Course overview and logistics

CS861: Theoretical Foundations of Machine Learning

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AI/ML is popular nowadays!

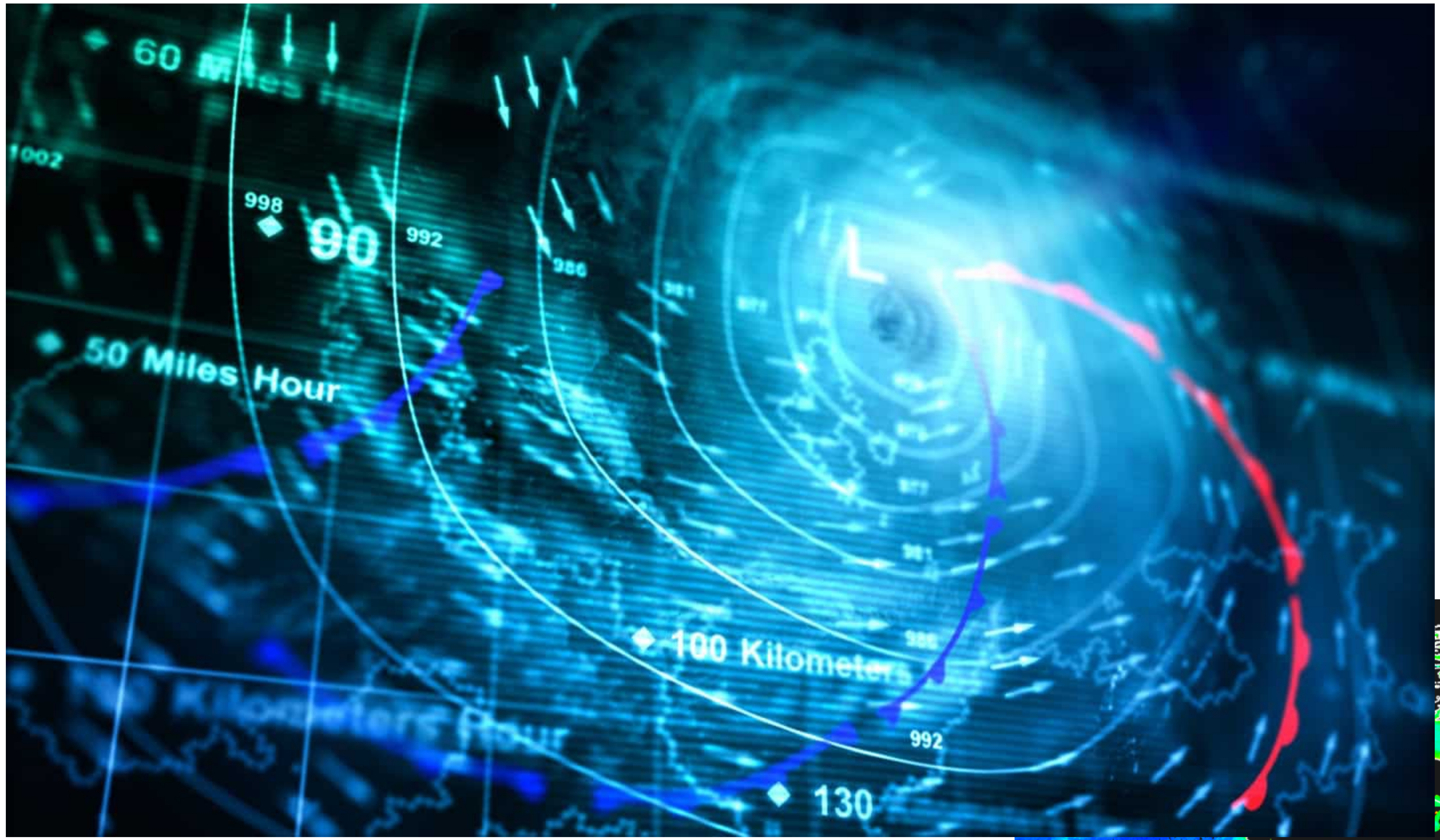
- *"A breakthrough in ML will be worth 10 Microsofts"*
  - Bill Gates

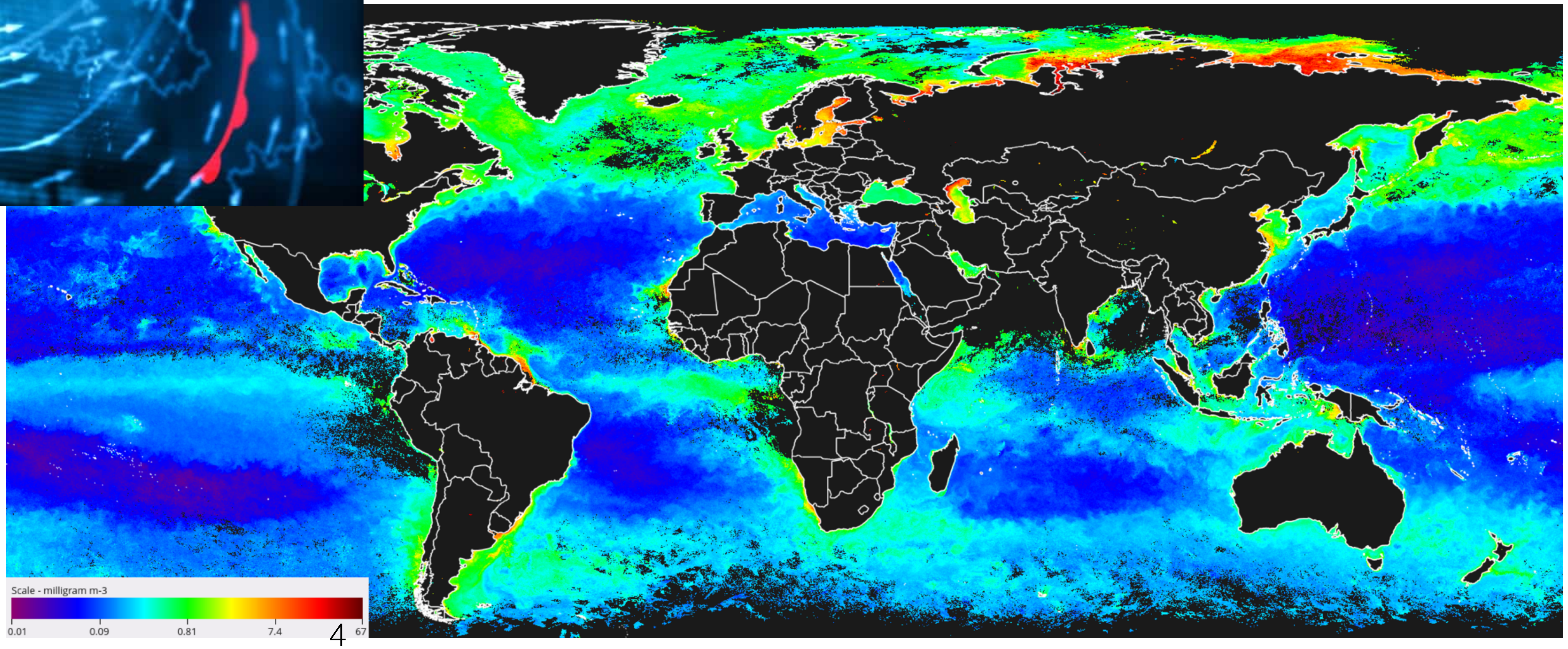
- *"ML is the new internet"*
  - Tony Tether, Director, DARPA

- *"AI will be the best or worst thing ever for humanity"*
  - Elon Musk

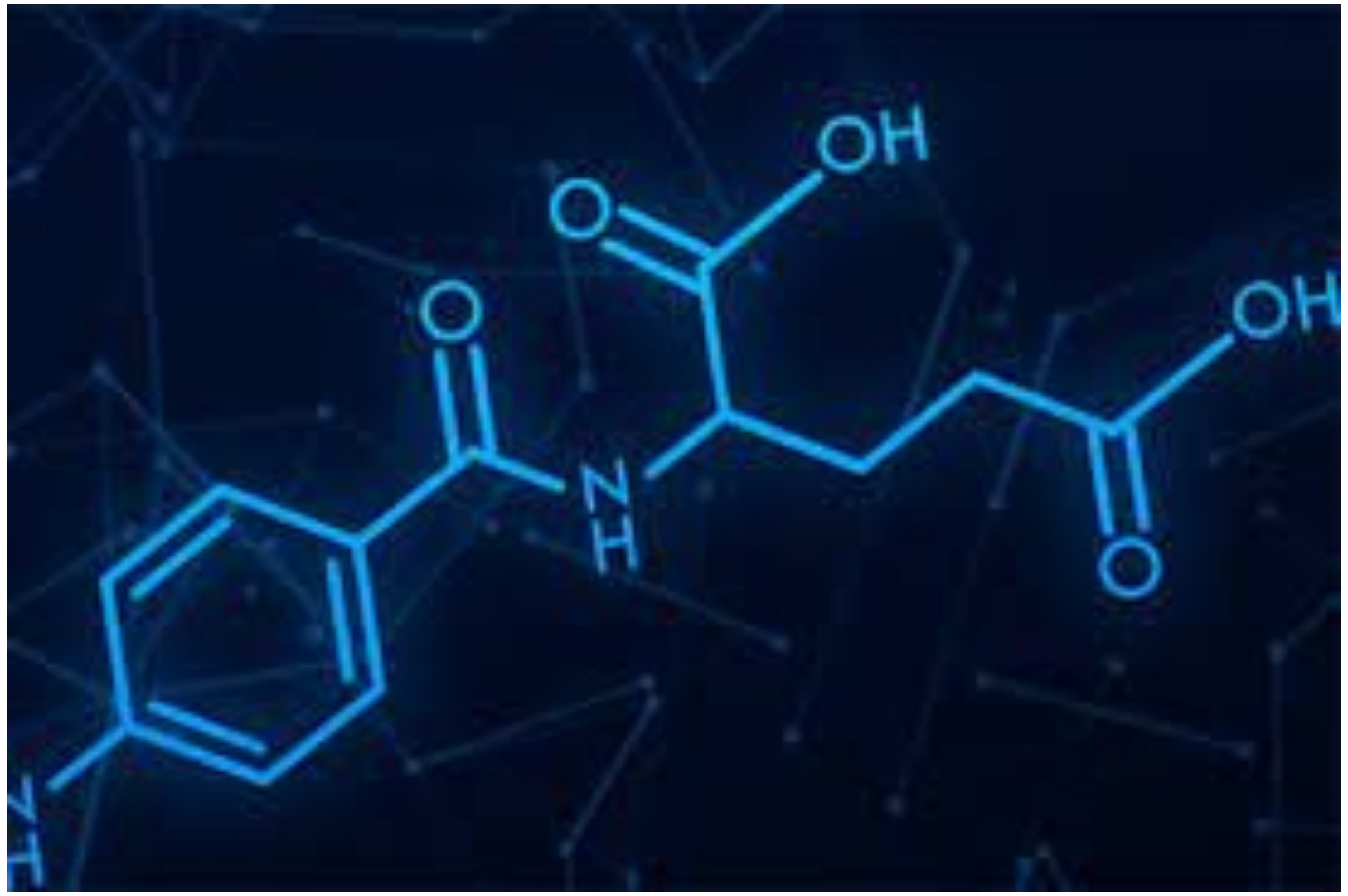
Object detection & segmentation

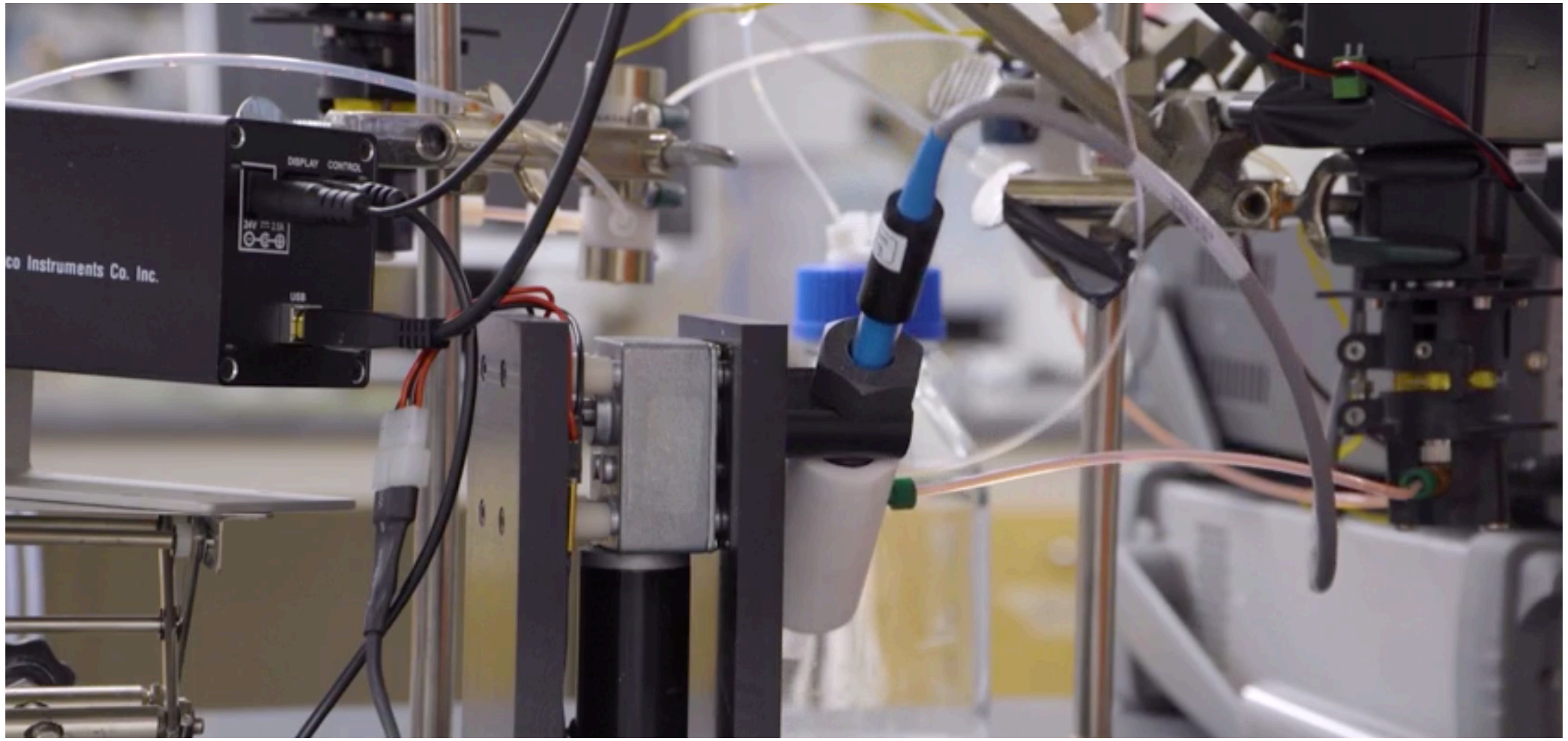
Weather forecasting & Climatology





Optimizing drugs and materials





Autonomous vehicles

Language generation & LLMs

Q: What is your favorite animal?
A: My favorite animal is a dog.

Q: Why?
A: Because dogs are loyal and friendly.

Q: What are two reasons that a dog might be in a bad mood?
A: Two reasons that a dog might be in a bad mood are if it is hungry or if it is hot.

Q: How many eyes does a giraffe have?
A: A giraffe has two eyes.

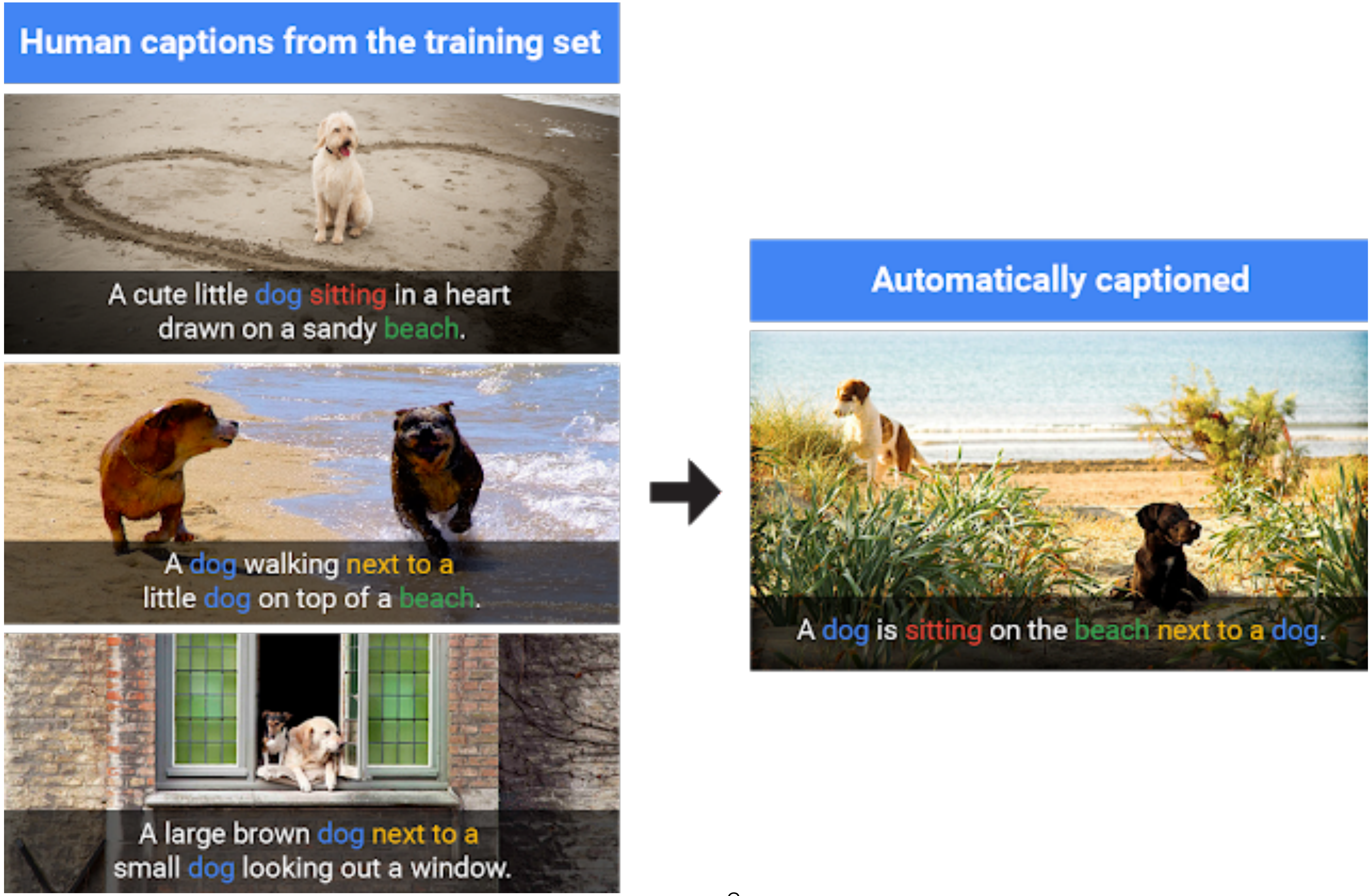
Q: How many legs does a frog have?
A: A frog has four legs.

Q: Are there any animals with three legs?
A: No, there are no animals with three legs.

Q: Why don't animals have three legs?
A: Animals don't have three legs because they would fall over.

Image generation

Image to text generation



This class: *Theoretical Foundations* of ML

Why take this class? Why study ML theory?

1. Understand fundamental limitations about a learning problem.
    - When is it possible to learn?
    - What are the primary challenges we need to solve?
    - How much data do we need to learn?

This class: *theoretical foundations* of ML

Why take this class? Why study ML theory?

2. Develop fundamental intuitions for designing learning algorithm
    - What is the "correct" way to think about these challenges?
    - How do we trade-off between multiple challenges?

Will focus on simple (as opposed to *"realistic/practical"*) settings

3. It is fun!

Outline

1. Course logistics
2. Syllabus
3. Who should take this class? Prerequisites and expectations

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Logistics: Lectures, OHs, Grader, Enrollment

- **Lectures**
  - MWF, 11 am - 12.15 pm at ENGR HALL 3534.
  - 27-30 lectures. Class will conclude around the first or second week of Nov.
  - Slides will be posted ahead of the lecture.
  - Lectures will be mainly on I-Pad and Whiteboard.

- **My office hours:** Wed 1.30 - 2.50 pm at MH5066
- **Grader:** Julia Nakhleh
- **Enrollment**
  - If you cannot enroll due to pre-requisites, please speak to me.

Logistics: Webpages

- **Course website**
  - https://pages.cs.wisc.edu/~kandasamy/courses/25fall-cs861
  - Logistics, syllabus, lectures, homeworks, and grading

- **Piazza**
  - https://piazza.com/wisc/fall2025/csece861
  - Ask public questions whenever possible.
  - Announcements, peer discussions on lectures, homework clarifications.

- **Canvas**
  - Homeworks, exams, and some announcements

Grading

- **Proofreading lecture notes (slides): 4%**

- **Homeworks: 42%**

- **Take-home Exam: 32%**

- **Course project (setting a homework question): 22%**

Proofreading lecture notes (slides)

- Each student will proofread ~2 lectures. Two students per lecture. (This may change if enrollment drops.)
  - See course website for sign-up link

- **Instructions (see course website as well)**
  - Proofreaders **must** attend class.
  - After class, carefully read and identify typos, errors, and unclear explanations.
  - Within **2 days**, each student will **email separate submissions**, either marked on downloaded slides or typed up as a separate pdf.
  - If you are unsure about taking the class, sign up for after Oct 6. If you decide to drop, *delete your name* ***and*** *email me*.
  - After you sign up, please don't change your slot without informing me.

Homework

- 5 Homeworks (including homework 0)
- Typically due every other Saturday at 11.59pm on Canvas.

- A total of 3 late days for the entire course. Extensions only for documented emergencies.

- Homeworks will be *difficult*.
  - Expect to spend multiple hours/days on some problems.
  - On starred (*) problems, you *are allowed* to collaborate with up to 2 classmates. You should attempt other problems on your own.
  - Do not search the internet or use LLM-based tools.

Take-home Exam

- Take-home exam from Mon 11/17 12.01 AM – Fri 11/21 11.59 PM.
- You have 48 hours to complete the exam.
- No collaboration allowed on the exam.

Course project (setting a homework problem)

- You will work in groups of size up to 3, to design a homework problem.
- Your peers will attempt and evaluate your question.
- Model depth/difficulty based on starred homework problems in HW 1 - 4 (not HW 0).
- See webpage for guidelines.

Key dates

- A preliminary draft of the problem (with solutions) due on Sat 10/18.
- Final problems due on Sat 11/15.
- I will assign 1-2 questions to each of you. Solutions and evaluation of the questions due on 12/06.
- If you set a good question, I will include it in future courses and acknowledge your contribution!

Outline

1. Course logistics

2. **Syllabus**

3. Who should take this class? Prerequisites and expectations

Syllabus: Overview

0. Background topics
1. Statistical lower bounds
2. Nonparametric methods
3. Statistical learning theory
4. Stochastic bandits
5. Online learning and adversarial bandits
6. Online convex optimization

1. Statistical lower bounds (6-9 lectures)

- Lower bounds for for point estimation
- Lower bounds for hypothesis testing: Le Cam & Fano methods
- Going from estimation to testing
- Plan: lower bounds for mean estimation in Ch 1, but we will apply the ideas to classification, regression, density estimation, online learning, bandits etc.

2. Nonparametric methods (2-3 lectures)

- Nonparametric regression, Nadaraya-Watson estimator
- Kernely density estimation
- Lower bounds for regression and density estimation

3. Statistical Learning Theory (7-10 lectures)

- Basic framework: loss, hypothesis classes, excess risk
- Empirical risk minimization
- Uniform convergence
- Rademacher complexity
- VC dimension and Sauer's Lemma
- Dudley entropy integral and chaining
- Lower bounds: binary classification, linear regression

4. Stochastic bandits (4-6 lectures)

- Optimism in the face of uncertainty and the Upper Confidence Bound (UCB) algorithm
- Lower bounds for stochastic K-armed bandits
- Linear bandits, martingale concentration
- Best arm identification (if time permits)

5. Online learning, Adversarial bandits (5-7 lectures)

- Learning from experts and the Hedge algorithm
- Adversarial bandits and EXP3
- Lower bounds for adversarial bandits and learning from experts
- Contextual bandits and EXP4
- Learning in games (if time permits)
- Regret minimization in non-stationary environments (if time permits)

6. Online Convex Optimization (4-5 lectures)

- Follow the leader, Follow the regularized leader
- FTRL with convex regularizers
- Online gradient descent
- Follow the perturbed leader, online shortest paths
- Lower bounds for OCO

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Target audience for the class

- Ph.D students doing research in theoretical **(statistical)** machine learning.

- **Background knowledge**
  - **Formal prerequisite:** CS761 or equivalent.
  - Strong background (intermediate-level graduate course) in statistics, probability, and mathematics (calculus, linear algebra etc).

- **Who should not take this class**.
  - *“I want to learn about ML/AI”* (Take 540, 532)
  - *“I want to apply ML in an applied area of research*" (Take 760)
  - *“I want to learn take an introductory ML theory class”* (Take 761)

Homework 0

Three problems:

1. Normal mean estimation
2. A simple bandit model and algorithm
3. Some questions from Chapter 0

Three Objectives

I. A preview of some topics

II. Lets you assess if you are ready to take this class

General advice when taking this class

1. Focus on learning, and not on grades.
    - Class will be challenging. But if you are able to keep up, you will get a good grade.

2. Give me feedback about the course.

3. Be good citizens: attend class, ask questions, answer questions, let others answer/ask questions, respond to questions on piazza.