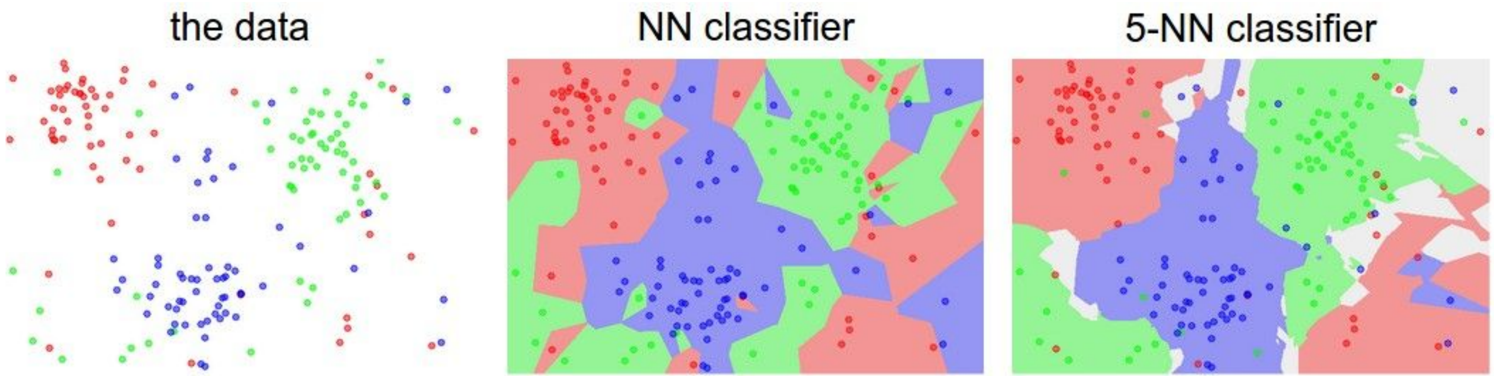


CS 106S Week 4

Cancer Detection with K-Nearest Neighbors

Ben Yan, Spring 2025 🌸

cs106s.stanford.edu

Stanford | ENGINEERING
Computer Science

Welcome to Week 4 of Class!

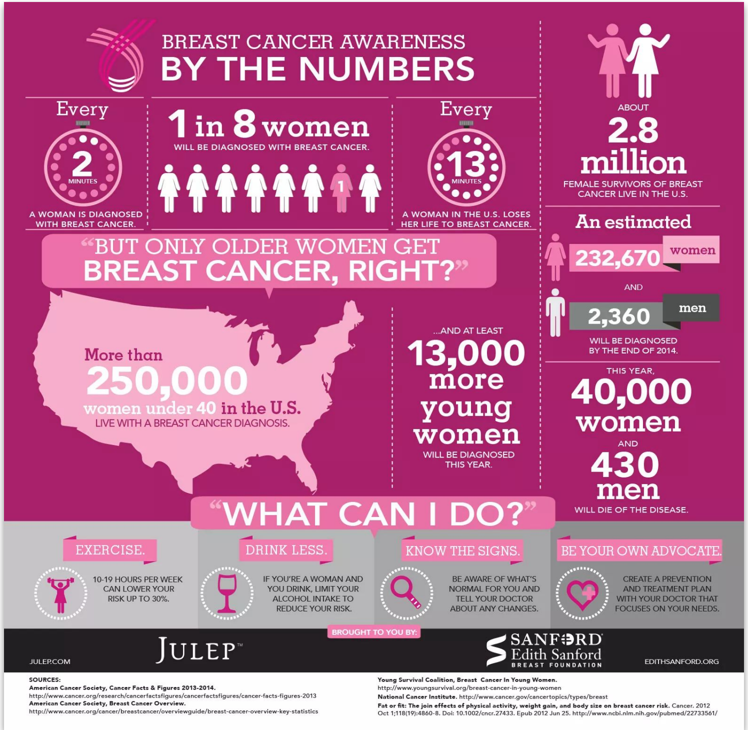
Spring

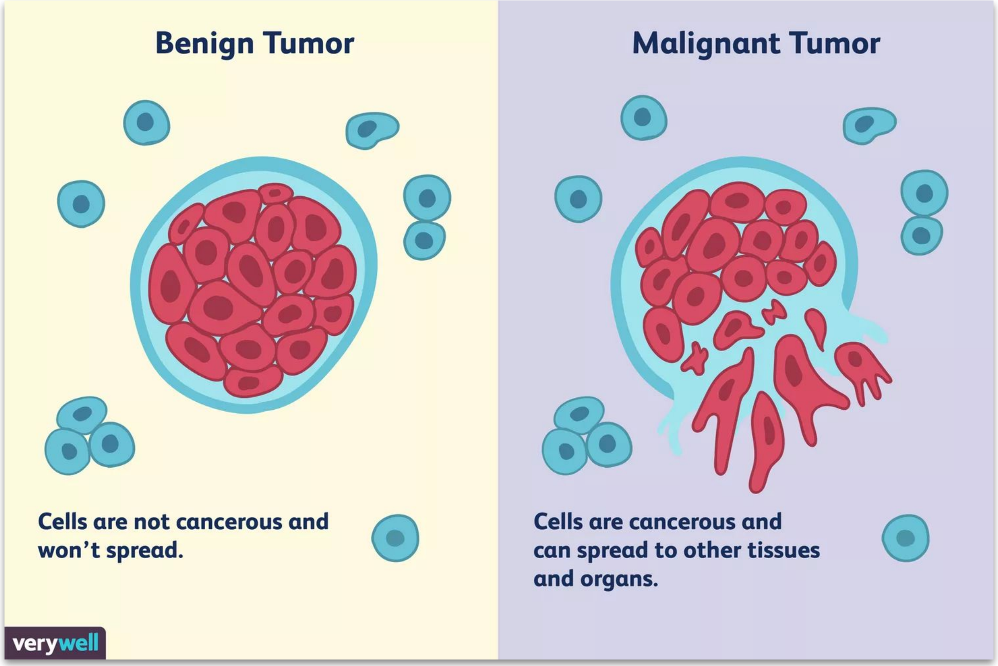
Summer

Map for Today

1. Brief overview of machine learning and its paradigms, e.g., supervised vs. unsupervised learning
2. Overview of K-nearest neighbors (KNN) algorithm
3. project: breast tumor classification with KNN
4. implementation & check-off form

The Problem


BREAST CANCER AWARENESS
BY THE NUMBERS
Every 2 MINUTES
A WOMAN IS DIAGNOSED WITH BREAST CANCER.
1 in 8 women
WILL BE DIAGNOSED WITH BREAST CANCER.
1
Every 13 MINUTES
A WOMAN IN THE U.S. LOSES HER LIFE TO BREAST CANCER.
ABOUT
2.8 million
FEMALE SURVIVORS OF BREAST CANCER LIVE IN THE U.S.
An estimated
232,670 women
AND
2,360 men
WILL BE DIAGNOSED BY THE END OF 2014.
"BUT ONLY OLDER WOMEN GET BREAST CANCER, RIGHT?"
More than
250,000
women under 40 in the U.S.
LIVE WITH A BREAST CANCER DIAGNOSIS.
...AND AT LEAST
13,000
more
young
women
WILL BE DIAGNOSED THIS YEAR.
THIS YEAR,
40,000
women
AND
430
men
WILL DIE OF THE DISEASE.
"WHAT CAN I DO?"
EXERCISE.
10-19 HOURS PER WEEK CAN LOWER YOUR RISK UP TO 30%.
DRINK LESS.
IF YOU'RE A WOMAN AND YOU DRINK, LIMIT YOUR ALCOHOL INTAKE TO REDUCE YOUR RISK.
KNOW THE SIGNS.
BE AWARE OF WHAT'S NORMAL FOR YOU AND TELL YOUR DOCTOR ABOUT ANY CHANGES.
BE YOUR OWN ADVOCATE.
CREATE A PREVENTION AND TREATMENT PLAN WITH YOUR DOCTOR THAT FOCUSES ON YOUR NEEDS.
BROUGHT TO YOU BY:
JULEP.COM
JULEP™
SANFORD Edith Sanford BREAST FOUNDATION
EDITHSANFORD.ORG
SOURCES:
American Cancer Society, Cancer Facts & Figures 2013-2014.
http://www.cancer.org/research/cancerfactsfigures/cancerfactsfigures/cancer-facts-figures-2013
American Cancer Society, Breast Cancer Overview.
http://www.cancer.org/cancer/breastcancer/overviewguide/breast-cancer-overview-key-statistics
Young Survival Coalition, Breast Cancer In Young Women.
http://www.youngsurvival.org/breast-cancer-in-young-women
National Cancer Institute. http://www.cancer.gov/cancertopics/types/breast
Fat or fit: The join effects of physical activity, weight gain, and body size on breast cancer risk. Cancer. 2012 Oct 1;118(19):4860-8. Doi: 10.1002/cncr.27433. Epub 2012 Jun 25. http://www.ncbi.nlm.nih.gov/pubmed/22733561/


Benign Tumor
Malignant Tumor
Cells are not cancerous and won't spread.
Cells are cancerous and can spread to other tissues and organs.
verywell

Today's Task

Given medical data about cell growths, can we accurately classify these tumors as **benign** or **malignant**?

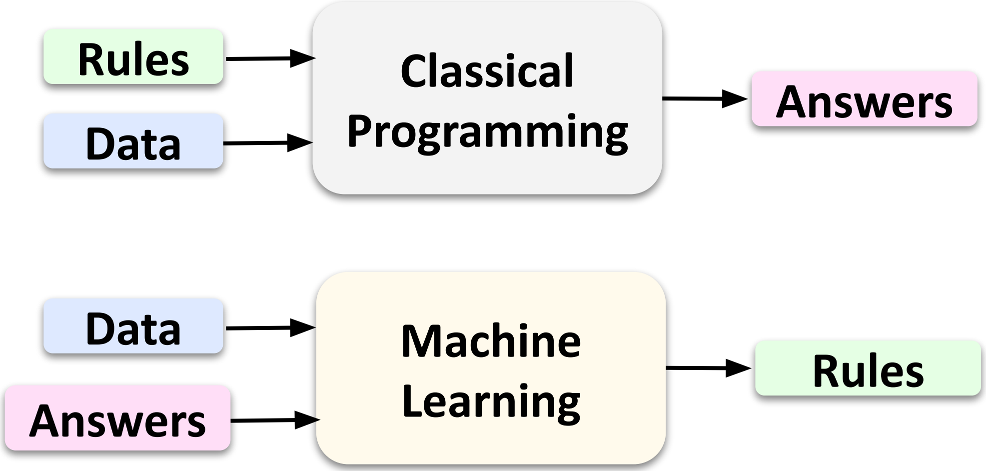
Test Sample ID	Correct?	Actual Label	Predicted Label
🔬 666942	✅	Benign	Benign
🔬 667204	✅	Malignant	Malignant
🔬 673637	✅	Benign	Benign
🔬 684955	✅	Benign	Benign
🔬 688033	✅	Benign	Benign
🔬 691628	✅	Malignant	Malignant

First, an overview of machine learning

Machine Learning

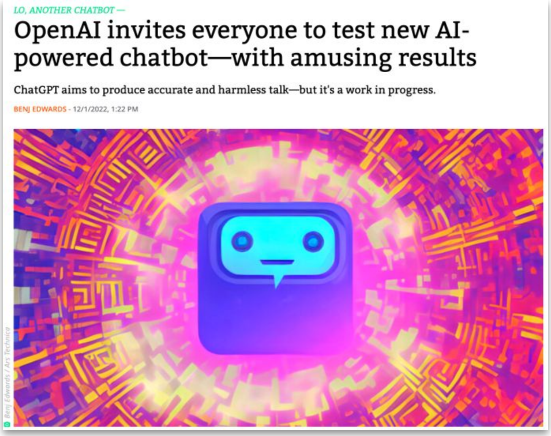
Machine learning is a "field of study that gives computers the ability to learn **without being explicitly programmed"** – Arthur Samuel

Game-Playing AI (AlphaGo)



Deep Learning

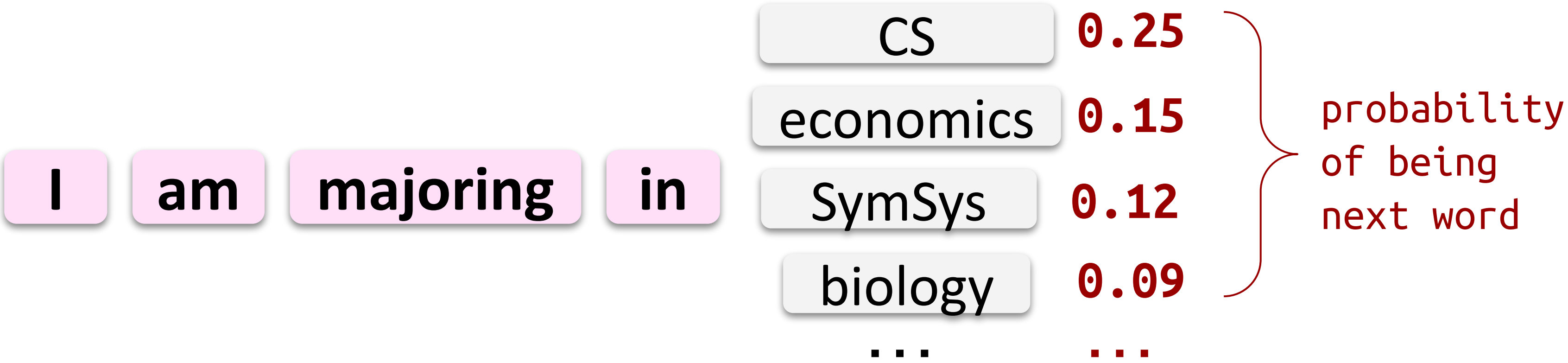
Deep learning (neural networks) requires **very large amounts of data** to learn complex rules, and is the core paradigm behind large language models, or *generative pre-trained transformers*.


LO, ANOTHER CHATBOT —

OpenAI invites everyone to test new AI-powered chatbot—with amusing results

ChatGPT aims to produce accurate and harmless talk—but it's a work in progress.

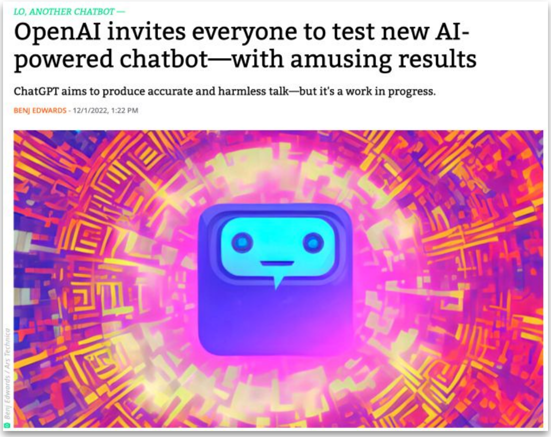
BENJ EDWARDS - 12/1/2022, 1:22 PM



Next word prediction—the rule is a **probability distribution** over all possible next words, which is learned from ingesting massive amounts of Internet-based text 🌐📚📗📒

Deep Learning

Deep learning (neural networks) requires **very large amounts of data** to learn complex rules, and is the core paradigm behind large language models, or ***generative pre-trained*** *transformers*.


LO, ANOTHER CHATBOT —

OpenAI invites everyone to test new AI-powered chatbot—with amusing results

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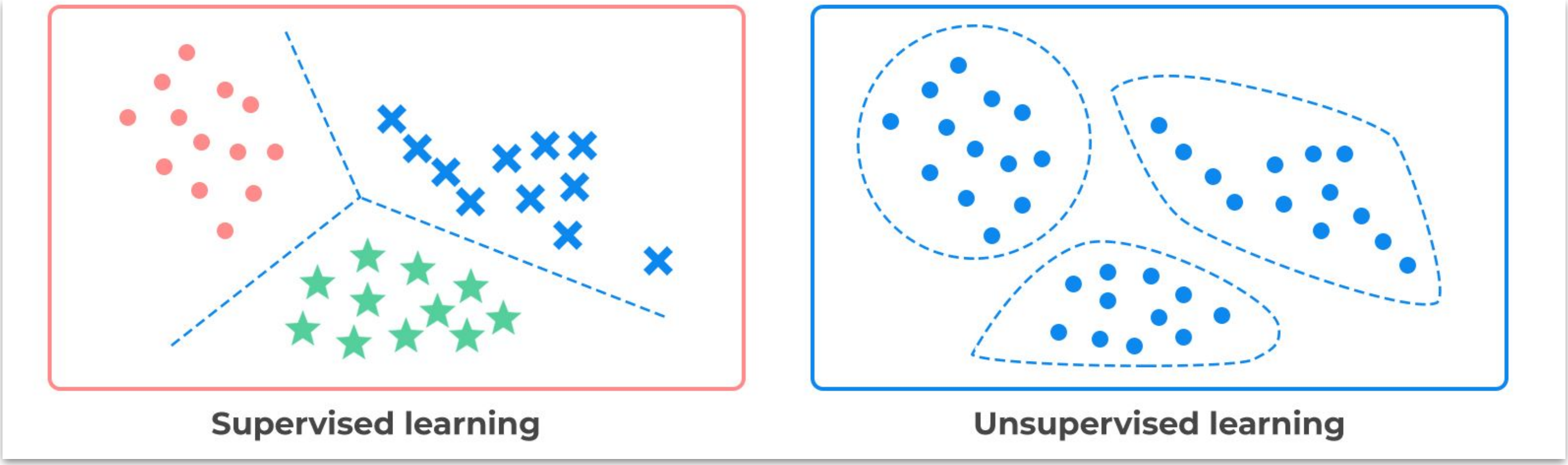
BENJ EDWARDS - 12/1/2022, 1:22 PM

I **am** **majoring** **in** **CS** **because** **of**

passion	0.45
love	0.35
money!	0.10
conformity	0.05
...	...

Next word prediction – the algorithm, after choosing a word, proceeds to choose the next word from another **learned probability distribution**, and so forth iteratively.

Supervised vs Unsupervised Learning

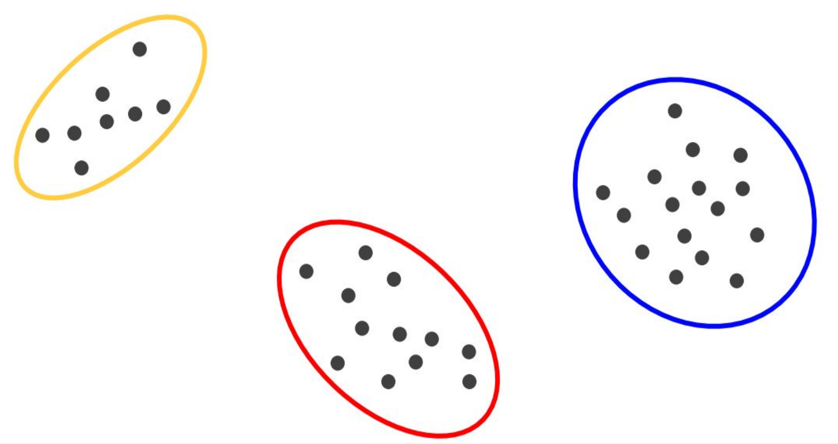


- **Supervised learning** uses **labeled training data** (input features/points and expected outputs) to train an algorithm to predict outputs for new inputs
- **Unsupervised learning** uses **unlabeled data**, and attempts to find patterns/ groupings on input features/points without them being explicitly tagged

Unsupervised Learning: Clustering

A common application of unsupervised learning is **clustering**, which involves grouping a dataset into some number of independent, related clusters.

E,g., Based on locality, we can identify **3 groups** from the `(x,y)` points below.

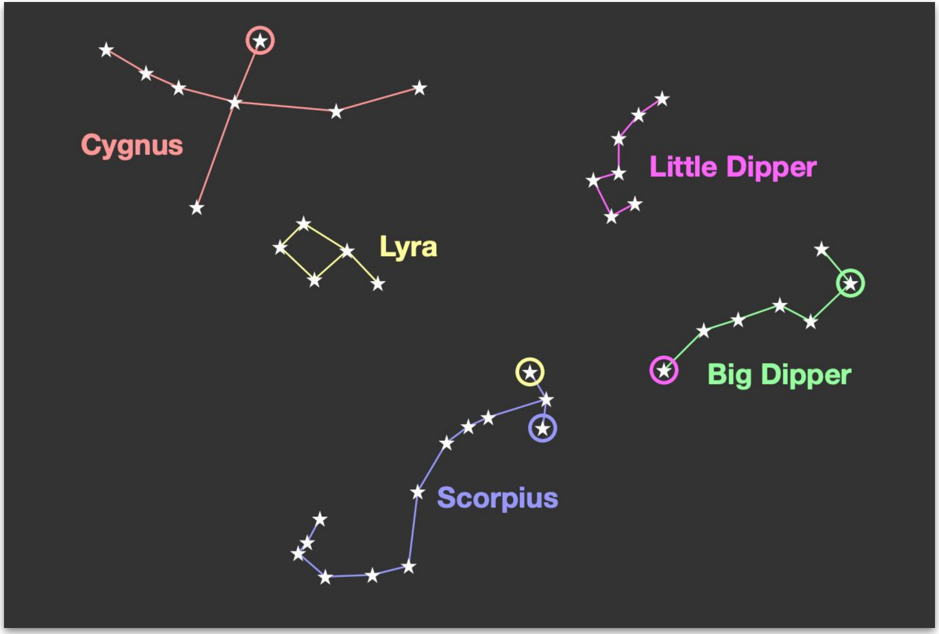


Ex. We can **group movies** based on genre.

Based on CS106AX materials (J. Cain, E. Roberts)

Clustering Example

🌠 Star Constellations

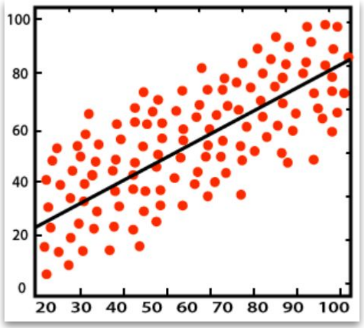


😔 **Star constellations aren't "real"** – in the sense the lines are imaginary, and the stars aren't actually physically connected.

Instead, they're **clusters / patterns** of stars that we see from Earth. It's a matter of perception.

Two main types of supervised learning

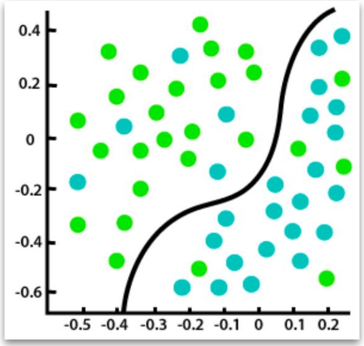
Regression



What numerical value is this data point affiliated with?

Avg Temp. Today 🌡️	Avg Wind Today 💨	Precip. Today ☔	⇨	Temp (F) Tomorrow 🌡️
51 F	5 mph	1 in		48 F?

Classification



Which category / label does this data point belong to?

Avg Temp. Today 🌡️	Avg Wind Today 💨	Precip. Today ☔	⇨	Weather Type 🥶
-3 F	25 mph	10 in		Sunny / Cloudy / Rainy / **Snow** ✅

🔬 Our Dataset

	A	B	C	D	E	F
1	666942	1	1	1	1	2
2	667204	7	8	7	6	4
3	673637	3	1	1	1	2
4	684955	2	1	1	1	3

Training: ~630 samples | **Testing: ~70 samples**

~700 samples (rows) in total

💾 Each **row** has 11 columns: a **sample ID #** (col 0), a **binary label** (last col), and **9 input features** (each a value between **1-10**) in between.

- In JavaScript, we represent each row as an **array of numbers**.

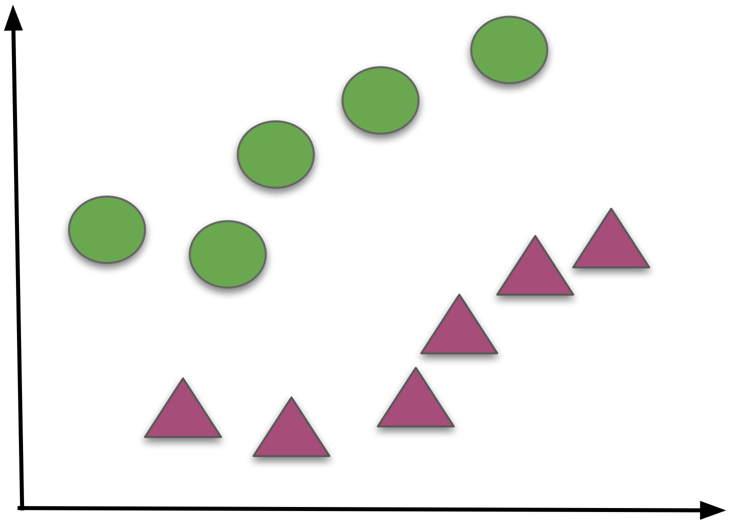
1001	1.0	3.0	4.0	2.0	7.0	6.0	8.0	5.0	1.0	0

9 Input Features

1. Clump Thickness
2. Uniformity of Cell Size
3. Uniformity of Cell Shape
4. Marginal Adhesion
5. Single Epithelial Cell Size
6. Bare Nuclei
7. Bland Chromatin
8. Normal Nucleoli
9. Mitoses

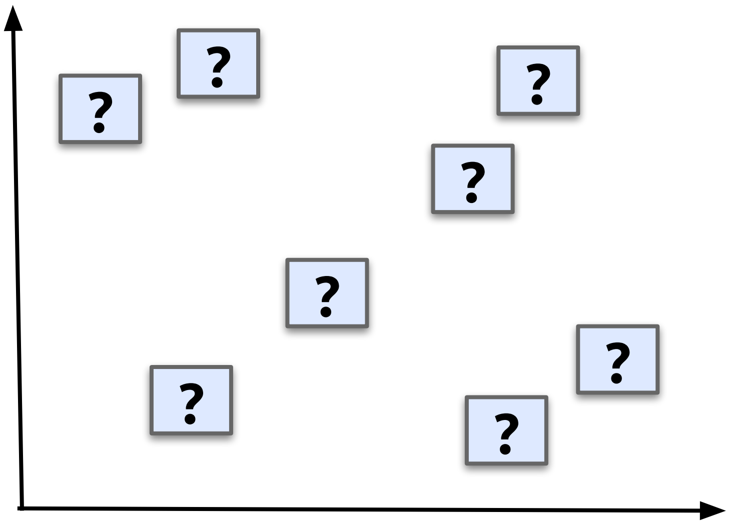
Training / Testing Split

Training Set



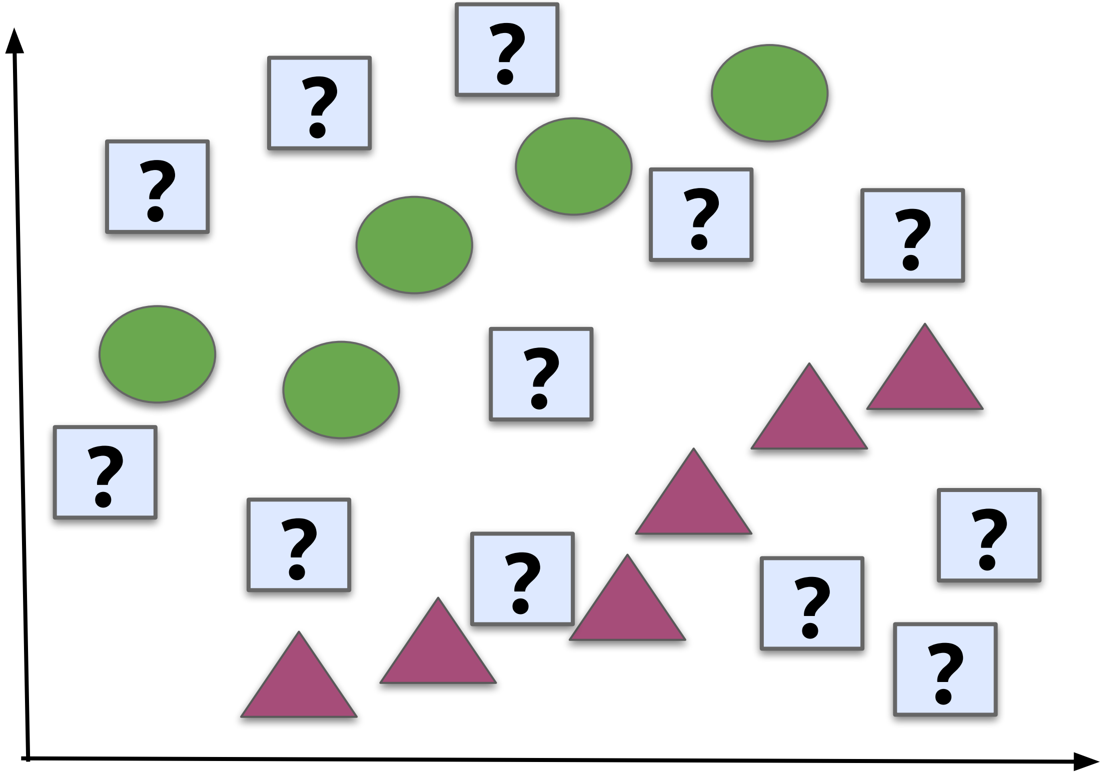
We use this labeled set of tumor samples to train/inform the model

Test Set

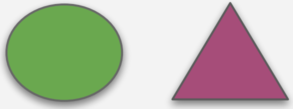


We use this to evaluate the model's performance

How to classify the test set?



Training Set

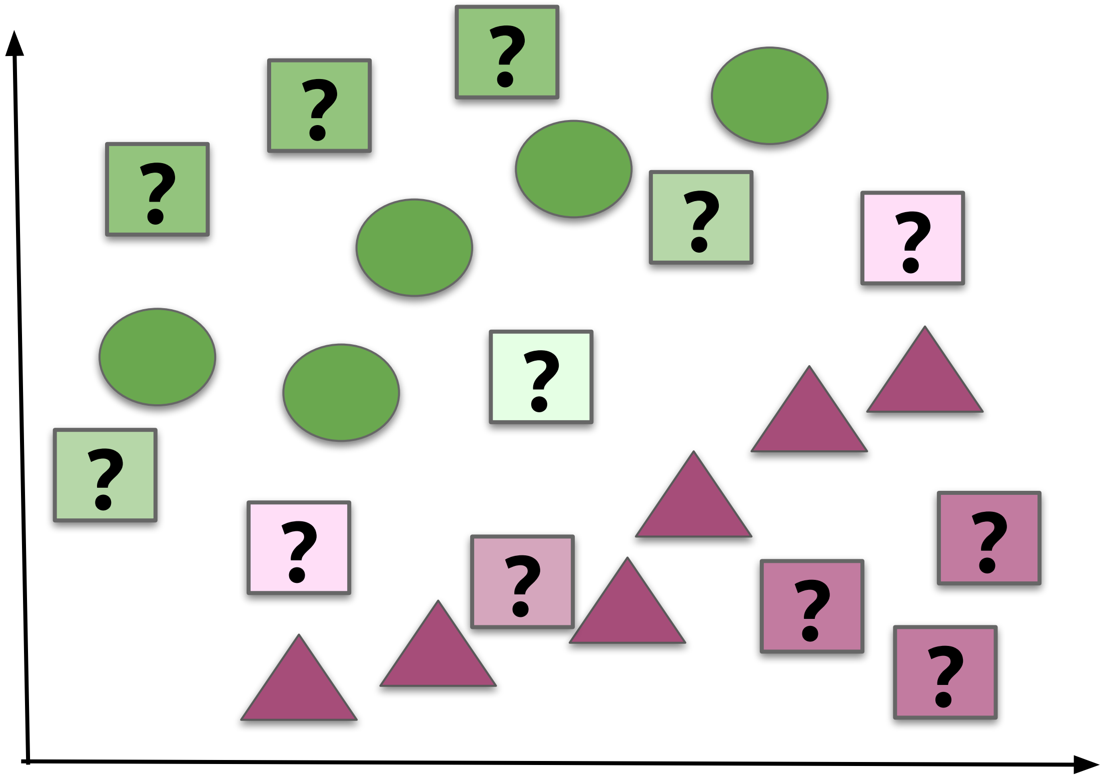


Data points whose **label** the model already knows

Test Set

Data points whose **label** the model doesn't know

Maybe like this:



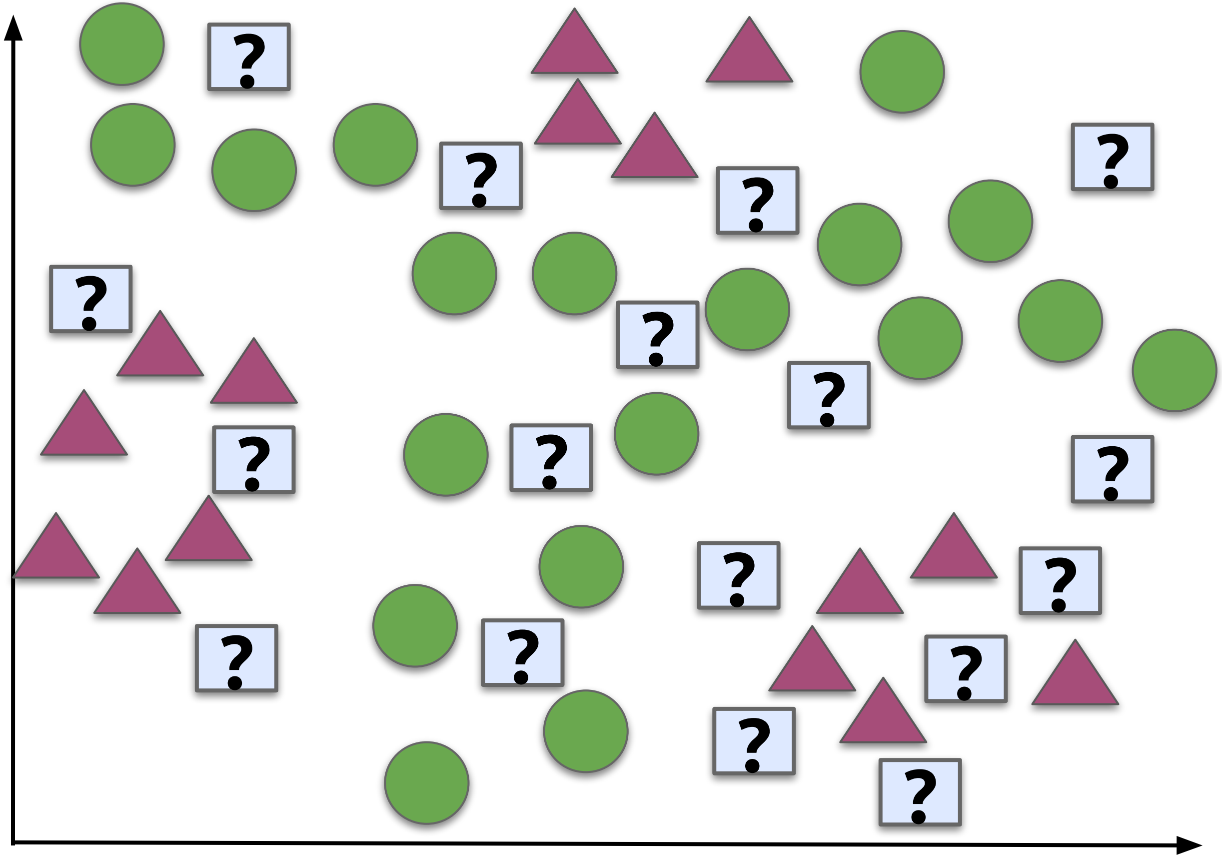
Training Set

Data points whose **label** the model already knows

Test Set

Data points whose **label** the model doesn't know

How about this one? Oof



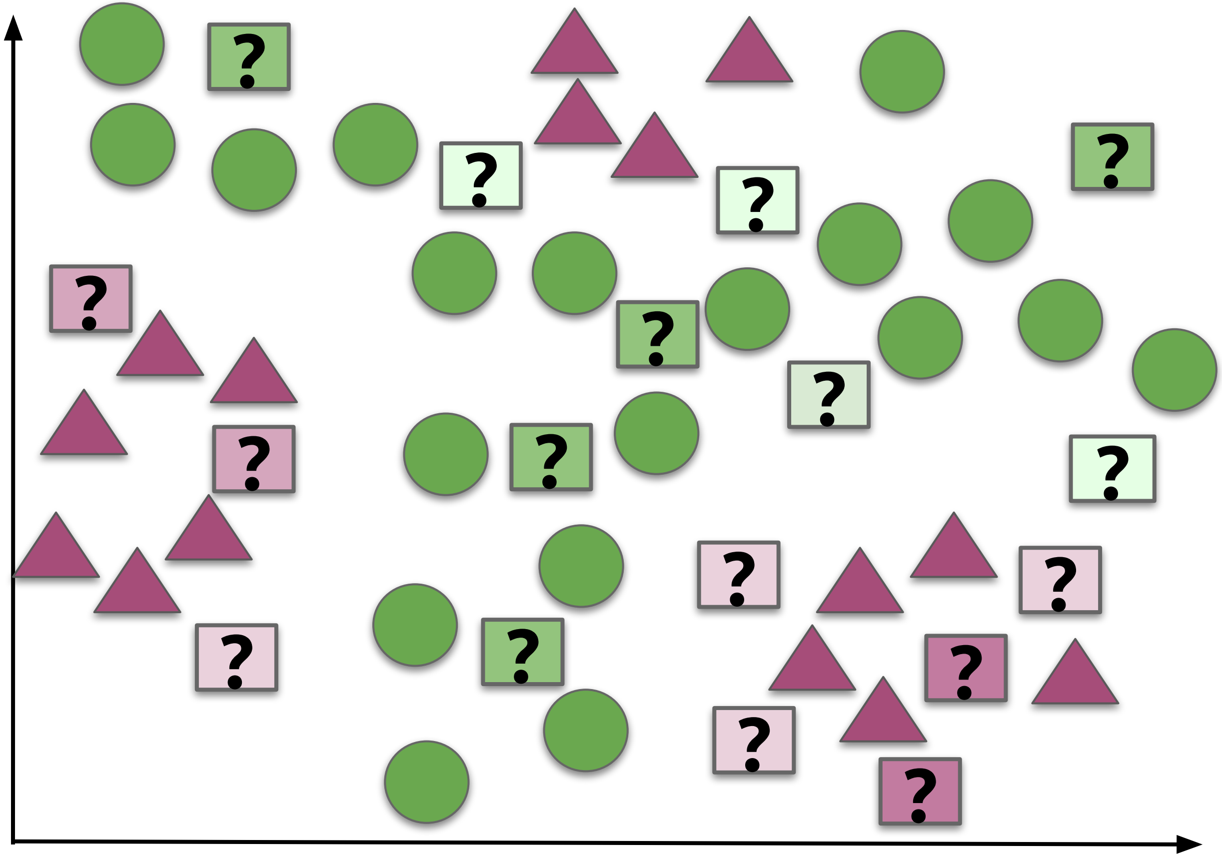
Training Set

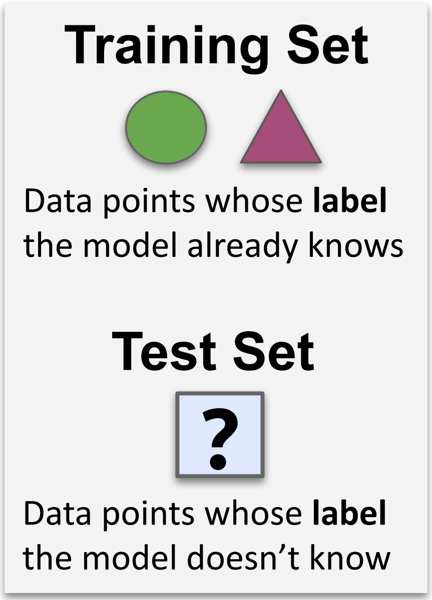
Data points whose **label** the model already knows

Test Set

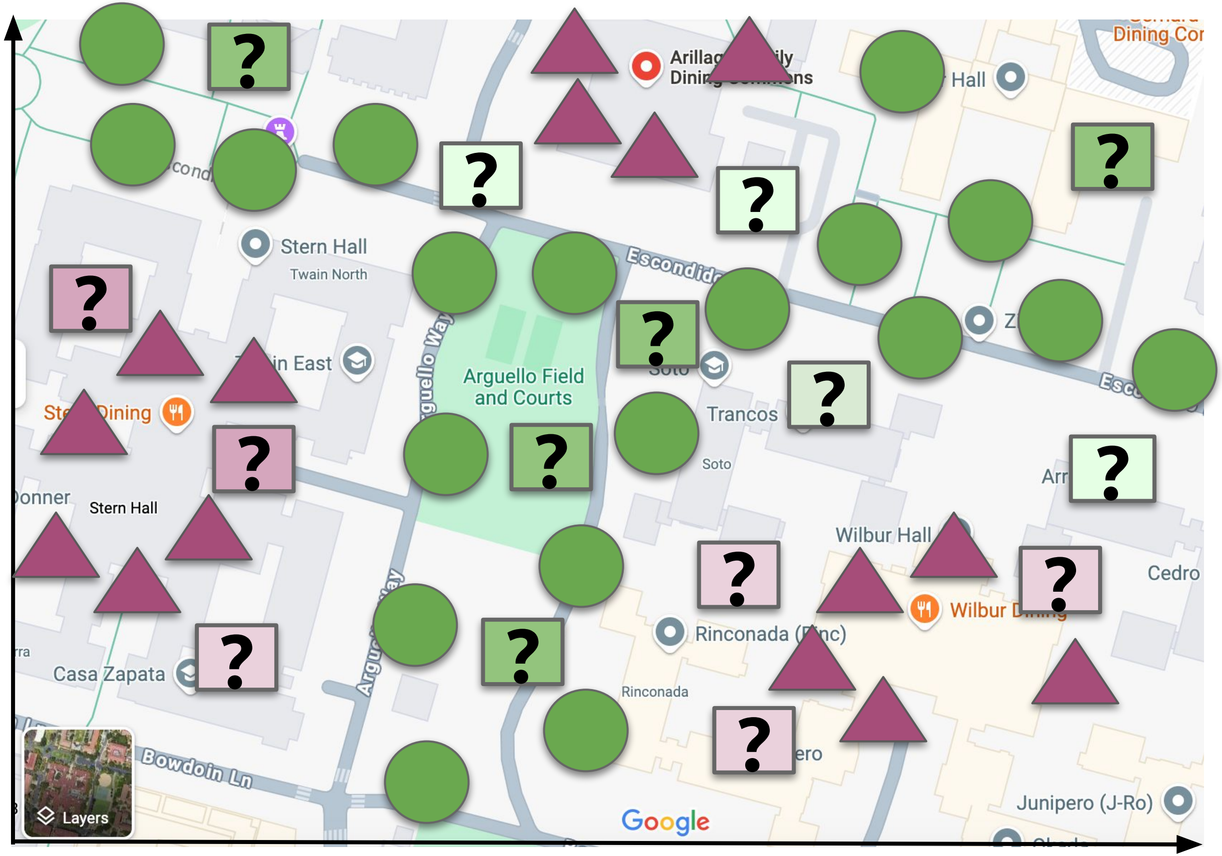
Data points whose **label** the model doesn't know

Maybe like this:





Real data doesn’t look like that…



Within a dining hall, or the surrounding tables outside

Not within a dining hall area

Training Set

Data points whose **label** the model already knows

Test Set

?

Data points whose **label** the model doesn’t know

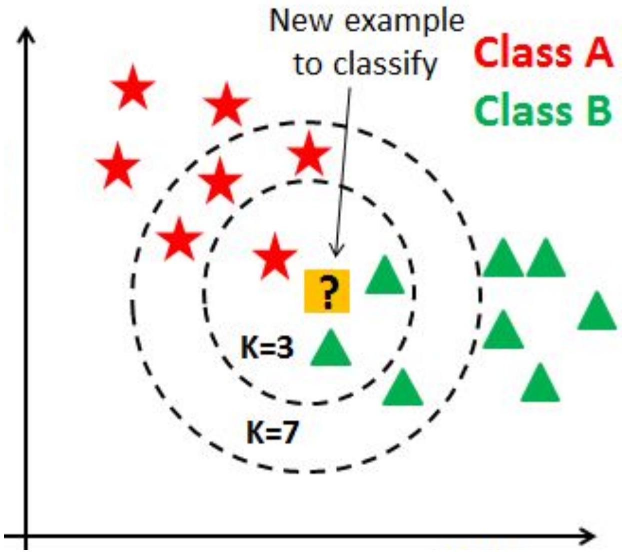
K-Nearest Neighbors Algorithm

Guiding Principle: Use **locality / proximity** in the dataset to predict new points!

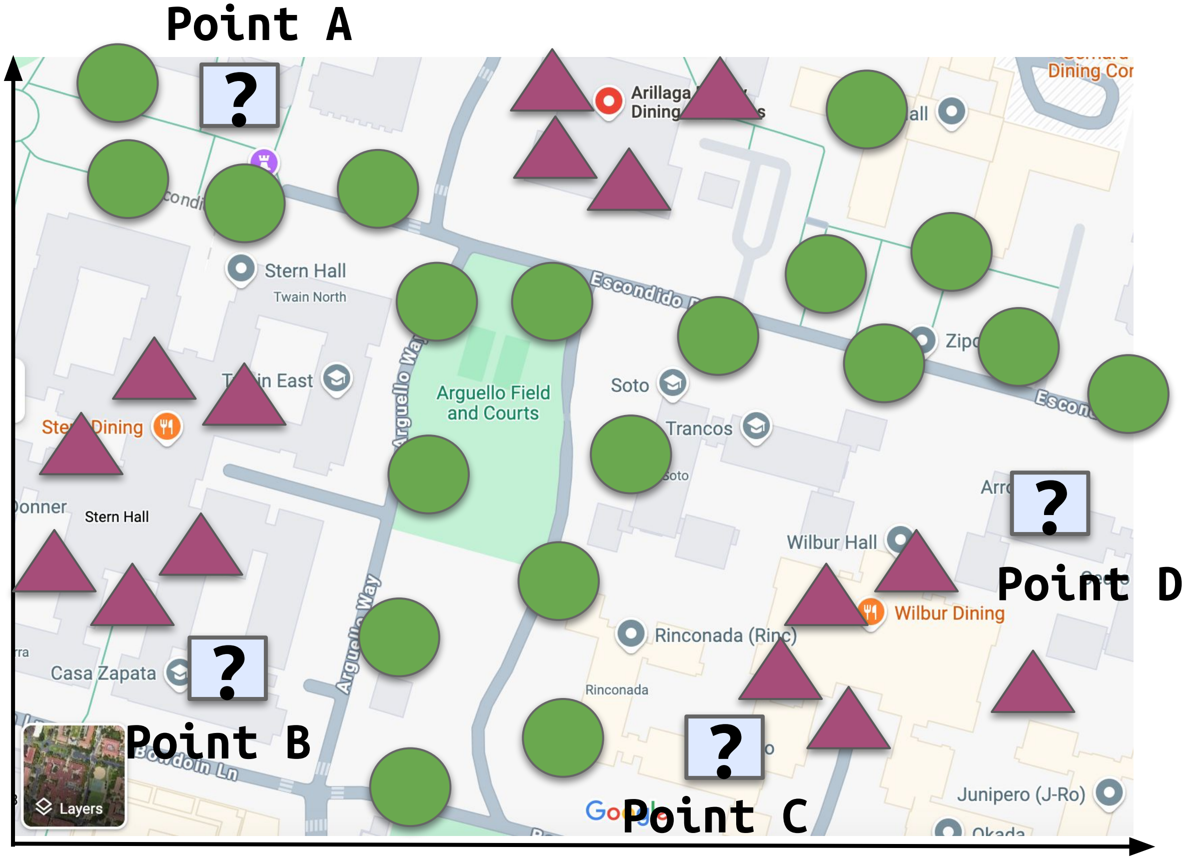
- Points with the **same label** are likely to be **close to each other**
- Points with **different labels** are likely to be **far away** from each other

For each test sample / point to classify:

1. Calculate distance between test sample and every training point.
2. Pick the K training points with the smallest distances to the test sample (i.e. its "nearest neighbors")
3. **Of those K points, do a vote:** how many are classified as **malignant** vs. **benign**?
4. **Majority wins:** pick the majority label



KNN (K=3): Campus Map Example



Point A

3 Nearest Neighbors

Predict

Point B

3 Nearest Neighbors

Predict

Point C

3 Nearest Neighbors

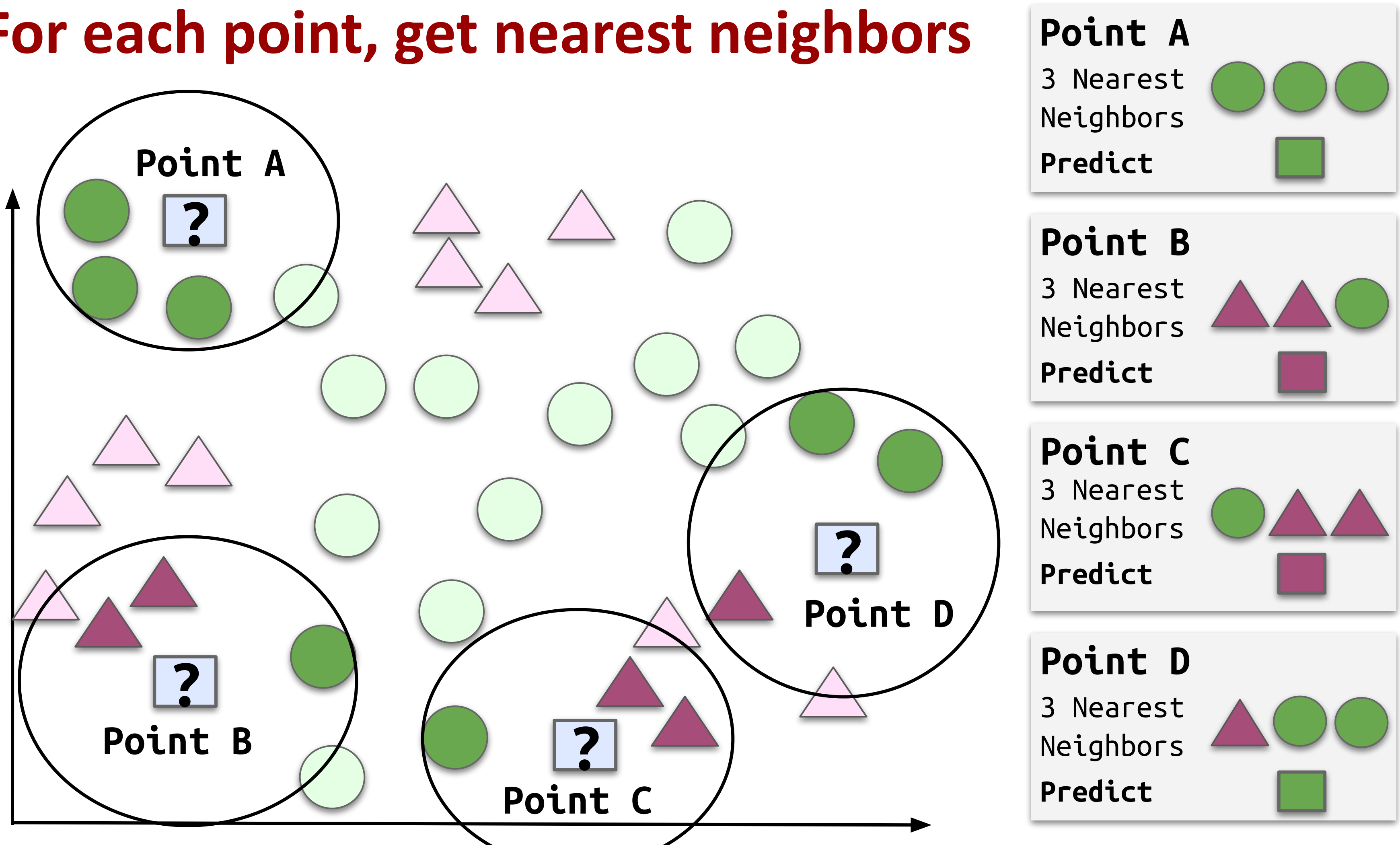
Predict

Point D

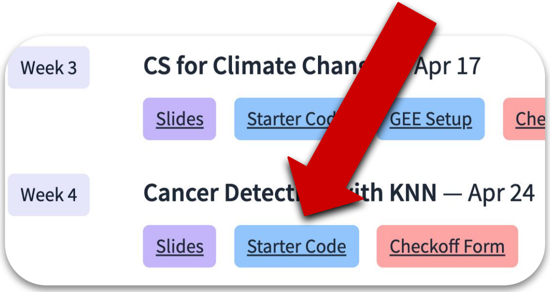
3 Nearest Neighbors

Predict

For each point, get nearest neighbors

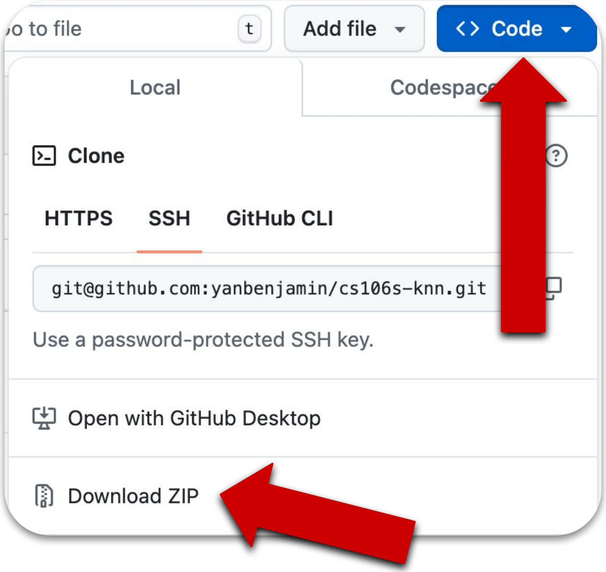


Let's get started!

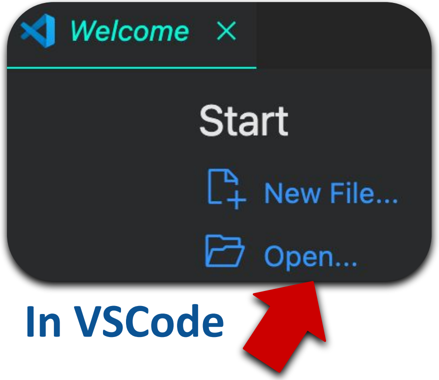


1 Navigate to Week 4 of the Schedule section of **cs106s.stanford.edu**

Also, at this link: https://github.com/yanbenjamin/cs106s-knn



2 Click the bright **"Code"** button, then click "Download ZIP"



In VSCode

3 Unzip the download (clicking .zip file should do the trick) and open the folder / files in your editor

Array Methods

`arr.push(element)`

Adds element to end of array.

`arr.pop()`

Removes and returns last element.

`arr.slice(start,finish)`

Returns subarray beginning at index **start** and ending **just before finish**

```
> let arr = [1,2,3];
> arr.push(4);
// arr is now [1,2,3,4]
> newArr = arr.slice(0,2);
// newArr is [1,2]
```

Object Methods

To **create an object** / dictionary in JS, you list a sequence of **key-value pairs**, enclosed in curly braces.

```
let bratAlbum = {
  “name”: “Brat”,
  “artist”: “Charli XCX”,
  “year”: 2024
}
```

You can lookup **values** via their **keys!**

```
bratAlbum[“artist”] \\”Charli XCX”

\* alternative syntax *\
bratAlbum.year \\ 2024
```

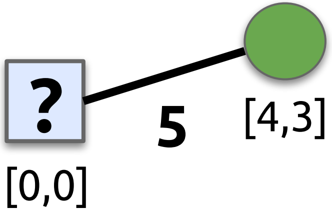
Link to JavaScript Guide!

3 Milestones for KNN Task

You'll want to work in the **`classify.js`** file; there's 3 functions to write, each accompanied by tips and documentation! See **`index.html`** in Chrome for results.

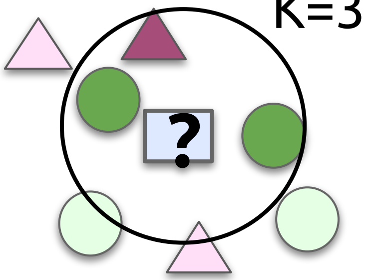
1 **calculateDistance**(testSample, trainSample)

Computes the Euclidean **distance** between a test sample and a training sample, i.e. sqrt(sum of squared differences over indices)



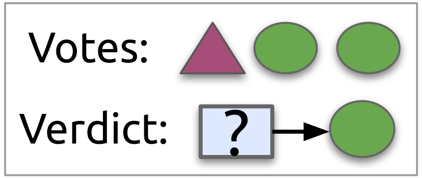
2 **findNearestPoints**(testSample, trainSamples, K)

Computes distance of each trainSample with testSample, determining the K closest training samples and returning them.



3 **predictSample**(testSample, trainSamples, K)

Among the K closest samples, count how many are benign (label 0) and malignant (label 1). Return the majority label / "vote".



🧩 JavaScript: Sorting

Recall: **JavaScript is a “vibes”-based language** ✨💅


```
> let arr = [3,2,1];
> arr.sort();
> console.log(arr)
[1, 2, 3]
```

Okay makes sense

```
> let arr = [200,60,3,1000];
> arr.sort();
> console.log(arr)
[1000, 200, 3, 60]
```

um excuse me what the actual–

Everything is a string if you have the willpower! JavaScript interprets and sort the inputs alphabetically, as though they are strings, so “200” < “3”, “3” < “60”

We gotta teach JavaScript how to sort 😒🧑‍🏫

1 < 2 < 4 < 8

*Sorting is really just knowing **how to compare items***

```
> let arr = [200,60,3,1000];
> arr.sort((a,b) => (a – b));
> console.log(arr)
[3, 60, 200, 1000]  Okay slay
```

This is a **comparison function**, written here like lambda functions in Python, i.e.

```
lambda a,b: a – b
```

A **comparison function** should return:

- Negative (<0) if **a** goes before **b**
- Positive (>0) if **a** goes after **b**
- 0 if **a** has the same ordering as **b**

In Milestone 2, we have to sort an array of point objects from **lowest to highest distance**, e.g.,

arr = [{"distance": 1.2, "id": 7, "label": 0},
{"distance": 3.7, "id": 9, "label": 1}, **...**] → **How should we sort?**

```
arr.sort((pointA, pointB) => (pointA.distance – pointB.distance));
```

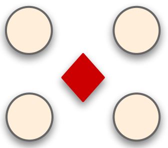
This is negative when pointA has lower distance ✅, positive when pointA has higher distance ✅, and zero when they have equal distance ✅.

Optional Extension: K-Means

Code is in the **extensions.js** file. The challenging task is to classify the samples **without any training data or labels**—see the documentation for more details!

1 **calculateAverage**(points)

Computes the average (i.e. center) of an array of points, e.g., for input points = [[0,0,0],[2,4,6]], it should return [1,2,3].



2 **KMeans**(testSamples, numIterations)

The core idea is dividing the sample points into K=2 clusters / groups, keeping track of which samples are in which group, and each group's center, e.g.,

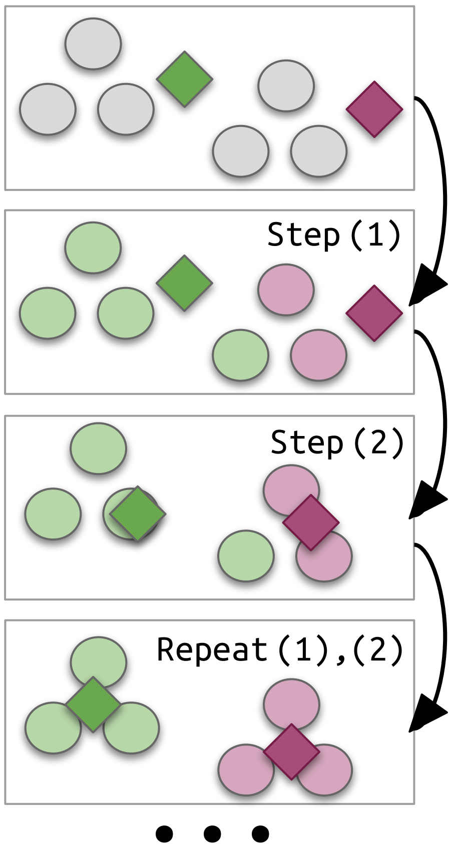
benignPoints = [sample1, sample3,…], **benignCenter** = avg of benignPoints
malignantPoints = [sample2, sample5,…], **malignantCenter** = avg of malignantPoints

We repeatedly refine the groupings / point assignments with these steps:

(1) For each testSample, assign it to **benignPoints** if closer to **benignCenter** than **malignantCenter**; otherwise, assign it to **malignantPoints**

(2) Recalculate the **benign**/**malignant** centers based on the new assignments.

(3) Repeat steps (1) and (2) over multiple iterations.



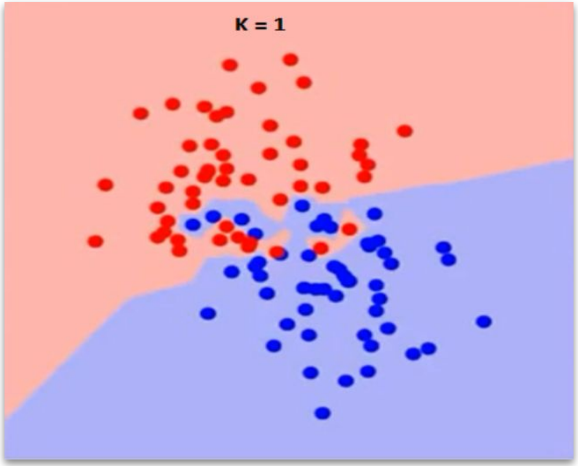
KNN Predictions

Test Sample ID	Correct?	Actual Label	Predicted Label	K-Nearest Neighbors (K=3)		
🔬666942	✅	Benign	Benign	🔬 1059552	🔬 1156272	🔬 1164066
🔬667204	✅	Malignant	Malignant	🔬 1223793	🔬 1228152	🔬 1296572
🔬673637	✅	Benign	Benign	🔬 128059	🔬 1133136	🔬 1043999
🔬684955	✅	Benign	Benign	🔬 1136142	🔬 1036172	🔬 1067444
🔬688033	✅	Benign	Benign	🔬 1190485	🔬 1204242	🔬 1214092
🔬691628	✅	Malignant	Malignant	🔬 314428	🔬 1102573	🔬 1096800
🔬693702	✅	Benign	Benign	🔬 1190485	🔬 1204242	🔬 1214092
🔬704097	✅	Benign	Benign	🔬 1320077	🔬 1344449	🔬 1035283
🔬704168	❌	Benign	Malignant	🔬 1096800	🔬 1115282	🔬 1253955
🔬706426	✅	Malignant	Malignant	🔬 1168736	🔬 1185609	🔬 1174428
🔬709287	✅	Malignant	Malignant	🔬 1205138	🔬 1231387	🔬 1193544
🔬718641	✅	Benign	Benign	🔬 1136142	🔬 1185610	🔬 1155546
🔬721482	❌	Benign	Malignant	🔬 1091262	🔬 1148278	🔬 1185609
🔬730881	✅	Malignant	Malignant	🔬 1176881	🔬 1189266	🔬 1171710
🔬733639	✅	Benign	Benign	🔬 169356	🔬 1177027	🔬 1197270
🔬733639	✅	Benign	Benign	🔬 1177027	🔬 1197270	🔬 1198641

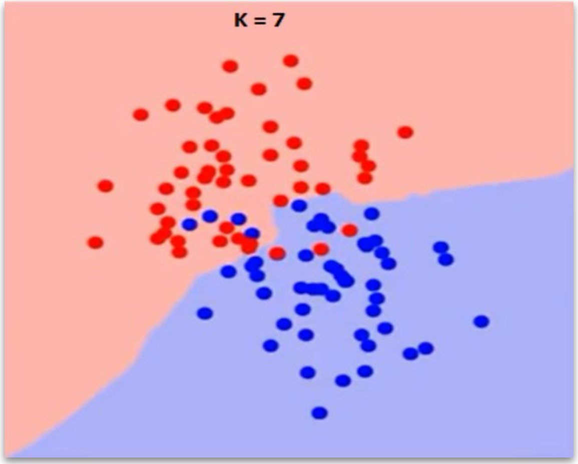
What value of K is best?

Case-Specific: Depends on dataset! Just have to try out different values

Low K – Very sensitive to noise, but advantage is selectivity (looking just at the closest possible / most similar points)



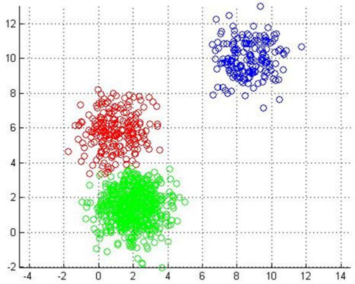
High K – Smoother decision boundaries, but at a trade-off of diminishing locality and what qualifies as a nearest neighbor



Further resources

- More on KNN and classification broadly from CS231N course notes
- Related algorithms and techniques:

More on K-means Clustering



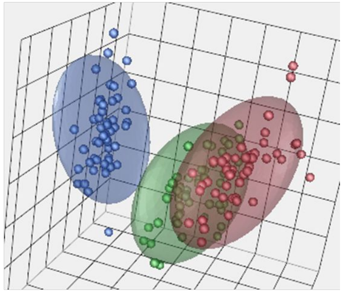
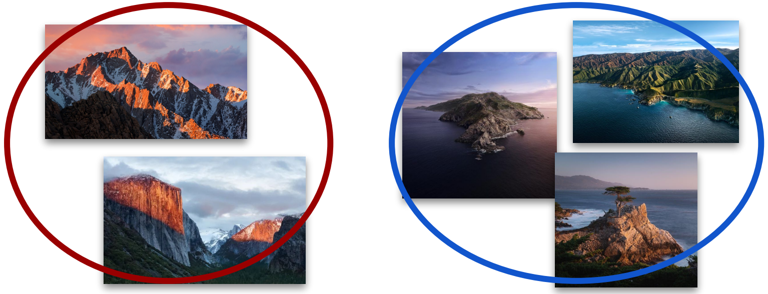
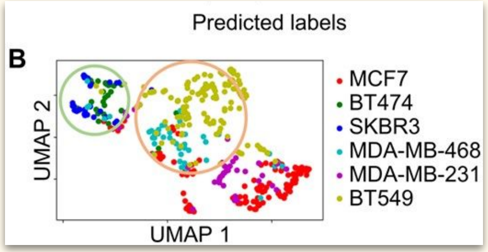


Image-based KNN

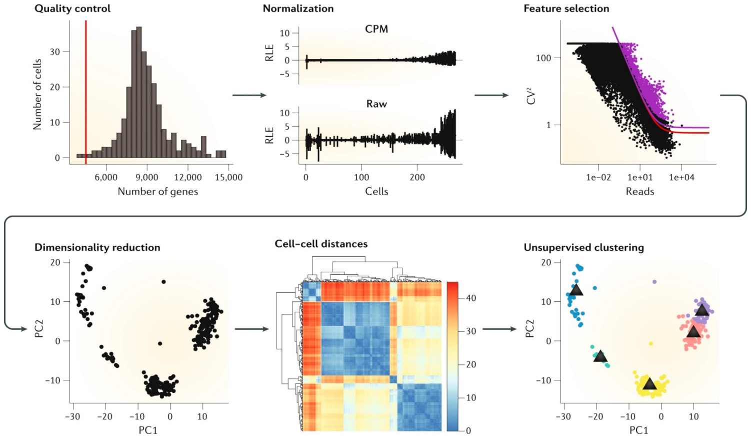


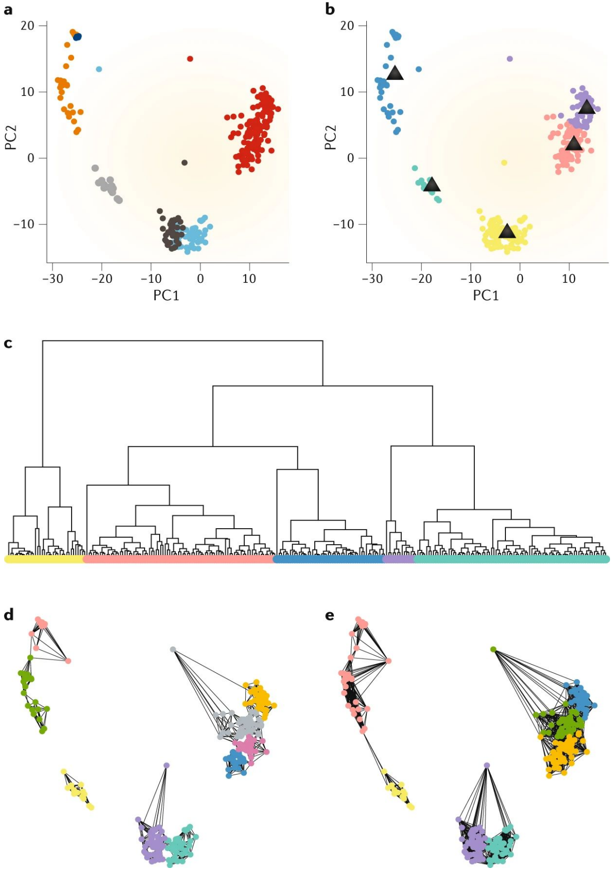
- Real world connection: "Deep learning-based classification of breast cancer cells using transmembrane receptor dynamics" (Kim et al. 2022) applies deep learning to assess the metastatic potential of breast cancer cells



Further Resources

clustering scRNA-seq data





Clusters for scRNA sequences reveal and categorize **different cell types!**

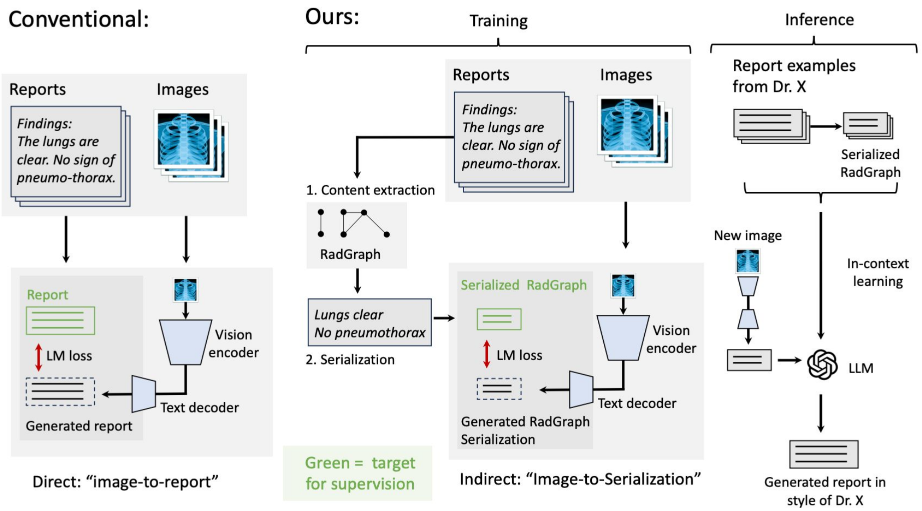
https://www.nature.com/articles/s41576-018-0088-9/figures/1
https://www.nature.com/articles/s41576-018-0088-9/figures/3

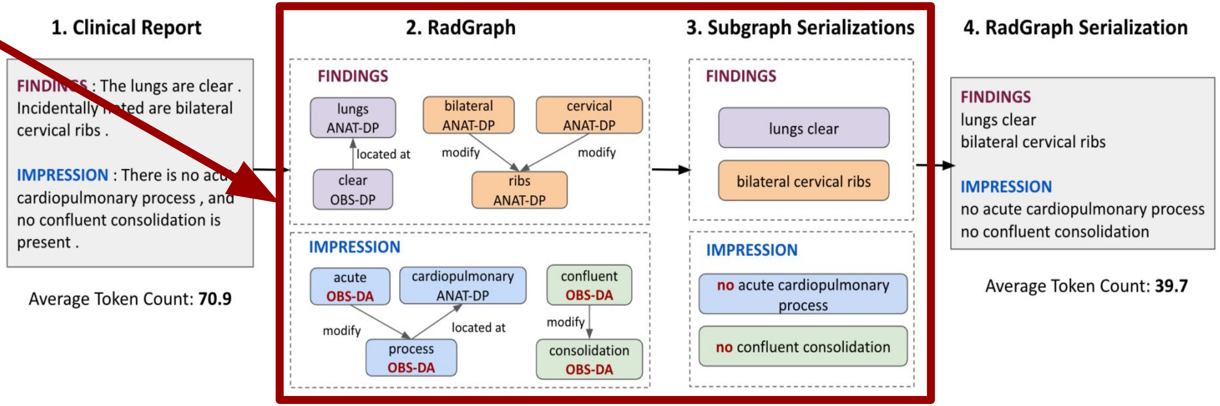
Some research I've worked on, '23

Clustering related medical entities in radiology reports—for helping image-to-text models generate **accurate, focused findings** from chest X-rays 🩻

Happy to talk more about research on campus / at least my experience with it!

Would also love to hear about other experiences!





"Style-Aware Radiology Report Generation with RadGraph and Few-Shot Prompting", Yan et. al, EMNLP 2023

Check-Off Form

Another **brief check-off form** (< 5 min to complete) for checking attendance!

For today, click the "Check-Off Form" link in the **Week 4** section of **cs106s.stanford.edu**.

Thank you so much!

Have an awesome week, and good luck on any midterms! 🍀

You’re going to do awesome