

Lecture 1

# Introduction to Modeling

DSC 40A, Spring 2024

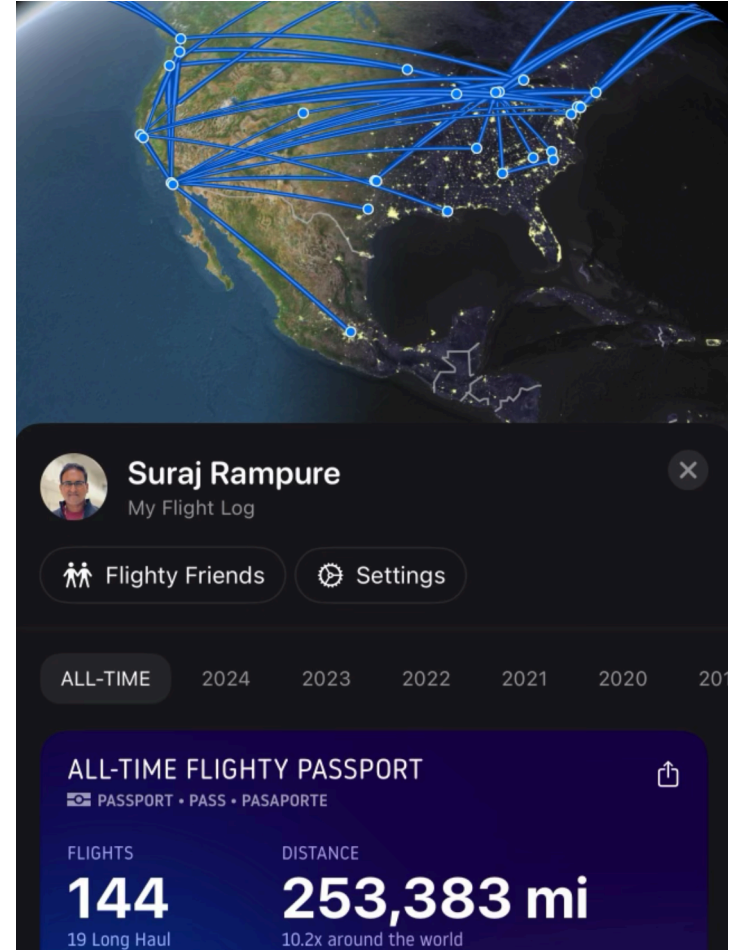
# Agenda

- Introductions.
- What is DSC 40A about?
- Logistics.
- Modeling.
- The constant model.

# Introductions

## Instructor: Suraj Rampure ("soo-rudge")

- Originally from Windsor, ON, Canada 🇨🇦.
- BS and MS in Electrical Engineering and Computer Sciences from UC Berkeley 🐻.
- Third year teaching in the Halıcıoğlu Data Science Institute at UC San Diego.
  - 2nd time teaching DSC 40A (last time: Fall 2021!).
  - Also teaching DSC 95 and running the senior capstone program (DSC 180A + 180B).
  - Previously taught DSC 10 (5x) and DSC 80 (3x).
- Outside interests: traveling, hiking, eating out, FaceTiming my dog 🐕, etc.



My spring break.

## Course staff

We have 12 tutors, all of whom are excited to help you in discussion and office hours!

Jack Determan

Yosen Lin

Utkarsh Lohia

Zoe Ludena

Mert Ozer

Varun Pabreja

Javier Ponce

Harshita Saha

Candus Shi

Charlie Sun

Nicholas Swetlin

Benjamin Xue

Read more about us at [dsc40a.com/staff](https://dsc40a.com/staff).

## Throughout lecture, ask questions!

- You're always free to ask questions during lecture, and I'll try and stop for them frequently. But still, you may not feel like asking your question out loud.
- You can **type your questions anonymously** at the following link and I'll try and answer them.

[q.dsc40a.com](https://q.dsc40a.com)

- You'll also use this form to answer questions that I ask you during lecture.
- If the direct link doesn't work, use the 🤔 **Lecture Questions** link in the top right corner of [dsc40a.com](https://dsc40a.com).



Ed



Gradescope



Practice



Lecture Questions

## Question 🤔

Answer at [q.dsc40a.com](http://q.dsc40a.com)

Select the **FALSE** statement below.

A: I have size 16 feet.

B: I skipped Grade 1.

C: I have a California driver's license.

D: Soulja Boy (the rapper) used to follow me on Twitter.

E: I am less than 26 years old.



**What is DSC 40A about?**

# Theoretical Foundations of Data Science I

## What have you *heard* about DSC 40A?

Here are some responses from the Welcome Survey this quarter.

*I've heard the class seeks to uncover a lot of the key concepts of the math behind machine learning, while utilizing a lot of linear algebra. I've heard that the class can be difficult and proof-heavy.*

*I heard it is conceptual, and therefore, a pretty hard class (to understand conceptually). I also heard it has a lot to do with linear algebra.*

*That it's the most awful class in the DSC major, pretty much just pure math/all proofs.*

*It's a pretty hard class but rewarding in the end.*

**Why** do we need to study theoretical foundations?



Machine learning is about **automatically learning patterns from data.**

Humans are good at understanding handwriting – but how do we get computers to understand handwriting?

# Course overview

## Part 1: Learning from Data (Weeks 1 through 6)

- Summary statistics and loss functions; empirical risk minimization.
- Linear regression (including multiple variables); linear algebra.
- Clustering.

## Part 2: Probability (Weeks 7 through 10)

- Set theory and combinatorics; probability fundamentals.
- Conditional probability and independence.
- The Naïve Bayes classifier.

# Learning objectives

After this quarter, you'll...

- understand the basic principles underlying almost every machine learning and data science method.
- be better prepared for the math in upper division: vector calculus, linear algebra, and probability.

## What do DSC 80 students have to say about DSC 40A?

Here are some responses from the End-of-Quarter Survey last quarter in DSC 80.

*study hardy, pay attention in DSC 40A and start work early :)*

*40A and Math 18 is super important for this class. Don't wait till the last minute too!*

*I think DSC40[A] was the most important prerequisite for this class.*



# Logistics

## Getting started

- The course website, [dsc40a.com](https://dsc40a.com), contains all content. **Read the syllabus carefully!**
  - Click around; you'll find other helpful resources.
- Other sites you'll need to use:
  - **Gradescope** is where you'll submit all assignments. You'll be automatically added within 24 hours of enrolling.
  - **Ed** is where all announcements will be made. If you're not enrolled, there's a join link in the syllabus.
  - We aren't using Canvas.
- Make sure to fill out the **Welcome Survey** ASAP.

# Lectures

- There are two lecture sections, and anyone can attend either section\*, as long as there's space for everyone officially enrolled.
  - A: Tuesdays and Thursdays, 12:30-1:50PM, Center Hall 212.
  - B: Tuesdays and Thursdays, 2-3:20PM, Center Hall 212.
- Lecture slides will be posted on the course website before class, and annotated slides will be posted after class.
- Both sections will be podcasted.
- **The value of lecture is interaction and discussion, so even though attendance isn't required, it's highly, highly recommended.**

\*Apart from on the day of the Midterm Exam, when you must take the exam during your officially assigned lecture slot.

# Discussions

- There are two discussion sections, and anyone can attend either section, as long as there's space for everyone officially enrolled.
  - A: Mondays, 4-4:50PM, Center Hall 214.
  - B: Mondays, 5-5:50PM, Center Hall 109.
- Discussion will primarily be used for **groupwork** – that is, working on problems in small groups of size 2-4.
  - You may work in a self-organized group outside of a discussion section for 80% credit, but no matter what, **you cannot work alone.**
- Groupwork worksheets are due to Gradescope on **Mondays at 11:59PM.**
  - Only one group member needs to submit, and should add the rest of the group to the submission.
- **The value of attending is getting support from tutors.**

# Grading

- **Homeworks (40%):** Due to Gradescope on **Thursdays at 11:59PM**.
  - Graded for correctness. Lowest score is dropped.
  - You have 4 slip days, and can use up to 1 per homework.
- **Groupworks (10%):** Due to Gradescope on **Mondays at 11:59PM**.
  - Graded for effort. Lowest score is dropped.
- **Midterm Exam (20%):** Tuesday, May 7th, in class, during your officially assigned lecture slot.
- **Final Exam (30%):** Saturday, June 8th, 8-11AM, location TBD. See the [syllabus](#) for the redemption policy.

Let us know about exam conflicts on the [Welcome Survey](#).

# Support

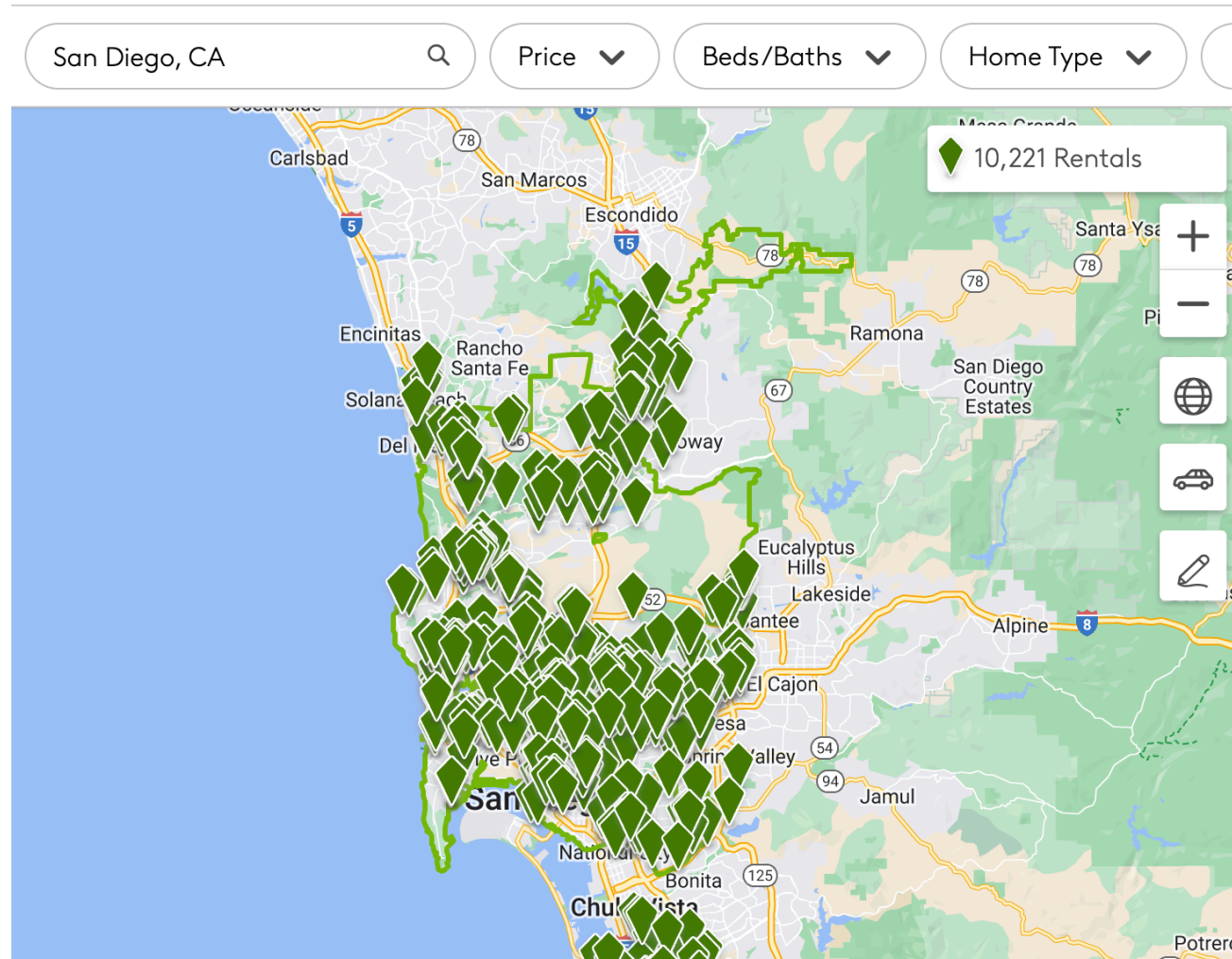
We know this is a challenging class, and we're here to help:

- **Office hours:** Over 24 hours a week, all in HDSI 155. Plan to attend at least once a week.
- **Ed:** Use it! We're here to help you. Post conceptual questions publicly – just don't post answers to homework questions.

This quarter, we're trying a bunch of new things to improve the student experience:

- We're developing [practice.dsc40a.com](https://practice.dsc40a.com) to give you access to practice exam problems, categorized by topic.
- We're recording walkthrough videos to show you our thought process when answering questions.
- We're planning to spend more time reviewing linear algebra.

# Modeling



You might be starting to look for off-campus apartments, none of which are affordable.

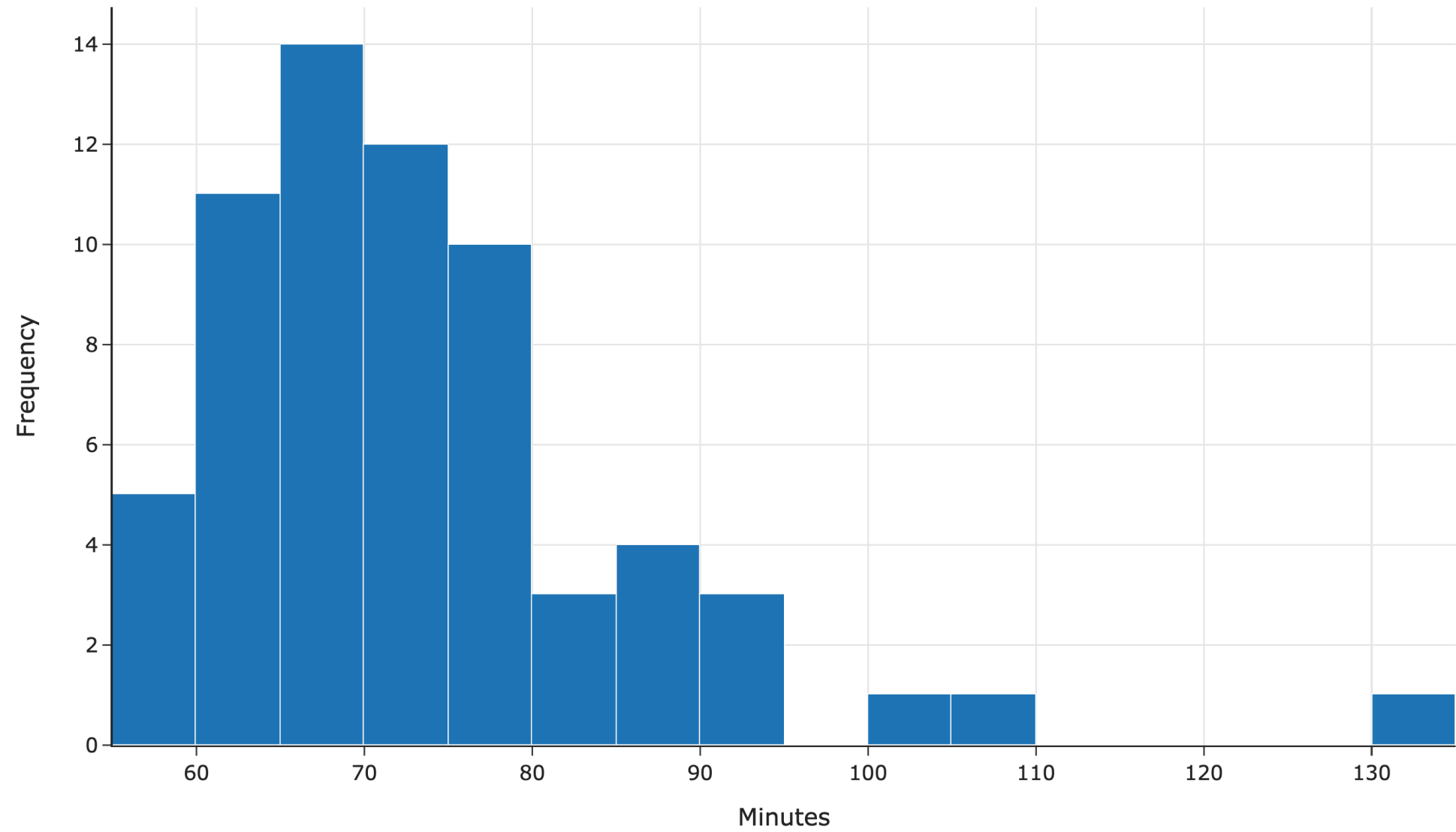


|          | <b>date</b> | <b>day</b> | <b>departure_hour</b> | <b>minutes</b> |
|----------|-------------|------------|-----------------------|----------------|
| <b>0</b> | 5/22/2023   | Mon        | 8.450000              | 63.0           |
| <b>1</b> | 9/18/2023   | Mon        | 7.950000              | 75.0           |
| <b>2</b> | 10/17/2023  | Tue        | 10.466667             | 59.0           |
| <b>3</b> | 11/28/2023  | Tue        | 8.900000              | 89.0           |
| <b>4</b> | 2/15/2024   | Thu        | 8.083333              | 69.0           |

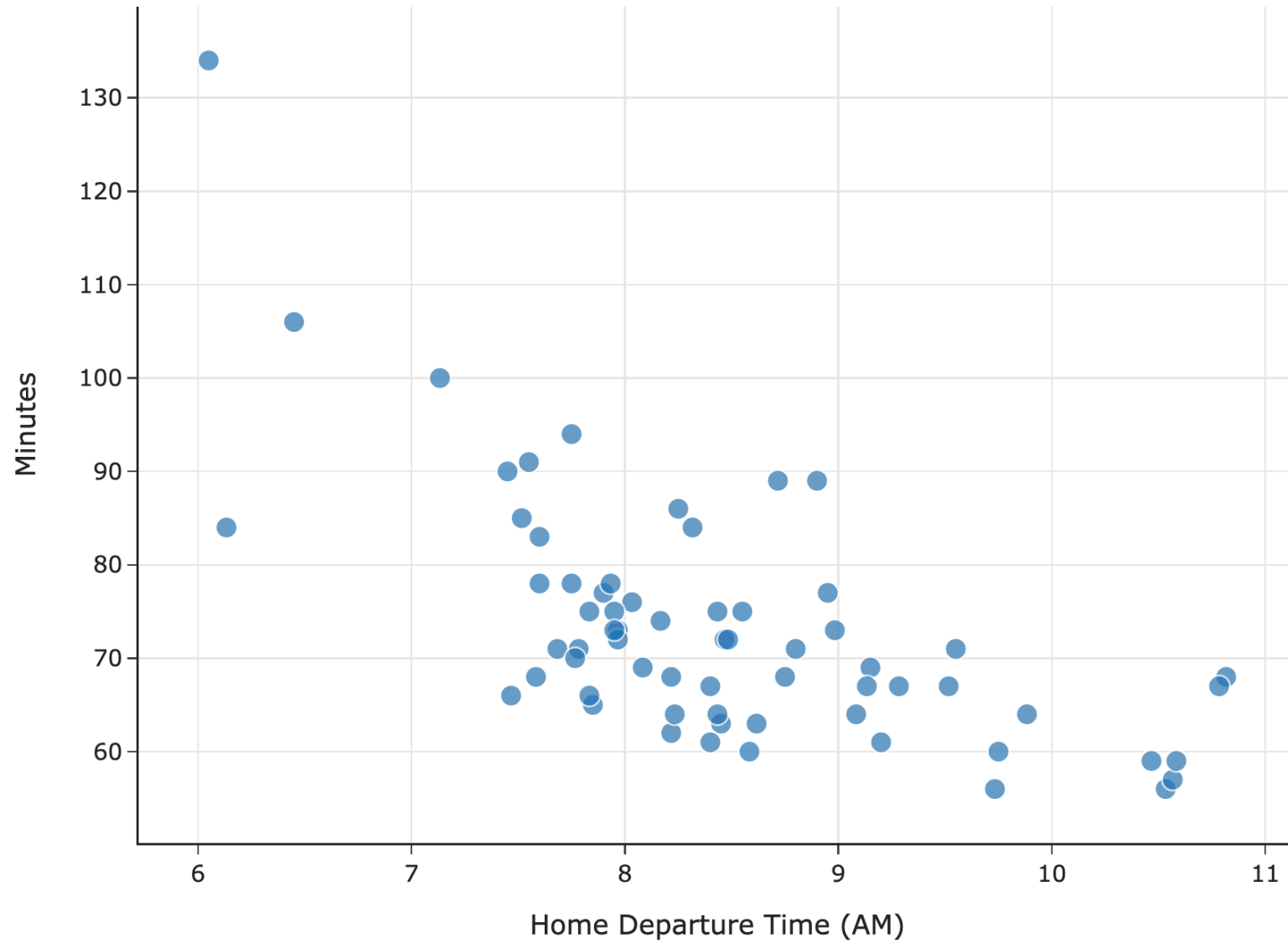
...

You decide to live with your parents in Orange County and commute.  
You keep track of how long it takes you to get to school each day.

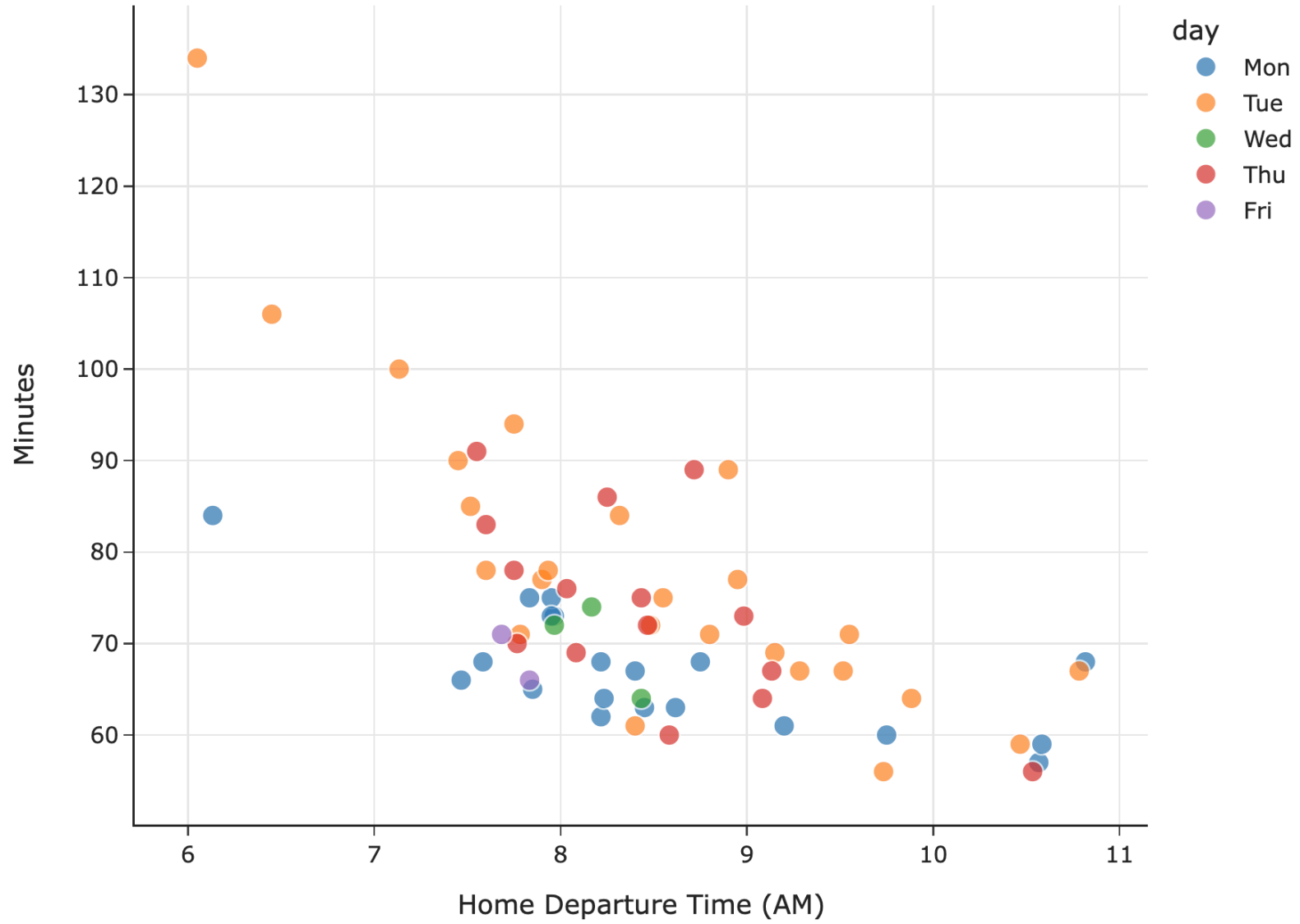
Distribution of Commuting Time



Commuting Time vs. Home Departure Time



### Commuting Time vs. Home Departure Time



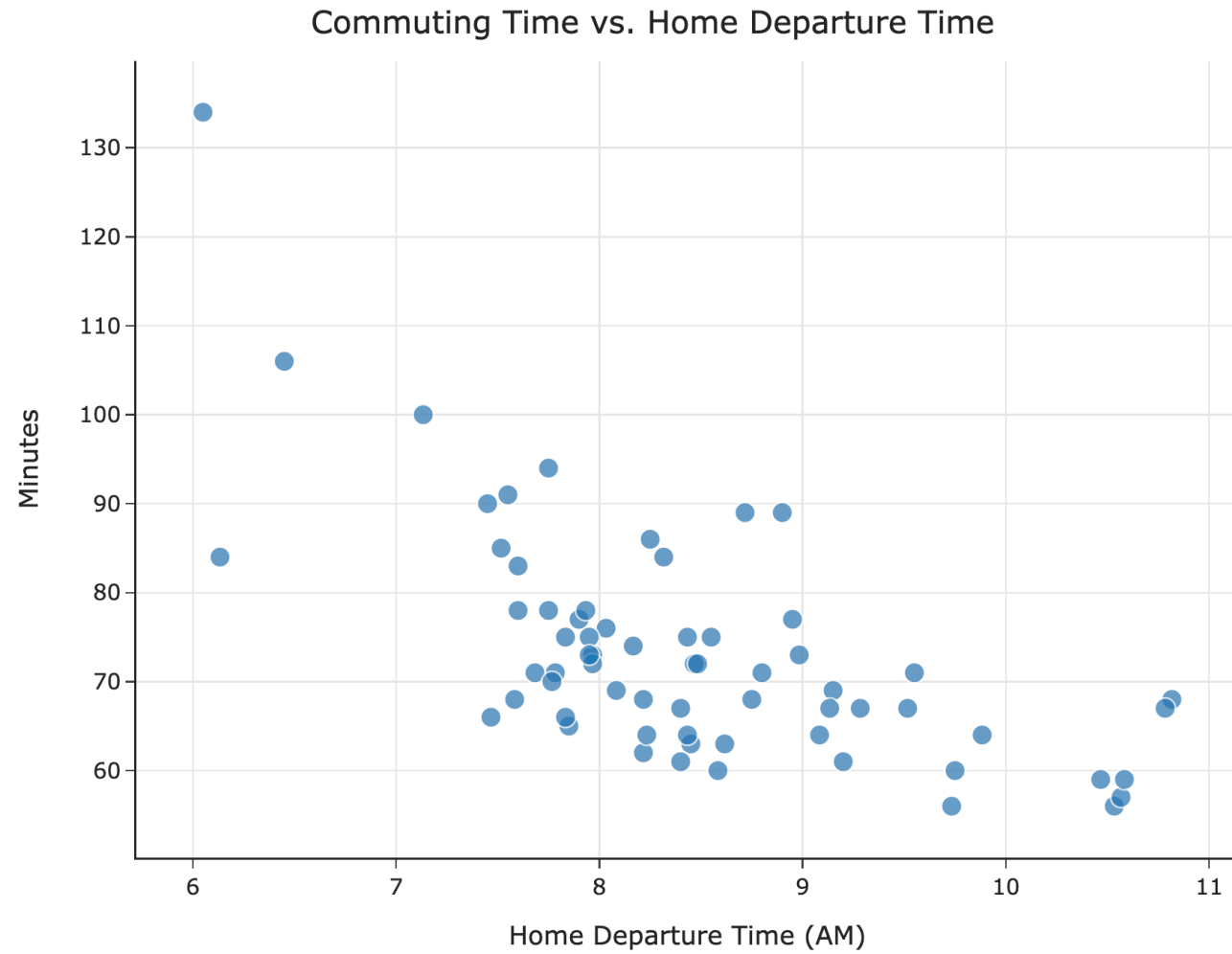
**Goal:** Predict your commute time.  
That is, predict how long it'll take to get to school.

How can we do this?

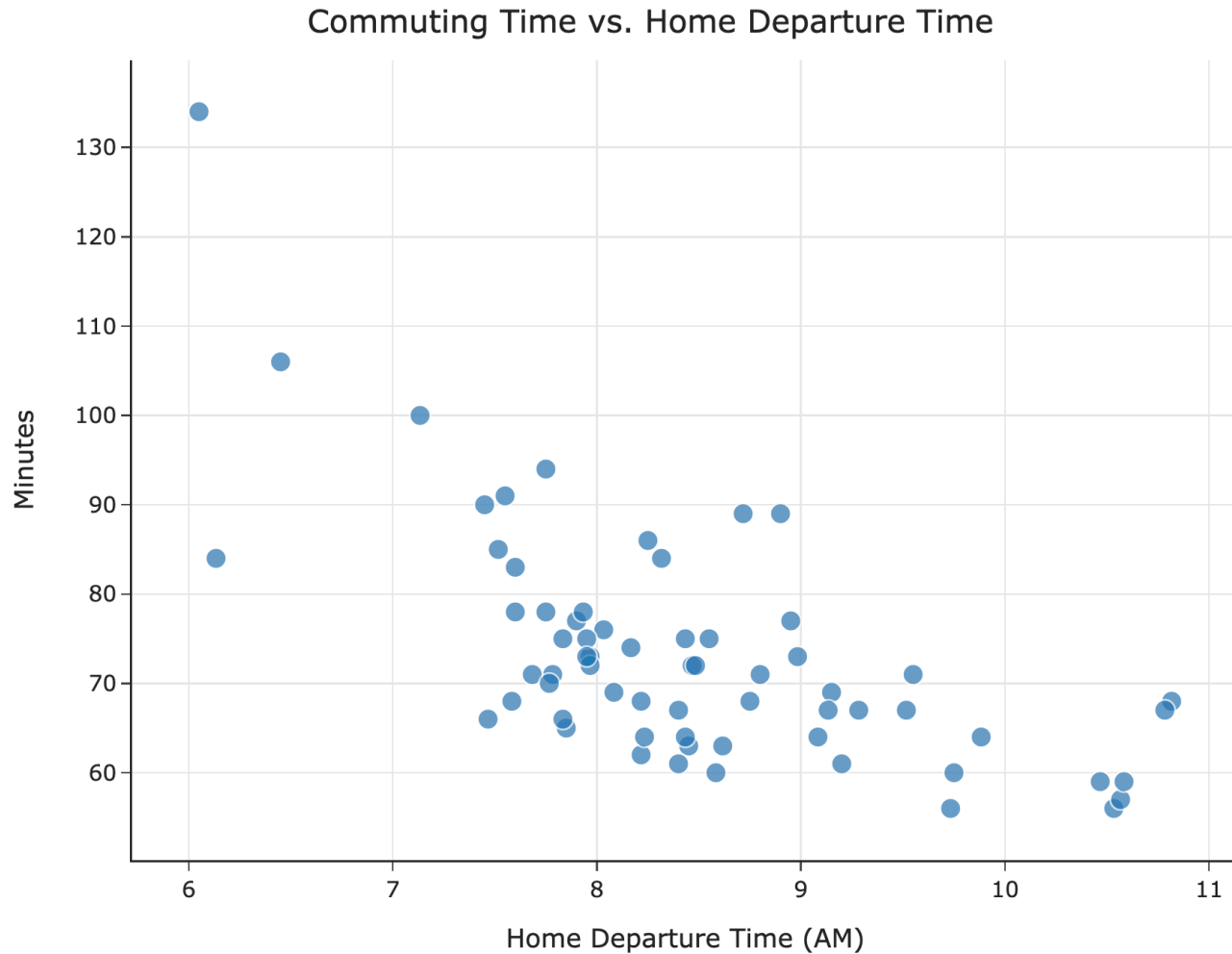
What will we need to assume?

A **model** is a set of assumptions about how data were generated.

# Possible models



# Notation



$x$ : "input", "independent variable",  
or "feature"

$y$ : "response", "dependent  
variable", or "target"

**We use  $x$  to predict  $y$ .**

The  $i$ th observation is denoted  
 $(x_i, y_i)$ .

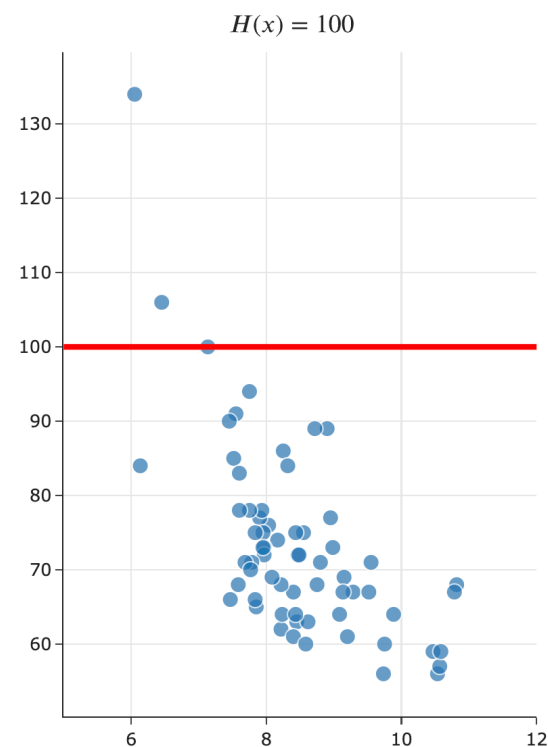
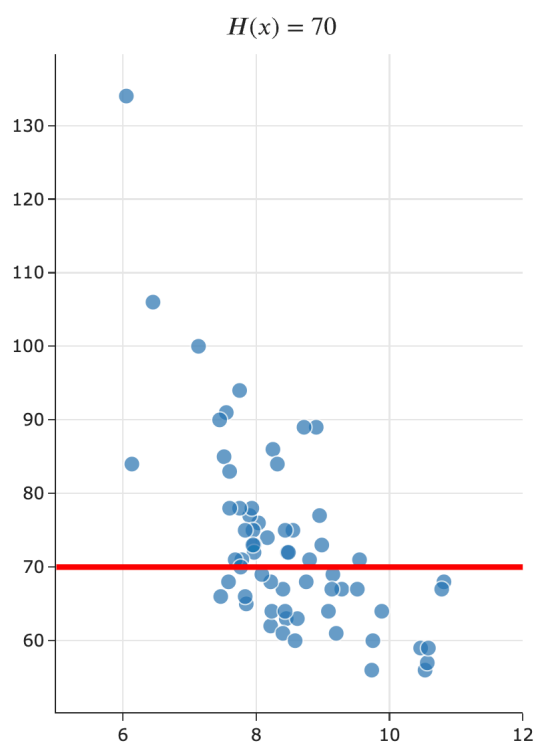
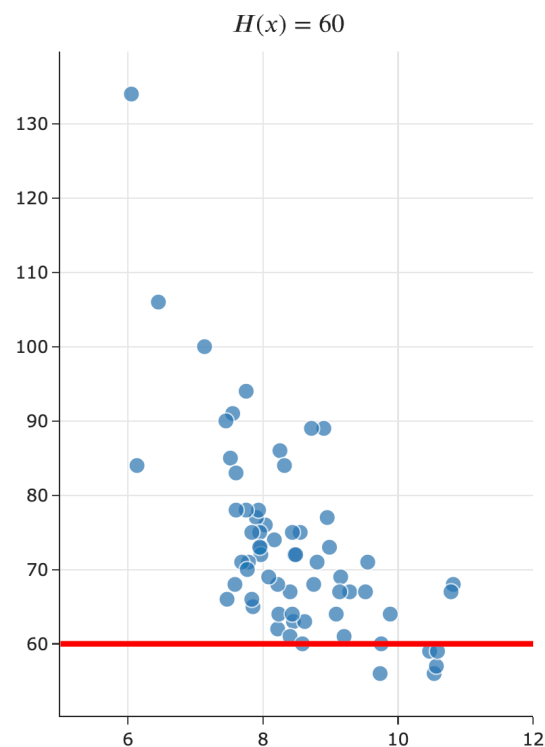


# Hypothesis functions and parameters

A hypothesis function,  $H$ , takes in an  $x$  as input and returns a predicted  $y$ .

**Parameters** define the relationship between the input and output of a hypothesis function.

The constant model,  $H(x) = h$ , has one parameter:  $h$ .

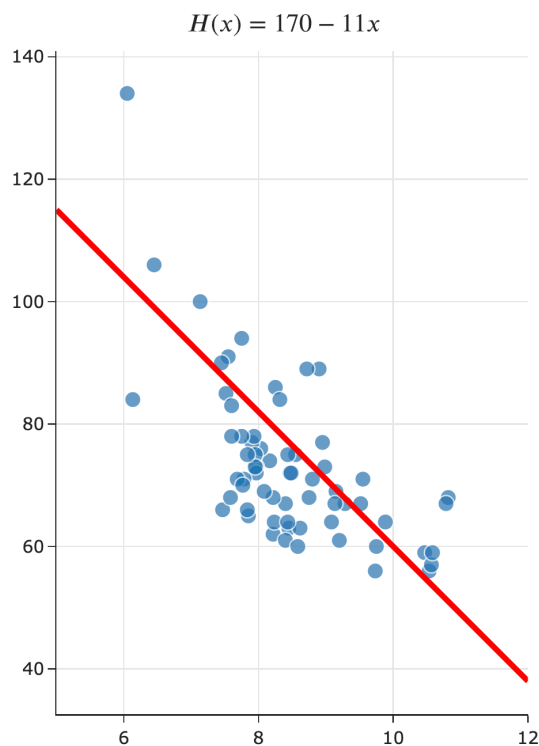
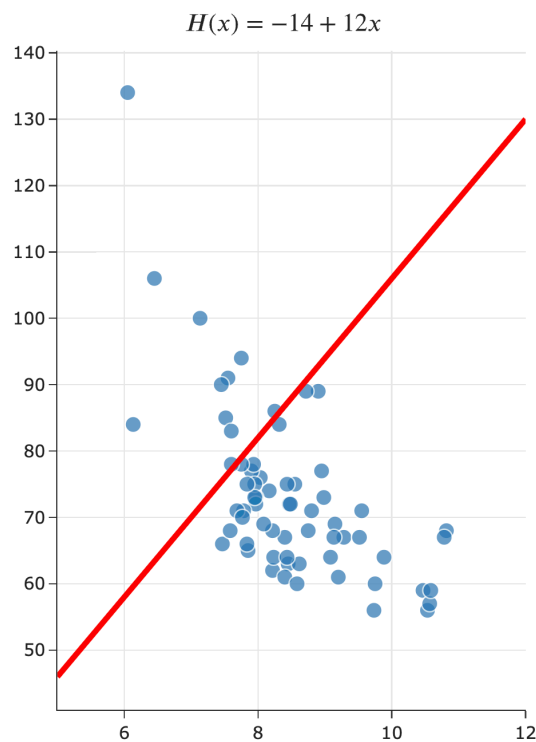


# Hypothesis functions and parameters

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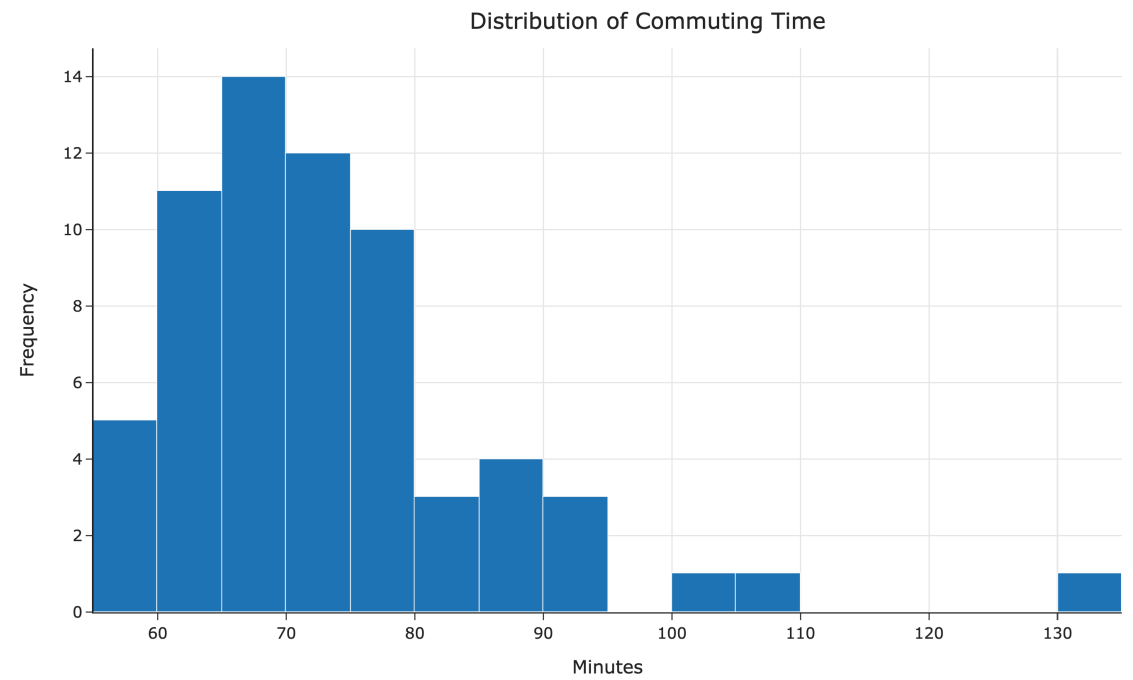
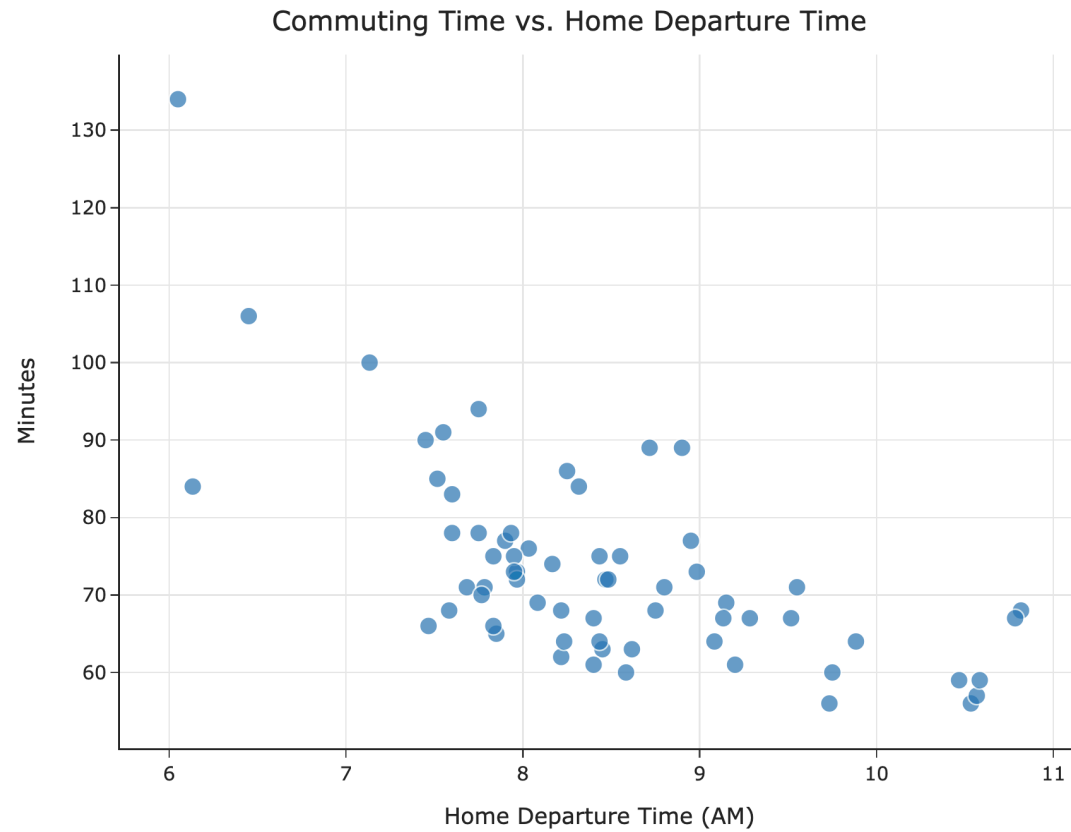
**Parameters** define the relationship between the input and output of a hypothesis function.

The simple linear regression model,  $H(x) = w_0 + w_1x$ , has two parameters:  $w_0$  and  $w_1$ .



# The constant model

# The constant model



## A concrete example

Let's suppose we have just a smaller dataset of just five historical commute times in minutes.

$$y_1 = 72$$

$$y_2 = 90$$

$$y_3 = 61$$

$$y_4 = 85$$

$$y_5 = 92$$

Given this data, can you come up with a prediction for your future commute time? How?

## Some common approaches

- The mean:

$$\frac{1}{5}(72 + 90 + 61 + 85 + 92) = \boxed{80}$$

- The median:

$$61 \quad 72 \quad \boxed{85} \quad 90 \quad 92$$

- Both of these are familiar **summary statistics** – they summarize a collection of numbers with a single number.
- But which one is better? Is there a "best" prediction we can make?

## The cost of making predictions

A **loss function** quantifies how bad a prediction is for a single data point.

- If our prediction is **close** to the actual value, we should have **low** loss.
- If our prediction is **far** from the actual value, we should have **high** loss.

A good starting point is error, which is the difference between **actual** and **predicted** values.

$$e_i = y_i - H(x_i)$$

Suppose my commute **actually** takes 80 minutes.

- If I predict 75 minutes:
- If I predict 72 minutes:
- If I predict 100 minutes:

## Squared loss

One loss function is squared loss,  $L_{\text{sq}}$ , which computes (actual – predicted)<sup>2</sup>.

$$L_{\text{sq}}(y_i, H(x_i)) = (y_i - H(x_i))^2$$

Note that for the constant model,  $H(x_i) = h$ , so we can simplify this to:

$$L_{\text{sq}}(y_i, h) = (y_i - h)^2$$

Squared loss is not the only loss function that exists! Soon, we'll learn about absolute loss.



## A concrete example, revisited

Consider again our smaller dataset of just five historical commute times in minutes.

Suppose we predict the median,  $h = 85$ . What is the squared loss of 85 for each data point?

$$y_1 = 72$$

$$y_2 = 90$$

$$y_3 = 61$$

$$y_4 = 85$$

$$y_5 = 92$$

## Averaging squared losses

We'd like a single number that describes the quality of our predictions across our entire dataset. One way to compute this is as the **average of the squared losses**.

- For the median,  $h = 85$ :

$$\frac{1}{5} \left( (72 - 85)^2 + (90 - 85)^2 + (61 - 85)^2 + (85 - 85)^2 + (92 - 85)^2 \right) = \boxed{163.8}$$

- For the mean,  $h = 80$ :

$$\frac{1}{5} \left( (72 - 80)^2 + (90 - 80)^2 + (61 - 80)^2 + (85 - 80)^2 + (92 - 80)^2 \right) = \boxed{138.8}$$

Which prediction is better? Could there be an even better prediction?

## Mean squared error

- Another term for average squared loss is mean squared error (MSE).
- The mean squared error on our smaller dataset for any prediction  $h$  is of the form:

$$R_{\text{sq}}(h) = \frac{1}{5} \left( (72 - h)^2 + (90 - h)^2 + (61 - h)^2 + (85 - h)^2 + (92 - h)^2 \right)$$

$R$  stands for "risk", as in "empirical risk." We'll see this term again soon.

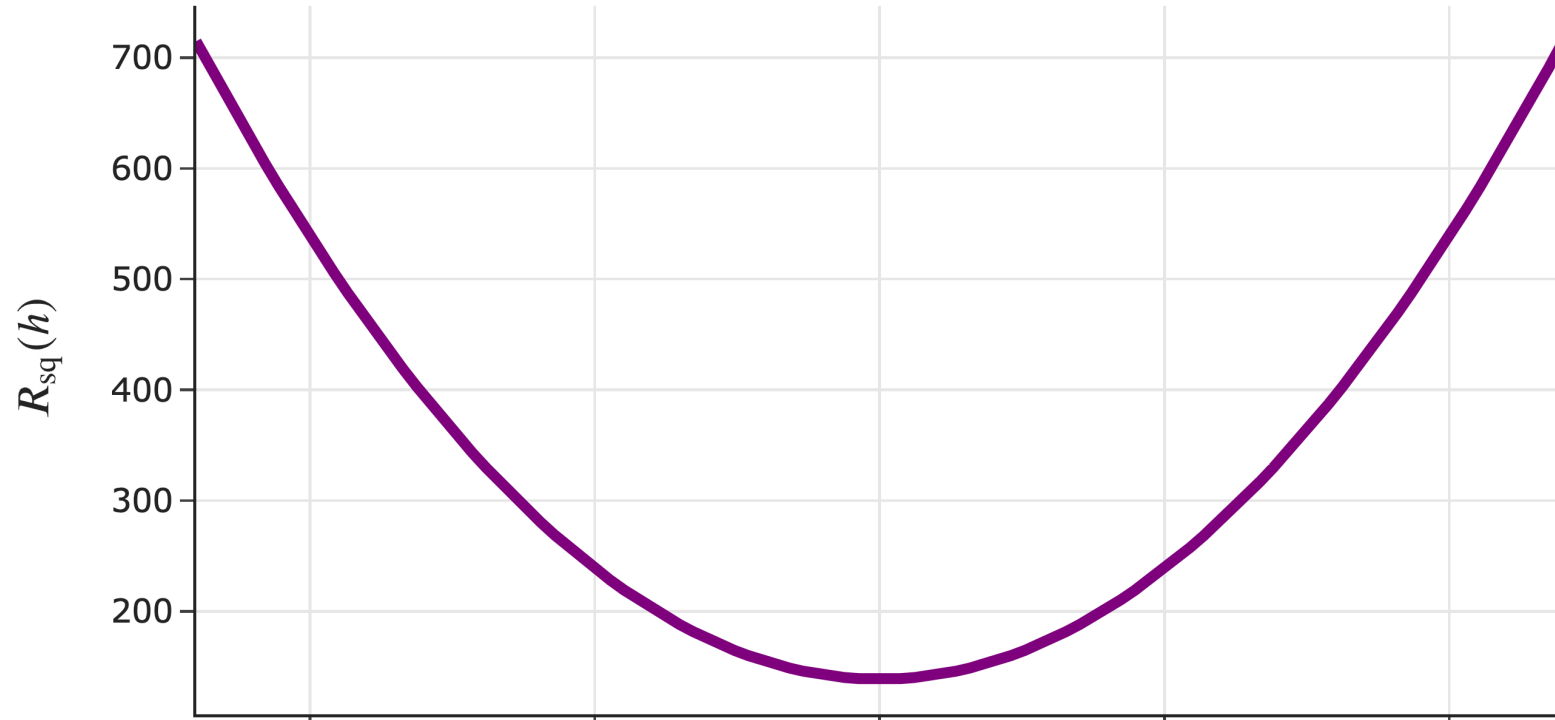
- For example, if we predict  $h = 100$ , then:

$$\begin{aligned} R_{\text{sq}}(100) &= \frac{1}{5} \left( (72 - 100)^2 + (90 - 100)^2 + (61 - 100)^2 + (85 - 100)^2 + (92 - 100)^2 \right) \\ &= \boxed{538.8} \end{aligned}$$

- We can pick any  $h$  as a prediction, but the smaller  $R_{\text{sq}}(h)$  is, the better  $h$  is!

## Visualizing mean squared error

$$R_{\text{sq}}(h) = \frac{1}{5}((72 - h)^2 + (90 - h)^2 + (61 - h)^2 + (85 - h)^2 + (92 - h)^2)$$



Which  $h$  corresponds to the vertex of  $R_{\text{sq}}(h)$ ?



## The best prediction

$$R_{\text{sq}}(h) = \frac{1}{n} \sum_{i=1}^n (y_i - h)^2$$

- We want the **best** prediction,  $h^*$ .
- The smaller  $R_{\text{sq}}(h)$  is, the better  $h$  is.
- **Goal:** Find the  $h$  that minimizes  $R_{\text{sq}}(h)$ .  
The resulting  $h$  will be called  $h^*$ .
- **How do we find  $h^*$ ?**

## Summary, next time

- We started with the abstract problem:

Given historical commute times, predict your future commute time.

- We've turned it into a formal optimization problem:

Find the prediction  $h^*$  that has the smallest mean squared error  $R_{\text{sq}}(h)$  on the data.

- Implicitly, we introduced a three-step modeling process that we'll keep revisiting:

- i. Choose a model.
- ii. Choose a loss function.
- iii. Minimize average loss,  $R$ .

- **Next time:** We'll solve this optimization problem by-hand.