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

<table>
<thead>
<tr>
<th>Instructor</th>
<th>TA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erkut ERDEM</td>
<td>Aysun KOCAK</td>
</tr>
<tr>
<td><a href="mailto:erkut@cs.hacettepe.edu.tr">erkut@cs.hacettepe.edu.tr</a></td>
<td><a href="mailto:aysunkocak@cs.hacettepe.edu.tr">aysunkocak@cs.hacettepe.edu.tr</a></td>
</tr>
<tr>
<td>Office: 114</td>
<td>Office: Vision Lab</td>
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**Communication**

• The course webpage will be updated regularly throughout the semester with lecture notes, programming and reading assignments and important deadlines.
  
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/fall2015/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 19th

- **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)

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 8th
  - PA 2: October 22nd
  - PA 3: November 12th
  - PA 4: November 26th
  - PA 5: December 10th
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

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

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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.
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 15th 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

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

• 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
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

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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
  \[ f(x) = u(x) + n(x) \]
  - Observed image
  - Desired image
  - Irrelevant data

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

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

**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 Filtering**

- **Difficulty:** Some of the irrelevant image information have characteristics similar to those of important image features

**Image Denoising**

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

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

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- Edges to object boundaries
- Geman

- Restoration results of different methods: MSM, DDBSM, ISM, original image.
**Non-local Means Denoising**

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

Preserve fine image details and texture during denoising.

**Context-Guided Smoothing**

- Use local image context to steer filtering.

Preserve main image structures during 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

**Structure-Preserving Smoothing**

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

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

Detail Enhancement

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

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

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

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

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

- Reconstructing lost or deteriorated parts of images

**Image Resizing**

- Resize an image to arbitrary aspect ratios

**Image Retargetting**

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

**What do these examples demonstrate?**

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

Image Retargeting

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

Next week

- Image formation
- Digital camera and images