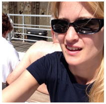
CSC420: Intro to Image Understanding
Introduction

Sanja Fidler

January 7, 2019

The Team

- **Instructor**:



Sanja Fidler (fidler@cs.toronto.edu)

- **Office**: DH 3084
- **Office hours**: Monday 12-1pm, or by appointment
- **TA**:

Sayyed Nezhadi (snezhadi@cs.toronto.edu)

Course Information

- **Class time**: Monday at 1-3pm
- **Location**: NE 2110
- **Tutorials**: TUT0101 on Monday 4-5pm (DH 4001), TUT0102 on Monday 5-6pm (IB 210), demos and Q&A, we'll do it on demand
- **Class Website**:

  http://www.cs.toronto.edu/~fidler/teaching/2019/CSC420.html

- The class will use Piazza for **announcements** and **discussions**:

  https://piazza.com/utoronto.ca/winter2019/csc420

- Your grade will **not depend on your participation on Piazza**. It's just a good way for asking questions, discussing with your instructor, TAs and your peers

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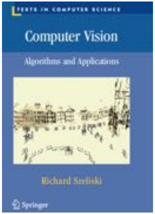
Course Information

- **Textbook**: We won't directly follow any book, but extra reading in this textbook will be useful:



Rick Szeliski

Computer Vision: Algorithms and Applications

available free online:

http://szeliski.org/Book/

- Links to other material (papers, code, etc) will be posted on the class webpage

Course Prerequisites:

- Data structures
- Linear Algebra
- Vector calculus

Without this you'll need some serious catching up to do!

Knowing some basics in this is a plus:

- Python, Matlab, C++
- Machine Learning
- Neural Networks
- Solving assignments sooner rather than later

Requirements

- Each student expected to complete 4 assignments and a project
- **Assignments:**
  - Short **theoretical questions** and **programming exercises**
  - Will be given roughly every **two weeks** (starting second week of class)
  - You will have **a week to hand in the solution** to each assignment
  - You need to solve the assignment **alone**

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  - You will be able to choose from a list of projects or come up with your own project (discussed prior with your instructor)
  - Need to hand in a **report** and do an oral **presentation**
  - Can work **individually** or in **pairs**

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Grading

- **Grade breakdown**
  - **Assignments**: 60% (15% each)
  - **Project**: 40%

- For the project you will need to do
  - Short project proposal
  - Project report
  - Project presentation (oral)

- I will be asking questions about relevant part of the class material during project presentations which will influence the grade

Term Work Dates

Term Work	Post Date	Due Date
Assignment 1	Jan 17	Jan 24
Assignment 2	Jan 31	Feb 7
Assignment 3	Feb 14	Feb 21
Assignment 4	Mar 7	Mar 14
Project Report		First week of April
Project Presentation		First week of April

- All dates are for 2019
- Dates are approximate (depend on what material we cover in class)

Programming Language?

- Your assignments / project can be in Python, Matlab, C++
- As long as it compiles, runs, and you know how to defend it, we're happy
- HOWEVER, most code and examples we will provide during the class will be in Python, Matlab
- Choose wisely

Lateness

Deadline The solutions to assignments / project should be submitted **by 11.59pm on the date they are due**. Anything from 1 minute late to 24 hours will count as **one late day**.

Lateness Each student will be given a total of **3 free late days**. This means that you can hand in three of the assignments one day late, or one assignment three days late. It is up to the you to make a good planning of your work. **After you have used the 3 day budget, the late assignments will not be accepted.**

Syllabus

Tentative syllabus

Week nb.	Date	Topic
1	Jan 7	Intro
2	Jan 14	Linear filters, edges
3	Jan 21	Image features
4	Jan 28	Keypoint detection
5	Feb 4	Matching
6	Feb 11	Grouping
7	Feb 18	Stereo, multi-view
8	Feb 25	Stereo, multi-view
9	March 4	Object recognition
10	March 11	Object detection
11	March 18	Neural Networks
12	March 25	Segmentation
13	April ?	Project Presentations

Introduction

Let's begin!

Introduction to Intro to Image Understanding

- What is Computer Vision?
- Why study Computer Vision?
- Which cool applications can we do with it?
- Is vision a hard problem?

What is Computer Vision?

What is Computer Vision?

- A field trying to develop automatic algorithms that would **"see"**

Embodied Agents

- Understand the scene in order to take actions: perception, planning, reasoning

Figure: How do I make dinner in this household?

Many simulators: Carla, Thor, House3D, VirtualHome, etc

What is Computer Vision?

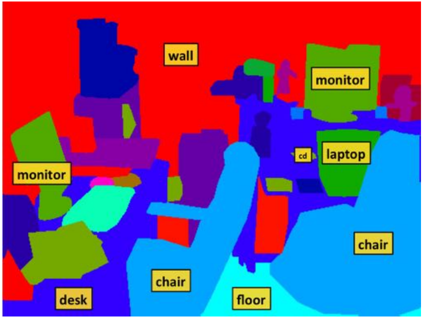
[text adopted from A. Torralba]

- What does it mean to see?
  - To know what is where by looking – Marr, 1982

What is Computer Vision?

[text adopted from A. Torralba]

- What does it mean to see?
  - To know what is where by looking – Marr, 1982
  - Understand where things are in the world

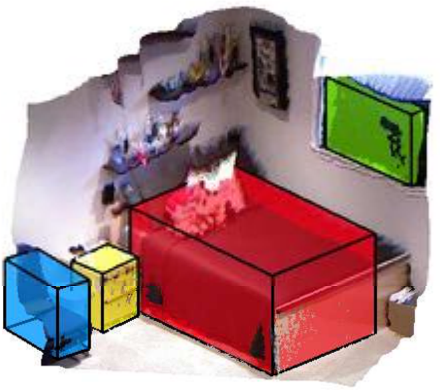


What is Computer Vision?

[text adopted from A. Torralba]

- What does it mean to see?
  - To know what is where by looking – Marr, 1982
  - Understand where things are in the world
  - What are their 3D/material properties?

image



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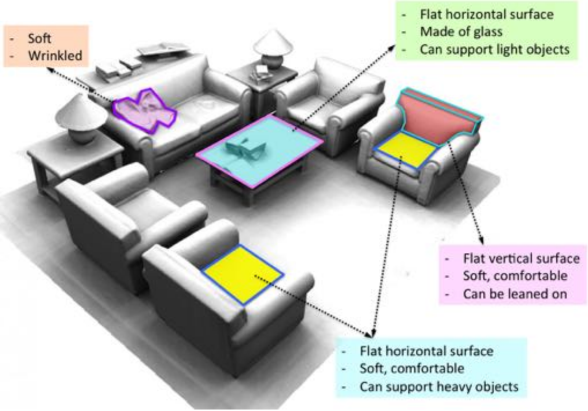

Depth pic from `http://vladlen.info`

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- What does it mean to see?
  - To know what is where by looking – Marr, 1982
  - Understand where things are in the world
  - What are their 3D/material properties?
  - What actions are taking place?

Pic from www.cobblehillpuzzles.com

“Full” Image Understanding?

- Full understanding of an image?

"Full" Image Understanding?

- Full understanding of an image? **You can answer any question about it**

[M. Malinowski, M. Fritz, A Multi-World Approach to Question Answering about Real-World Scenes based on Uncertain Input, *NIPS*, 2014]

"Full" Image Understanding?

- Full understanding of an image? **You can answer any question about it**

Q: What is behind the table?
A: window

Q: What is in front of the toilet?
A: door

Q: What is on the counter in the corner? A: microwave

"Full" Image Understanding?

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Q: What is behind the table?
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Q: What is the shape of the green chair? A: horse shaped

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Q: Where is the oven?
A: on the right side of the fridge

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Q: What is the shape of the green chair? A: horse shaped

Q: Where is the oven?
A: on the right side of the fridge

Q: What is the largest object?
A: bed

"Full" Image Understanding?

- Full understanding of an image? **You can answer any question about it**

Q: Which object is red?
A: toaster

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- Full understanding of an image? **You can answer any question about it**

Q: Which object is red?
A: toaster

Q: How many drawers are there?
A: 6

Q: How many doors are open
A: 1

Q: How many lights are on?
A: 6

"Full" Image Understanding?

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Q: Which object is red?
A: toaster

Q: How many drawers are there?
A: 6

Q: How many doors are open
A: 1

Q: How many lights are on?
A: 6

Q: Can you make pizza in this room?
A: yes

Q: Where can you sit?
A: chairs, table, floor

Why study Computer Vision?

Why study Computer Vision?

- You are curious how to one day make the robot walk your dog

http://www.cs.toronto.edu/~fidler/videos/robotsmovies.mov

Why study Computer Vision?

- ... and fold your laundry

https://www.youtube.com/watch?v=gy5g33S0Gzo

https://www.youtube.com/watch?v=KKUaVzf3Oqw

Why study Computer Vision?

- ... and drive you to work

Amnon Shashua's Mobileye autonomous driving system

https://www.youtube.com/watch?v=4fxFDypHZLs

Why study Computer Vision?

- Allows you to manipulate your images

Scene Completion using Millions of Photographs, Hays & Efros, SIGGRAPH 2007

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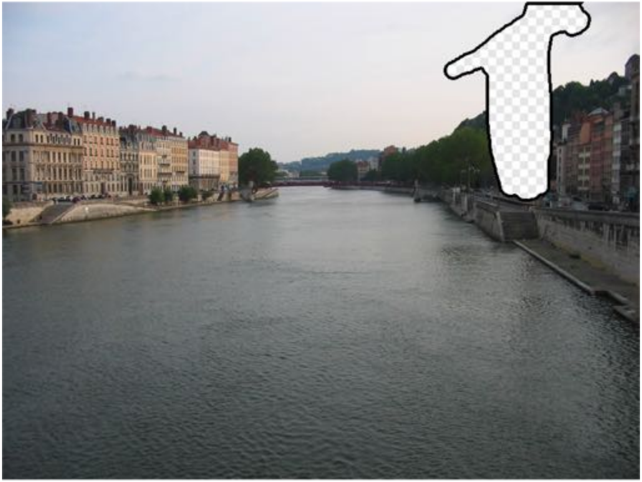

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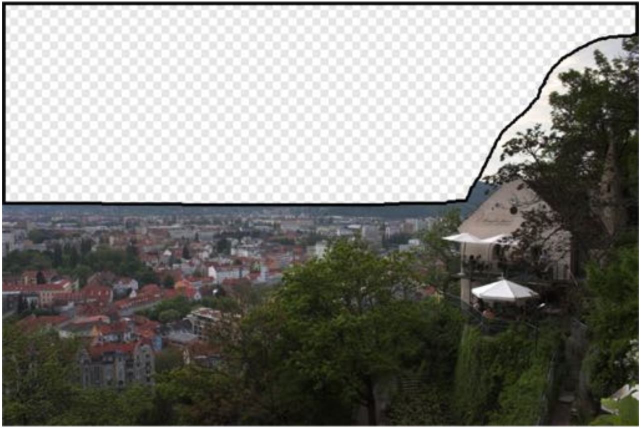

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Why study Computer Vision?

- Change style of images

[Gatys, Ecker, Bethge. A Neural Algorithm of Artistic Style. Arxiv'15.]

Why study Computer Vision?

- Change style of videos

https://www.youtube.com/watch?v=Khuj4ASldmU

[Ruder, Dosovitskiy, Brox. Artistic style transfer for videos, 2016]

Why study Computer Vision?

- Change style of videos

Bringing Impressionism to Life with Neural Style Transfer in *Come Swim*

Bhautik J Joshi*
Research Engineer, Adobe

Kristen Stewart
Director, *Come Swim*

David Shapiro
Producer, Starlight Studios

Figure 1: *Usage of Neural Style Transfer in Come Swim; left: content image, middle: style image, right: upsampled result. Images used with permission, (c) 2017 Starlight Studios LLC & Kristen Stewart.*

1 [cs.CV] 18 Jan 2017

Abstract

Neural Style Transfer is a striking, recently-developed technique that uses neural networks to artistically redraw an image in the style of a source style image. This paper explores the use of this technique in a production setting, applying Neural Style Transfer to redraw key scenes in *Come Swim* in the style of the impressionistic painting that inspired the film. We document how the technique can be driven within the framework of an iterative creative process to achieve a desired look, and propose a mapping of the broad parameter space to a key set of creative controls. We hope that this mapping can provide insights into priorities for future research.

execute efficiently and predictably. In a production setting, however, a great deal of creative control is needed to tune the result, and a rigid set of algorithmic constraints run counter to the need for this creative exploration. While early investigations to better map the low-level neural net evaluations to stylistic effects are underway [Li et al. 2017], in our paper we focused on examining the higher-level parameter space for Neural Style Transfer and found a set of working shortcuts to map them to a reduced but meaningful set of creative controls.

2 Realizing Directorial Intent

https://arxiv.org/pdf/1701.04928.pdf

Why study Computer Vision?

- ... and make cool videos using a single image

http://www.cs.cmu.edu/~om3d/

3D Object Manipulation in a Single Photograph using Stock 3D Models, Kholgade, Simon, Efros, Sheikh, SIGGRAPH 2014

Why study Computer Vision?

- Fancy visualization and game analysis in sports

Why study Computer Vision?

- Fancy visualization and special effects in movies

[Source: `http://cvfxbook.com` and `http://vimeo.com/100095868`]

Why study Computer Vision?

- Reconstruct the world in 3D from online photos!

https://www.youtube.com/watch?v=IgBQCoEfiMs

Photosynth, https://photosynth.net/ (try it!)

Why study Computer Vision?

- Figure out what people are wearing

`http://clothingparsing.com` (try it!)

Why study Computer Vision?

- How Fashionable Are You?

Figure: An example of a post on `http://www.chictopia.com`. We crawled the site for 180K posts.

Why study Computer Vision?

- How Fashionable Can You Become?

Figure: Examples of recommendations provided by our model. The parenthesis we show the fashionability scores.

[E. Simo-Serra, S. Fidler, F. Moreno, R. Urtasun. CVPR'15.]

Why study Computer Vision?

[S. Zhu, C.C Loy, D. Lin, R. Urtasun, S. Fidler. In submission.]

The lady's upper-clothes contain the pattern of flowers

Why study Computer Vision?

[S. Zhu, C.C Loy, D. Lin, R. Urtasun, S. Fidler. In submission.]

The woman is wearing a blue short-sleeved T-shirt and blue jeans

Why study Computer Vision?

[S. Zhu, C.C Loy, D. Lin, R. Urtasun, S. Fidler. In submission.]

A woman wearing a black overcoat and white shorts

Why study Computer Vision?

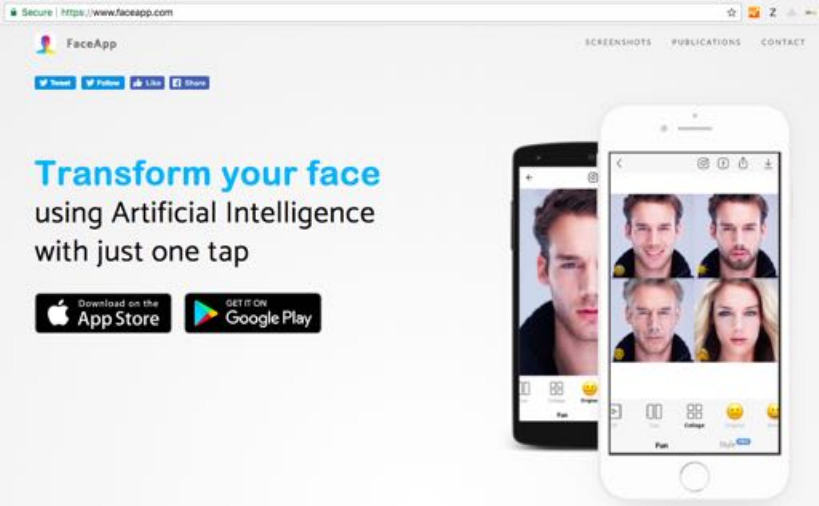
[S. Zhu, C.C Loy, D. Lin, R. Urtasun, S. Fidler. In submission.]

Why study Computer Vision?

Figure: Modiface: Toronto-based startup

Why study Computer Vision?

- Play with faces



Why study Computer Vision?

- Play with faces

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Why study Computer Vision?

- Generate image captions automatically

[Source: L. Zitnick, NIPS'14 Workshop on Learning Semantics]

Why study Computer Vision?

- Generate image captions automatically

A man with a colorful umbrella walking down a street.

[Source: L. Zitnick, NIPS'14 Workshop on Learning Semantics]

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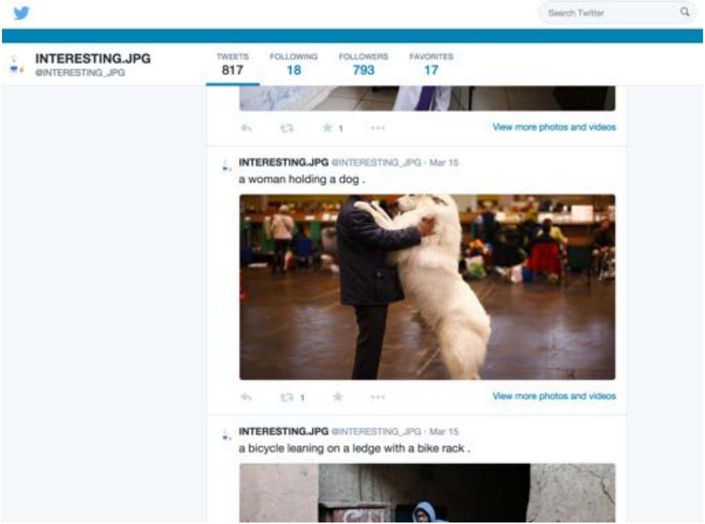


[Kiros, Salakhutdinov, Zemel. Unifying Visual-Semantic Embeddings with Multimodal Neural Language Models. 2014]

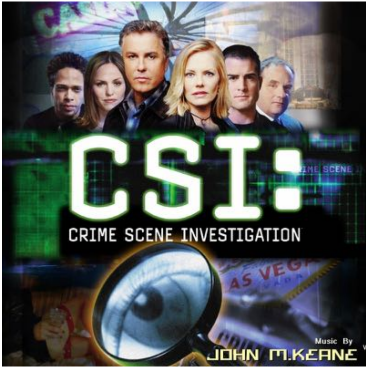
Why study Computer Vision?

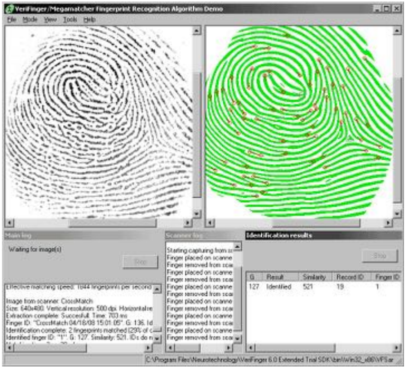
- Have a computer do math for you

Figure: Photomath: https://photomath.net/, http://www.youtube.com/watch?v=XlbVB50mIh4

Why study Computer Vision?

- Fingerprint recognition





[Source: S. Lazebnik]

Why study Computer Vision?

- You can do some movie-like Forensics

Figure: Source: Nayar and Nishino, Eyes for Relighting

[Source: N. Snavely]

Why study Computer Vision?

[Source: N. Snavely]

Why study Computer Vision?

Figure: Source: Nayar and Nishino, Eyes for Relighting

[Source: N. Snavely]

Why study Computer Vision?

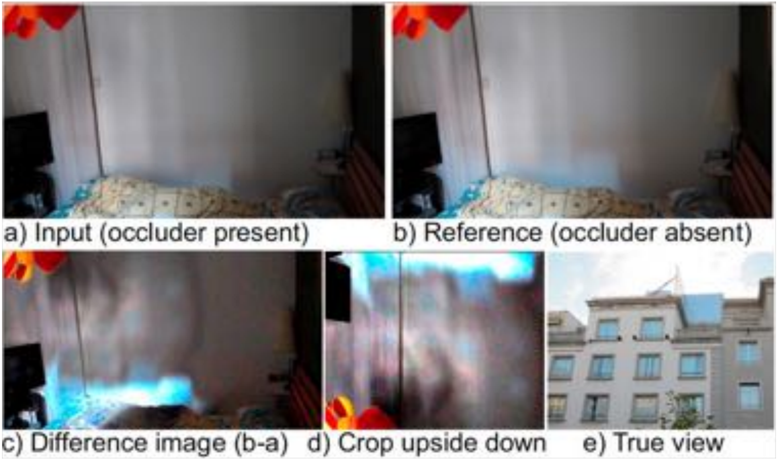
- Some more CSI

- Can you see something on the wall?

Torralba & Freeman, CVPR'12

Why study Computer Vision?

- Some more CSI



Why study Computer Vision?

- Object recognition (in mobile phones)

[Source: S. Seitz]

Why study Computer Vision?

- Games, games & games: 3D Pose Estimation with Depth Sensors

[Source: Microsoft Kinect]

How It All Began...

How It All Began...

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Artificial Intelligence Group July 7, 1966

Vision Memo. No. 100.

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".

[Slide credit: A. Torralba]

50 years and thousands of PhDs later...

Popular benchmarks: KITTI, PASCAL, Cityscapes, MS-COCO

Car

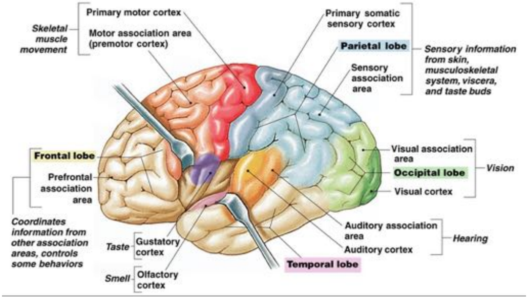
	Method	Setting	Code	Moderate	Easy	Hard	Runtime	Environment	Compare
1	THU CV-AI			91.97 %	91.96 %	84.57 %	0.38 s	GPU @ 2.5 Ghz (Python)	
2	DH-ARI			91.48 %	90.87 %	82.25 %	4s	GPU @ 2.5 Ghz (C/C++)	
3	HRI-SH			90.71 %	91.34 %	84.28 %	3.6 s	GPU @ >3.5 Ghz (Python + C/C++)	
4	BM-NET			90.50 %	90.81 %	83.92 %	0.5 s	GPU @ 2.5 Ghz (Python + C/C++)	
5	MVRA + I-FRCNN+			90.36 %	90.78 %	80.48 %	0.18 s	GPU @ 2.5 Ghz (Python)	
6	TuSimple		code	90.33 %	90.77 %	82.86 %	1.6 s	GPU @ 2.5 Ghz (Python + C/C++)	

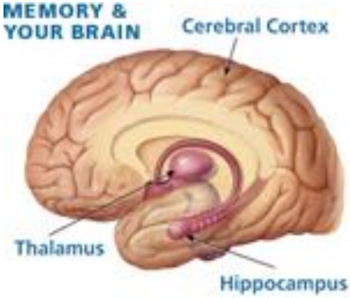
Reasoning demo: http://vqa.cloudcv.org/

Why is vision hard?

Why is vision hard?

- Half of the cerebral cortex in primates is devoted to processing visual information. This is a lot. Means that vision has to be pretty hard!





Why is vision hard?

All this is dog...

[slide adopted from: R. Urtasun]

Why is vision hard?

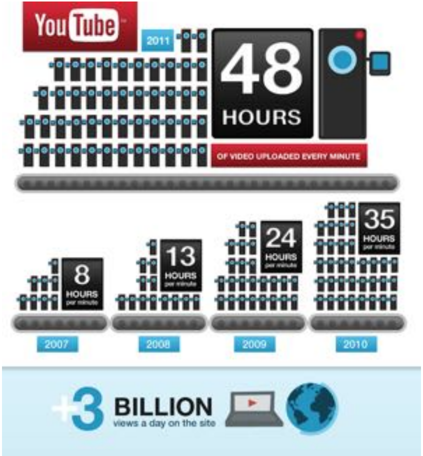
Biederman, 1987

[slide credit: R. Urtasun]

Why is vision hard?

Lots of data to process:

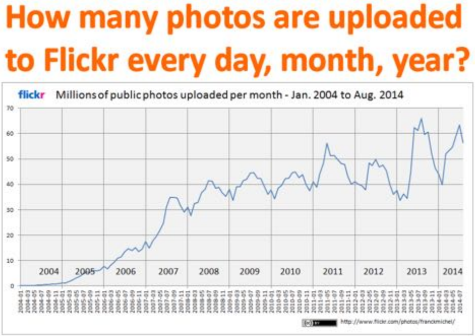
- Thousands to millions of pixels in an image
- 100 hours of video added to YouTube per minute [source: YouTube]
- Over 6 billion hours of video are watched each month on YouTube – almost an hour for every person on Earth [source: YouTube]

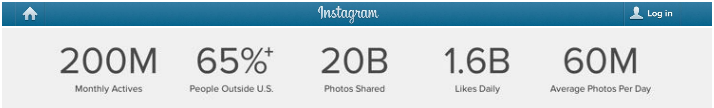


Why is vision hard?

Lots of data to process:

- $\sim$ 5000 new tagged photos added to Flickr per minute (7M per day)
- $\sim$ 60M photos uploaded to Instagram every day [source: Instagram]





Exploit so Much Data!

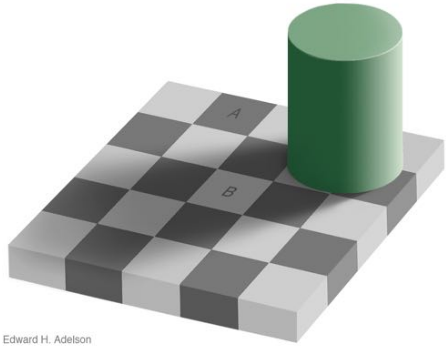
Figure: Vemodalen: The Fear That Everything Has Already Been Done, https://www.youtube.com/watch?v=8ftDjebw8aA

[Source: L. Zitnick, NIPS'14 Workshop on Learning Semantics]

Why is vision hard?

- Human vision seems to work quite well.
- How well does it really work?
- Let's play some games!

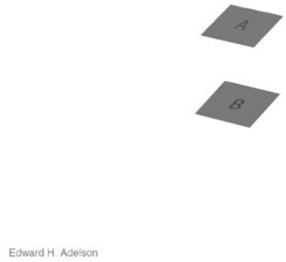
How good are humans?



- Which square is lighter, A or B?

[Slide credit: A. Torralba]

How good are humans?



- Which square is lighter, A or B?

[Slide credit: A. Torralba]

How good are humans?

Figure: 2006 Walt Anthony

- Which red line is longer?

[Slide credit: A. Torralba]

Figure: 2006 Walt Anthony

- Which red line is longer?

[Slide credit: A. Torralba]

How good are humans?

Figure: Ames room

- Assumptions can be wrong

[Slide credit: A. Torralba]

How good are humans?

Figure: Chabris & Simons, https://www.youtube.com/watch?v=vJG698U2Mvo

- Count the number of times the white team pass the ball
- Concentrate, it's difficult!

How good are humans?

Figure: Simons et al., http://www.perceptionweb.com/perception/perc1000/a_d_ex1.mov (more videos here: http://www.perceptionweb.com/misc.cgi?id=p3104)

- Is something happening in the picture?

How good are humans?

Figure: Torralba et al., http://people.csail.mit.edu/torralba/courses/6.870/slides/blur.avi

- Can you describe what's going on in the video?

How good are humans?

Figure: Torralba et al., http://people.csail.mit.edu/torralba/courses/6.870/slides/highres.avi

- Can you describe what's going on in the video?

What do I need...

What do I need to become a good Computer Vision researcher?

- Technical capabilities
- Good programming skills
- Imagination
- Even better intuition
- Lots of persistence
- Some luck always helps