CSC420: Intro to Image Understanding Introduction

Sanja Fidler

September 15, 2015

UNIVERSITY OF TORONTO

The Team

- **Instructor**:

Sanja Fidler (fidler@cs.toronto.edu)

- **Office**: 283B in Pratt
- **Office hours**: Tuesday 1.20-2.50pm, or by appointment
- **TAs**:

Sara Sabour (saaraa@cs.toronto.edu)

Yukun Zhu (yukun@cs.toronto.edu)

Kaustav Kundu (kkundu@cs.toronto.edu)

Course Information

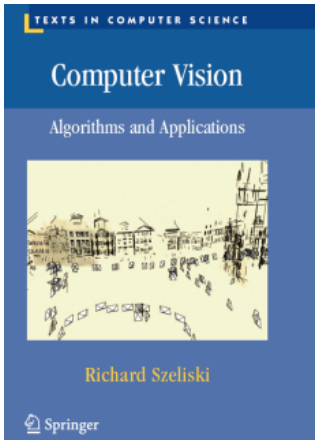
- **Class time**: Tuesday and Thursday at 3-4pm
- **Location**: BA1200
- **Tutorials**: demos and Q&A, we'll do it on demand
- **Class Website**:

  http://www.cs.toronto.edu/~fidler/teaching/2015/CSC420.html
- The class will use Piazza for **announcements** and **discussions**:

  https://piazza.com/utoronto.ca/fall2015/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

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

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:

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

Requirements and Grading

- Each student expected to complete 5 assignments and a project
- **Grading**
  - **Assignments**: 60% (12% each)
  - **Project**: 40%
- **Assignments:**
  - Short **theoretical questions** and **programming exercises**
  - Will be given every **two weeks** (starting with second week of class)
  - You will have **a week to hand in the solution** to each assignment
  - You need to solve the assignment **alone**
- **Project:**
  - 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**

Term Work Dates

Term Work	Post Date	Due Date	% of grade
Assignment 1	Sept 22	Sept 29	12%
Assignment 2	Oct 6	Oct 13	12%
Assignment 3	Oct 20	Oct 27	12%
Assignment 4	Nov 3	Nov 10	12%
Assignment 5	Nov 17	Nov 24	12%
Project Report		Dec 5	25%
Project Presentation		Dec 8	15%

- All dates are for 2015. ;)

Programming Language?

- Your assignments / project can be in Matlab, Python, 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 Matlab
- Choose wisely

Lateness

Deadline The solutions to the 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	Sept 15	Intro
2	Sept 17 & Sept 22	Linear filters, edges
3	Sept 24 & Sept 29	Image features
4	Oct 1 & Oct 6	Keypoint detection
5	Oct 8 & Oct 13	Matching
6	Oct 15 & Oct 20	Segmentation
7	Oct 22 & Oct 27	Grouping
8	Oct 29 & Nov 3	Object recognition
9	Nov 5 & Nov 12	Object detection
10	Nov 17 & Nov 19	Neural Networks
11	Nov 24 & Nov 26	Stereo, multi-view
12	Dec 1 & Dec 3	Recognition in 3D
13	Dec 8 & Dec 9	Project Presentations

Let's begin!

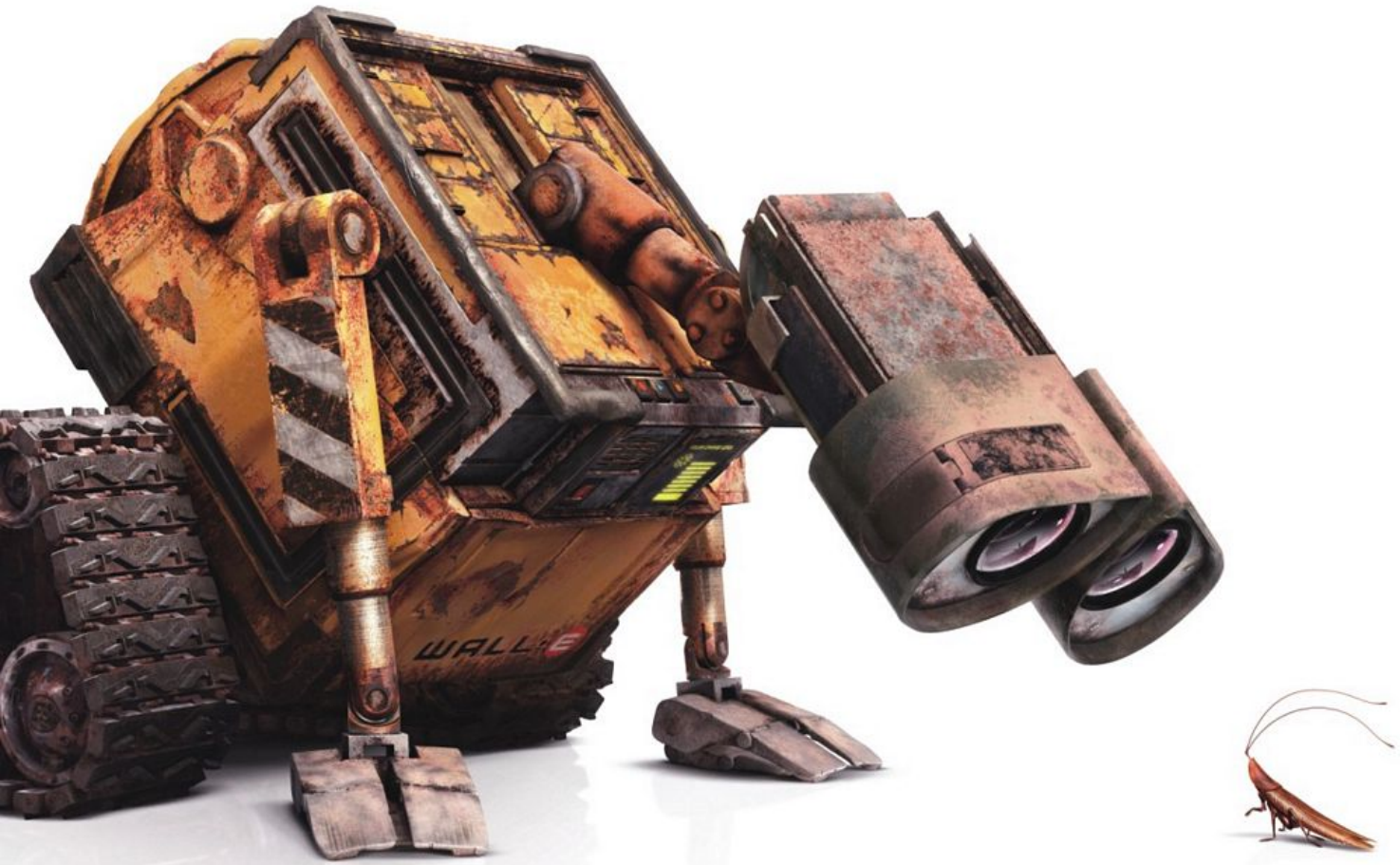
Introduction to Intro to Image Understanding

- 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"**



Disney · PIXAR
WALL·E

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?

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- What does it mean to see?
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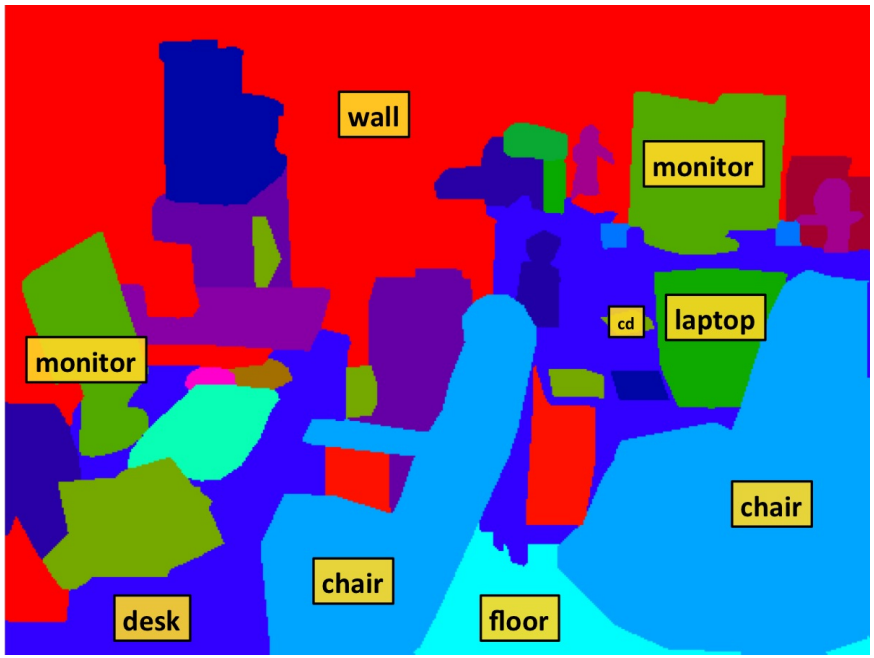
  - Understand where things are in the world



What is Computer Vision?

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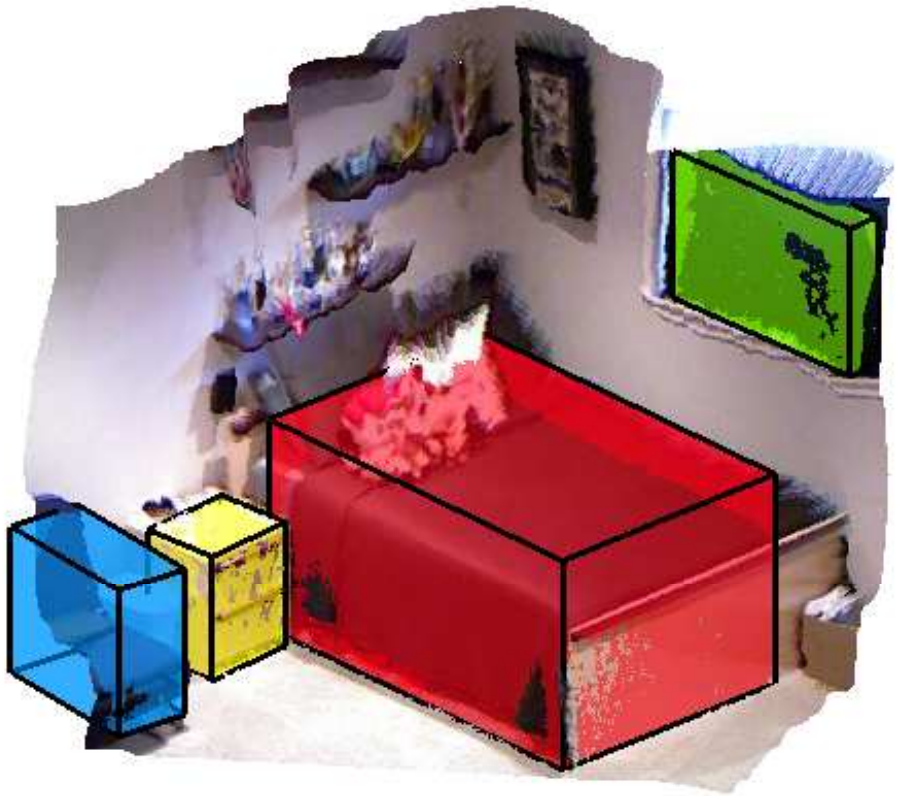
  - Understand where things are in the world
  - What are their 3D properties?

image



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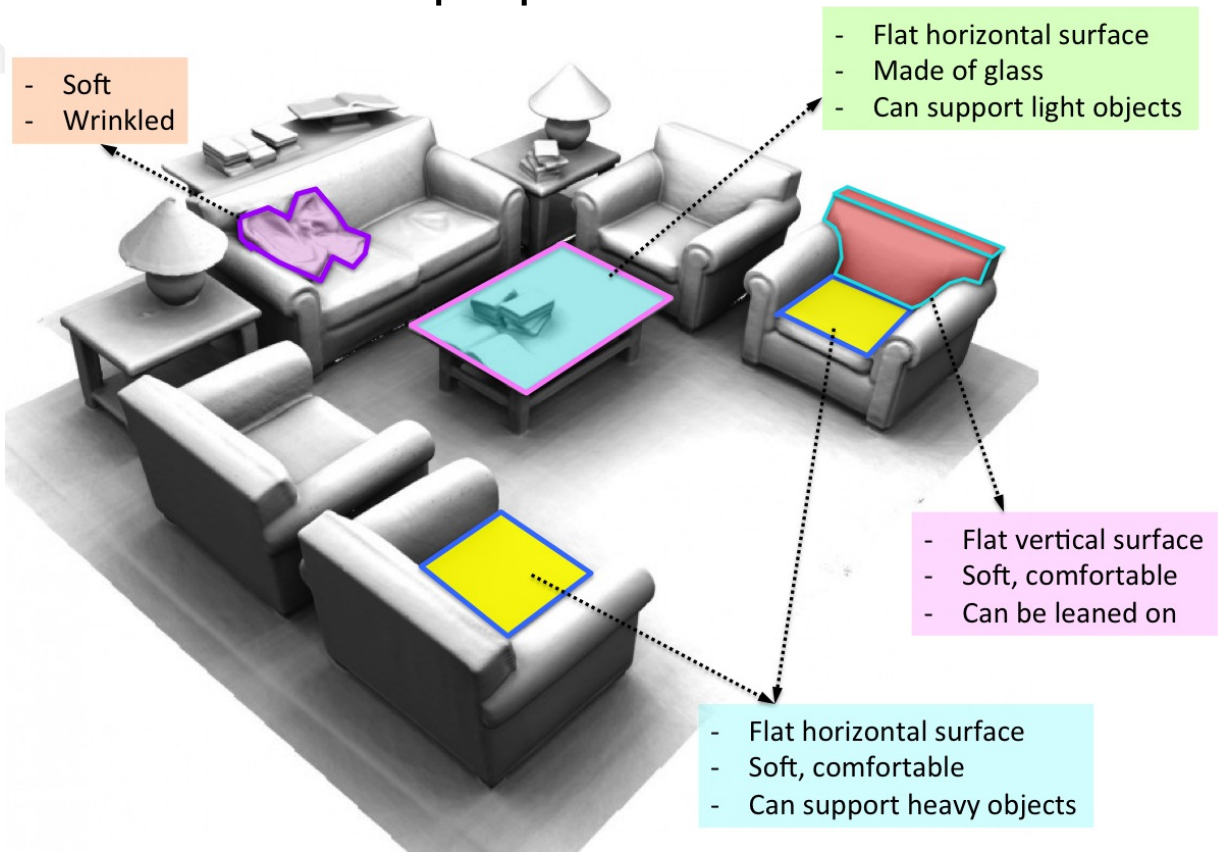

Depth pic from `http://vladlen.info`

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 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]

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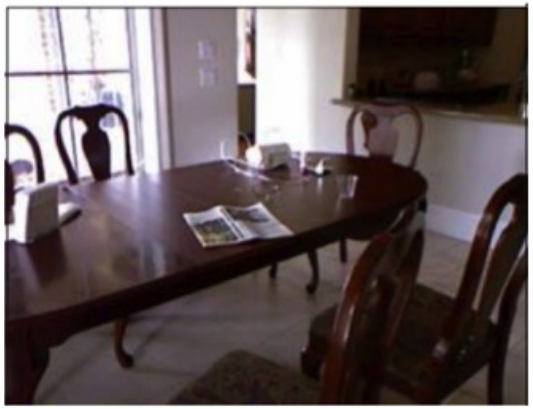

Q: What is behind the table?
A: window

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

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

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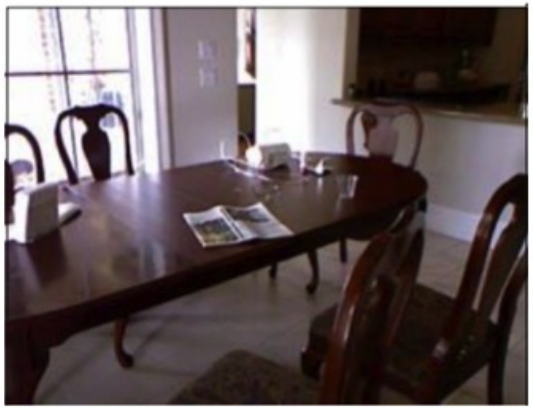

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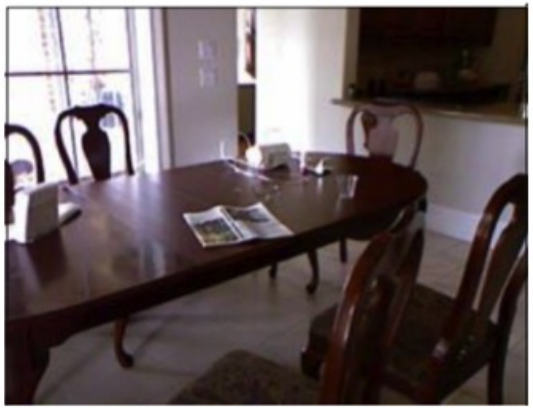

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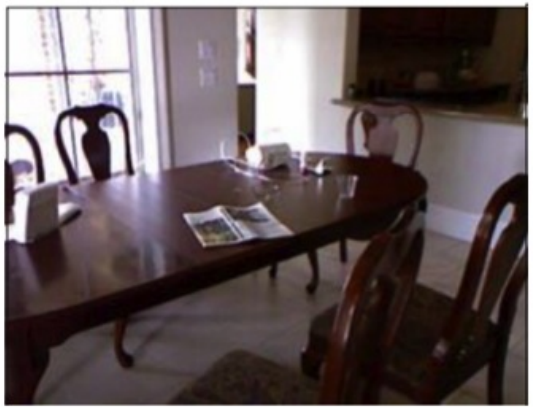

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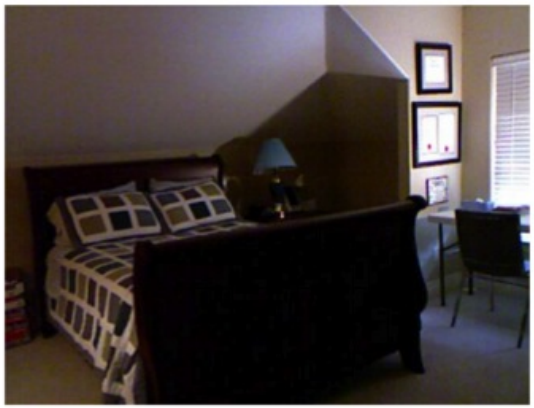

Q: What is the largest object?
A: bed

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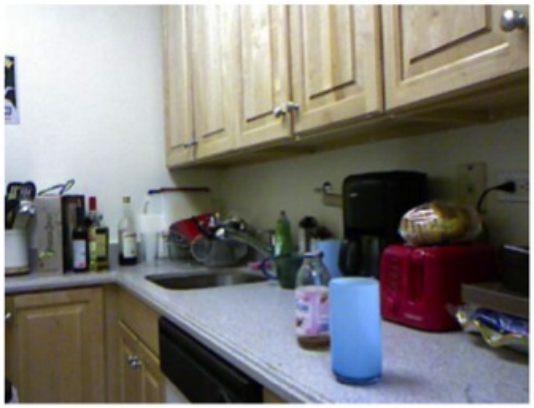

Q: Which object is red?
A: toaster

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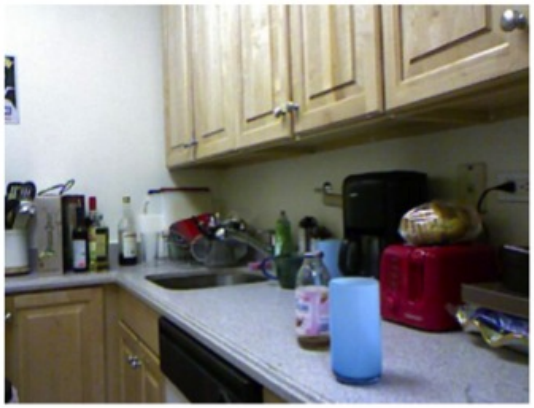

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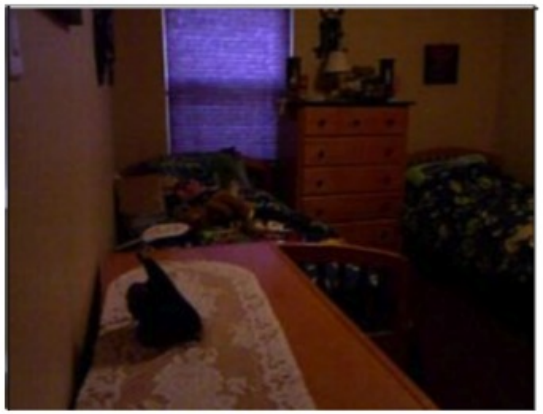
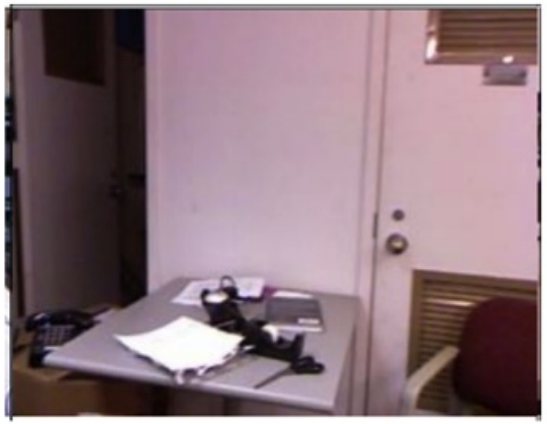


Q: How many drawers are there?
A: 6



Q: How many doors are open
A: 1

Q: How many lights are on?
A: 6

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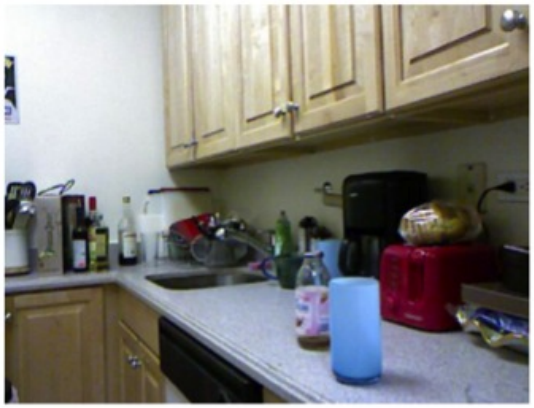

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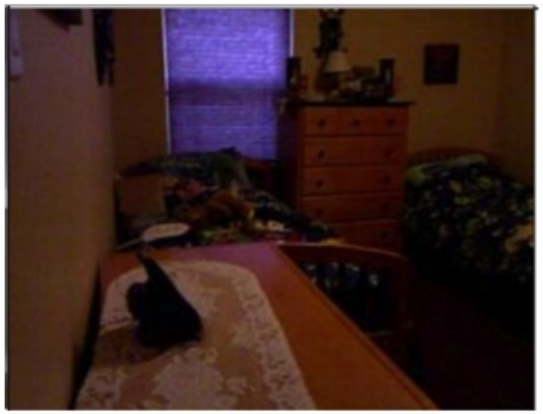

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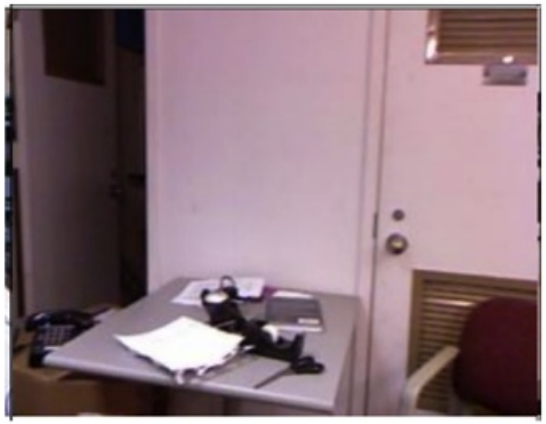

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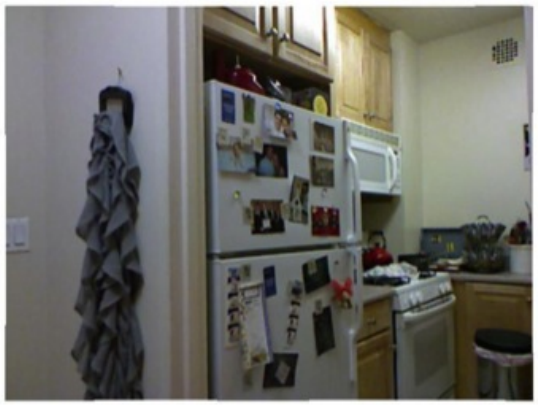


Q: Can you make pizza in this room?
A: yes

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

Why study Computer Vision?

Why study Computer Vision?

- Because it is challenging and fun

Jialiang Wang's (4th undergraduate year, UofT) video about his summer research in computer vision (click on the pic to see video – you'll need internet connection)

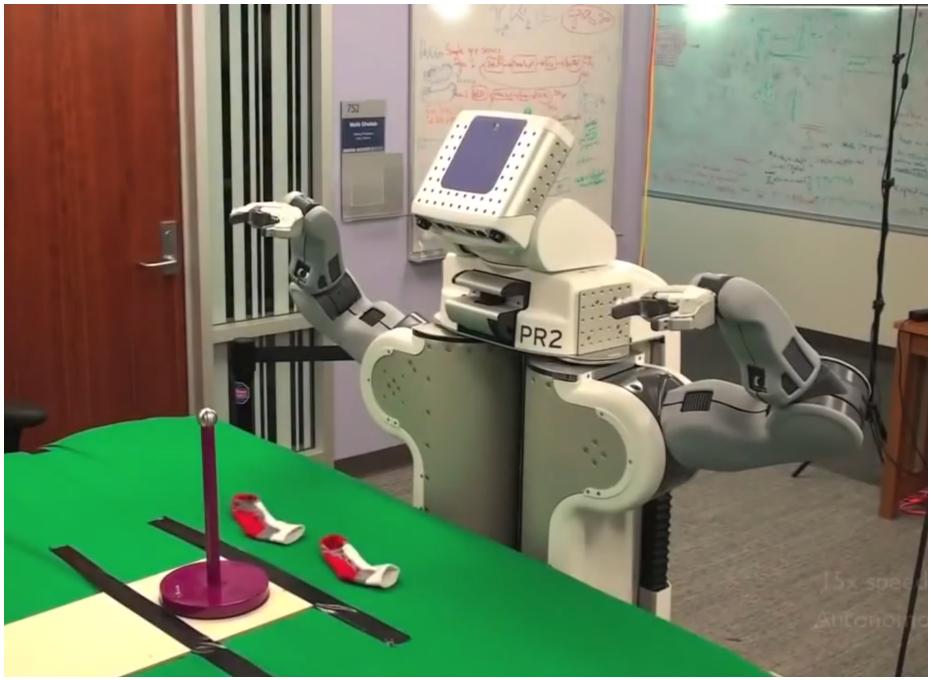
Why study Computer Vision?

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

(click on the pic to see video)

Why study Computer Vision?

- ... and fold your laundry



(click on each pic to see videos)

Why study Computer Vision?

- ... and drive you to work (video)

Amnon Shashua's Mobileye autonomous driving system

Why study Computer Vision?

- Allows you to manipulate your images

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

Why study Computer Vision?

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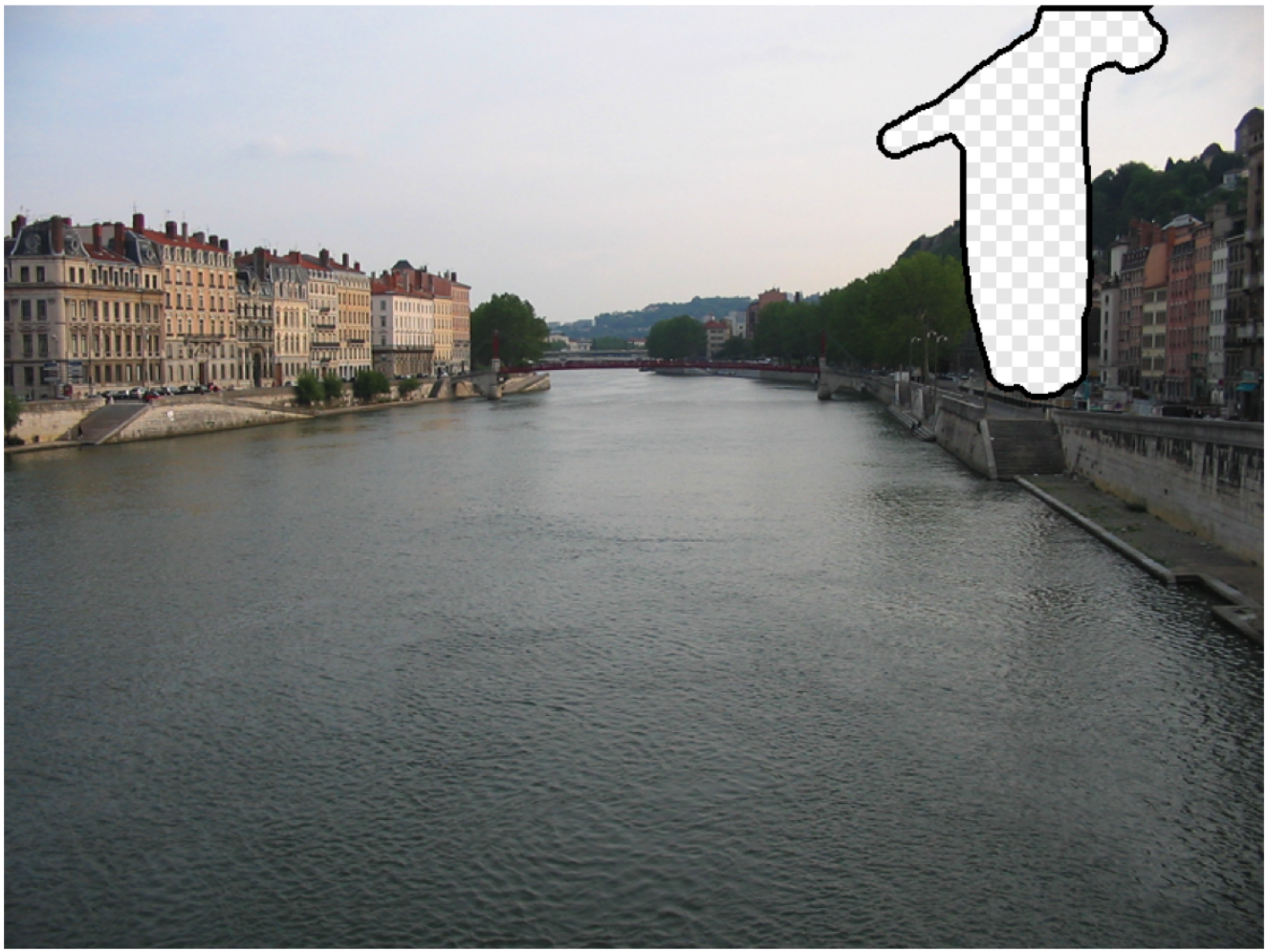

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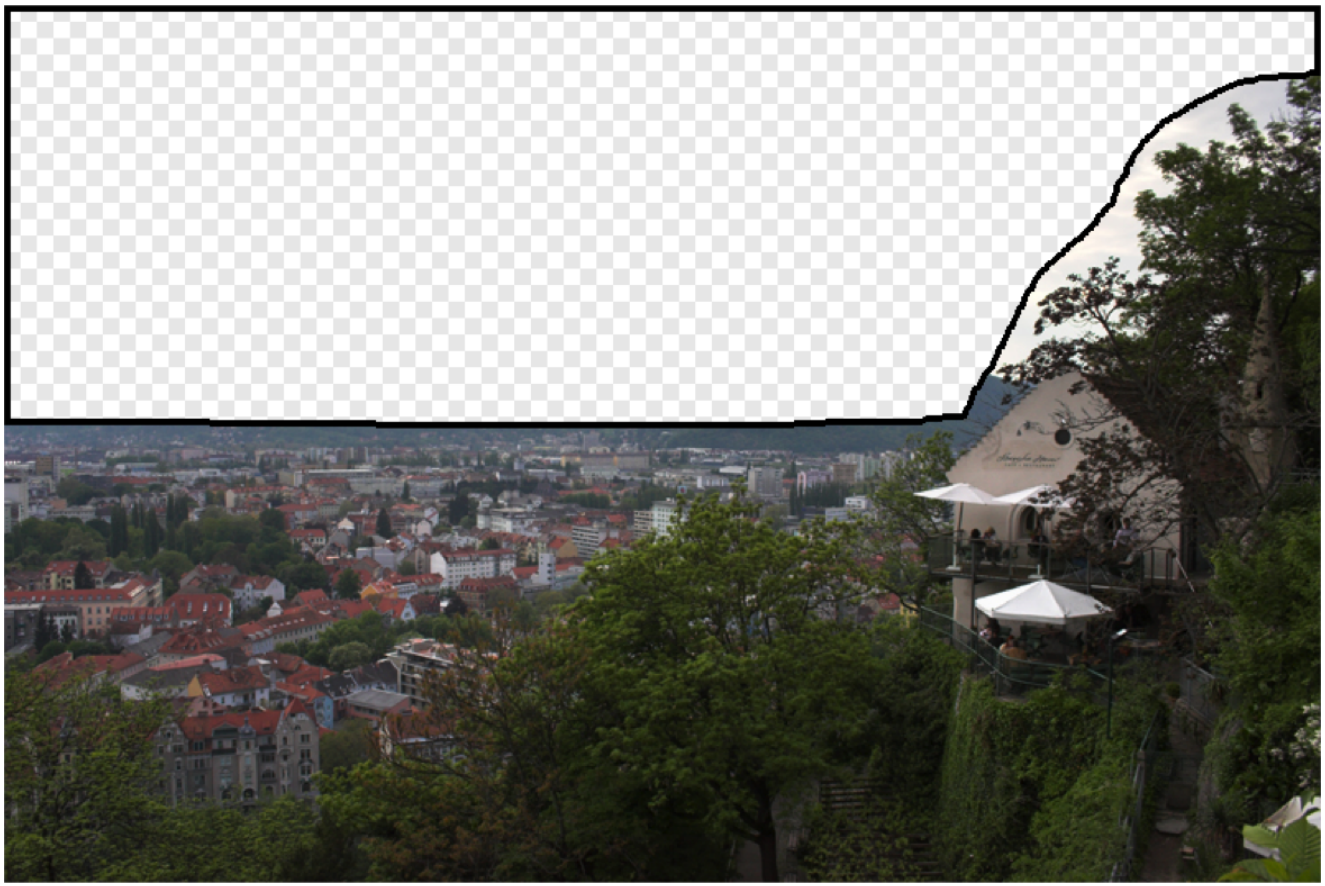

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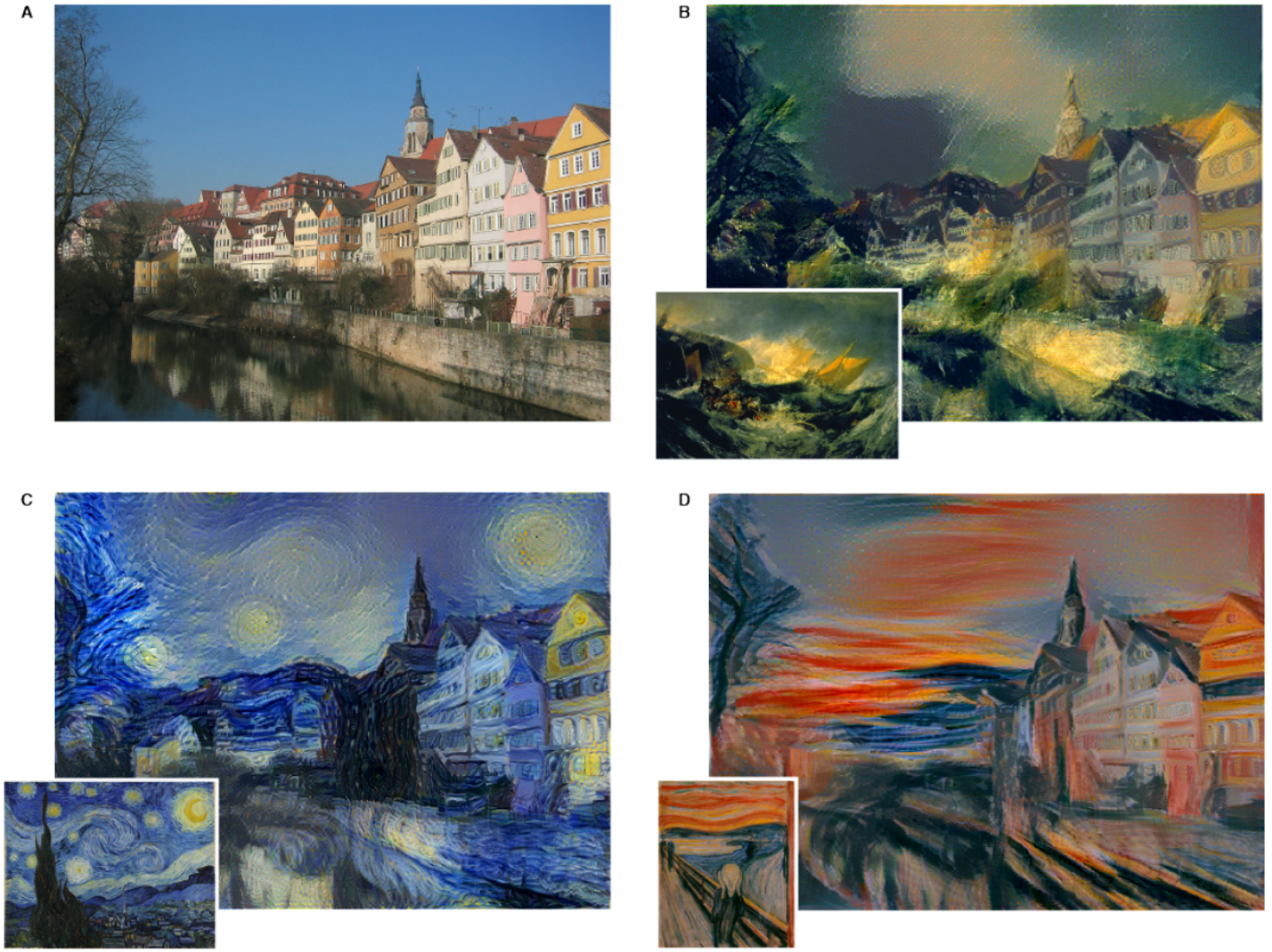
Scene Completion using Millions of Photographs, Hays & Efros, SIGGRAPH 2007

Why study Computer Vision?

- Change style of images



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

Why study Computer Vision?

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

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

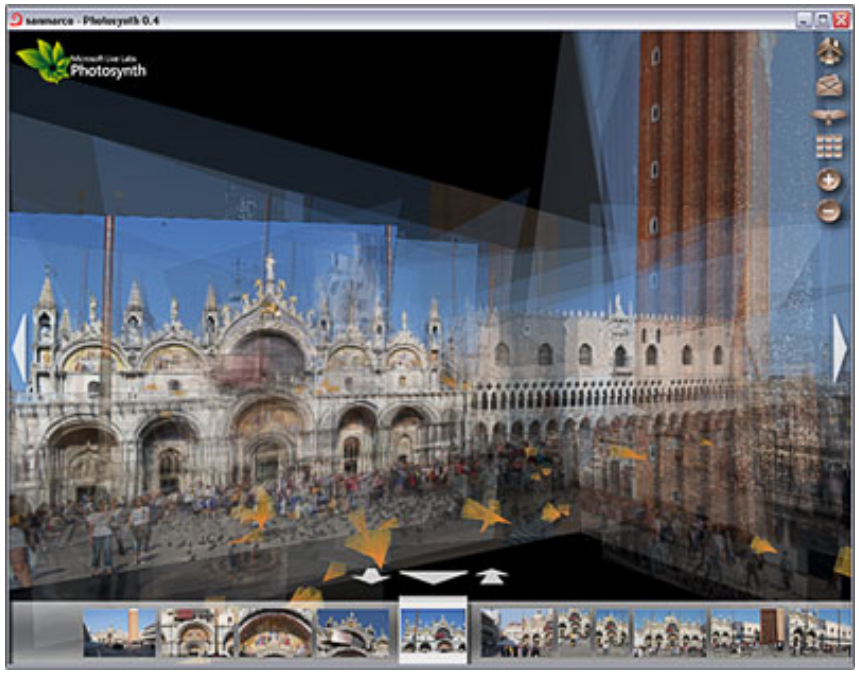
Why study Computer Vision?

- Fancy visualization and special effects in movies

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

Why study Computer Vision?

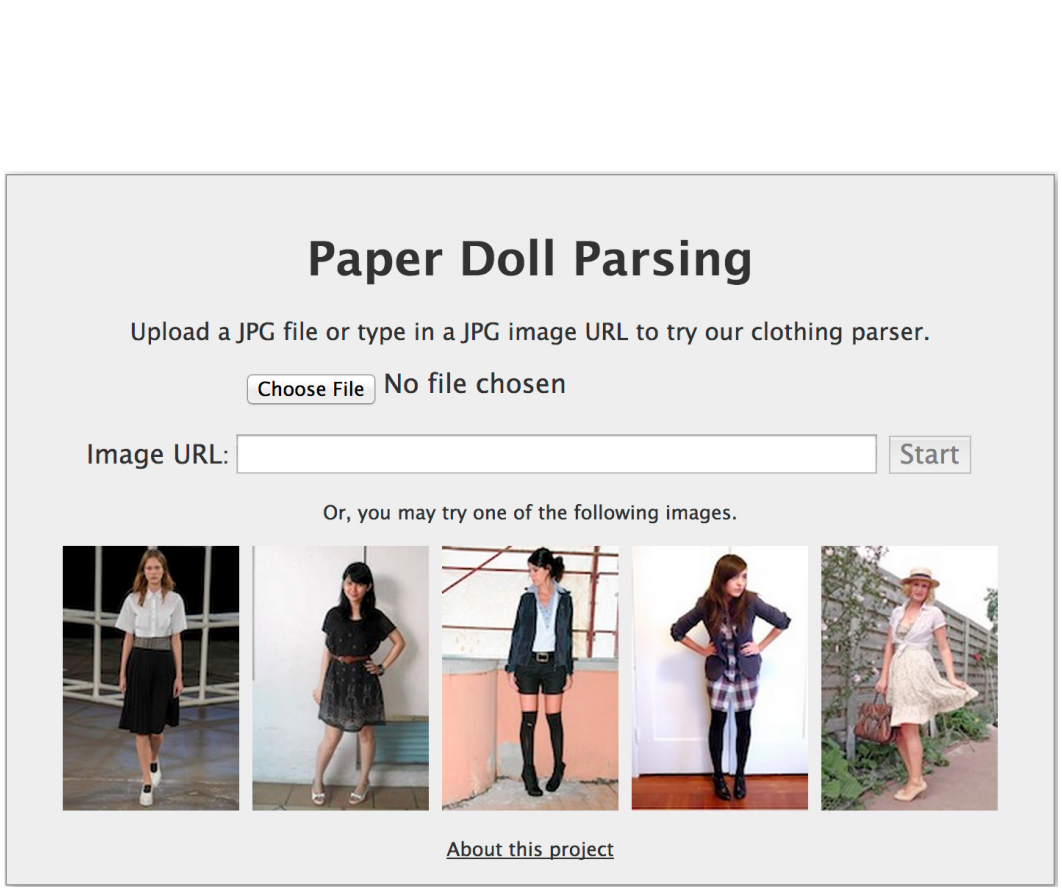
- Reconstruct the world in 3D from online photos!



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?

LOS ANGELES, CA

466 FANS
288 VOTES
62 FAVOURITES

TAGS
CHIC
EVERDAY
FALL

COLOURS
WHITE-BOOTS

NOVEMBER 10, 2014

GARMENTS
White Cheap Monday Boots
Chilli Beans Sunglasses
Missguided Romper
Daniel Wellington Watch

COMMENTS
Nice!!
Love the top!
cute
...

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

Why study Computer Vision?

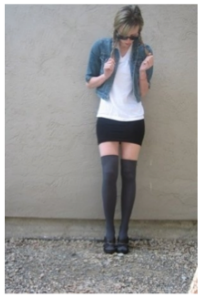
- How Fashionable Can You Become?

Current Outfit:
Pink Outfit (3)

Recommendations:
Heels (8)
Pastel Shirts/Skirts (8)
Black/Gray Tights/Sweater (5)

Current Outfit:
Pink/Blue Shoes/Dress Shorts (3)

Recommendations:
Black/Gray Tights/Sweater (5)
Black Casual (5)
Black Boots/Tights (5)

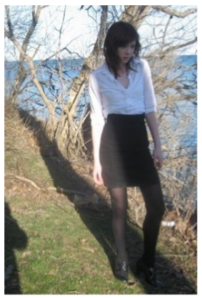


Current Outfit:
Pink/Black Misc. (5)

Recommendations:
Pastel Dress (8)
Black/Blue Going out (8)
Black Casual (8)

Current Outfit:
Blue with Scarf (3)

Recommendations:
Heels (8)
Pastel Shirts/Skirts (8)
Black Casual (8)



Current Outfit:
Pink/Blue Shoes/Dress Shorts (3)

Recommendations:
Black Casual (7)
Black Heavy (3)
Navy and Bags (3)

Current Outfit:
Formal Blue/Brown (5)

Recommendations:
Pastel Shirts/Skirts (9)
Black/Blue Going out (8)
Black Boots/Tights (8)

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?

- Crazy media attention!!!

New Scientist

Quartz

Tech Times

Wired, UK

Mashable

AOL News (video)

Huffington Post, UK (video)

Huffington Post, Canada

MSN, Canada

Protein

Yahoo, Canada

Science Daily

Daily Mail, UK

PSFK

Toronto Star

Gizmag

TheRecord.com

iDigitalTimes

Scientific Computing

Bustle

Harper's Bazaar

Glamour

Elle

Cosmopolitan, UK

Marie Claire

Fashion Magazine

Yahoo style

Red Magazine, UK

The Pool, UK

FashionNotes

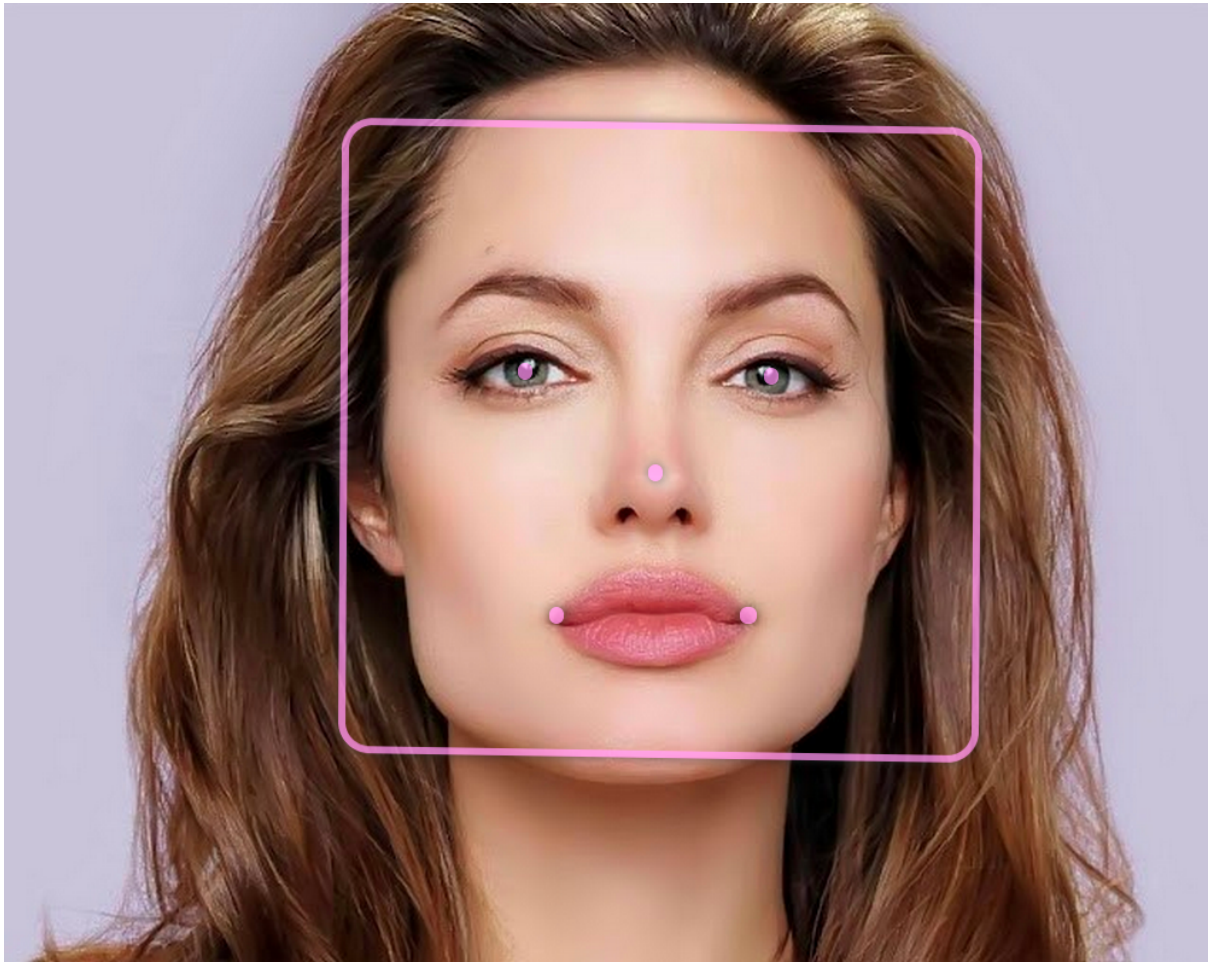
Why study Computer Vision?

- Crazy media attention!!!

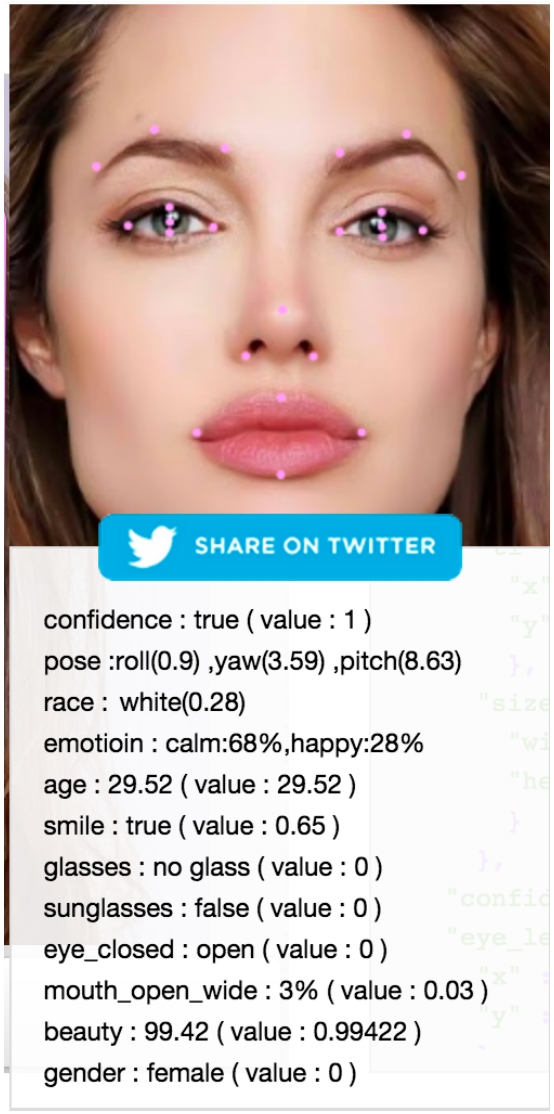
From Cosmopolitan: *The technology scores your facial attributes (this just keeps getting better, doesn't it) from your looks, to your age, and the emotion you're showing, before combining all the information* **using an equation SO complex we won't begin to go into it**.

Why study Computer Vision?

- Detect and analyze faces



http://www.rekognition.com (try it!)



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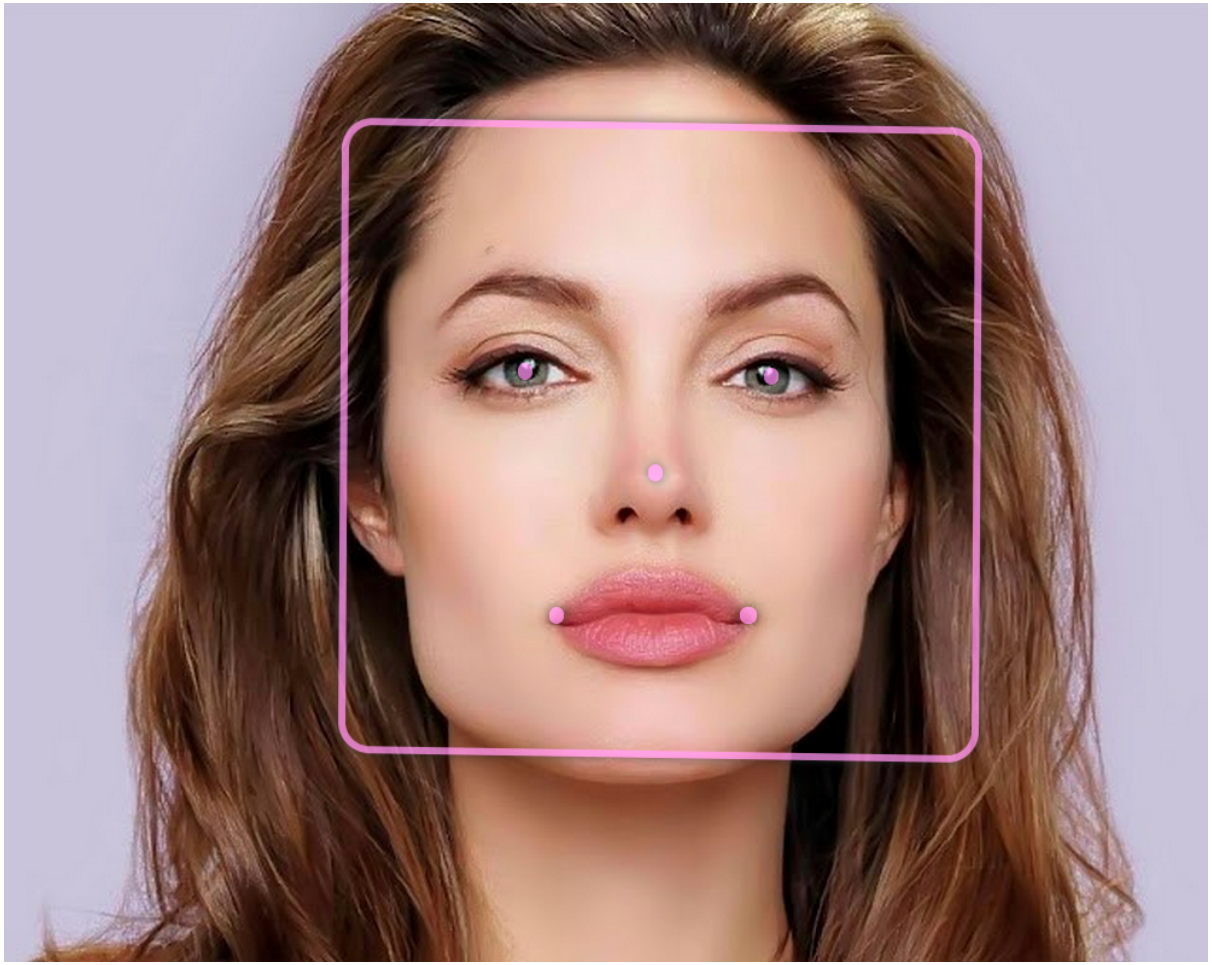

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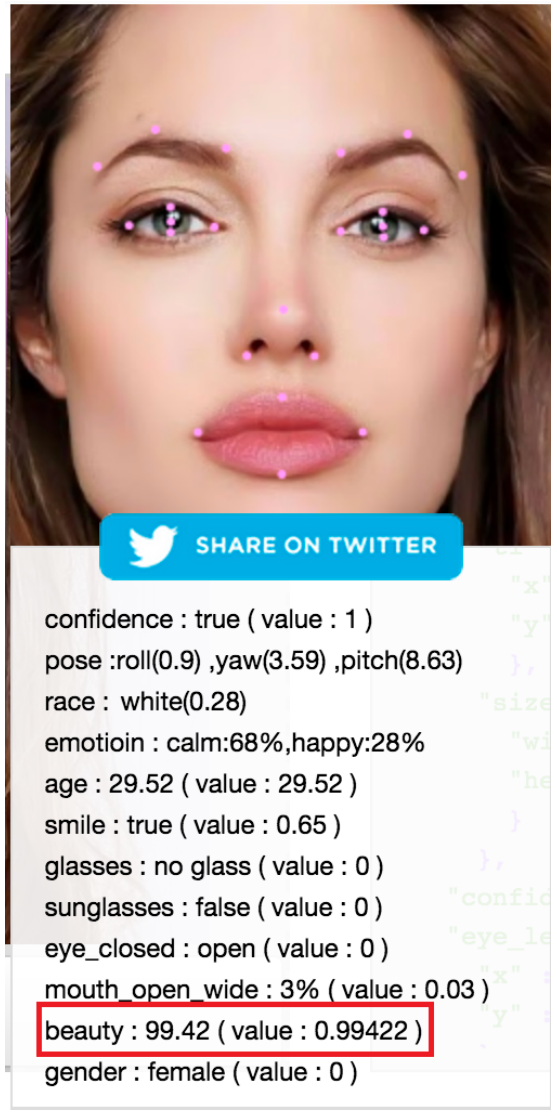

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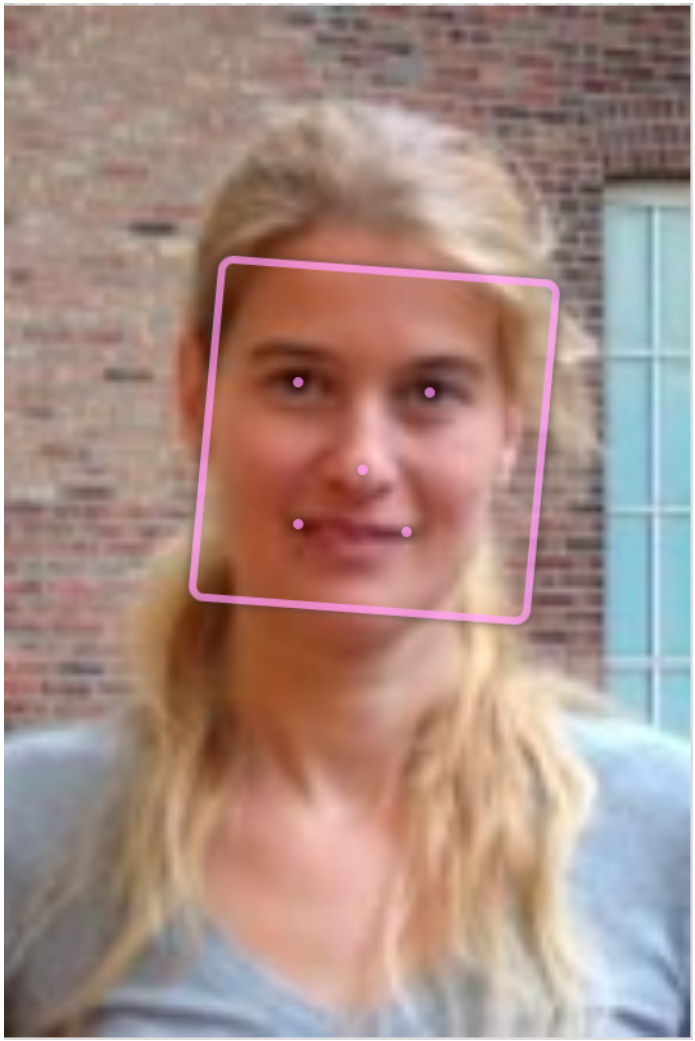

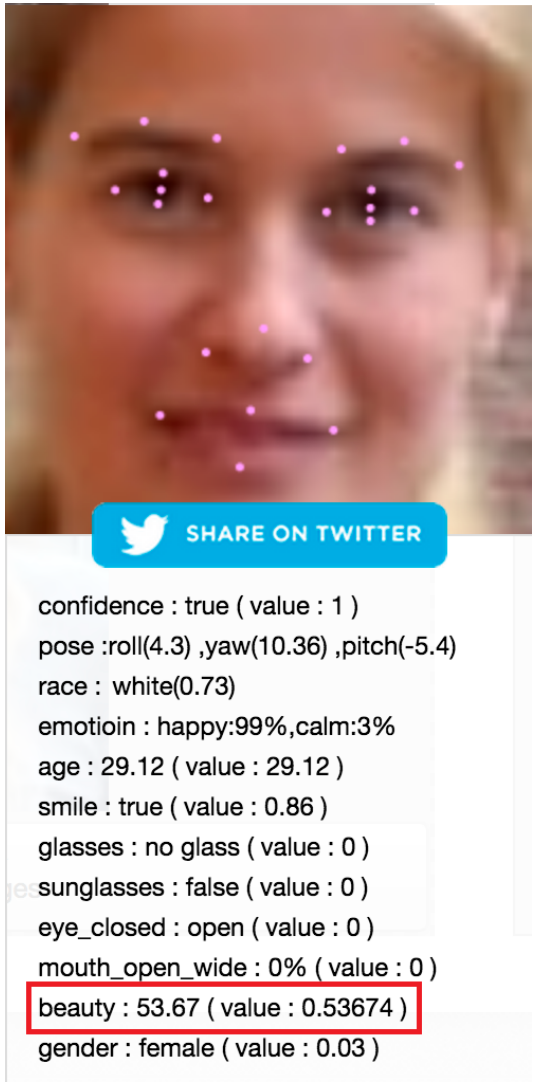

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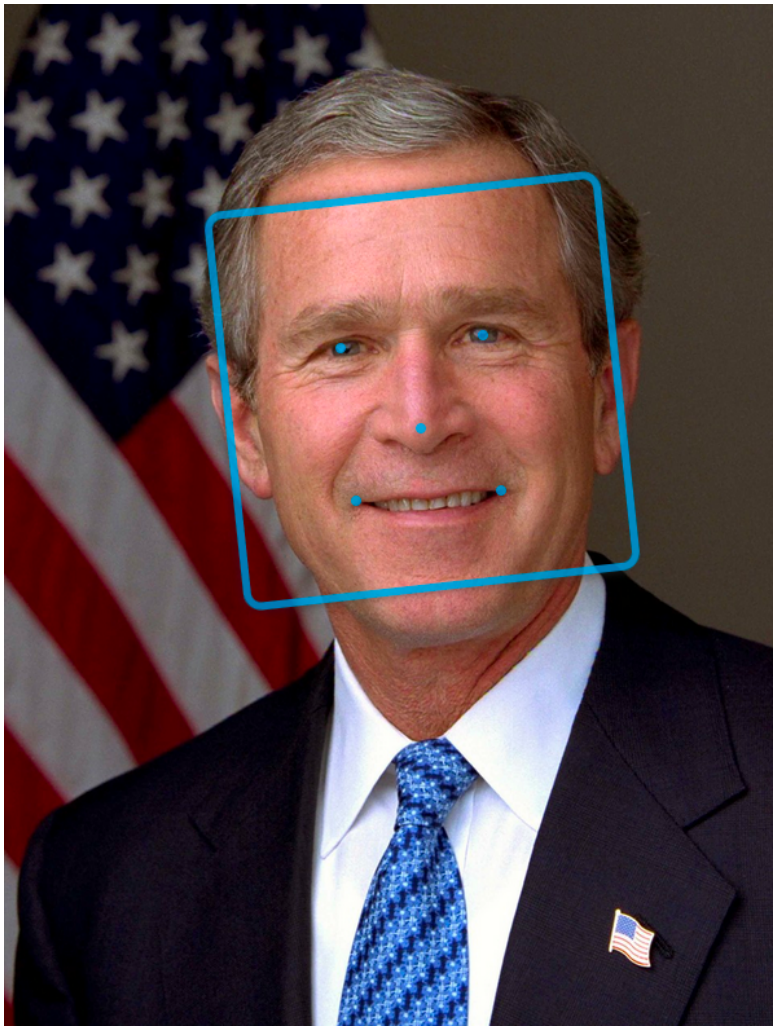
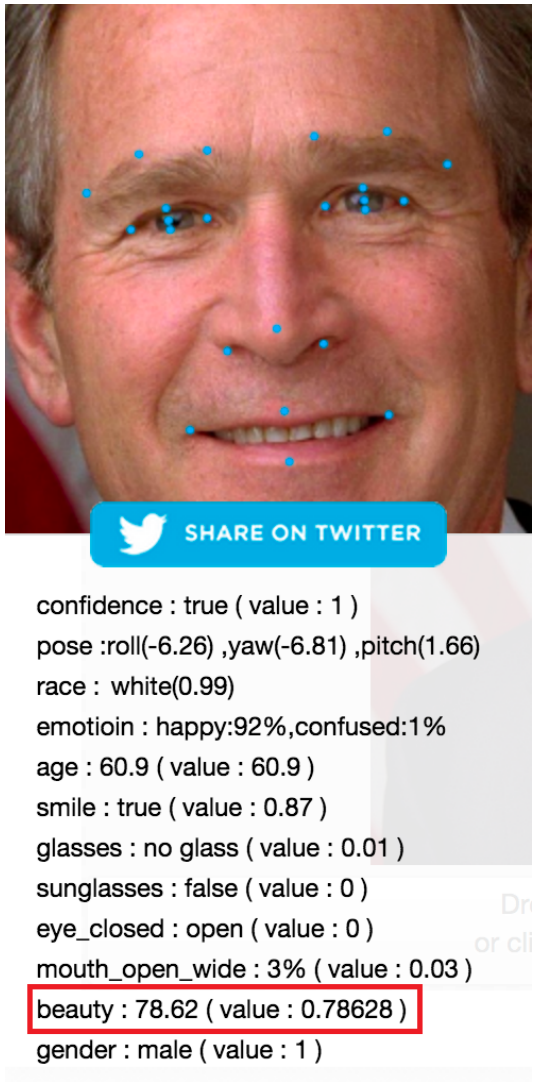
- Detect and analyze faces

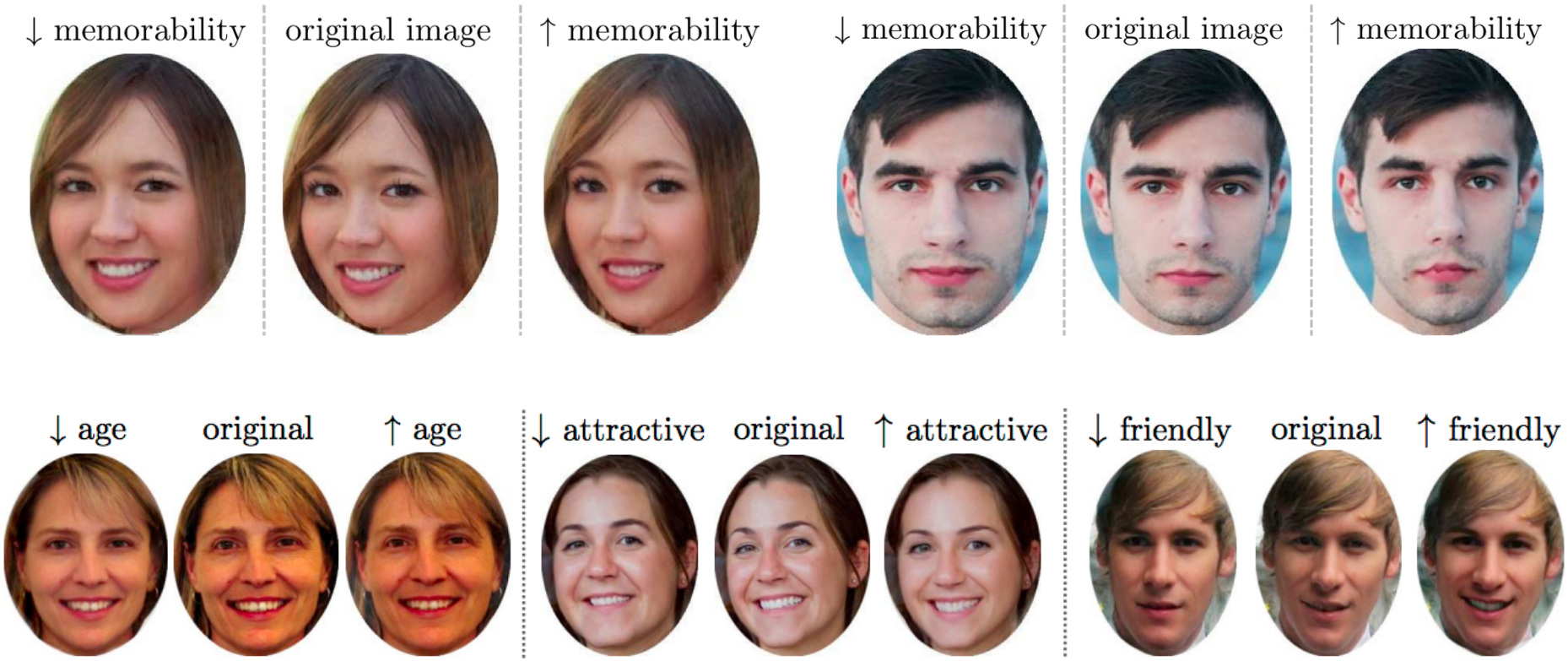




`http://www.rekognition.com` (try it!)

Why study Computer Vision?

- You can make yourself look better (and competitors worse)



[Khosla, Bainbridge, Oliva, Torralba, Modifying the Memorability of Face Photographs, ICCV 2013]

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]

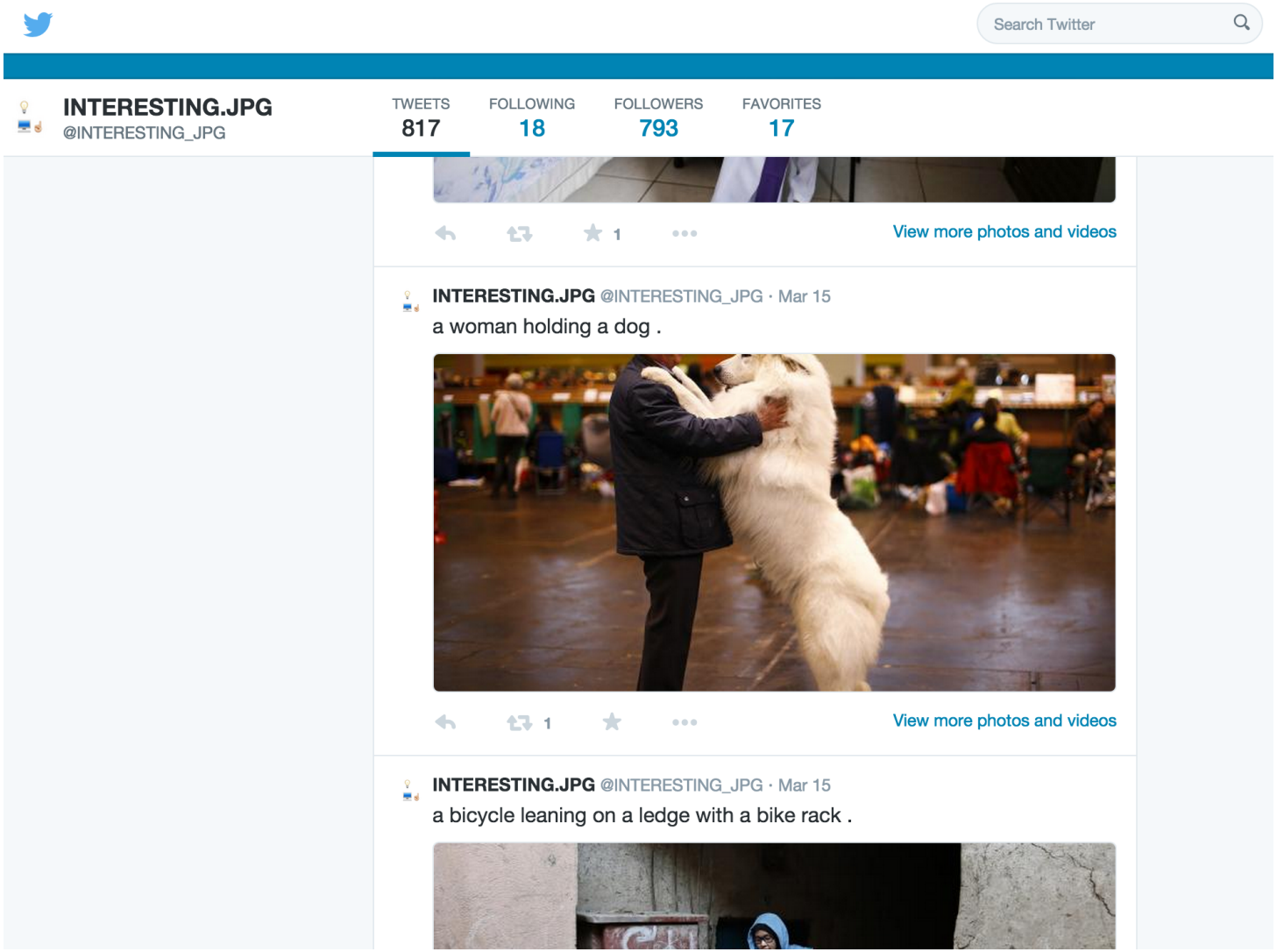
Why study Computer Vision?

- Generate image captions automatically

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

Why study Computer Vision?

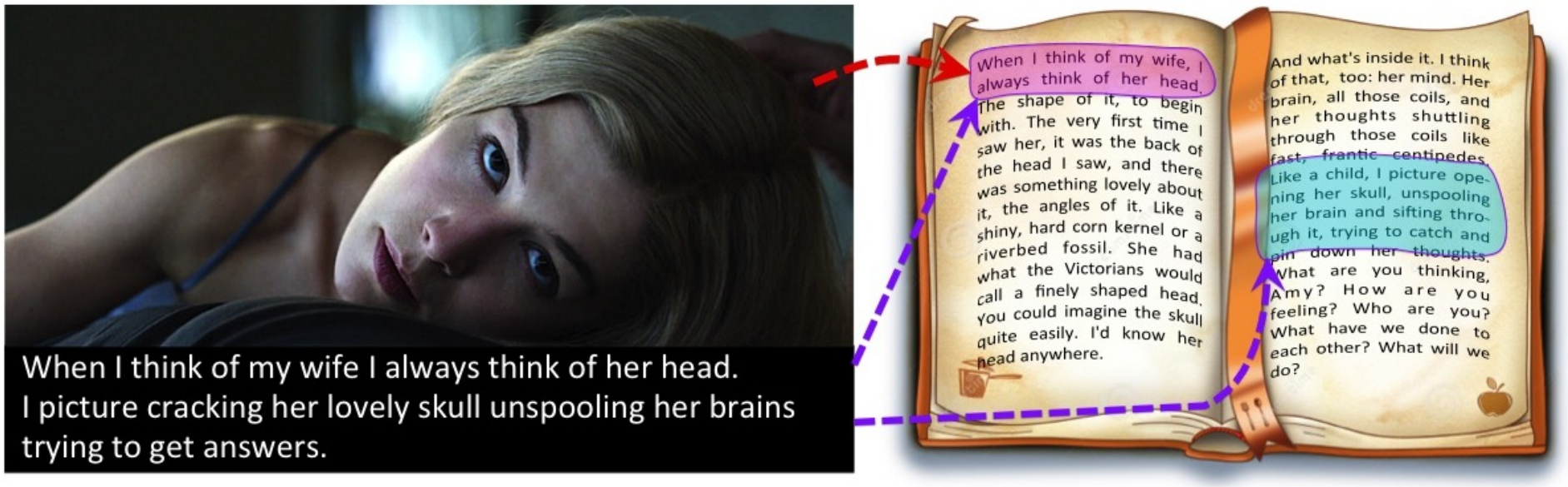
- Generate image captions automatically



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

Why study Computer Vision?

- Align movies and books



[Zhu, Kiros, Zemel, Salakhutdinov, Urtasun, Torralba, Fidler. ICCV'15.]

Why study Computer Vision?

- Have a computer do math for you

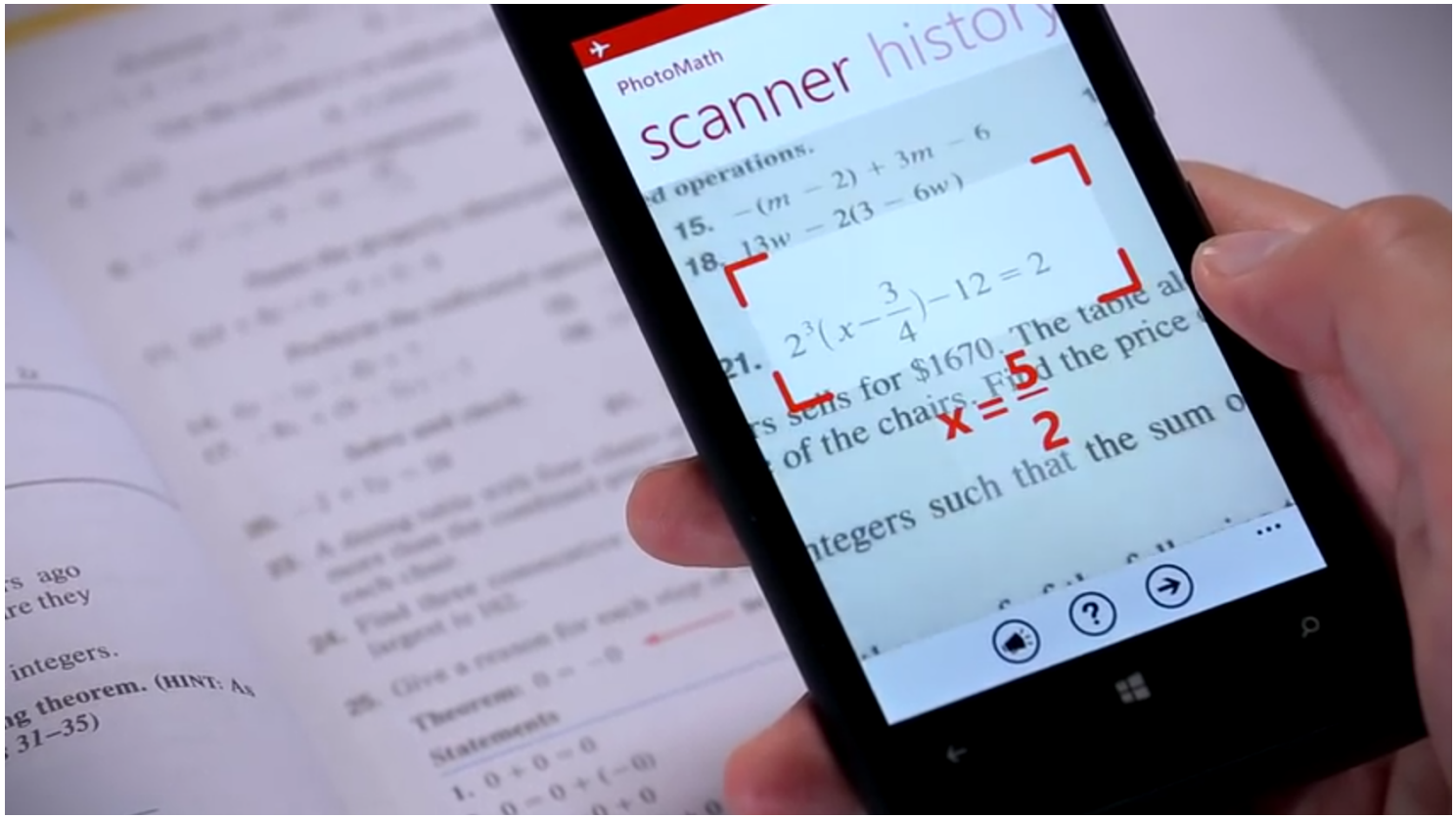
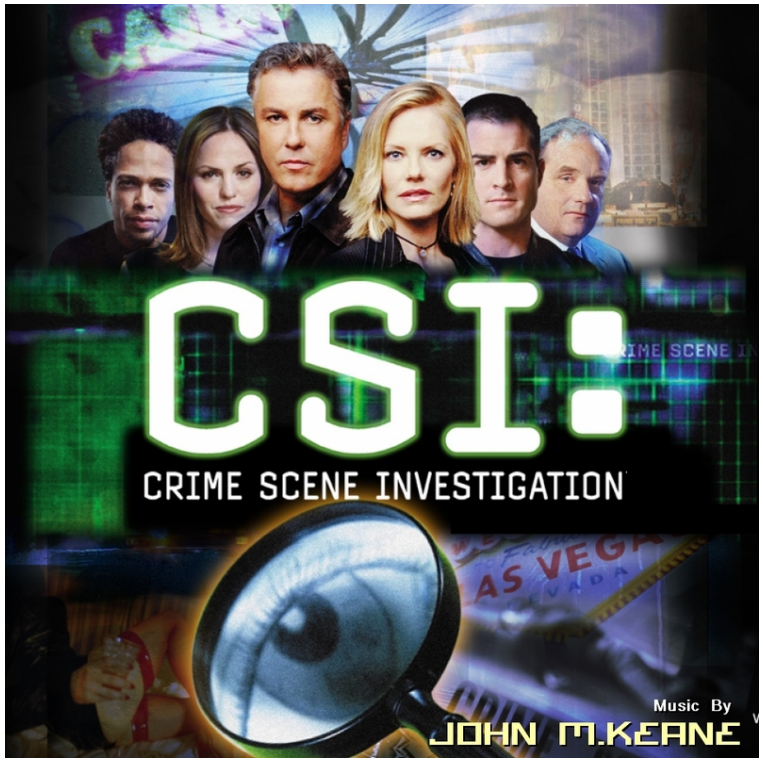
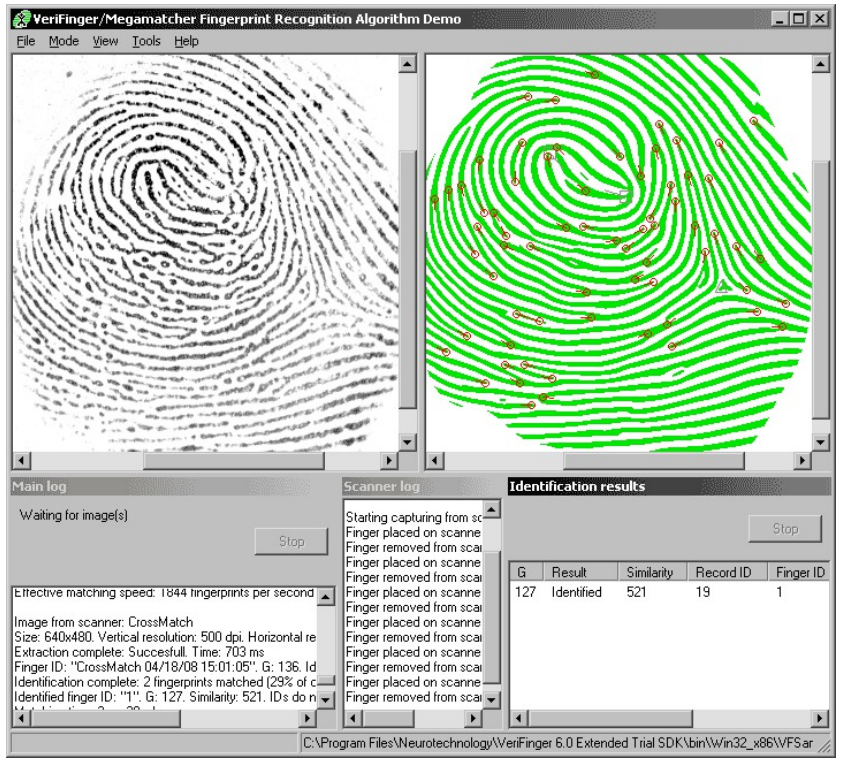


Figure: Photomath: https://photomath.net/

Why study Computer Vision?

- Fingerprint recognition





[Source: S. Lazebnik]

Why study Computer Vision?

- You can do some movie-like Forensics

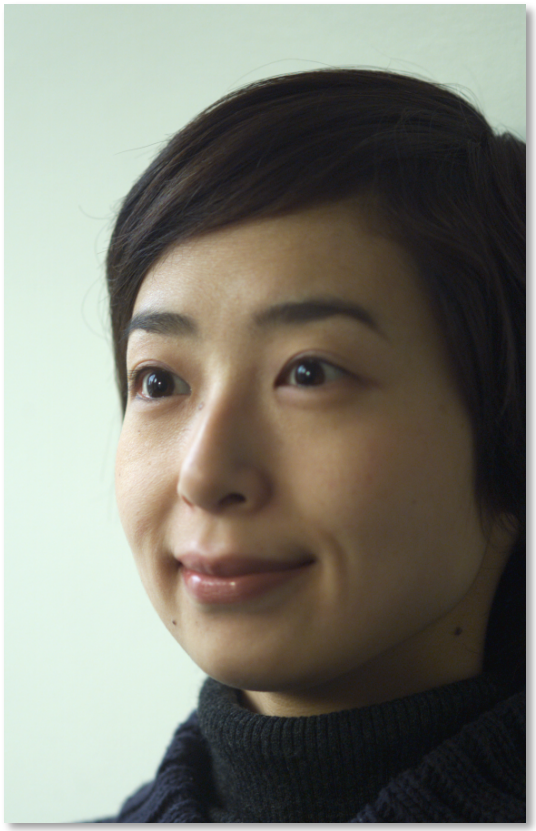


Figure: Source: Nayar and Nishino, Eyes for Relighting

[Source: N. Snavely]

Why study Computer Vision?

[Source: N. Snavely]

Why study Computer Vision?

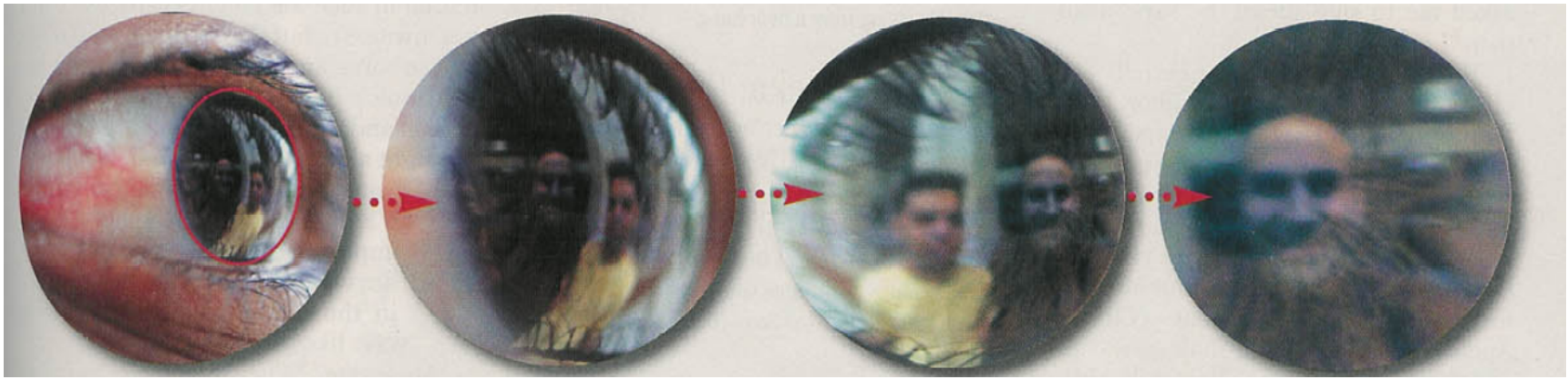


Figure: Source: Nayar and Nishino, Eyes for Relighting

[Source: N. Snavely]

Why study Computer Vision?

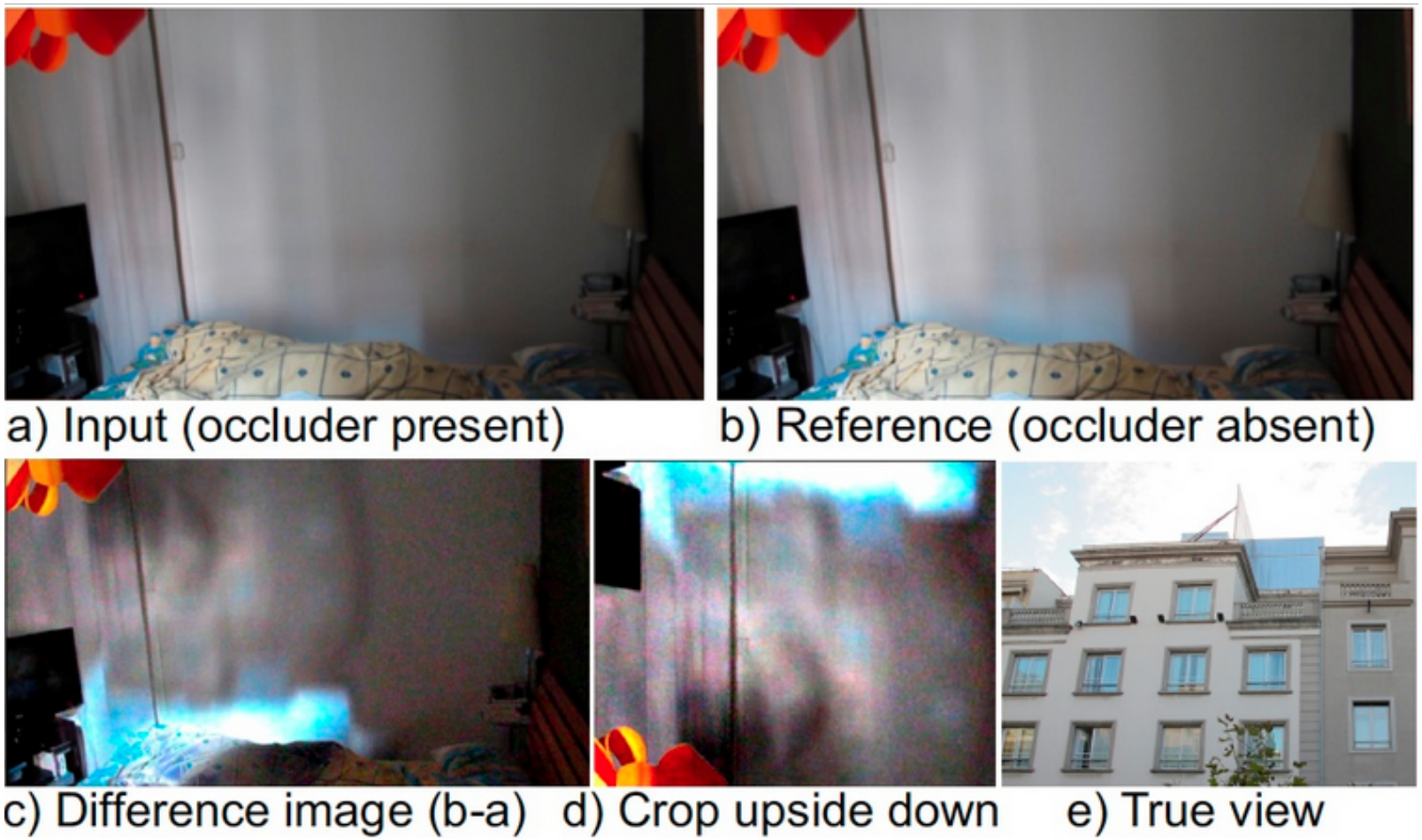
- Some more CSI

- Can you see something on the wall?

Torralba & Freeman, CVPR'12

Why study Computer Vision?

- Some more CSI



Why study Computer Vision?

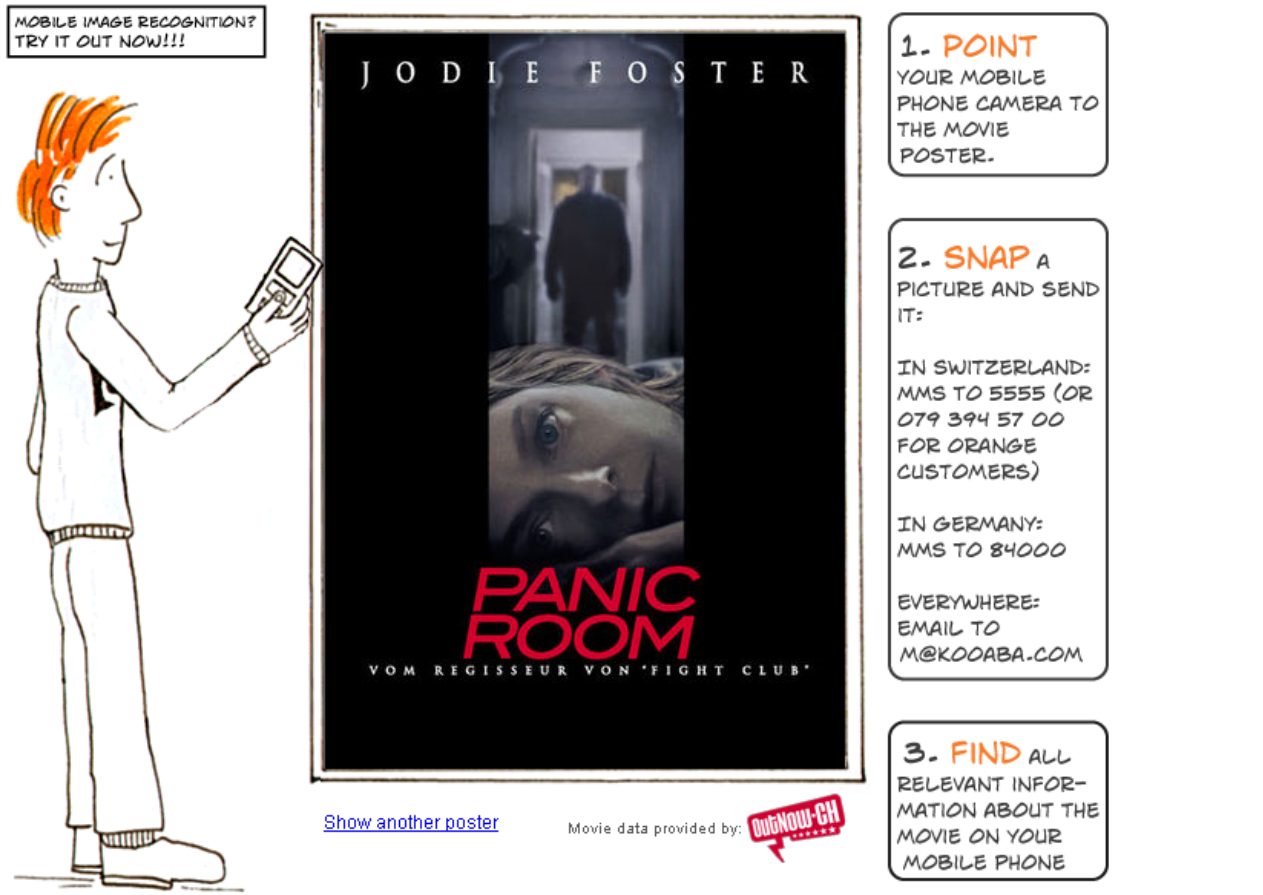
- Object recognition (in mobile phones)

[Source: S. Seitz]

Why study Computer Vision?

- Recognizing movie posters (in mobile phones)

iPhone Apps: kooaba (www.kooaba.com)



Source: S. Lazebnik

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:

The KITTI Vision Benchmark Suite
A project of Karlsruhe Institute of Technology and Toyota Technological Institute at Chicago

PASCAL2 Pattern Analysis, Statistical Modelling and Computational Learning

Car

	Method	Setting	Code	Moderate	Easy	Hard	Runtime	Environment	Compare
1	DenseBox2			89.32 %	93.94 %	79.81 %	5 s	GPU @ 2.5 Ghz (C/C++)	
2	DJML			88.79 %	91.31 %	77.73 %	x s	GPU @ 1.5 Ghz (Matlab + C/C++)	
3	3DOP			88.64 %	93.04 %	79.10 %	3s	GPU @ 2.5 Ghz (Matlab + C/C++)	

X. Chen, K. Kundu, Y. Zhu, A. Berneshawi, H. Ma, S. Fidler and R. Urtasun: 3D Object Proposals for Accurate Object Class Detection. NIPS 2015.

Cyclist

	Method	Setting	Code	Moderate	Easy	Hard	Runtime	Environment	Compare
1	3DOP			68.94 %	78.39 %	61.37 %	3s	GPU @ 2.5 Ghz (Matlab + C/C++)	

X. Chen, K. Kundu, Y. Zhu, A. Berneshawi, H. Ma, S. Fidler and R. Urtasun: 3D Object Proposals for Accurate Object Class Detection. NIPS 2015.

2	Regionlets			58.72 %	70.41 %	51.83 %	1 s	>8 cores @ 2.5 Ghz (C/C++)	

X. Wang, M. Yang, S. Zhu and Y. Lin: Regionlets for Generic Object Detection. International Conference on Computer Vision 2013.
C. Long, X. Wang, G. Hua, M. Yang and Y. Lin: Accurate Object Detection with Location Relaxation and Regionlets Relocalization. Asian Conference on Computer Vision 2014.

3	MV-RGBD-RF			42.61 %	52.97 %	37.42 %	4 s	4 cores @ 2.5 Ghz (C/C++)	

A. Gonzalez, G. Villalonga, J. Xu, D. Vazquez, J. Amores and A. Lopez: Multiview Random Forest of Local Experts Combining RGB and LIDAR data for Pedestrian Detection. IEEE Intelligent Vehicles Symposium (IV) 2015.

		mean	aero plane	bicycle	bird	boat	bottle	bus	car	cat	chair	cow	dining table	dog	horse	motor bike	person	potted plant	sheep	sofa	train	tv/ monitor	submission date
▶	Fast R-CNN + YOLO [?]	70.8	82.7	77.7	74.3	59.1	47.1	78.0	73.1	89.2	49.6	74.3	55.9	87.4	79.8	82.2	75.3	43.1	71.4	67.8	81.9	65.6	05-Jun-2015
▷	Fast R-CNN VGG16 extra data [?]	68.8	82.0	77.8	71.6	55.3	42.4	77.3	71.7	89.3	44.5	72.1	53.7	87.7	80.0	82.5	72.7	36.6	68.7	65.4	81.1	62.7	18-Apr-2015
▷	segDeepM [?]	67.2	82.3	75.2	67.1	50.7	49.8	71.1	69.6	88.2	42.5	71.2	50.0	85.7	76.6	81.8	69.3	41.5	71.9	62.2	73.2	64.6	29-Jan-2015
▷	BabyLearning [?]	63.8	77.7	73.8	62.3	48.8	45.4	67.3	67.0	80.3	41.3	70.8	49.7	79.5	74.7	78.6	64.5	36.0	69.9	55.7	70.4	61.7	12-Nov-2014

50 years and thousands of PhDs later...

- Algorithms work **pretty** well
- Still some embarrassing mistakes...
- The general vision problem is not yet solved

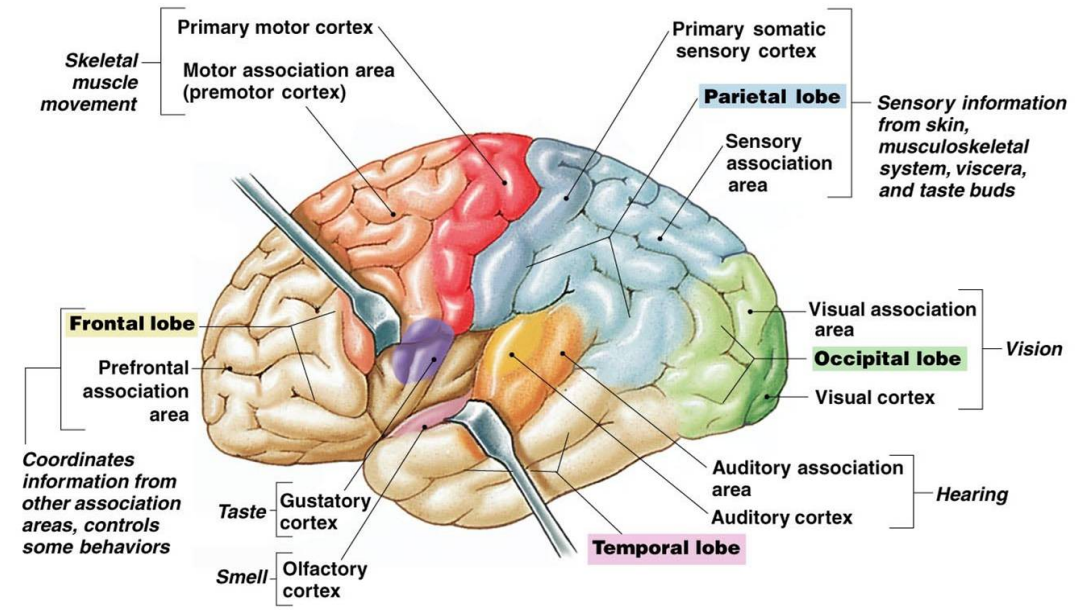
Where pink means "person"

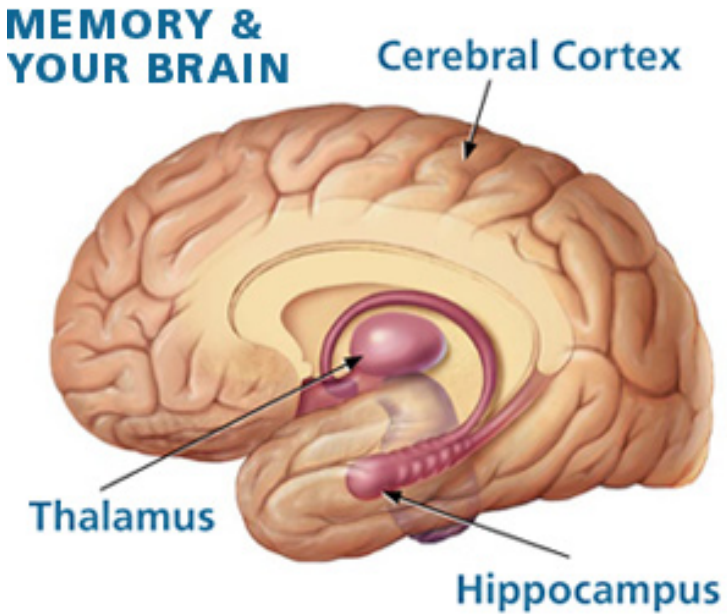
[This pic is from 2014]

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!

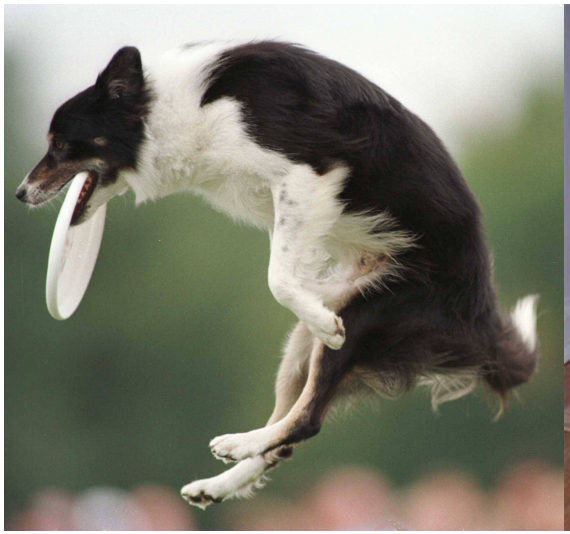




Why is vision hard?

All this is dog...

[slide adopted from: R. Urtasun]



Why is vision hard?

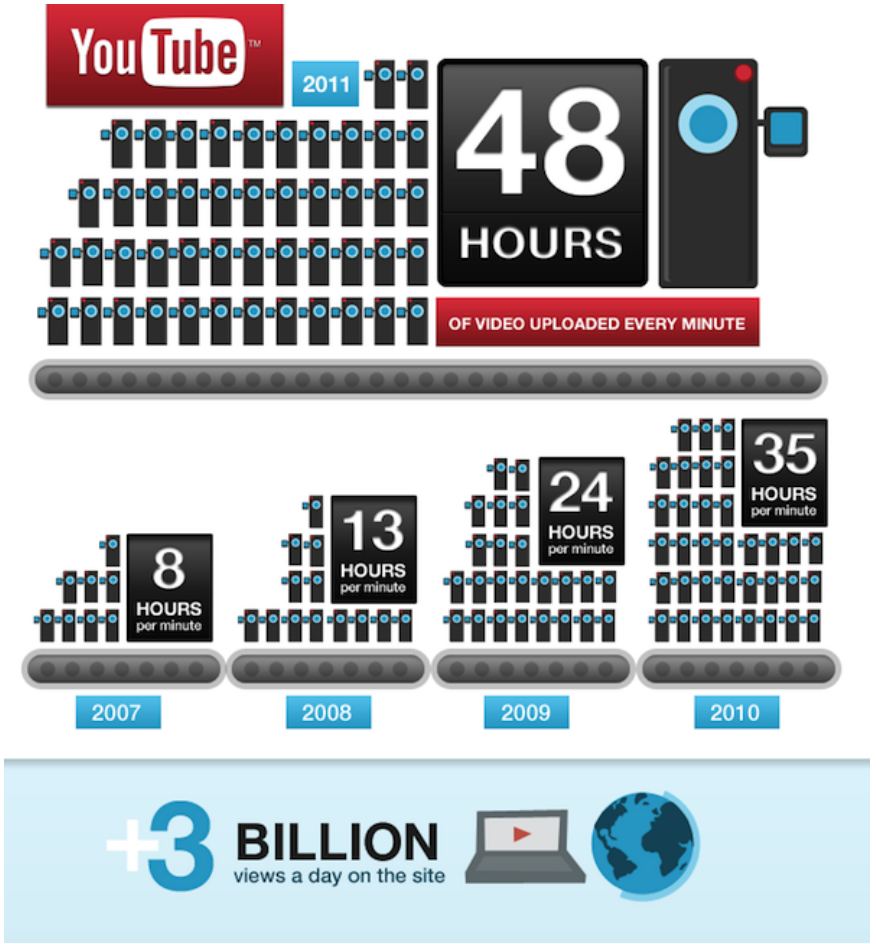
Biederman, 1987

[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]

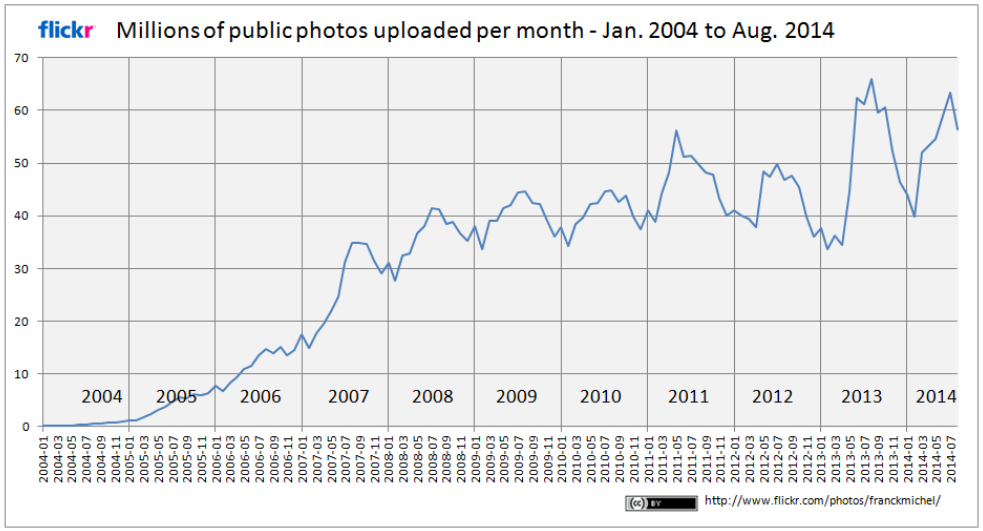


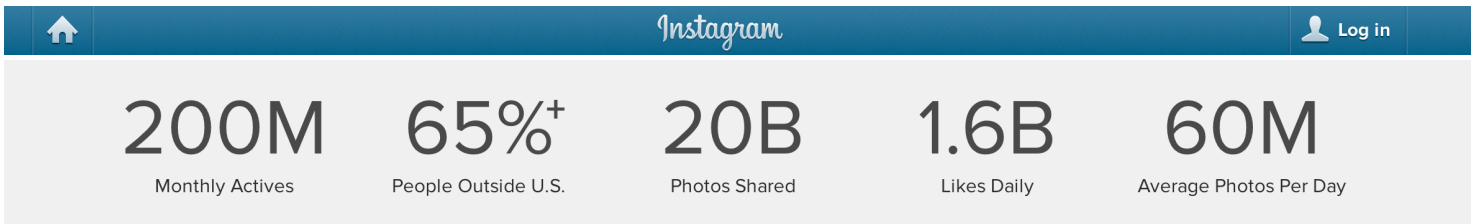
Why is vision hard?

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]

How many photos are uploaded to Flickr every day, month, year?





Exploit so Much Data!

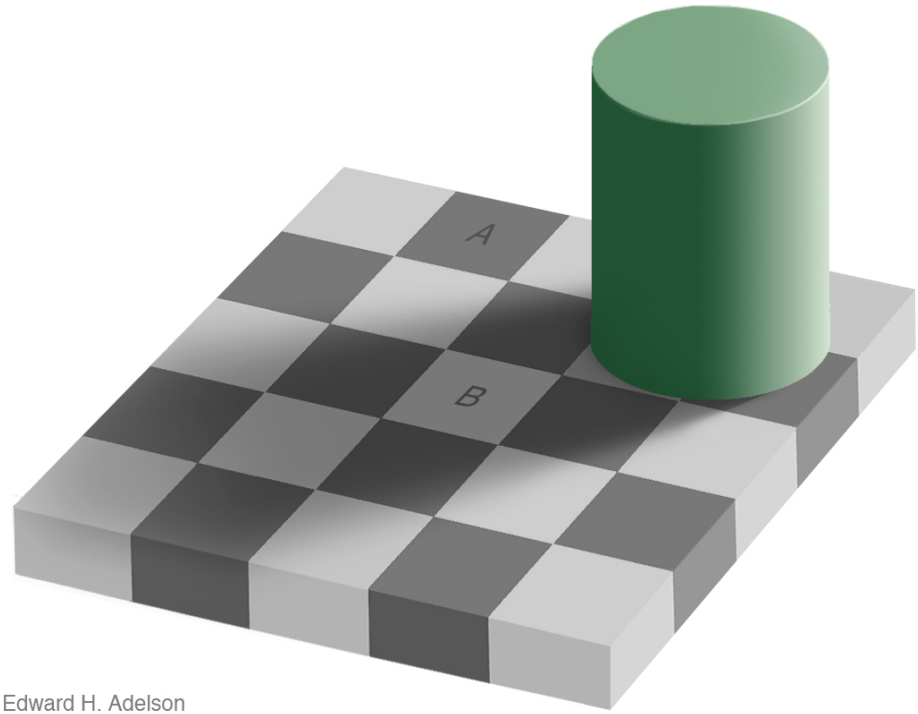
Figure: Vemodalen: The Fear That Everything Has Already Been Done

[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?

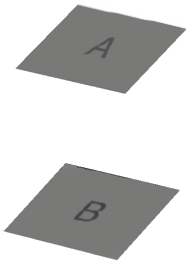


Edward H. Adelson

- Which square is lighter, A or B?

[Slide credit: A. Torralba]

How good are humans?



Edward H. Adelson

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[Slide credit: A. Torralba]

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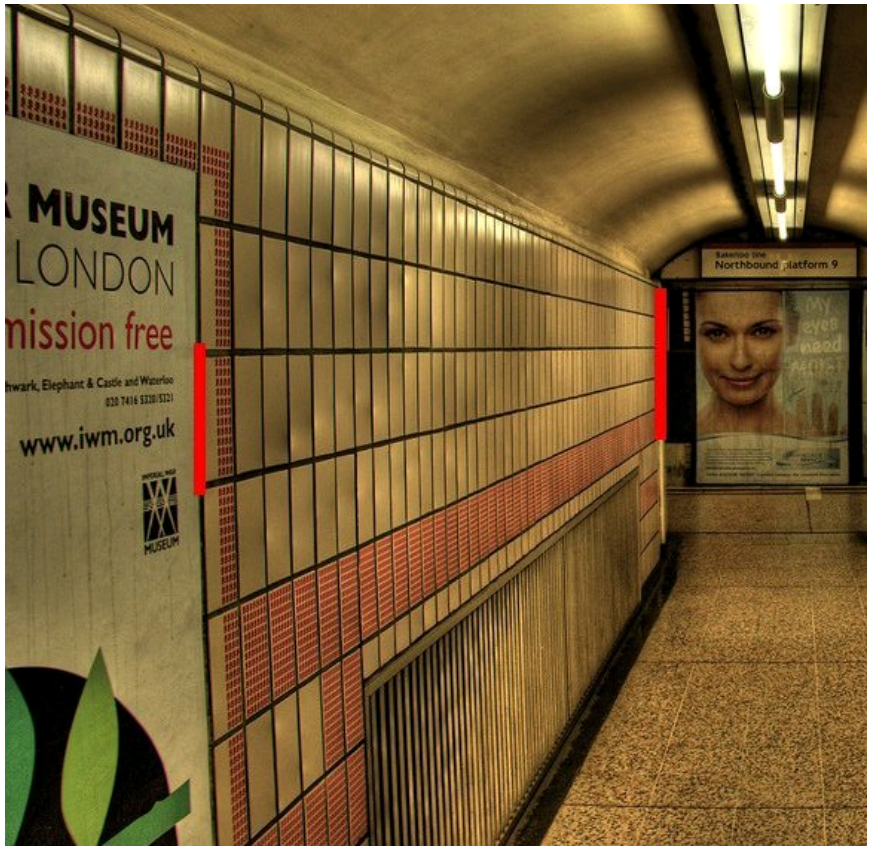

Figure: 2006 Walt Anthony

- Which red line is longer?

[Slide credit: A. Torralba]

How good are humans?

Figure: 2006 Walt Anthony

- Which red line is longer?

[Slide credit: A. Torralba]

How good are humans?

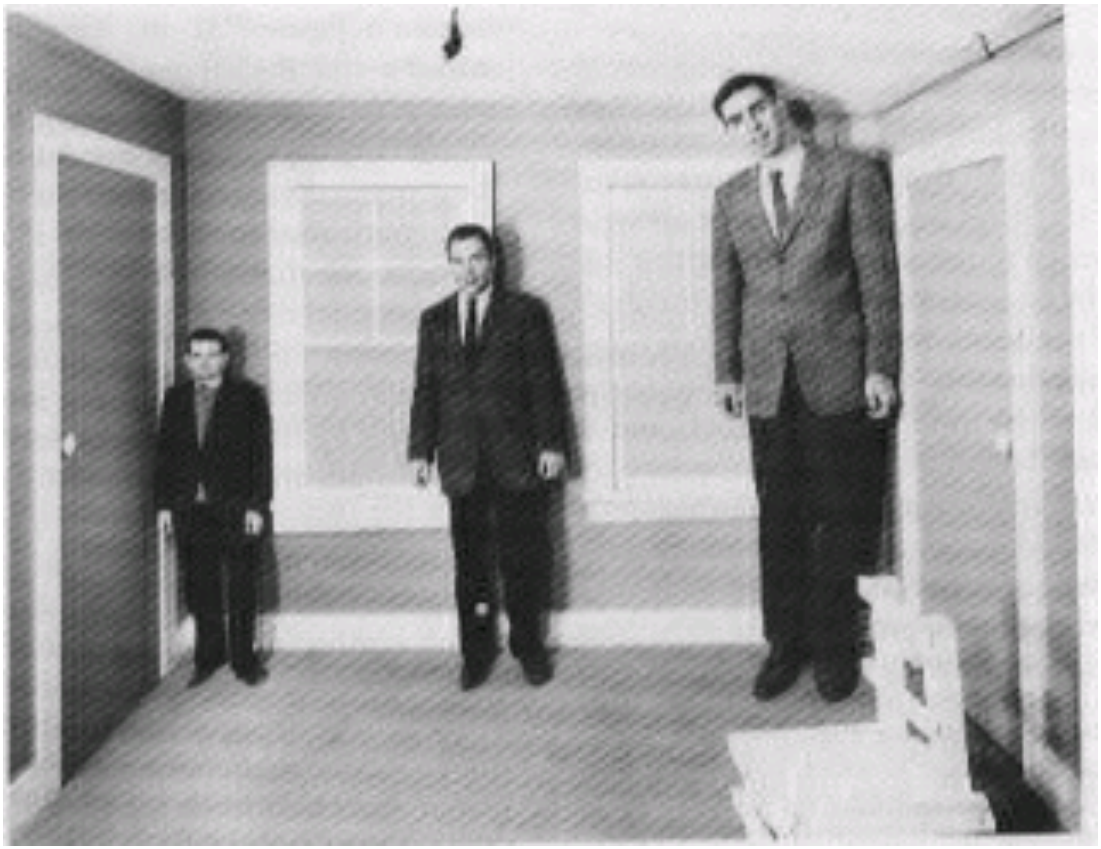

Figure: Ames room

- Assumptions can be wrong

[Slide credit: A. Torralba]

How good are humans?

Figure: Chabris & Simons

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

How good are humans?

Figure: Simons et al. (more videos here: `http://www.perceptionweb.com/misc.cgi?id=p3104`)

- Is something happening in the picture?

How good are humans?

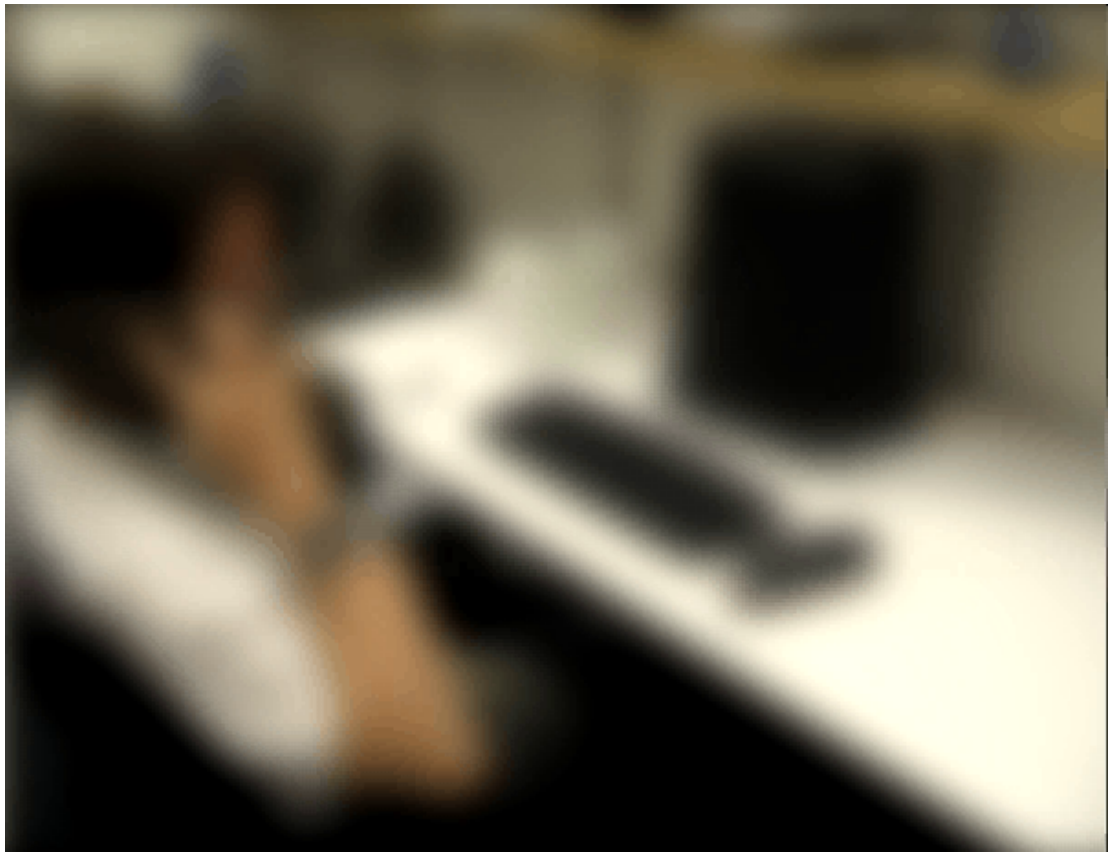

Figure: Torralba et al.

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

How good are humans?

Figure: Torralba et al.

- 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?

- Some math knowledge
- Good programming skills
- Imagination
- Even better intuition
- Lots of persistence
- Some luck always helps