guided Smoothing**

- Use local image context to steer filtering

E. Erdem and S. Tari, Mumford-Shah Regularizer with Contextual Feedback, JMIV, 2009

**Structure-Preserving Smoothing**

L. Karacan, E. Erdem and A. Erdem, Structure Preserving Image Smoothing via Region Covariances, TOG, 2013
Image Abstraction

Detail Enhancement

Artistic Stylizations

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

Normalized Cuts

- A graph-theoretic formulation for segmentation
Normalized Cuts

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
**Image Inpainting**

- Reconstructing lost or deteriorated parts of images

What do these examples demonstrate?

M. Bertalmio, G. Sapiro, V. Caselles and C. Ballester, Image Inpainting, SIGGRAPH, 2000

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**Image Resizing**

- Resize an image to arbitrary aspect ratios

S. Avidan and A. Shamir, Seam Carving for Content-Aware Image Resizing, SIGGRAPH, 2007

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**Image Retargetting**

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

S. Avidan and A. Shamir, Seam Carving for Content-Aware Image Resizing, SIGGRAPH, 2007
Image Retargeting

Next week

- Image formation
- Digital camera and images

L. Karacan, E. Erdem and A. Erdem, Structure Preserving Image Smoothing via Region Covariances. TOG, 2013