Symmetries and Specialized Architectures
&
Machine Vision

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How will class work today?

- Three lessons, each with:
  - Learning goals
  - A 15-minute lecture
  - A 45-minute chance to work on coding in teams
  - Links to supplementary instructional materials if you’re lost
  - Ideas for extension activities if you’re bored

- Lessons cover:
  1. Convolutional Neural Networks
  2. Convolutional Neural Network Interpretability
  3. Graph Neural Networks

INTRO TO MACHINE VISION

Learning goal #0: Explain the benefits and pitfalls of feature engineering in machine vision.

Image Textures: Animal or Food?

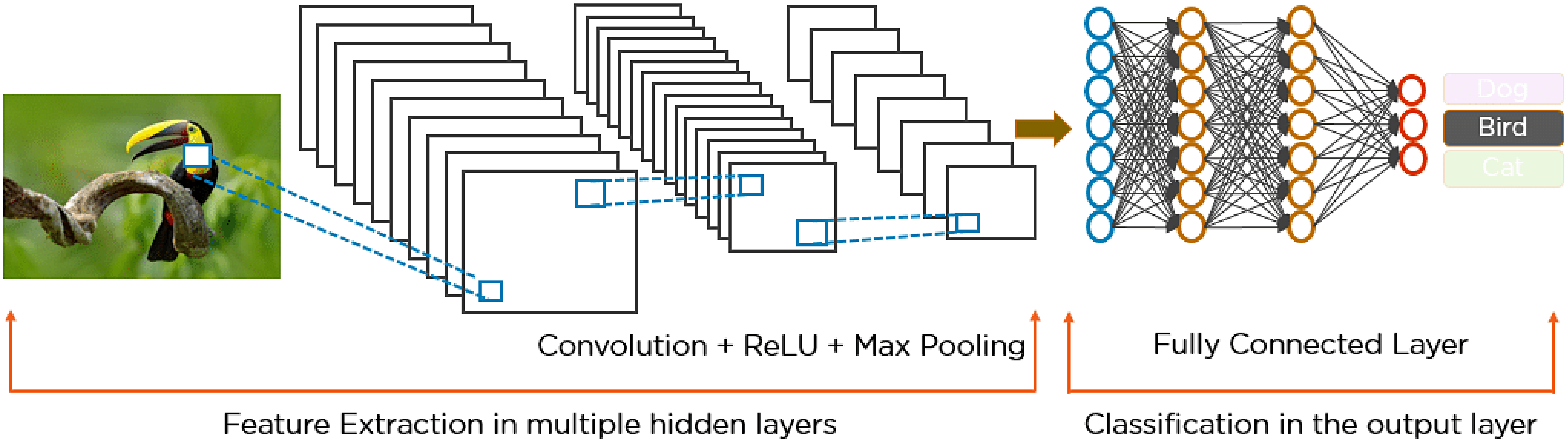
Image Textures: Animal or Food?

Image Textures: Animal or Food?

CONVOLUTIONAL NEURAL NETWORKS

Learning goal #1: Describe a convolutional neural network's architecture. List the problems that a CNN is well-suited for.

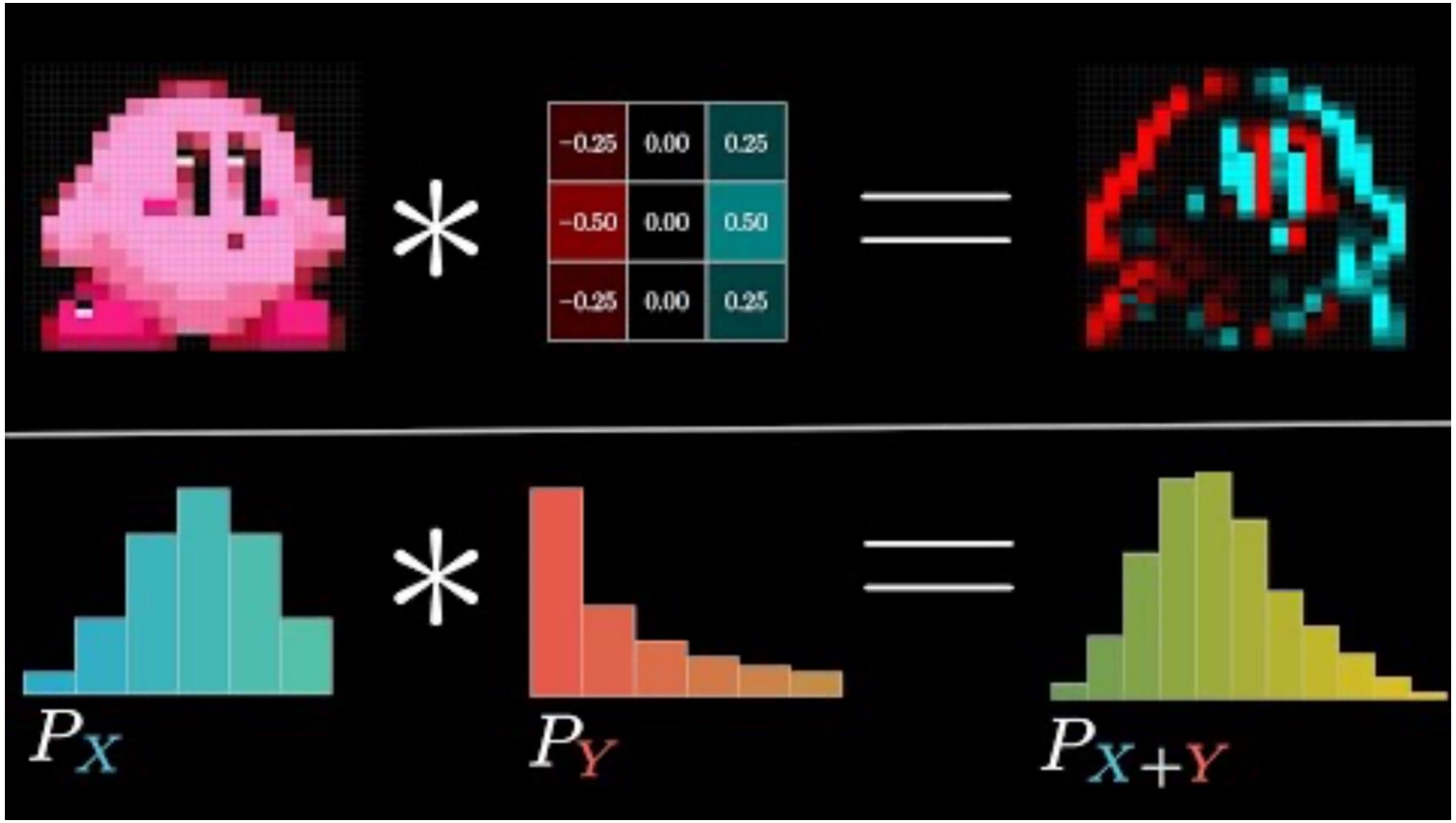
Visit #1 of 2: A Typical CNN Architecture



CONVOLUTIONAL FILTERS

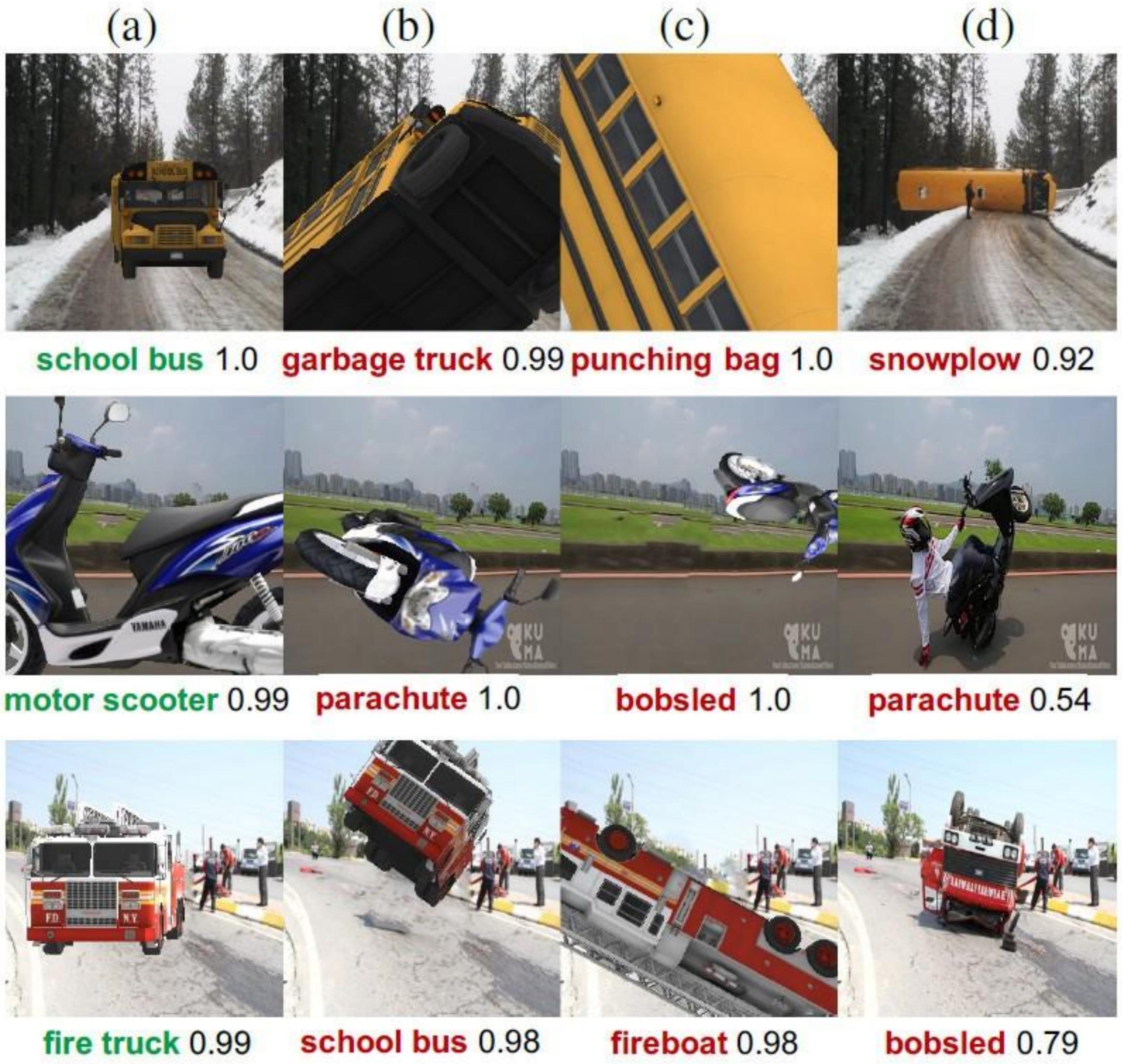
Learning goal #2: Describe a convolutional filter. Build a filter that can find particular shapes.

What are convolutions?



This video is available at https://youtu.be/KuXjwB4LzSA?si=1iErbpMDAatXooCy&t=510

Translational and Rotational Invariance



Translational and Rotational Invariance

Google sheet implementation of a simple convolution here.

Sample Image #1

0	0	5	5	5	0	0
0	0	5	5	5	0	0
0	0	5	5	5	0	0
0	0	5	5	5	0	0
0	0	5	5	5	0	0
0	0	5	5	5	0	0
0	0	5	5	5	0	0

output #1

15	15	0	-15	-15
15	15	0	-15	-15
15	15	0	-15	-15
15	15	0	-15	-15
15	15	0	-15	-15

Filter

-1	0	1
-1	0	1
-1	0	1

Activity (10 minutes)
Translational and Rotational Invariance

Instructions:

1. Make a copy of the google sheet. Change the image and filters to test your ideas. https://tinyurl.com/manualCNN
2. Talk in groups!

Prepare an answer for these two questions

- Do CNNs have translational invariance? Can you move an image to the right or left and still have it be recognized?
- Do CNNs have rotational invariance? Can you turn an image 90 degrees and still have it be recognized?

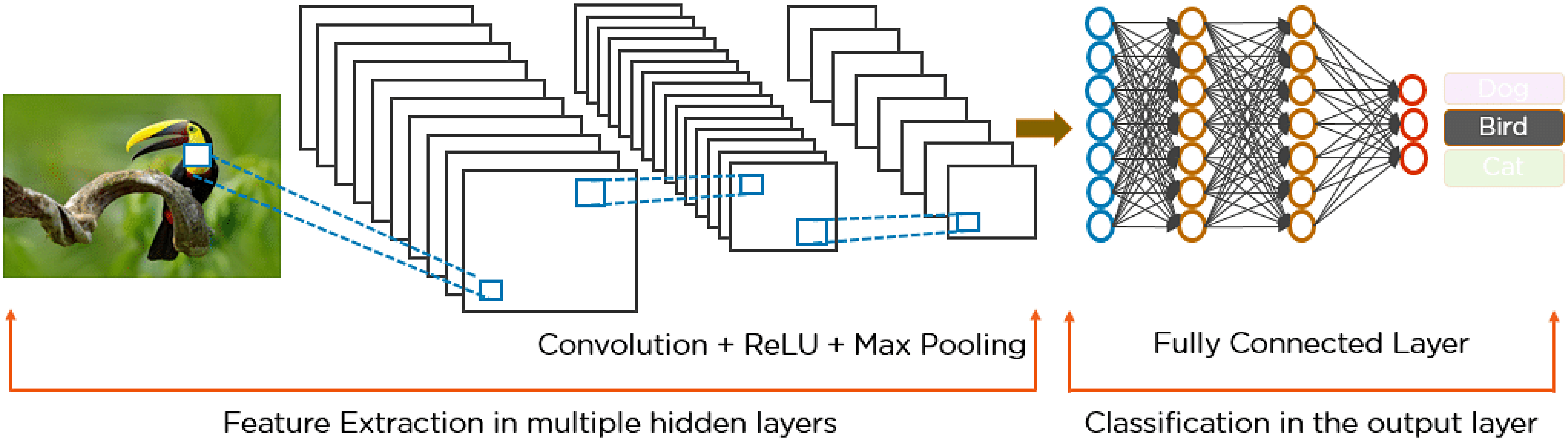
How do the convolutional filters in CNNs differ from these toy examples?

1. They are data-driven (and less intuitive). They start from random numbers!

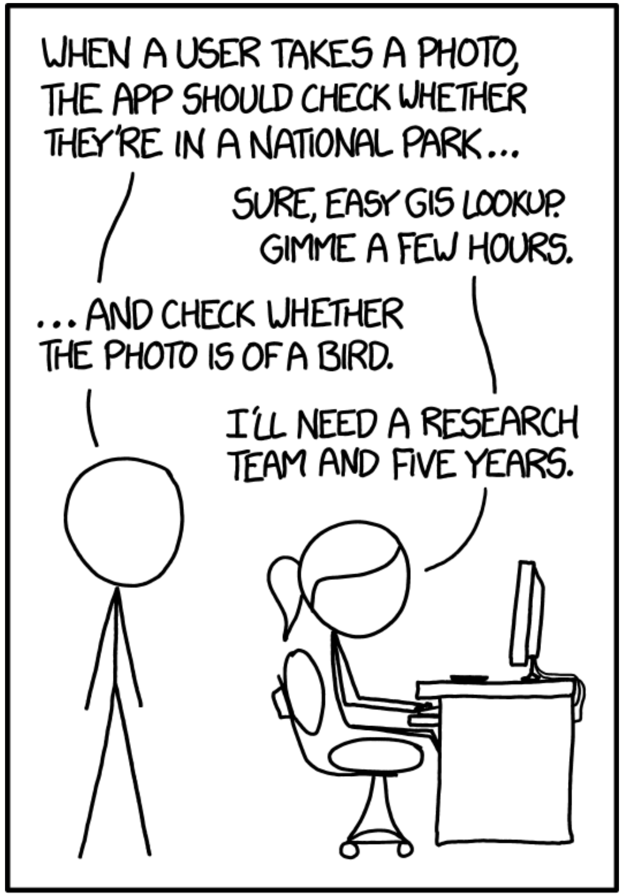
2. In sequence, they can find increasingly complex patterns

3. Most of the training time of a CNN is teaching it how to find edges (this is why transfer learning works!)

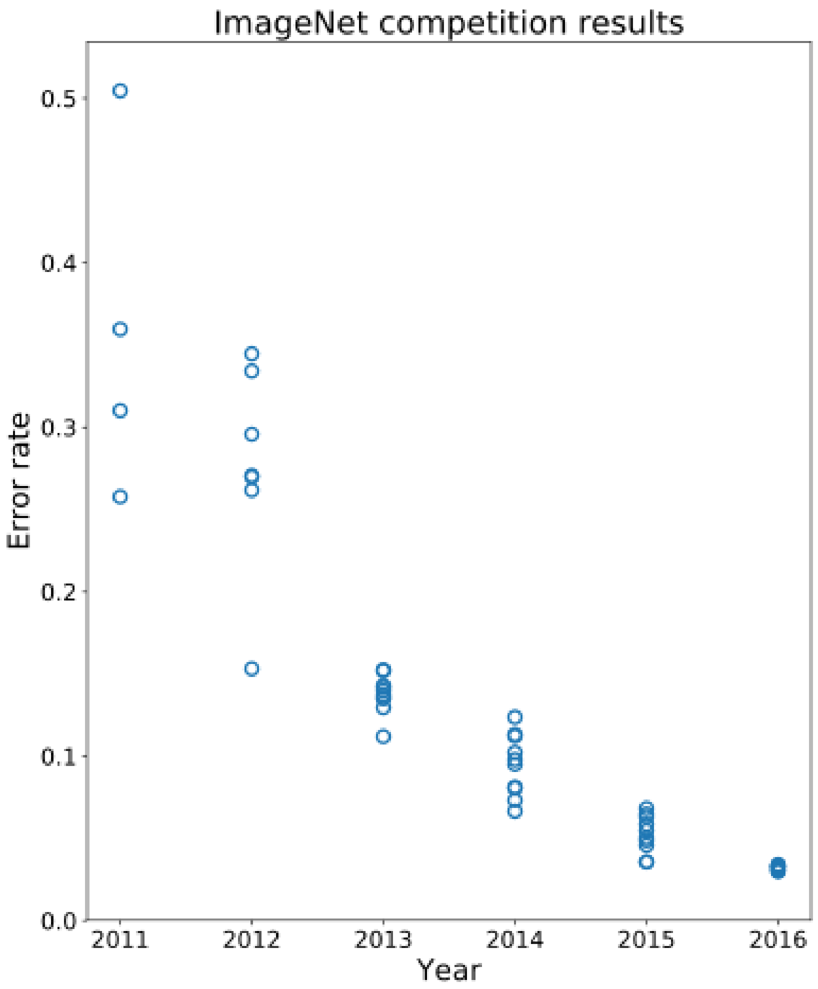
Visit #1 of 2: A Typical CNN Architecture



CNNs changed the game of image recognition



IN CS, IT CAN BE HARD TO EXPLAIN THE DIFFERENCE BETWEEN THE EASY AND THE VIRTUALLY IMPOSSIBLE.



CNNS IN KERAS/TENSORFLOW

Learning goal #3: Run a CNN classifier in keras.

Activity (30-45 minutes)
Classify Galaxy Mergers with CNNs

Feeling lost? Here are two tutorials!

Instructions:

1. Download the notebook at https://archive.stsci.edu/hello-universe/deepmerge
2. Change `lr = 0.002` to `learning_rate = 0.002`
3. In teams of 2 or 3, talk and work together through the example tutorial

Did you finish early? Learn more by trying one of these:

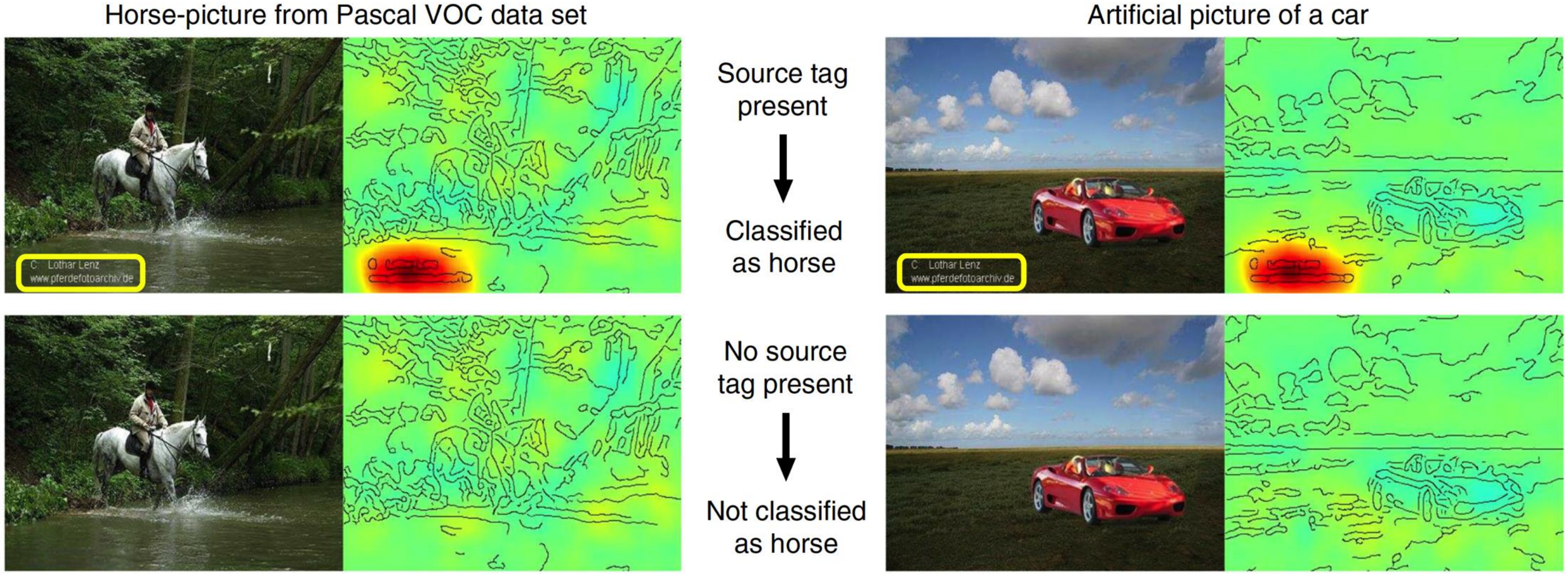
1. Learn more about CNN classifiers by working through the extension exercises at the bottom of the notebook
2. Learn more about science platforms at https://timeseries.science.stsci.edu/ (this notebook is available in "all Jupyter tutorial notebooks")
3. Learn more about CNN regression by repurposing this notebook with a toy data set to do *regression* rather than classification. *(hint: make images of blurry circles, and ask the CNN to estimate what size the circle is)*

INTERPRETING CNNS

Learning goal #4: Develop techniques for interpreting CNNs and understanding what pixels are most informative in the model's decision-making

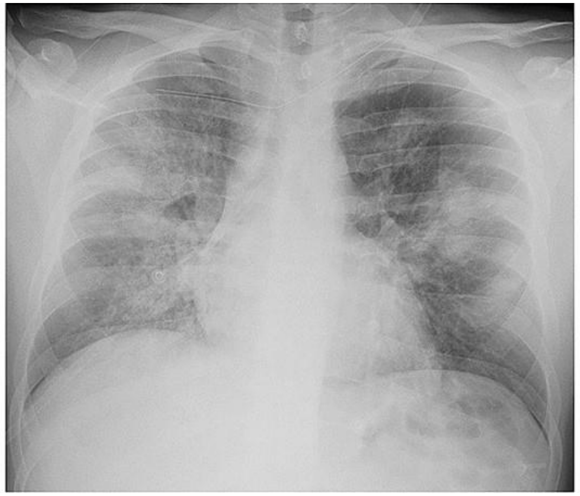
How can you tell that this is a horse? How can ML tell that this is a horse?


© Horse Photographer



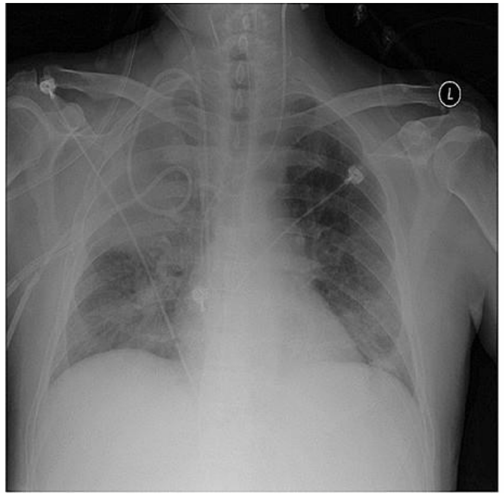
Lapuschkin et al., 2019

(A)



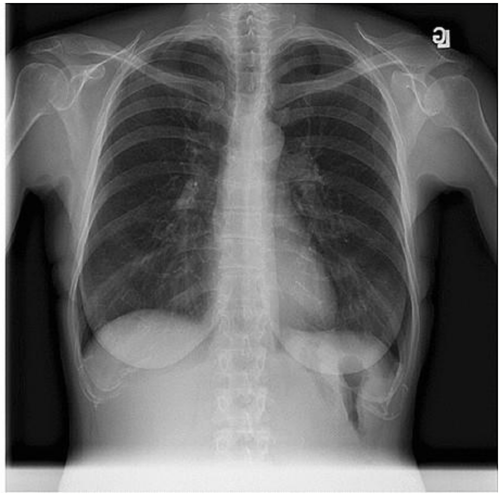
Covid

(B)



Pneumonia

(C)



Healthy

image credit: Nishia et al., 2020

ARTIFICIAL INTELLIGENCE

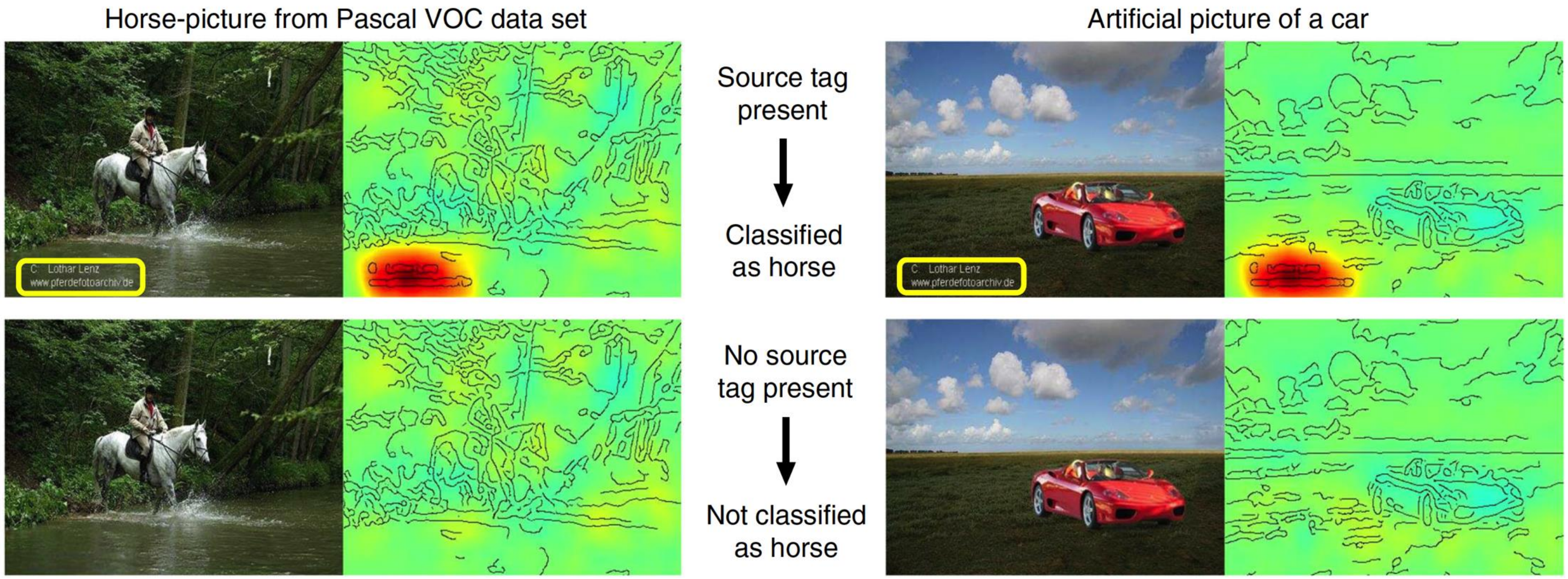
Hundreds of AI tools have been built to catch covid. None of them helped.

Some have been used in hospitals, despite not being properly tested. But the pandemic could help make medical AI better.

By Will Douglas Heaven

July 30, 2021

Saliency Maps



Lapuschkin et al., 2019

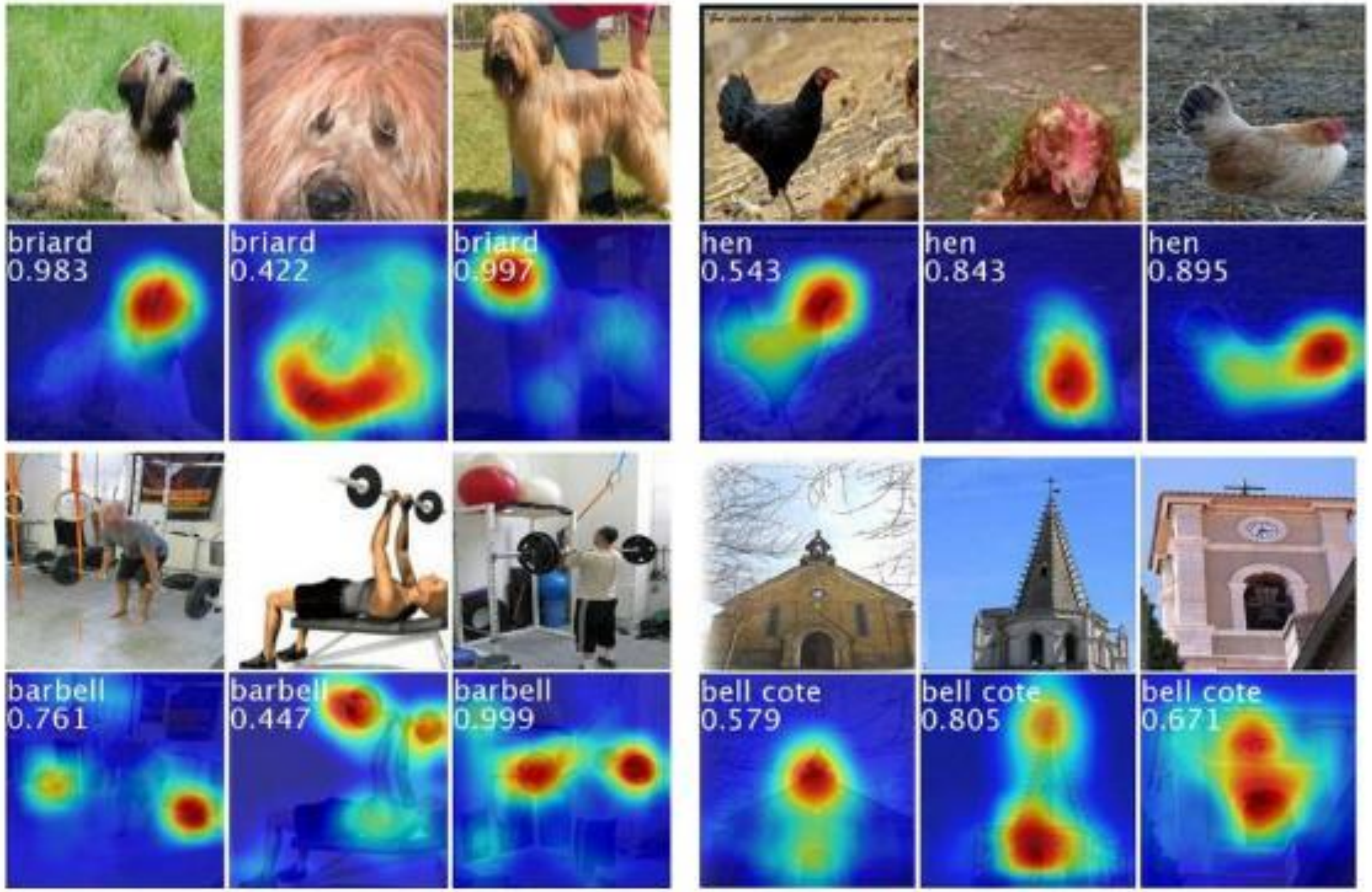
Saliency Maps

$$S = \frac{\delta y}{\delta x}$$

where

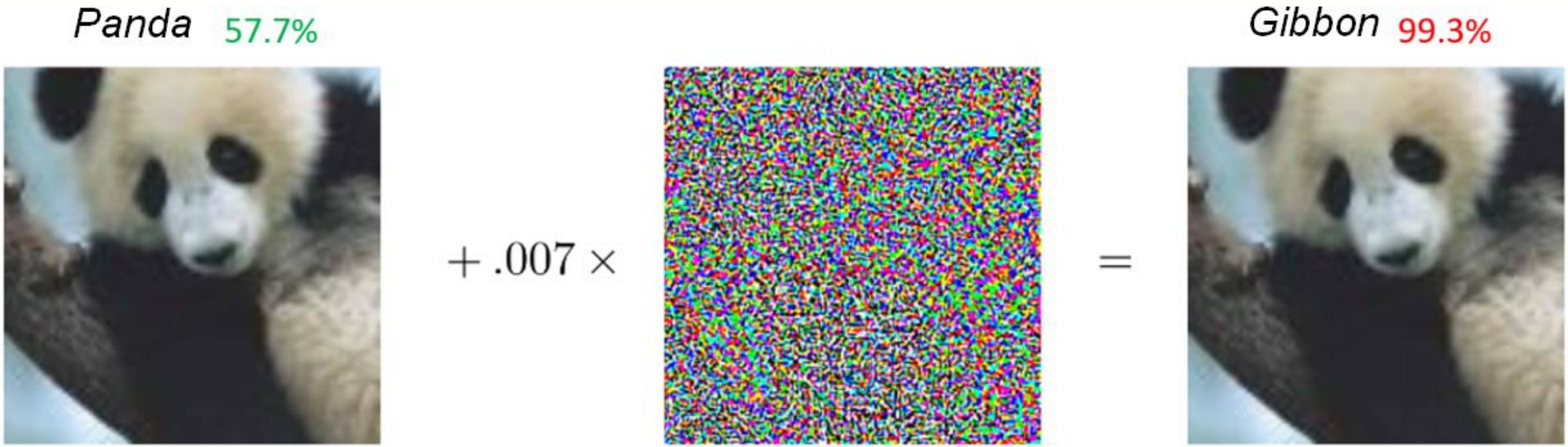
- y is the model output
- x is the pixel of interest

Saliency Maps



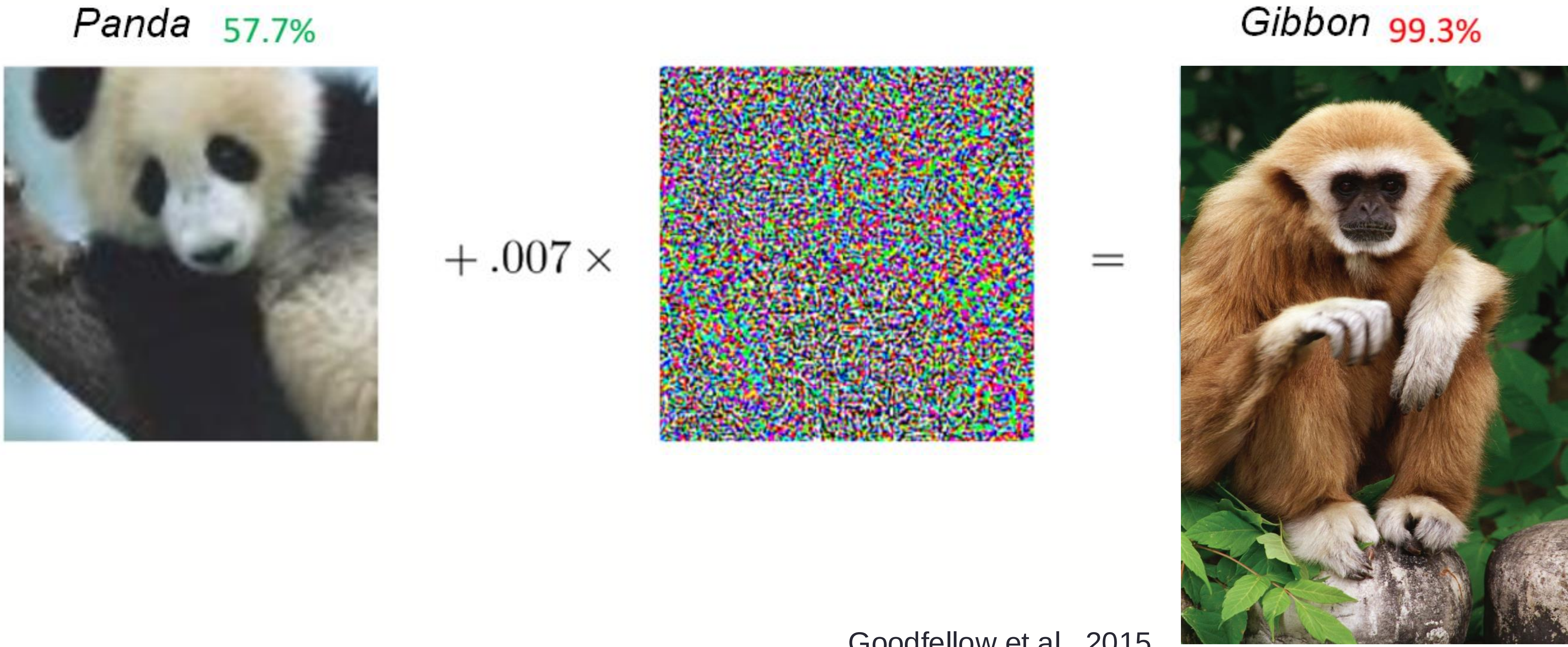
Zhou et al., 2015

Adversarial Attacks



Goodfellow et al., 2015

Adversarial Attacks



Goodfellow et al., 2015

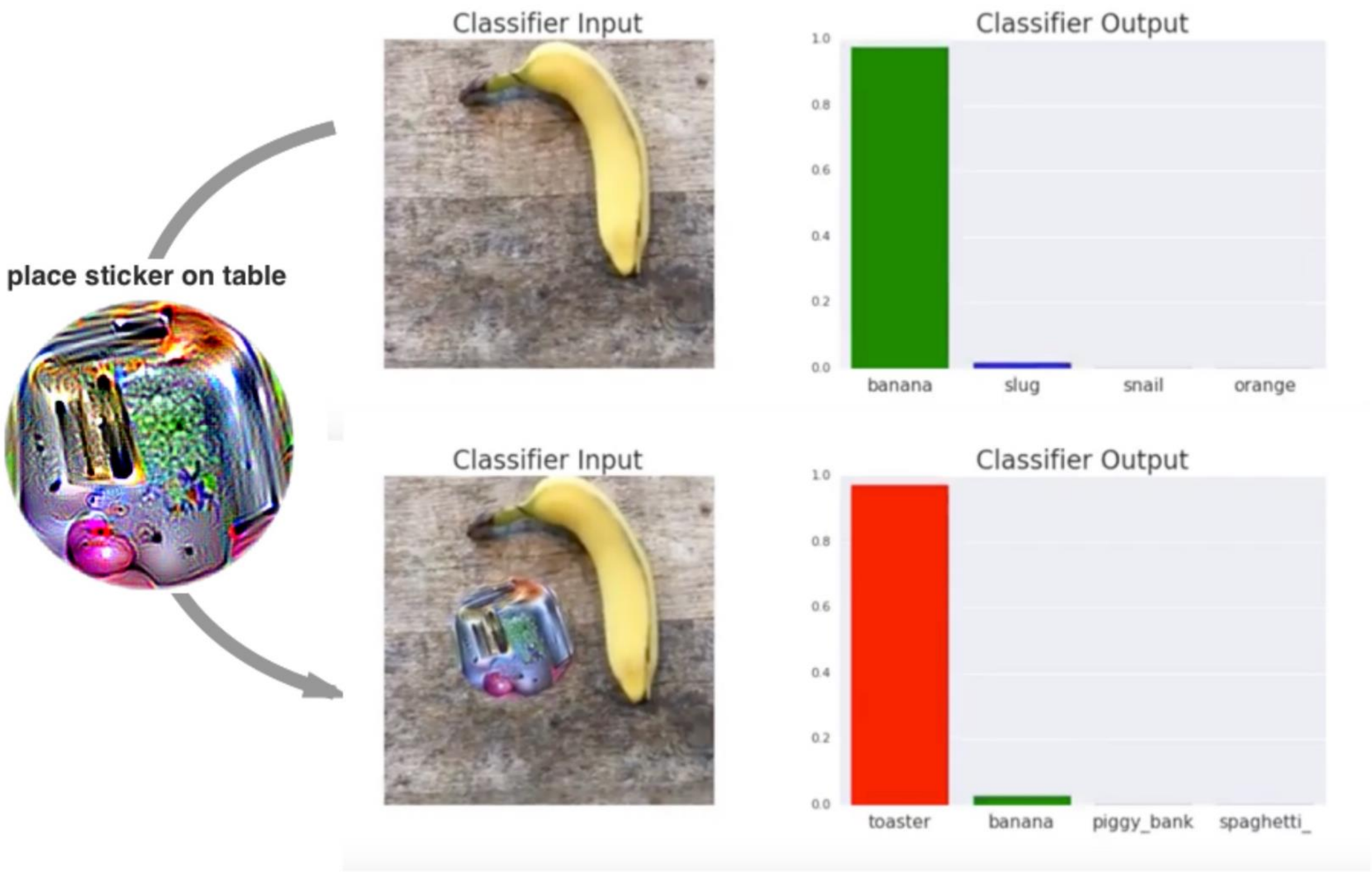


Figure 1: A real-world attack on VGG16, using a physical patch generated by the white-box ensemble method described in Section 3. When a photo of a tabletop with a banana and a notebook (top photograph) is passed through VGG16, the network reports class 'banana' with 97% confidence (top plot). If we physically place a sticker targeted to the class "toaster" on the table (bottom photograph), the photograph is classified as a toaster with 99% confidence (bottom plot). See the following video for a full demonstration: `https://youtu.be/i1sp4X57TL4`

Brown, Mané et al., 2017

Activity (45 minutes)
Classify Galaxy Mergers with CNNs

Feeling lost?
Start here!

Instructions:

1. Download the notebook at
   https://archive.stsci.edu/hello-universe/interpretability
2. Change `from keras.models import Model` to
   `from tensorflow.keras.models import Model`
3. In teams of 2 or 3, talk and work together through the tutorial

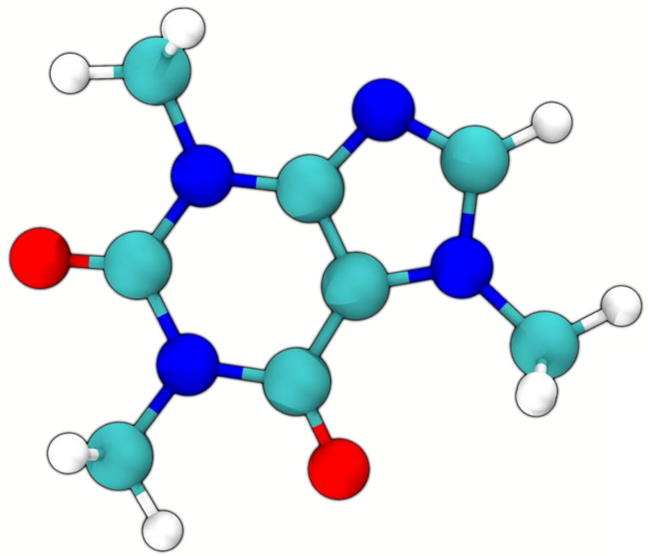
Did you finish early? Learn more by trying one of these:

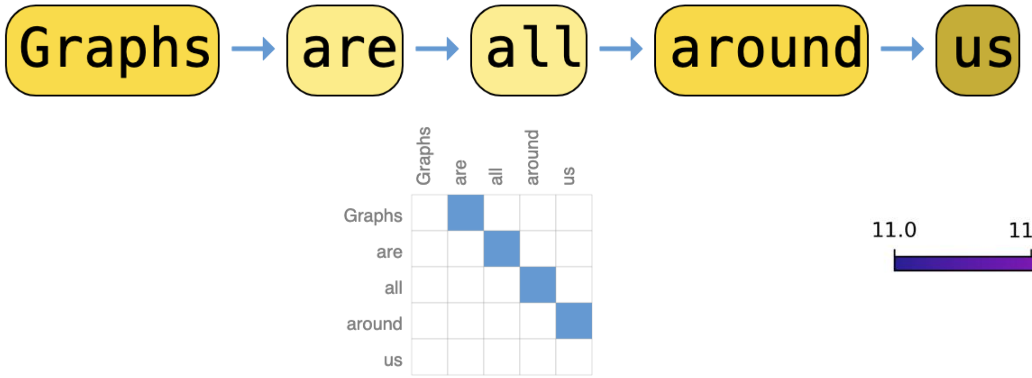
1. Learn more about adversarial patches (arxiv 1712.09665)
2. Repurpose this notebook with a toy data set to do *regression* rather than classification. *(hint: make images of blurry circles, and ask the CNN to estimate what size the circle is, then look for where it finds the information. Try offsetting the blurry circles from the center of your image.)*

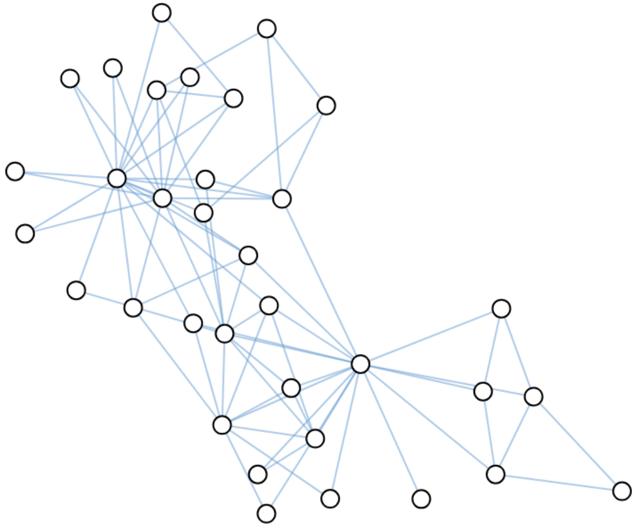
GRAPH NEURAL NETWORKS

Learning goal #5: Describe a graph. Describe pooling. List the types of problems that a GNN is well-suited for.

GNNs are good for Heterogeneously Structured Data







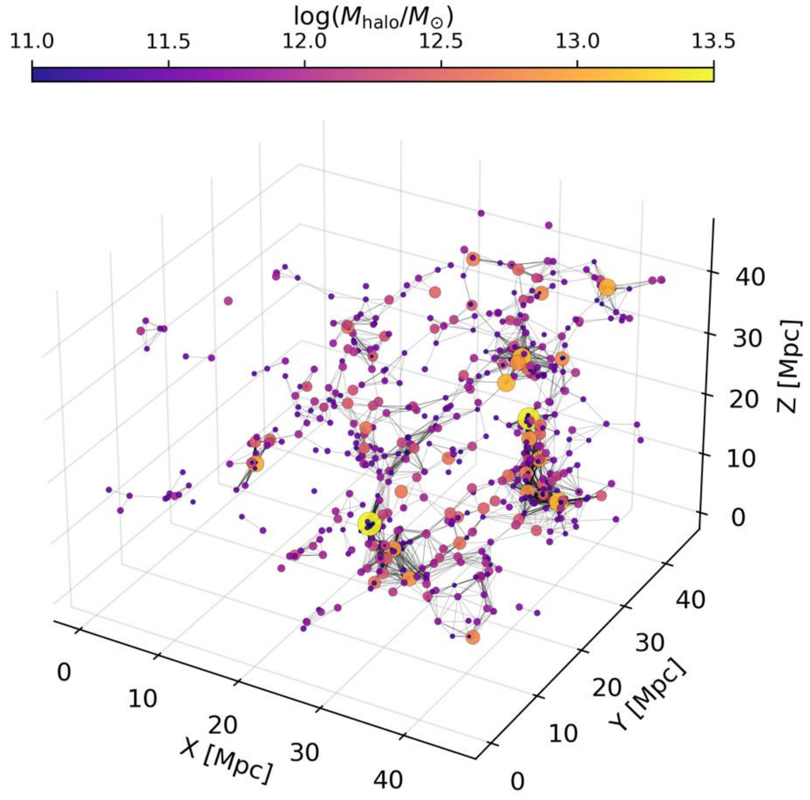


Image credit: distill.pub

What is a graph?

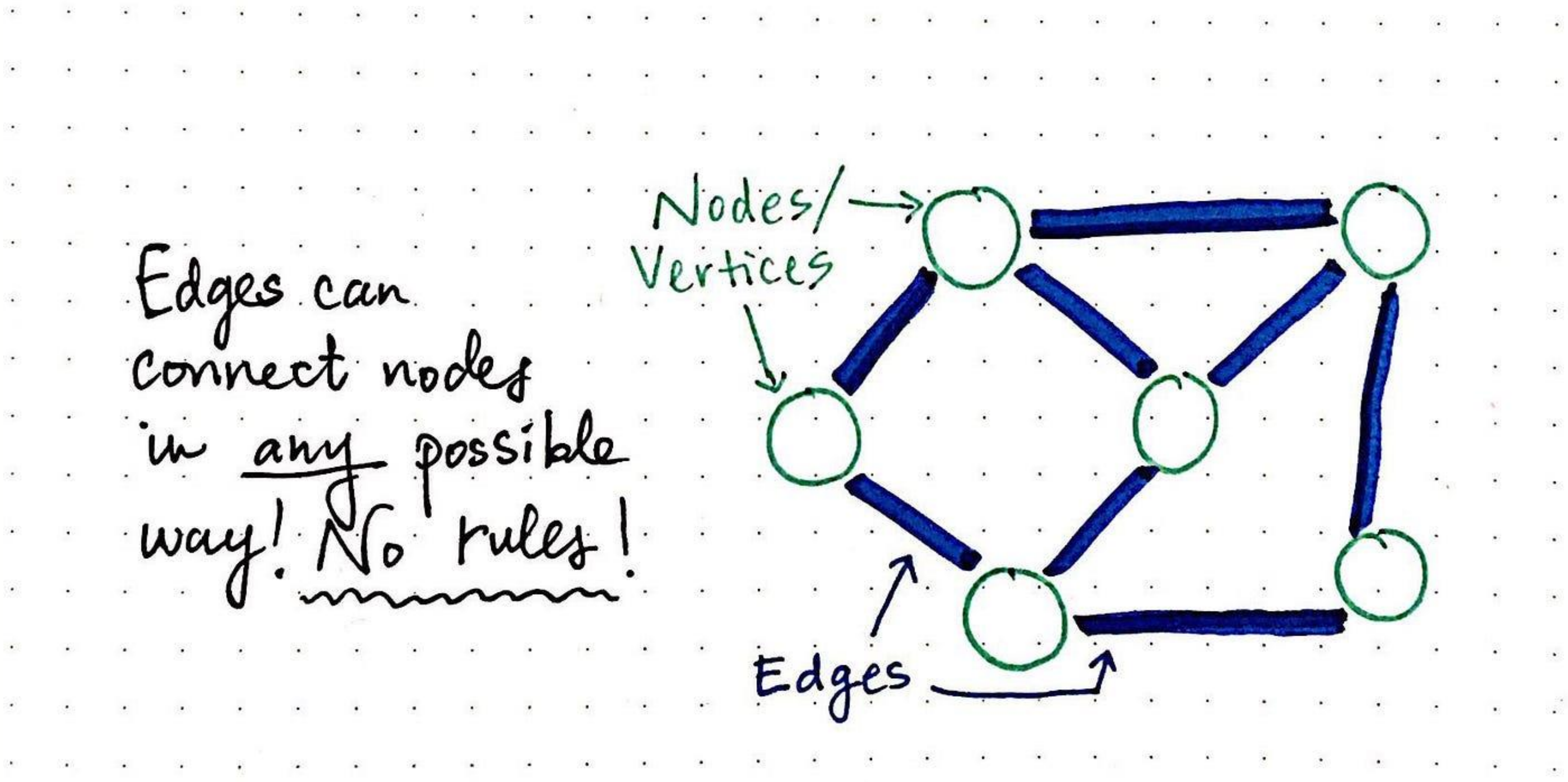
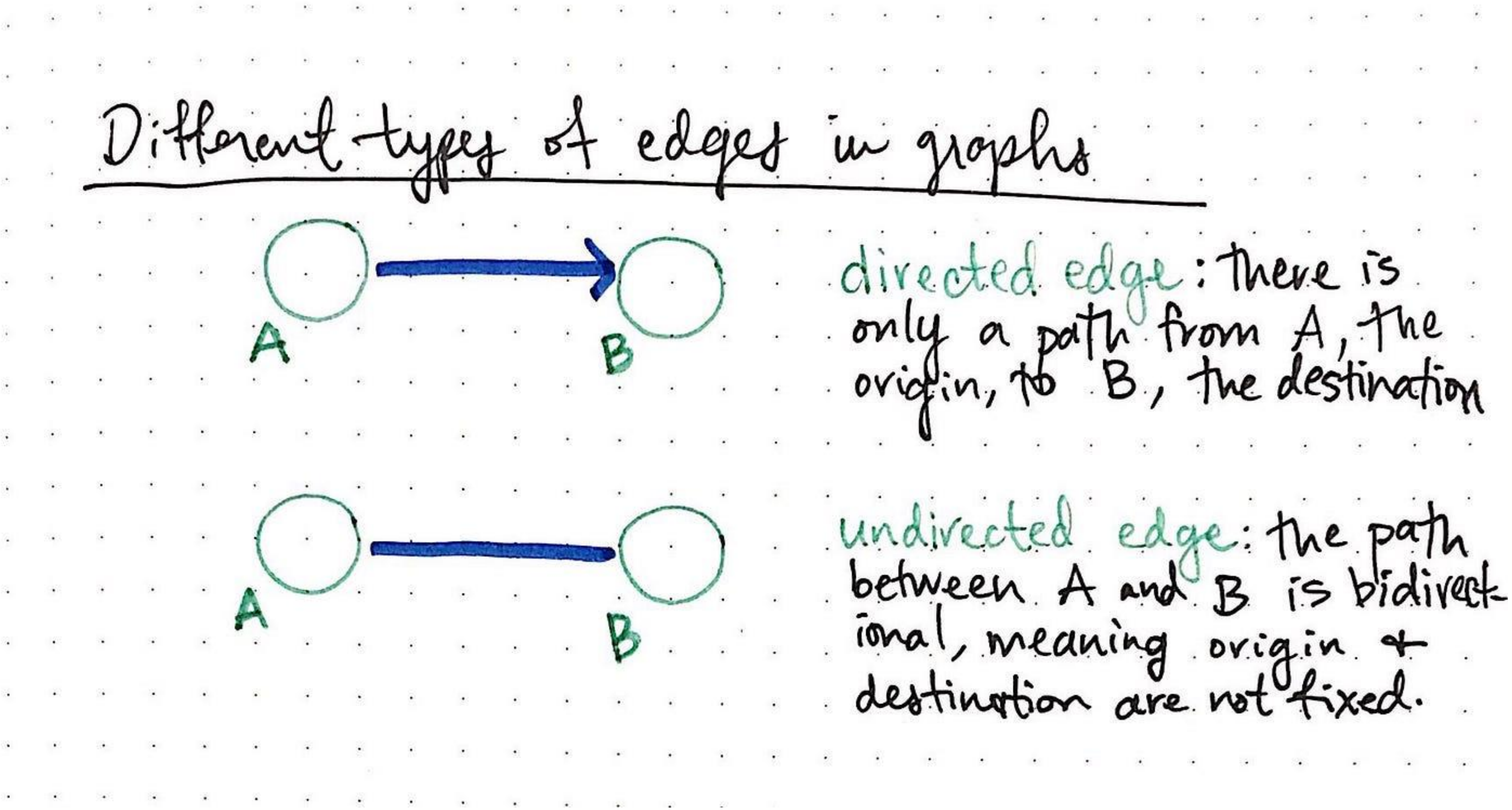


Image credit: Vaidehi Joshi, A Gentle Introduction to Graph Theory

What is a graph?



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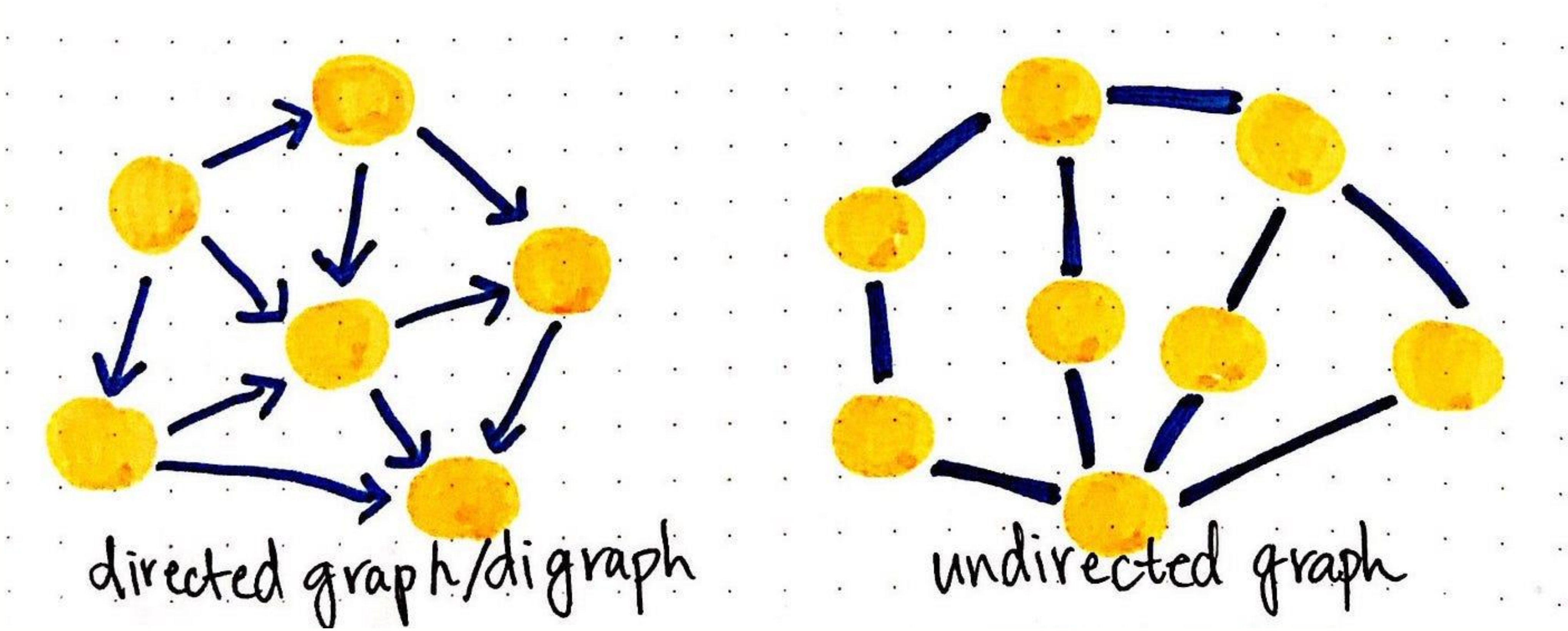

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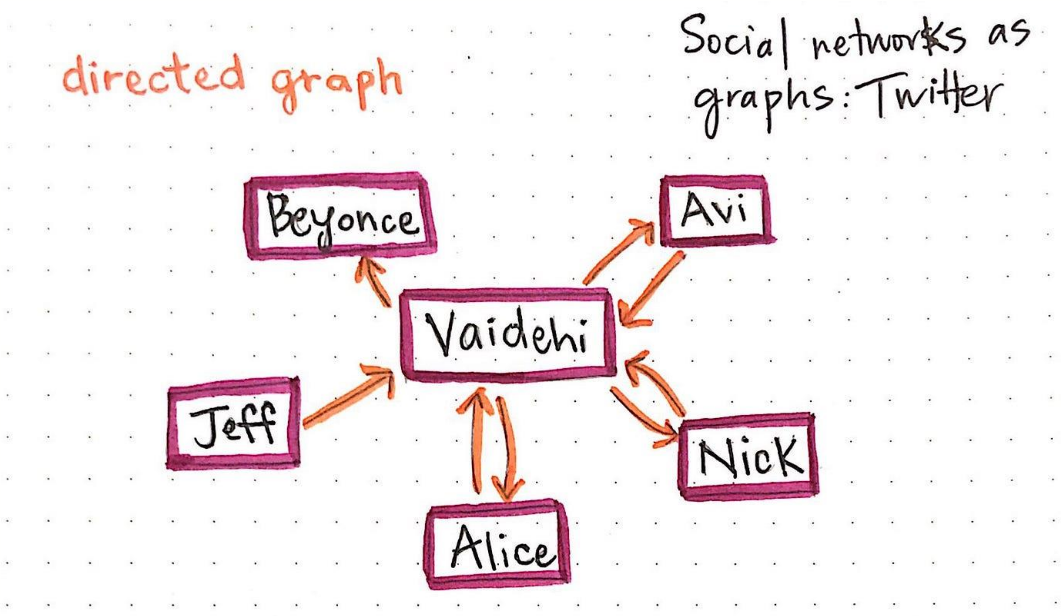
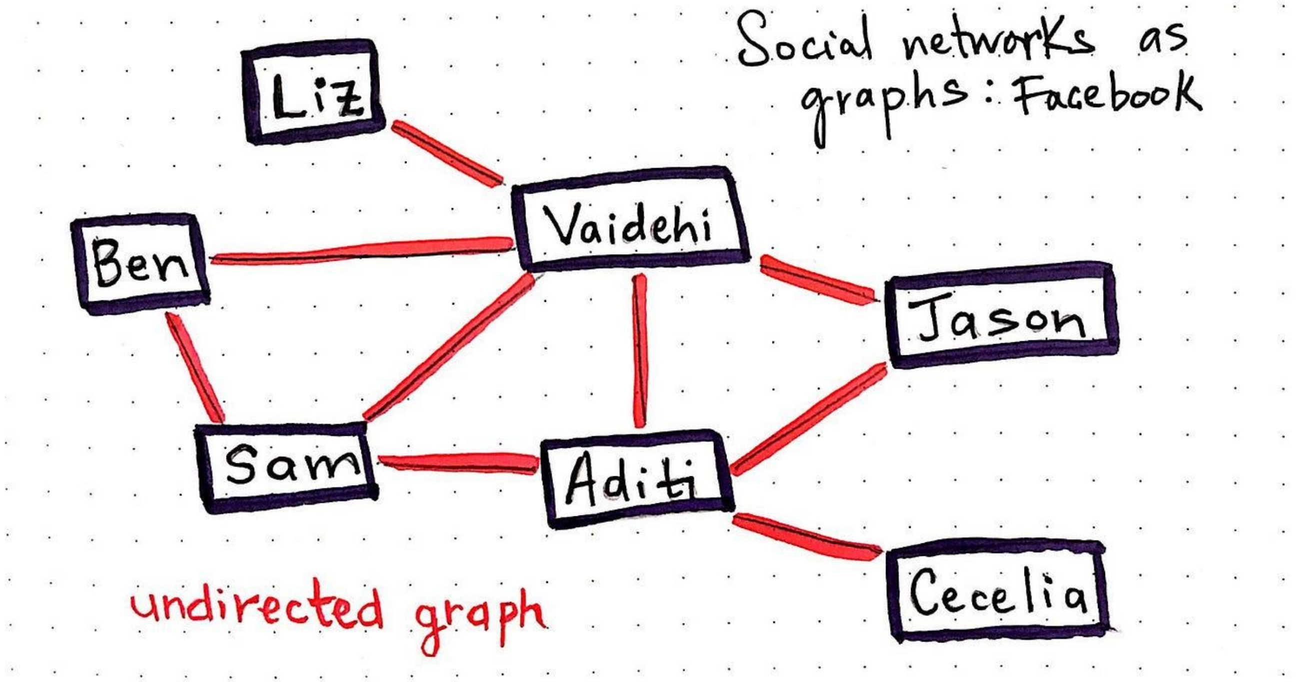
What is a graph?





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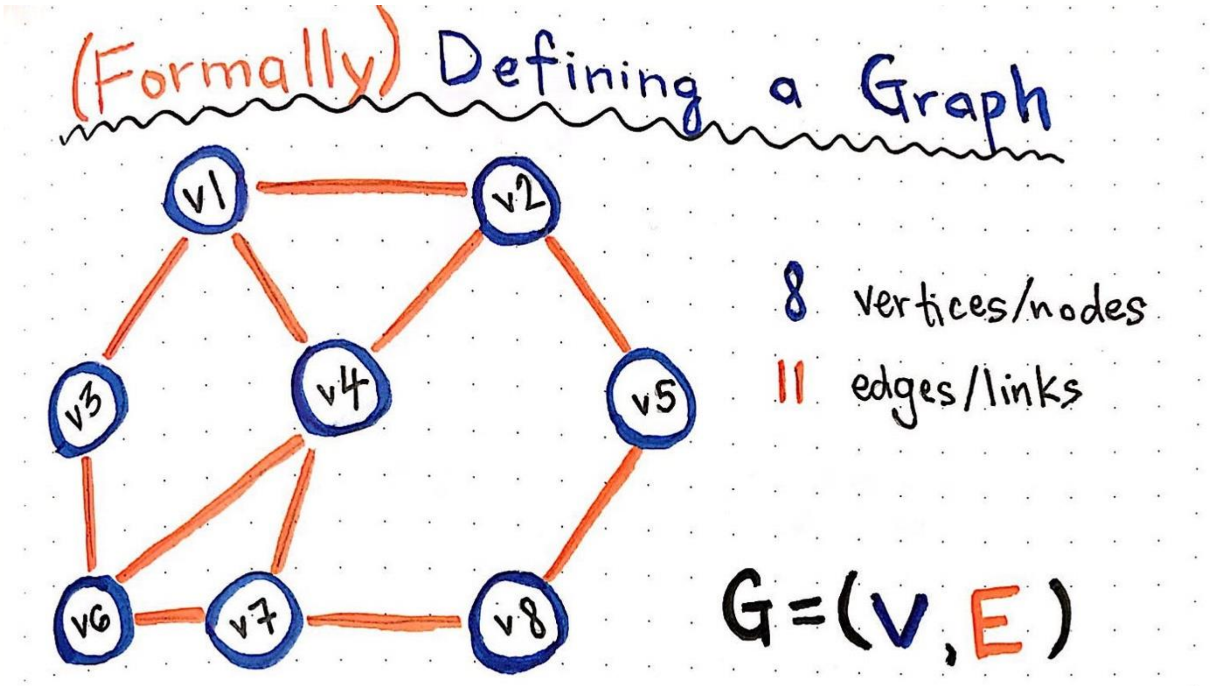


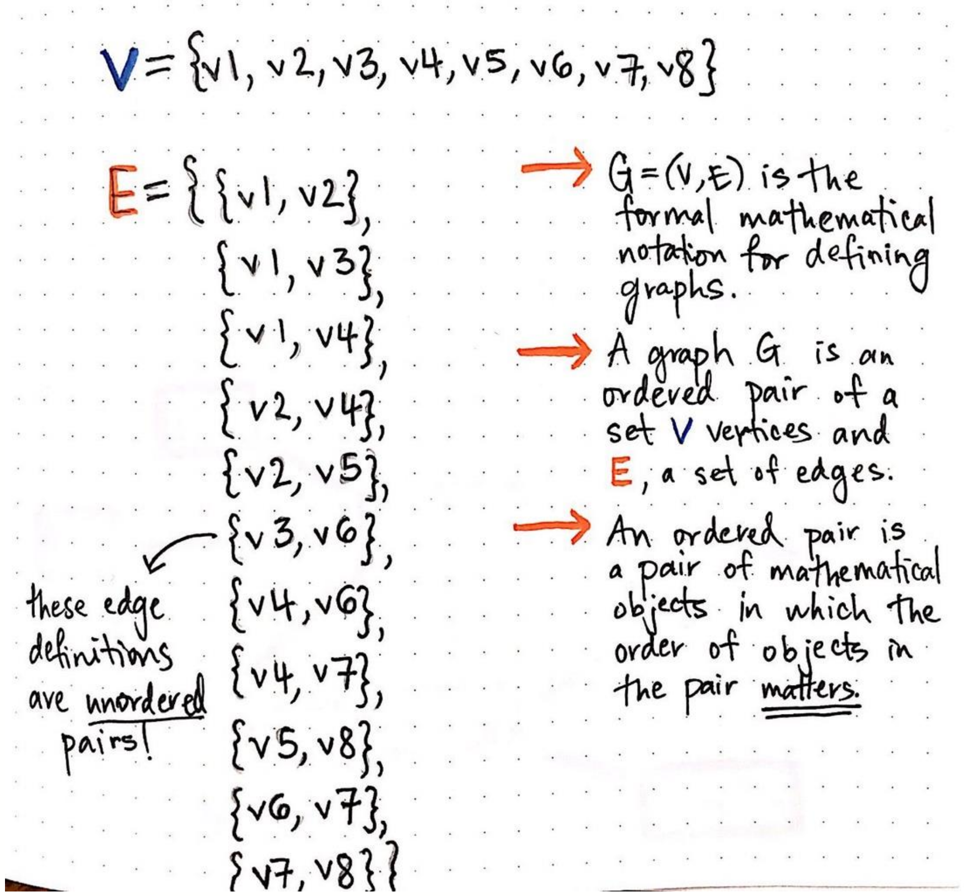
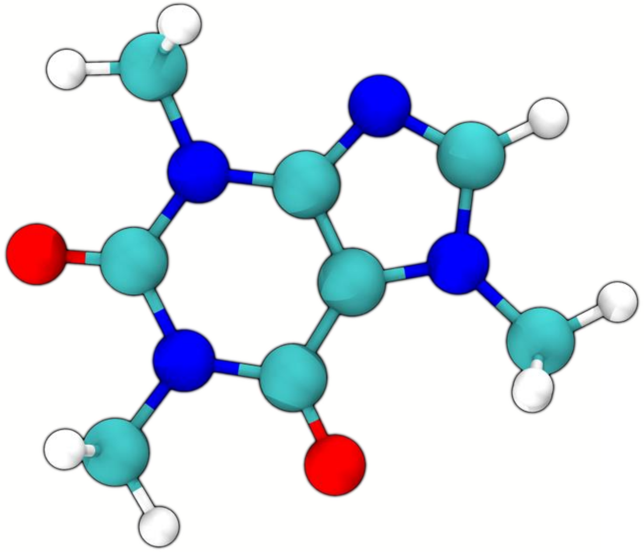
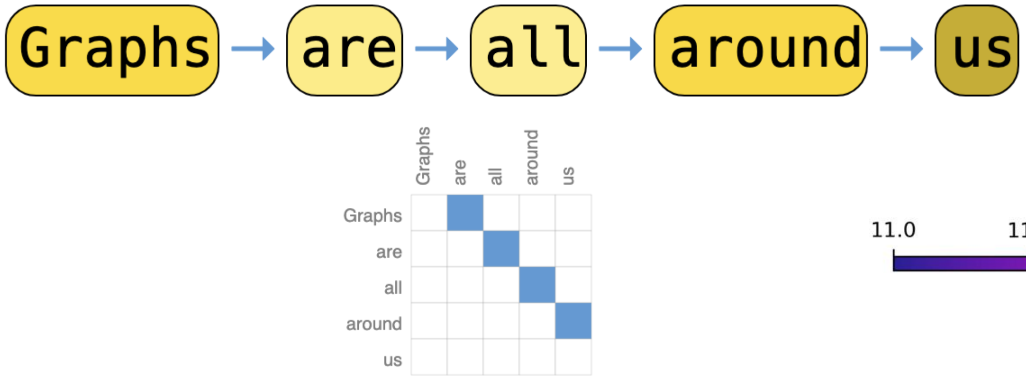
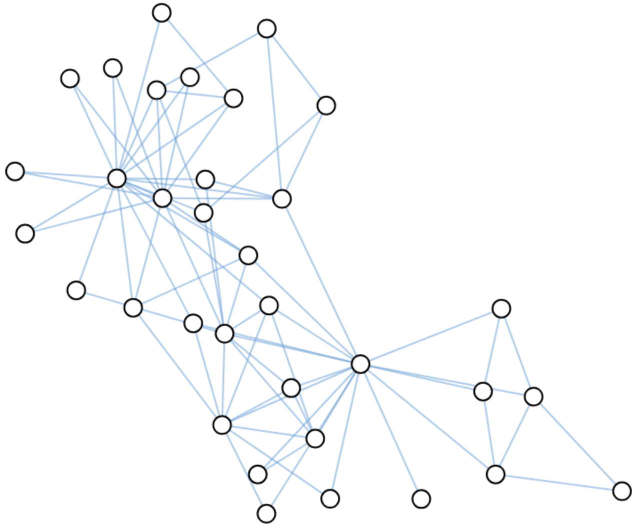


Image credit: Vaidehi Joshi, A Gentle Introduction to Graph Theory

GNNs are good for Heterogeneously Structured Data







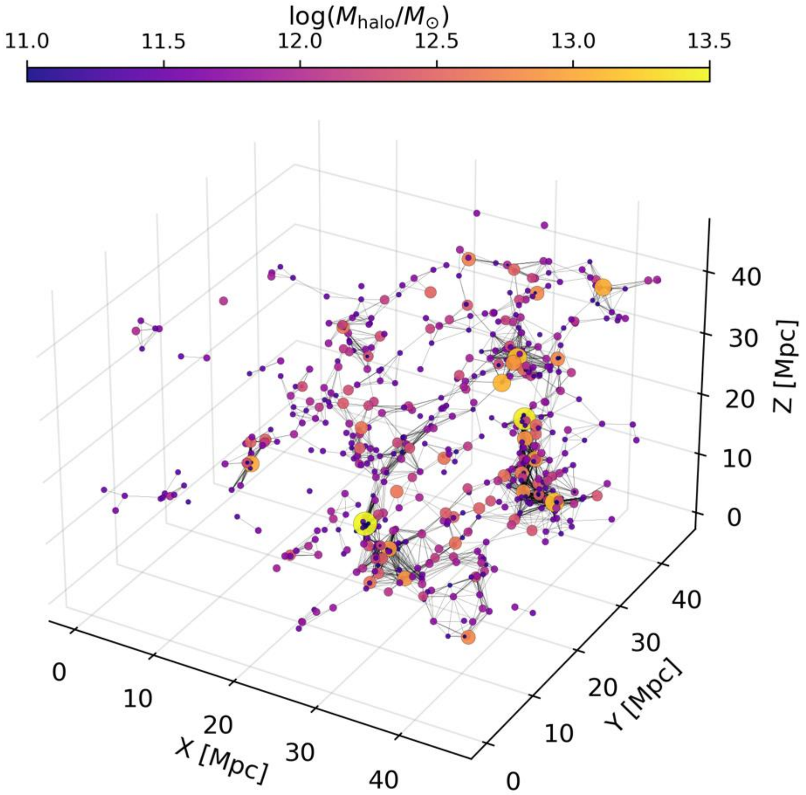
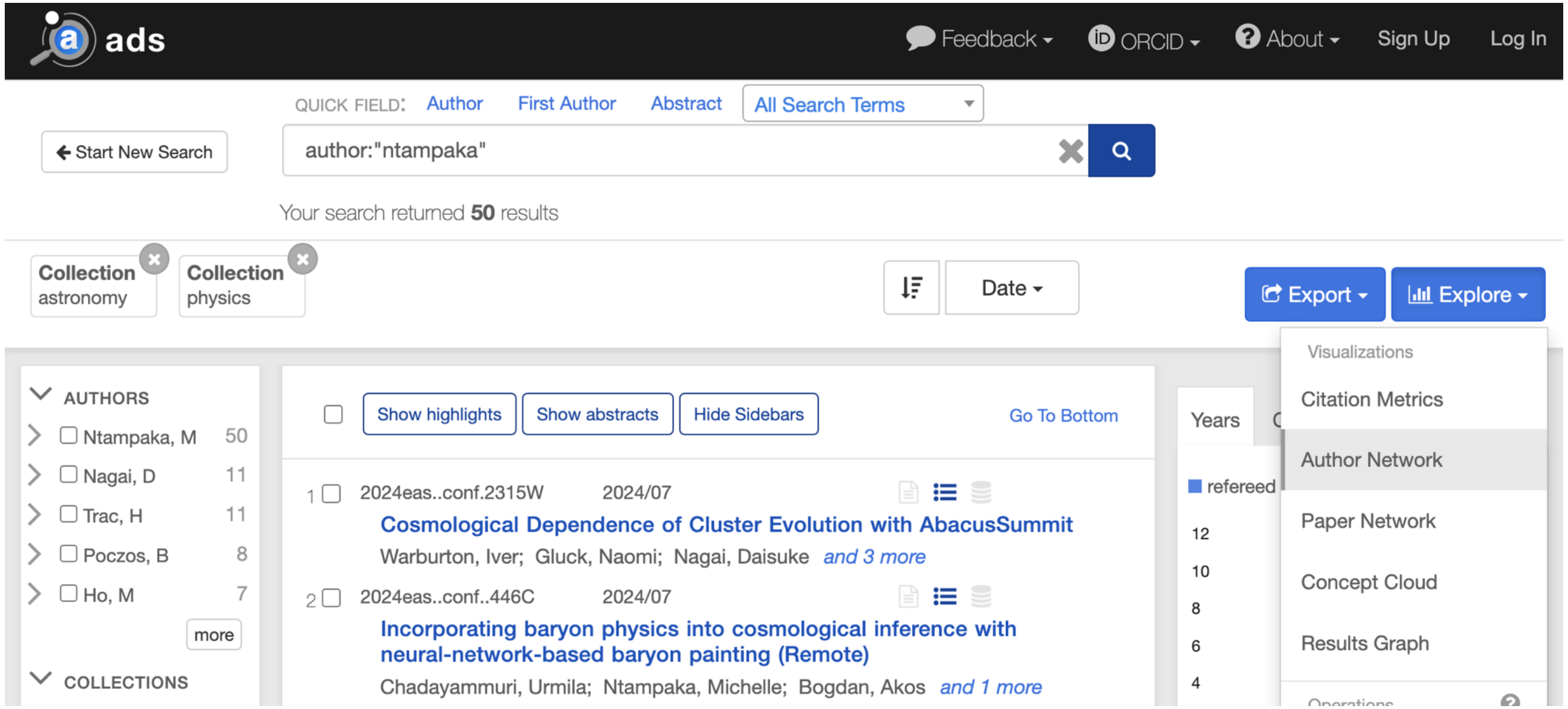


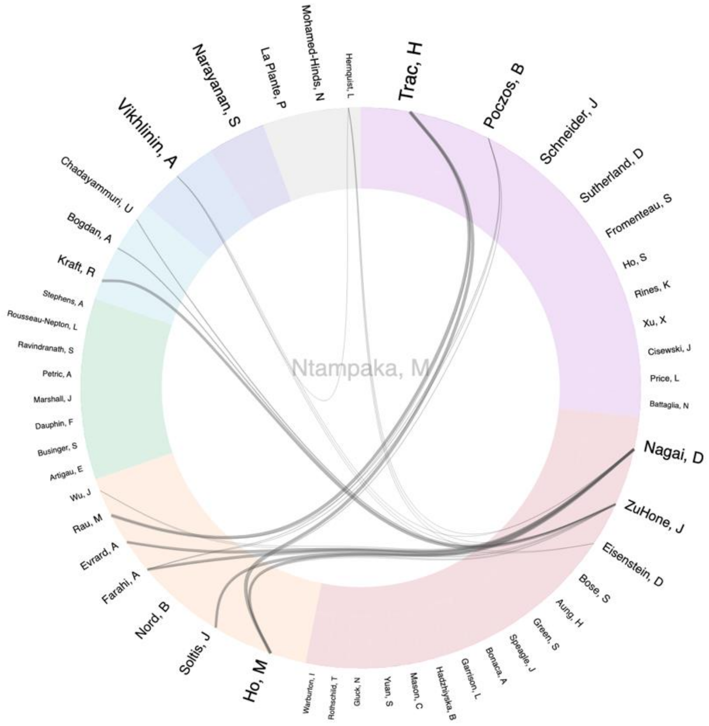
Image credit: distill.pub

Activity (10 minutes)
Graphs and Networks

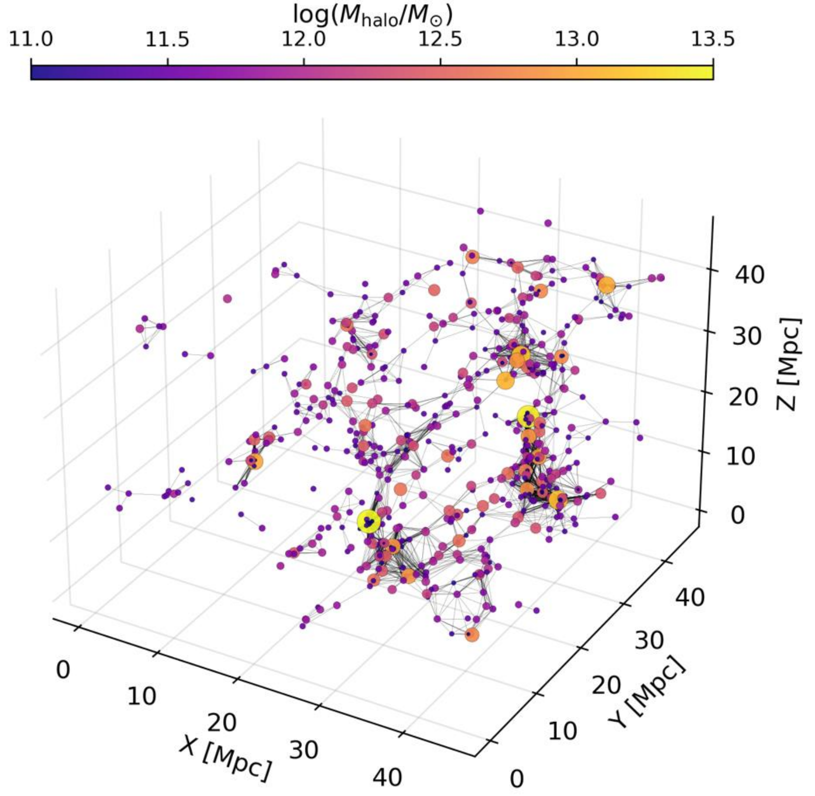
Build the authorship network for yourself or a collaborator!

1. Learn more at https://ui.adsabs.harvard.edu/help/actions/visualize
2. Build yours at ui.ads.harvard.edu



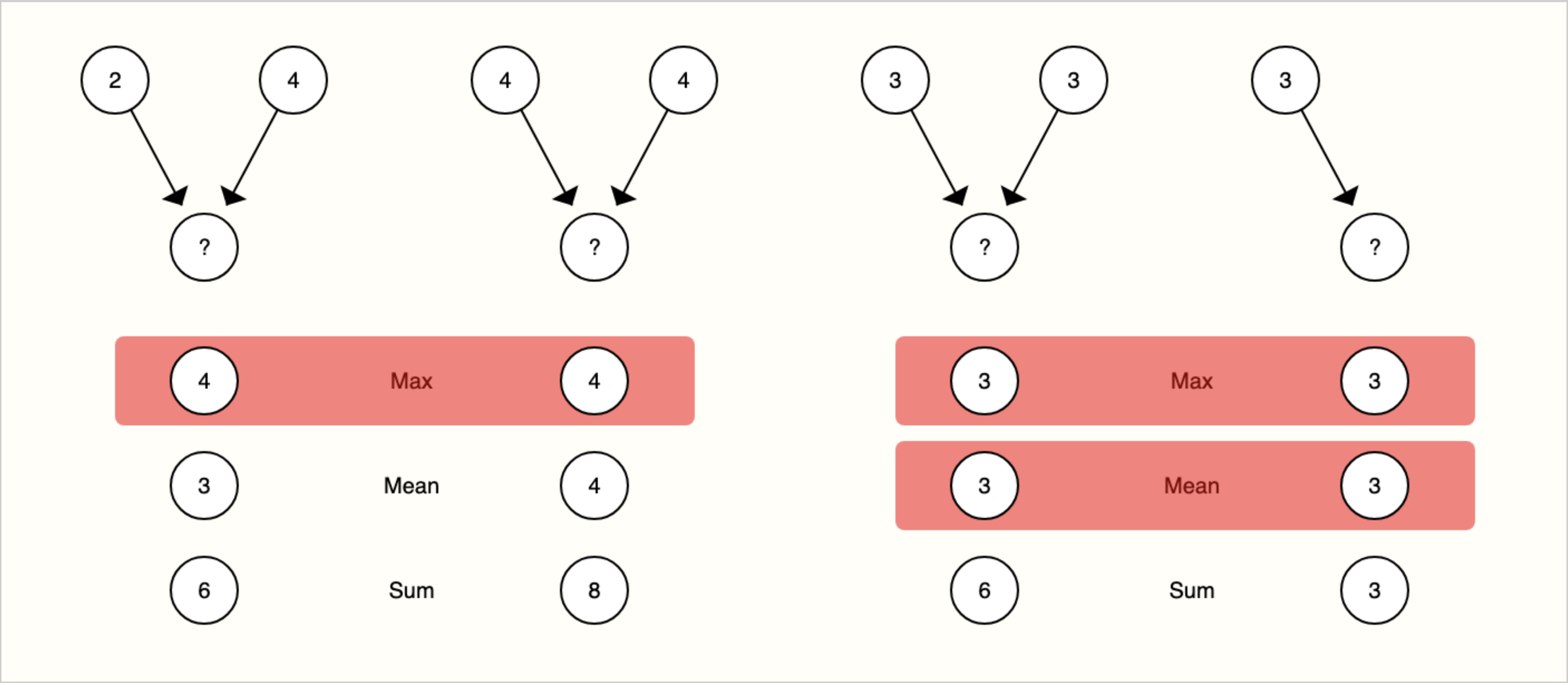


- In a graph-level task, we predict a single property for a whole graph.
- For a node-level task, we predict some property for each node in a graph.
- For an edge-level task, we want to predict the property or presence of edges in a graph.



Pooling

The <u>building block</u> of GNNs is *pooling*: nearby graph attributes are combined and summarized.



No pooling type can always distinguish between graph pairs such as max pooling on the left and sum / mean pooling on the right.

Image credit: distill.pub

GNNS IN PYTORCH

Learning goal #6: Run a GNN regressor in pytorch.

Activity (45 minutes)
More on GNNs

Feeling lost?
Start here!

Instructions: Estimate Stellar Mass with GNNs

1. Open the GNN notebook on colab at https://tinyurl.com/john-wu-gnn
2. In teams of 2 or 3, talk and work together through the example tutorial

Did you finish early?

1. Revisit some key ideas of NNs and CNNs (or learn about transformers and attention!) at the 3blue1brown youtube page:

CONCLUSION & REVIEW

Learning Goals:

0: Explain the benefits and pitfalls of feature engineering in machine vision.

1: Describe a convolutional neural network’s architecture.   List the problems that a CNN is well-suited for.

2: Describe a convolutional filter. Build a filter that can find particular shapes.

3: Run a CNN classifier in keras.

4: Develop techniques for interpreting CNNs and understanding what pixels are most informative in the model’s decision-making

5: Describe a graph. Describe pooling.   List the types of problems that a GNN is well-suited for.

6: Run a GNN regressor in pytorch.

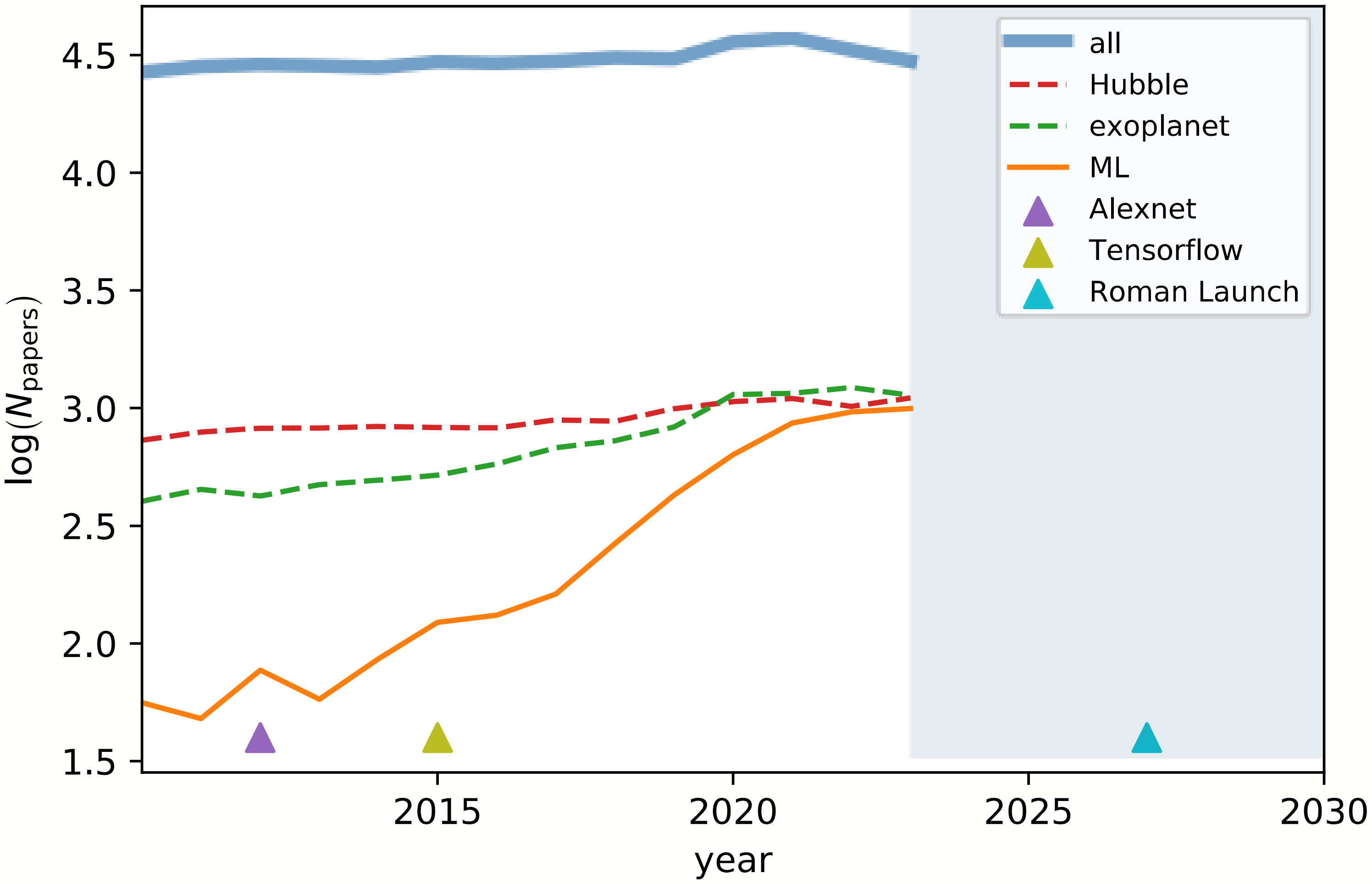
Astro2020 Decadal Report:

Machine learning has already shown significant success at providing tools for identifying anomalies in data, and can speed up parameter estimation in large data sets by significant factors… These techniques could lead to **transformative discoveries** from the new data sets available in the 2020s.

Astronomy a perfect sandbox for machine learning.

- Minimal privacy concerns.
- Culture of sharing data.
- Well-posed questions.
- Public interest and support.
- Data are non-monetizable.
- *This does not exempt us from ethical concerns!*

MLxAstro is Fast-Moving



Rewrite the plans for A3Net Summer School, in the style of "This is Just to Say," the William Carlos Williams poem about the plums and the icebox.

This is just to say

We have set up
the summer school
in Osaka
this fall

to teach you
the ways
of machines
and galaxies

Forgive us
it will be demanding
but rich
and full of light