Welcome!

slides at dsc40a.com

Lecture 1

Introduction to Modeling

DSC 40A, Spring 2024

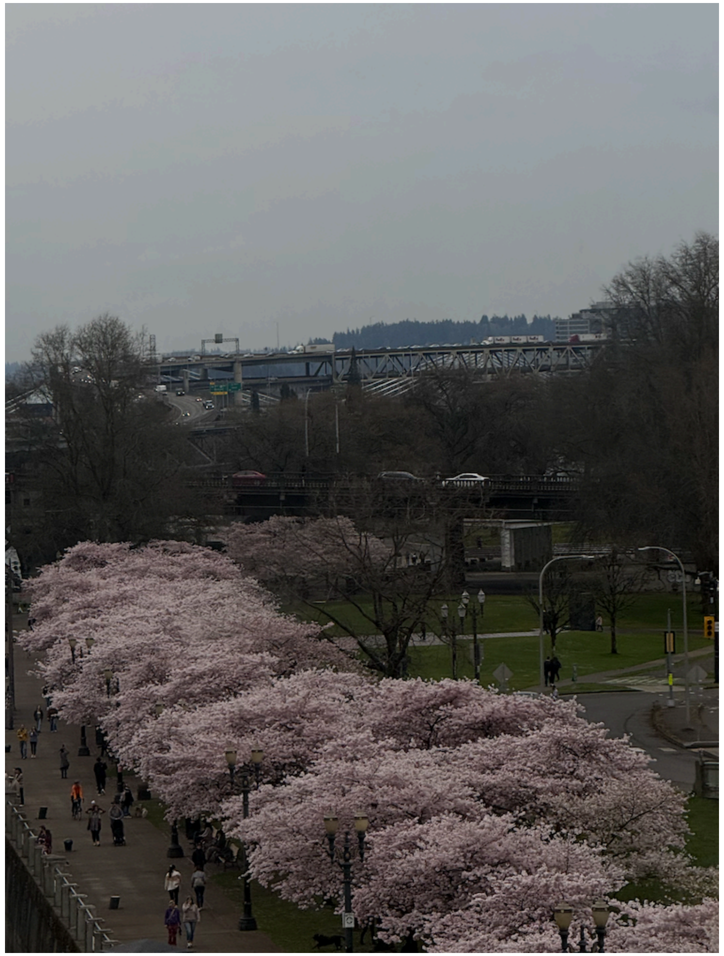
Agenda

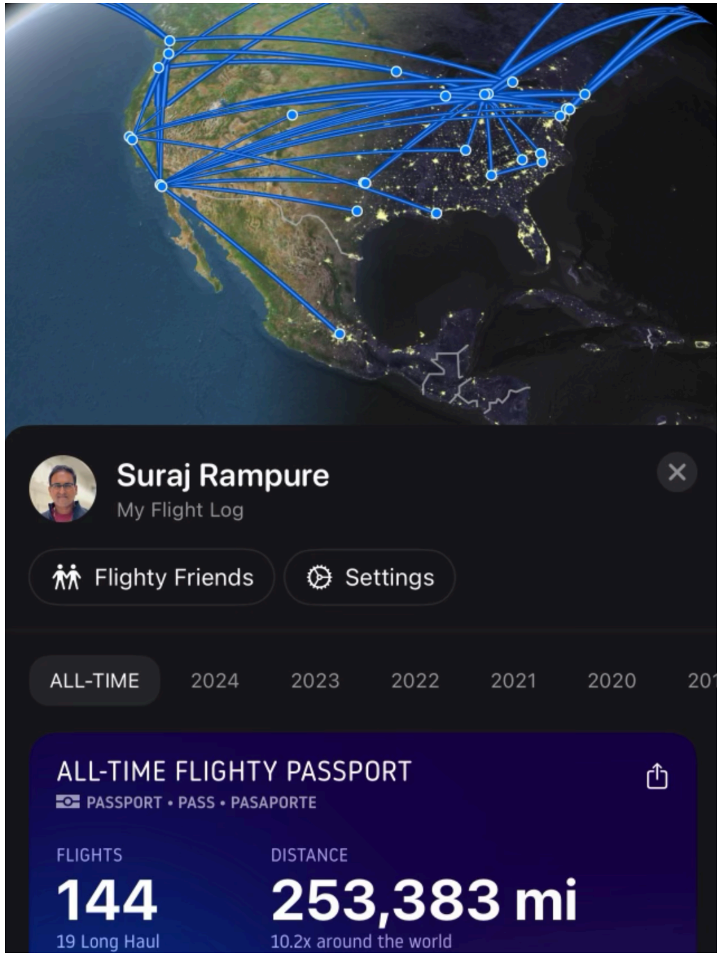
- Introductions.
- What is DSC 40A about?
- Logistics.
- Modeling.
- The constant model.

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	Javier Ponce
Yosen Lin	Harshita Saha
Utkarsh Lohia	Candus Shi
Zoe Ludena	Charlie Sun
Mert Ozer	Nicholas Swetlin
Varun Pabreja	Benjamin Xue

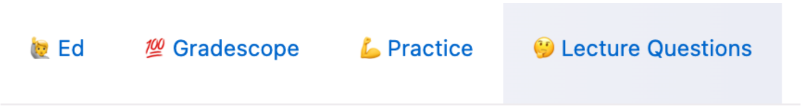
Read more about us at dsc40a.com/staff.

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

- 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.



Question 🤔

Answer at 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

Mathematical Foundations of
Machine Learning

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.

hopefully not!

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, 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

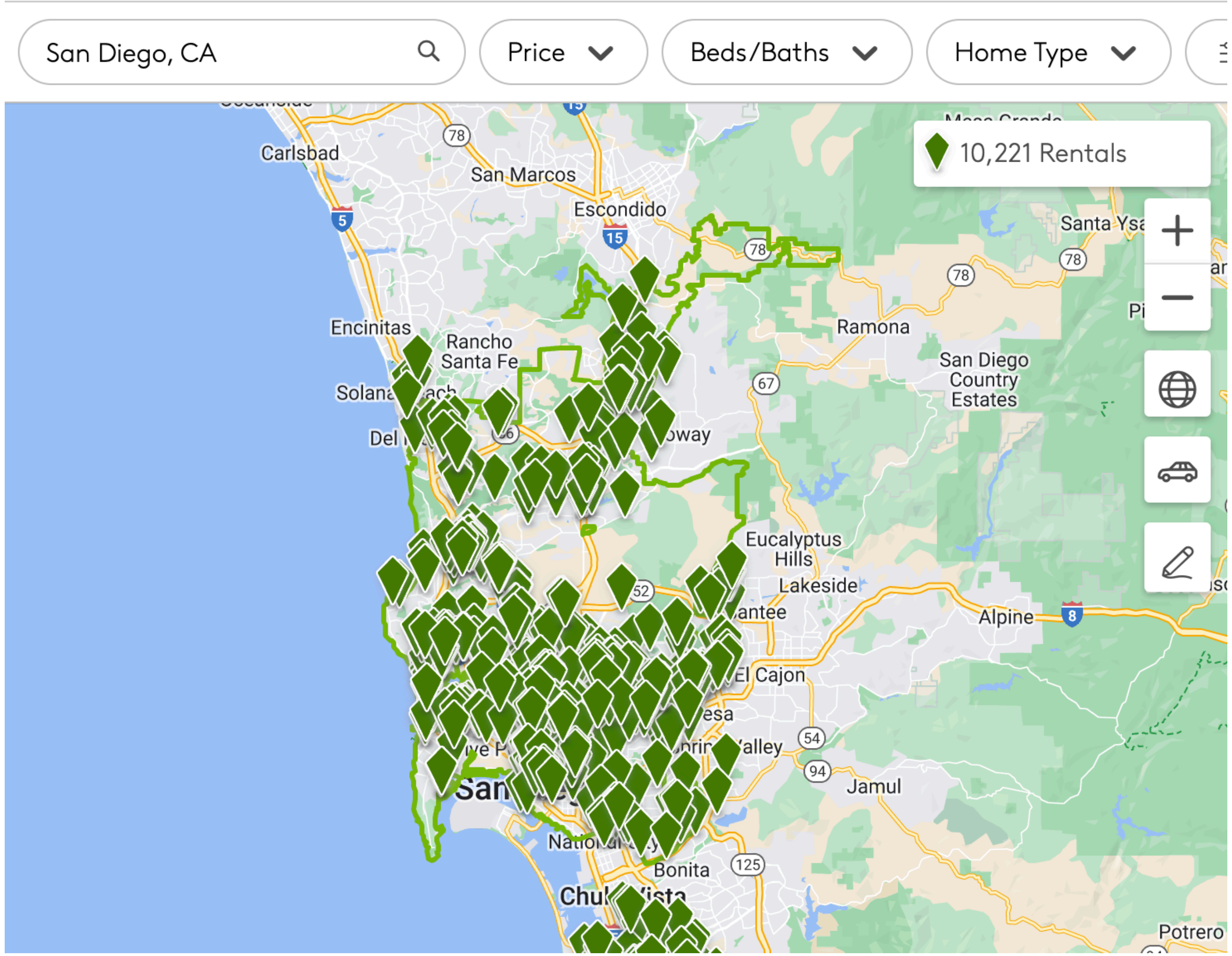
We know this is a challenging class, and we're here to help:

- **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 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.

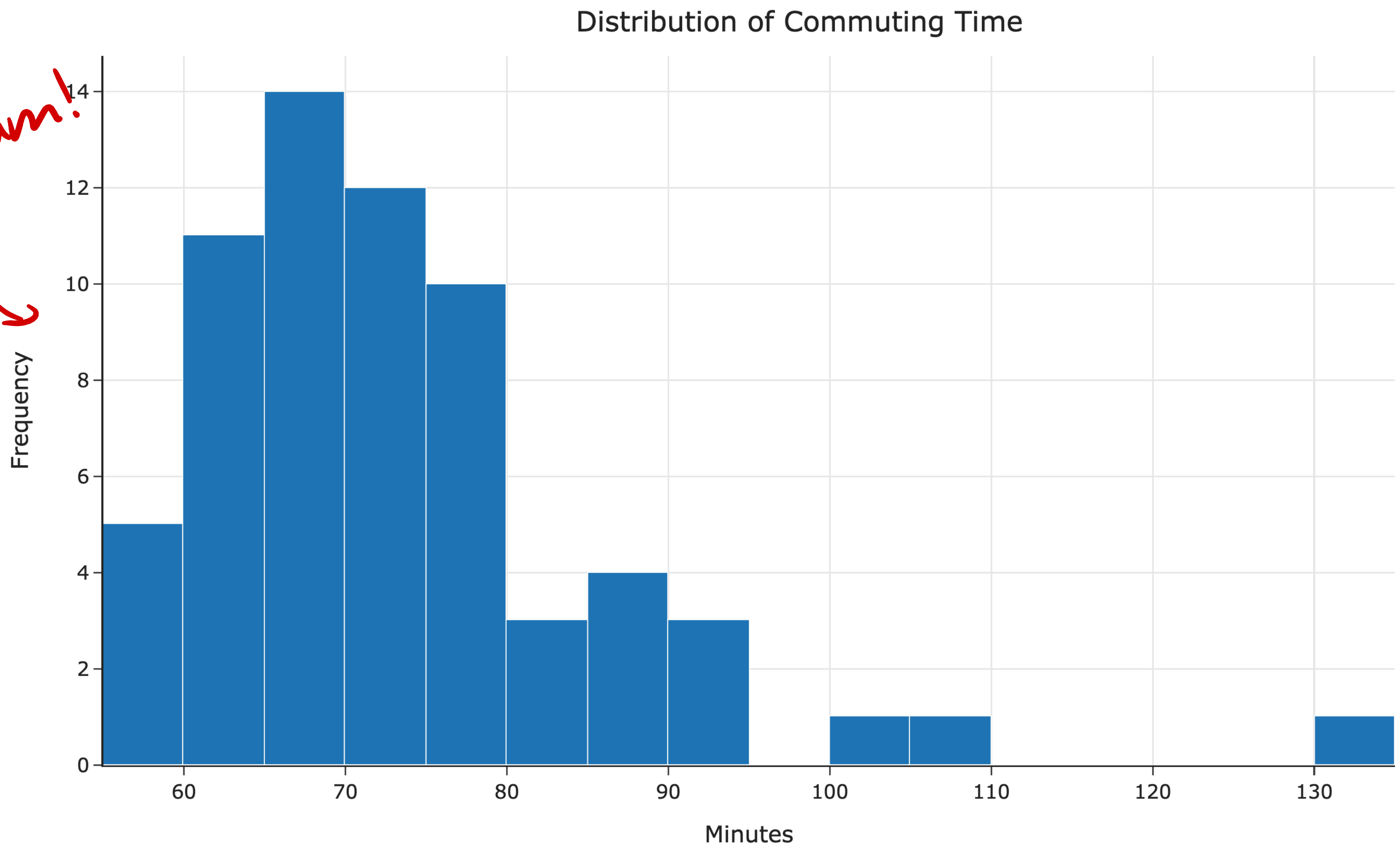
	date	day	departure_hour	minutes
0	5/22/2023	Mon	8.450000	63.0
1	9/18/2023	Mon	7.950000	75.0
2	10/17/2023	Tue	10.466667	59.0
3	11/28/2023	Tue	8.900000	89.0
4	2/15/2024	Thu	8.083333	69.0

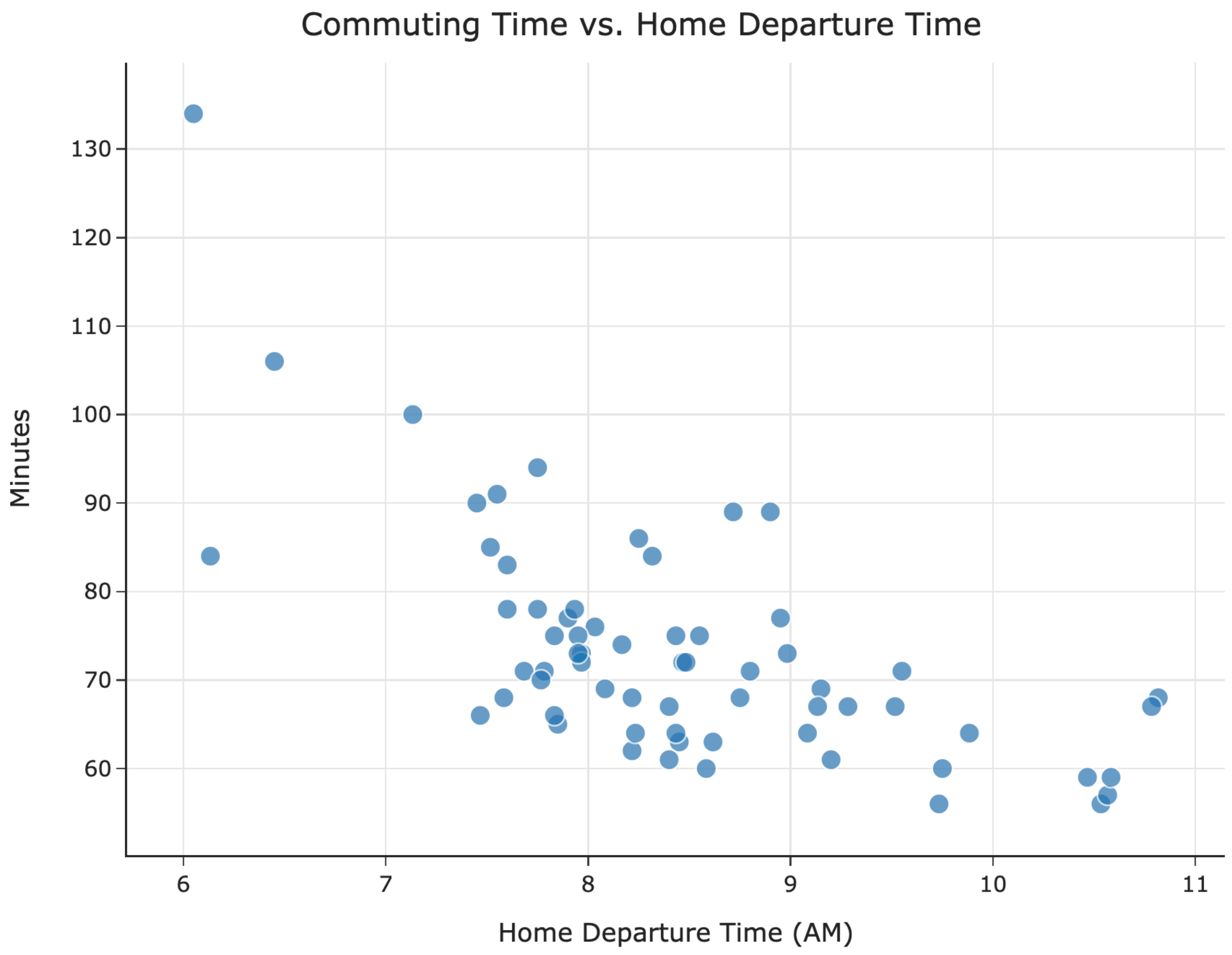
...

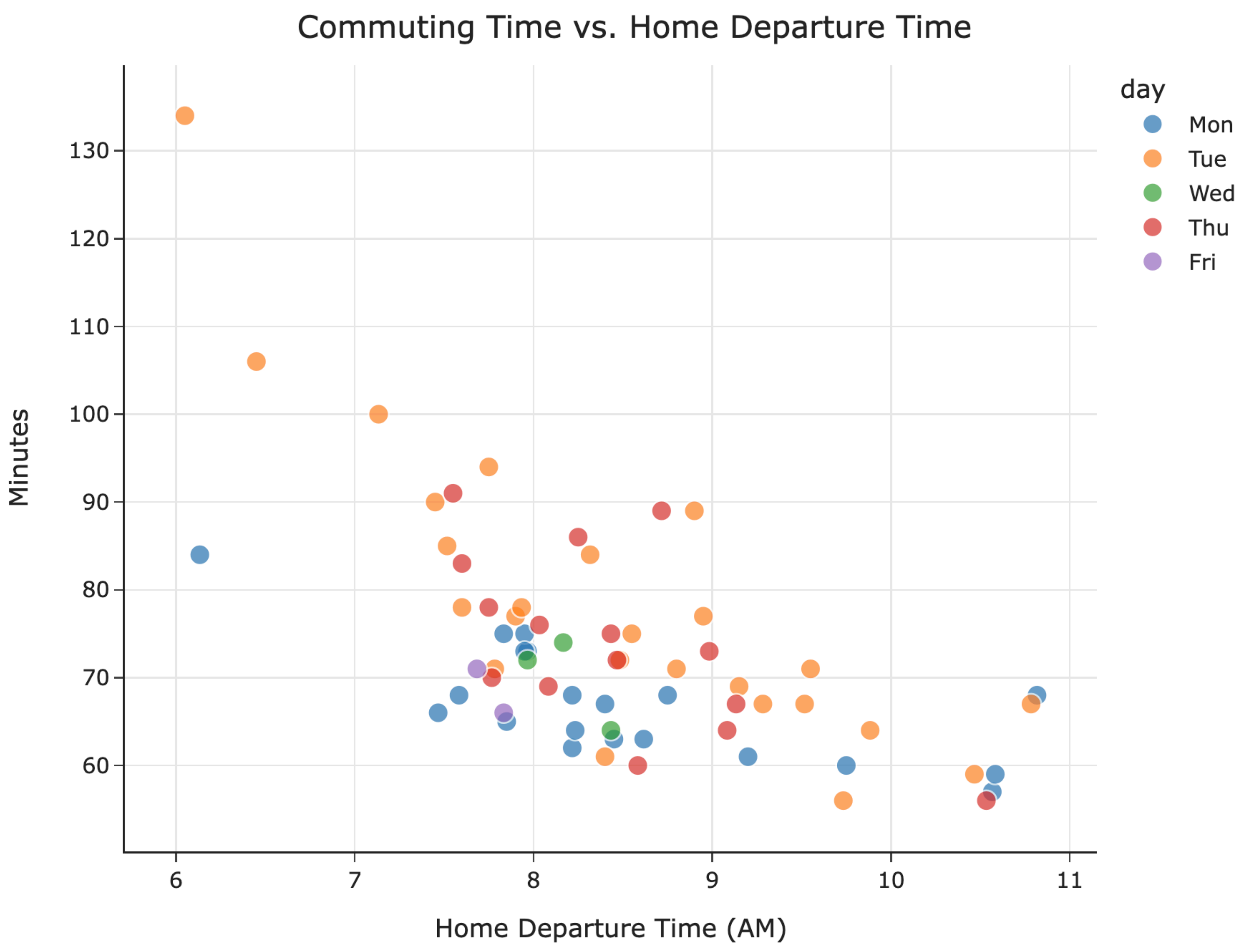
You decide to live with your parents in Orange County and commute.
You keep track of how long it takes you to get to school each day.

This is a real dataset, collected by Joseph Hearn! However, he lived in the Seattle area, not San Diego.

not a density histogram!




Commuting Time vs. Home Departure Time
Minutes
130
120
110
100
90
80
70
60
6
7
8
9
10
11
Home Departure Time (AM)


Commuting Time vs. Home Departure Time
Minutes
130
120
110
100
90
80
70
60
6
7
8
9
10
11
Home Departure Time (AM)
day
Mon
Tue
Wed
Thu
Fri

Goal: Predict your commute time.

That is, predict how long it'll take to get to school.

learn pattern from data!

data in the future looks like data in the past!

How can we do this?

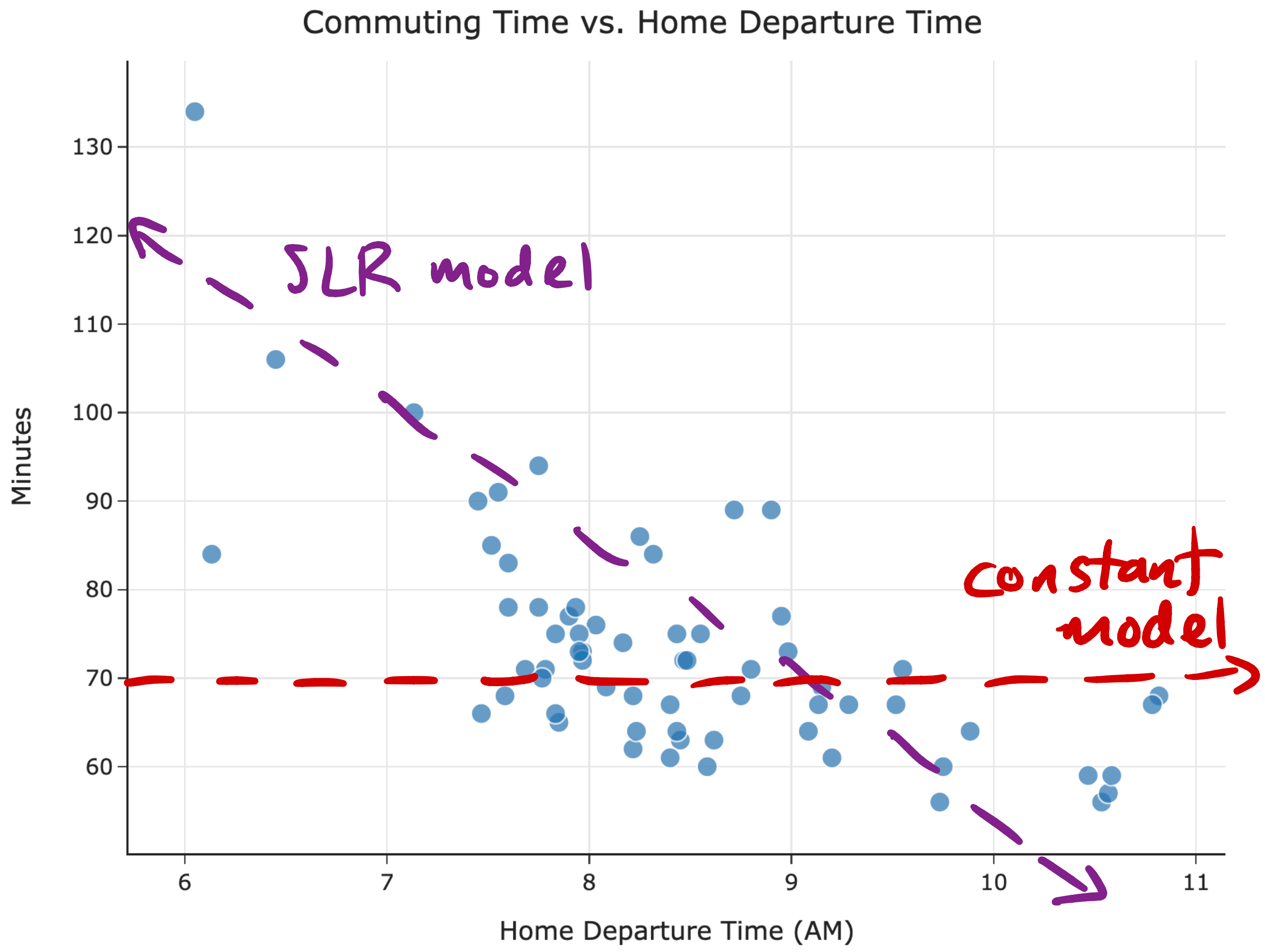
What will we need to assume?

"datum" singular

A **model** is a set of assumptions about how data $\underbrace{\text{were}}_{\text{was?}}$ generated.

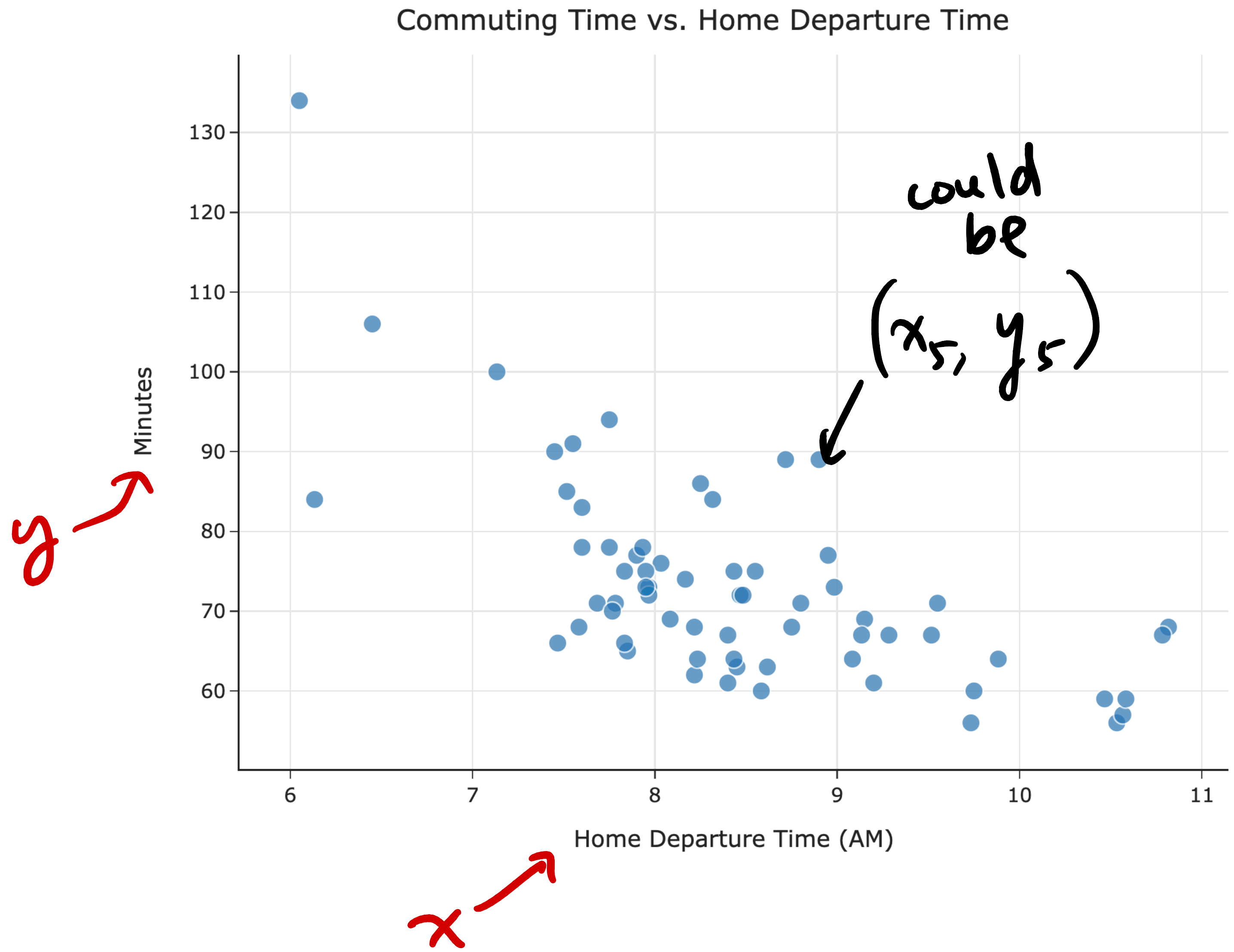
Possible models

simple linear regression
model



constant model

Notation



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

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

We use x to predict y.

The ith observation is denoted (x_i, y_i).

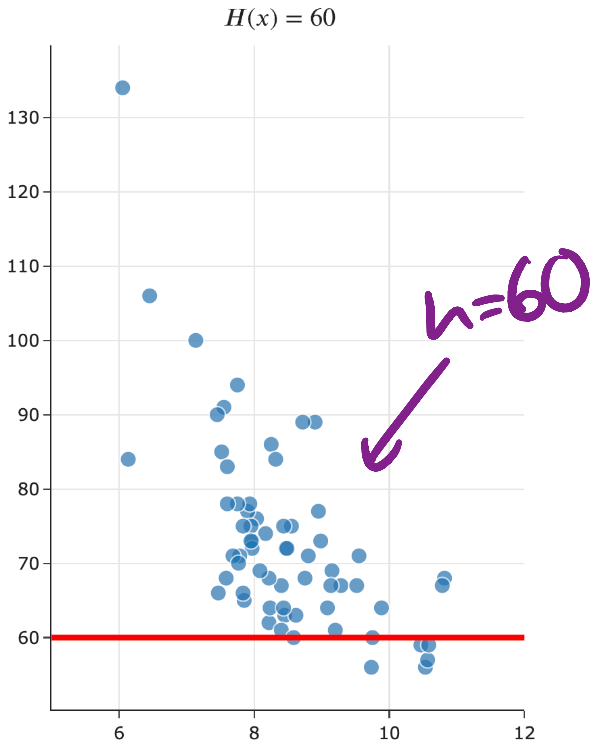
H is used to make predictions!

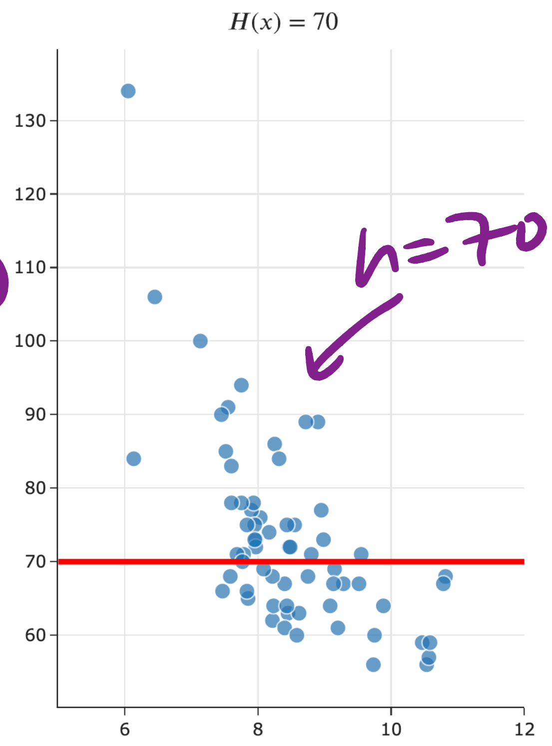
Hypothesis functions and parameters

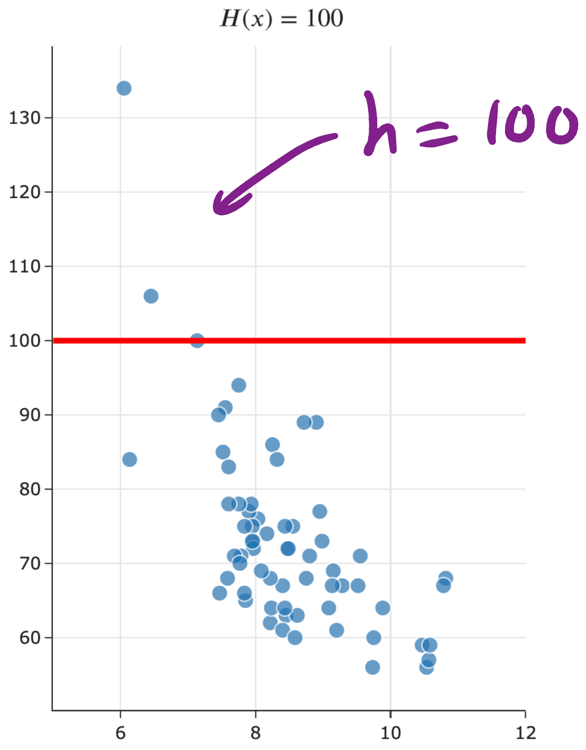
A hypothesis function, H, takes in an x as input and returns a predicted y.

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

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





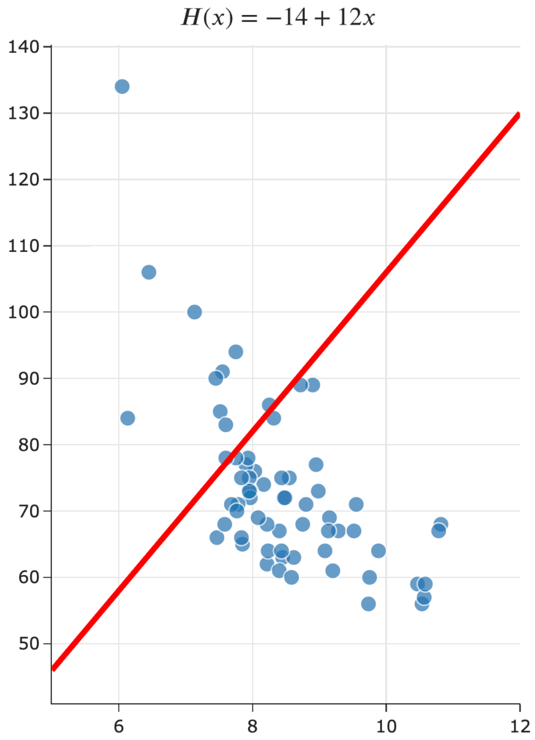


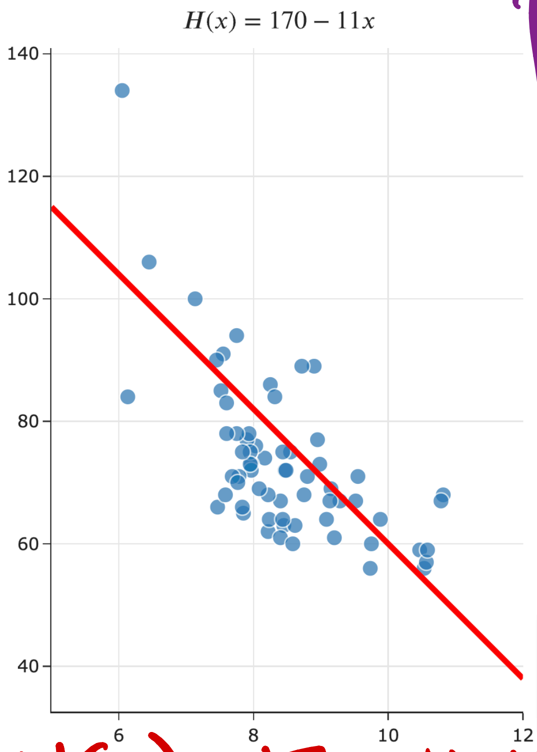
Hypothesis functions and parameters

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





Fancy $y = mx + b$!

slope

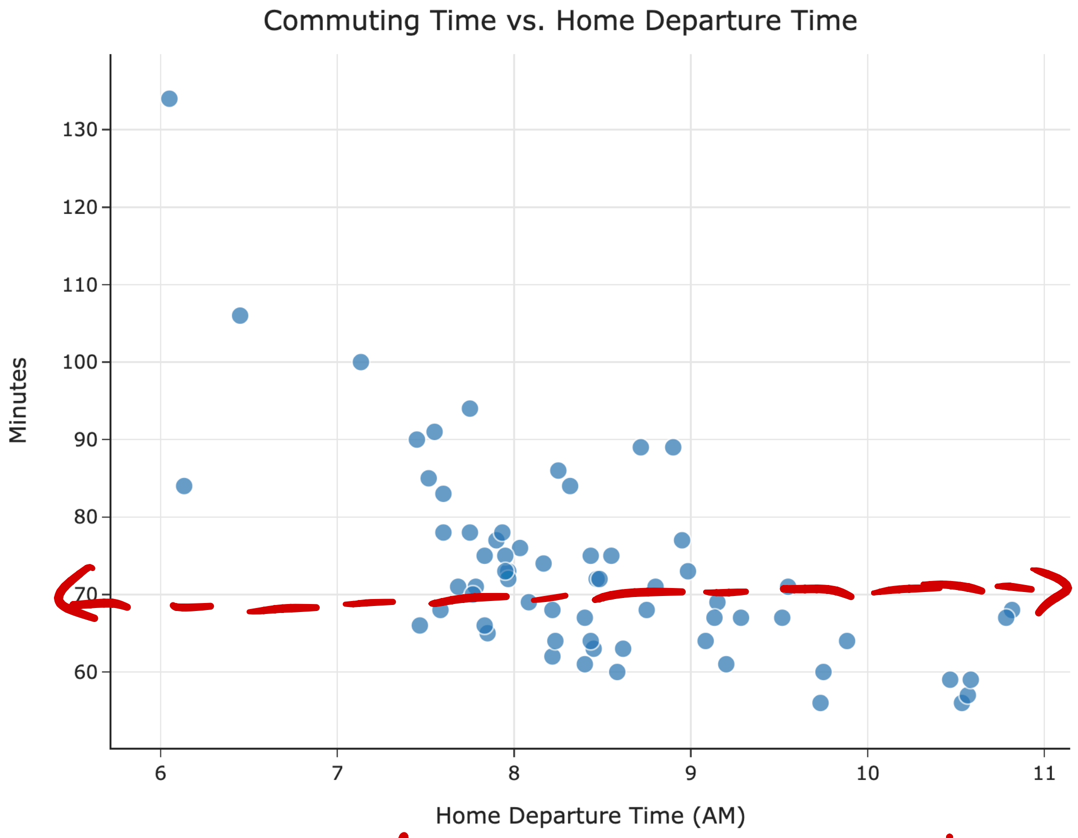
intercept

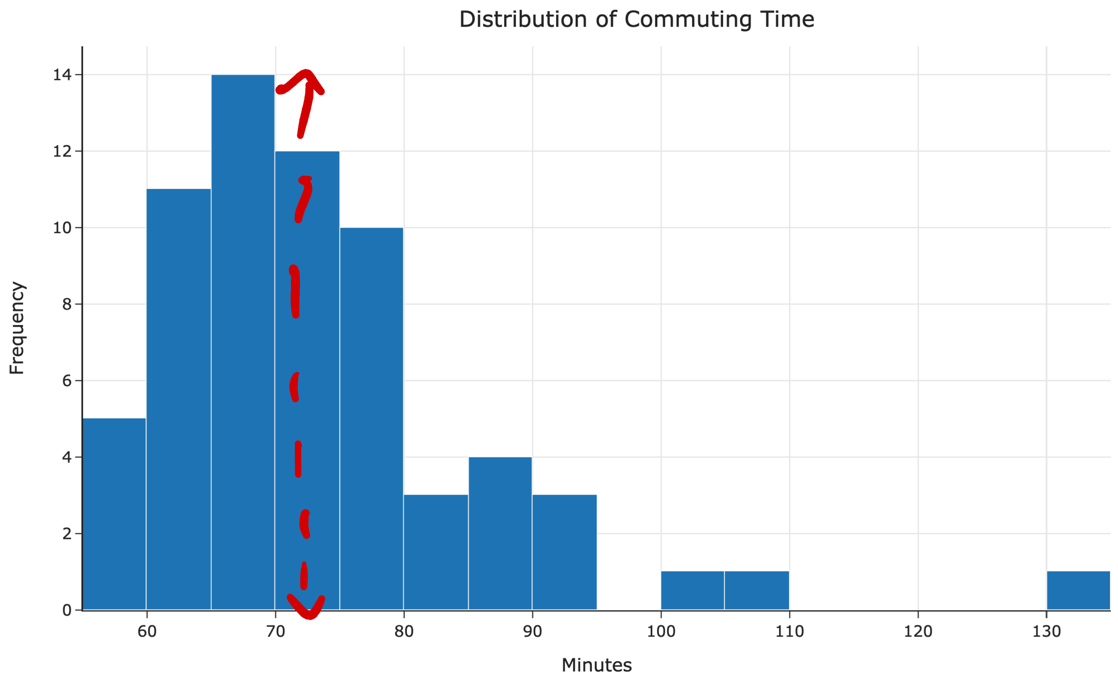
Change parameters: change how predictions are made!

e.g. $H(10) = 170 - 11 \cdot 10 = 60$ minutes @ 10am

The constant model

The constant model





where to draw a horizontal line for making predictions? = where to draw a vertical line to summarize the distribution?

A concrete example

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

$$
\begin{aligned}
y_1 &= 72 \\
y_2 &= 90 \\
y_3 &= 61 \\
y_4 &= 85 \\
y_5 &= 92
\end{aligned}
$$

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

- average : 80
- median : 85
- could average the differences
- midrange: 76.5
  average of min, max
- could draw a histogram and estimate
- min or max or mode
- could take the most recent value

Some common approaches

- The **mean**:

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

- The **median**:

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

- 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.

$$e_i = \underbrace{y_i}_{\text{actual commute time}} - \underbrace{H(x_i)}_{\text{predicted commute time}}$$

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

- If I predict 75 minutes: error = 80 − 75 = 5
- If I predict 72 minutes: error = 80 − 72 = 8
- If I predict 100 minutes: error = 80 − 100 = −20

Issue: some errors are negative, some are positive!

ideas:
- absolute value
- square

Squared loss

One loss function is squared loss, L_{sq}, which computes $(\text{actual} - \text{predicted})^2$.

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

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

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

Note: $(y_i - h)^2 = (h - y_i)^2$

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

↳ main pro: differentiable!

→ absolute: not differentiable

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

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?

$y_1 = 72 \rightarrow (72-85)^2 = 169$

$y_2 = 90 \rightarrow (90-85)^2 = 25$

$y_3 = 61 \rightarrow (61-85)^2 = 576$

$y_4 = 85 \rightarrow (85-85)^2 = 0$

$y_5 = 92 \rightarrow (92-85)^2 = 49$

Goal:
Find a single number that describes the loss for the prediction $h = 85$ on my entire dataset.

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, $h = 80$:

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

low loss is good!

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

80 is a better prediction: it has lower average squared loss.

L : loss for one data point

R : average loss over all data points

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 "**r**isk", as in "empirical **r**isk." We'll see this term again soon.

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

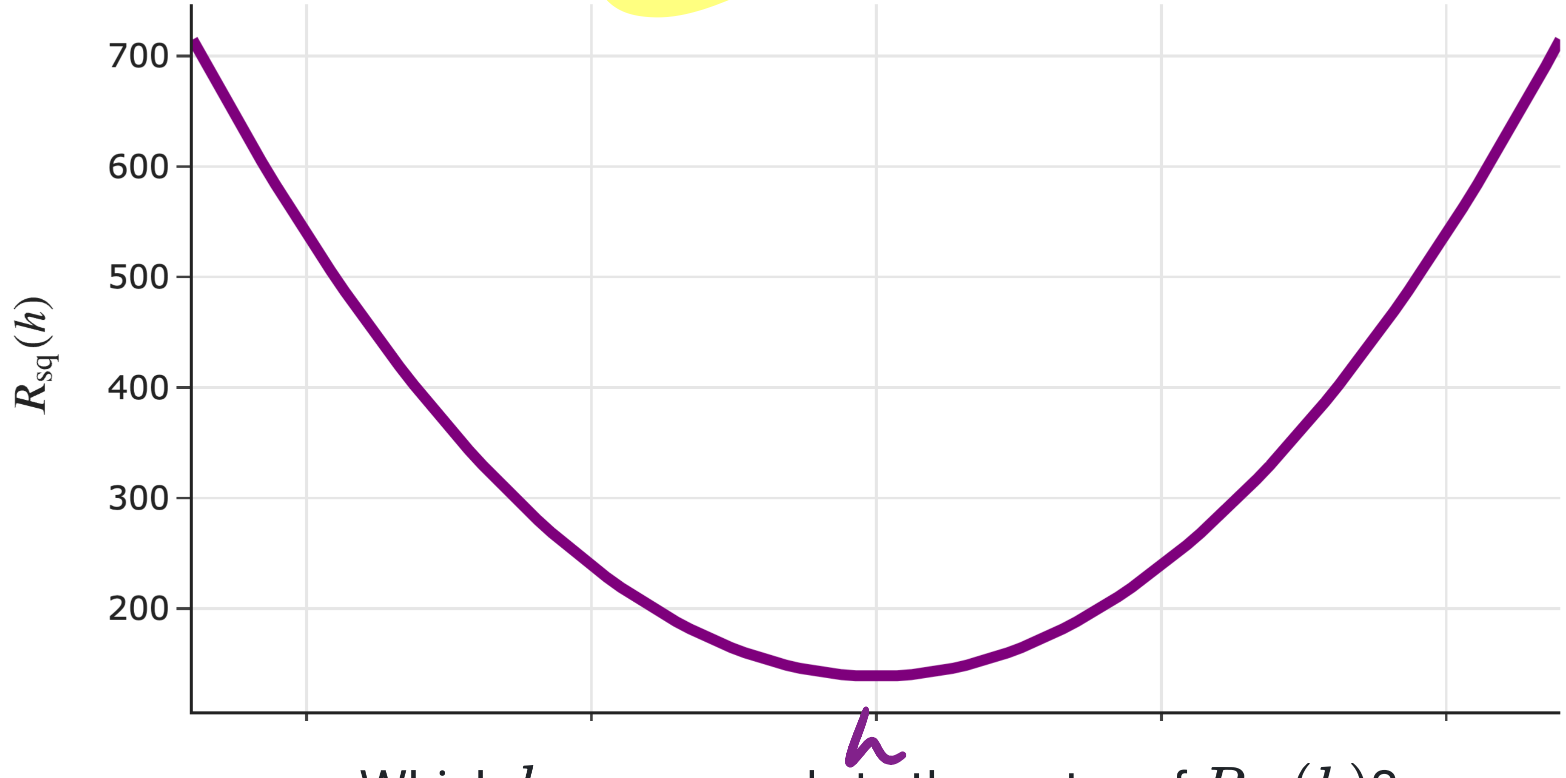
$$\begin{aligned} R_{\text{sq}}(100) &= \frac{1}{5}\left((72-100)^2 + (90-100)^2 + (61-100)^2 + (85-100)^2 + (92-100)^2\right) \\ &= \boxed{538.8} \end{aligned}$$

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

$(90-h)^2$ is a parabola centered at $h=90$

Visualizing mean squared error

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



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

Want to minimize MSE!

Mean squared error, in general

- Suppose we collect n commute times, $y_1, y_2, \ldots, y_n$.
- The mean squared error of the prediction h is:

$$R_{sq}(h) = \frac{1}{n}\left[(y_1 - h)^2 + (y_2 - h)^2 + \cdots + (y_n - h)^2\right]$$

- Or, using **summation notation**:

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

```
total = 0
for i in range(1, n+1):
    total += (y[i] - h) ** 2
total = total / n
```

equivalent

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^*?**

using calculus!

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.