Introduction to Linear Models

Prof. Wells

STA 209, 2/15/23

Outline

In this lecture, we will. . .

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- Investigate the linear model
- Discuss predictions and residuals
- Explore a formula for finding the line of best fit

Section 1

Introduction to Linear Regression

Overview

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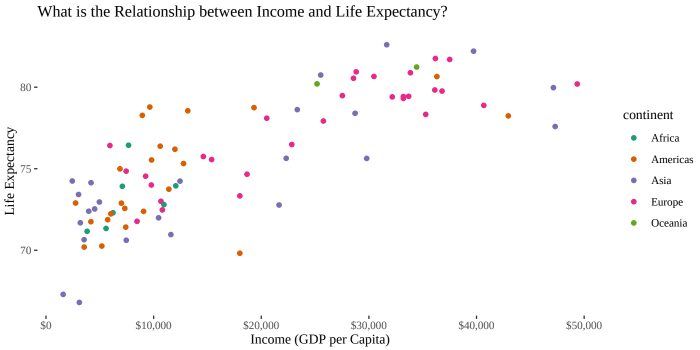

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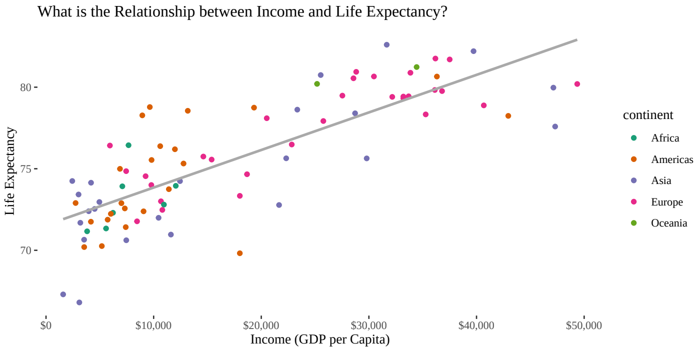

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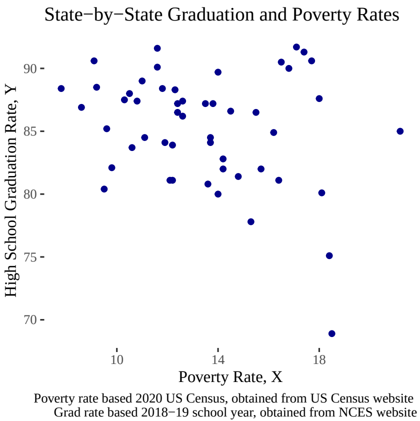
- Of course, in the wild, the observed values of Y will **not** be perfectly predicted by the values of X.

$$Y = \beta_0 + \beta_1 X + \epsilon \qquad \text{where } \epsilon \text{ is the error}$$

Scatterplots and Linear Relationships I



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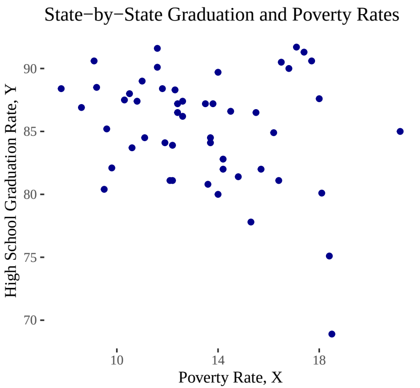

Poverty rate based 2020 US Census, obtained from US Census website
Grad rate based 2018−19 school year, obtained from NCES website

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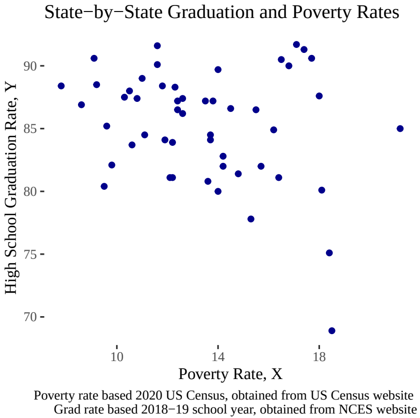

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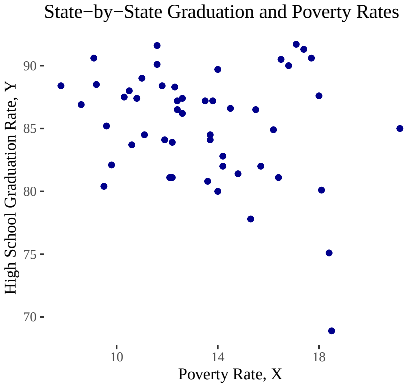

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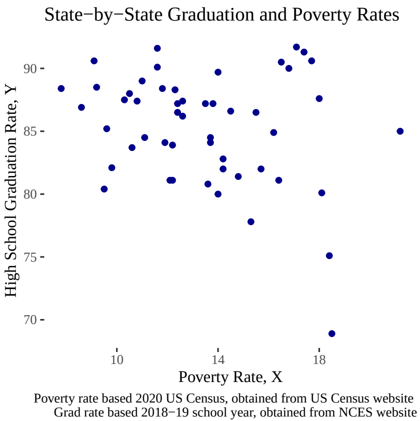

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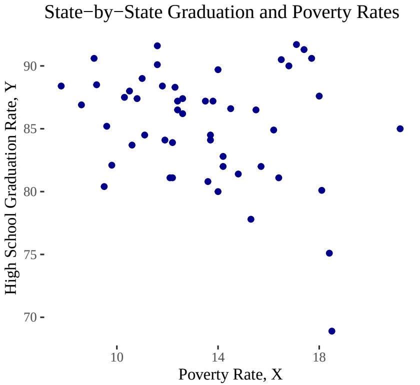

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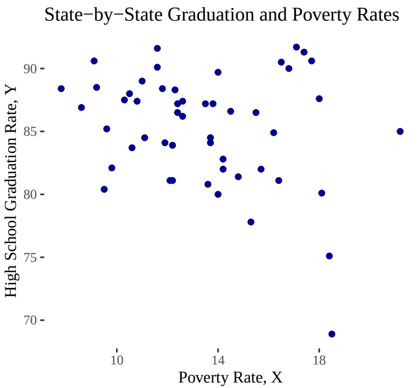

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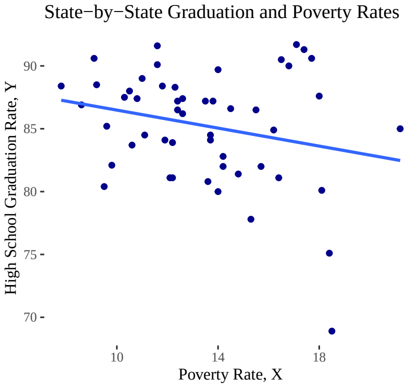
  - Linear, negative, moderate

Scatterplots and Linear Relationships II



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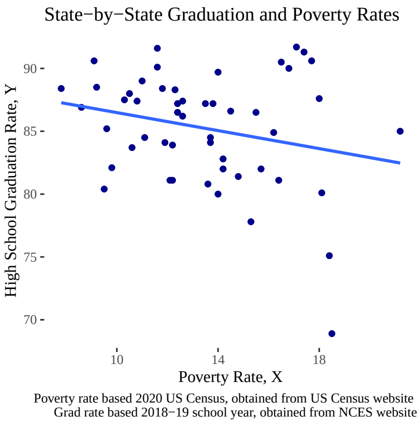

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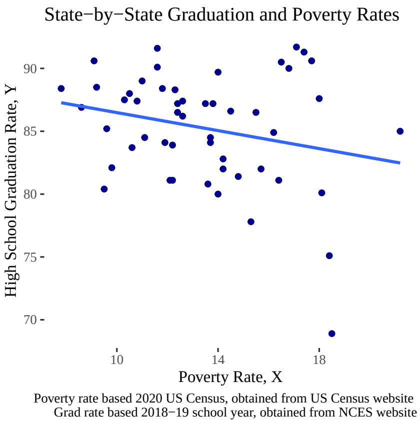

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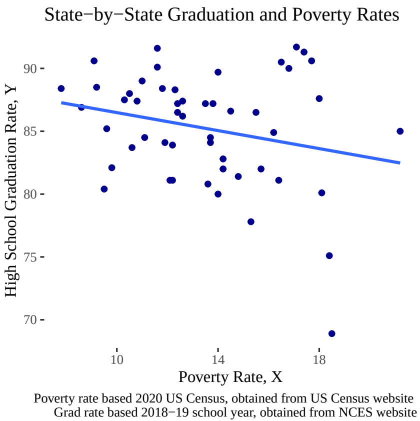

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- **Intercept** of $\beta_0 = 90$ means model predicts graduation rate of 90% when poverty rate is 0%.

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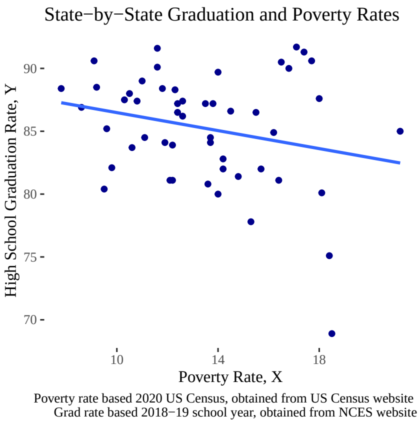

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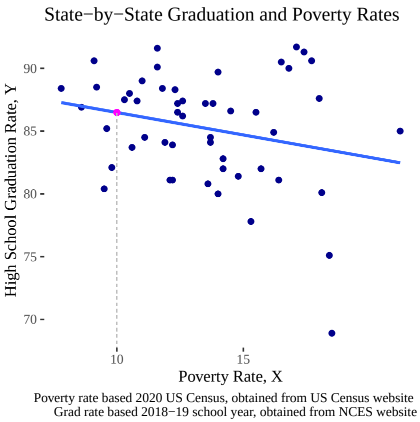

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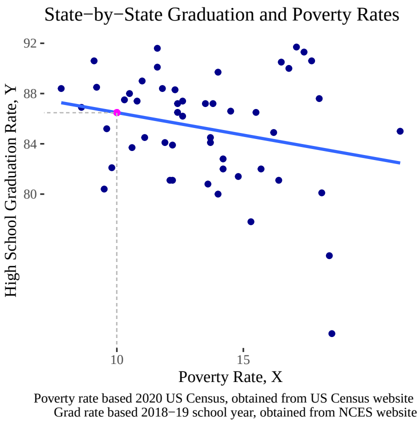


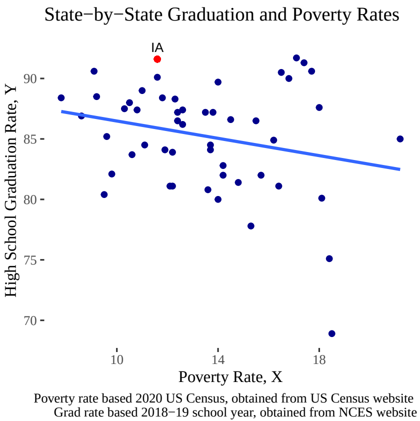
- Model:

$$\hat{Y} = 90 - 0.4 \cdot X$$

- What does the model predict to be the graduation rate for a state with theoretical poverty rate 7%?

$$\hat{Y} = 90 - 0.4 \cdot 10 = 86$$

Scatterplots and Linear Relationships IV



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$$\hat{Y} = 90 - 0.4 \cdot 11.6 = 85.36$$

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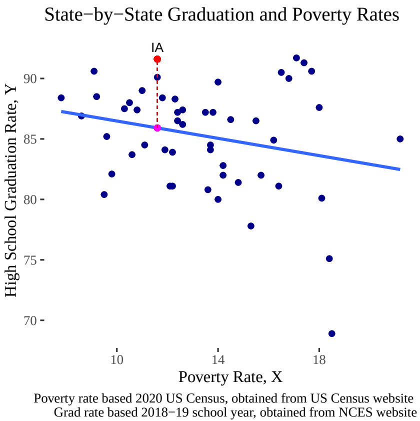

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But Iowa's actual graduation rate is 91.6

Residuals

- **Residuals** are the leftover variation in the data after accounting for model fit.
- Each observation (X_i, Y_i) has its own residual e_i, which is the difference between the observed (Y_i) and predicted $(\hat{Y}_i)$ value:

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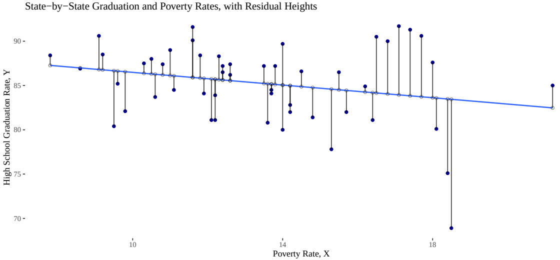

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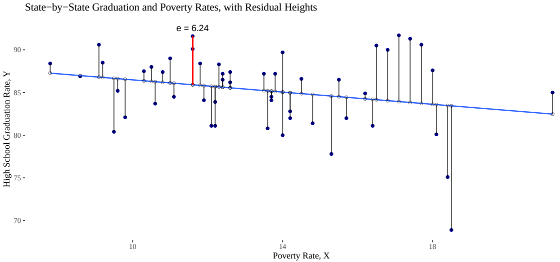
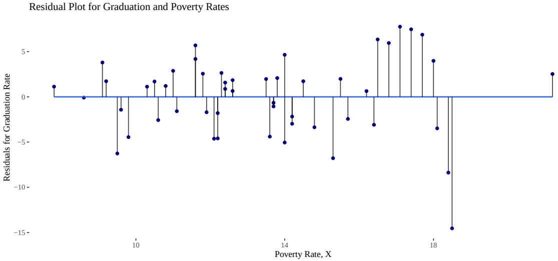


- Iowa's residual is

$$e = Y - \hat{Y} = 91.6 - 85.36 = 6.24$$

Residual Plot

- To visualize the degree of accuracy of a linear model, we use residual plots:



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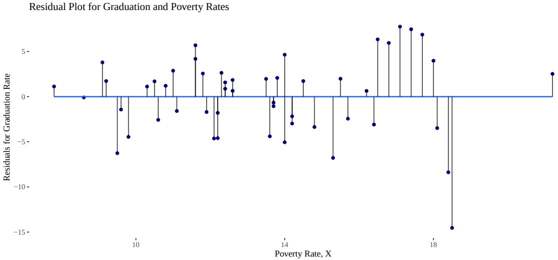

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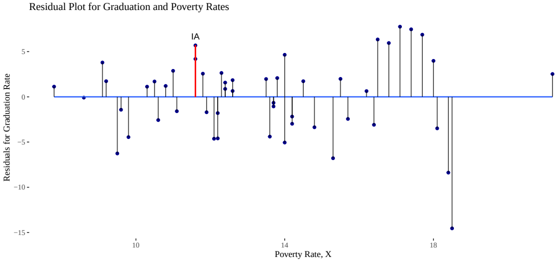

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Section 2

Quantifying Goodness-of-Fit

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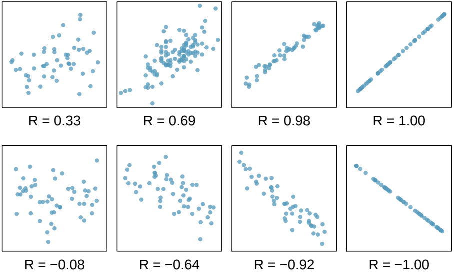

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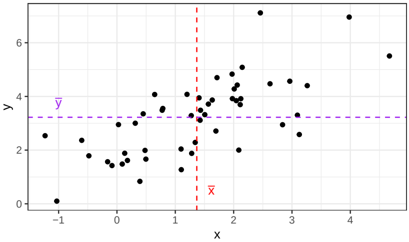

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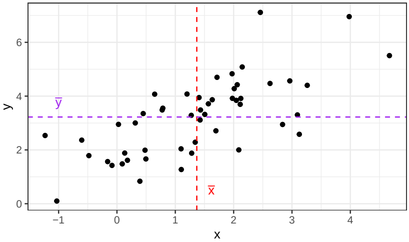

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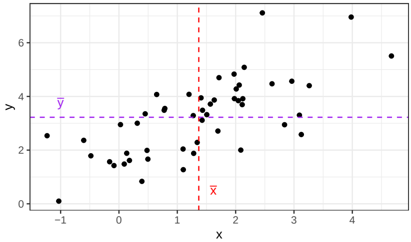

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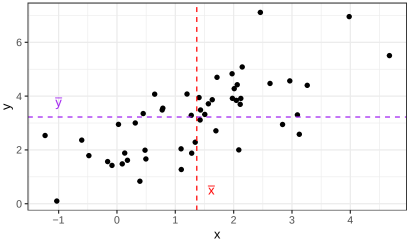

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$$R = 0.6995848$$

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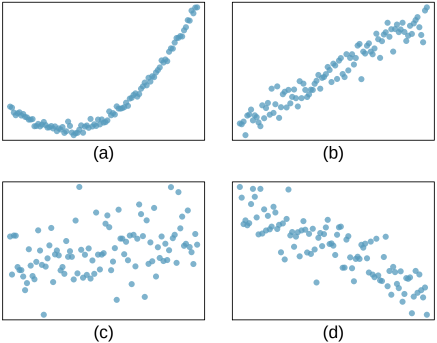

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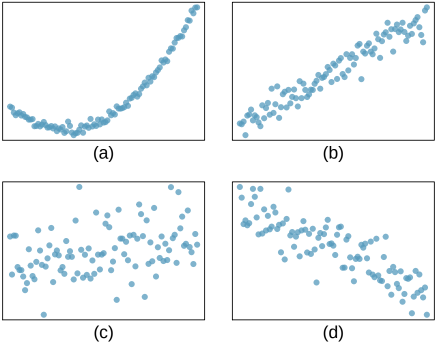

- Answer: (b), not (a)

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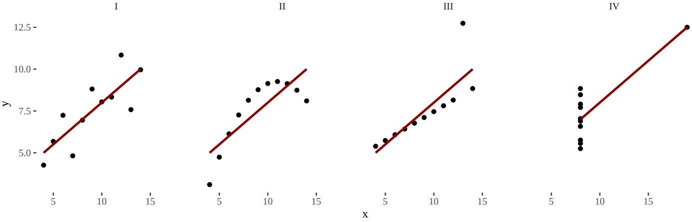


```
##                I   II  III   IV
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```

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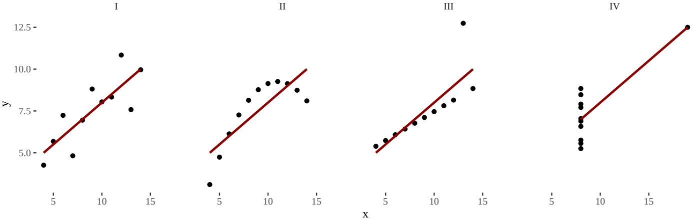


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- However, each graphic tells a radically different story about the relationship between the variables.

Section 3

Fitting a Line by Least-Squares Regression

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  2. More computationally efficient.

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  - Option 1: Minimizing the sum of absolute values

$$|e_1| + |e_2| + \cdots + |e_n|$$

  - Option 2: Minimize the sum of squares

$$e_1^2 + e_2^2 + \cdots + e_n^2$$

- Option 2 is usually preferred.
  1. Most commonly used.
  2. More computationally efficient.
  3. Has theoretical advantages (by analogy with distance and pythagorean thm.)

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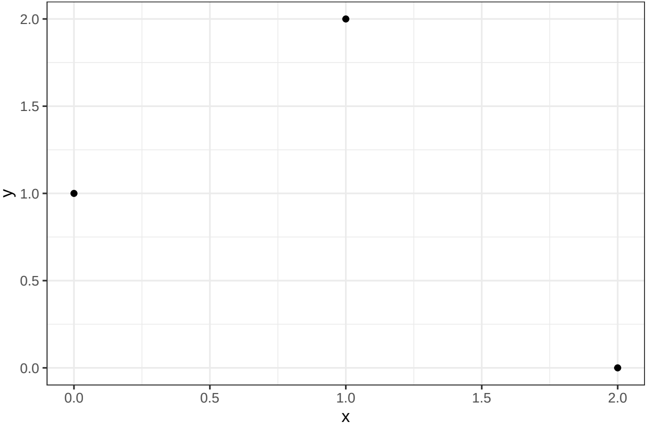
  4. Appropriately weights one large residuals as "worse" than many small ones.
  5. Has well-understood properties for inference

Line of Best Fit

- For the three data points below, consider candidates for the line of best fit:



$$\text{Goal: minimize } e_1^2 + e_2^2 + e_3^2$$

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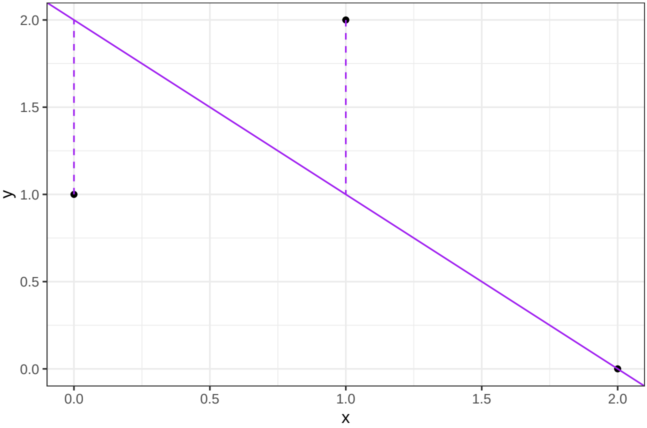

$$\text{Purple line}: \quad e_1^2 + e_2^2 + e_3^2 = 1^2 + 0^2 + 1^2 = 2$$

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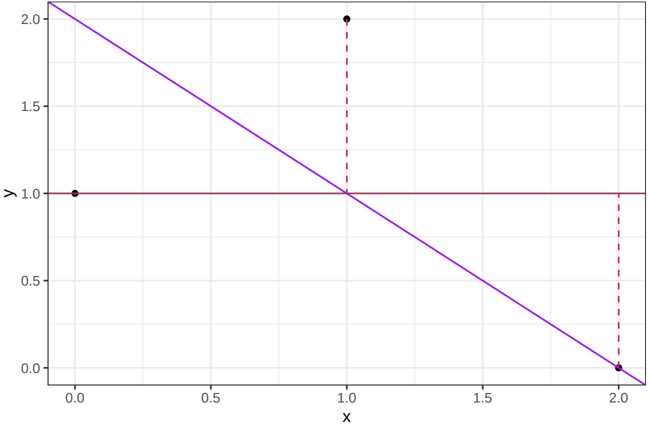

$$\text{Maroon line}: \quad e_1^2 + e_2^2 + e_3^2 = 0^2 + 1^2 + 1^2 = 2$$

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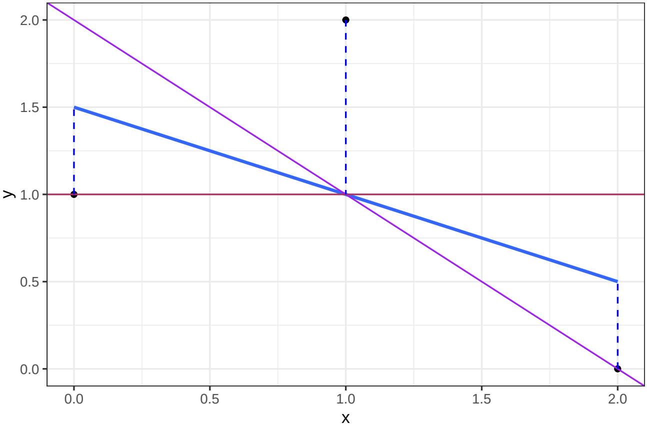

$$\text{Blue line}: \quad e_1^2 + e_2^2 + e_3^2 = 0.5^2 + 1^2 + 0.5^2 = 1.5$$

A Formula for the Least Squares Regression Line

- Suppose n observations for variables X and Y are collected:

$$(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$$

with means $\bar{x}, \bar{y}$, standard deviations s_x, s_y, and correlation R.

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Properties of the Least-Squares Regression line

- The least squares line is

$$\hat{Y} = \beta_0 + \beta_1 X \qquad \beta_1 = \frac{s_y}{s_x} R \qquad \beta_0 = \bar{y} - \beta_1 \bar{x}$$

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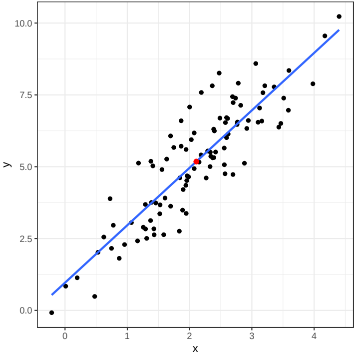


```
##     mean_x   mean_y
## 1 2.108887 5.179967
```

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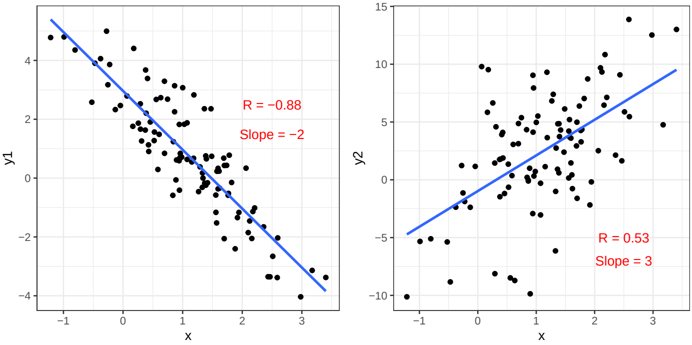

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