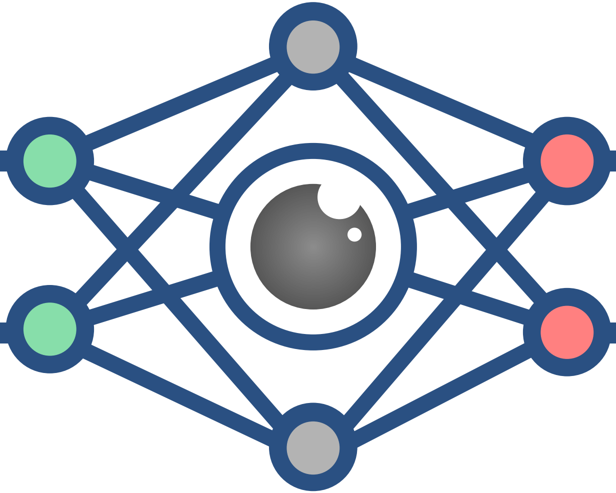
CS3485

Deep Learning for Computer Vision



Lec 1: Introduction to Computer Vision

Course Staff

- **Instructor**: Jeova Farias Sales Rocha Neto (can call me Jeova or Prof. Farias)
  - Email: j.farias@bowdoin.edu
  - Office Hours: Tues & Thurs 4:30-5:30pm at Searles 122 (or by appointment or **just come by!**)
  - Research interests:
    - Statistical Machine Learning and Optimization,
    - Image Processing and Computer Vision.
    - More recently: Unsupervised Deep Learning.

Contact me if you are interested in research in the field!

- **Learning Assistant**: Brian Liu
  - Email: bliu@bowdoin.edu
  - LA Hours: TBD

Learning Objectives

- At of the course, the students are expected to:
    a. Understand what **Computer Vision** is and how it's been applied in the industry and academia.
    b. Know what neural networks are and how that led to the development of **Deep Learning**.
    c. Have a concise knowledge of how Deep Learning has developed over the years and the problems it brought solutions to.
    d. Have enough working skills on **PyTorch** to developer Deep Learning applications for, and more broadly than, Computer Vision.
    e. Be able to read and understand the **recent literature** in Deep Learning and Computer Vision and present their content to a wider audience.

What you can expect from this course

- You can expect **organized lectures and assignments**. (*OBS*: Some lectures may not cover the whole 1.5 hours).
- I expect you to participate in our **in-class activities** and be kind to your peers' questions.
- Prerequisites:
  - In this course, we'll use **math** in some classes, especially calculus and linear algebra, so I assume you understand these math basics.
  - However, more importantly: **feel free to ask questions about these topics!** It's ok if you forgot some of these things or never learned them well. I'll try my best not to help you on them too.
- We'll go through the very basics of Deep Learning, so, for those who may already know some stuff: **be patient** (and also contribute to the class, if possible).
- Some classes will **have faster pace** than others. Let me know if they are too fast, tho!
- Most modern Deep Learning literature **is still being written**, and it is not concise, so We may use for different sources other than the textbook as we go.

Hardware for Deep Learning

- One big disadvantage when doing/teaching Deep Learning: it requires expensive hardware, i.e., Graphics Processing Units (GPUs).
- **Google Colab** is an option for codes in class, homeworks and your final project:
  - Uses Python notebooks (`.ipynb`).
  - It is free for anyone with a GDrive account,
  - Provides GPUs for us to run our codes on,
- *One problem*: in the free accounts, it may stop providing GPU access after a lot of usage on it.
- We can also use Bowdoin's HPC, but we'll leave it only for projects, for now.
- If you are interested in using it anyway, I'll write the instructions on how to.

Google Colaboratory

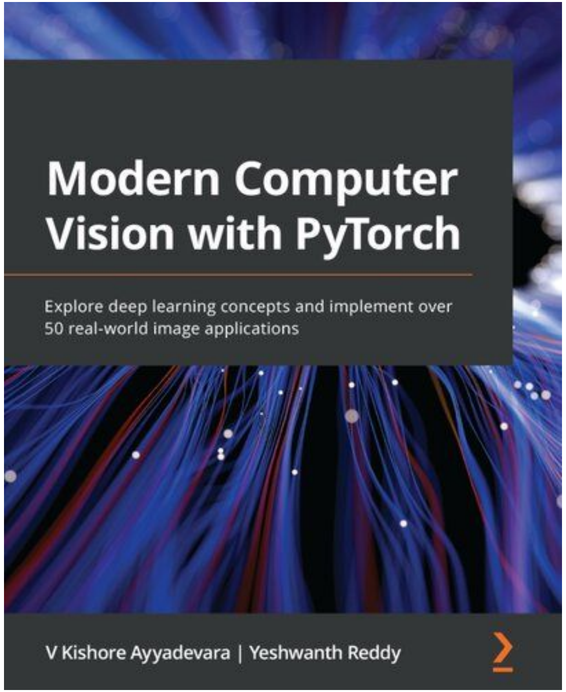
Textbook

- It is hard to find a textbook for this course: the field changes **extremely fast**.
- However, the book we will most use in this course is:

Modern Computer Vision with PyTorch, by V Kishore Ayyadevara and Yeshwanth Reddy. Packt Publishing Ltd, 2020.

It's not an academic book, more like a "hands-on" learning material.

- Most of the code will be inspired from it.
- For the theory, use the slides + (potential) papers I'll send to you.



Our Website

- We have a website for our course! It's jeovafarias.github.io/Bowdoin-CS3485.
- In it, you shall find:
  - The lecture slides + useful code and papers we discuss in each class;
  - The links to the assignment instructions (their submission will still be via Canvas)
  - The schedule of lectures, exams, breaks and review sessions;
  - Info on the final project.
  - The course syllabus and other materials.
- Despite having a website, we **will use canvas** for some activities.

Final grade

- **Labs (30 %):**
  - An **assignment** released every Thursday, 6-7 total, every 1-2 weeks.
  - You'll be given **4 late days for the semester** (budget your days wisely)
  - Deliverables will be reports **in Latex** (or else, for 80% of the grade), starting from Lab 2. Suggestion: Use Overleaf for starting off with Latex.
  - (*Tentative*) Students will pair-up in each lab and deliverable. *I may change this strategy later*.
- **Quizzes (30 %):**
  - Well have weekly quizzes, taking place on the last 15 min of our Thursday classes, starting next week. Check our schedule for more details.
- **Final Project (30 %):**
  - **Theme**: (1) an new application or model that uses deep learning **or** (2) a review of two or more papers with code **or** (3) an complete piece of software that uses AI in some manner
  - **Deliverables**: a **proposal**, code and presentation. Teams of 2-4 people.
- **Participation (10 %)**

Conferences

- This semester I'll be attending and presenting my research in two computer vision conferences:
  - SIBIGRAPI: from Set 30th - Oct 3rd in Manaus/Brazil
  - ICIP: from Oct 27-30 in Abu-Dhabi/UAE
- For the weeks when the conferences we'll follow the original plan as schedule **moving things online** as appropriate.
- Later, I'll follow up with how quizzes will work out on those weeks.

After Thanksgiving

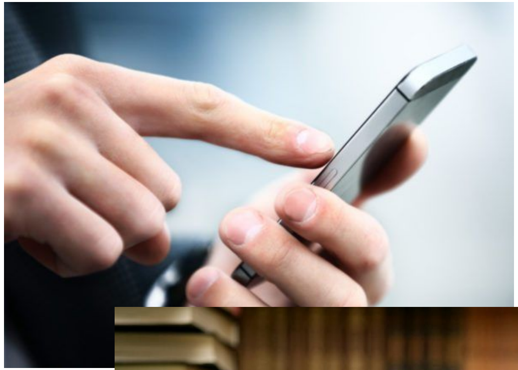
- There won't be any of my lectures after Thanksgiving. Instead I hope to:
  - Have guest lecturers from the industry and academia.
  - Have you guys focus on your final projects.
- In those days, attendance is **mandatory** and it will count towards your participation grade.

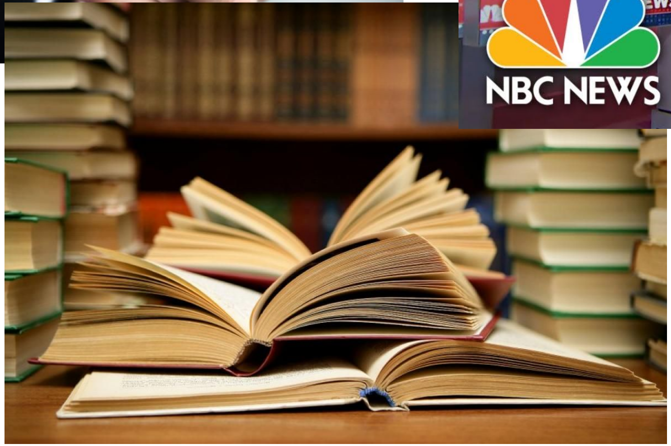
11/21/2024 Thursday	**Final Quiz**	All the material covered **during the whole course** may show up. It will be 3-4x longer than the usual quiz.
11/26/2024 Tuesday	**THANKSGING BREAK!!**	No lecture.
11/28/2024 Thursday	**THANKSGING BREAK!!**	No lecture.
12/03/2024 Tuesday	**Guest No. 1**	Mandatory student presence.
12/05/2024 Thursday	**Guest No. 2**	Mandatory student presence.
12/10/2024 Tuesday	Work on final projects.	No lecture. Students will work on final projects. Mandatory student presence. Instructor will be there to help students out with their projects!
12/12/2024 Thursday	Work on final projects.	No lecture. Students will work on final projects. Mandatory student presence. Instructor will be there to help students out with their projects!

Final Thoughts

- **What else counts as participation?**
  - **Asking** and **answering** questions in class (very important!)
  - Actively participating in in-class activities.
  - Attending office hours.
  - Sending me emails with questions, etc.
  - Basically, if **I can see that you are actively making effort to learn the content,** you'll get those 10%.
- The lectures will be primarily **in person**, but I can live stream them if *any student* (even if just one) needs it (just let me know a few hours before it).
- The all of this info (as a PDF) is on our **Syllabus**.
  - **Make sure to read it! It is our rule book here.**
  - The website also has this data.

Let's get started: Data and the modern world





A DAY IN DATA

The exponential growth of data is undisputed, but the numbers behind this explosion – fuelled by internet of things and the use of connected devcies – are hard to comprehend, particularly when looked at in the context of one day

500m

tweets are sent every day

Twitter

4PB

of data created by Facebook, including

350m photos

100m hours of video watch time

Facebook Research

294bn

billion emails are sent

Radicati Group

320bn

emails to be sent each day by 2021

306bn

emails to be sent each day by 2020

3.9bn

people use emails

4TB

of data produced by a connected car

Intel

DEMYSTIFIYING DATA UNITS

From the more familiar 'bit' or 'megabyte', larger units of measurement are more frequently being used to explain the masses of data

Unit		Value	Size
b	bit	0 or 1	1/8 of a byte
B	byte	8 bits	1 byte
KB	kilobyte	1,000 bytes	1,000 bytes
MB	megabyte	$1,000^2$ bytes	1,000,000 bytes
GB	gigabyte	$1,000^3$ bytes	1,000,000,000 bytes
TB	terabyte	$1,000^4$ bytes	1,000,000,000,000 bytes
PB	petabyte	$1,000^5$ bytes	1,000,000,000,000,000 bytes
EB	exabyte	$1,000^6$ bytes	1,000,000,000,000,000,000 bytes
ZB	zettabyte	$1,000^7$ bytes	1,000,000,000,000,000,000,000 bytes
YB	yottabyte	$1,000^8$ bytes	1,000,000,000,000,000,000,000,000 bytes

*A lowercase "b" is used as an abbreviation for bits, while an uppercase "B" represents bytes.

65bn

messages sent over WhatsApp and two billion minutes of voice and video calls made

Facebook

463EB

of data will be created every day by 2025

IDC

95m

photos and videos are shared on Instagram

Instagram Business

Searches made a day — 5bn

Searches made a day from Google — 3.5bn

Smart insights

28PB

to be generated from wearable devices by 2020

Statista

ACCUMULATED DIGITAL UNIVERSE OF DATA

2013	2020
4.4ZB	44ZB

PwC

RACONTEUR

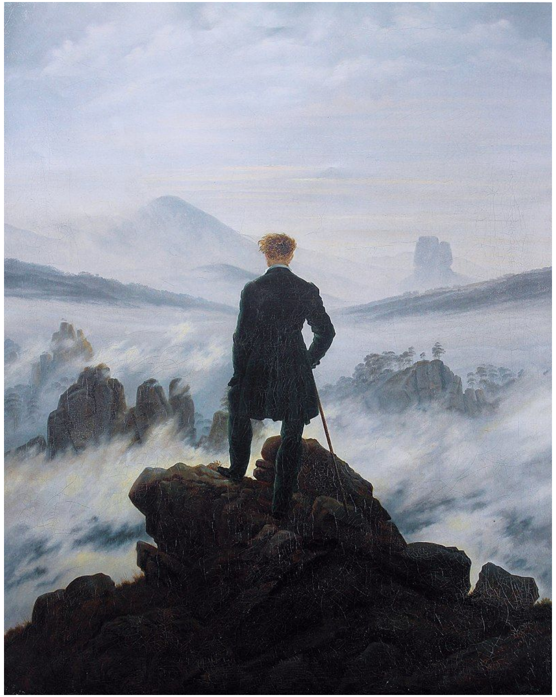
The richest data

- Arguably, the visual data (image and videos) is the **richest** among all types of data!
- In a simple image, we have have so much information:

1. A couple is drinking wine during the day.
2. The man has a beard, long hair and is wearing a white shirt.
3. The woman also has long hair and is wearing a typical French cap.
4. They seem in love with each other.

What else?

- The visual data is so rich that we perceive **up to 80%** of all impressions by means of our sight.
- **The vision system is our main door to the world!**

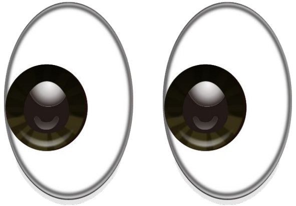


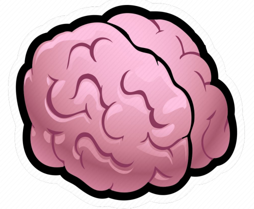
Caspar David Friedrich's *Wanderer above the Sea of Fog* (1817)

(Oversimplified) Vision pipeline

- In simple terms, our visual system proceeds as following when it sees an image:

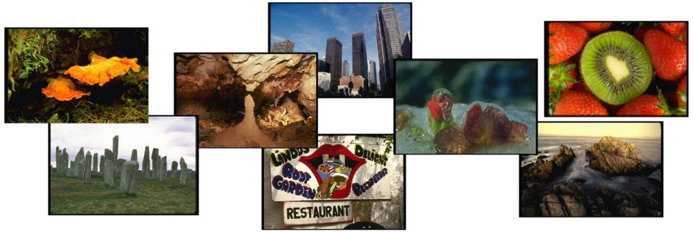
Image (or video) → **Sensing device** → **Interpreting device** → **Interpretation**





"A baby and a cat being extremely adorable"

- And it works very well: on average, we only need 150ms to detect whether there is an animal in a picture!



Computer Vision

- As Computer Scientists, we aim to do **Computer Vision**:

Computer Vision (CV) is the study of how computers can gain high-level understanding from **visual data**, such as images and videos.

- Here, we seek to **understand and automate** tasks proper to the human visual system.
- Our *desire* pipeline is:

Image (or video) → Sensing device → Interpreting device → Interpretation

"A baby and a cat being extremely adorable"

- Computer Vision is then about **finding the right algorithms** for the interpreting device.

Easy peasy

- At first, Computer Vision seems like an easy problem to solve: “*we humans do it so easily since we were children*”!
- It seemed so easy that its study started with an MIT **undergraduate summer project** in 1966.
- The goal was very “modest”: find a model that rightly mimics our visual system.
- Unfortunately (or fortunately!) vision is a much harder problem to solve, and one summer wasn’t enough time.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
PROJECT MAC

Artificial Intelligence Group July 7, 1966
Vision Memo. No. 100.

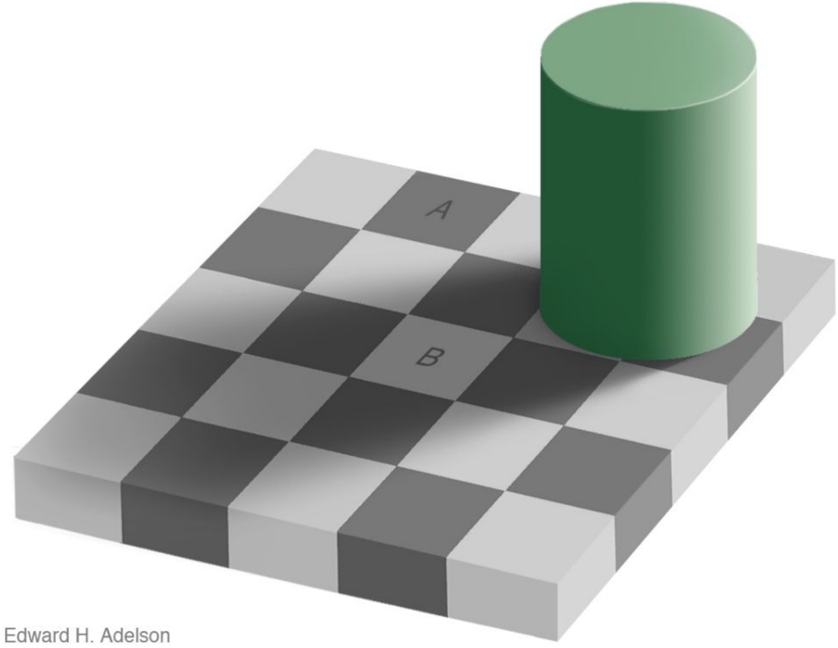
THE SUMMER VISION PROJECT

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".

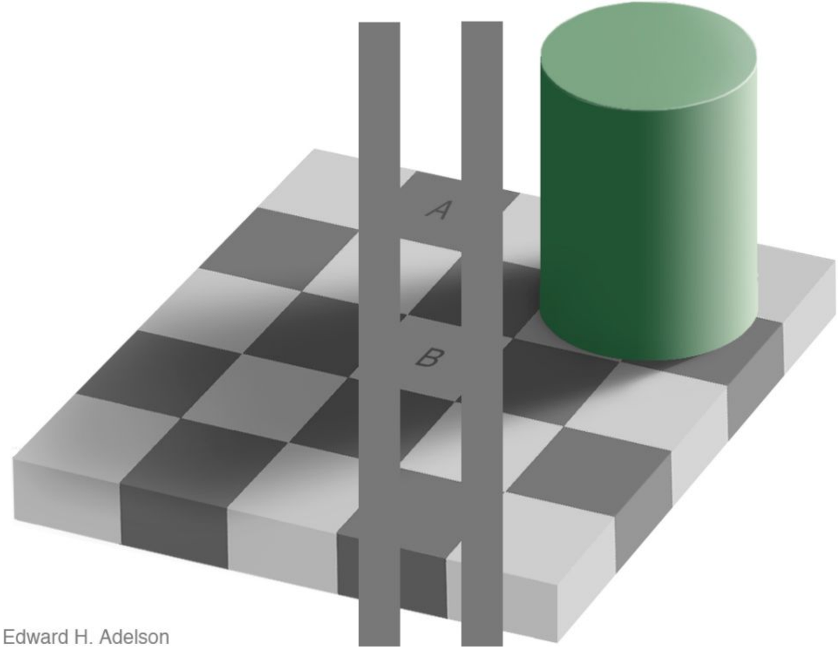
Example of why vision is complicated

- Which region is darker in the image below, A or B?



Example of why vision is complicated

- Believe it or not, but A and B are of the same shade of gray!

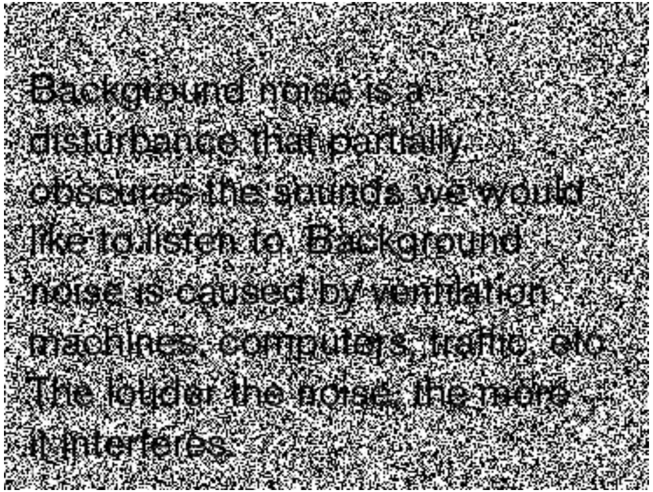


Exercise (*In pairs*)

- Answer the questions for the following images:

How many objects are there in this image?

Which object is the largest? What color is the sky?



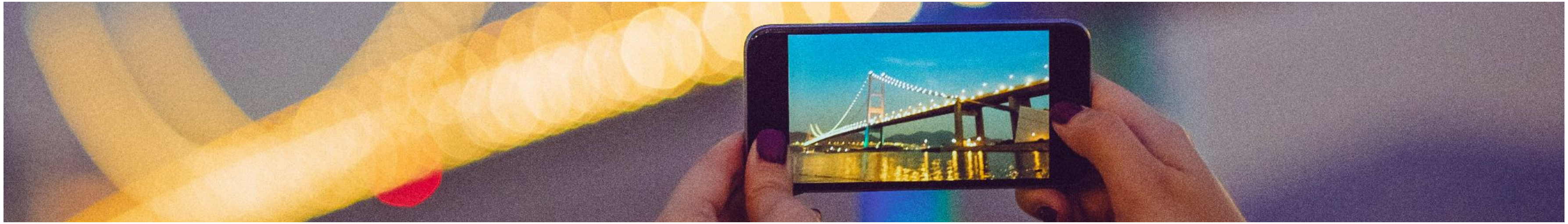
What is written in the above image?

Why vision is complicated

- Computer Vision is hard for many reasons, like:
  - **Our visual system is limited in some tasks**:
    - Our vision is prone to illusions that lead to misinterpretation of certain phenomena.
    - That raises the question of whether we want to necessarily mimic it using CV.
  - **Many vision problems are ambiguous**:
    - There is usually not an objective solution for some problems, as they may depend on human subjective reasoning.
    - That makes the modeling of those problems harder.
  - **Images remove important aspects of the observed scene:**
    - Usually the distance from the camera to the objects is unavailable, making the distance between the objects in a scene look wrong.
    - Also, some color information may not match to what the real scene's colors are.
  - **The sensing device is imperfect, and the images are noisy:**
    - It is usually impossible to capture a real world scene without adding noise to it.

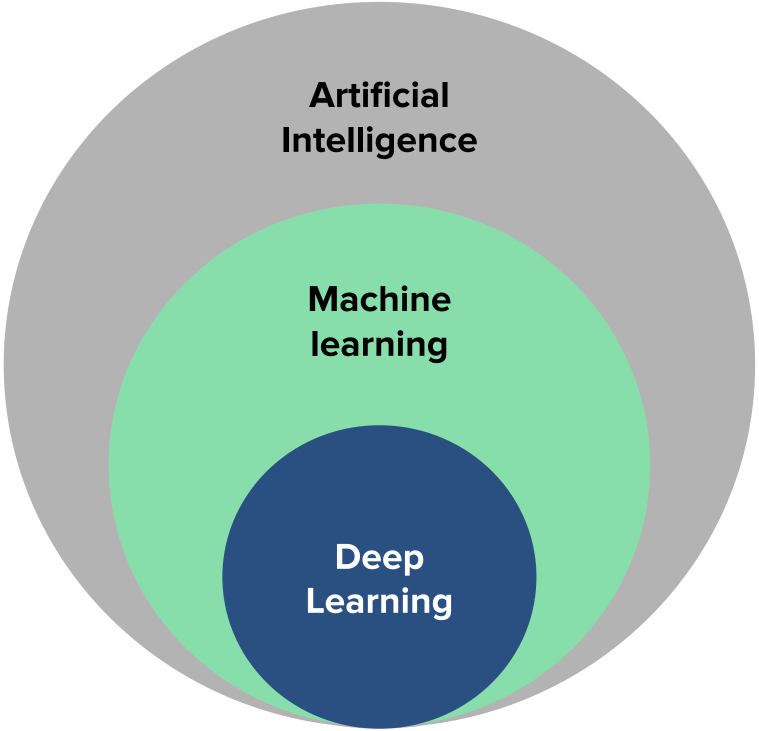
Why is Computer Vision so Important Now

- Despite these issues, technology is progressed at an exponential pace and computer vision solutions found numerous applications in modern society.
- This is due to the following factors:
  - **Computing Power**: Hardware designed for computer vision has become cheaper, faster, better and easily accessible.
  - **Big Data**: Availability of large training data sets due to mobile technology with built-in cameras saturating the world with photos and videos
  - **Open Source**: Availability of new algorithmic frameworks that can take advantage of hardware and software capabilities



Deep Learning and Computer Vision

- Largely, the great success of Computer Vision is due to recent use of **Deep Learning** as an “algorithmic framework” (the interpreting device).
- Based on Neural Networks, it a **supervised machine learning model** inspired by the way the brain propagates information.
- It was initially mainly used for image classification, it has been extended to **regression** and even **unsupervised tasks**.
- In fact, it has been extended to solve problems way beyond Computer Vision!



Deep Learning in the news

Deep learning helps predict traffic crashes before they happen

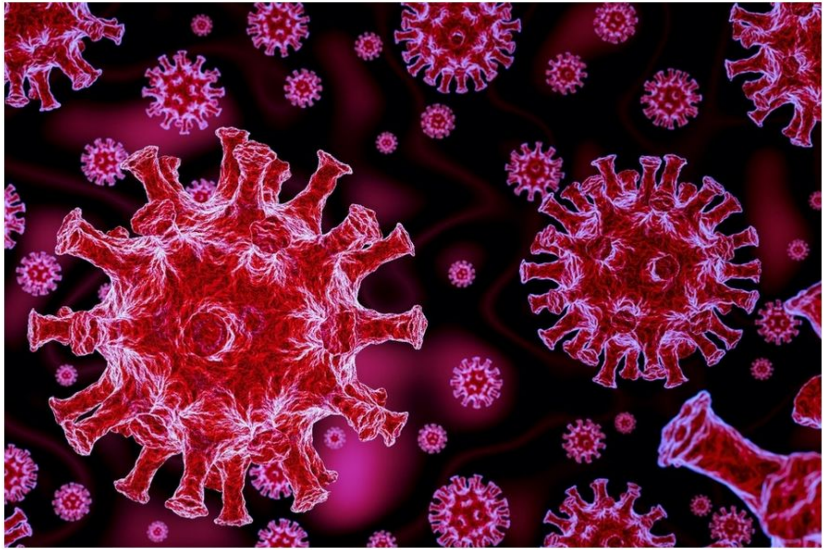
A deep model was trained on historical crash data, road maps, satellite imagery, and GPS to enable high-resolution crash maps that could lead to safer roads.

Rachel Gordon | MIT CSAIL
October 12, 2021

Deep learning helps predict new drug combinations to fight Covid-19

Neural network identifies synergistic drug blends for treating viruses like SARS-CoV-2.

Rachel Gordon | MIT CSAIL
September 24, 2021



Deep Learning in the news

Deep learning of quantum entanglement from incomplete measurements

DOMINIK KOUTNÝ, LAIA GINÉS, MAGDALENA MOCZAŁA-DUSANOWSKA, SVEN HÖFLING, CHRISTIAN SCHNEIDER, ANA PREDOJEVIĆ, AND MIROSLAV JEŽEK Authors Info & Affiliations

SCIENCE ADVANCES • 19 Jul 2023 • Vol 9, Issue 29 • DOI: 10.1126/sciadv.add7131

Machine learning refines earthquake detection capabilities

New methodology enables the detection of ground deformation automatically at a global scale

Date: November 11, 2021

Study finds ChatGPT boosts worker productivity for some writing tasks

A new report by MIT researchers highlights the potential of generative AI to help workers with certain writing assignments.

Zach Winn | MIT News Office
July 14, 2023

OCTOBER 27, 2021

Discovering exoplanets using artificial intelligence

by University of Geneva

How to do Deep Learning

- Over the years, many libraries in Python were implemented for developing applications using deep learning.
- Currently, the most famous ones (both open-sourced) are:

Tensorflow

- Created in 2015 by Google Brain department (Version 2.0 launched in 2019).
- Steep learning curve.
- Usually used in pair with Keras, an easy interface for it
- Large community, many tutorials.
- Use to be DL's main library.

Pytorch

- Developed in 2016 by Facebook's AI Research lab.
- Based on a library called Torch, written in Lua,
- Highly "Pythonic", easy to learn.
- Gives you more control.
- Small (but growing) community.
- Research preferable library.

- In our course, we'll use **PyTorch**, and we'll have a lecture solely on it.

Applications of Computer Vision

- **Shopping** will never be the same without Computer Vision!

Cashierless Shopping

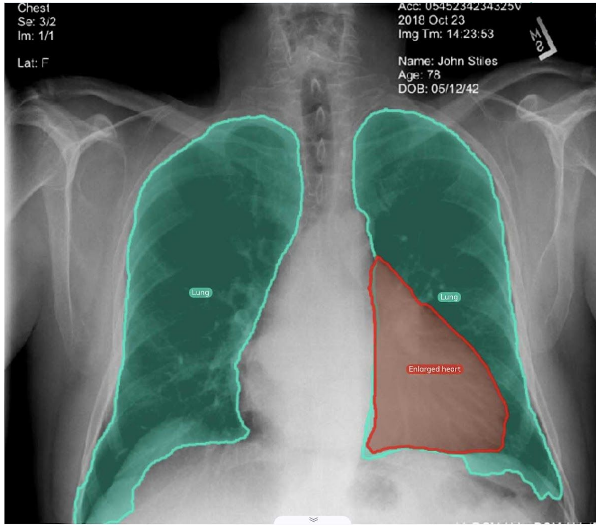
Customer tracking and Flow

Gaze detection

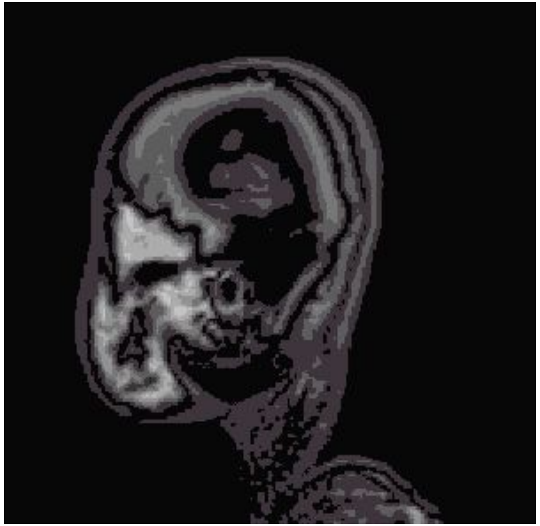
Applications of Computer Vision

- Without the Computer Vision, **healthcare** professionals would forced to spend hours manually analyzing patient data.

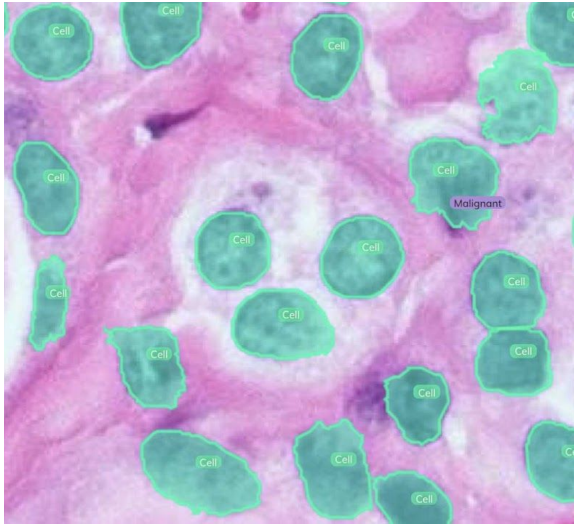
X-Ray image segmentation



MRI understanding



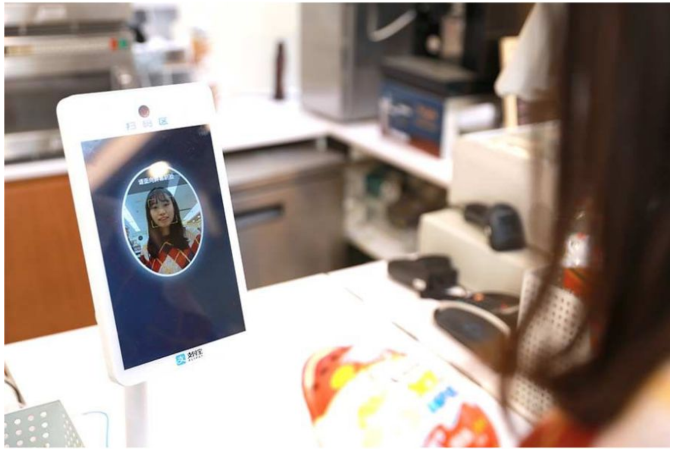
Pathology detection

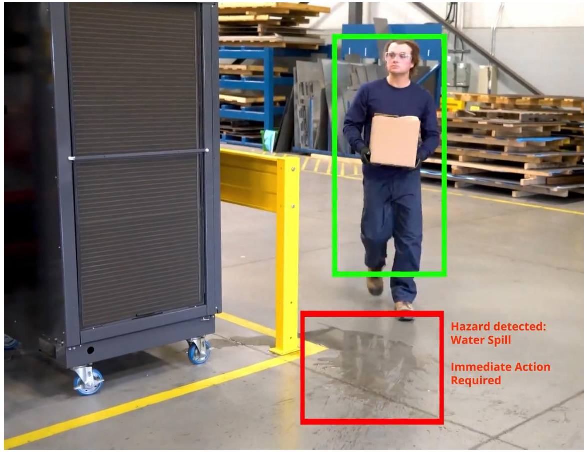


Applications of Computer Vision

- Computer vision enables many possibilities in **security and surveillance**!

Face Recognition	Hazard Detection	Crowd Counting/Control



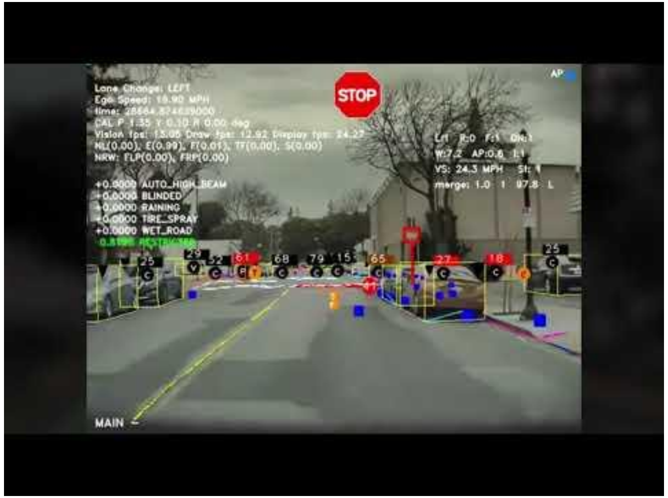


- Good news for public safety: helping police and first responders more easily spot crimes and accidents.

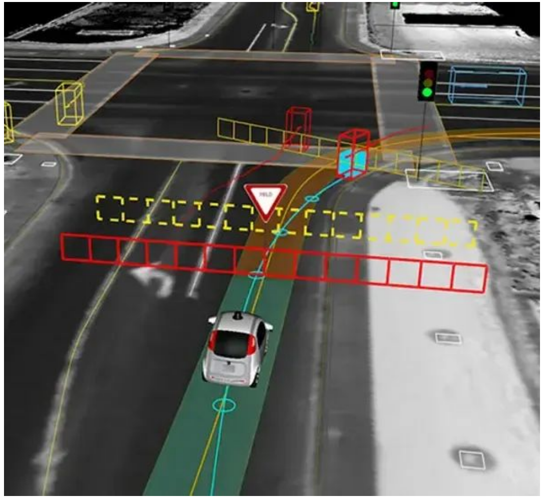
Applications of Computer Vision

- The future of **self-driving cars** depends on Computer Vision:

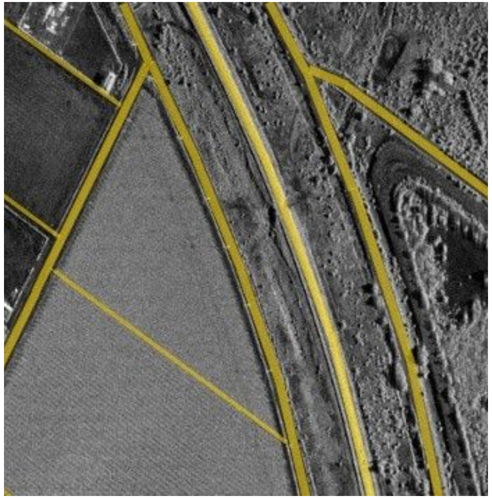
Car and pedestrian detection



Trajectory Planning



Road Detection



- And this all is already implemented on Tesla cars.

Applications of Computer Vision

- Also, many applications in the **fashion** industry:

Virtual Try-on

Garment Layering

Clothing editing

Source and more: cuiaiyu.github.io/dressing-in-order/

Applications of Computer Vision

- And it has overflown the **digital art** industry recently!

Style Transfer

Image Generation by Prompt

Image generated with the prompt: “an impressionist oil painting of a Canadian man riding a moose through a forest of maple trees"

Applications of Computer Vision

- And now Vision also intersects Language!

Image Captioning

A woman is throwing a frisbee in a park.

A dog is standing on a hardwood floor.

A little girl sitting on a bed with a teddy bear.

A group of people sitting on a boat in the water.

Image Generation by prompt

"a cute doll writing a letter"

"a bored smoking lizard surrounded by soldiers"

"a parking meter near a graffiti wall"

"a corgi in a field"

"a monkey eating a banana"

"a neapolitan pizza with mozzarella and tomatoes"

Applications of Computer Vision

- And now Vision also intersects Language!

Chatbots with Visual Input

(Tentative) Lecture Roadmap

Basics of Deep Learning

- Intro to Computer Vision
- Linear Classifiers and Perceptron
- Multilayer Perceptron
- Optimization in Deep Learning
- Pytorch I – MLPs
- Pytorch II – Images and Regularization
- Convolutional Neural Networks
- Data Augmentation and Deep CNNs
- Transfer Learning and Residual Nets
- Inception Net and what CNNs learn
- Adversarial Examples and Self-supervision

Deep Learning and Computer Vision in Practice

- Intro to MLOps
- Intro to Object Detection
- Fast Object Detection
- Intro to Image Segmentation
- Applications of Detection and Segmentation
- Autoencoders
- Image Generation with GANs
- Advanced GANs
- The Attention Mechanism
- Transformers and ChatGPT
- Image Generation by Prompt
- Misc. Topics

Video: *The Deep Learning Revolution*