**Today**

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

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**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.

Things that are easy for us are difficult for computers and viceversa ~ Marvin Minsky

http://xkcd.com/1425/
Origins of computer vision


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 24th 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

Figures: M. J. Black, The Astonishing Hypothesis, 1995
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

Image Filtering

- Filtering out the irrelevant information
  \[ f(x) = u(x) + n(x) \]
  
  Observed image \downarrow \quad \text{desired image} \downarrow \quad \text{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

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**Image Filtering**

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

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**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

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**Image Denoising**

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

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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

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

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

Preserve main image structures during filtering

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

**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

What do these examples demonstrate?

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**Image Resizing**

- Resize an image to arbitrary aspect ratios

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**Image Retargetting**

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

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**Image Retargetting**

S. Avidan and A. Shamir, Seam Carving for Content-Aware Image Resizing, SIGGRAPH, 2007
L. Karacan, E. Erdem and A. Erdem, Structure Preserving Image Smoothing via Region Covariances, TOG, 2013

Image Retargeting

Next week

- Image formation
- Digital camera and images