



DeepLearning.AI

## Math for Machine Learning

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# Probability and Statistics



DeepLearning.AI

## Math for Machine Learning

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# Probability and Statistics - Week 2

# W2 Lesson 1



DeepLearning.AI

# Describing Distributions

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**Measures of  
Central Tendency**

# Mean: Example

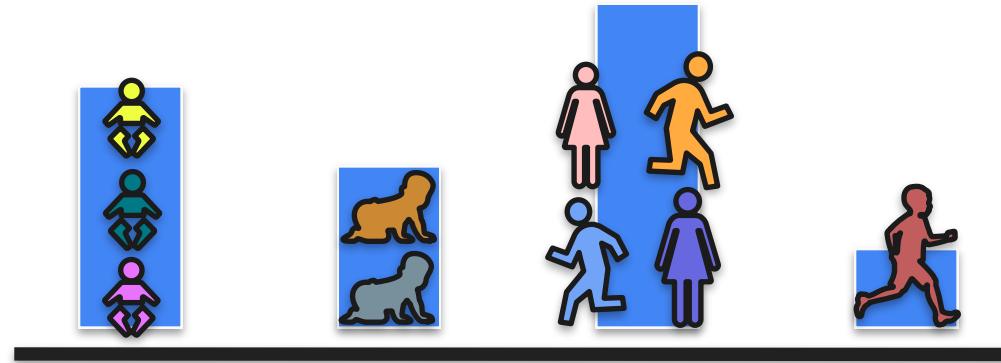
Age:

0

1

2

3



# Mean: Example

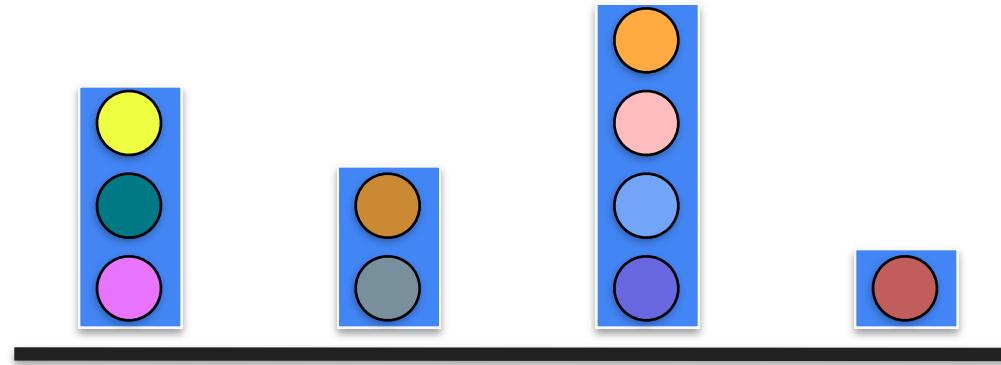
Age:

0

1

2

3



# Mean: Example

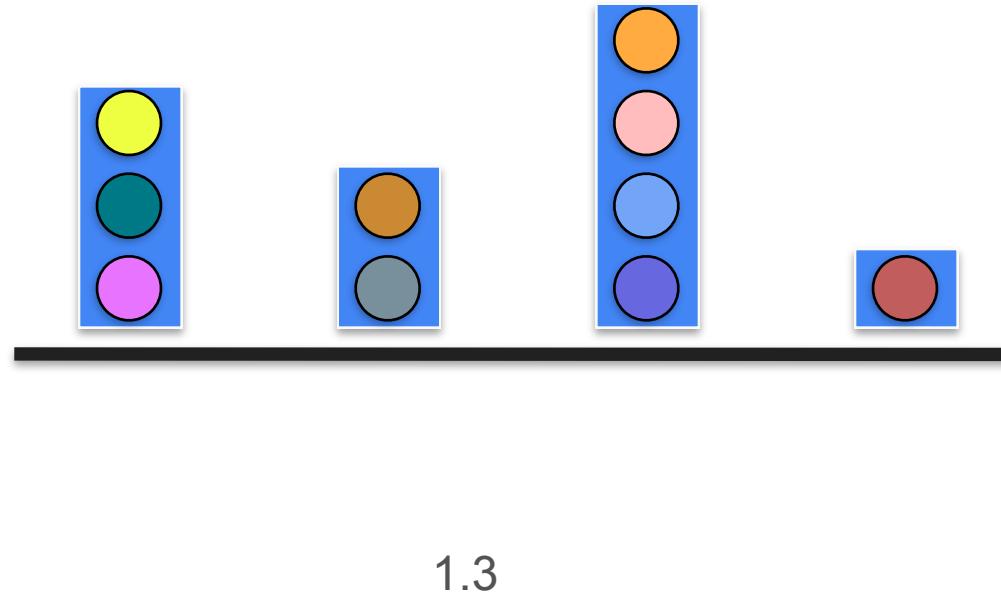
Age:

0

1

2

3



# Mean: Example

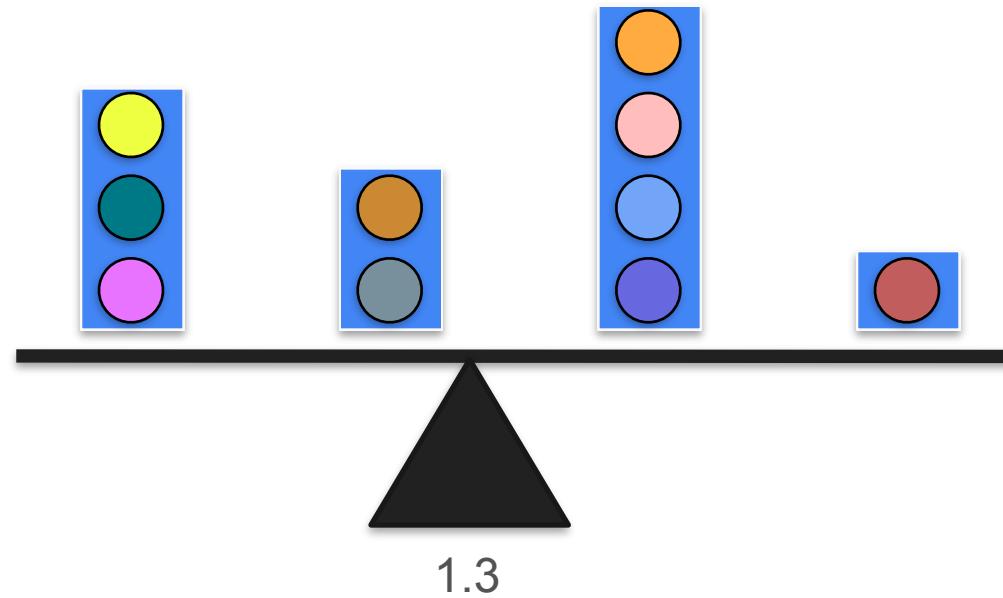
Age:

0

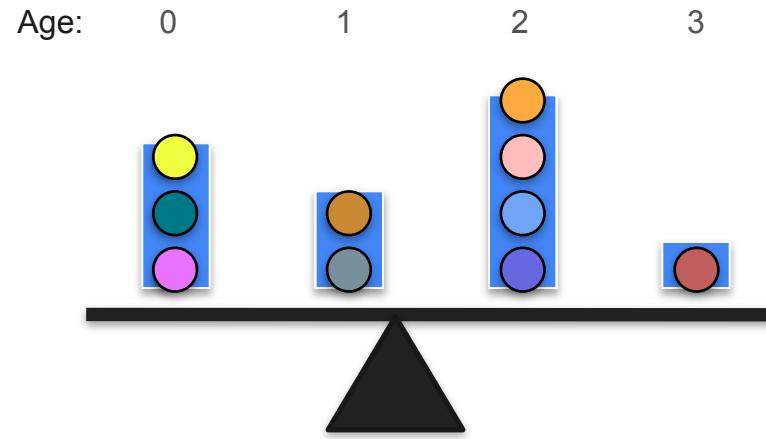
1

2

3

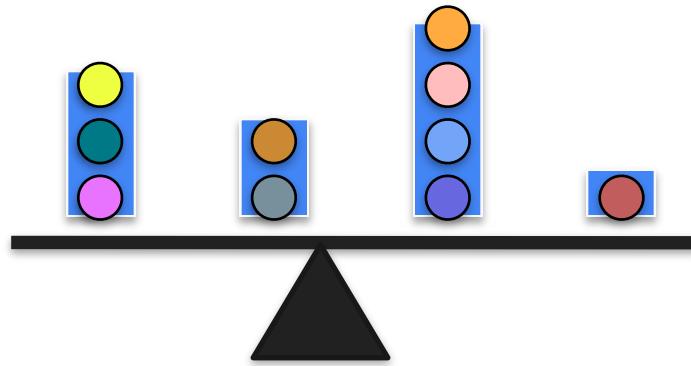


# Mean: Example



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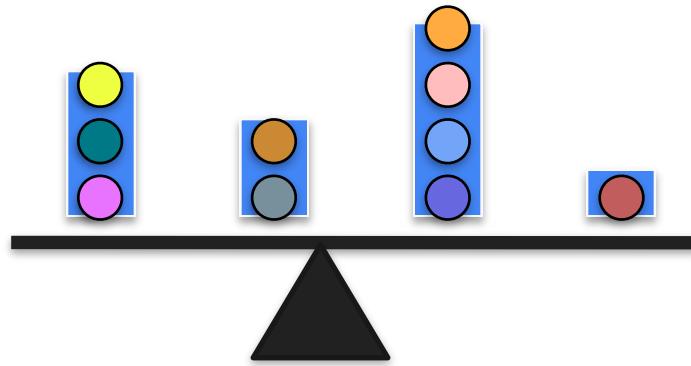
Age: 0      1      2      3       $0 + 0 + 0$



# Mean: Example

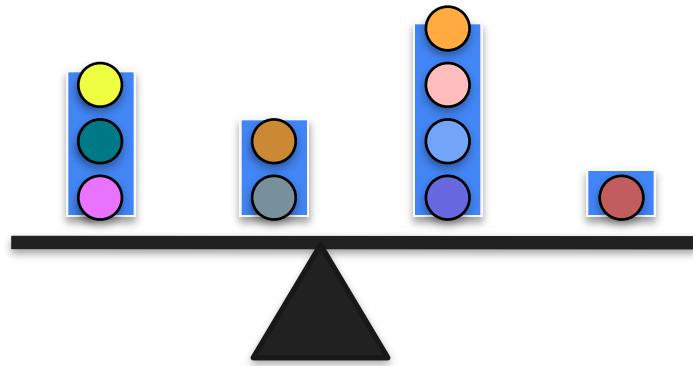
Age: 0 1 2 3

$0 + 0 + 0 + 1 + 1$



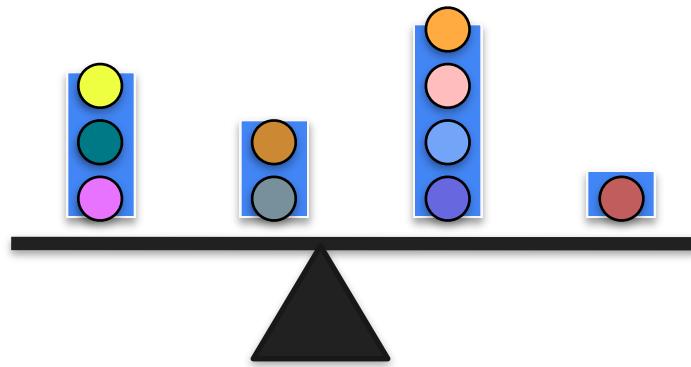
# Mean: Example

Age: 0 1 2 3       $0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 2$



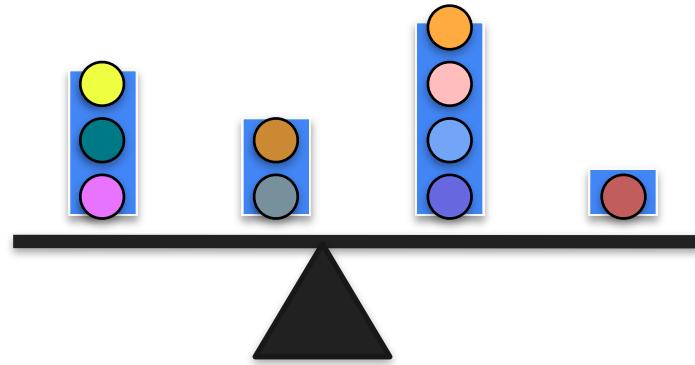
# Mean: Example

Age: 0      1      2      3       $0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 2 + 3$



# Mean: Example

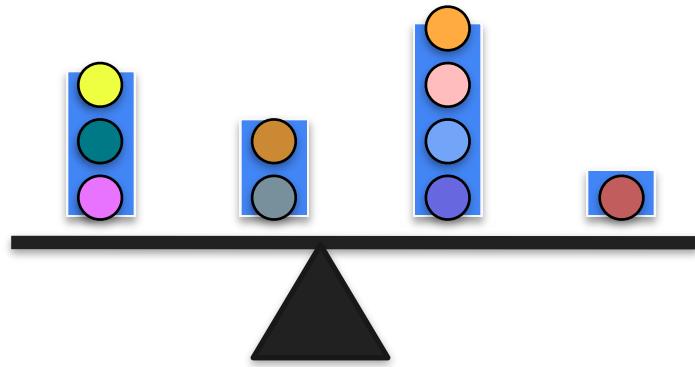
Age: 0      1      2      3



$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

# Mean: Example

Age: 0      1      2      3

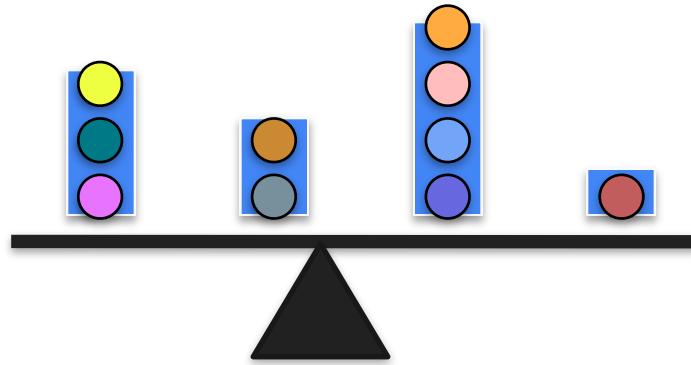


$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

$$= \frac{13}{10}$$

# Mean: Example

Age: 0      1      2      3



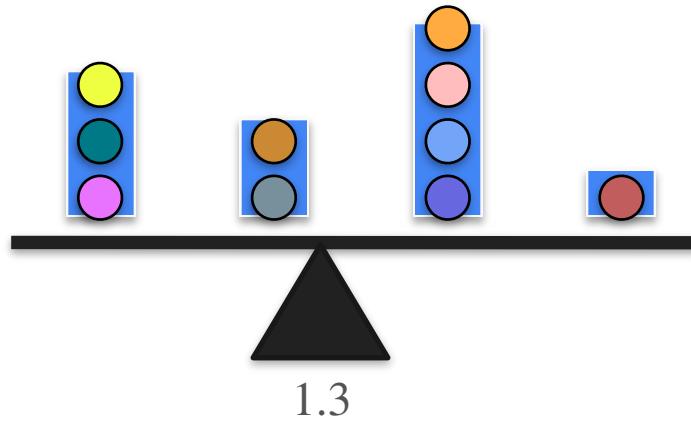
$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

$$= \frac{13}{10}$$

$$= 1.3$$

# Mean: Example

Age: 0      1      2      3

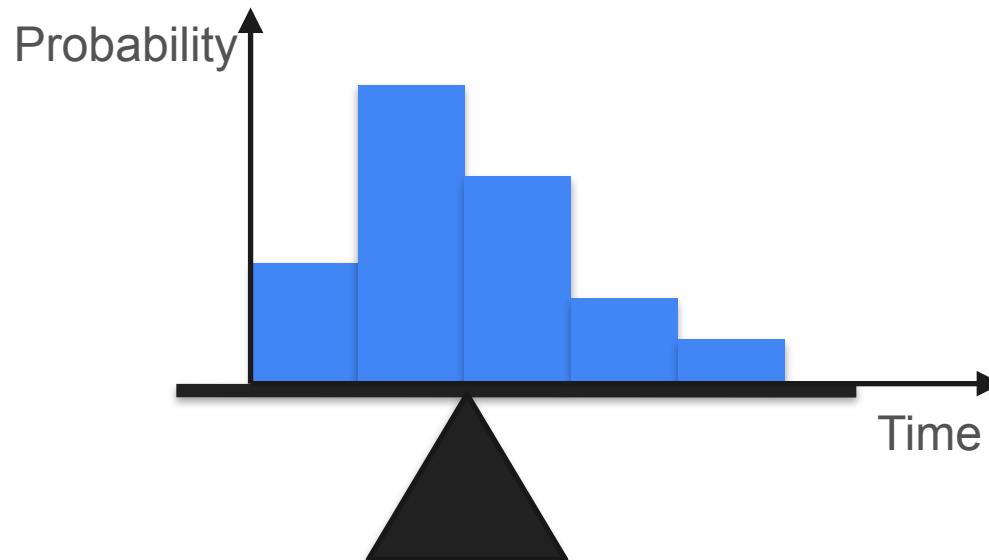
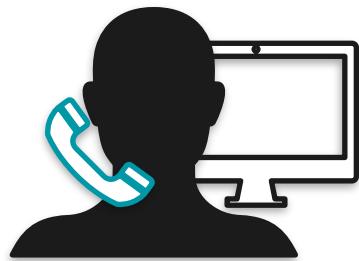


$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

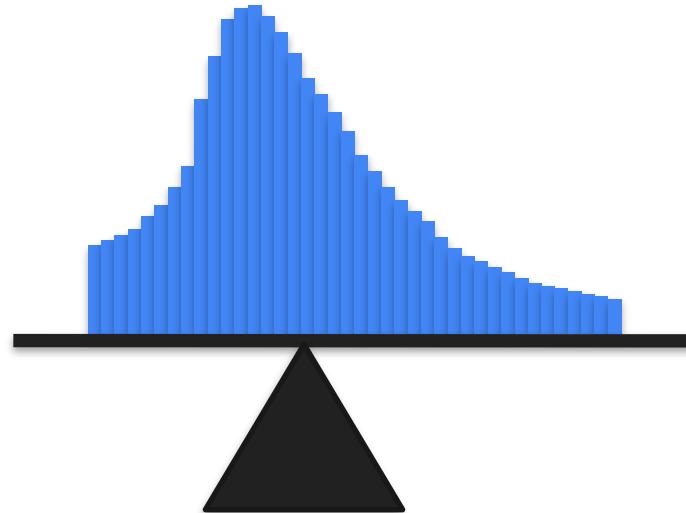
$$= \frac{13}{10}$$

$$= 1.3$$

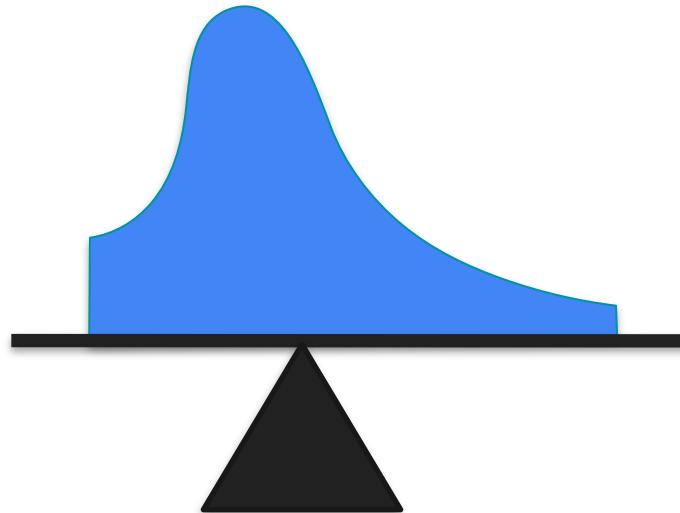
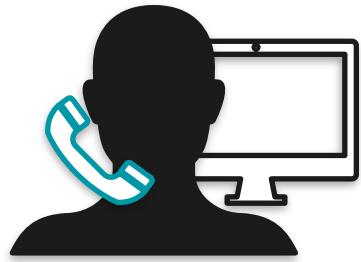
# Mean



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# Median: Motivation

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- Why?
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- 



Michael Jordan

# Outliers

# Outliers

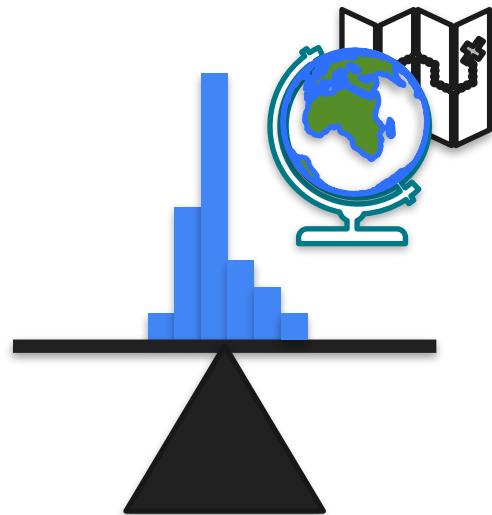


# Outliers



# Outliers

Graduates



Salary

# Outliers

Graduates



# Outliers

Graduates



# Outliers

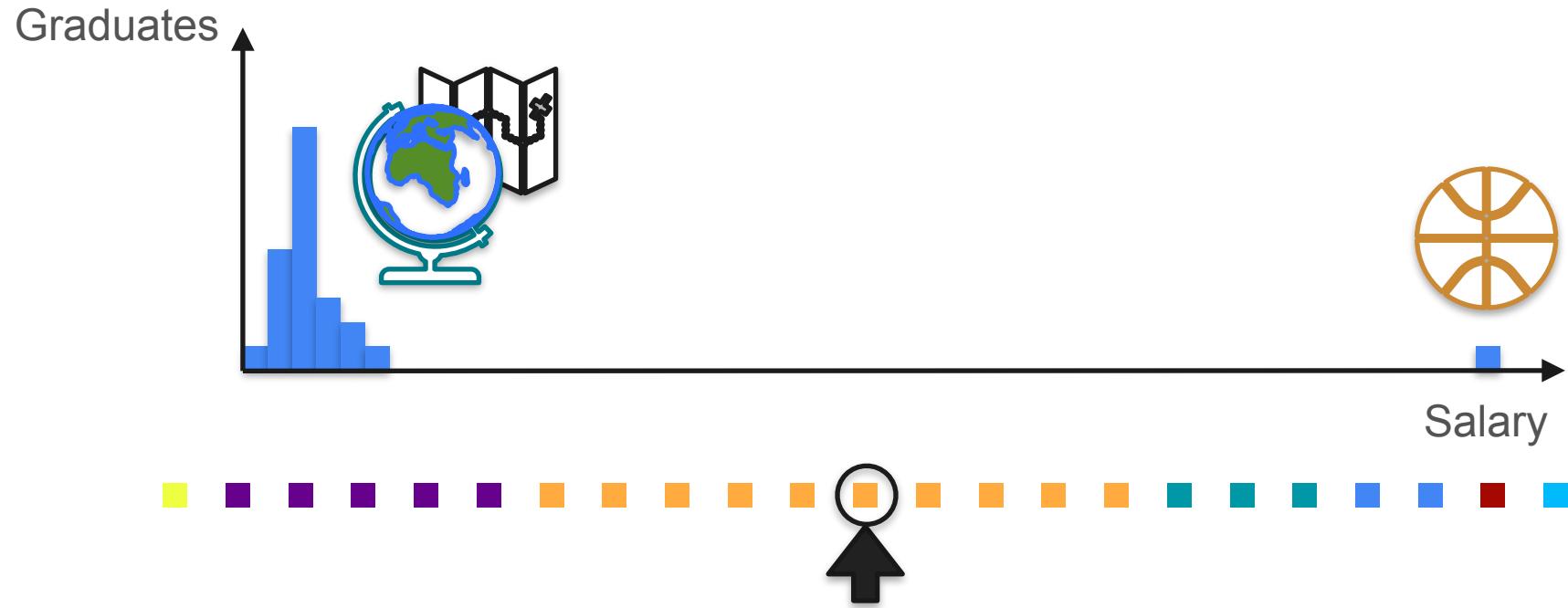


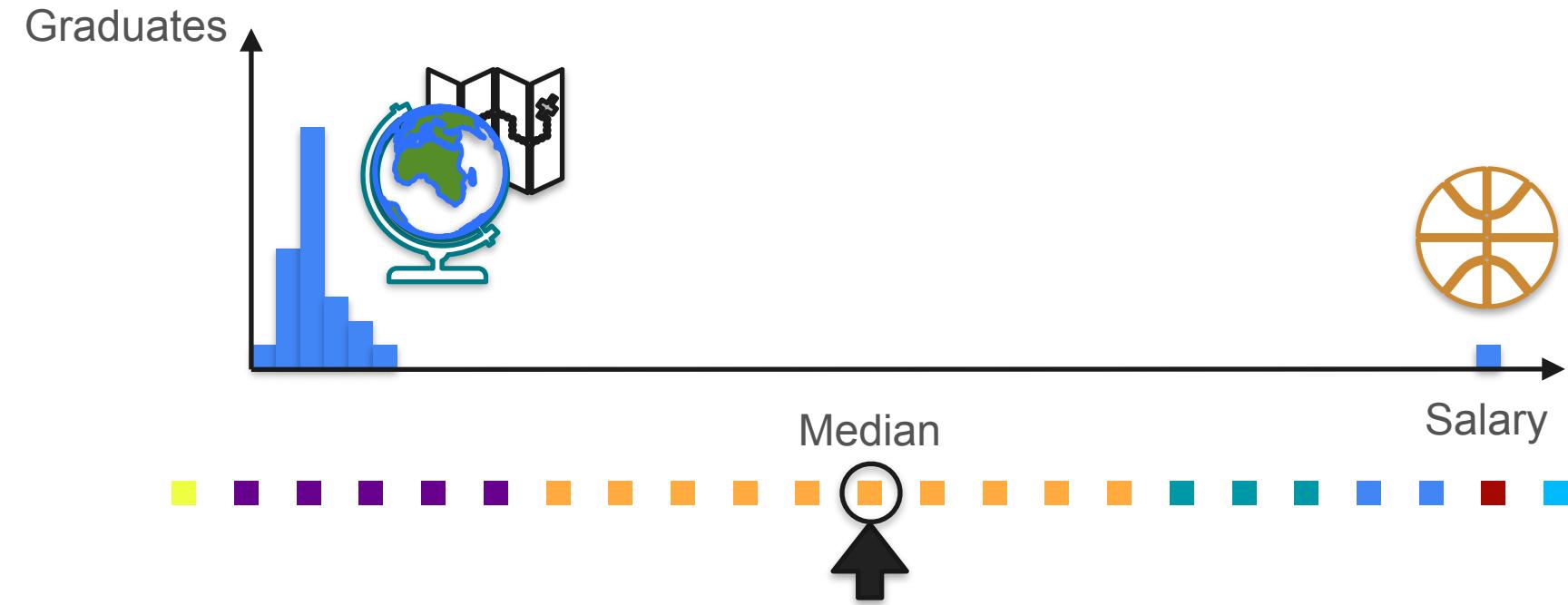
# Median

Graduates



# Median





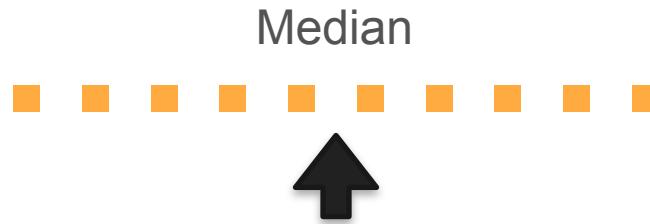
# Median



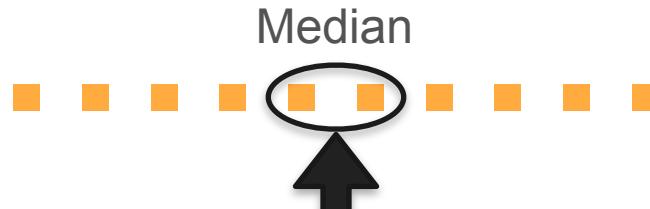
# Median



# Median

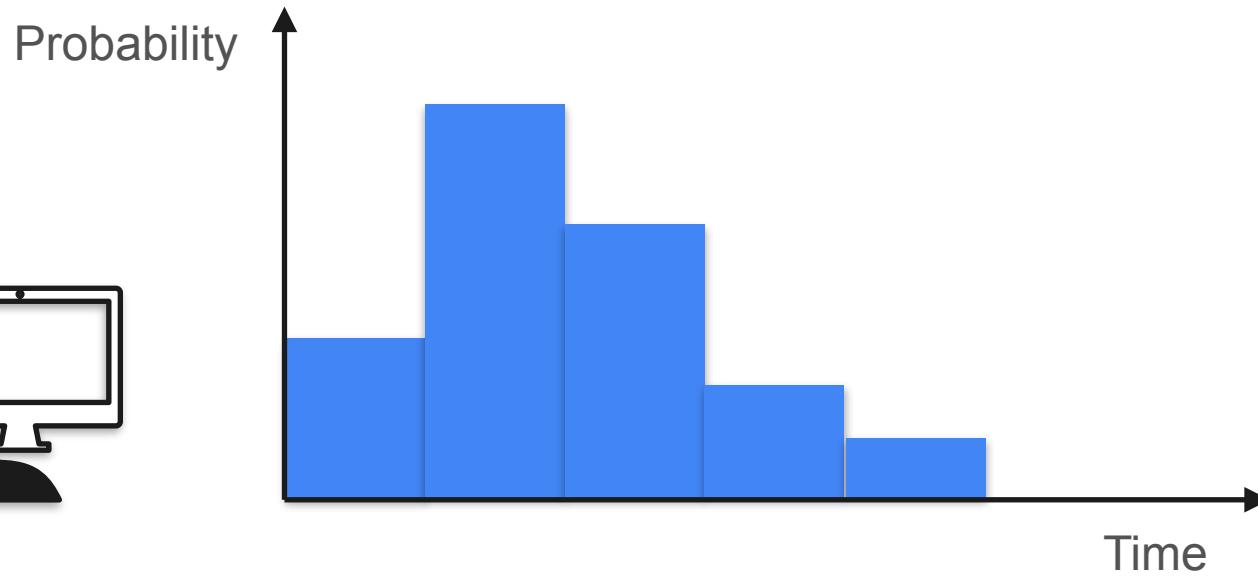


# Median

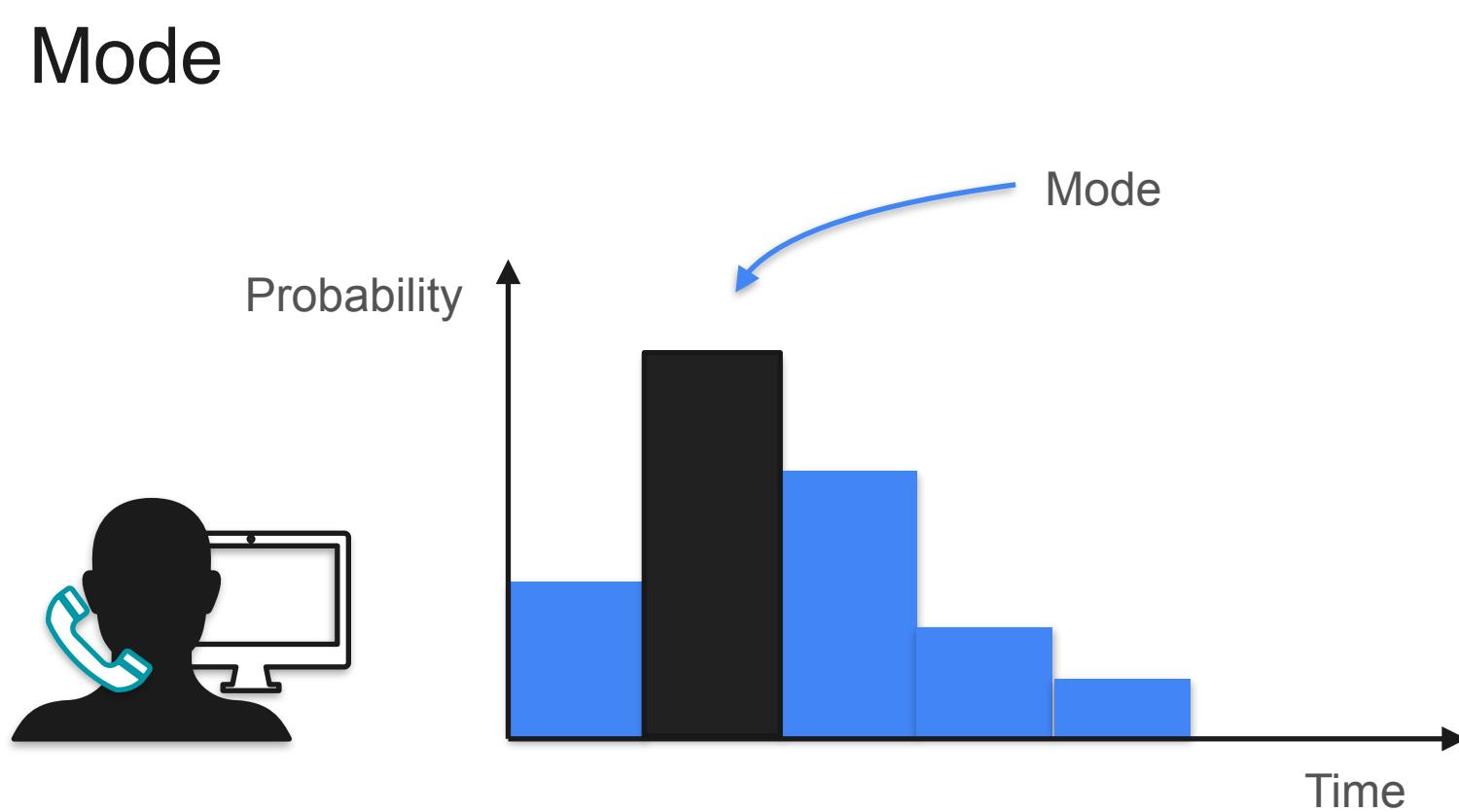


Median  
Average of the  
two middle ones

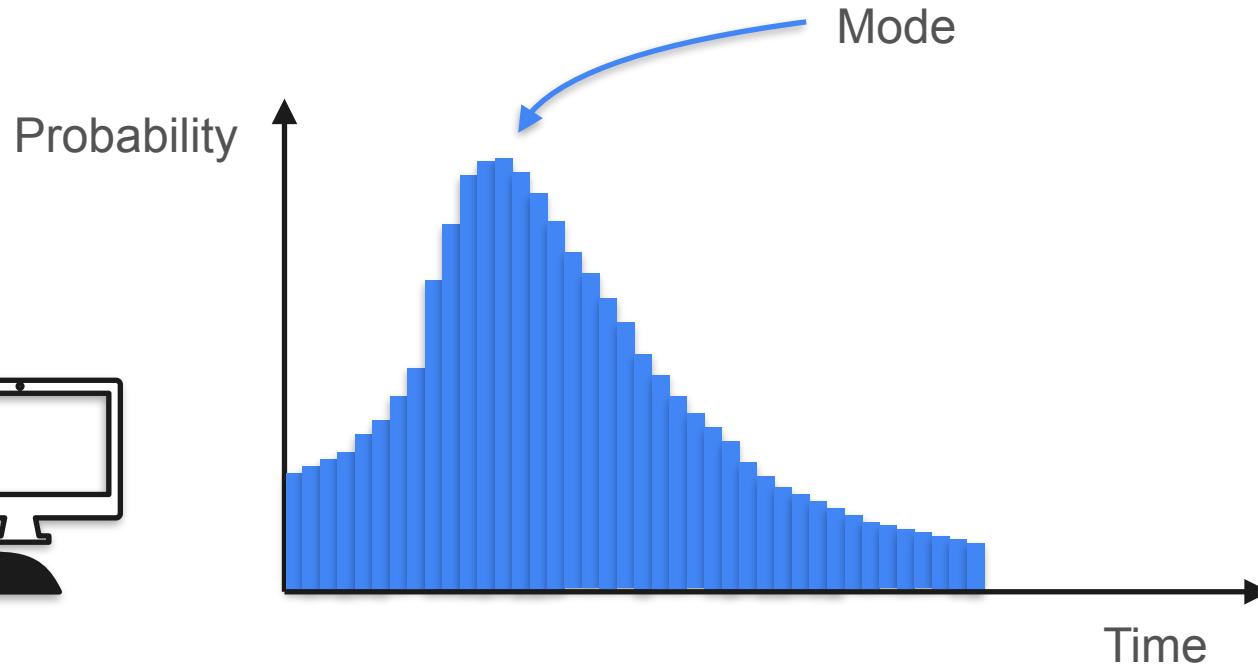
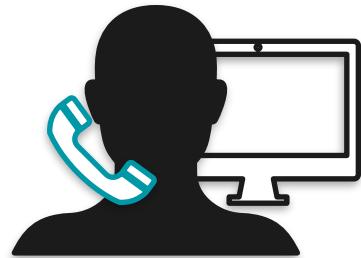
# Mode



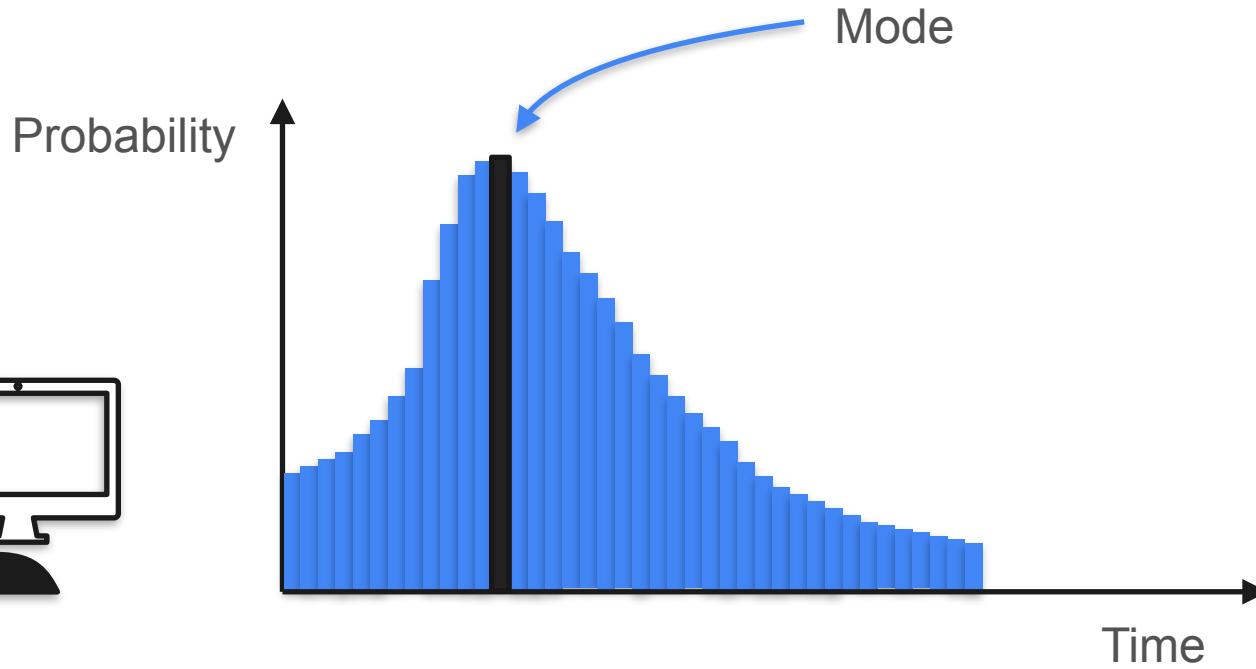
# Mode



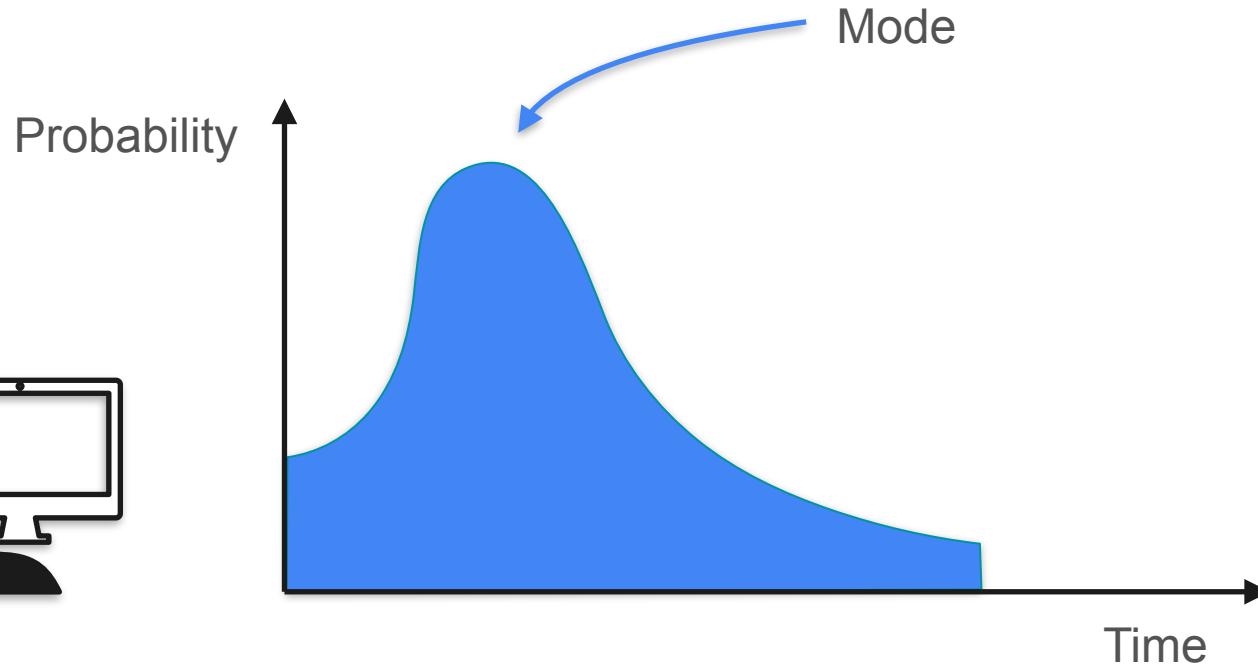
# Mode



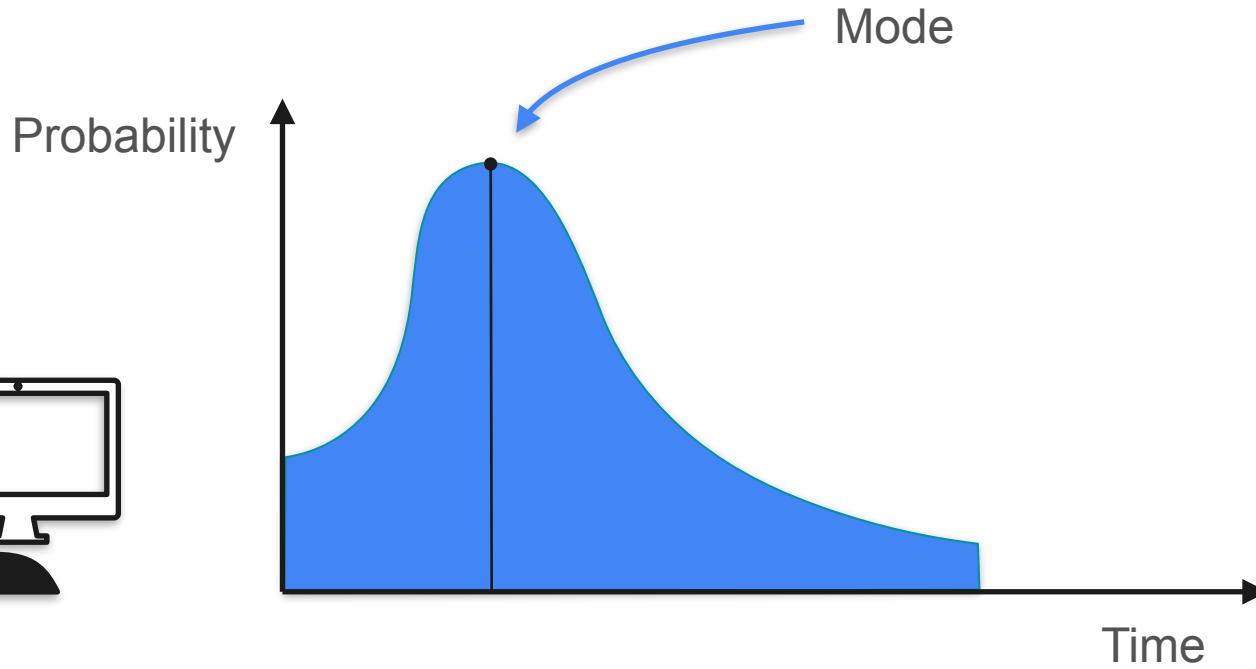
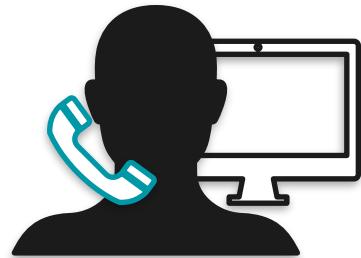
# Mode



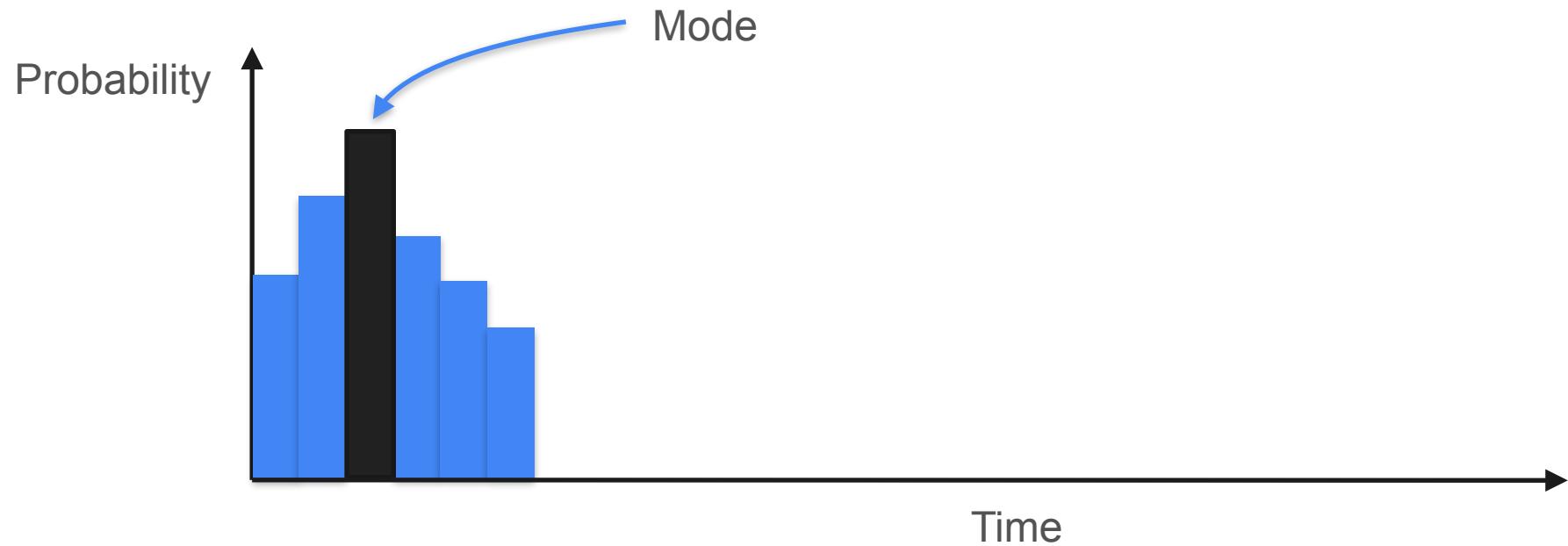
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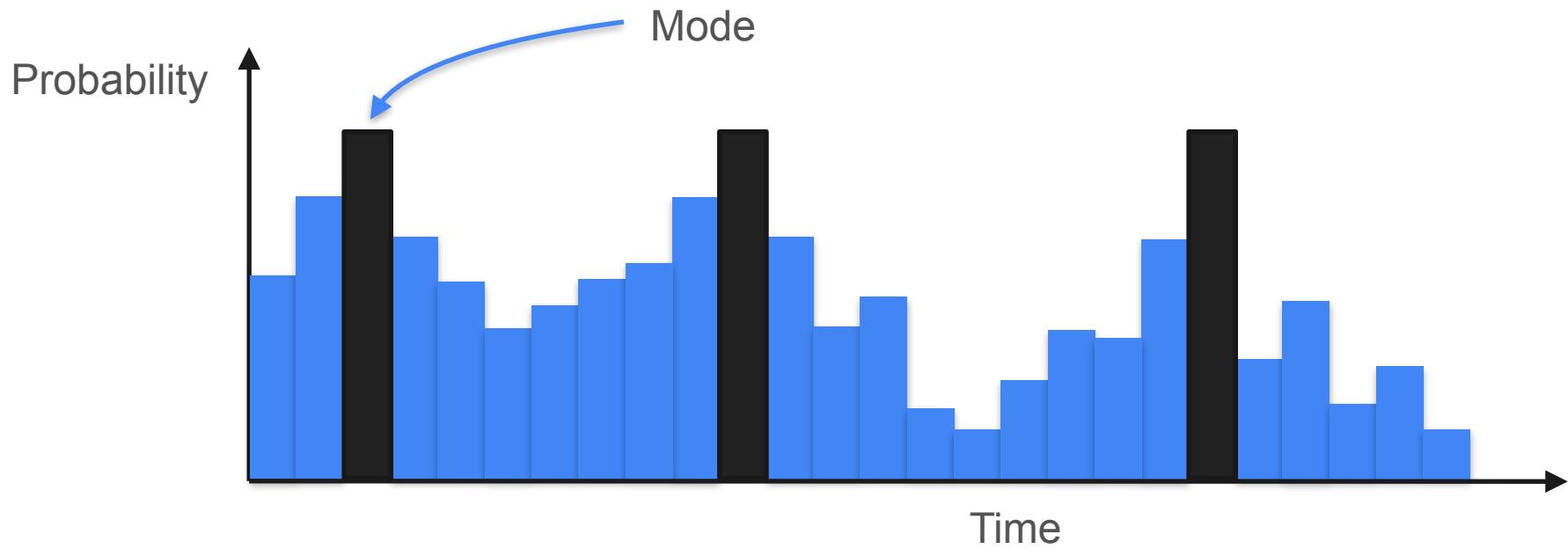
# Mode



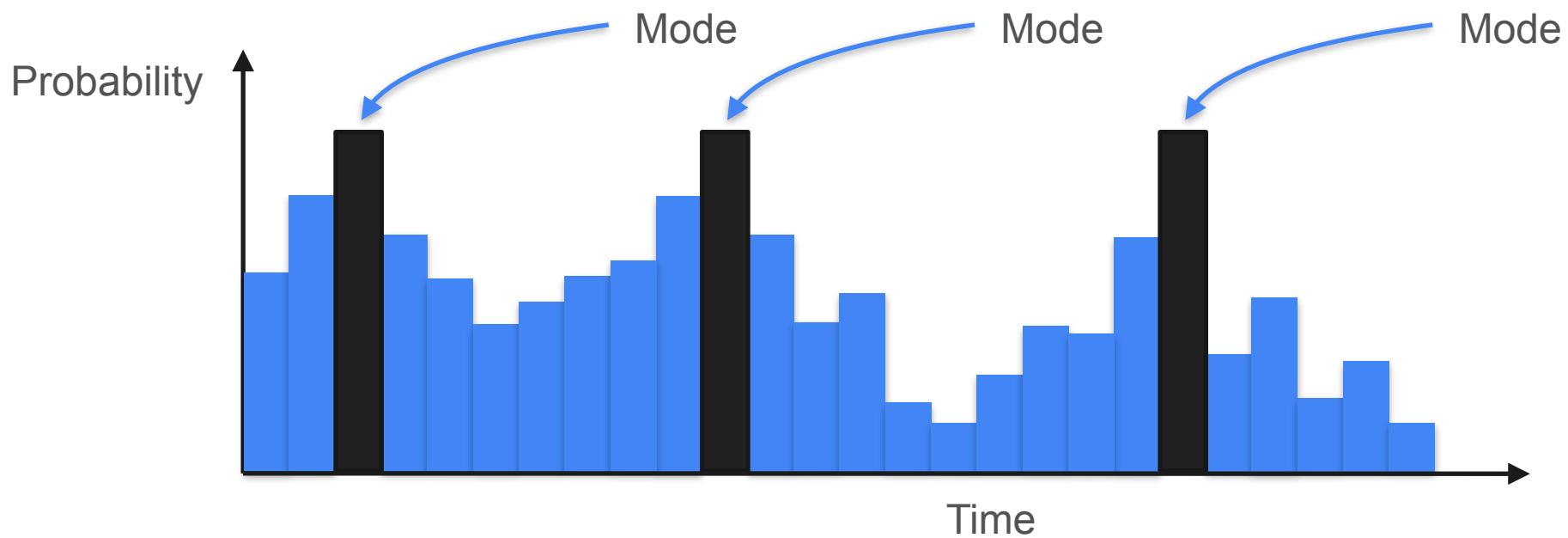
# Mode: Multimodal Distribution



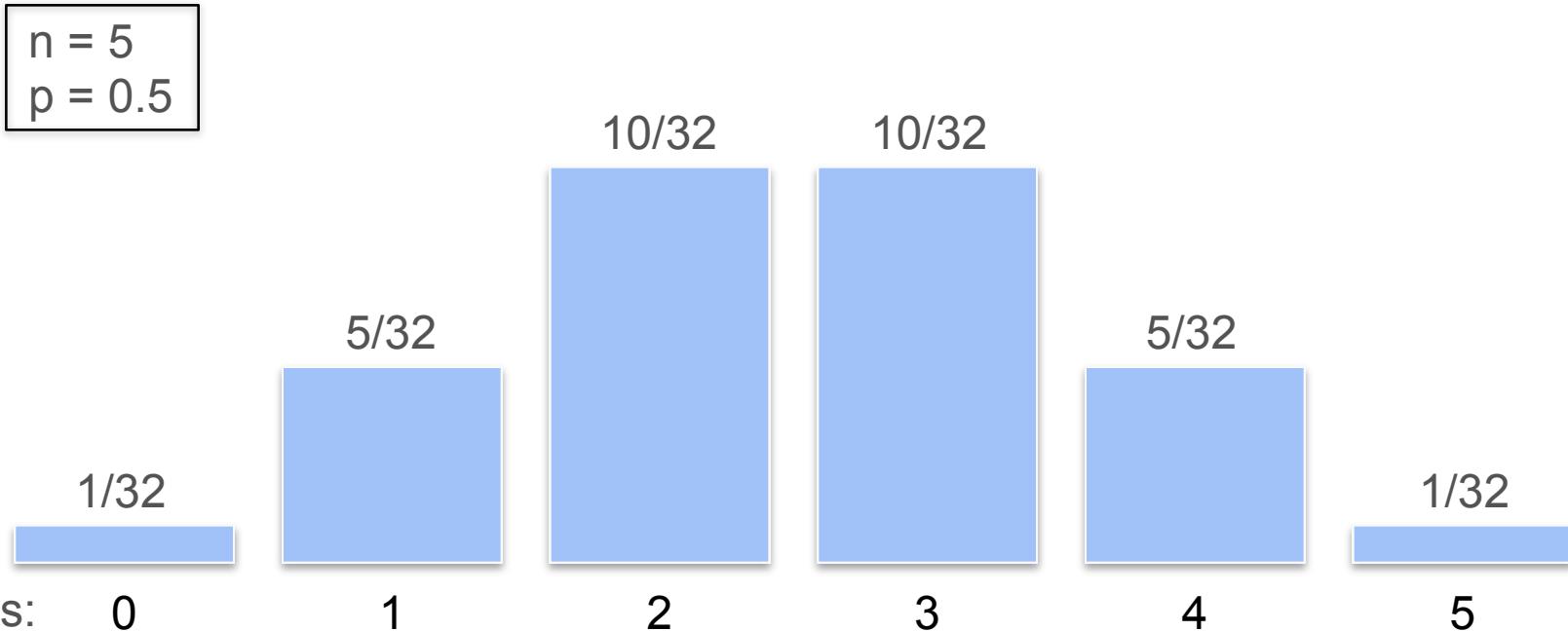
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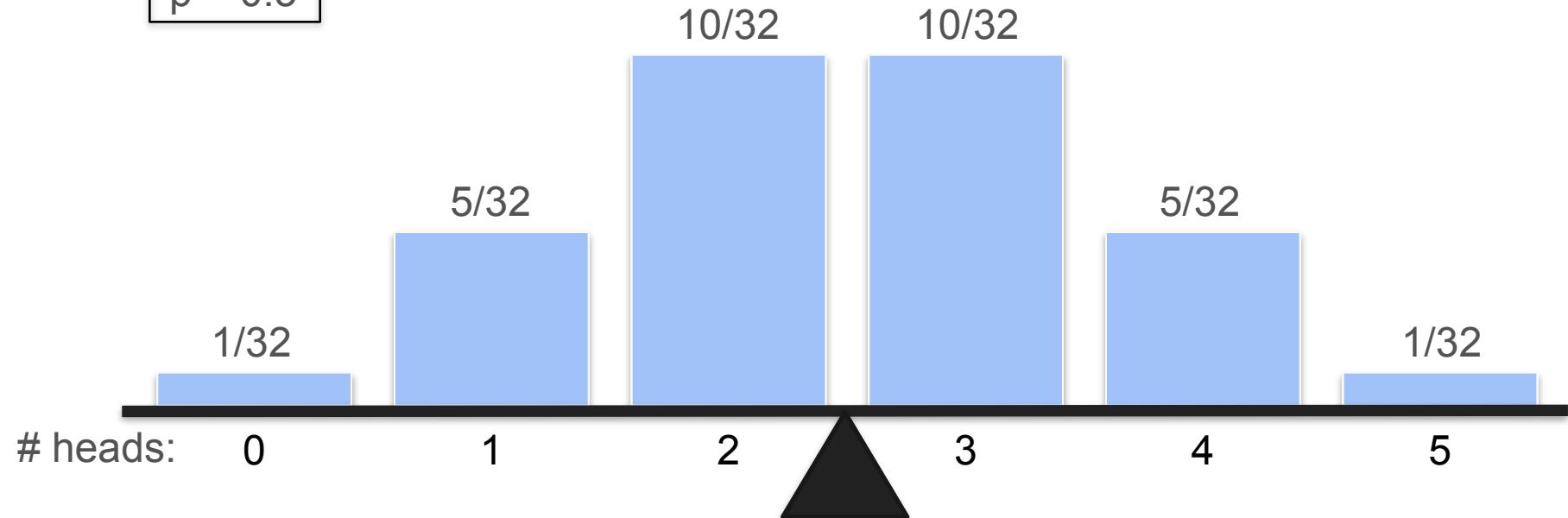


# Mean, Median and Mode in Binomial Distribution

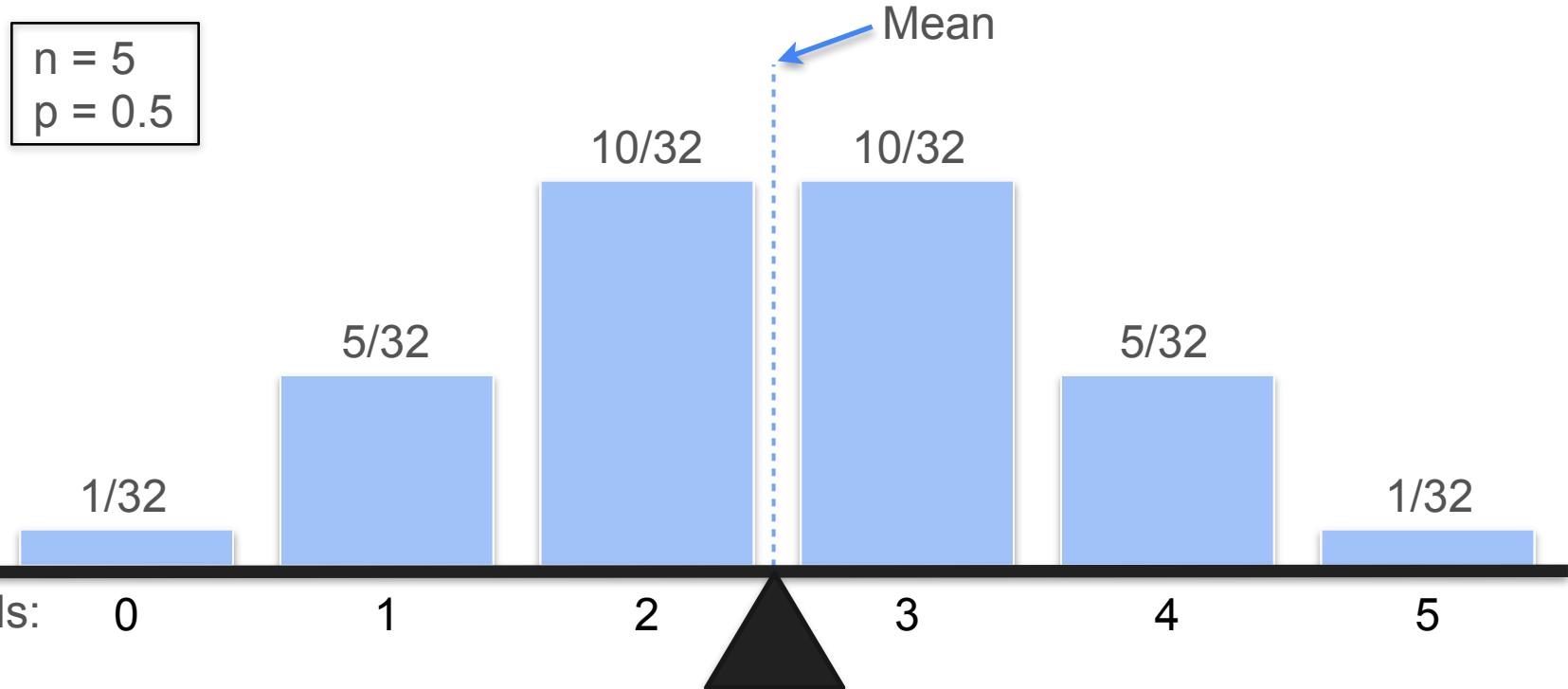


# Mean, Median and Mode in Binomial Distribution

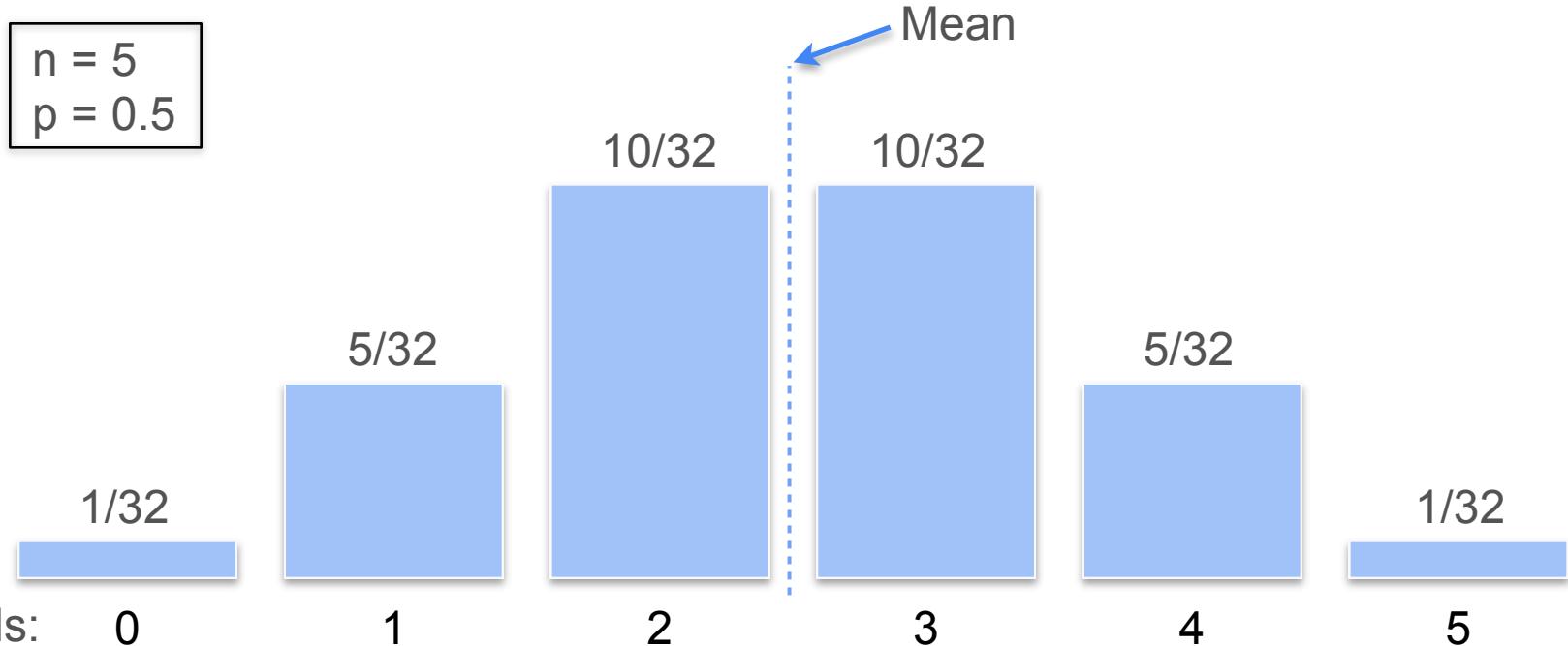
$n = 5$   
 $p = 0.5$



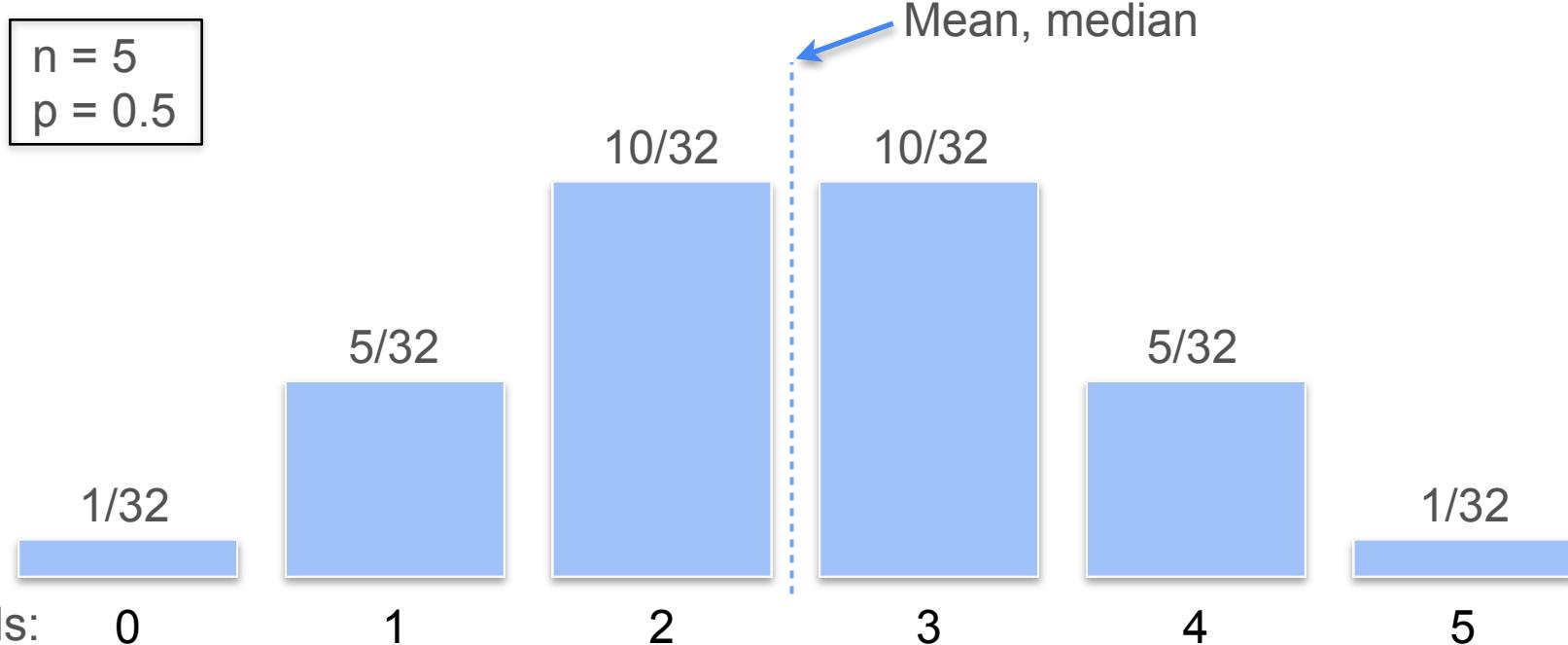
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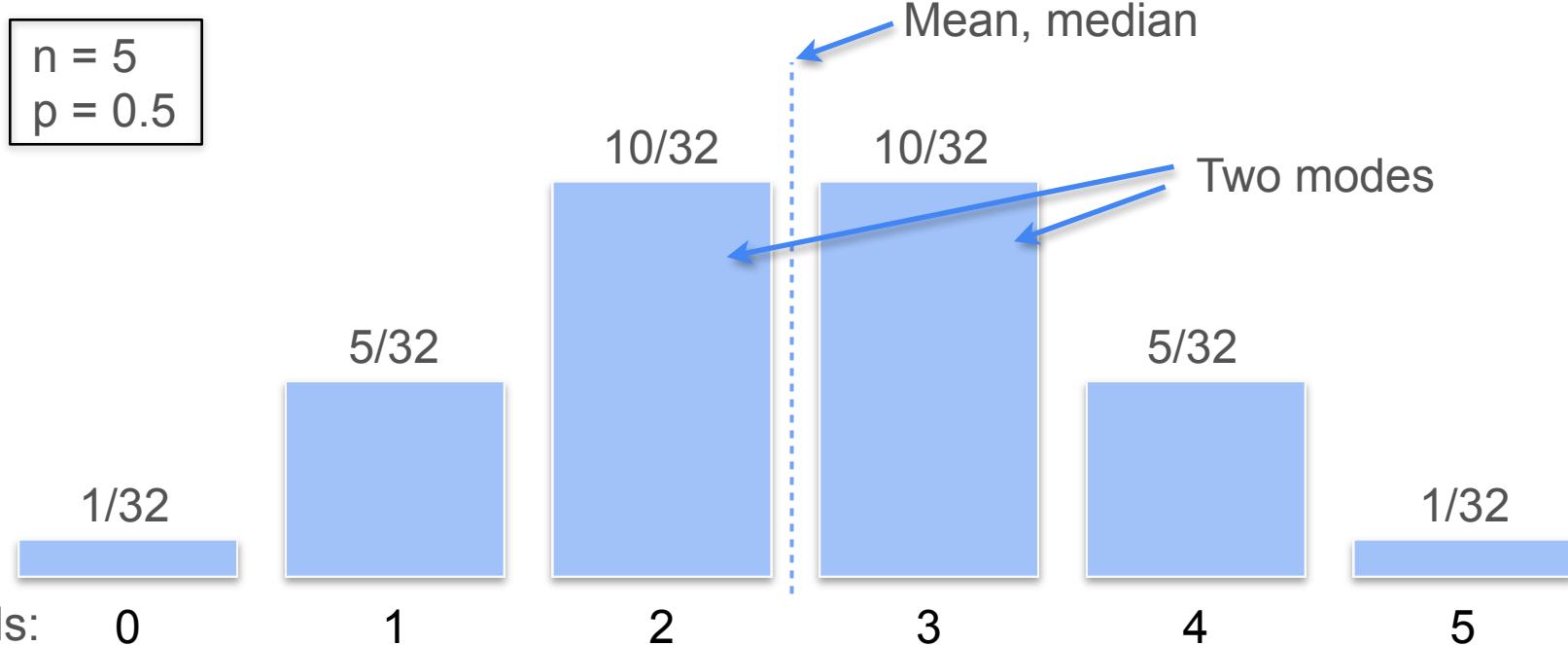
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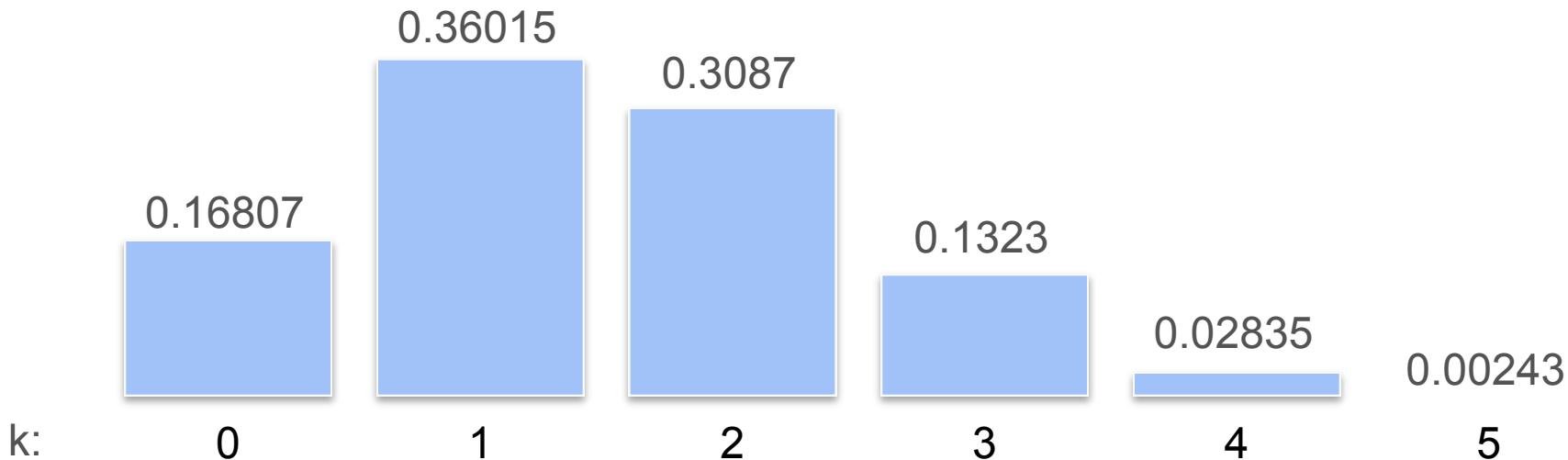


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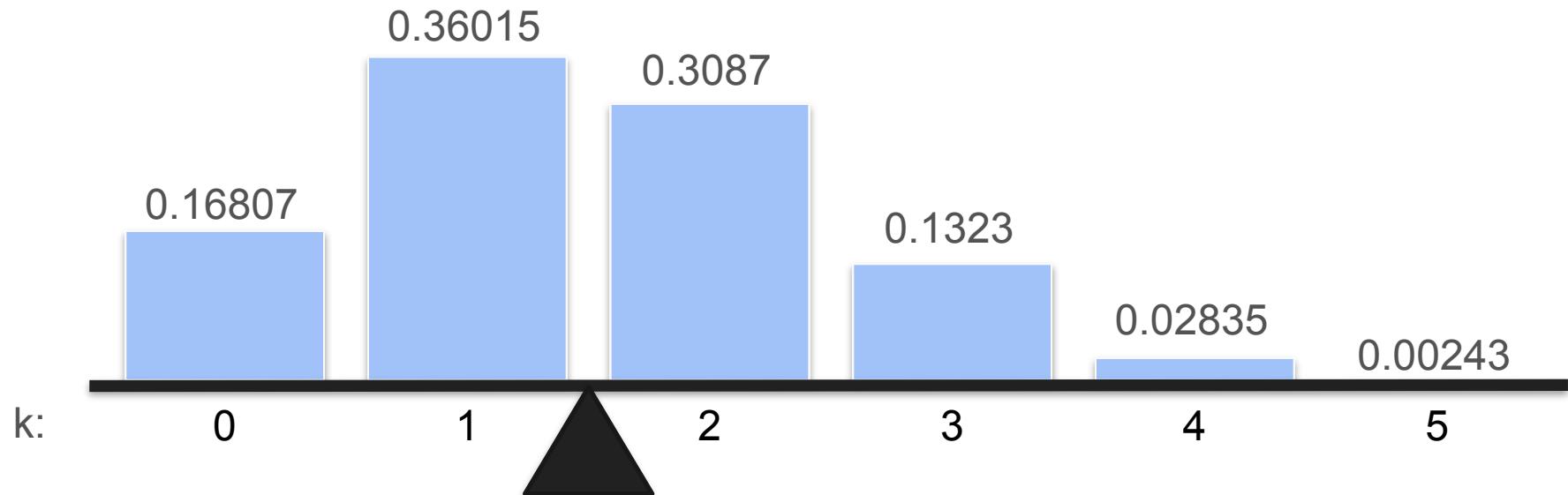
# Mean, Median and Mode in Binomial Distribution

$n = 5$   
 $p = 0.3$

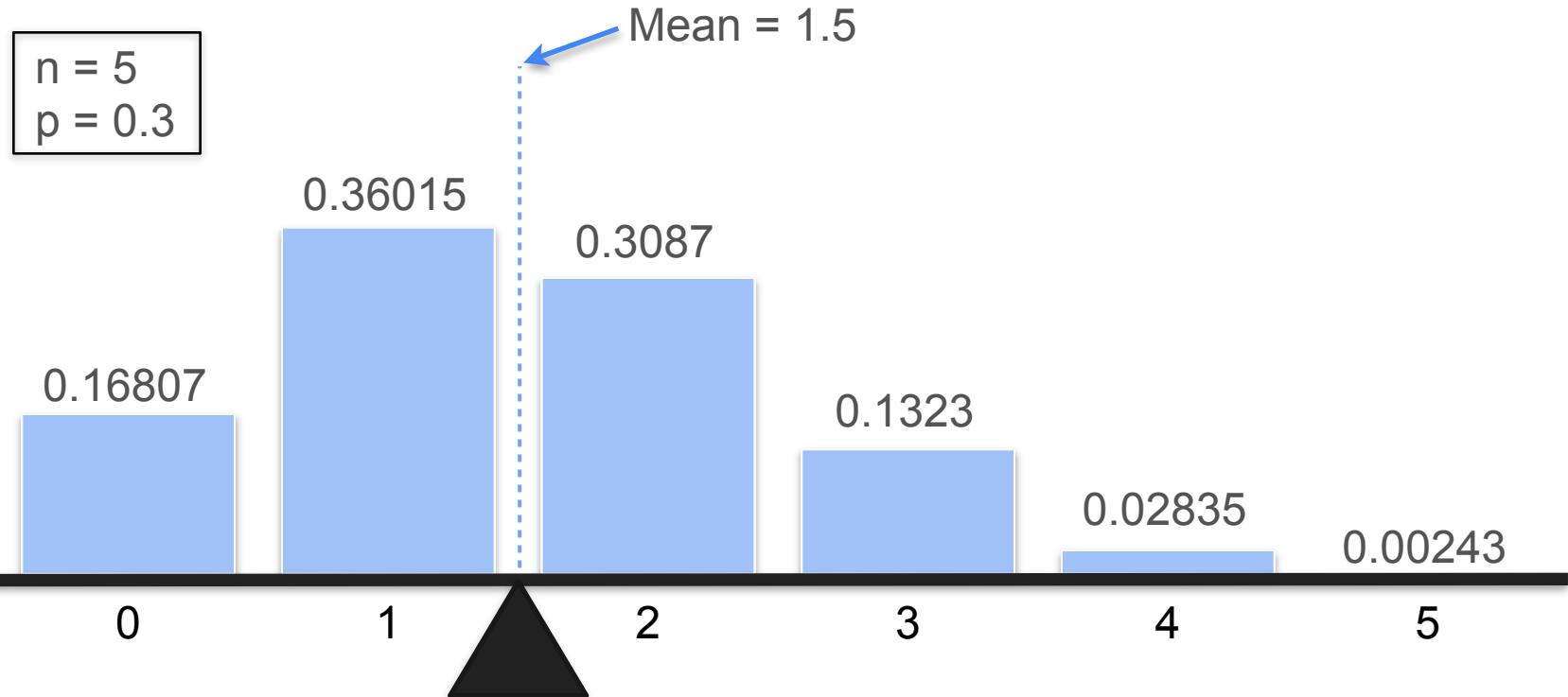


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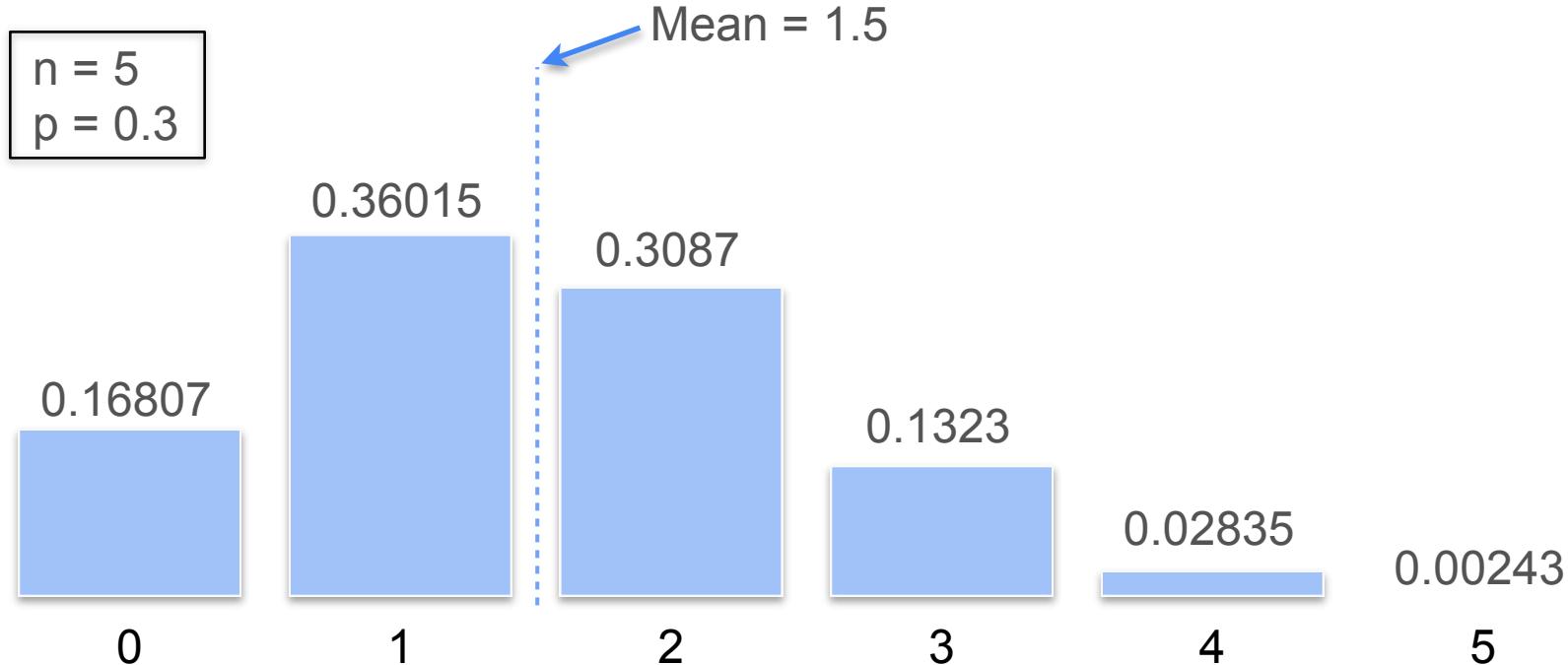
$n = 5$   
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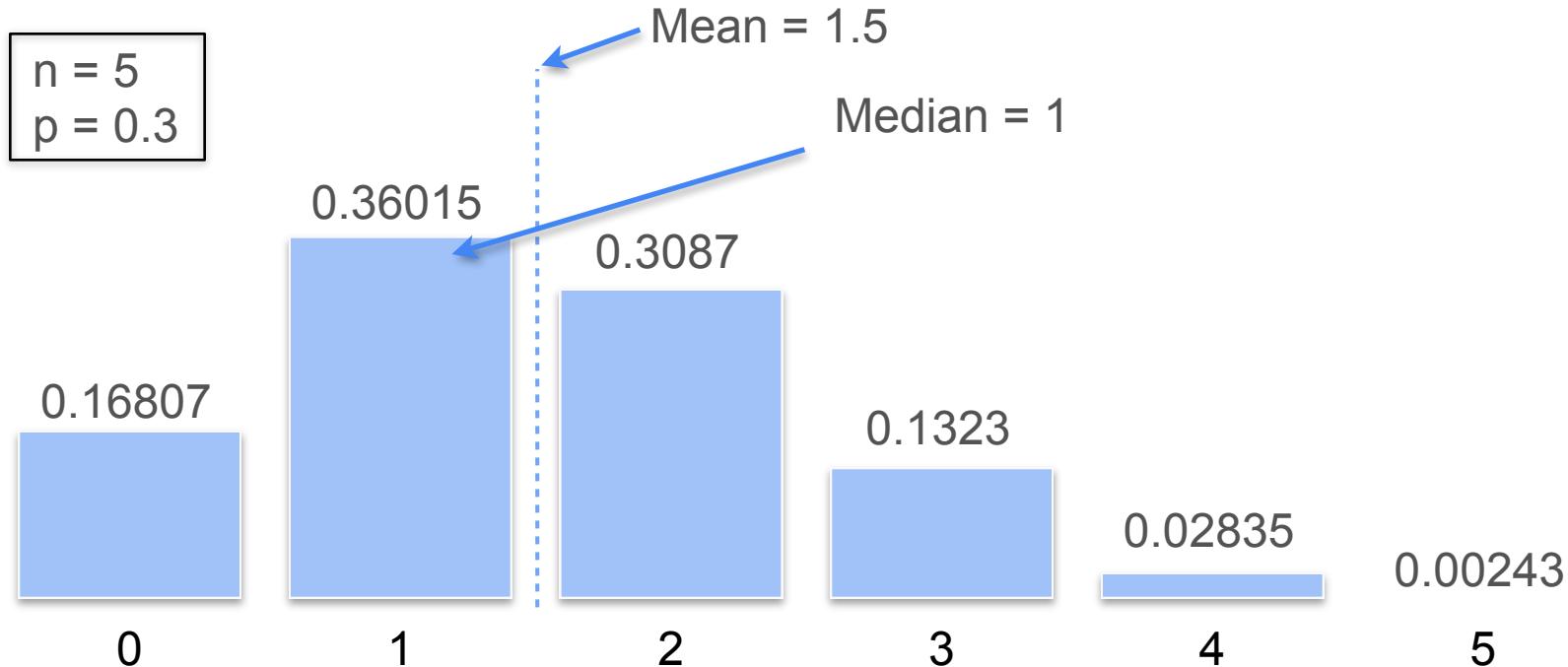
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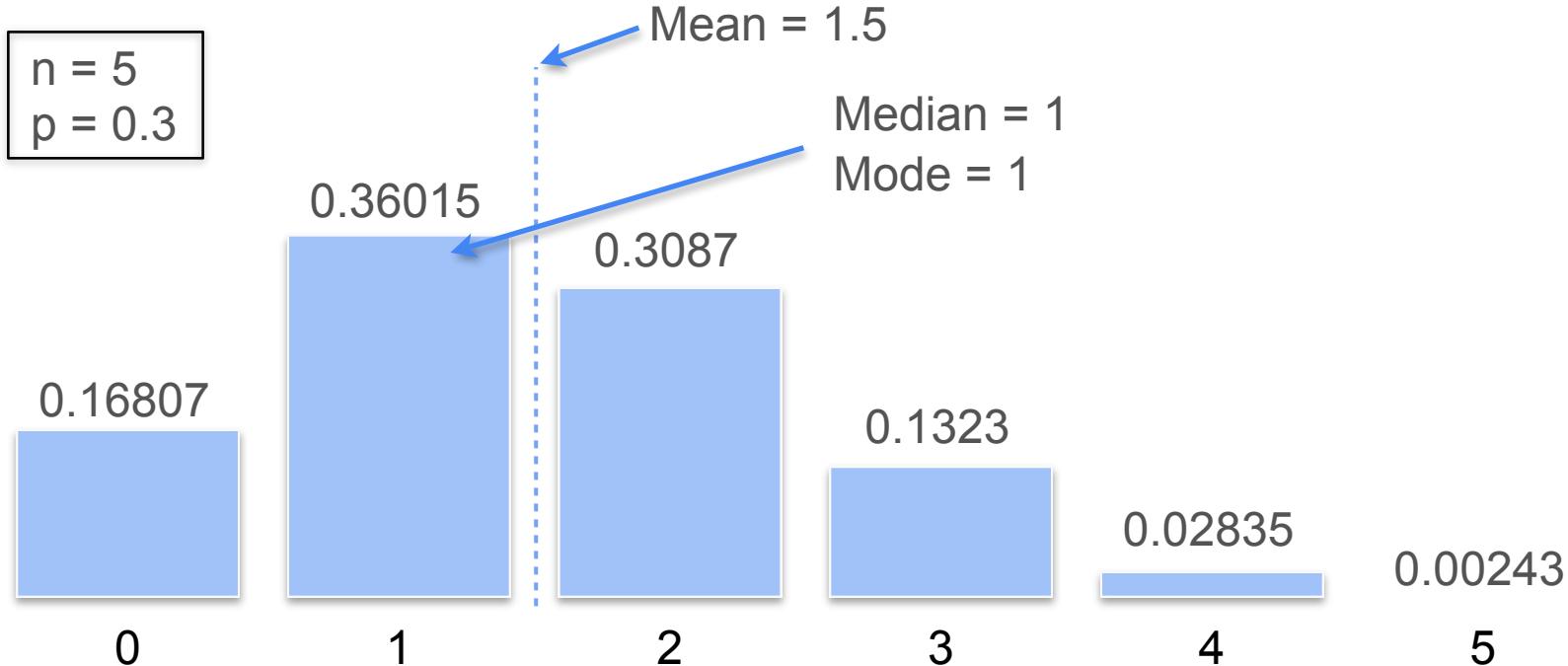
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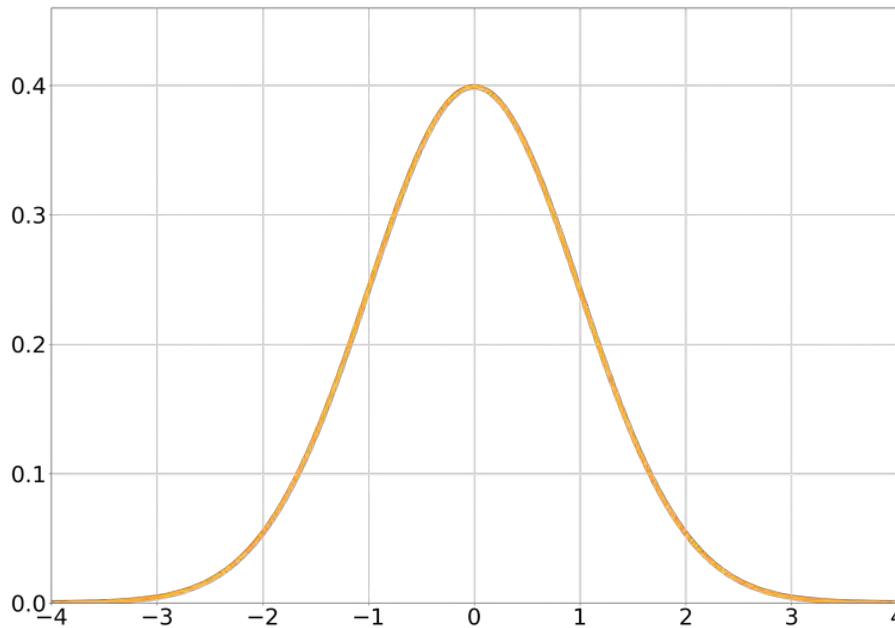
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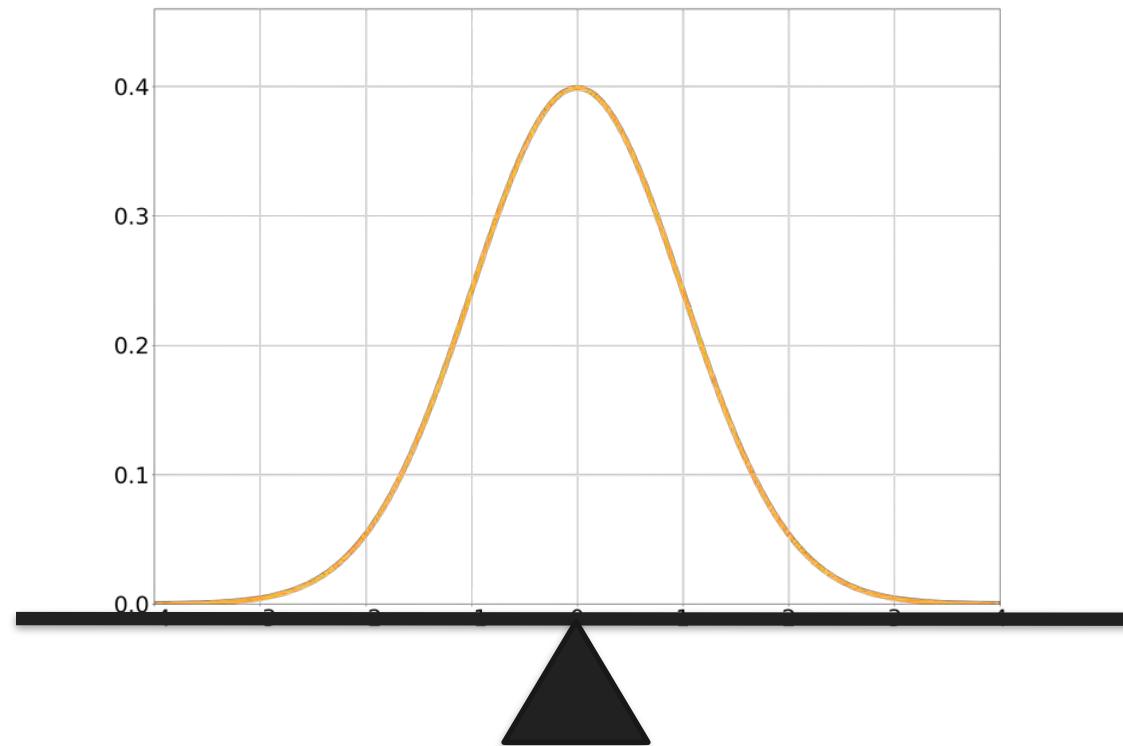
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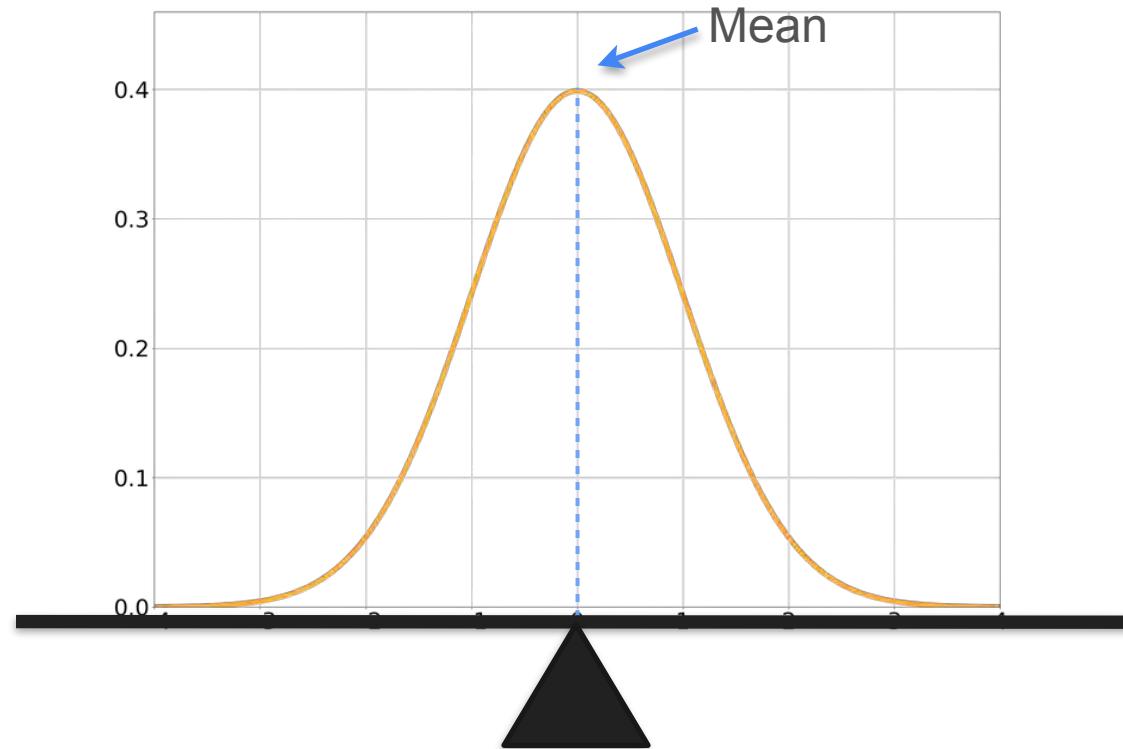
# Mean, Median and Mode in Normal Distribution



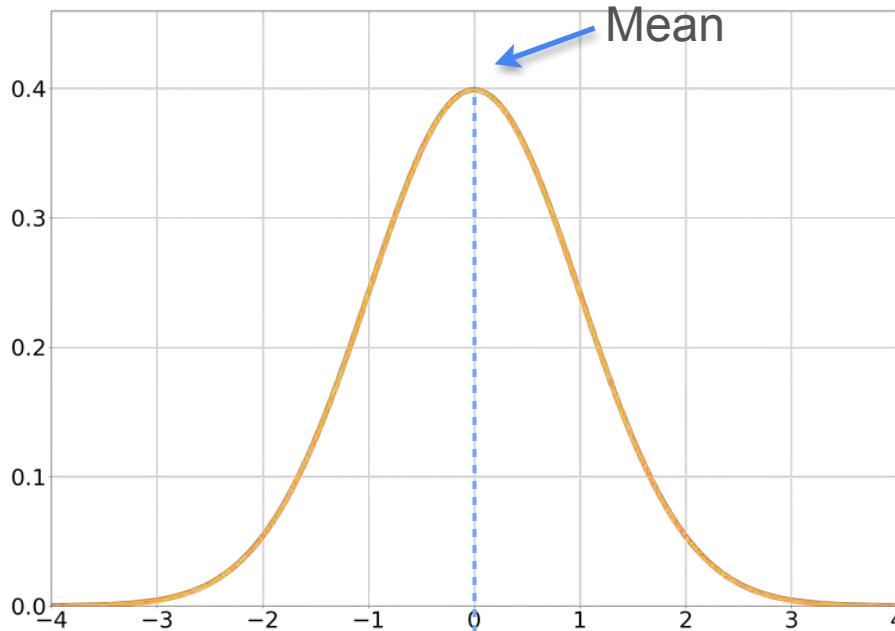
# Mean, Median and Mode in Normal Distribution



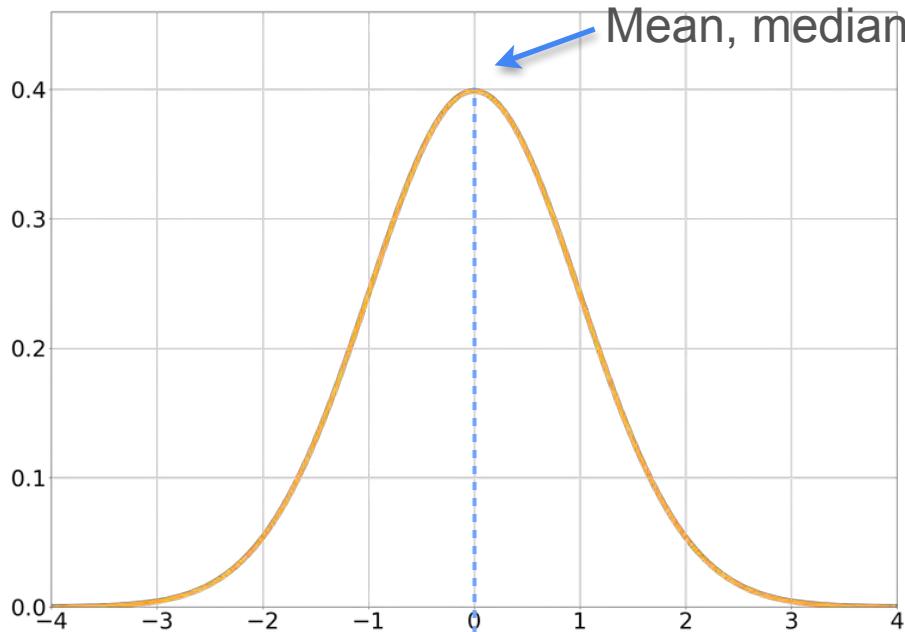
# Mean, Median and Mode in Normal Distribution



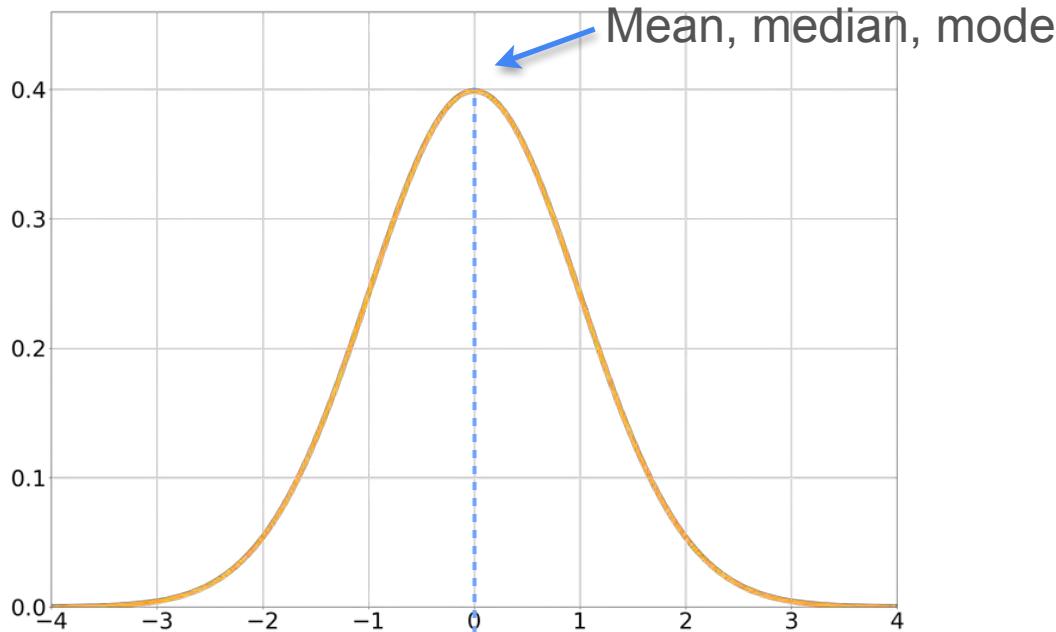
# Mean, Median and Mode in Normal Distribution



# Mean, Median and Mode in Normal Distribution



# Mean, Median and Mode in Normal Distribution





DeepLearning.AI

# Describing Distributions

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## Expected Value

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$6

Do you play the game?

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$4

Do you play the game?

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$4

Do you play the game?

What is the maximum amount of money you would pay to play this game?

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



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# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10$

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0$

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0 = \$5$

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You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0 = \$5 \rightarrow$  You expect to win \$5 on average  
 $\mathbb{E}[X] = 5$

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$5

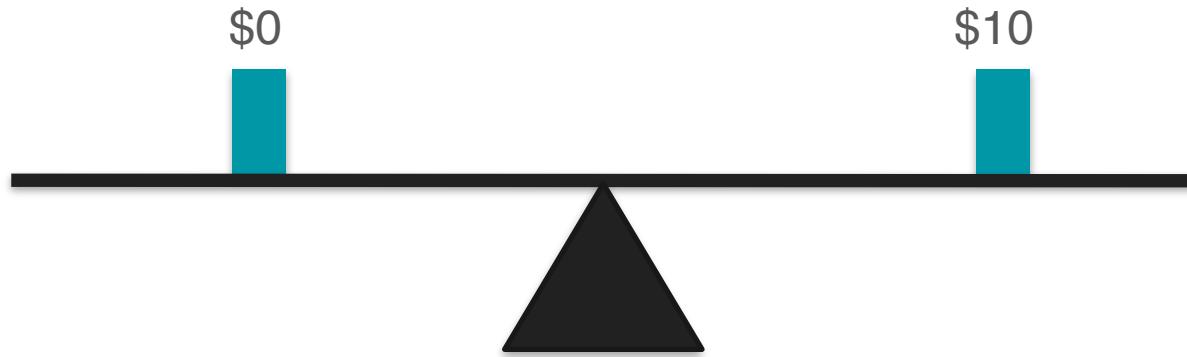
Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0 = \$5$  

You expect to win \$5 on average  
 $E[X] = 5$

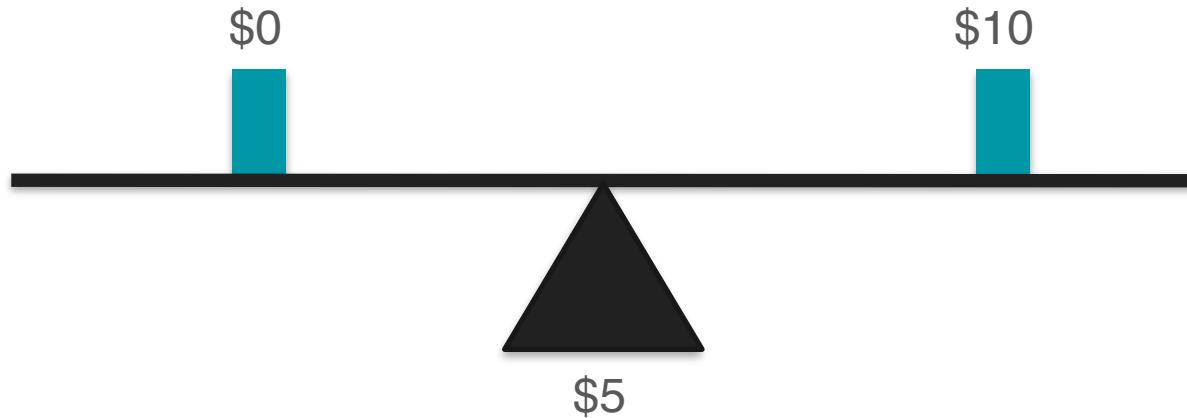
# Expected Value: Motivation Example 1



# Expected Value: Motivation Example 1



# Expected Value: Motivation Example 1



# Expected Value: Motivation Example 2

Play another game



Flip three coins. For each heads you win \$1

What is the maximum amount of money you would pay to play this game?

# Expected Value: Motivation Example 2

Number of heads:

0



1



2



3



# Expected Value: Motivation Example 2

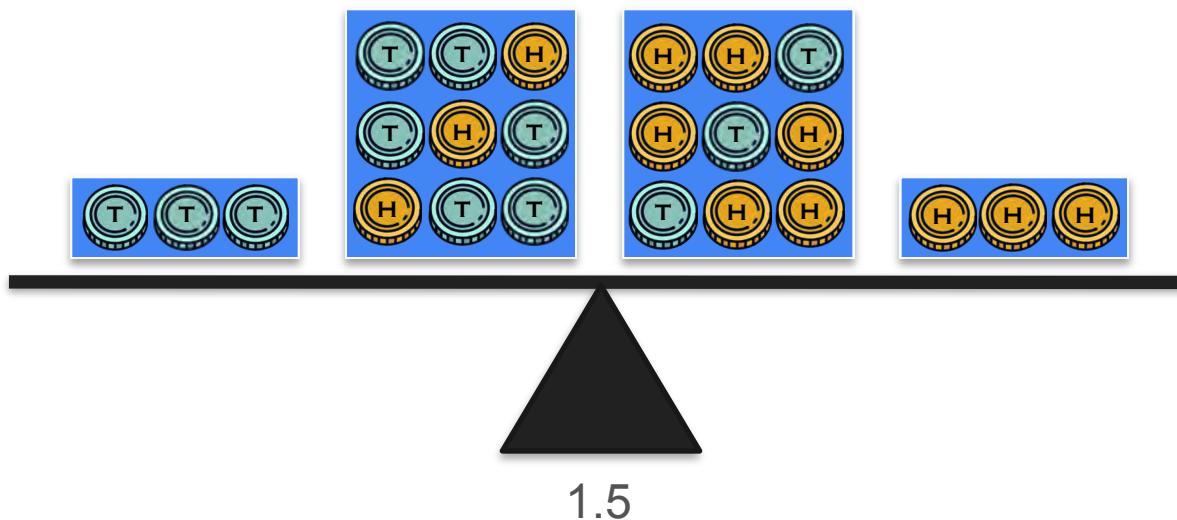
Number of heads:

0

1

2

3



# Expected Value: Motivation Example 2

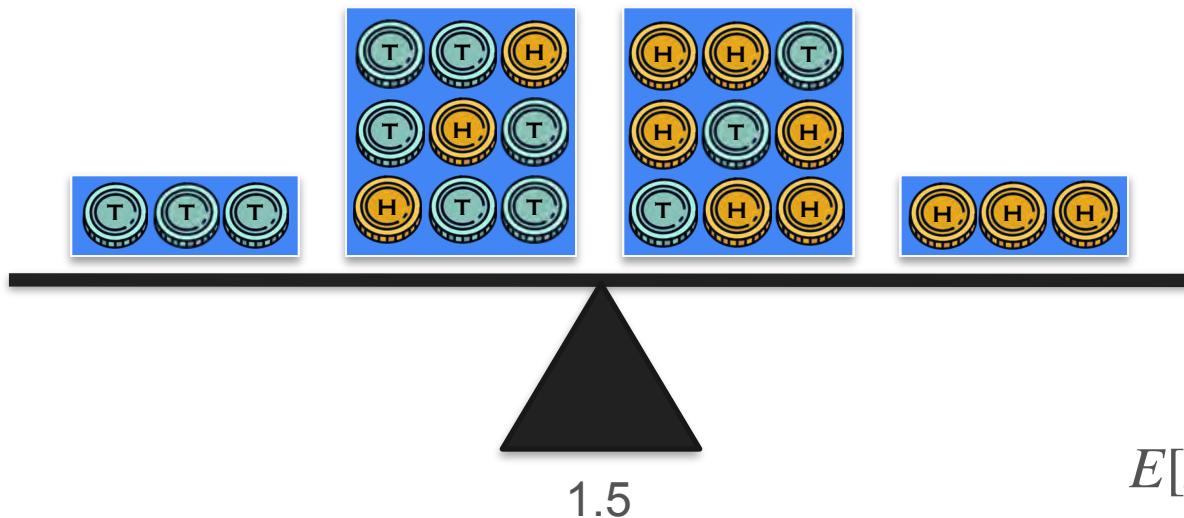
Number of heads:

0

1

2

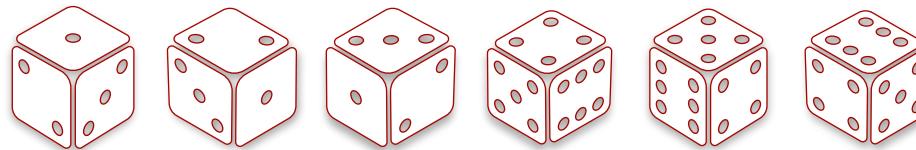
3



# Expected Value: Motivation Example 3

Probability:    1/6    1/6    1/6    1/6    1/6    1/6

Roll:        1        2        3        4        5        6

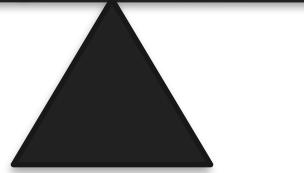
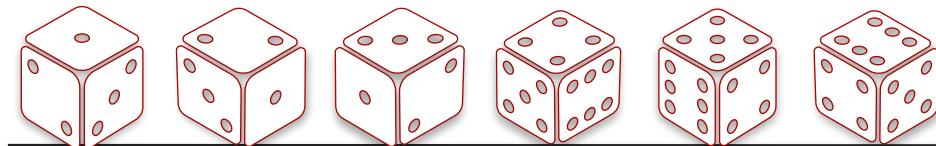


$$\frac{1 + 2 + 3 + 4 + 5 + 6}{6} = 3.5$$

# Expected Value: Motivation Example 3

Probability:     $1/6$      $1/6$      $1/6$      $1/6$      $1/6$      $1/6$

Roll:     $1$      $2$      $3$      $4$      $5$      $6$

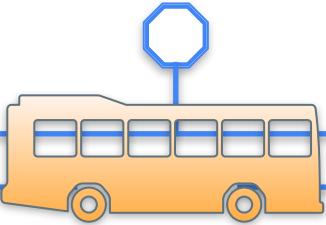


3.5

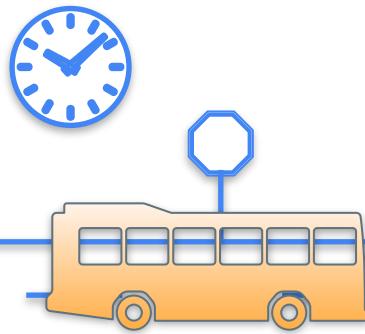
# Expected Value



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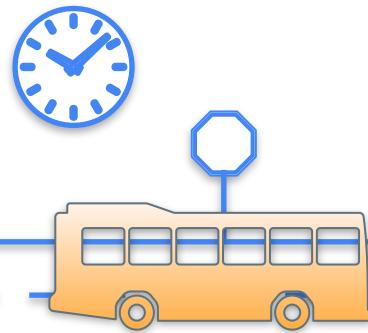
# Expected Value



# Expected Value

Waiting Time

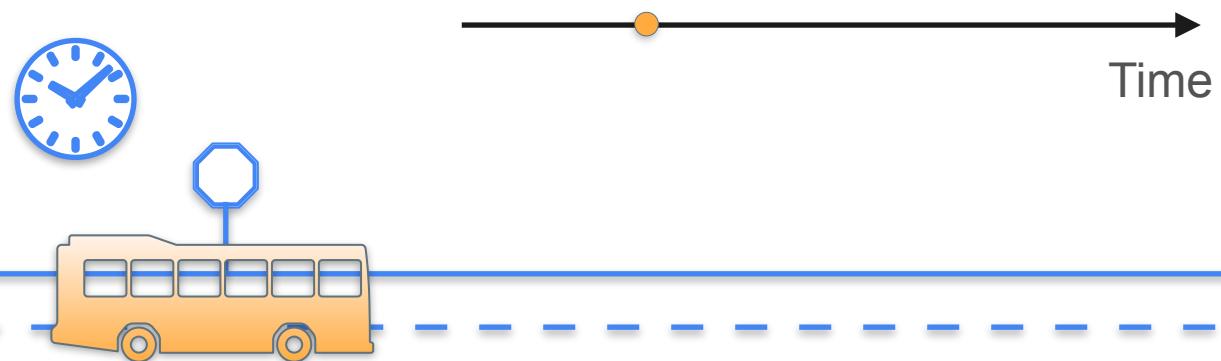
15 min



# Expected Value

Waiting Time

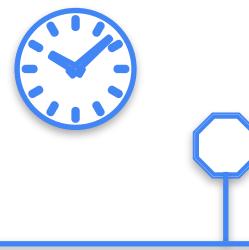
15 min



# Expected Value

Waiting Time

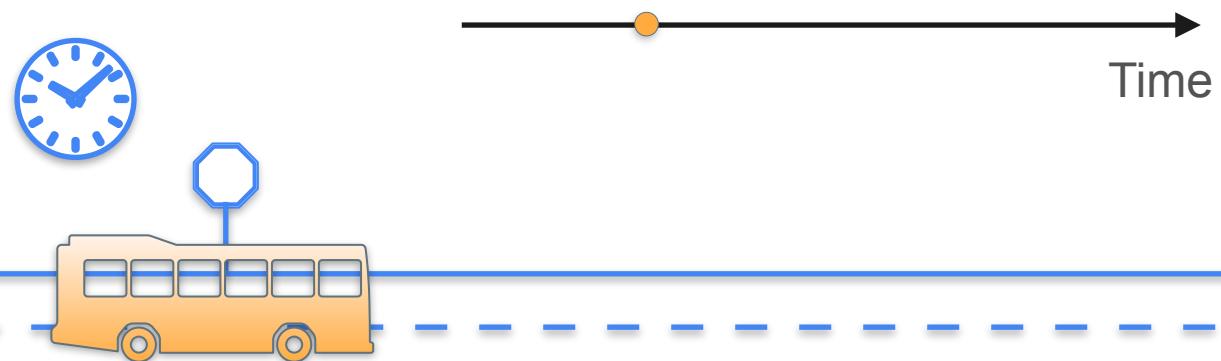
15 min



# Expected Value

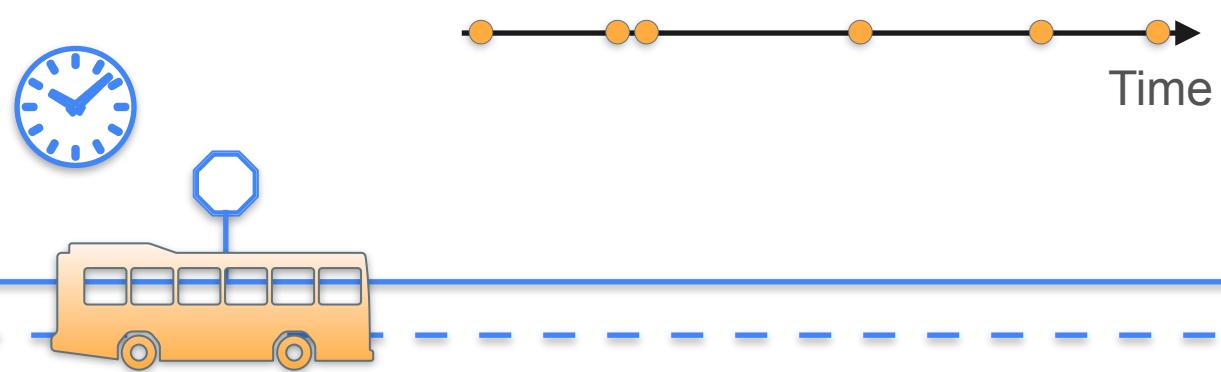
Waiting Time

15 min



# Expected Value

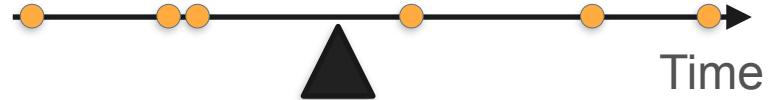
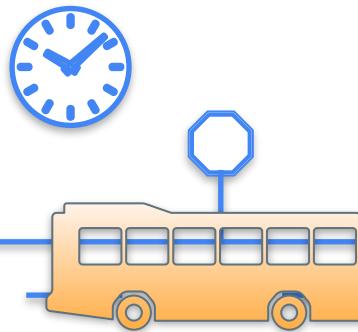
Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min



# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min

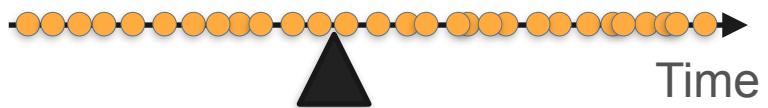
Average = 27.833



# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min
37 min
8 min
29 min
55 min
...

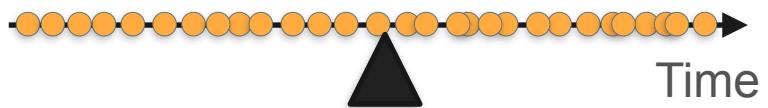
Average = 27.833



# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min
37 min
8 min
29 min
55 min
...

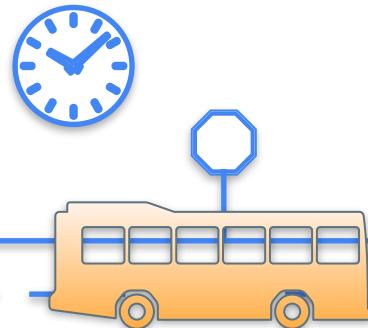
Average = 30



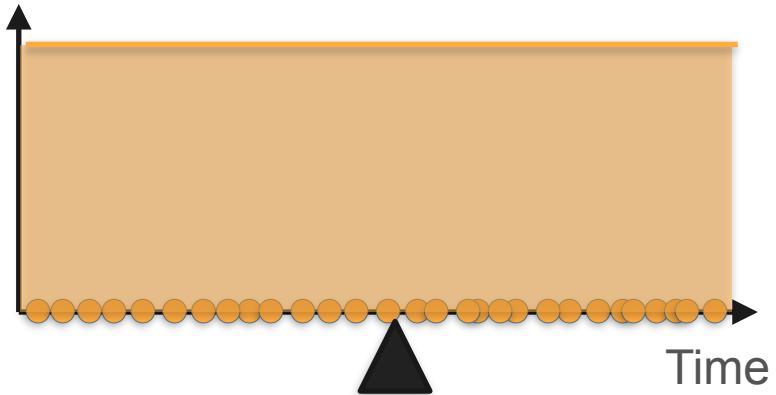
# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min
37 min
8 min
29 min
55 min
...

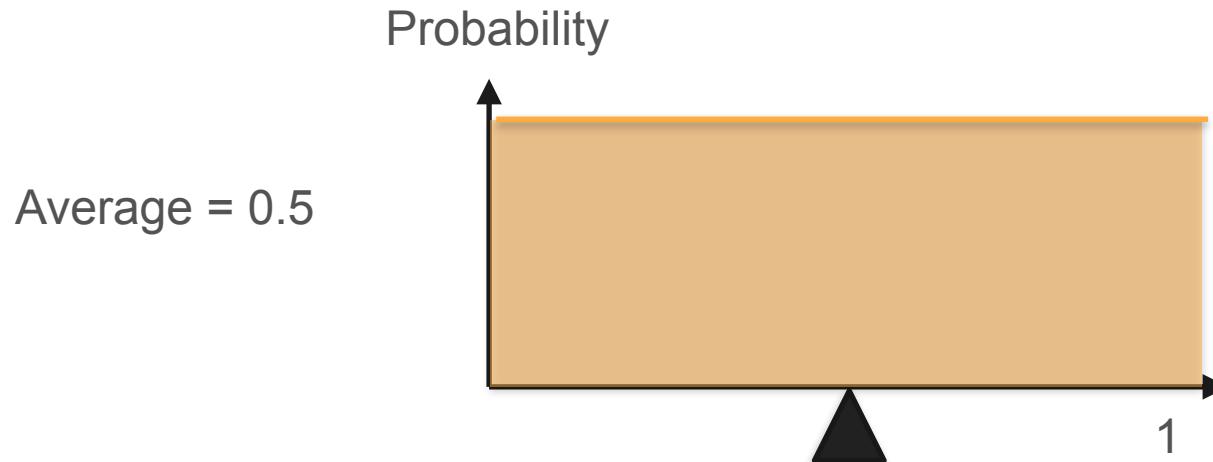
Average = 30



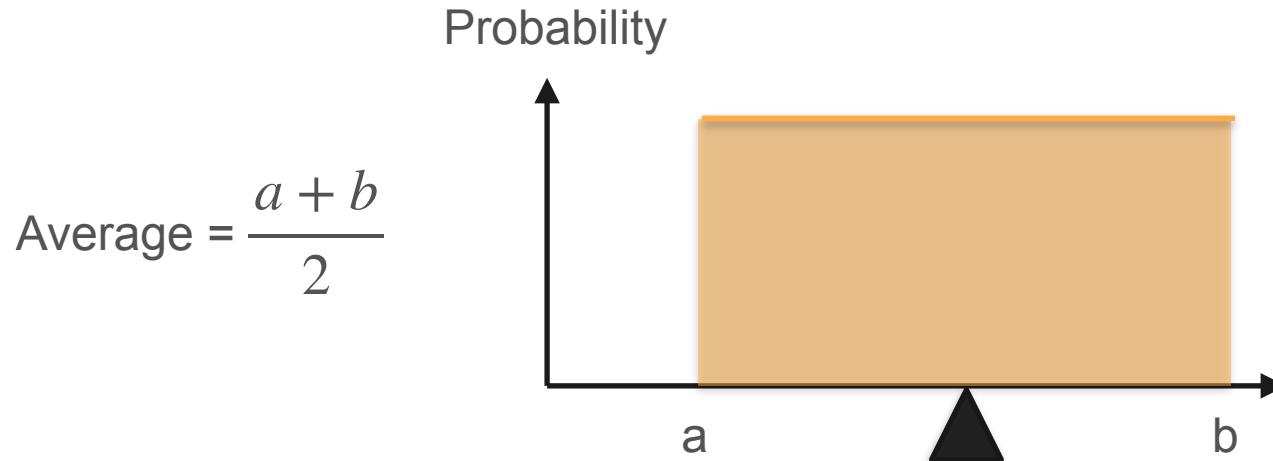
Probability



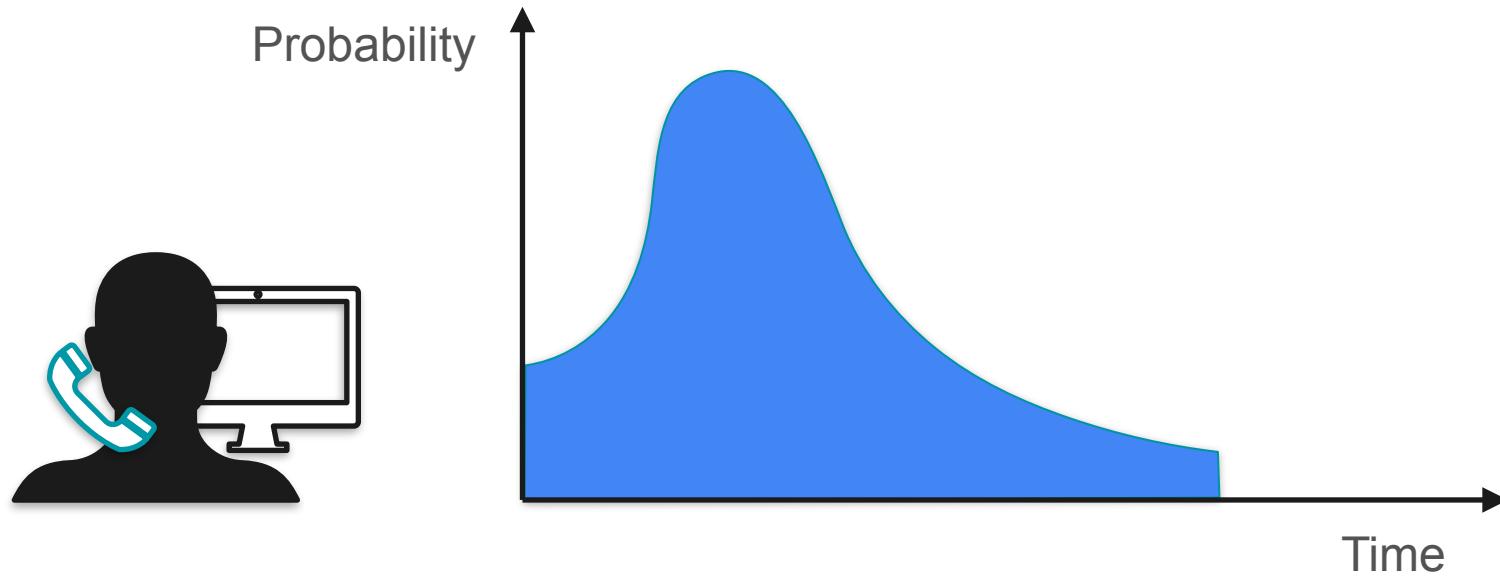
# Expected Value: Uniform Distribution



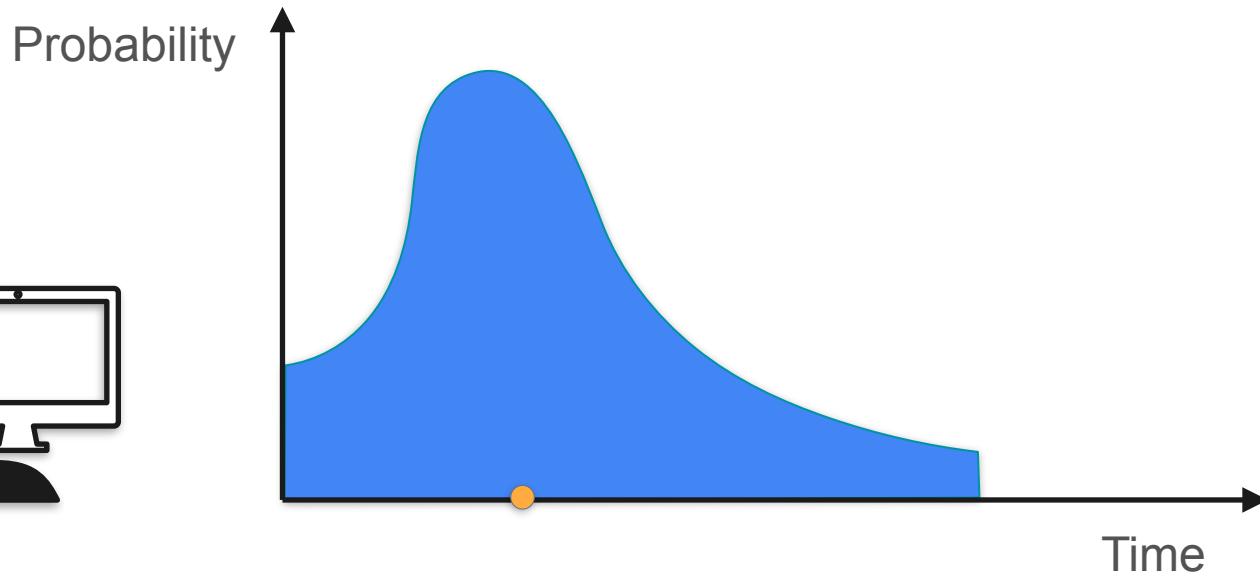
# Expected Value: Uniform Distribution



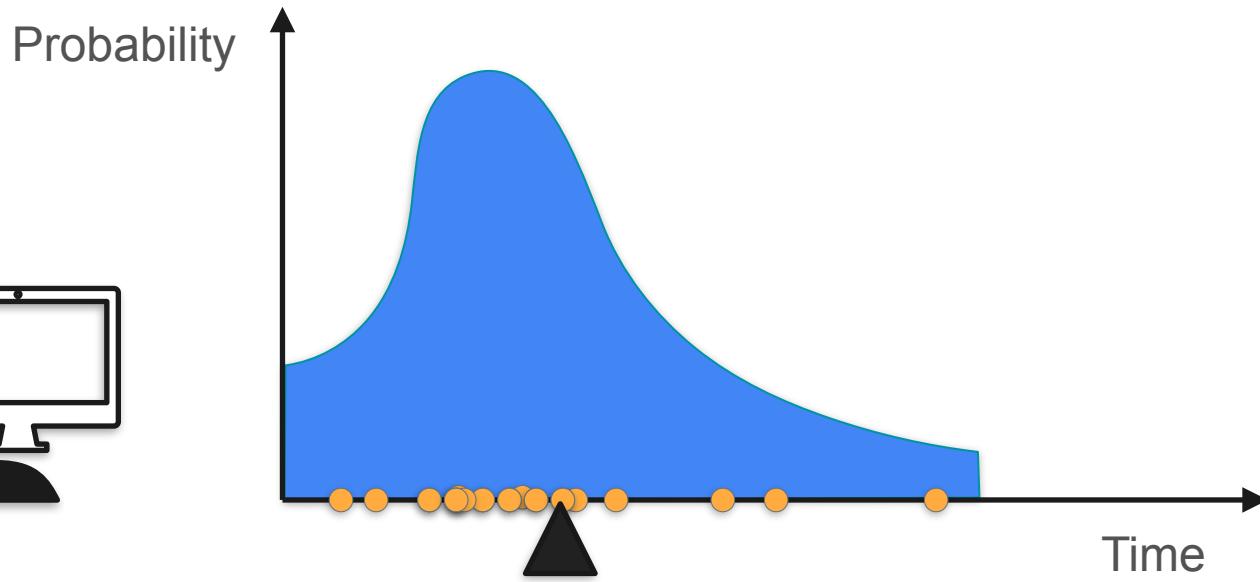
# Expected Value



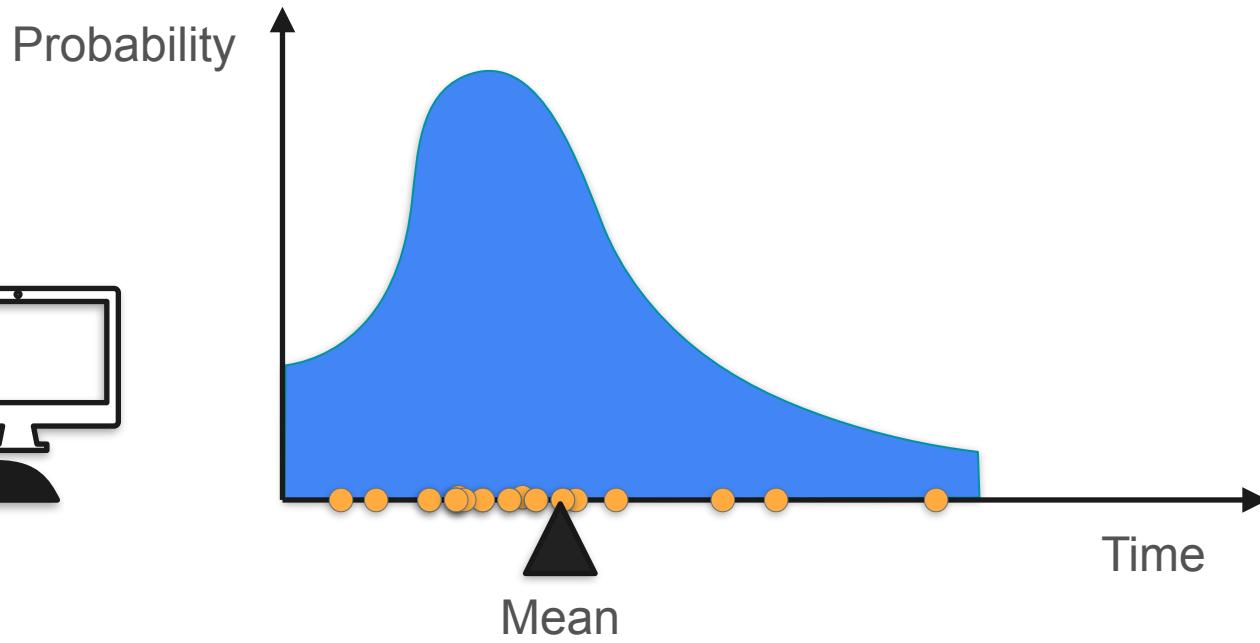
# Expected Value



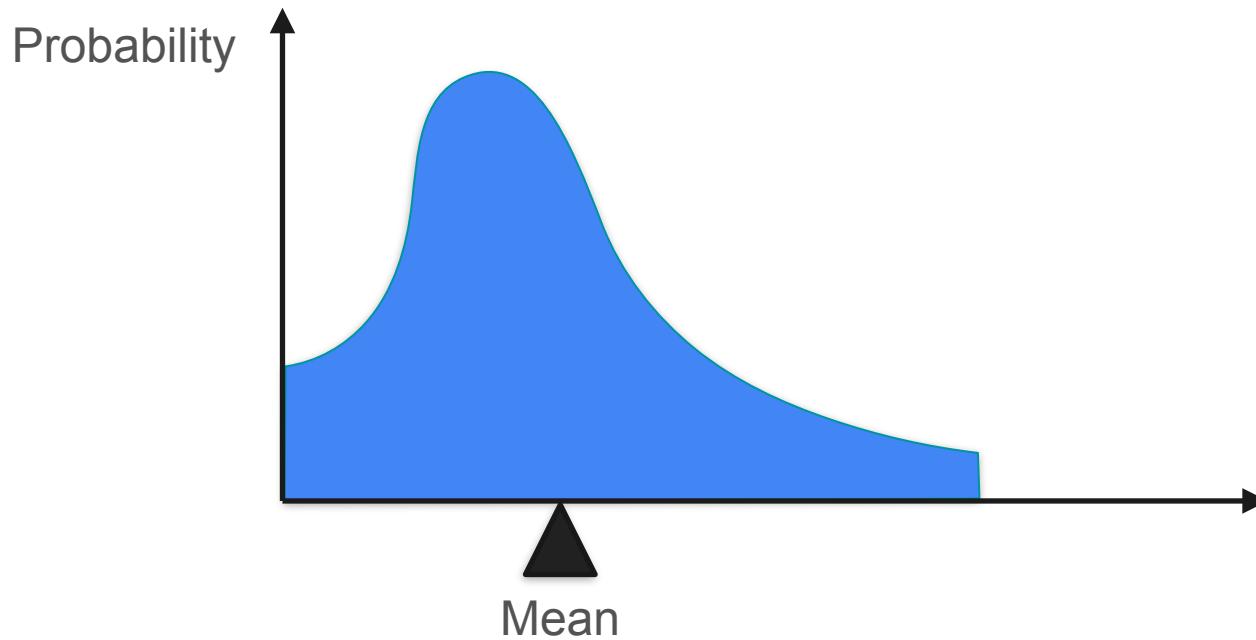
# Expected Value



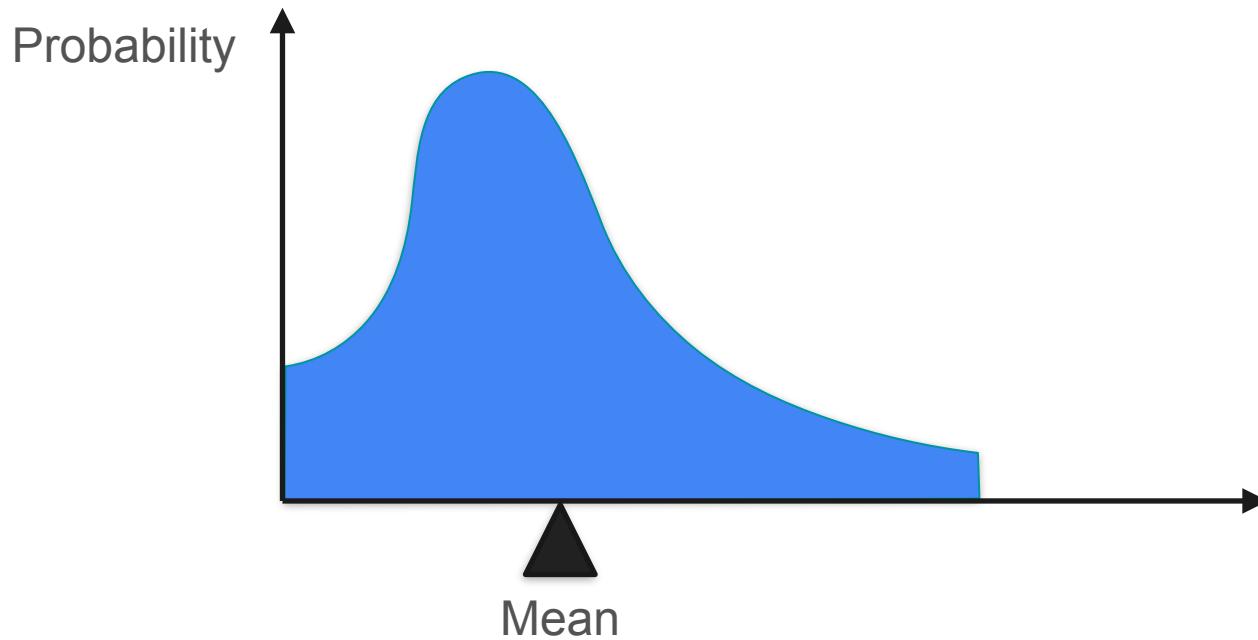
# Expected Value



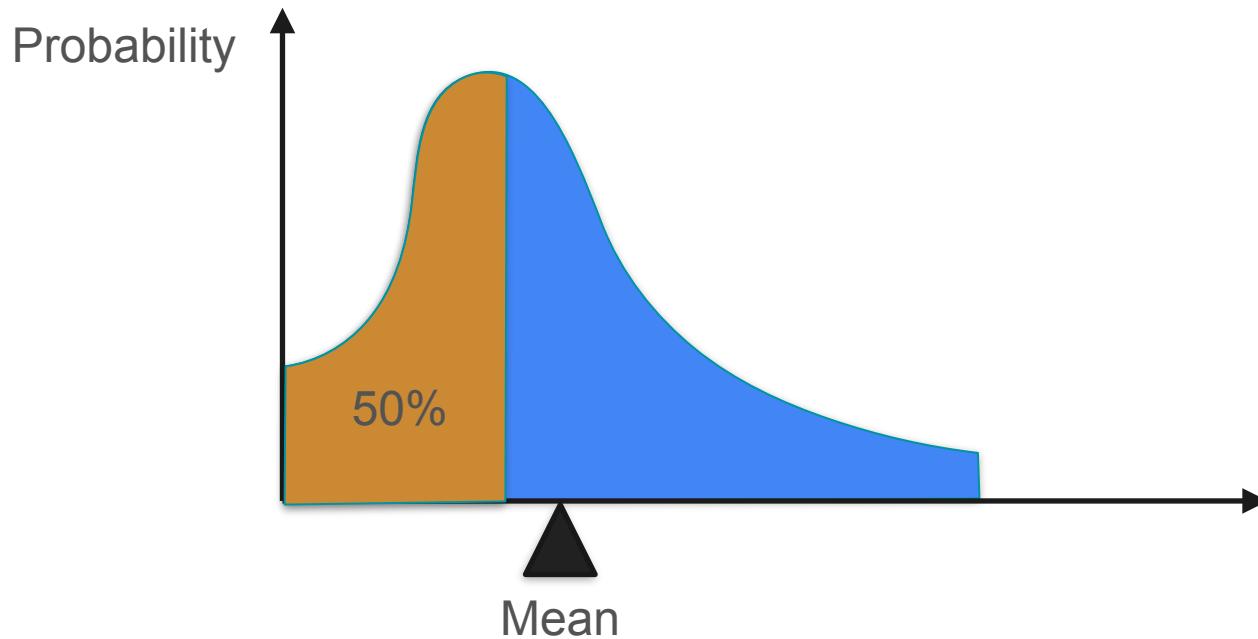
# Expected Value: General Case



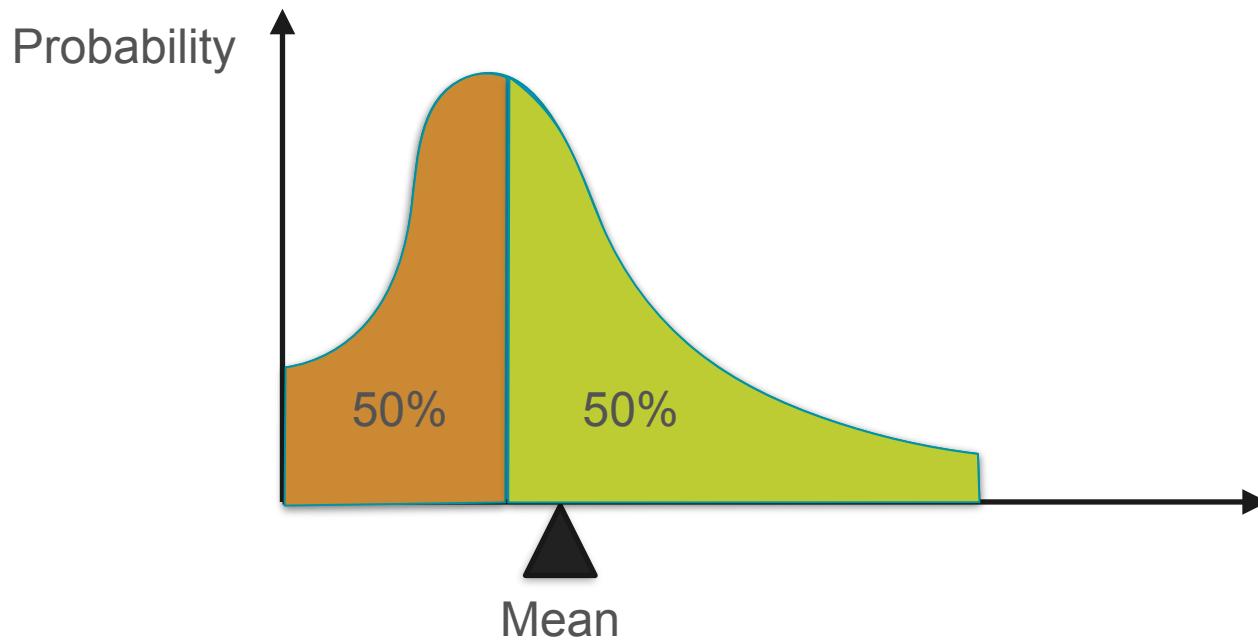
# Expected Value: Common Misconception



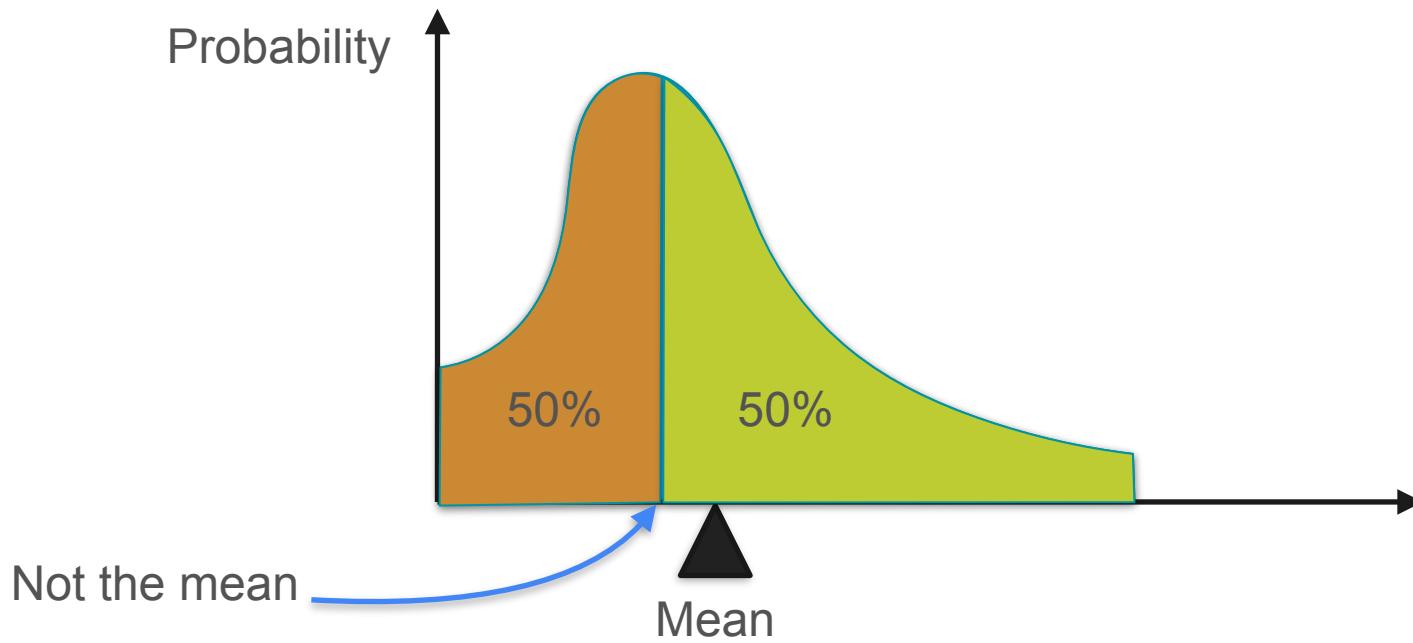
# Expected Value: Common Misconception



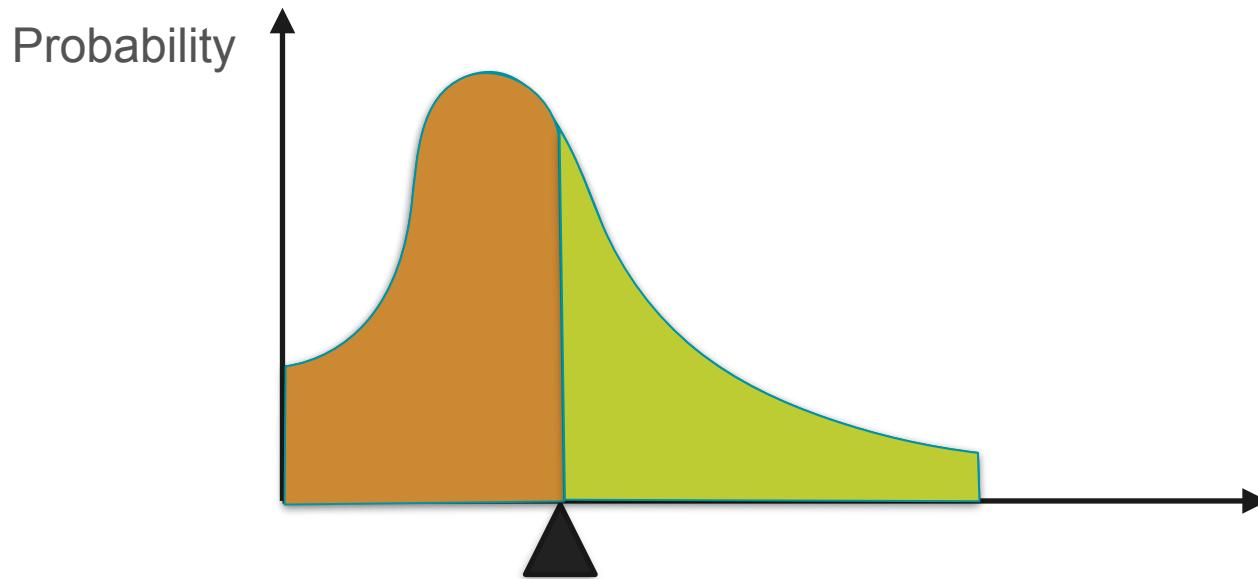
# Expected Value: Common Misconception



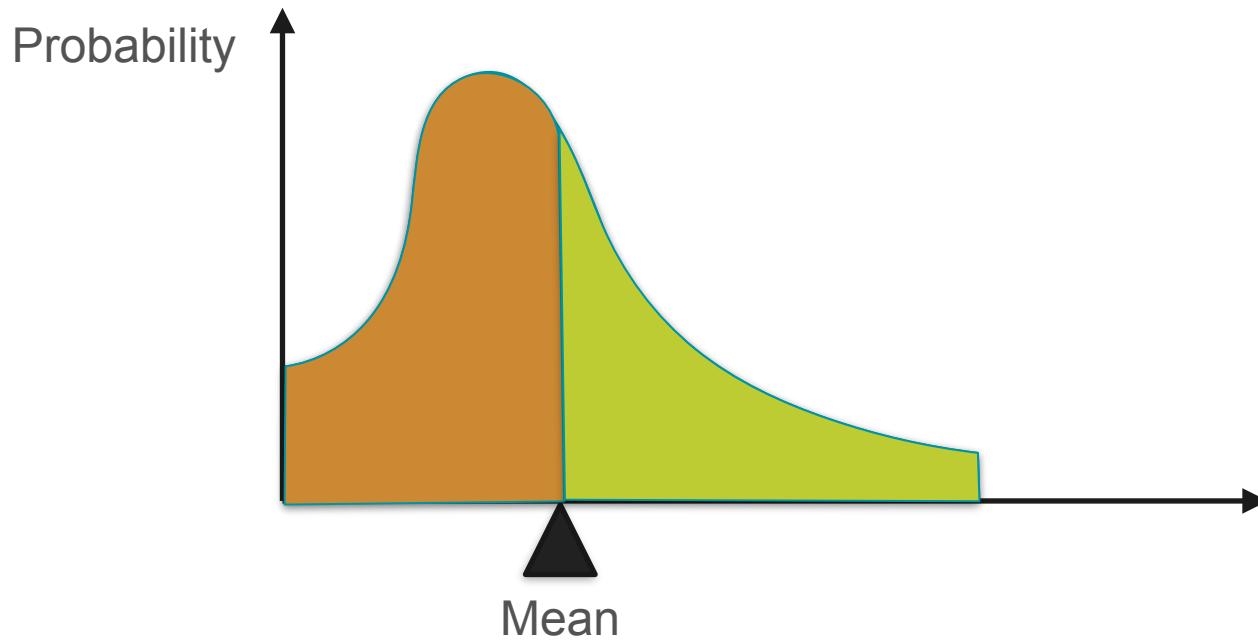
# Expected Value: Common Misconception



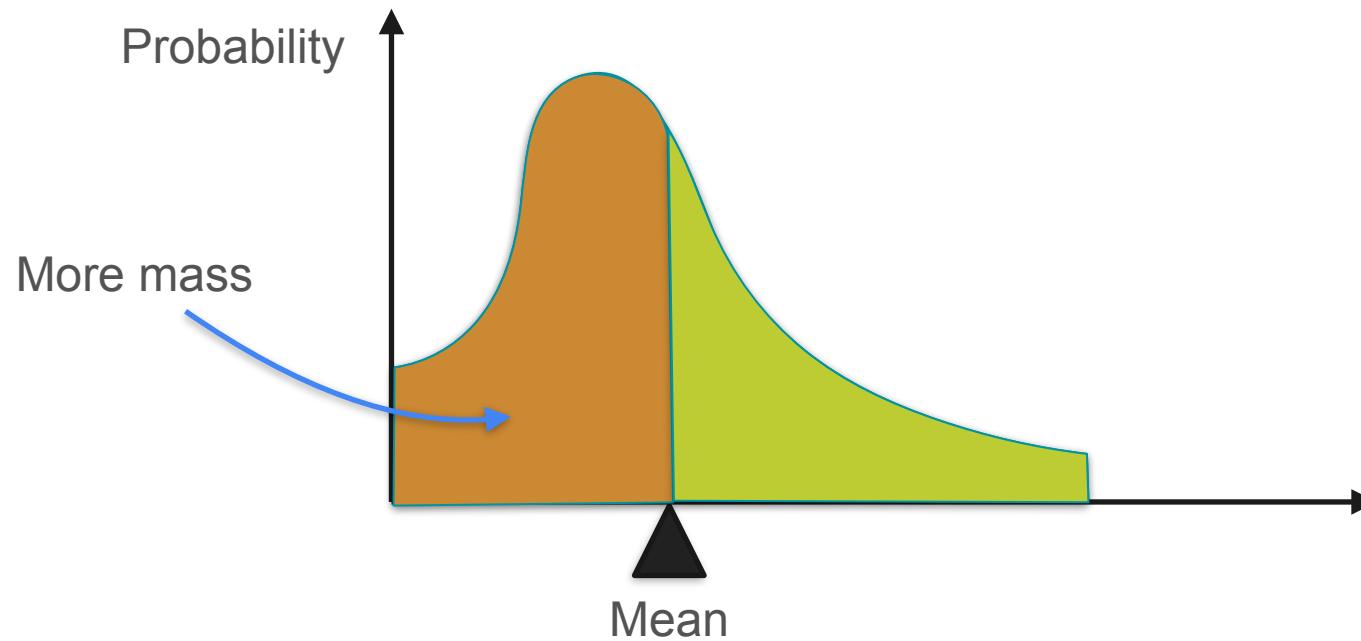
# Expected Value: Common Misconception



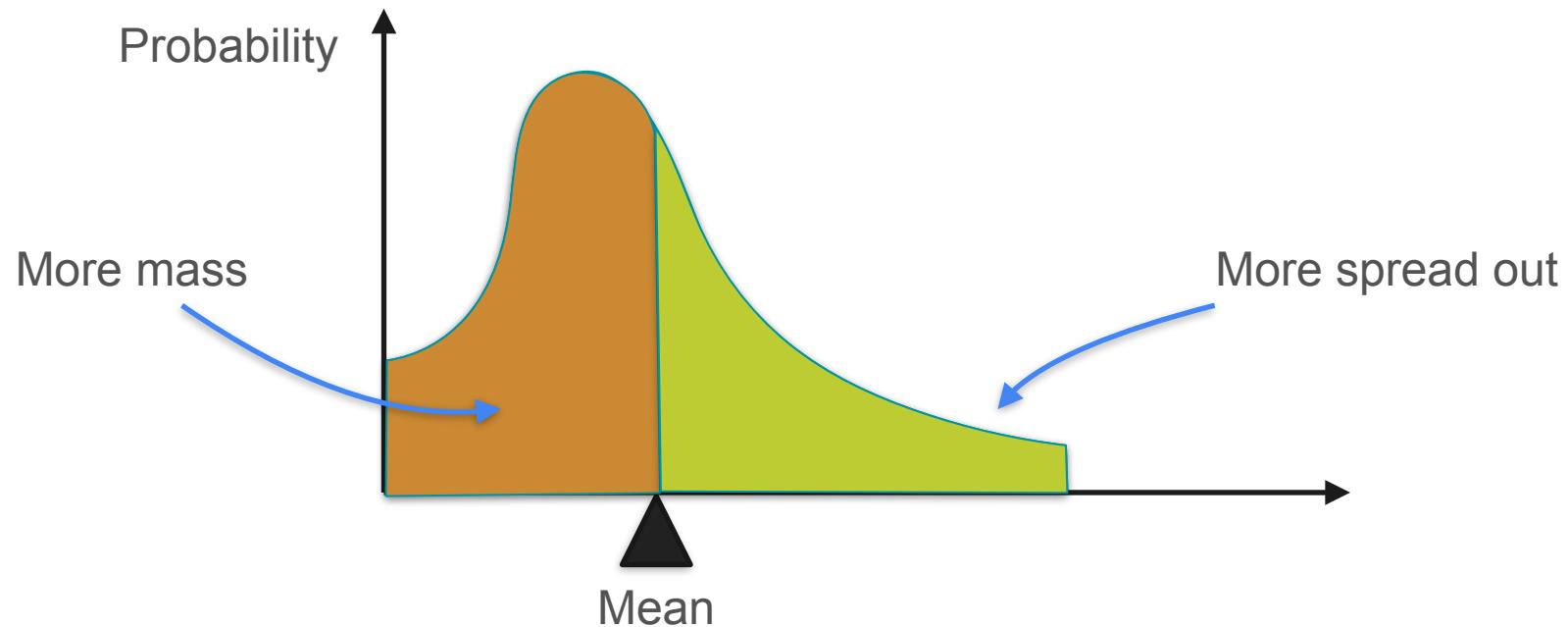
# Expected Value: Common Misconception



# Expected Value: Common Misconception



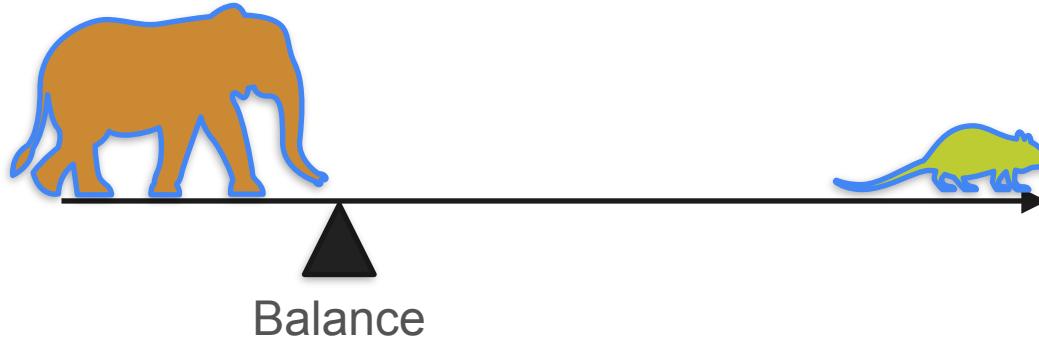
# Expected Value: Common Misconception



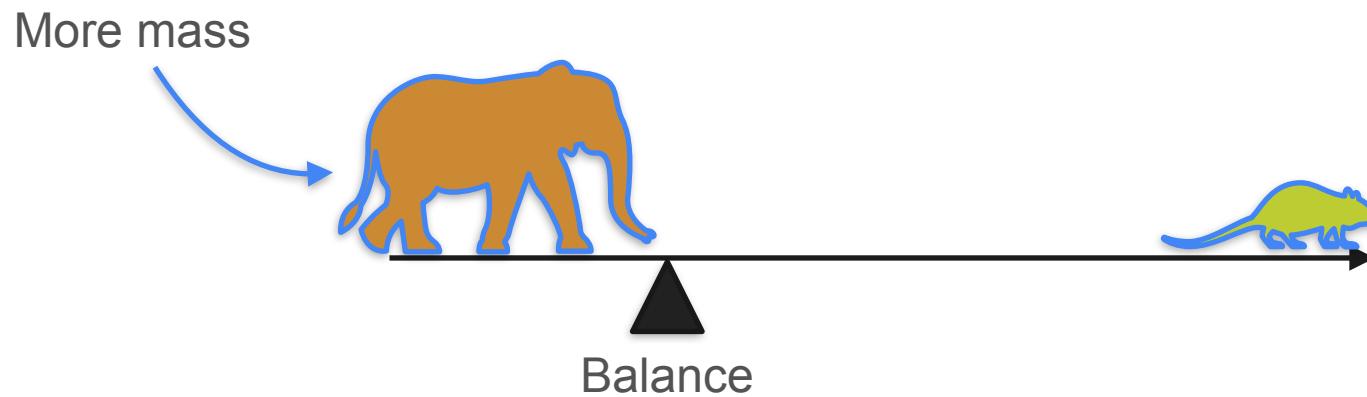
# Expected Value: Common Misconception



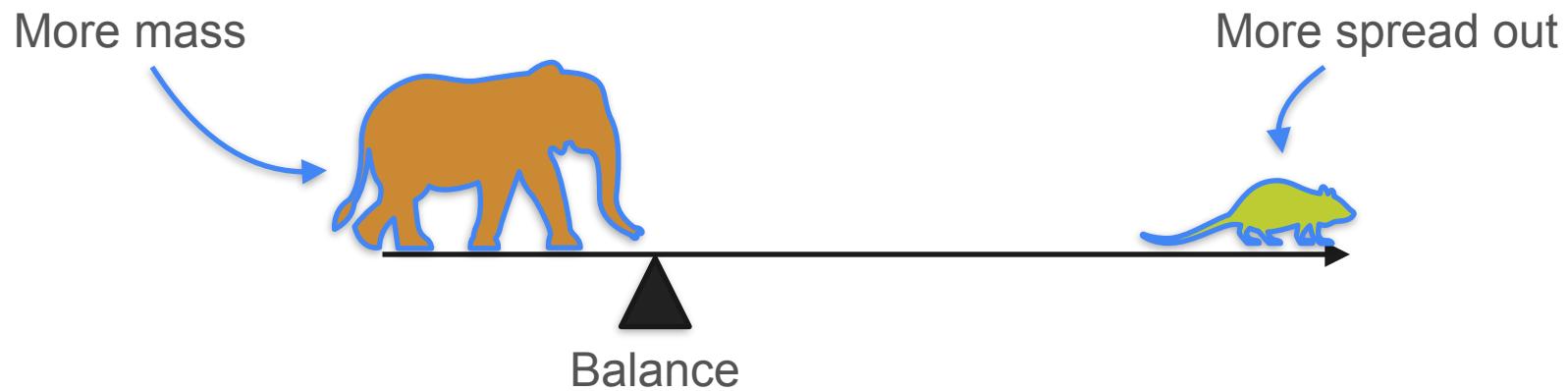
# Expected Value: Common Misconception



# Expected Value: Common Misconception



# Expected Value: Common Misconception





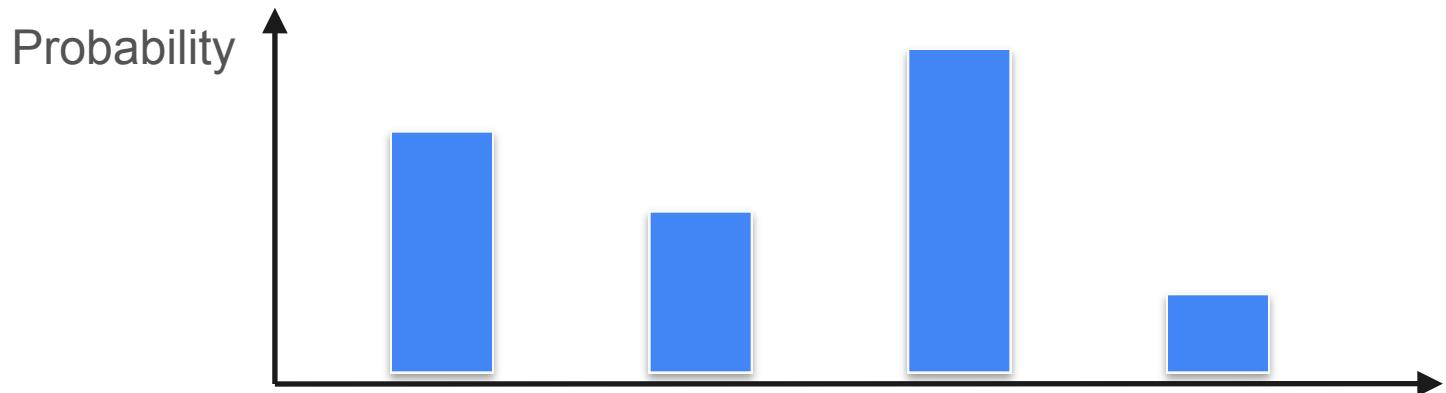
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# Describing Distributions

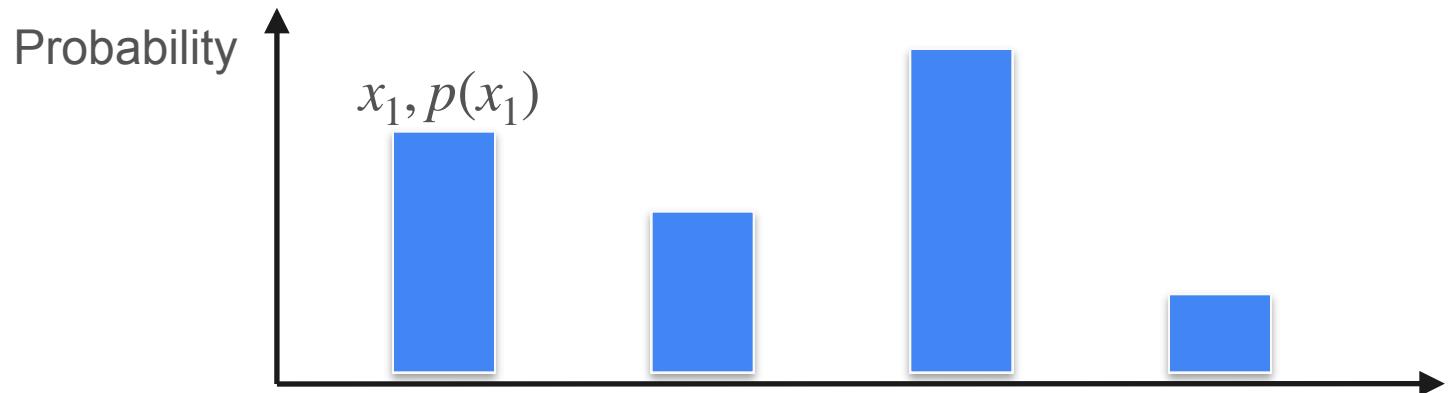
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## Expected value of a function

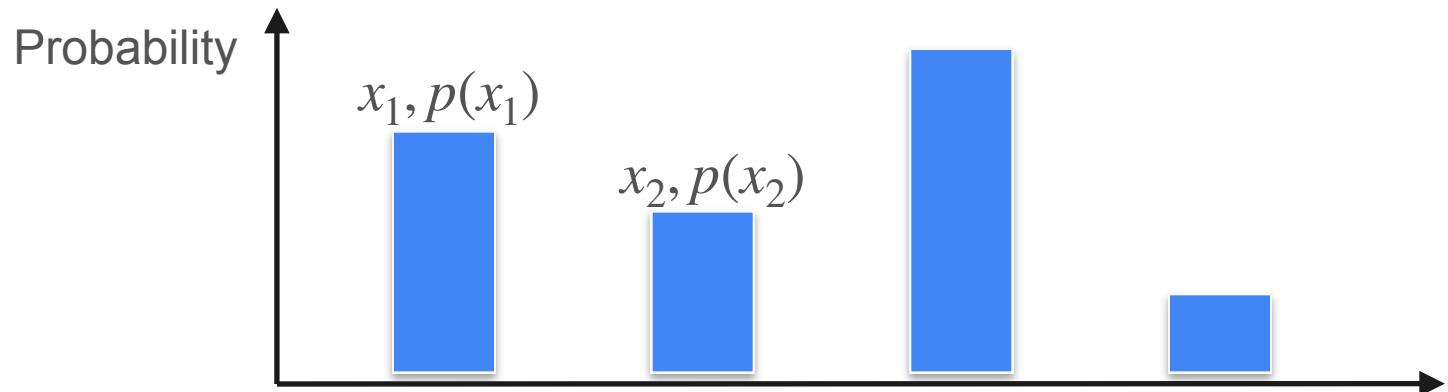
# Expected Value of a Function



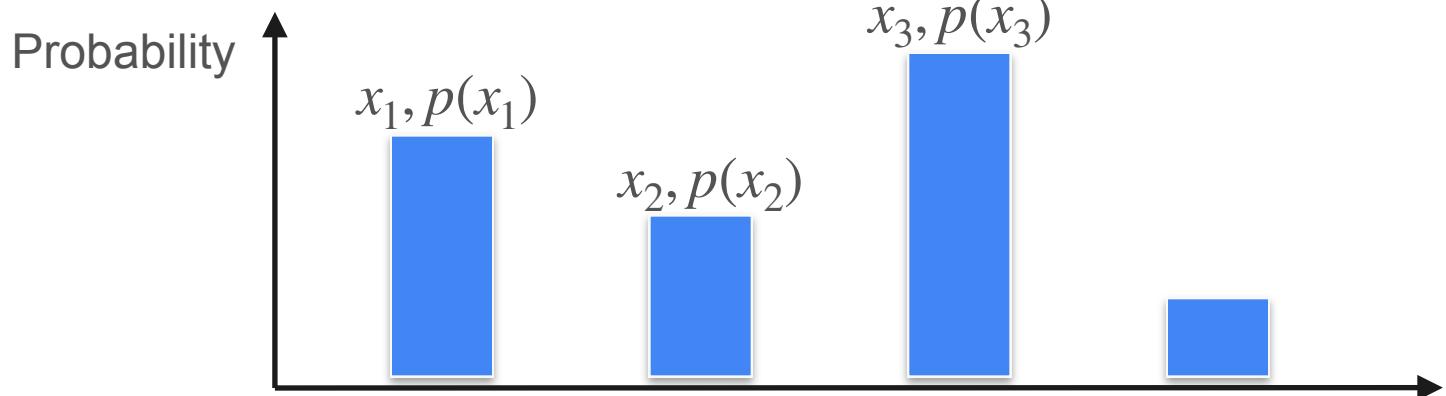
# Expected Value of a Function



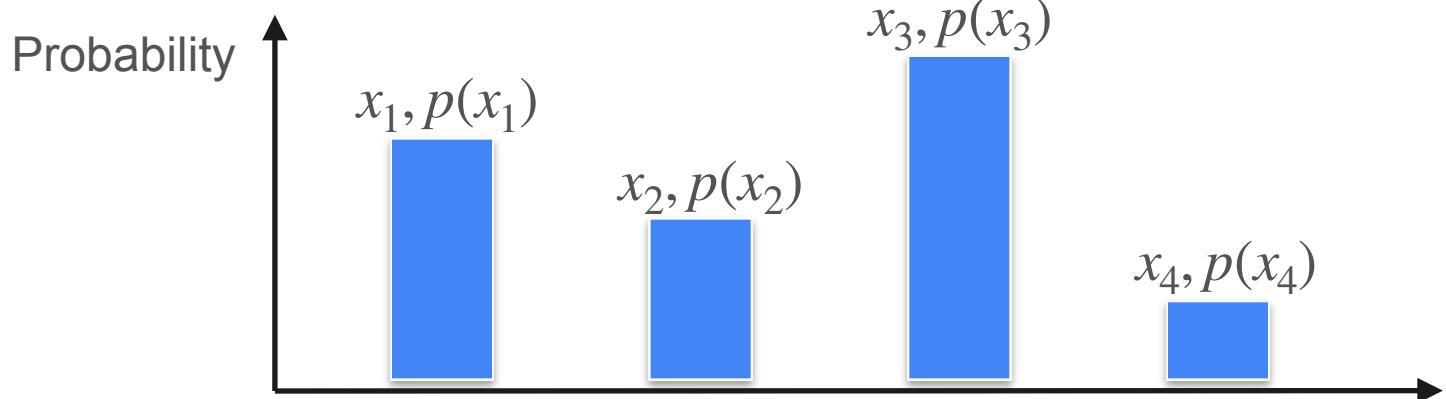
# Expected Value of a Function



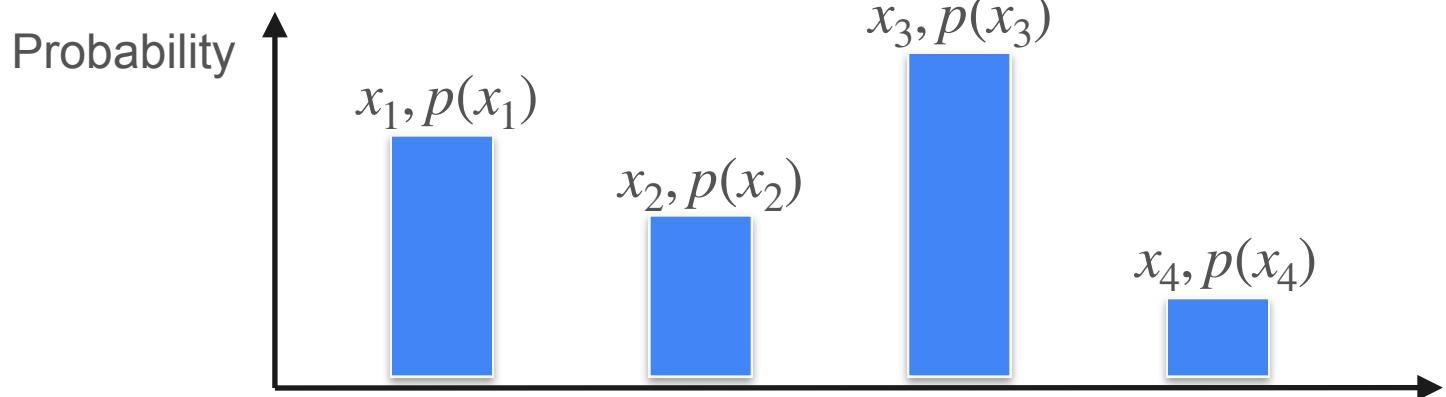
# Expected Value of a Function



# Expected Value of a Function

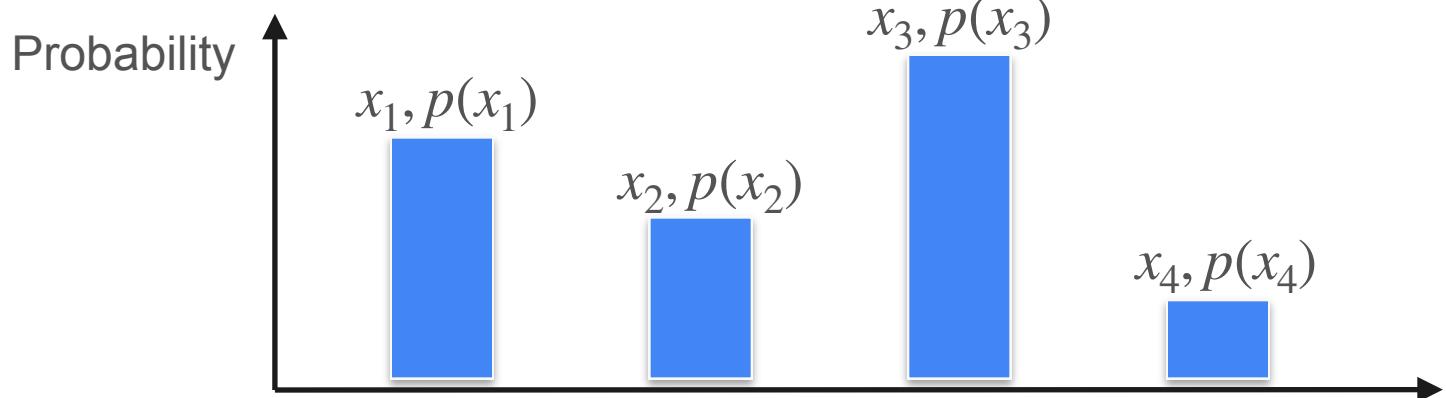


# Expected Value of a Function



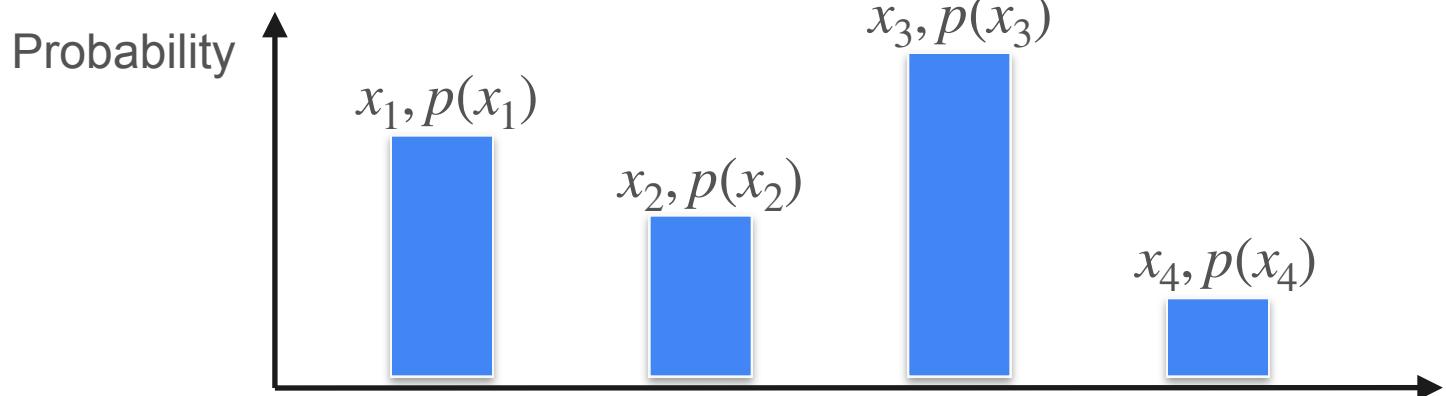
$$\mathbb{E}[X] =$$

# Expected Value of a Function



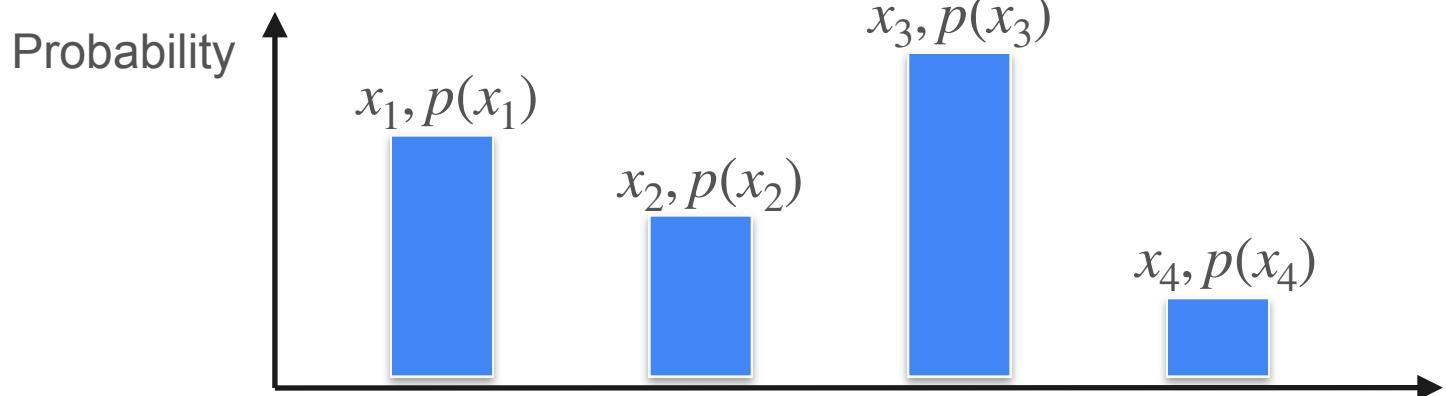
$$\mathbb{E}[X] = x_1 p(x_1)$$

# Expected Value of a Function



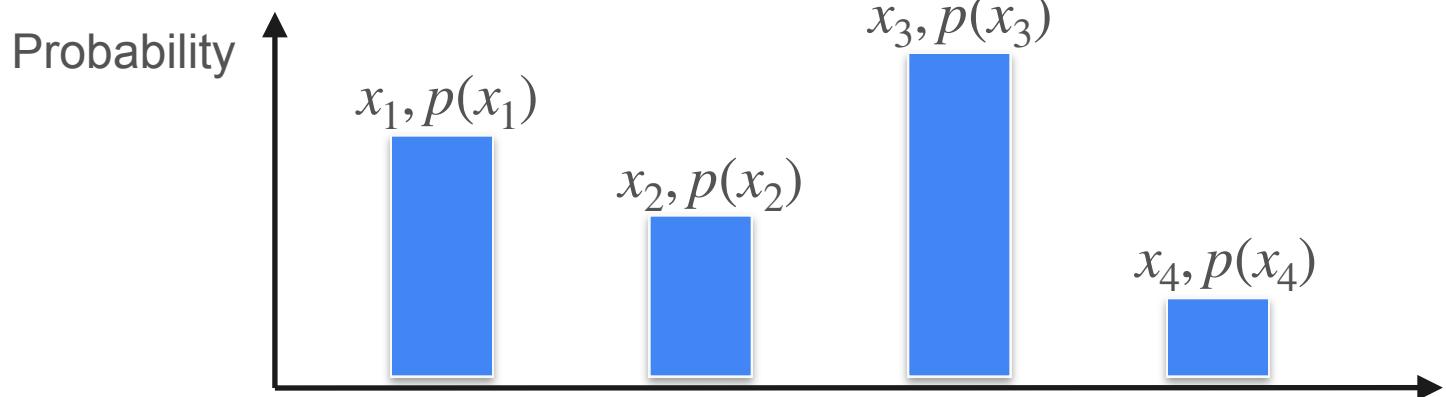
$$\mathbb{E}[X] = x_1 p(x_1) + x_2 p(x_2)$$

# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

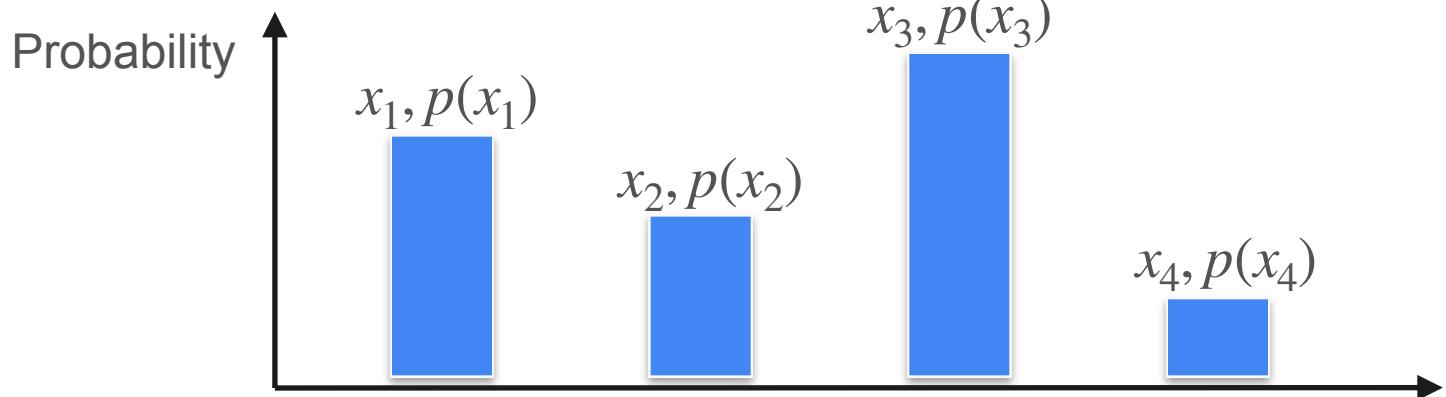
# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] =$$

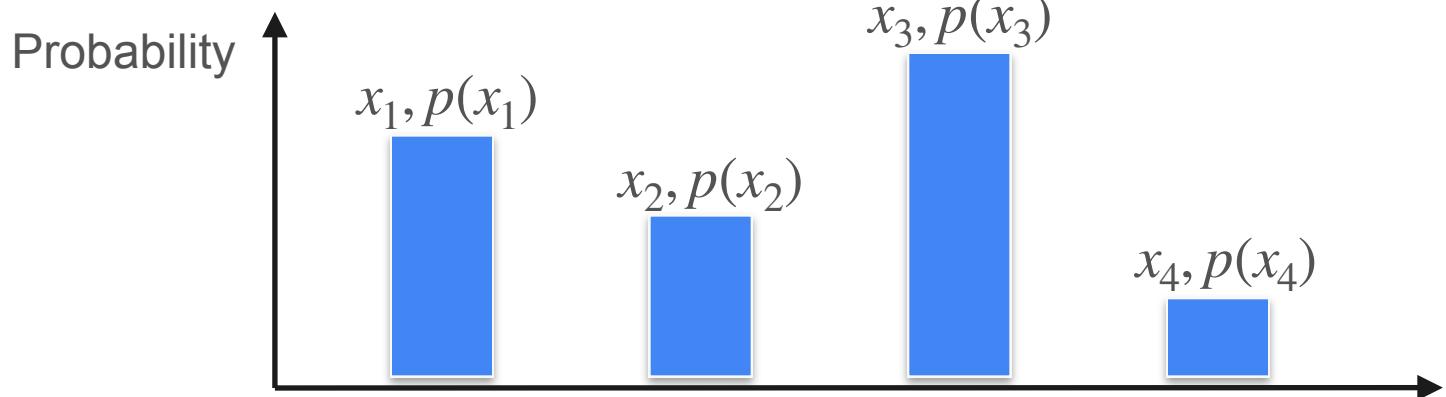
# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] = f(x_1)p(x_1)$$

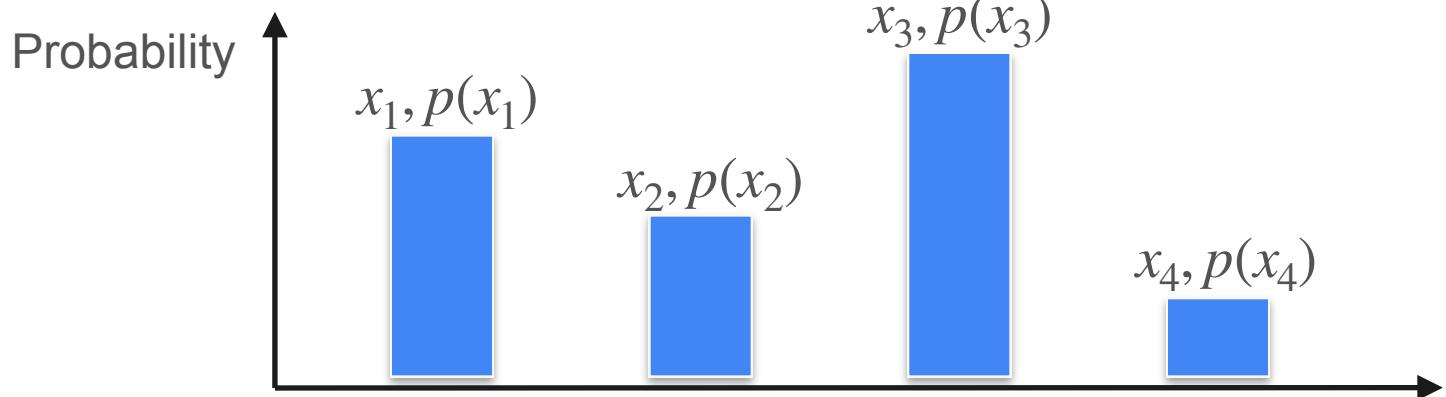
# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] = f(x_1)p(x_1) + f(x_2)p(x_2)$$

# Expected Value of a Function



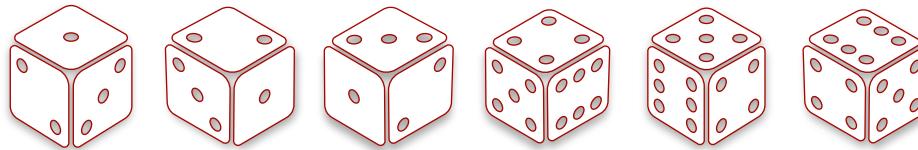
$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] = f(x_1)p(x_1) + f(x_2)p(x_2) + f(x_3)p(x_3) + f(x_4)p(x_4)$$

# Expected Value of a Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

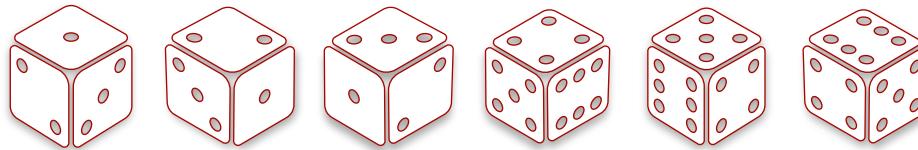
Roll:    1            2            3            4            5            6



# Expected Value of a Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

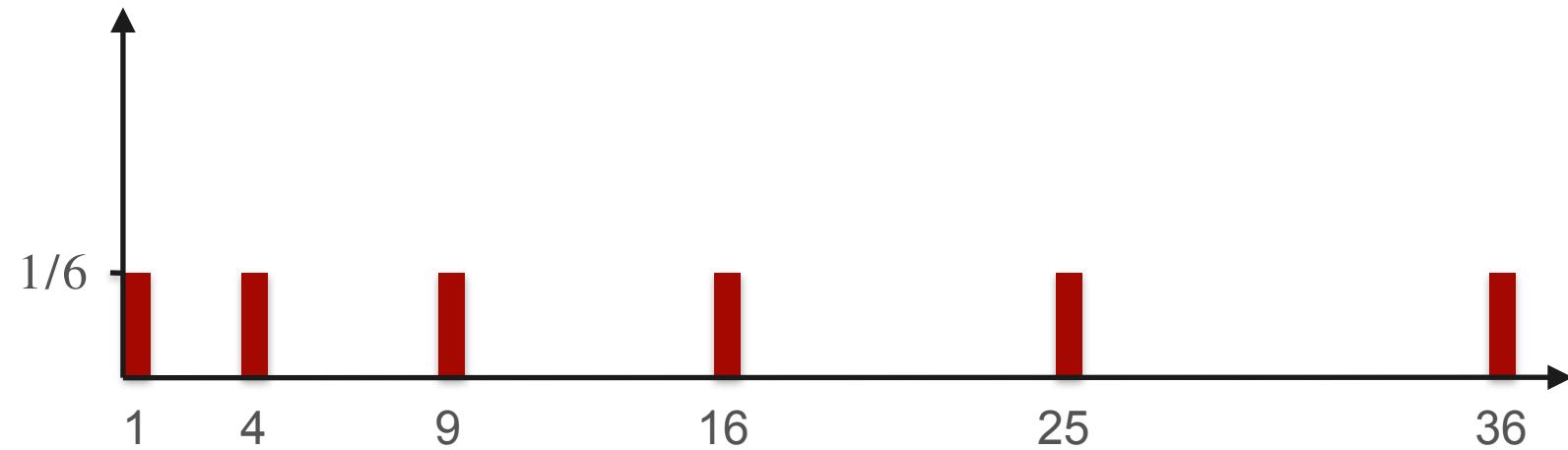
Roll:      1      2      3      4      5      6



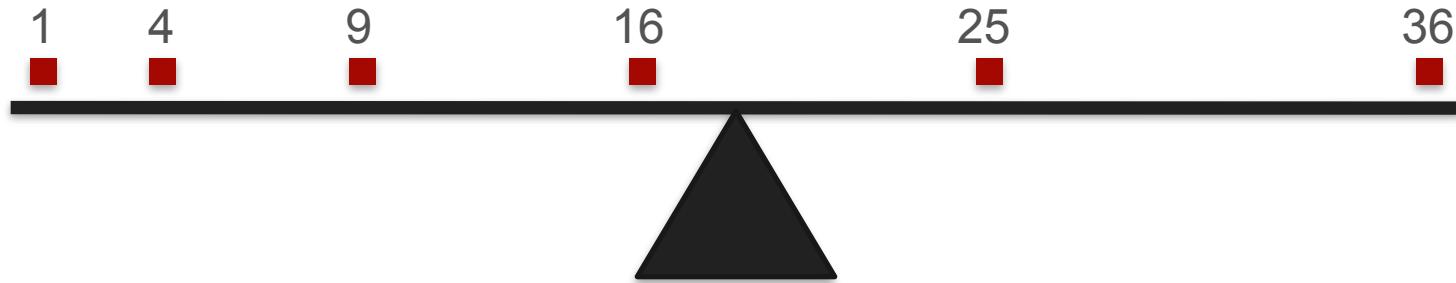
Square:      1      4      9      16      25      36

# Expected Value of a Function

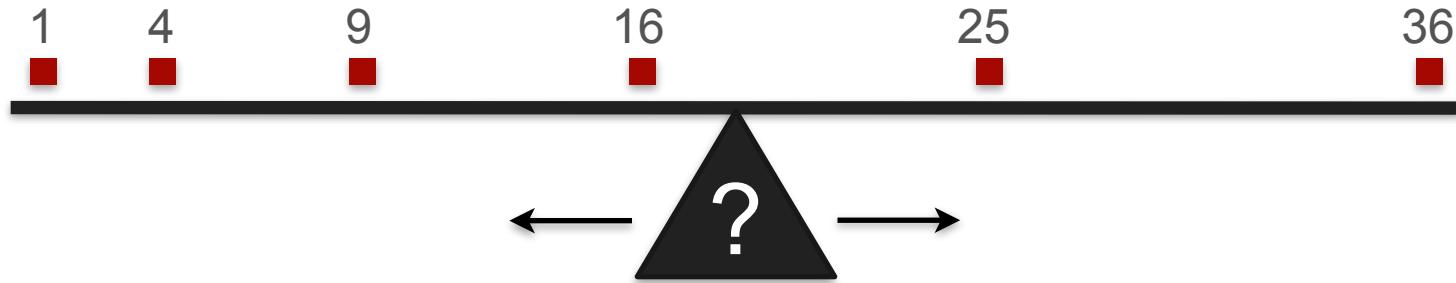
Probability



# Expected Value of a Function

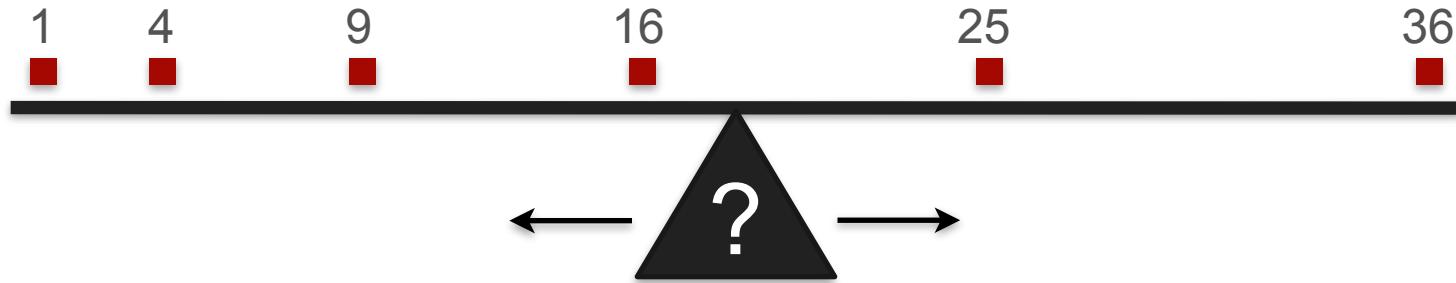


# Expected Value of a Function



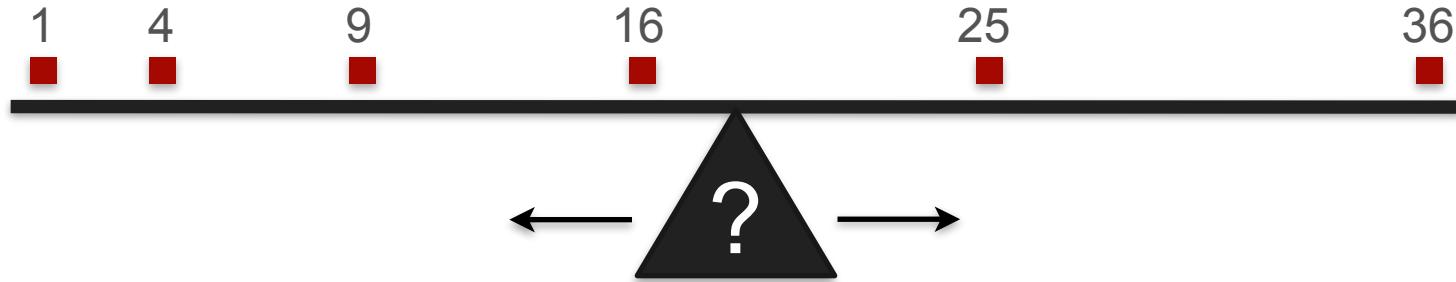
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6}$$



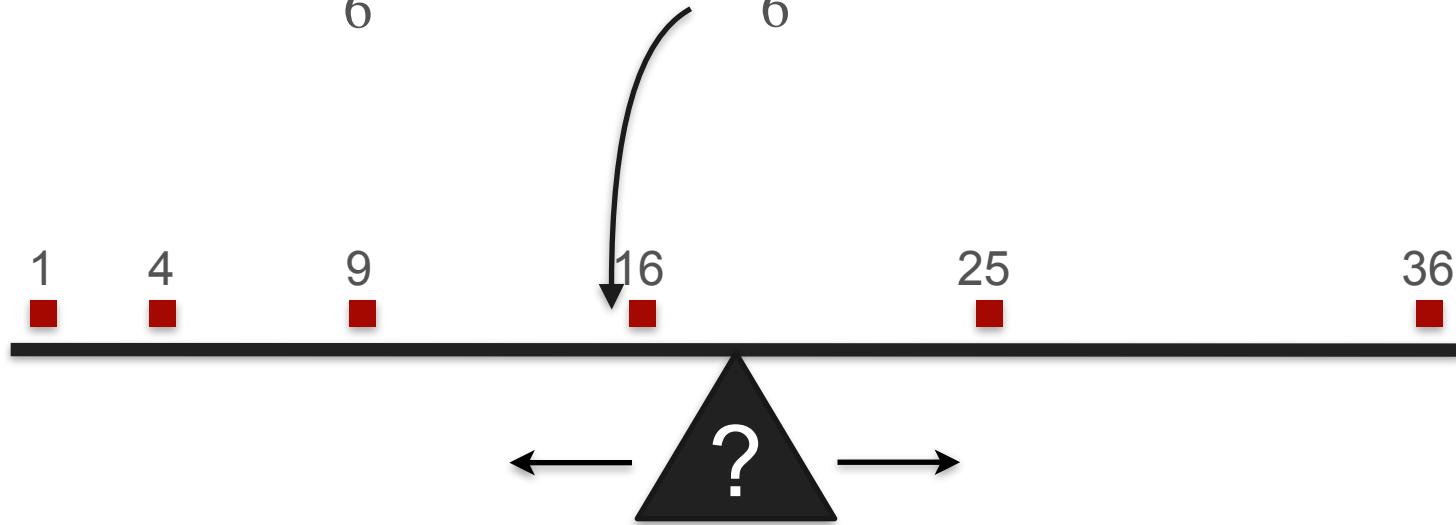
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6}$$



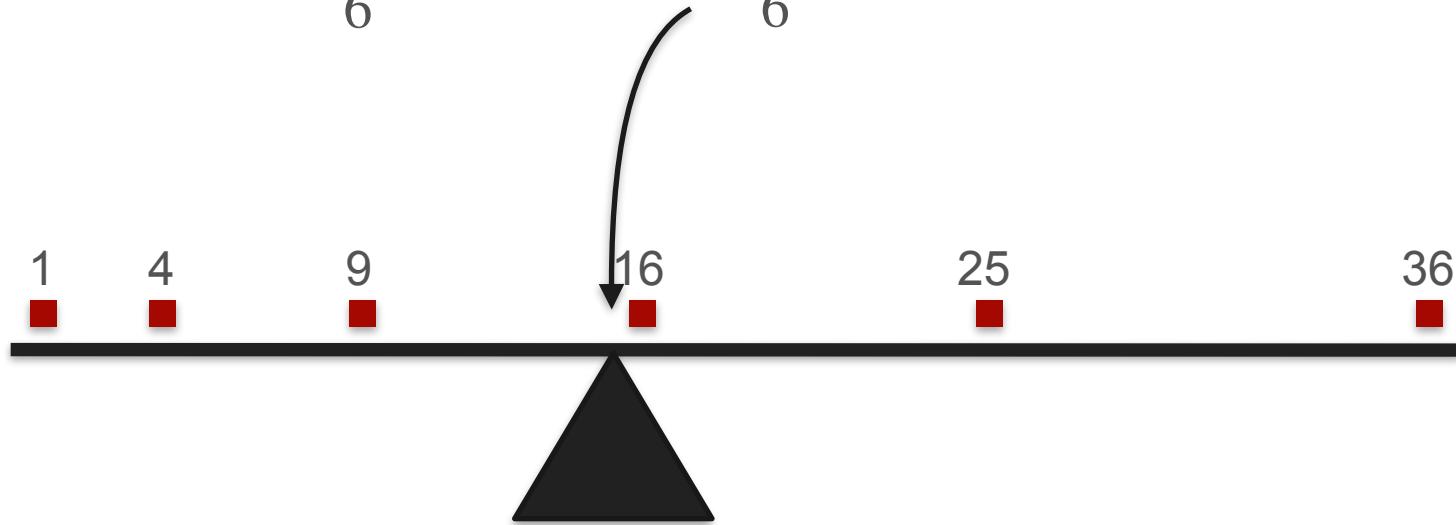
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6}$$



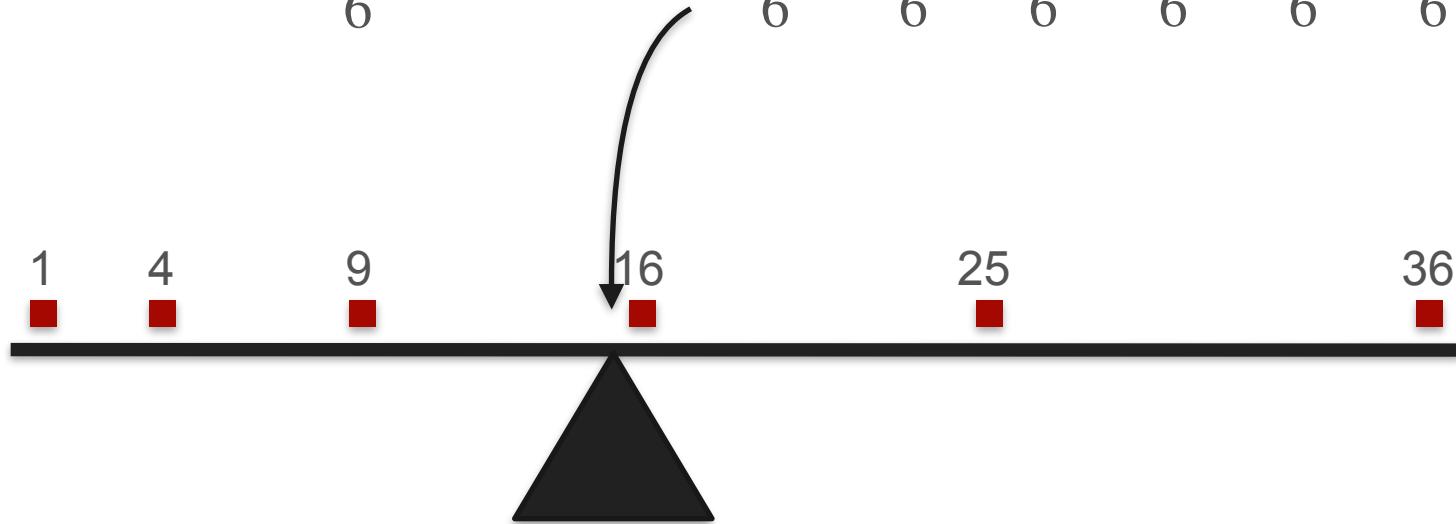
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6}$$



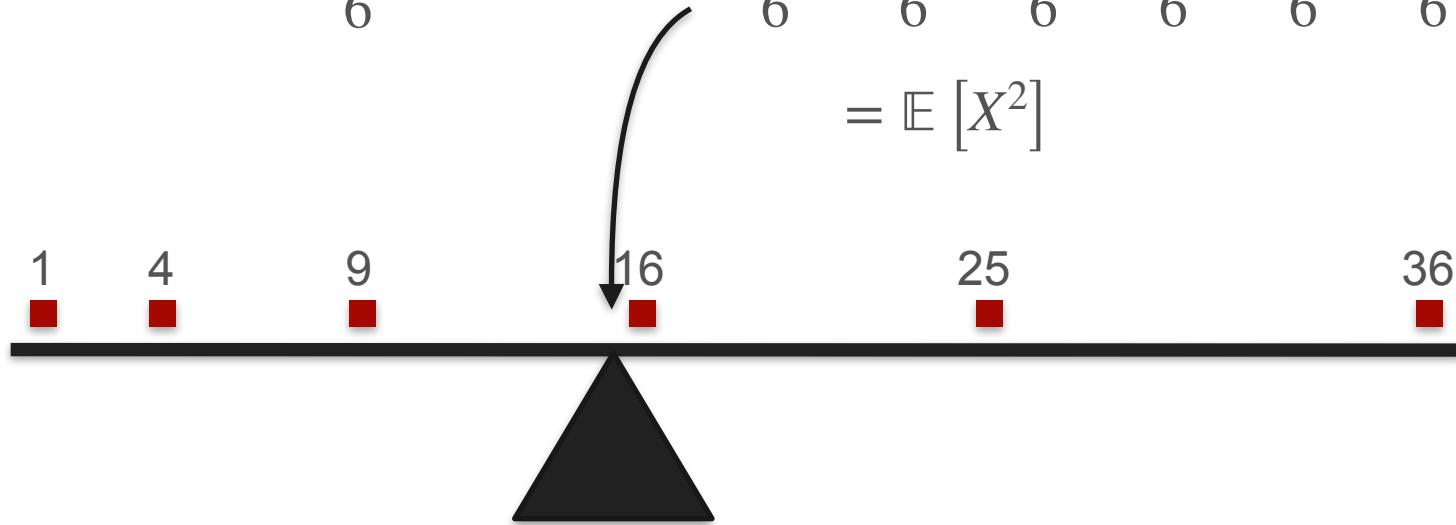
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6} = \frac{1^2}{6} + \frac{2^2}{6} + \frac{3^2}{6} + \frac{4^2}{6} + \frac{5^2}{6} + \frac{6^2}{6}$$



# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6} = \frac{1^2}{6} + \frac{2^2}{6} + \frac{3^2}{6} + \frac{4^2}{6} + \frac{5^2}{6} + \frac{6^2}{6}$$
$$= \mathbb{E}[X^2]$$





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# Describing Distributions

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## Sum of expectations

# Sum of Expectations

You play a game:

# Sum of Expectations

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

# Sum of Expectations

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.



Win \$1



Win nothing

# Sum of Expectations

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

Then roll a die. You win the amount you roll.



Win \$1



Win nothing

# Sum of Expectations

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

Then roll a die. You win the amount you roll.

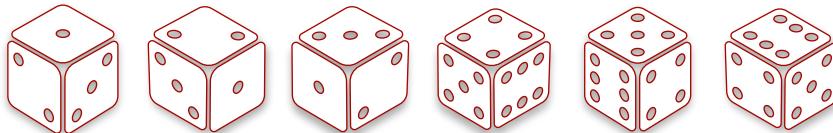


Win \$1



Win nothing

Win      \$1      \$2      \$3      \$4      \$5      \$6



# Sum of Expectations

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

Then roll a die. You win the amount you roll.



Win \$1



Win nothing

Win

\$1

\$2

\$3

\$4

\$5

\$6



What are your expected winnings for the game?

# Sum of Expectations

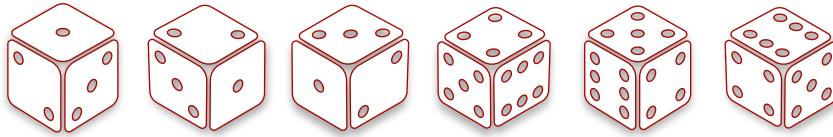


Win \$1



Win nothing

Win \$1 \$2 \$3 \$4 \$5 \$6



# Sum of Expectations

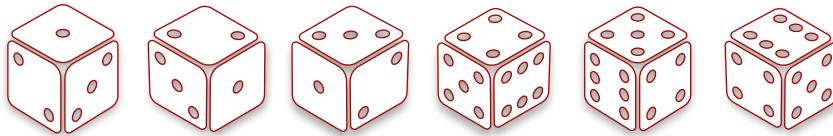


Win \$1



Win nothing

Win \$1 \$2 \$3 \$4 \$5 \$6



$$\mathbb{E} [X_{coin}] = \$0.5$$

# Sum of Expectations



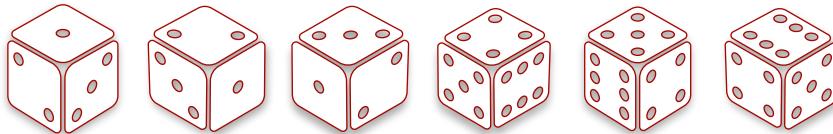
Win \$1



Win nothing

$$\mathbb{E} [X_{coin}] = \$0.5$$

Win \$1 \$2 \$3 \$4 \$5 \$6



$$\mathbb{E} [X_{dice}] = \$3.5$$

# Sum of Expectations

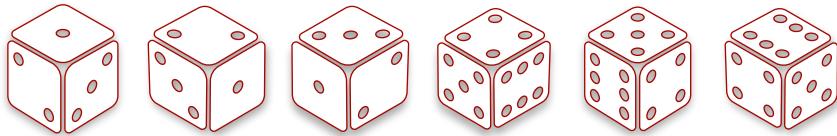


Win \$1



Win nothing

Win \$1 \$2 \$3 \$4 \$5 \$6



$$\mathbb{E}[X_{coin}] = \$0.5$$

$$\mathbb{E}[X_{dice}] = \$3.5$$

$$\mathbb{E}[X] = \mathbb{E}[X_{coin}] + \mathbb{E}[X_{dice}] = \$0.5 + \$3.5 = \$4$$

# Sum of Expectations

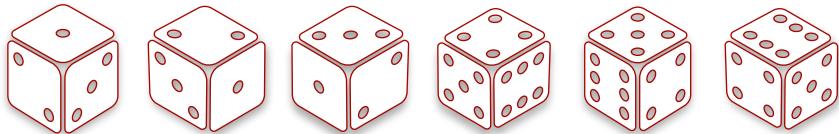


Win \$1



Win nothing

Win \$1 \$2 \$3 \$4 \$5 \$6



$$\mathbb{E}[X_{coin}] = \$0.5$$

$$\mathbb{E}[X_{dice}] = \$3.5$$

$$\mathbb{E}[X] = \mathbb{E}[X_{coin}] + \mathbb{E}[X_{dice}] = \$0.5 + \$3.5 = \$4$$

In general:  $\mathbb{E}[X_1 + X_2] = \mathbb{E}[X_1] + \mathbb{E}[X_2]$

# Sum of Expectations



8 billion people

# Sum of Expectations



8 billion people

# Sum of Expectations



# Sum of Expectations

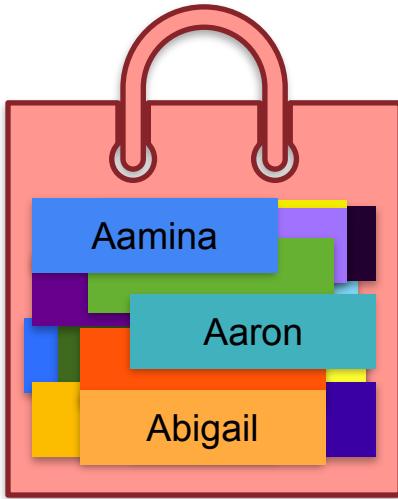


Expected number of  
correct assignments?



8 billion people

# Sum of Expectations



1

Expected number of  
correct assignments?



8 billion people

# Sum of Expectations



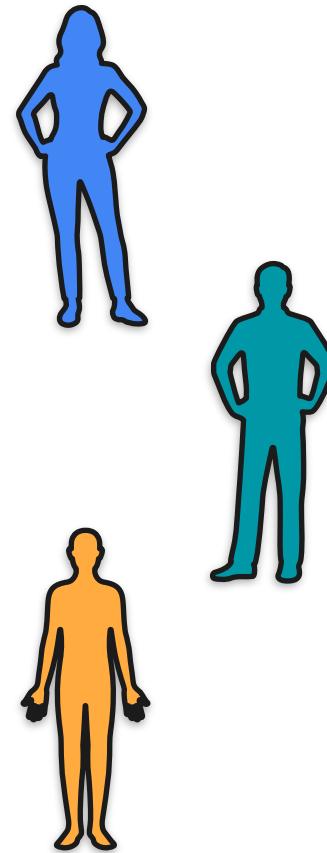
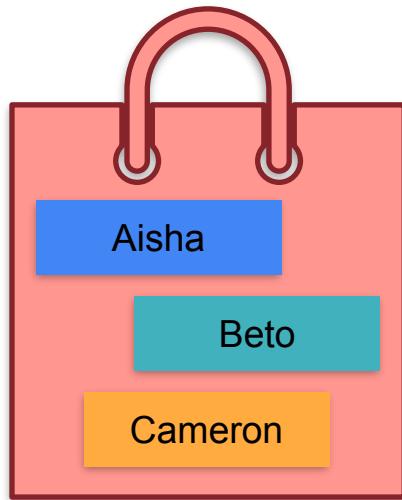
1

Expected number of  
correct assignments?

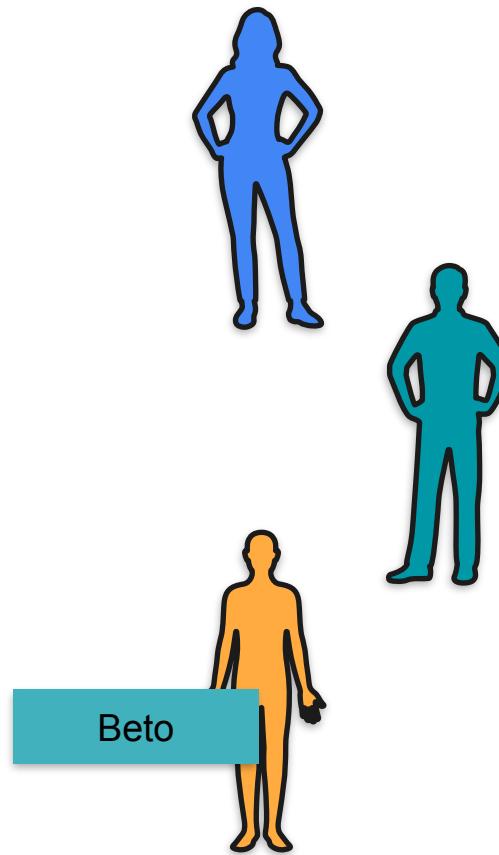
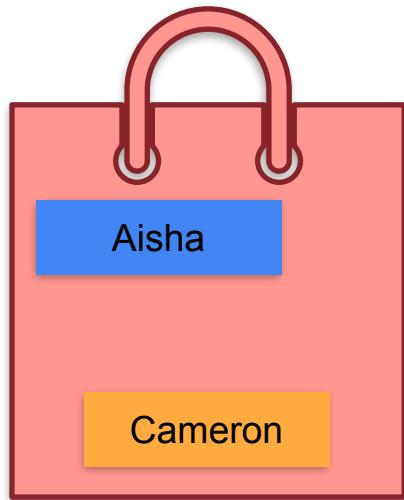


8 billion people

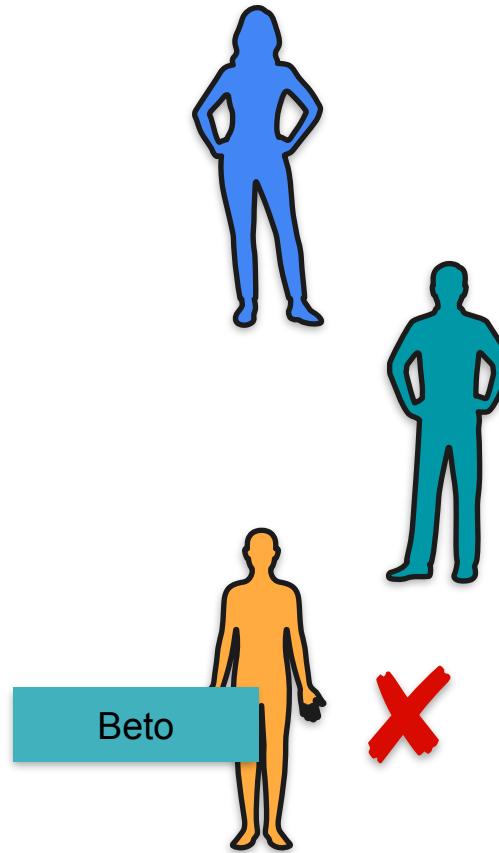
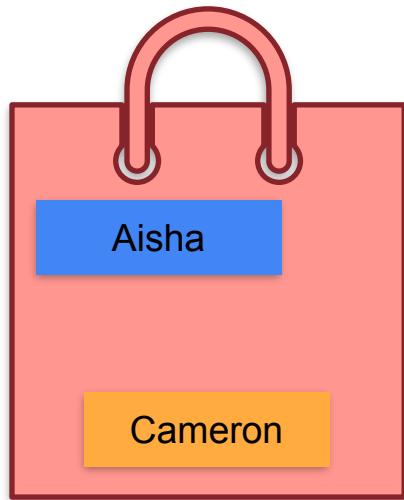
# Sum of Expectations



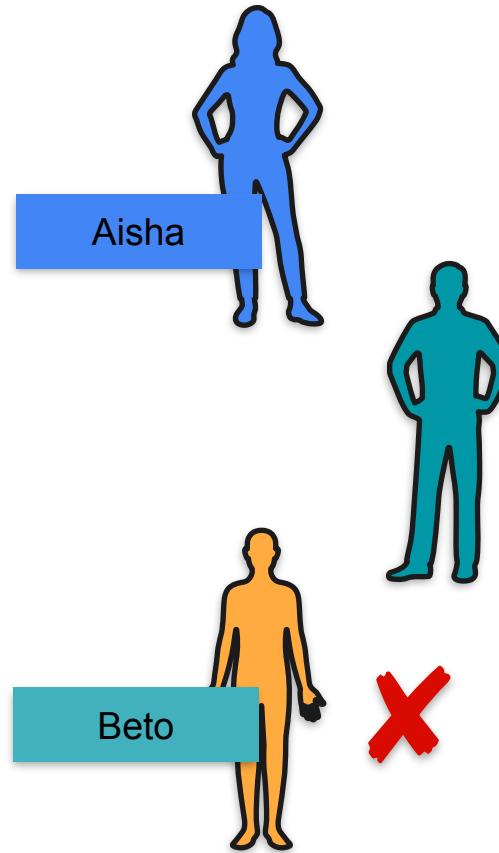
# Sum of Expectations



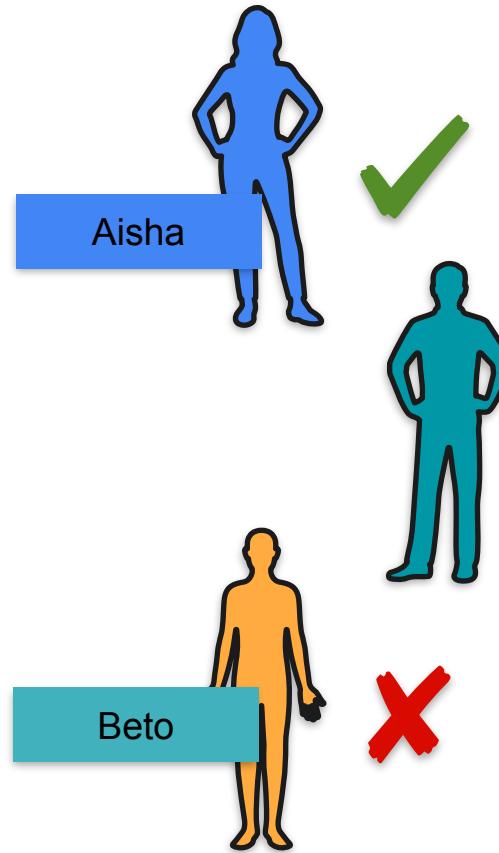
# Sum of Expectations



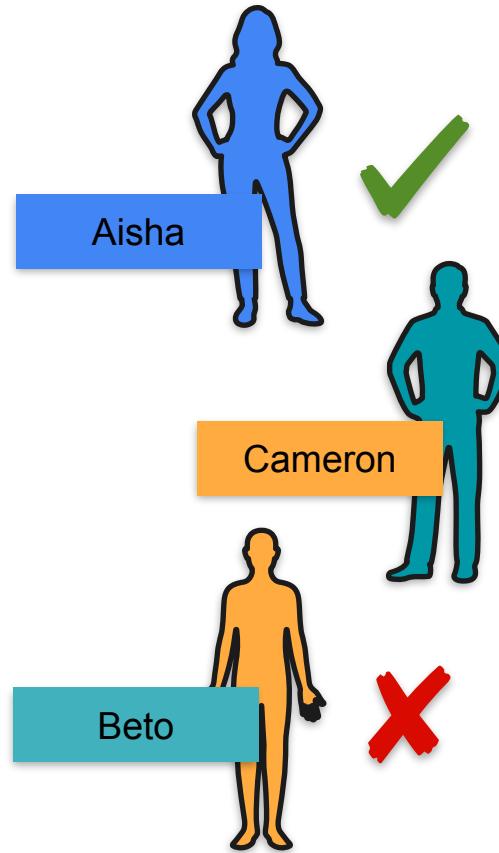
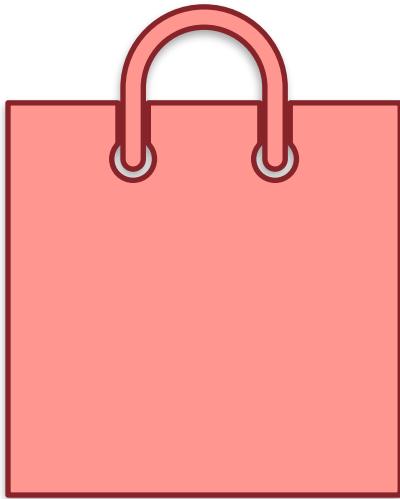
# Sum of Expectations



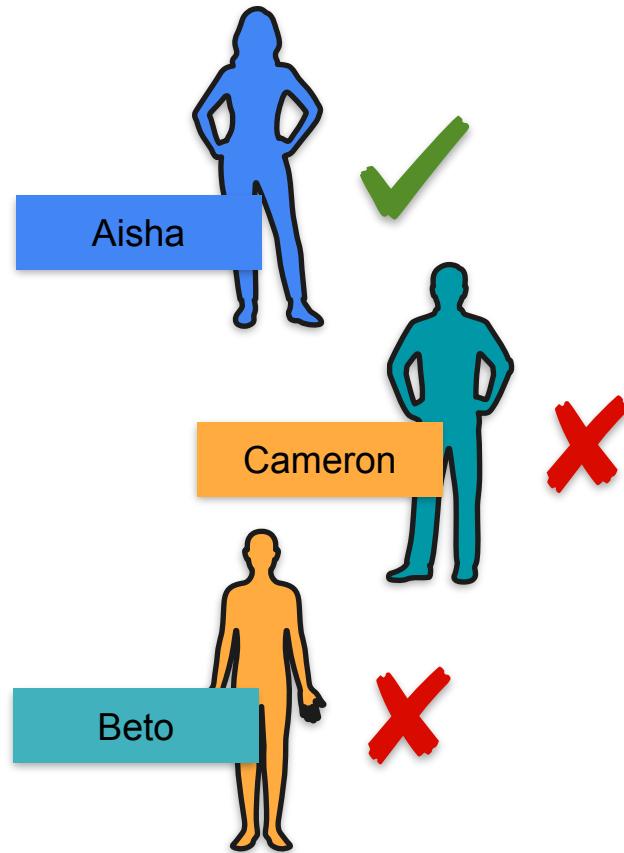
# Sum of Expectations



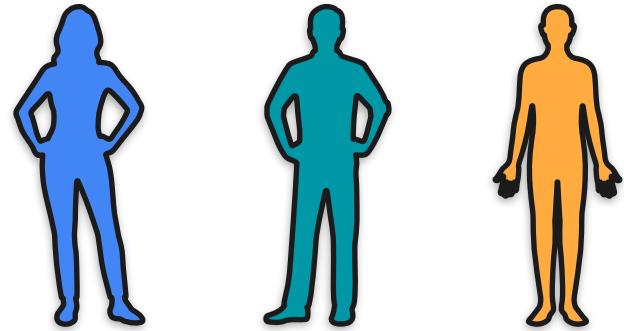
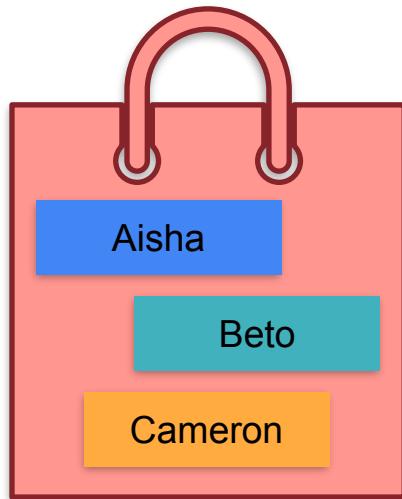
# Sum of Expectations



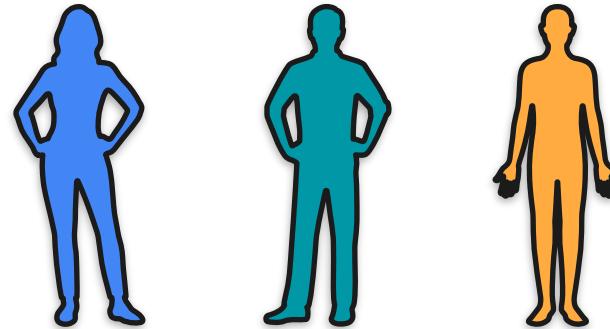
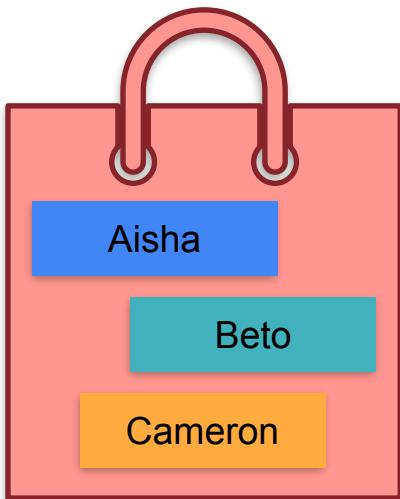
# Sum of Expectations



# Sum of Expectations

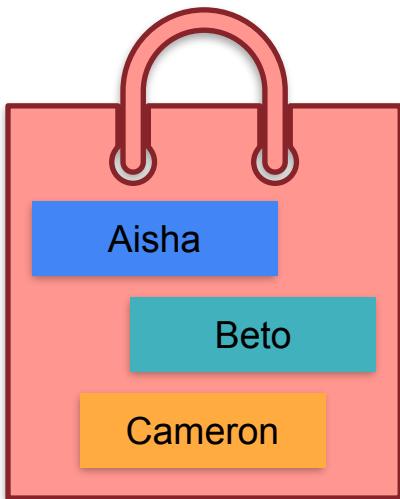


# Sum of Expectations

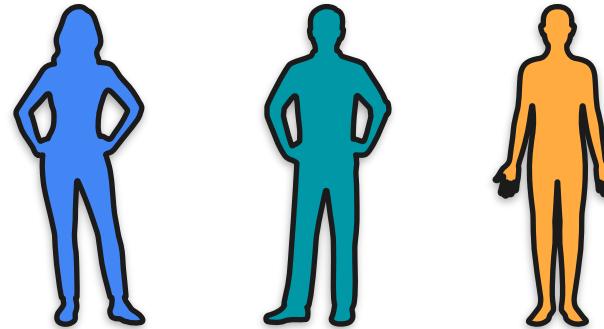


Aisha	Beto	Cameron
Aisha	Cameron	Beto
Beto	Aisha	Cameron
Beto	Cameron	Aisha
Cameron	Aisha	Beto
Cameron	Beto	Aisha

# Sum of Expectations

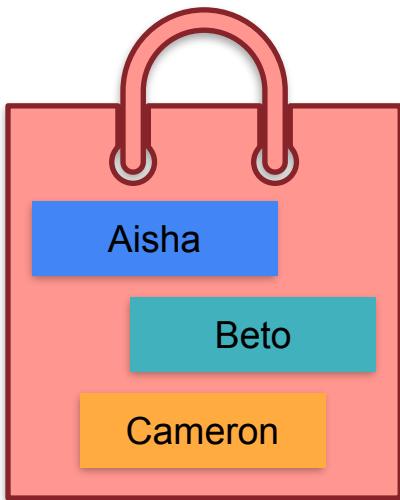


Correct

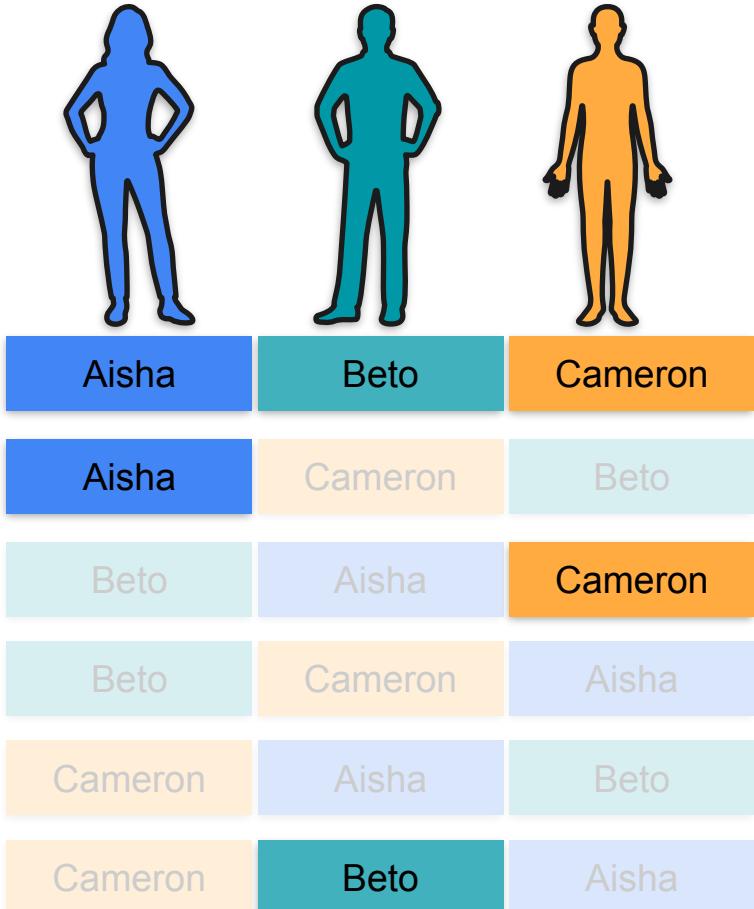


Aisha	Beto	Cameron
Aisha	Cameron	Beto
Beto	Aisha	Cameron
Beto	Cameron	Aisha
Cameron	Aisha	Beto
Cameron	Beto	Aisha

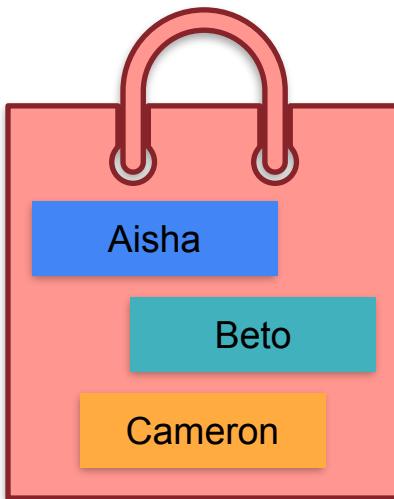
# Sum of Expectations



Correct

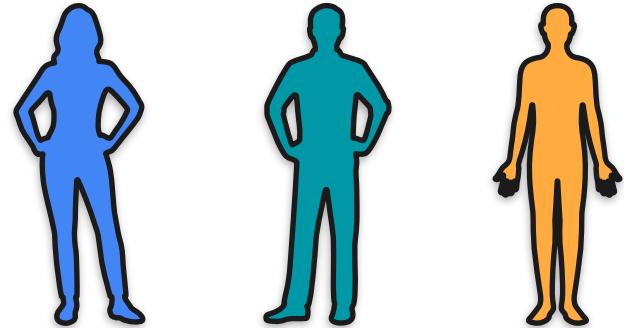


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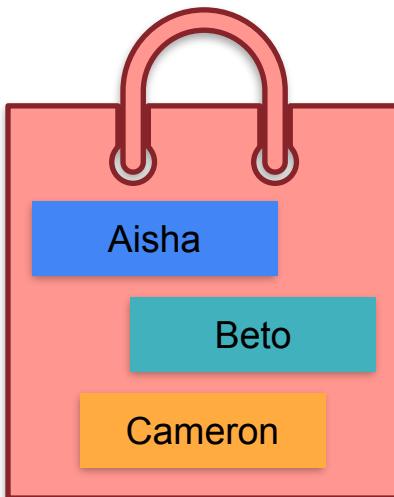


Correct

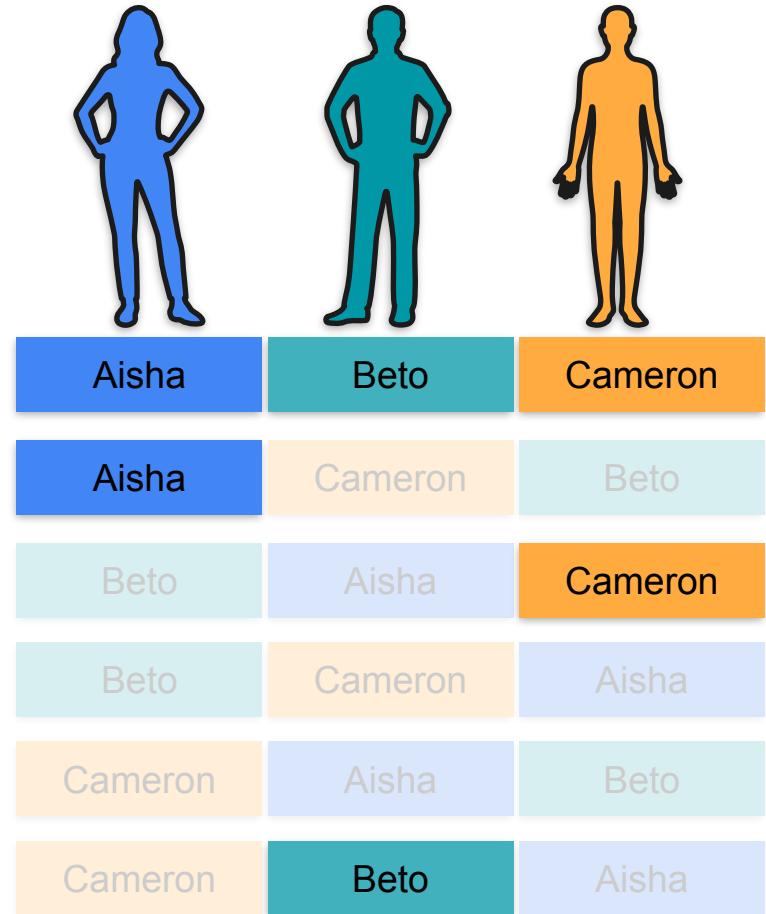
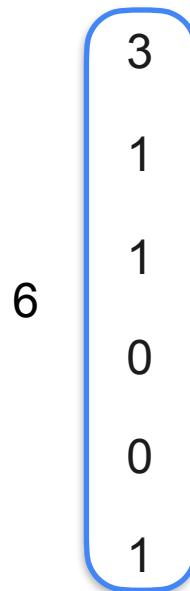
3	Aisha	Beto	Cameron
1	Aisha	Cameron	Beto
1	Beto	Aisha	Cameron
0	Beto	Cameron	Aisha
0	Cameron	Aisha	Beto
1	Cameron	Beto	Aisha



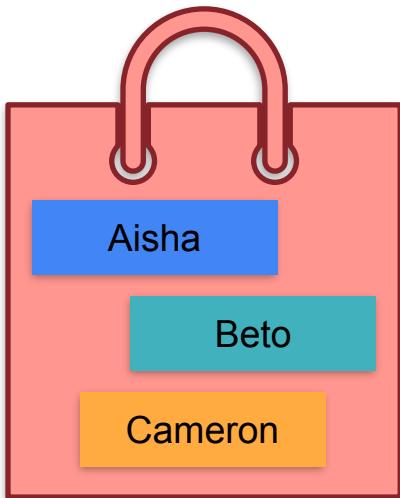
# Sum of Expectations



Correct



# Sum of Expectations

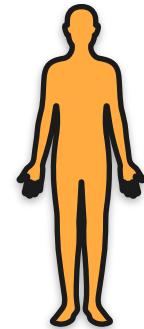
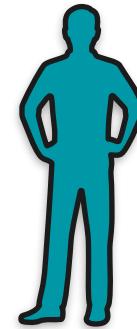
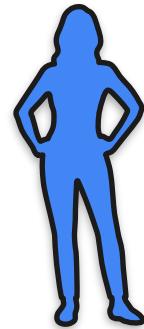
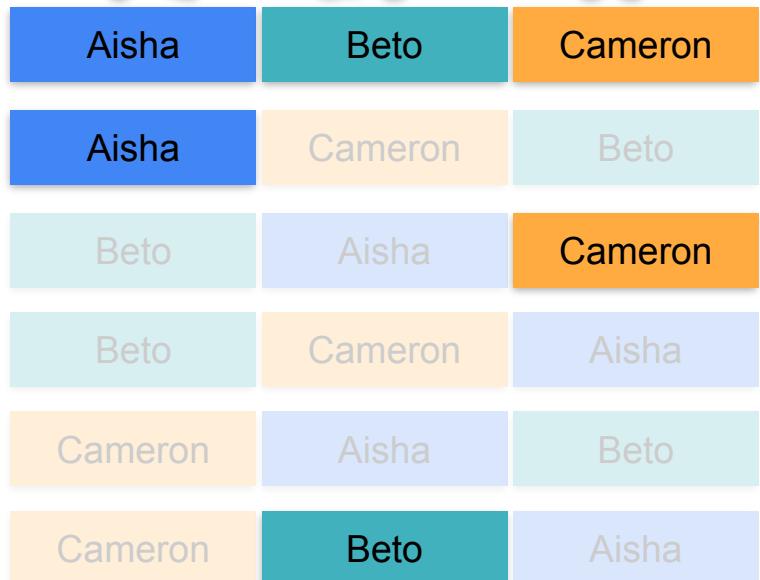


Average  
1

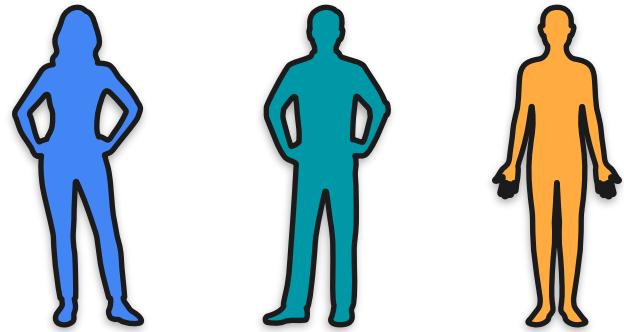
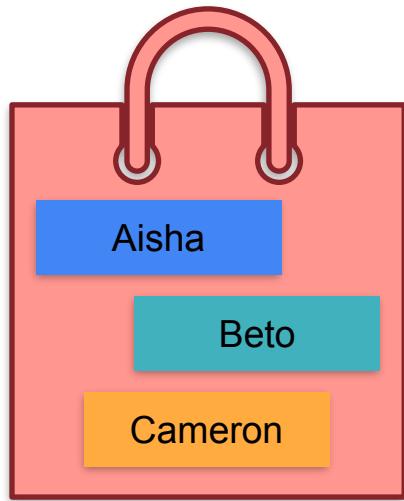
Correct

3  
1  
1  
0  
0  
1

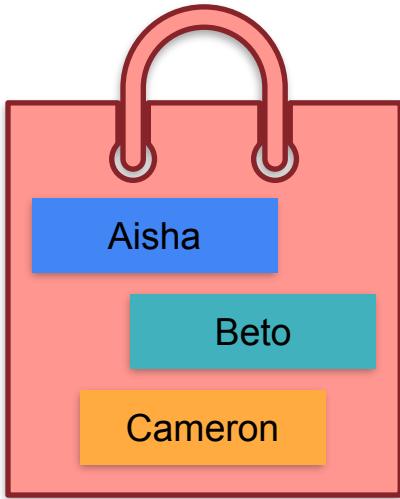
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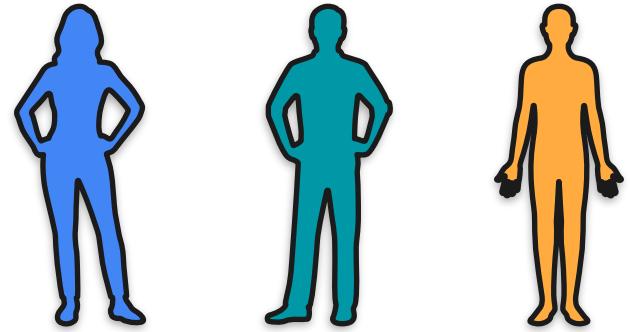
# Sum of Expectations



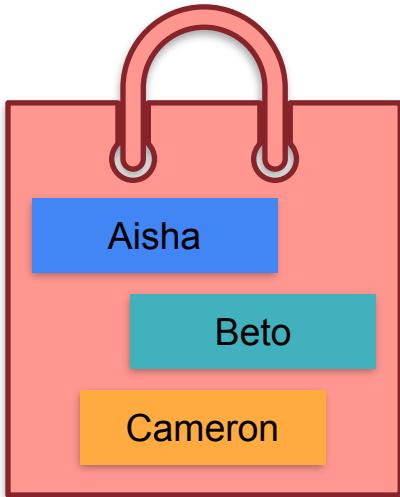
# Sum of Expectations



$\mathbb{E}[\text{Matches}]$



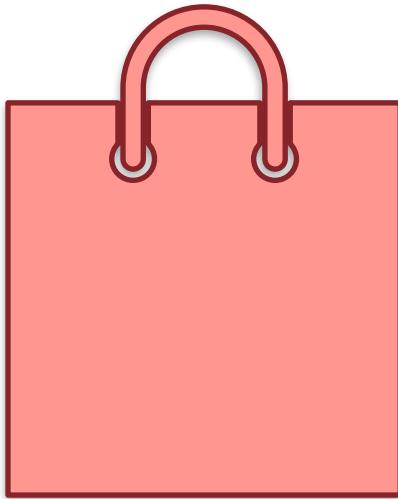
# Sum of Expectations



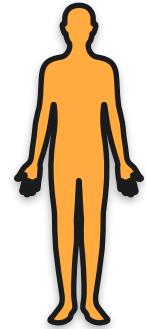
$$\mathbb{E}[\text{Matches}] = \mathbb{E}[A]$$



# Sum of Expectations



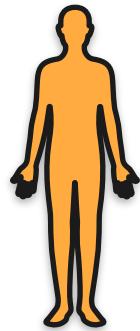
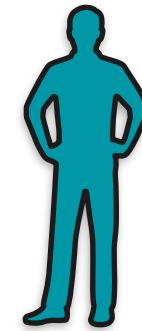
$$\mathbb{E}[\text{Matches}] = \mathbb{E}[A]$$



# Sum of Expectations



$\mathbb{E}[\text{Matches}]$

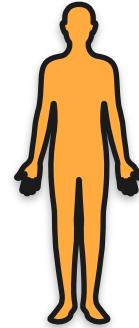


$= \mathbb{E}[A]$

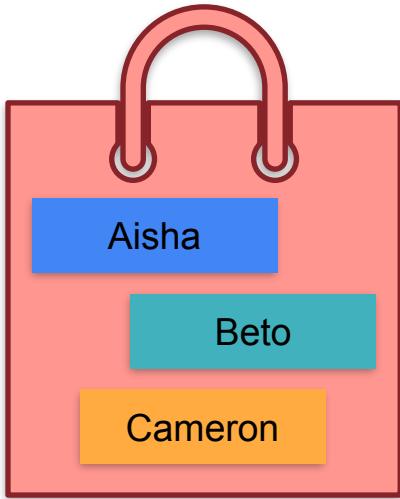
# Sum of Expectations



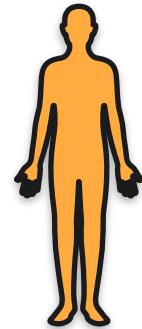
$$\mathbb{E}[\text{Matches}] = \mathbb{E}[A] = 1/3$$



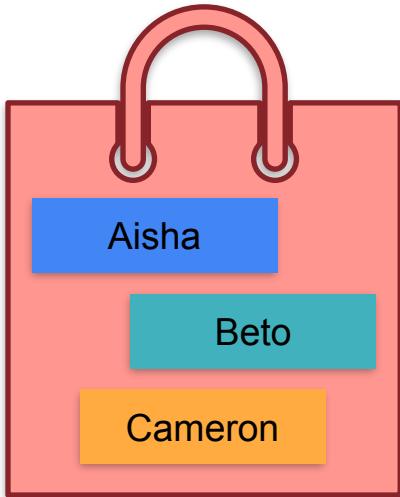
# Sum of Expectations



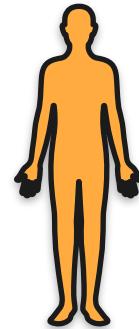
$$\mathbb{E}[\text{Matches}] = \mathbb{E}[A] = 1/3$$



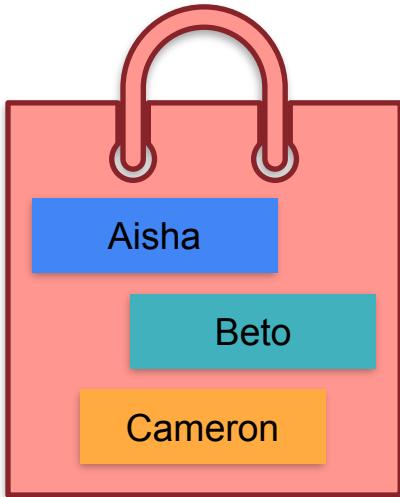
# Sum of Expectations



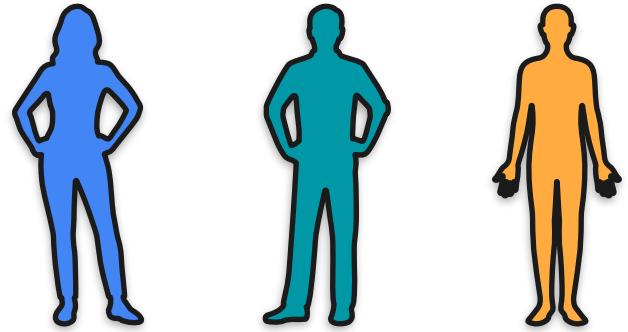
$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] \\ &= 1/3 + 1/3\end{aligned}$$



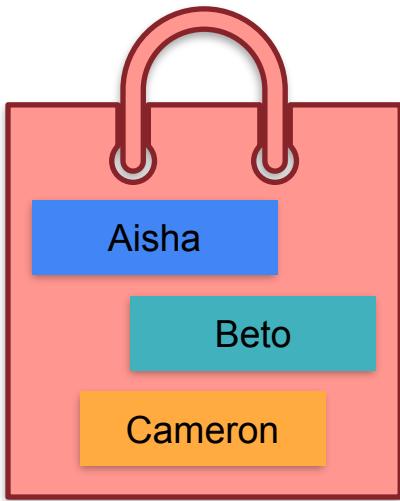
# Sum of Expectations



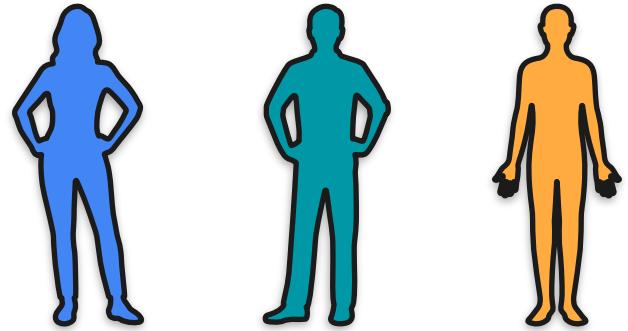
$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] + \mathbb{E}[C] \\ &= 1/3 + 1/3 + 1/3\end{aligned}$$



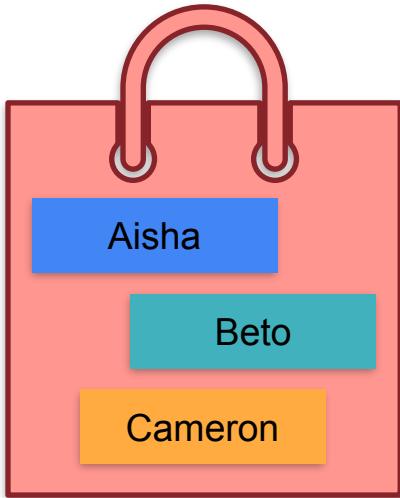
# Sum of Expectations



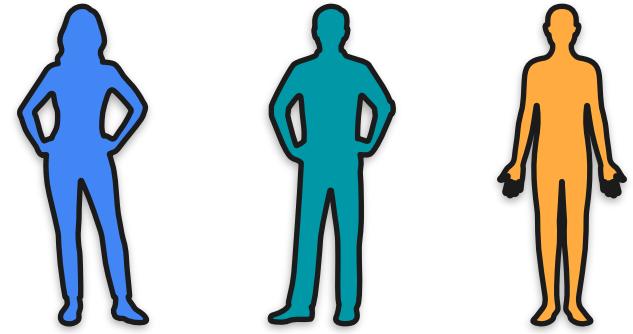
$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] + \mathbb{E}[C] \\ &= 1/3 + 1/3 + 1/3 \\ &= 1\end{aligned}$$



# Sum of Expectations



$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] + \mathbb{E}[C] \\ &= 1/3 + 1/3 + 1/3 \\ &= 1\end{aligned}$$



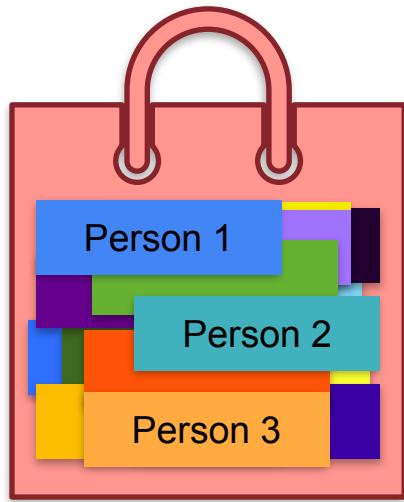
Average  
1

# Sum of Expectations



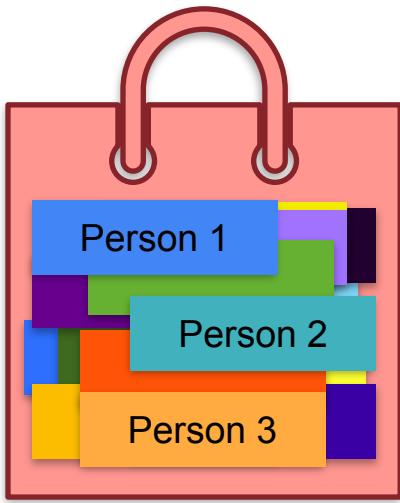
8 billion people

# Sum of Expectations



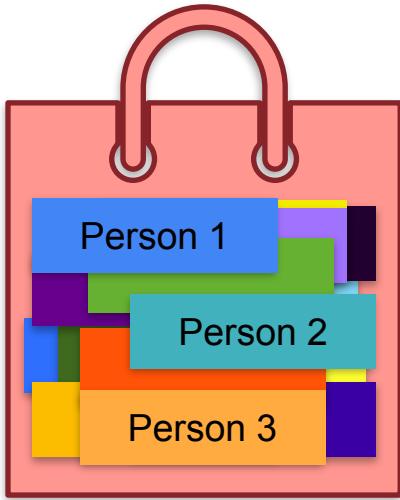
8 billion people

# Sum of Expectations



8 billion people

# Sum of Expectations



Expected number = ?



8 billion people

# Sum of Expectations



# Sum of Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}]$$

# Sum of Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}]$$

$n$  people ( $n = 8$  billion)

# Sum of Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}] \quad \overbrace{\qquad \qquad \qquad}^{\text{n people (n = 8 billion)}} = \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n}$$

# Sum of Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}]$$

$n$  people ( $n = 8$  billion)

$$= \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n}$$
$$= n \cdot \frac{1}{n}$$

# Sum of Expectations



$$\begin{aligned}\mathbb{E} [\text{Matches}] &= \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}] \\ &\quad \overbrace{\hspace{10em}}^{\text{n people (n = 8 billion)}} \\ &= \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n} \\ &= n \cdot \frac{1}{n} = 1\end{aligned}$$

# Sum of Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}]$$

$n$  people ( $n = 8$  billion)

$$= \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n}$$

In general:

$$\mathbb{E} [X_1 + X_2 + \dots + X_n] = \mathbb{E} [X_1] + \mathbb{E} [X_2] + \dots + \mathbb{E} [X_n]$$

$$= n \cdot \frac{1}{n} = 1$$



DeepLearning.AI

# Describing Distributions

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## Variance

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 1 dollar



You lose 1 dollar

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 1 dollar



You lose 1 dollar

Game cost:

\$0

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 100 dollars



You lose 100 dollars

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 100 dollars



You lose 100 dollars

Game cost:

\$0

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

How do you tell these two games apart?

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 100 dollars



You lose 100 dollars

# Variance Motivation: Fair Price To Play the Game

How do you tell these two games apart?

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



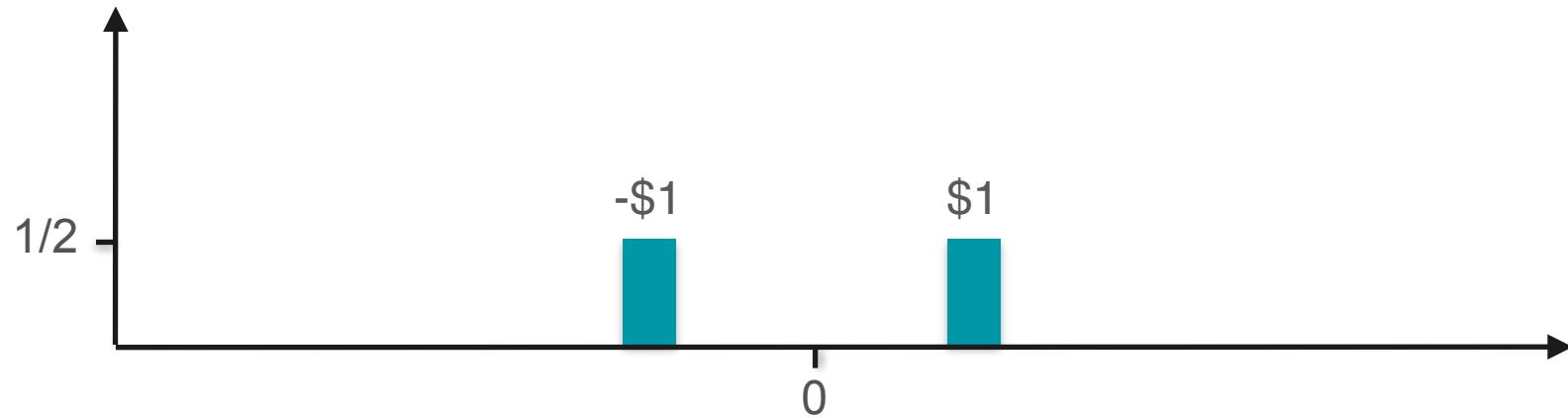
You win 100 dollars

You lose 100 dollars

Variance!

# Variance Motivation: Measuring Spread

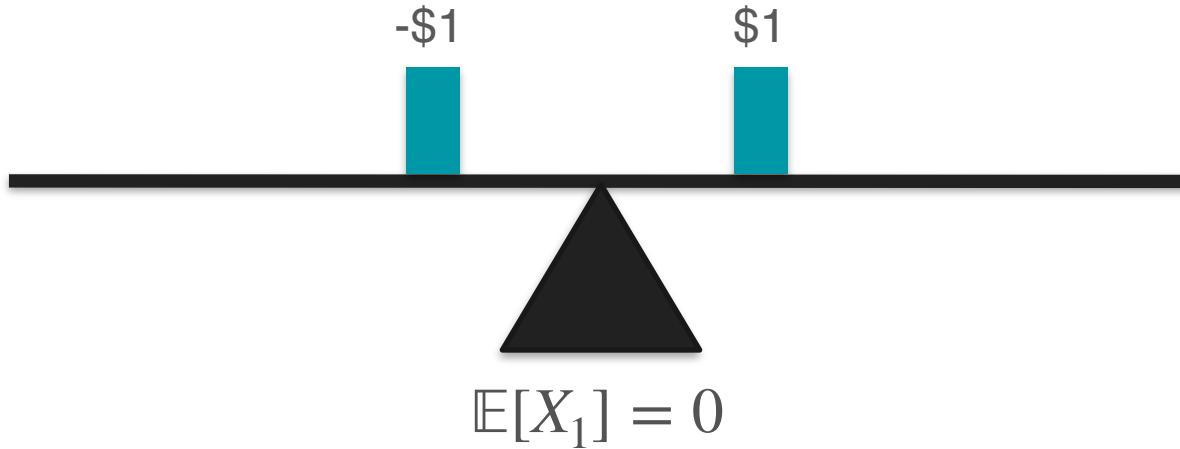
Probability



# Variance Motivation: Measuring Spread

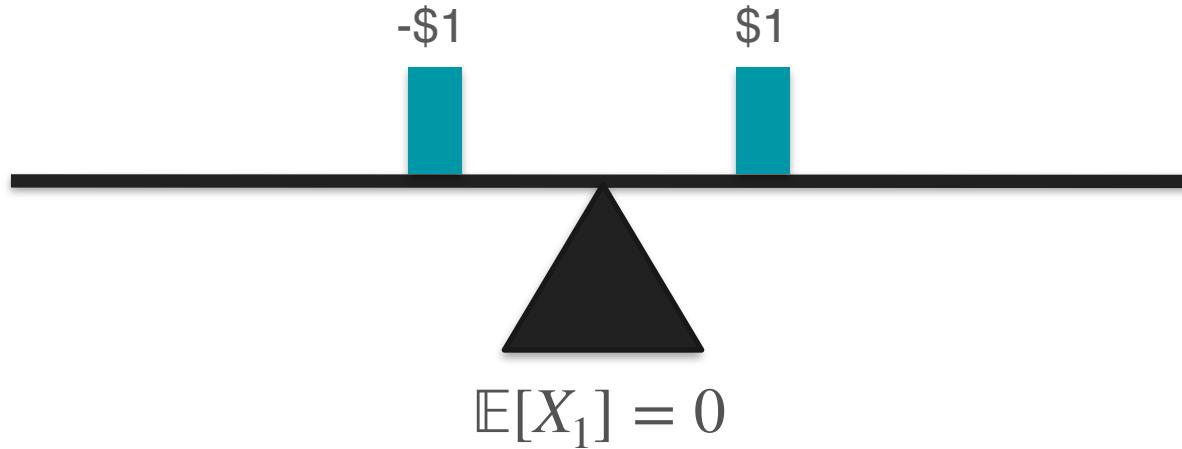


# Variance Motivation: Measuring Spread

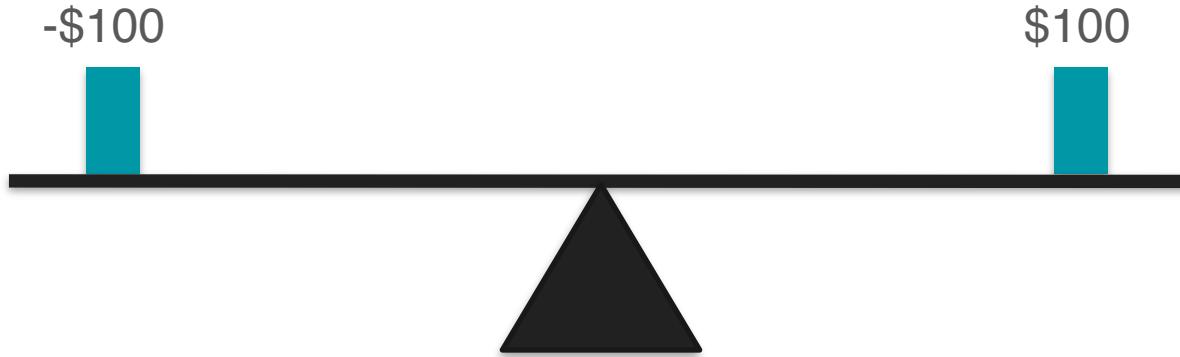


# Variance Motivation: Measuring Spread

$X_1$  = expected amount of money gained in game 1

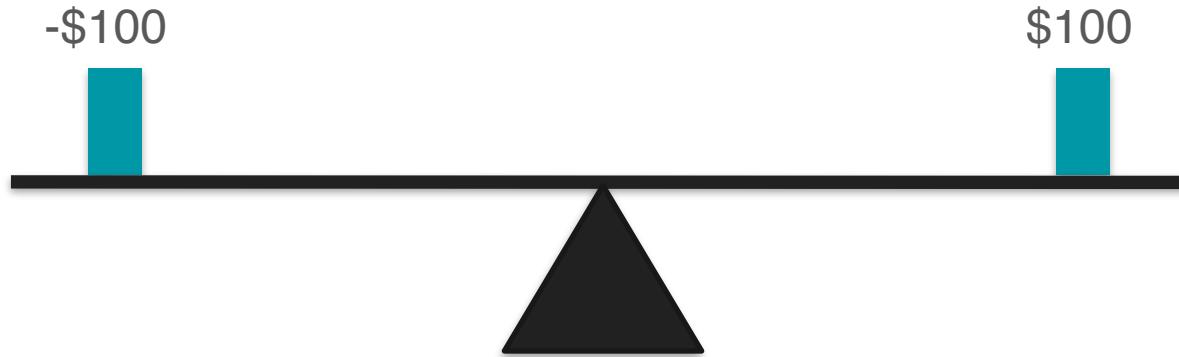


# Variance Motivation: Measuring Spread



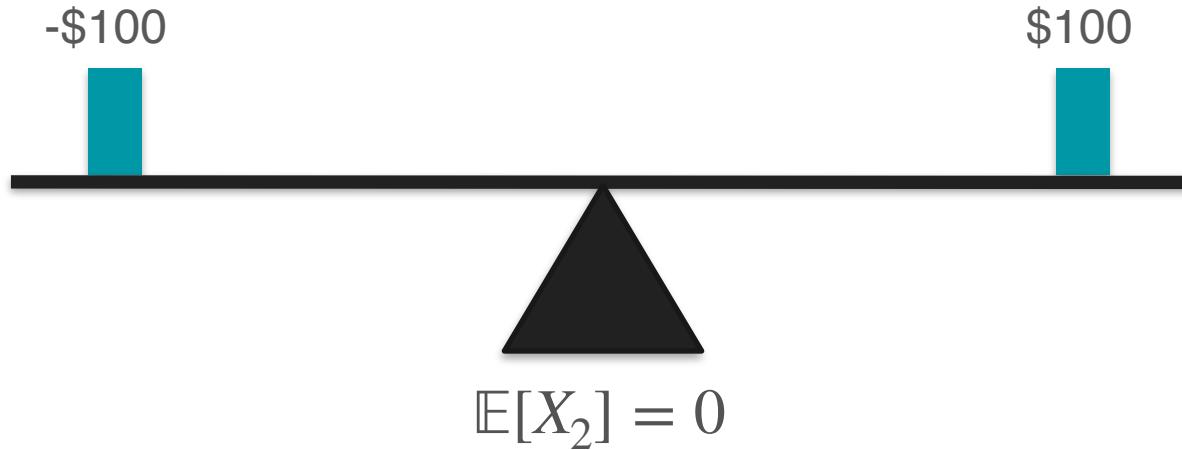
# Variance Motivation: Measuring Spread

$X_2$  = expected amount of money gained in game 2

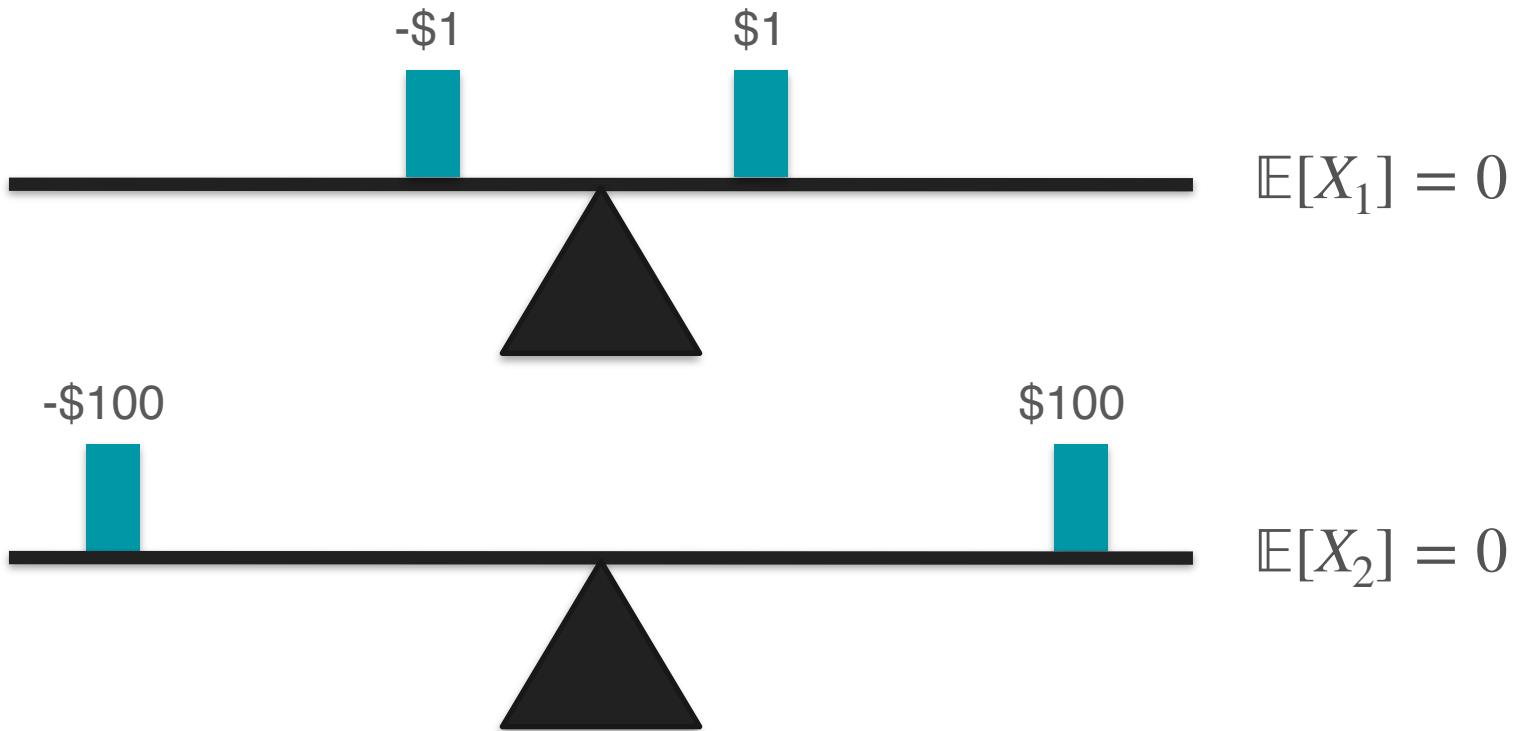


# Variance Motivation: Measuring Spread

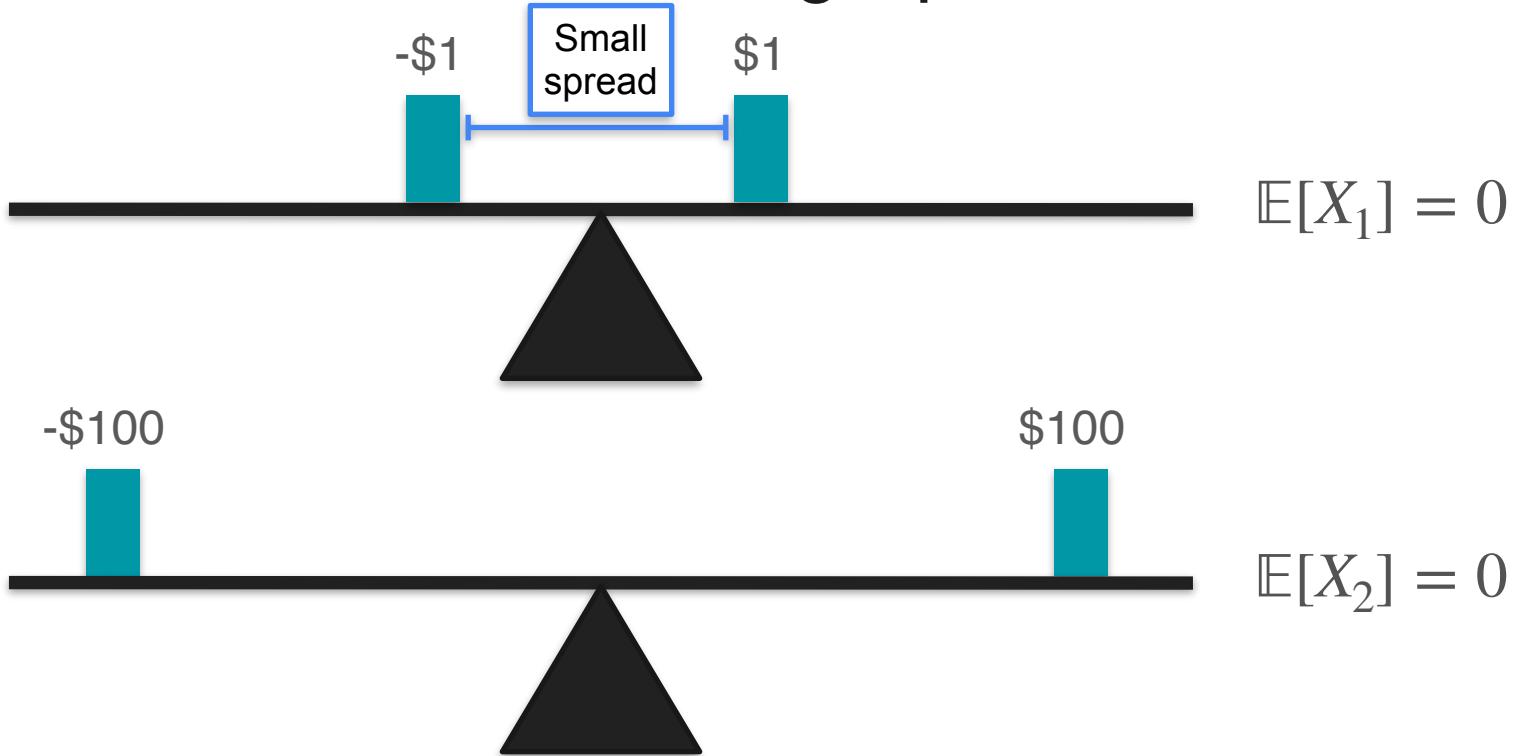
$X_2$  = expected amount of money gained in game 2



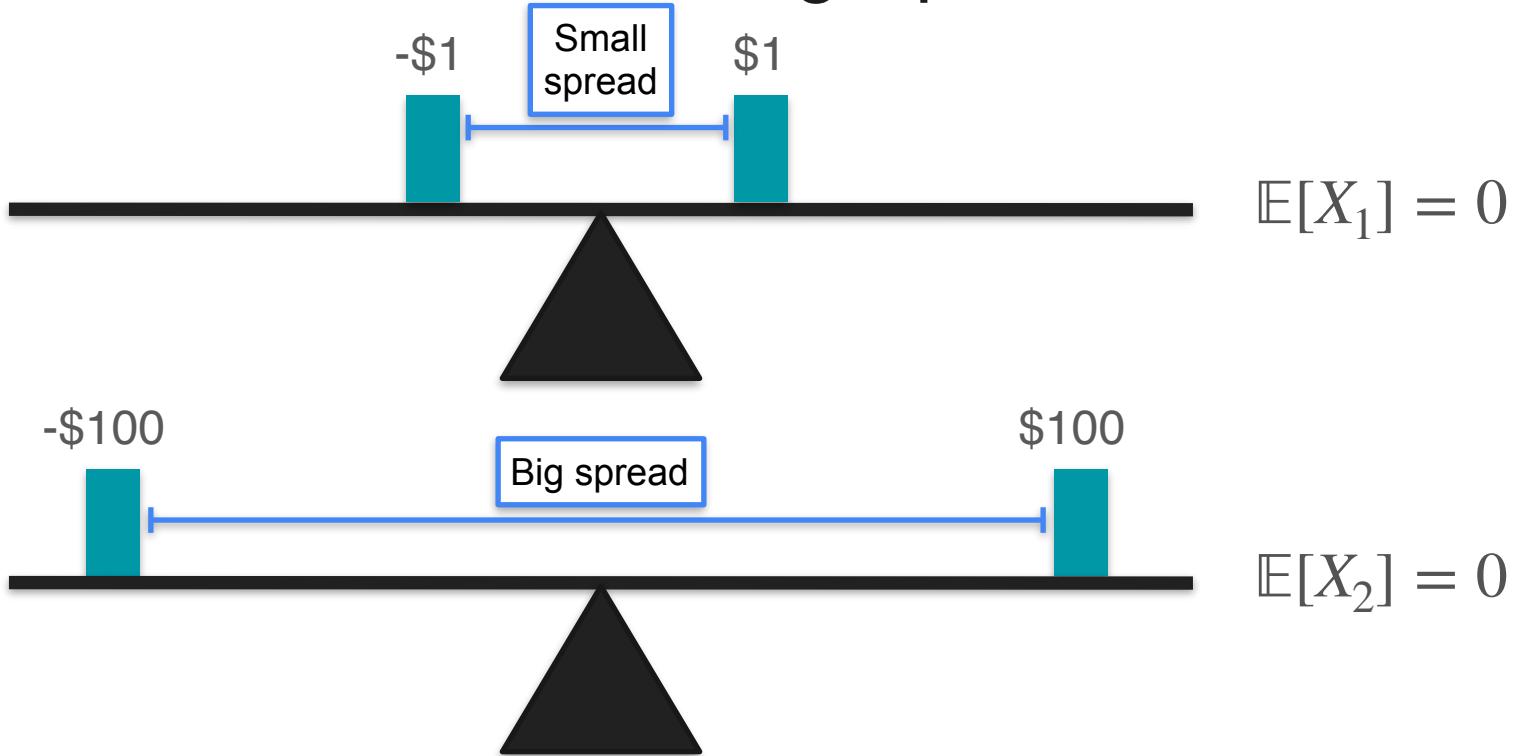
# Variance Motivation: Measuring Spread



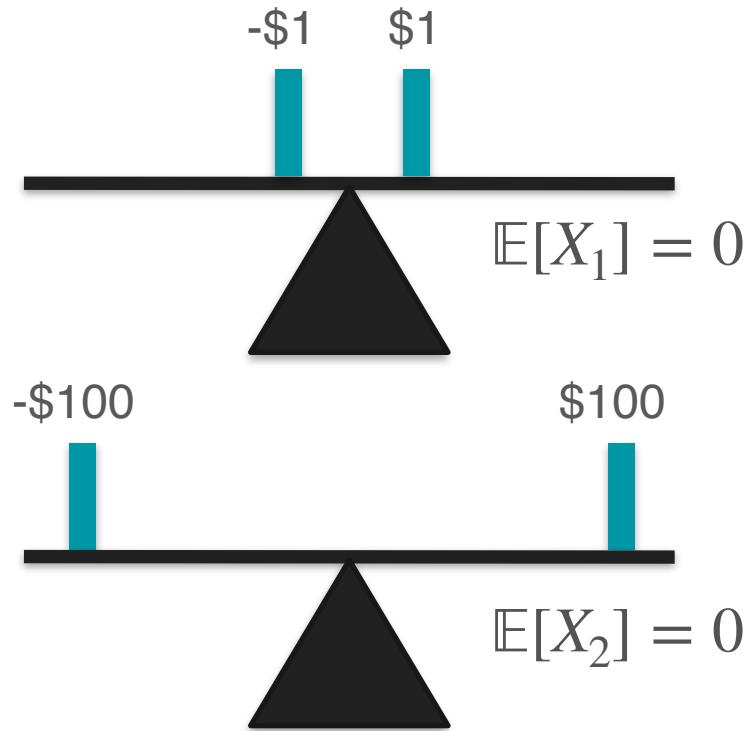
# Variance Motivation: Measuring Spread



# Variance Motivation: Measuring Spread



# Variance Motivation: Measuring Spread



# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1) + (-1)}{2} = 0$$



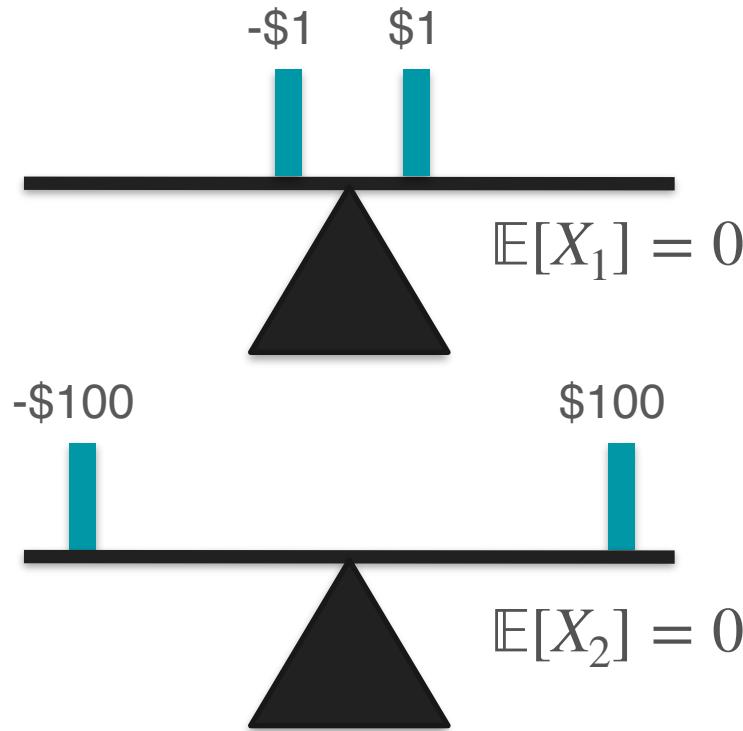
# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1) + (-1)}{2} = 0$$

$$\mathbb{E}[X_2] = \frac{(100) + (-100)}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1) + (-1)}{2} = 0$$

Turn into positive?

$$\mathbb{E}[X_2] = \frac{(100) + (-100)}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1)^2 + (-1)^2}{2} = 0$$

$$\mathbb{E}[X_2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1)^2 + (-1)^2}{2} = 0$$

$$\mathbb{E}[X_2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 0$$



$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$

$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

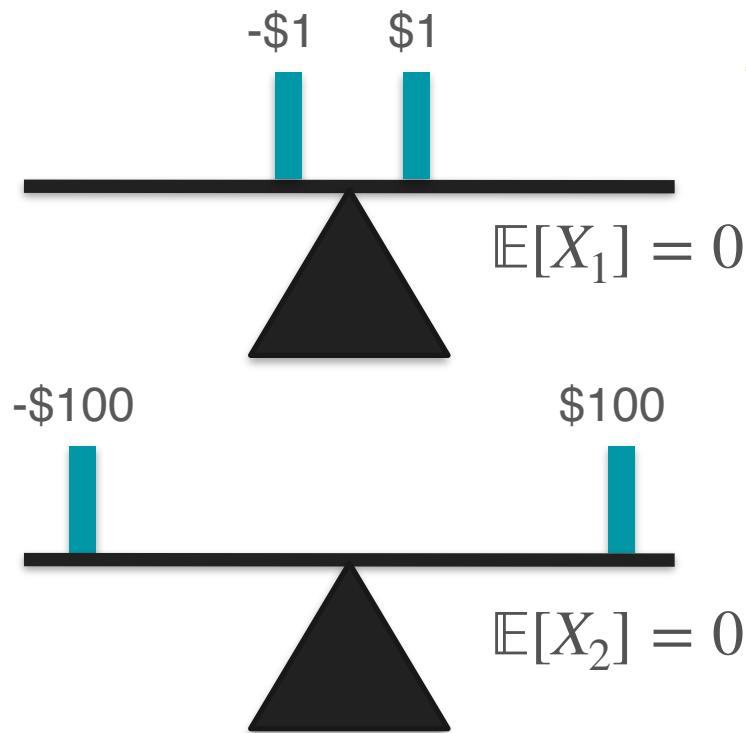
# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$

$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 10,000$$

# Variance Motivation: Measuring Spread

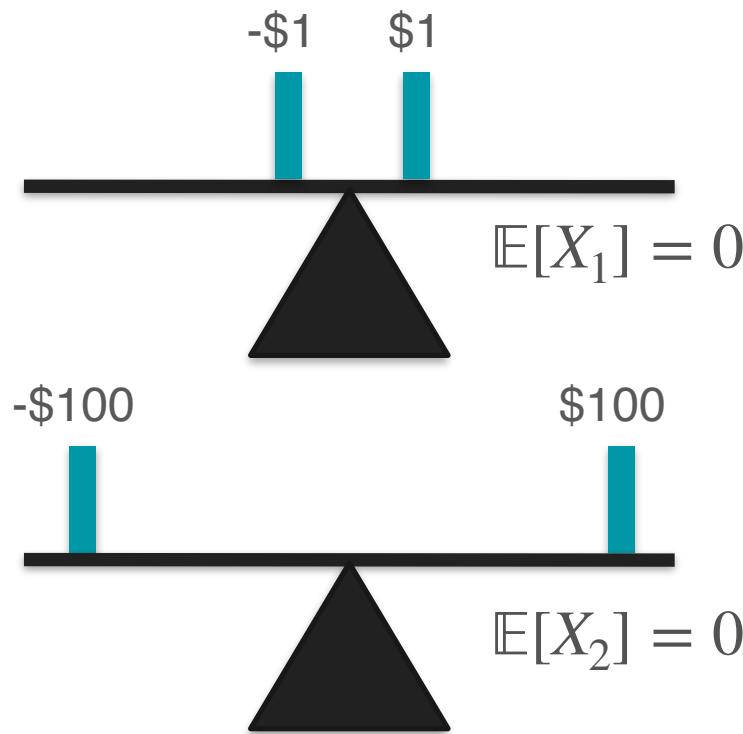


Key for telling game  
1 and game 2 apart!

$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$

$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 10,000$$

# Variance Motivation: Measuring Spread



Key for telling game  
1 and game 2 apart!

$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$

$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 10,000$$

Measure of spread

# Variance

$$\mathbb{E}[X^2]$$

# Variance

$$\mathbb{E}[X^2]$$

Almost...

# Variance Motivation: Centering With Mean

# Variance Motivation: Centering With Mean

## Game 1



You win 1 dollar



You lose 1 dollar

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

How risky are these two games in comparison?

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

How risky are these two games in comparison?

**Hint:** Think of the spread

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

They are equally risky

# Variance Motivation: Centering With Mean

## Game 1



You win 1 dollar



You lose 1 dollar

$$\mathbb{E}[X_1^2] = \frac{(-1)^2 + (1)^2}{2} = 1$$

## Game 2



You win 6 dollars



You win 4 dollars

$$\mathbb{E}[X_2^2] = \frac{(4)^2 + (6)^2}{2} = 26$$

# Variance Motivation: Centering With Mean

## Game 1



You win 1 dollar



You lose 1 dollar

$$\mathbb{E}[X_1^2] = \frac{(-1)^2 + (1)^2}{2} = 1$$



Same risk?



$$\mathbb{E}[X_2^2] = \frac{(4)^2 + (6)^2}{2} = 26$$

## Game 2



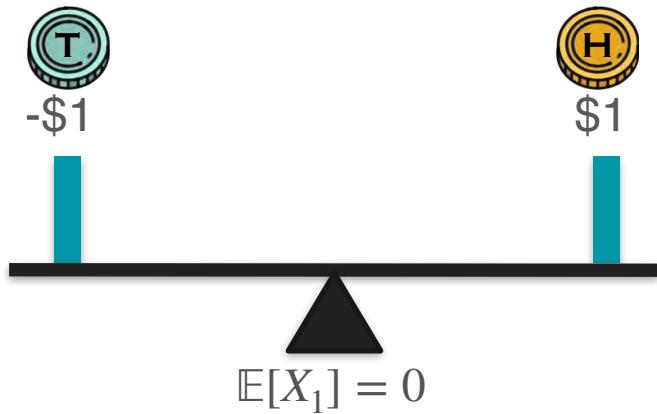
You win 6 dollars



You win 4 dollars

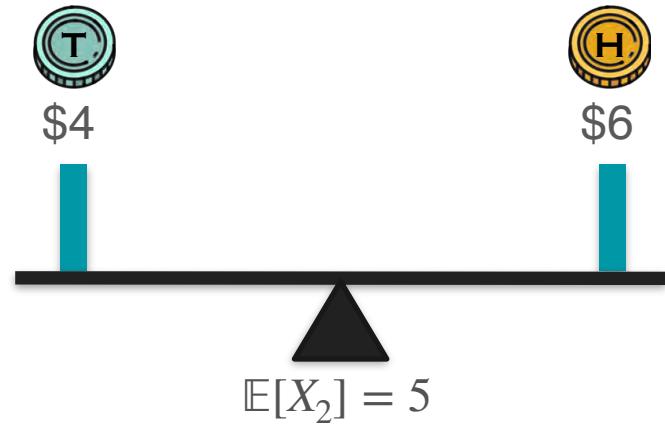
# Variance Motivation: Centering With Mean

$$\mathbb{E}[X_1^2] = \frac{(-1)^2 + (1)^2}{2} = 1$$



Game 1

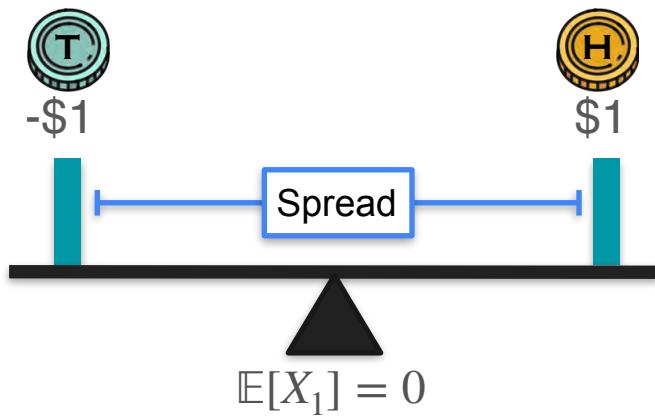
$$\mathbb{E}[X_2^2] = \frac{(4)^2 + (6)^2}{2} = 26$$



Game 2

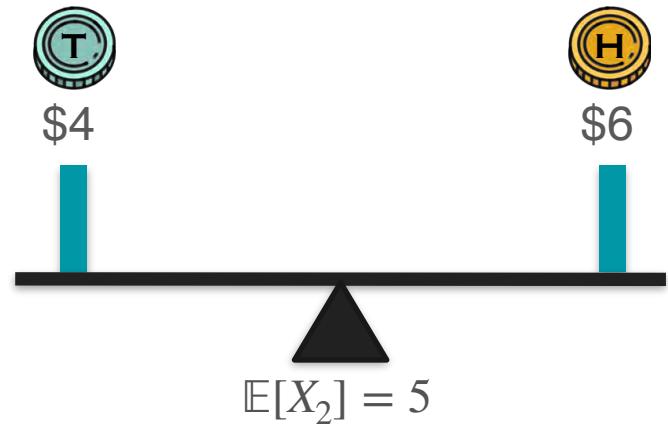
# Variance Motivation: Centering With Mean

$$\mathbb{E}[X_1^2] = \frac{(-1)^2 + (1)^2}{2} = 1$$



Game 1

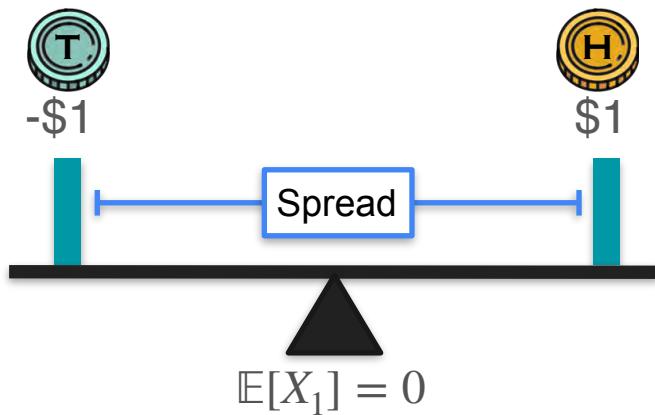
$$\mathbb{E}[X_2^2] = \frac{(4)^2 + (6)^2}{2} = 26$$



Game 2

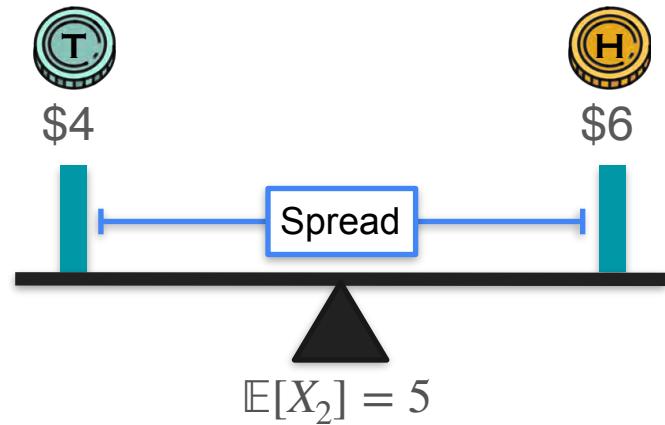
# Variance Motivation: Centering With Mean

$$\mathbb{E}[X_1^2] = \frac{(-1)^2 + (1)^2}{2} = 1$$



Game 1

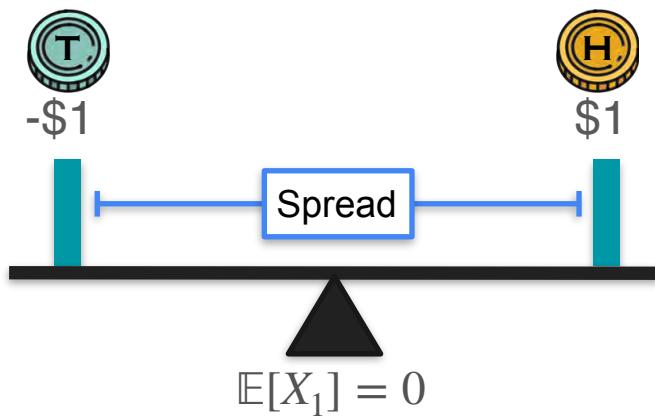
$$\mathbb{E}[X_2^2] = \frac{(4)^2 + (6)^2}{2} = 26$$



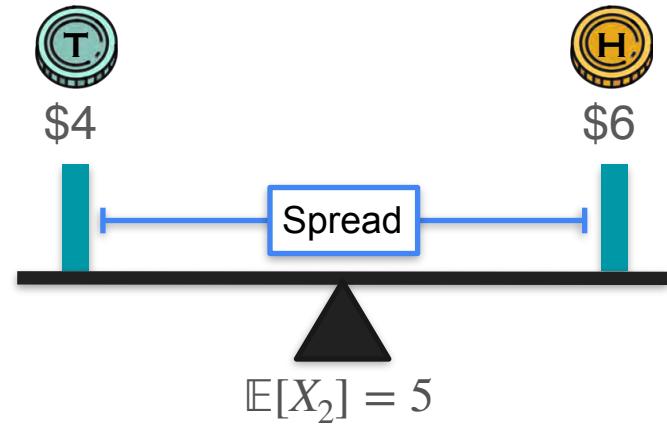
Game 2

# Variance Motivation: Centering With Mean

$$\mathbb{E}[X_1^2] = \frac{(-1)^2 + (1)^2}{2} = 1 \quad \leftarrow \text{Same spread?} \rightarrow \quad \mathbb{E}[X_2^2] = \frac{(4)^2 + (6)^2}{2} = 26$$



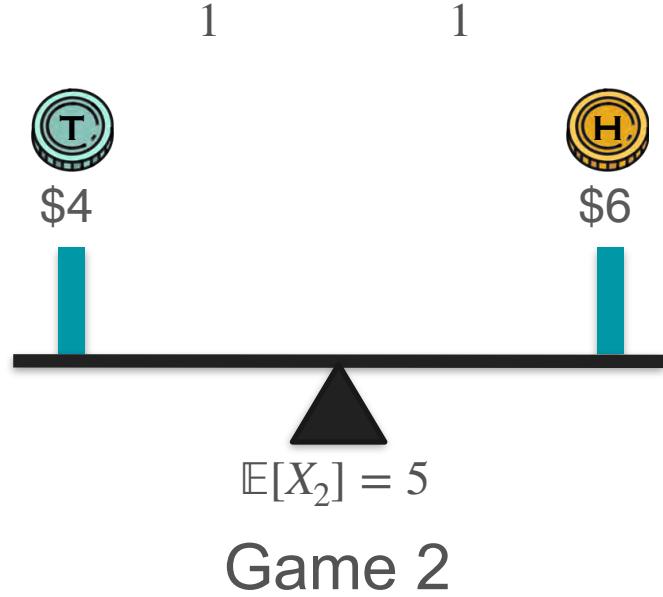
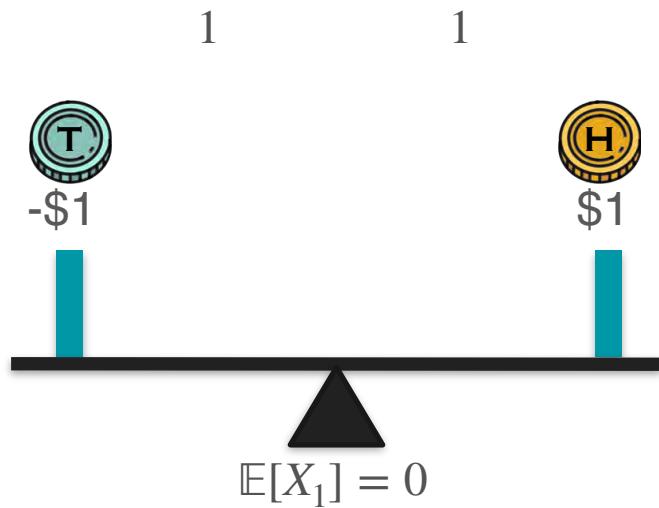
Game 1



Game 2

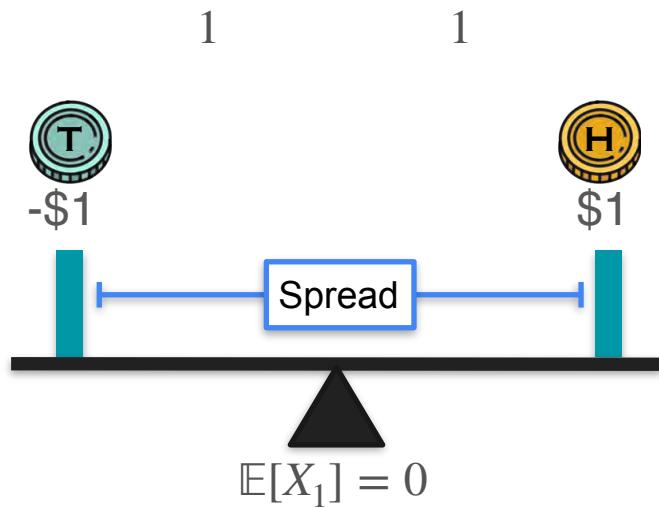
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$$\mathbb{E}[X_1^2] = 1$$

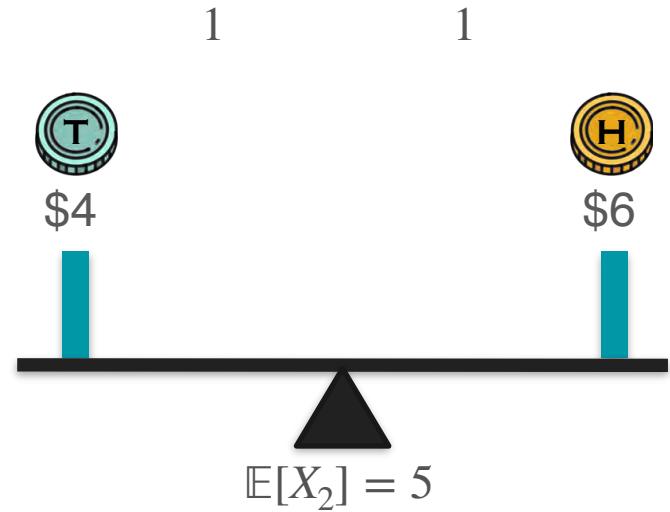


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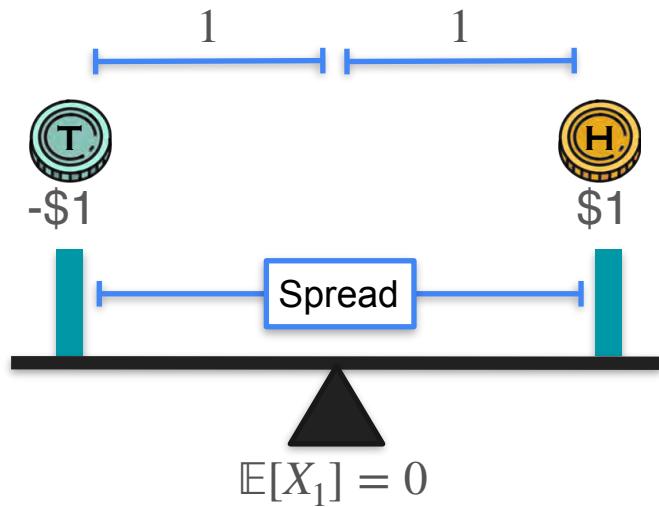
Game 1



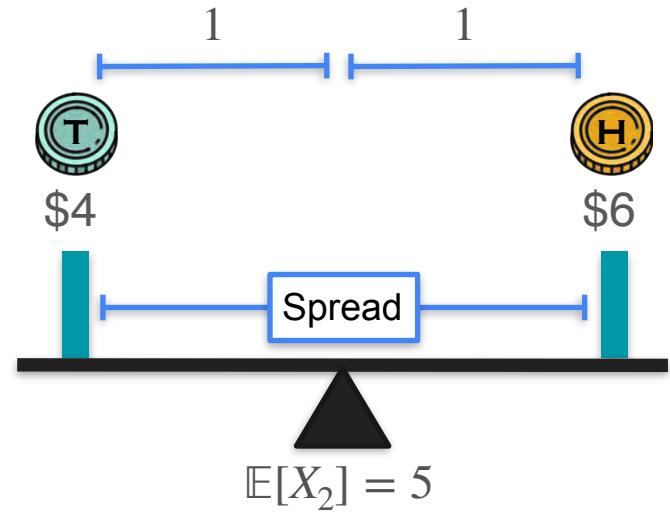
Game 2

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$$\mathbb{E}[X_1^2] = 1$$



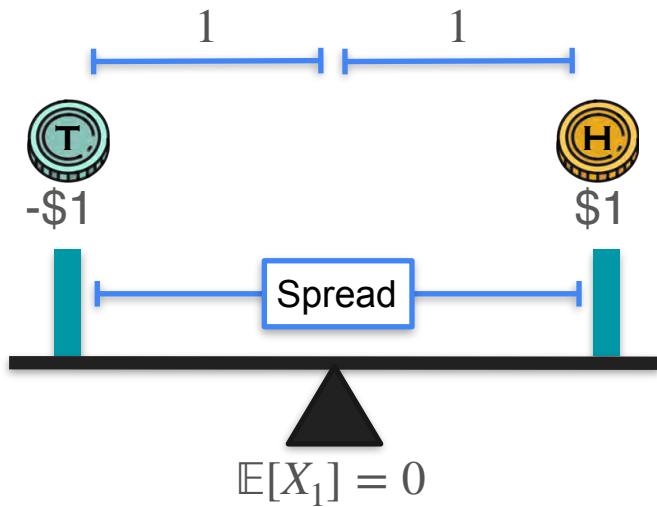
Game 1



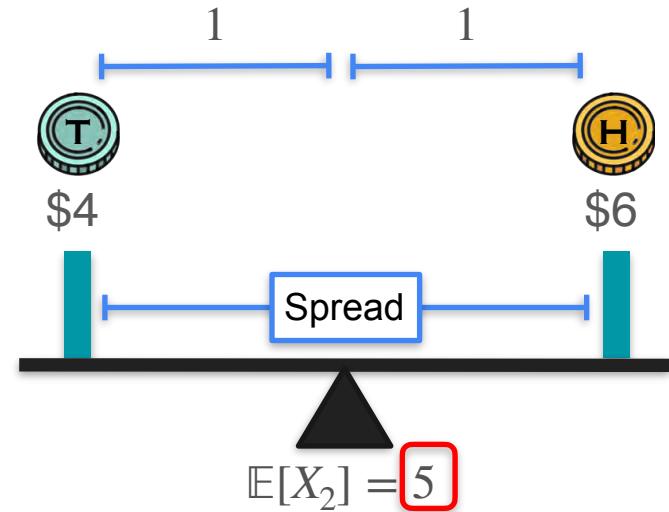
Game 2

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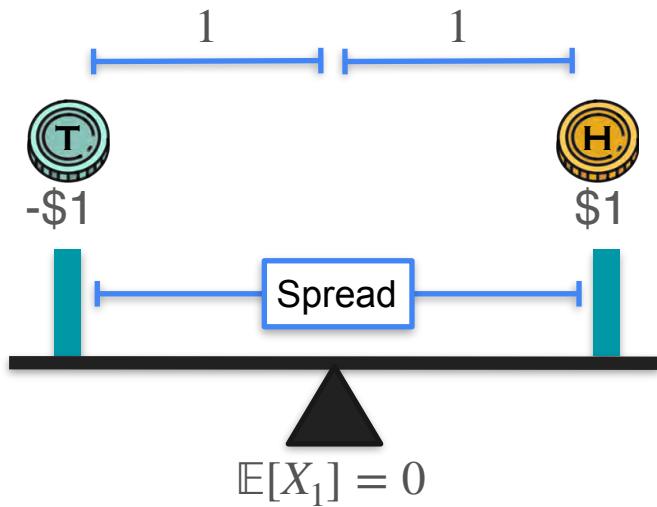
Game 1



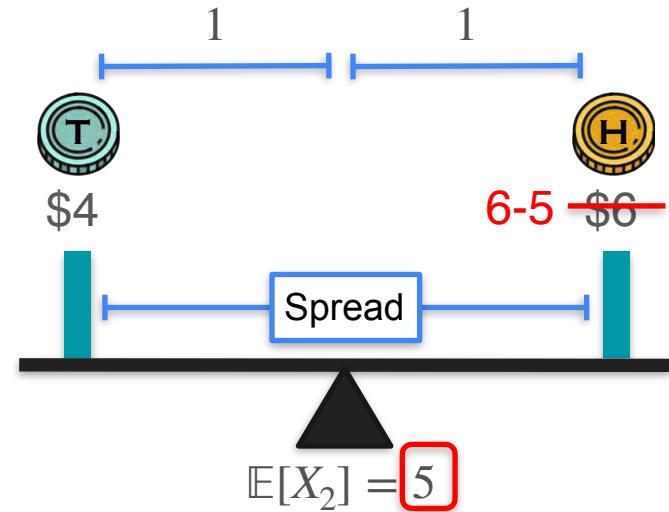
Game 2

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$$\mathbb{E}[X_1^2] = 1$$



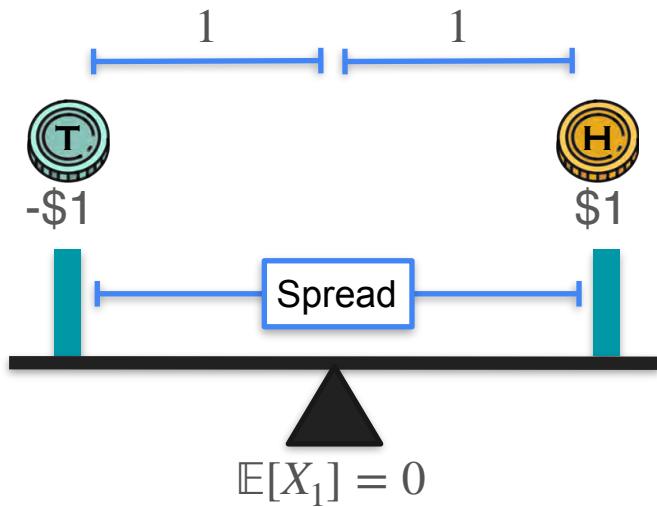
Game 1



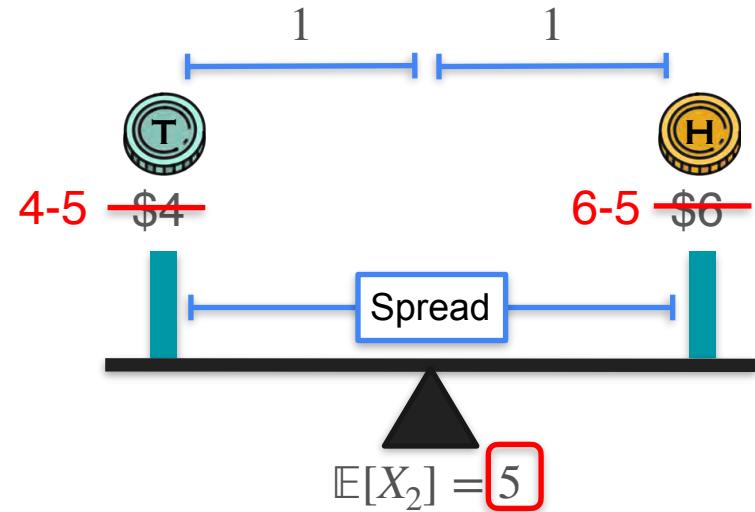
Game 2

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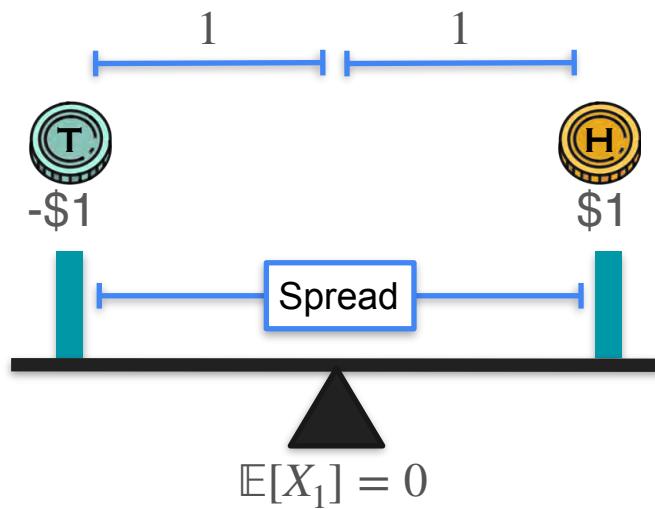
Game 1



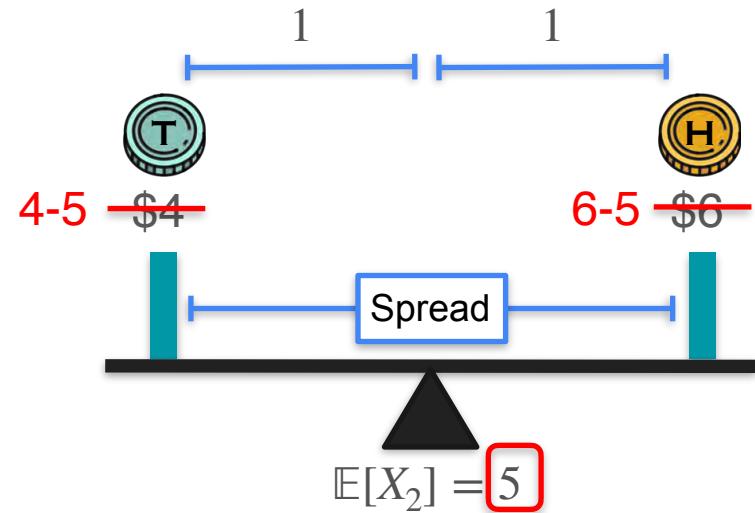
Game 2

# Variance: Spread and Shift

$$\mathbb{E}[X_1^2] = 1$$

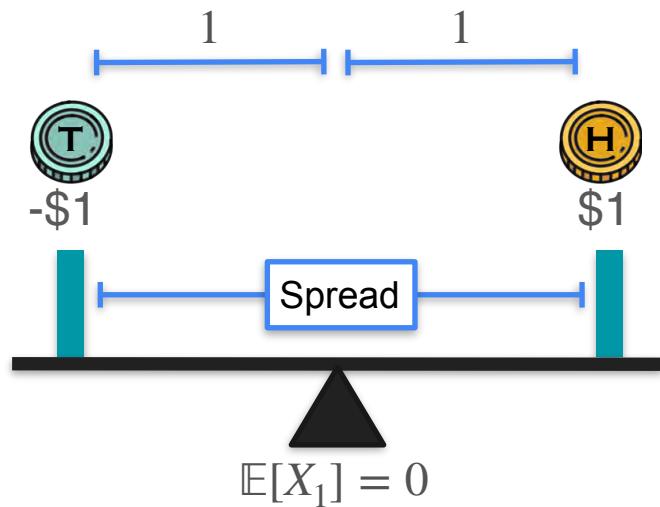


$$\mathbb{E}[(X_2 - 5)^2]$$



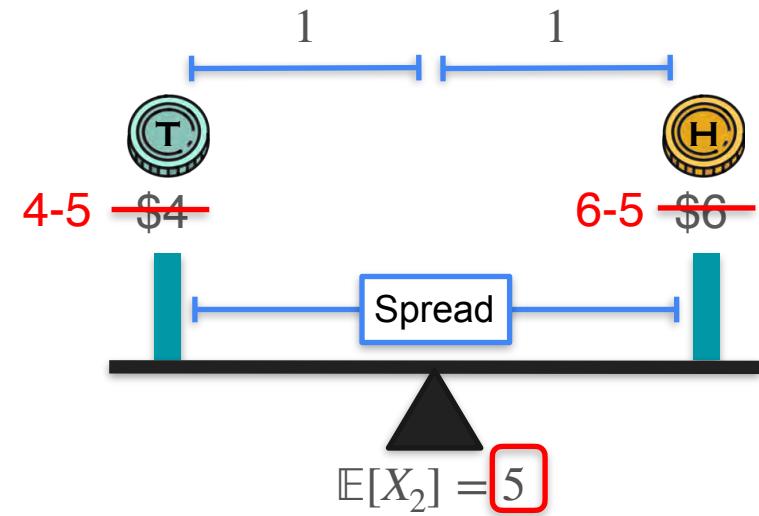
# Variance: Spread and Shift

$$\mathbb{E}[X_1^2] = 1$$



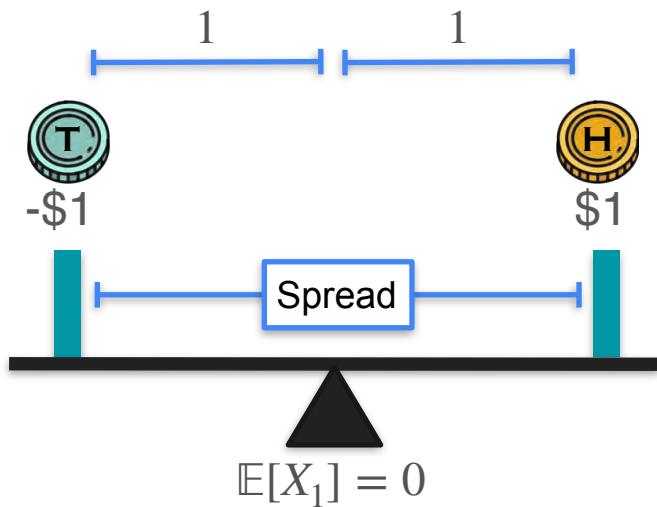
$$\text{Mean: } \mu$$

$$\mathbb{E}[(X_2 - 5)^2]$$



# Variance: Spread and Shift

$$\mathbb{E}[X_1^2] = 1$$

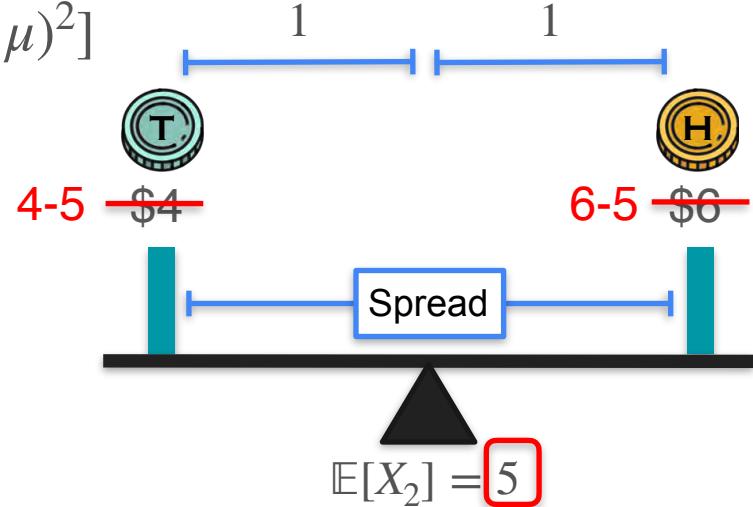


Game 1

Mean:  $\mu$

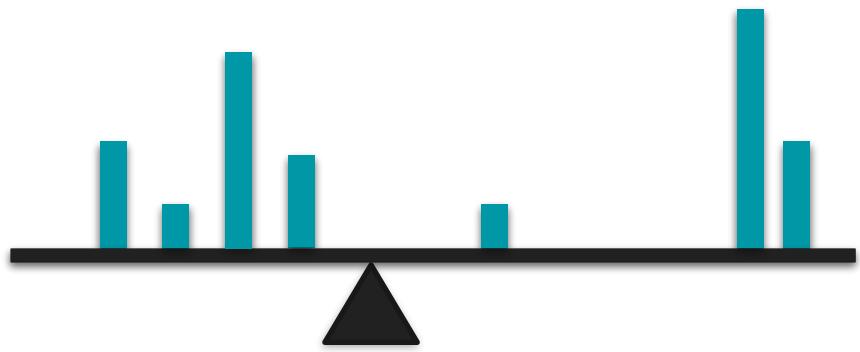
$$\text{Variance: } \mathbb{E}[(X - \mu)^2]$$

$$\mathbb{E}[(X_2 - 5)^2]$$

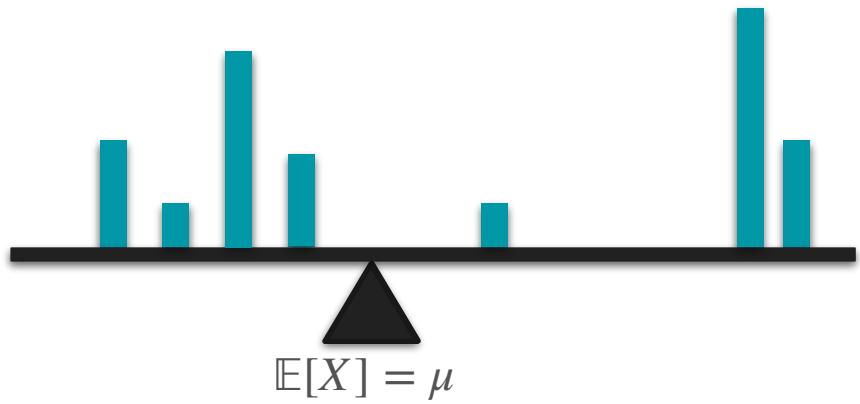


Game 2

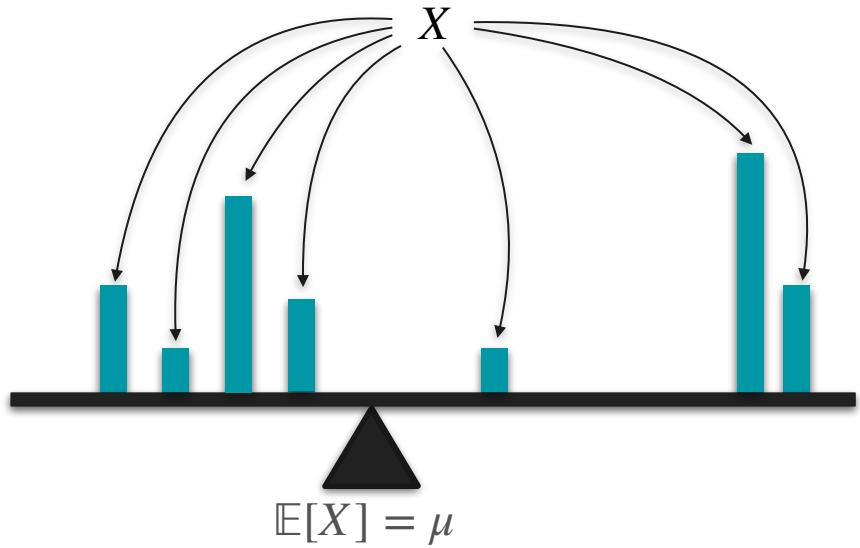
# Variance Formula



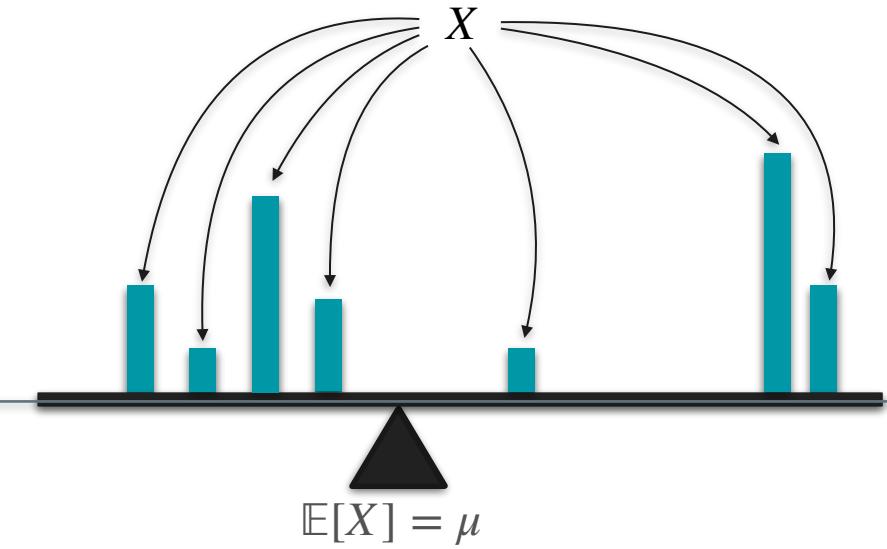
# Variance Formula



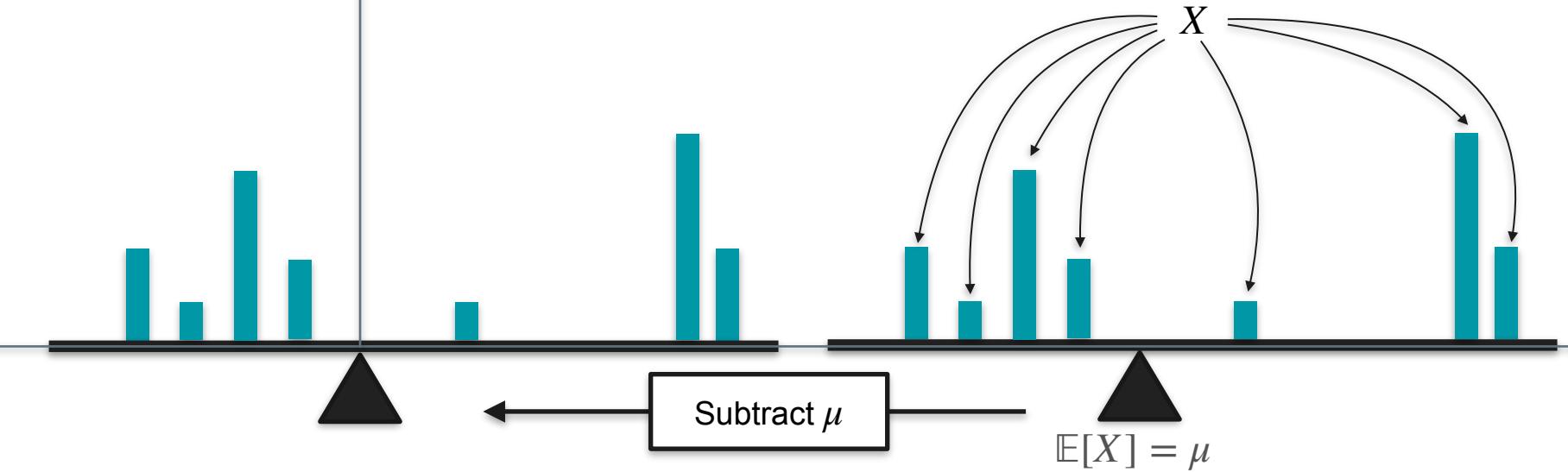
# Variance Formula



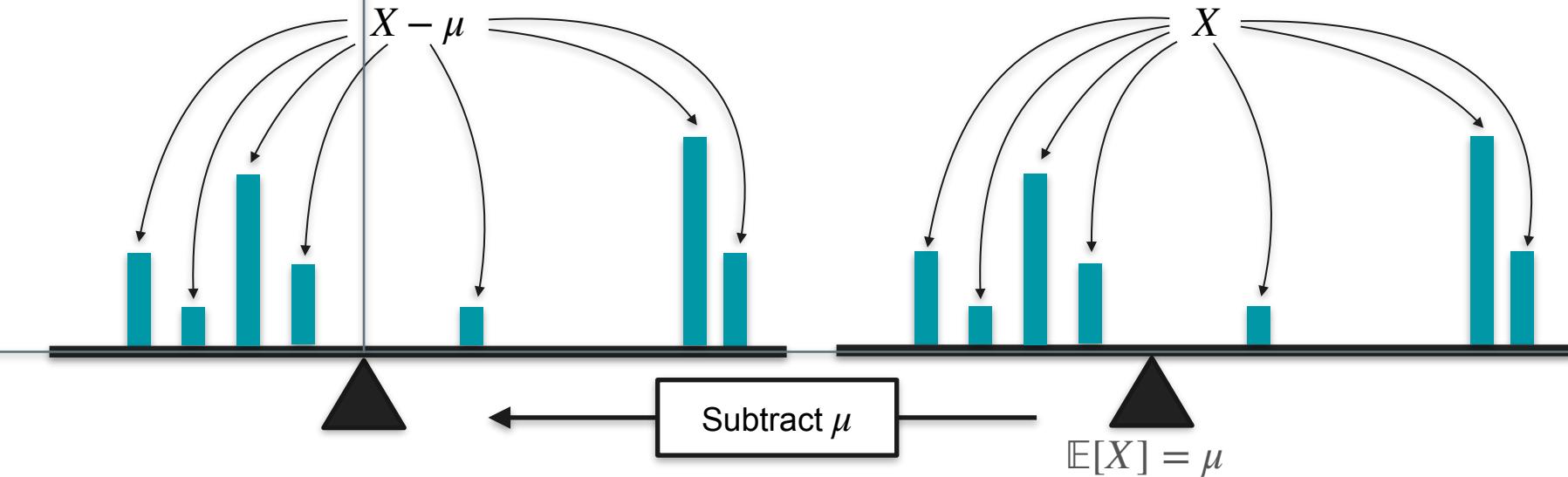
# Variance Formula



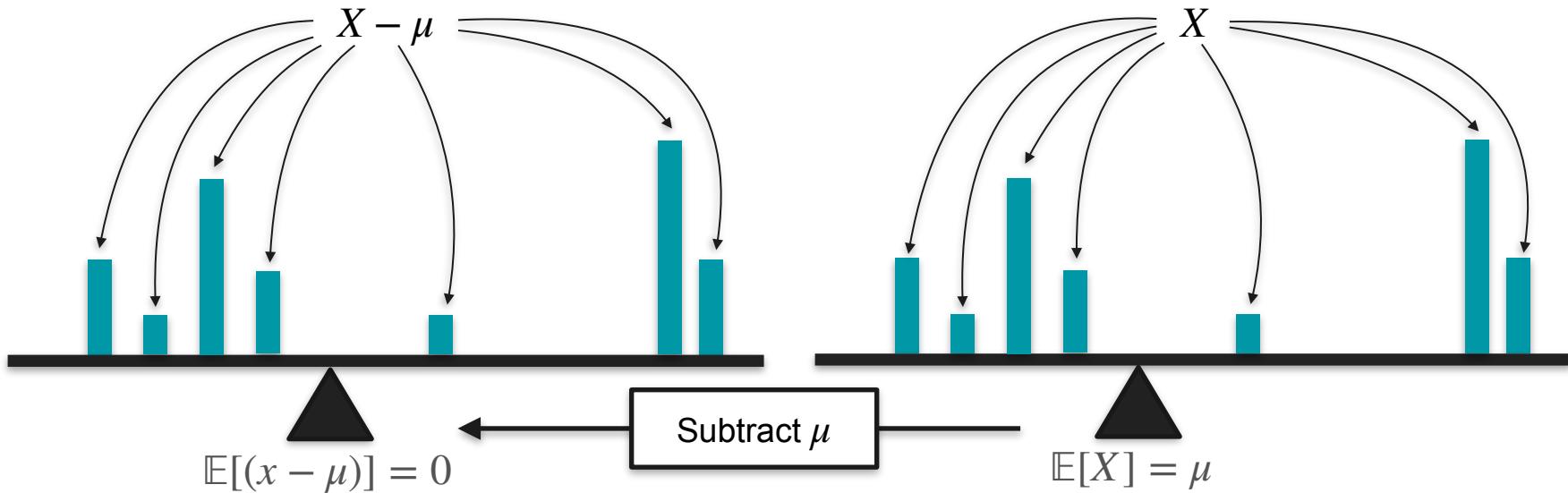
# Variance Formula



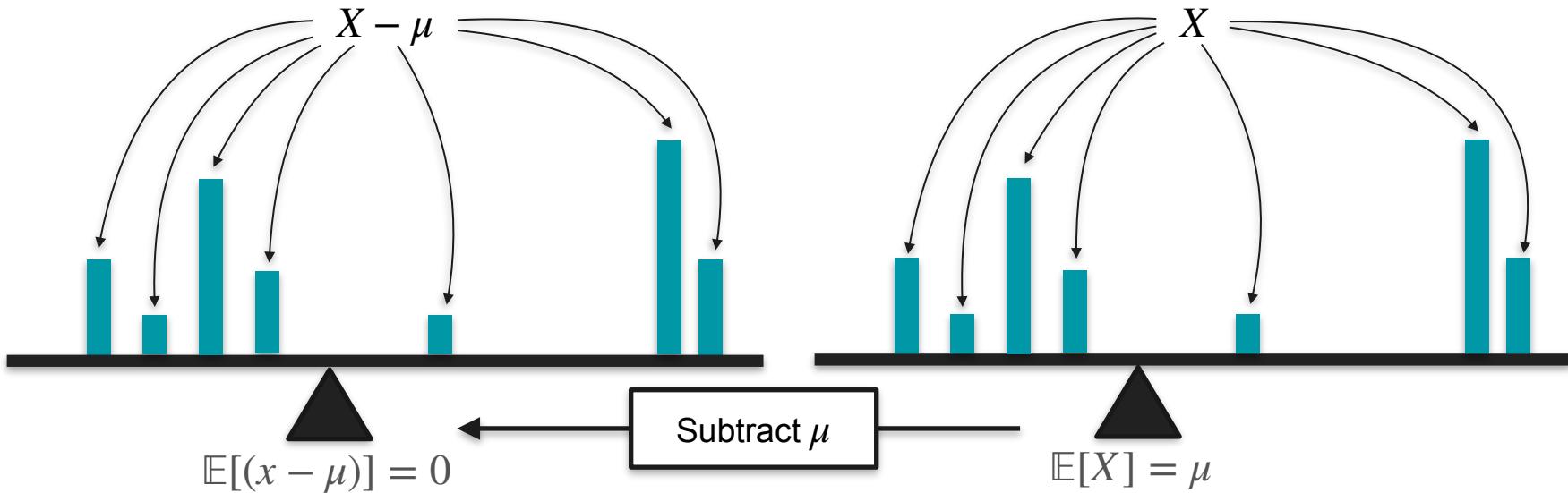
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# Variance Formula



$$Var(X) = \mathbb{E}[(X - \mu)^2]$$

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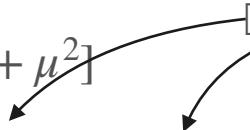
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$$\mathbb{E}[X + Y] = \mathbb{E}[X] + \mathbb{E}[Y]$$

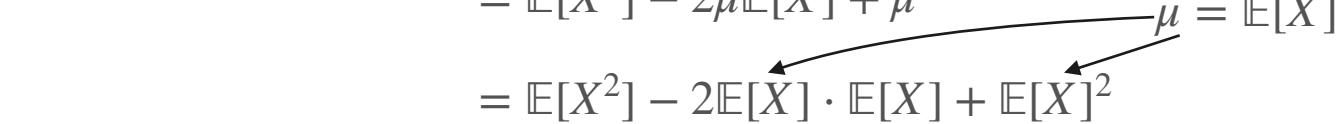
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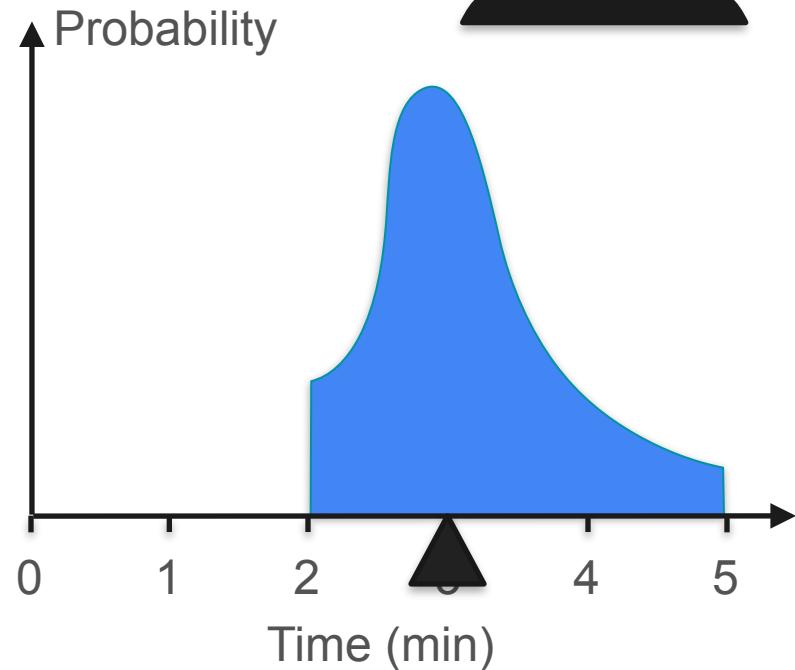
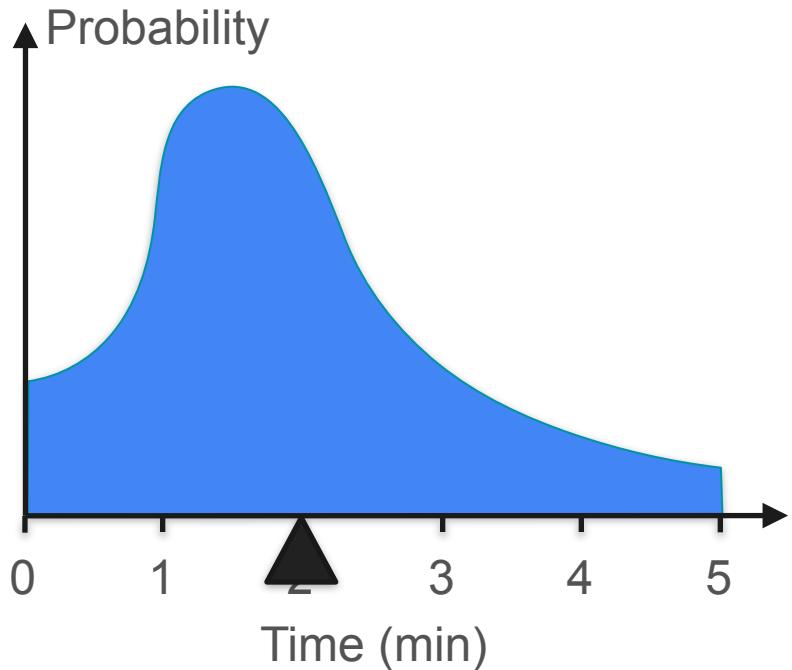
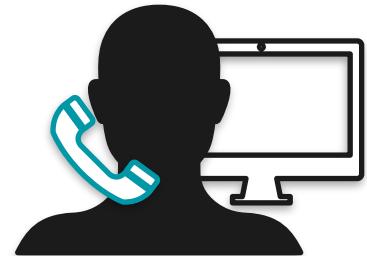
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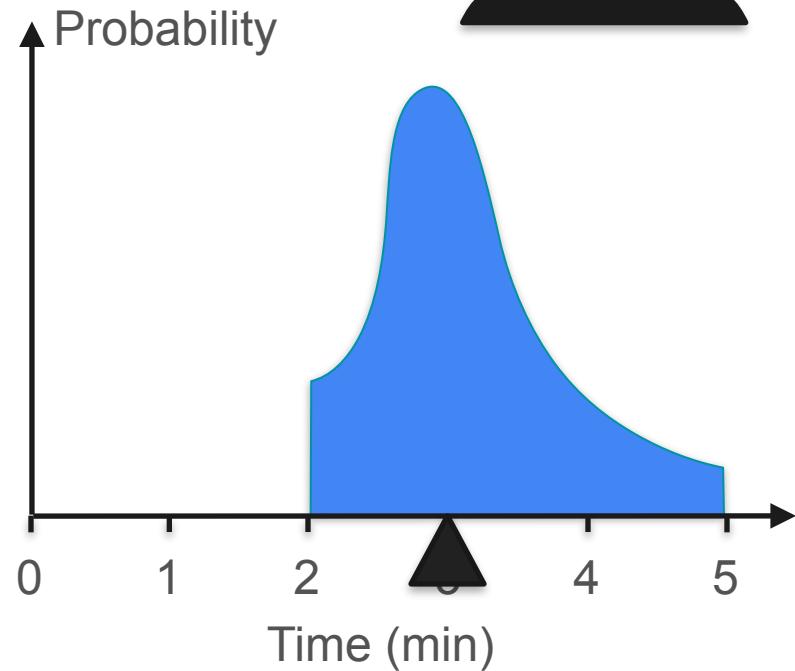
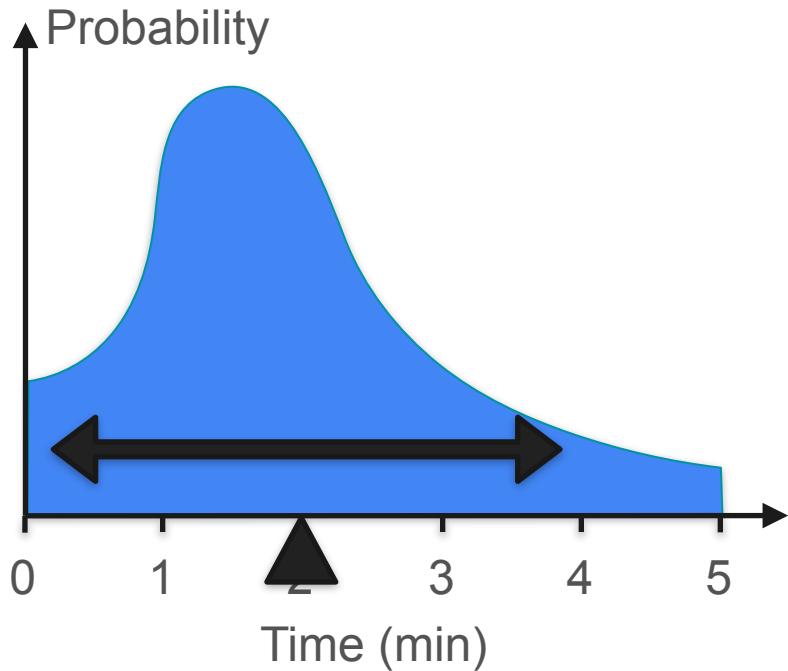
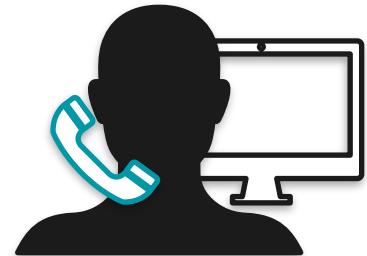
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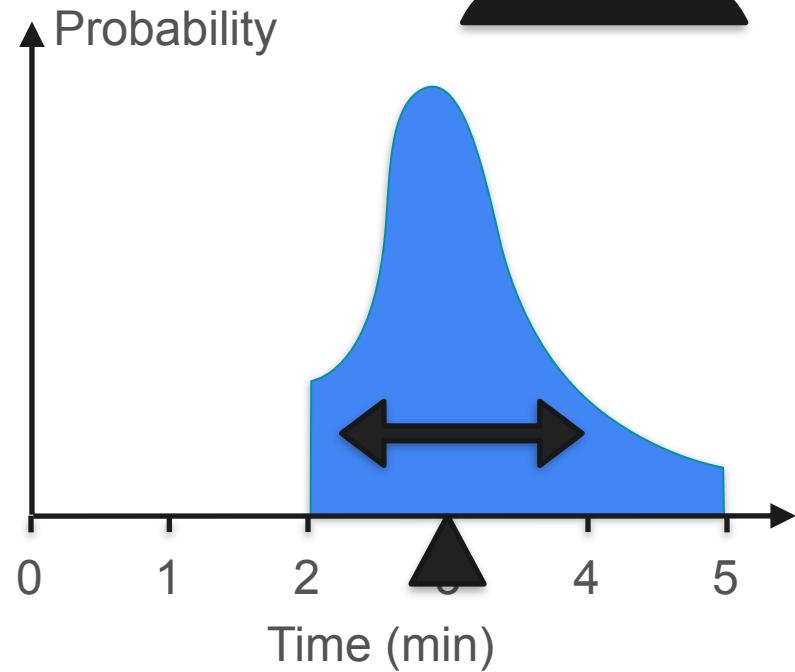
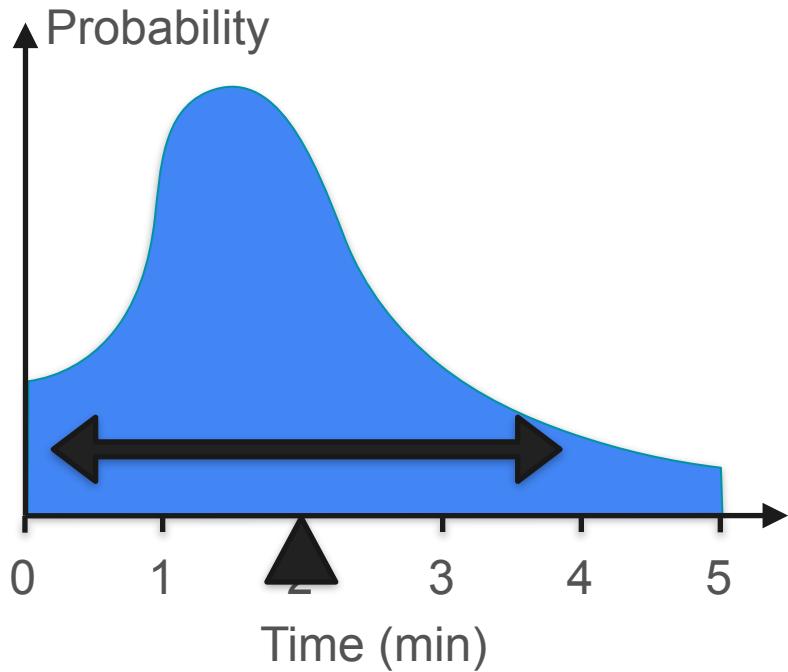
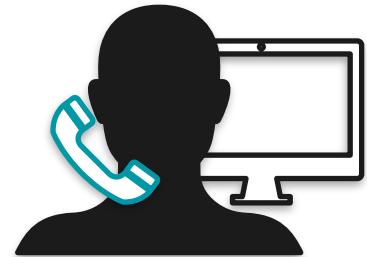
# Variance for Continuous Distributions



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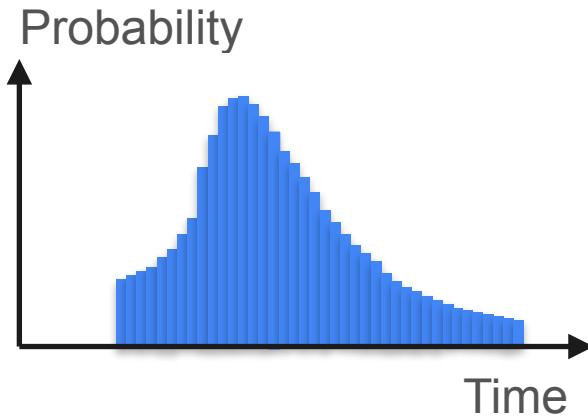


# Variance for Continuous Distributions



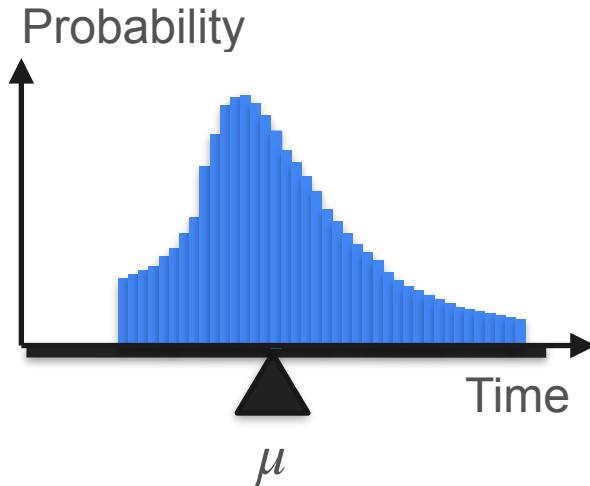
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$$\text{Var}(X) = \mathbb{E}[(X - \mu)^2] = \mathbb{E}[X^2] - \mathbb{E}[X]^2$$



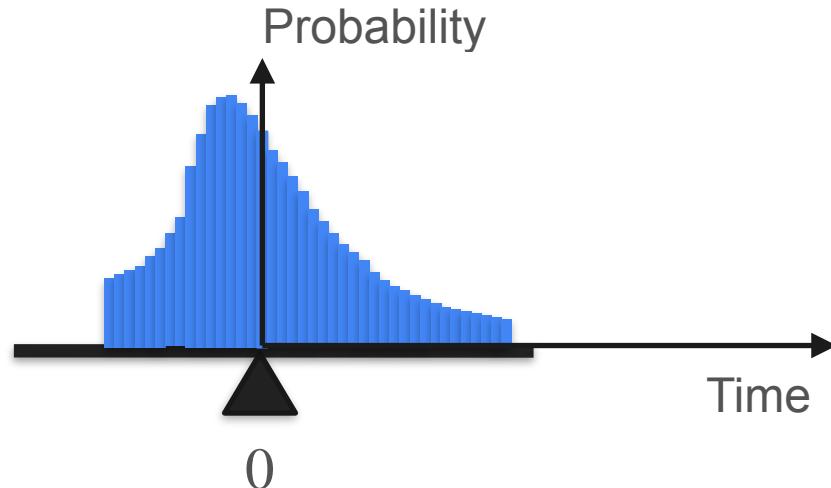
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DeepLearning.AI

# Describing Distributions

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**Measures of  
Central Tendency**

# Mean: Example

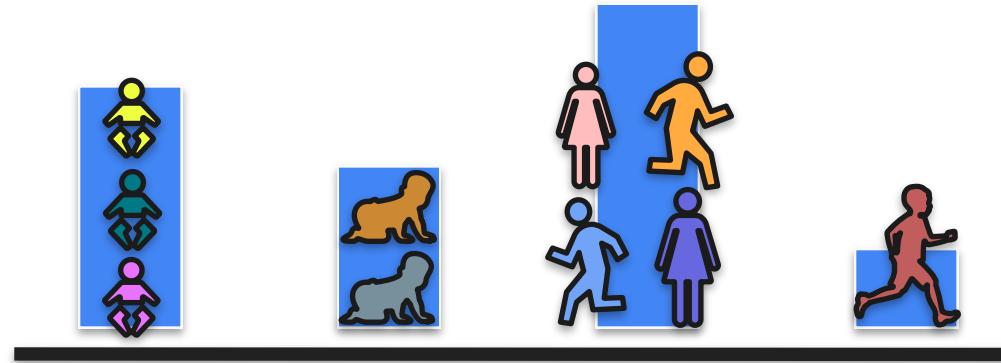
Age:

0

1

2

3



# Mean: Example

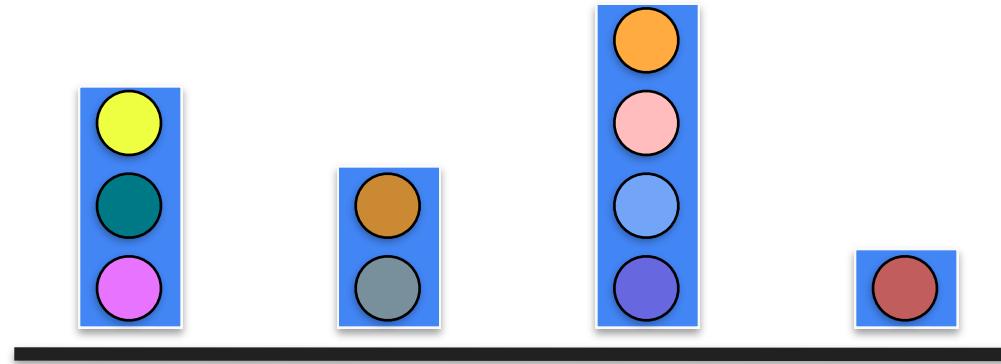
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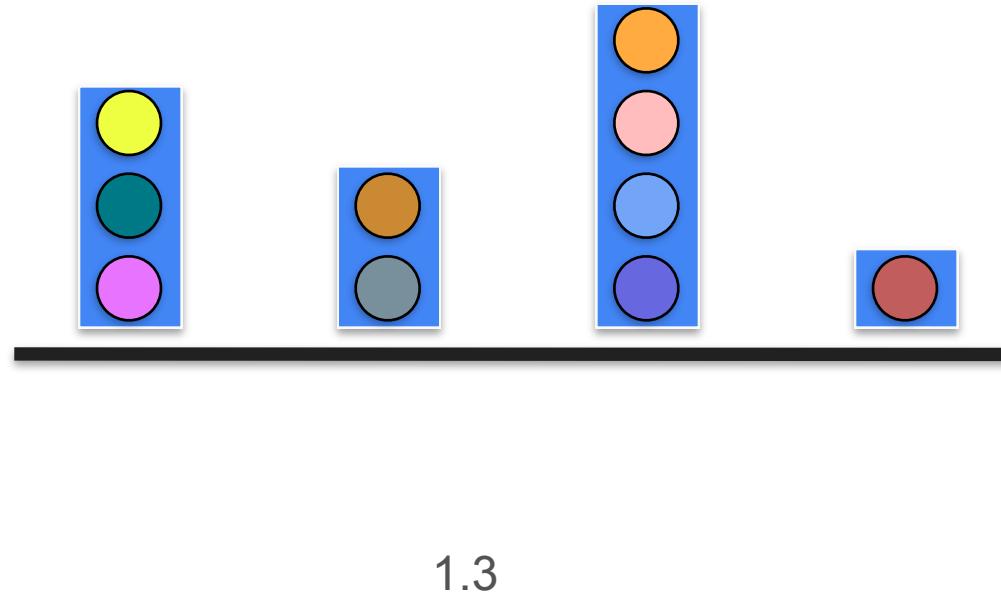
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0

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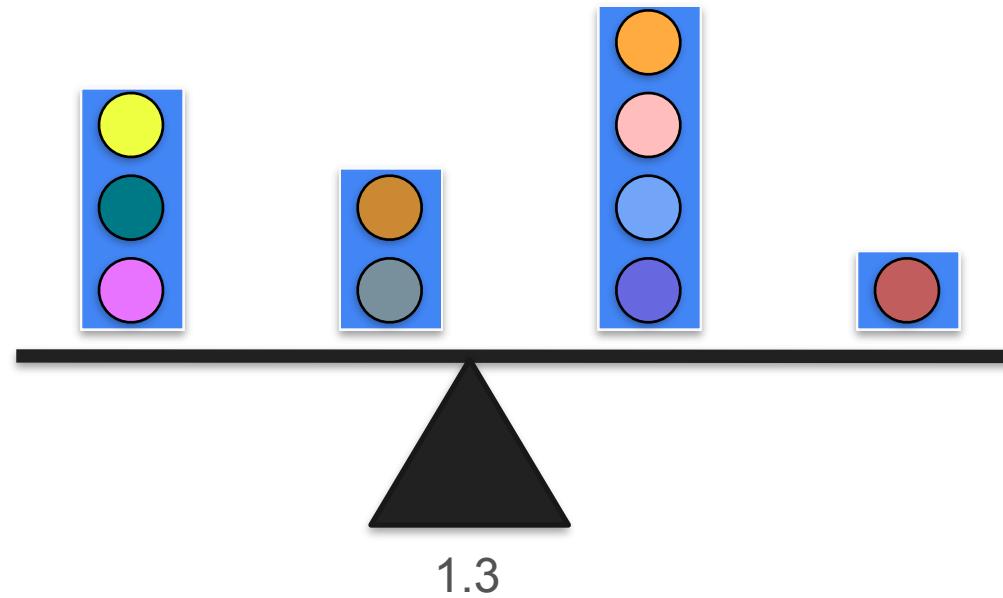
Age:

0

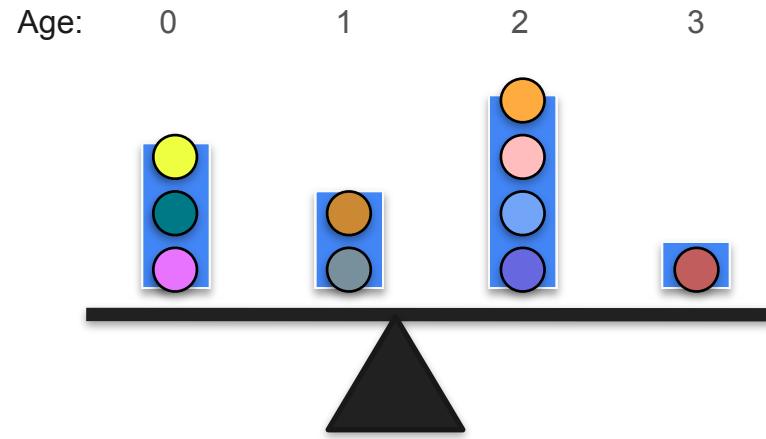
1

2

3

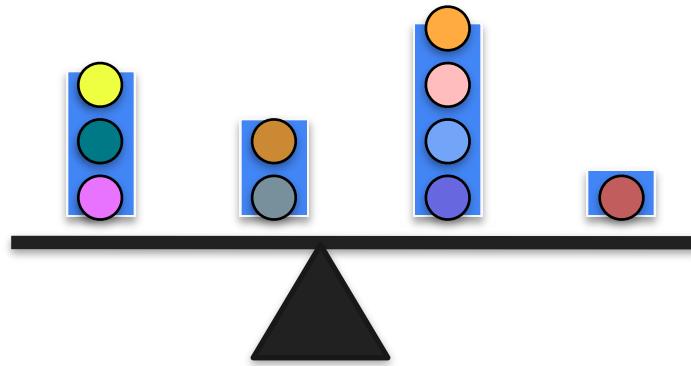


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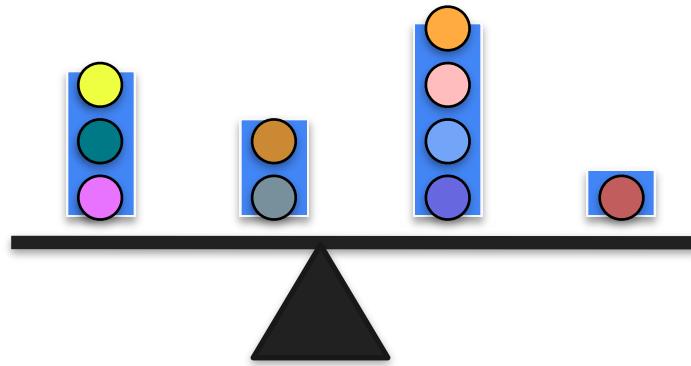
Age: 0      1      2      3       $0 + 0 + 0$



# Mean: Example

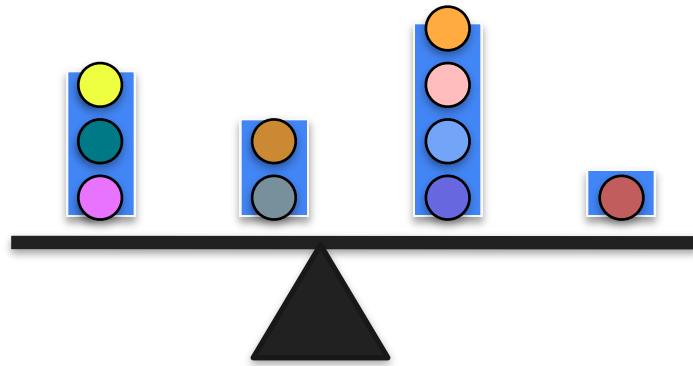
Age: 0 1 2 3

$0 + 0 + 0 + 1 + 1$



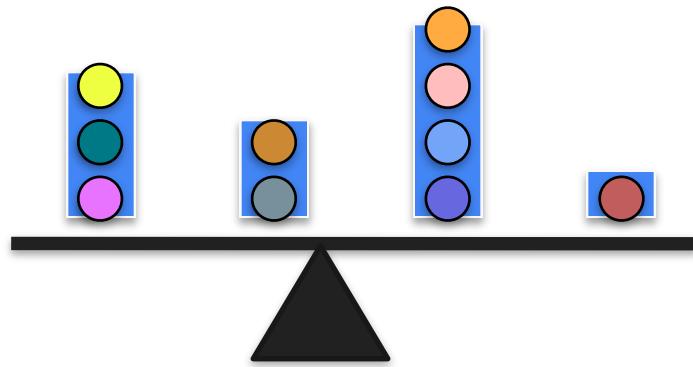
# Mean: Example

Age: 0 1 2 3       $0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 2$



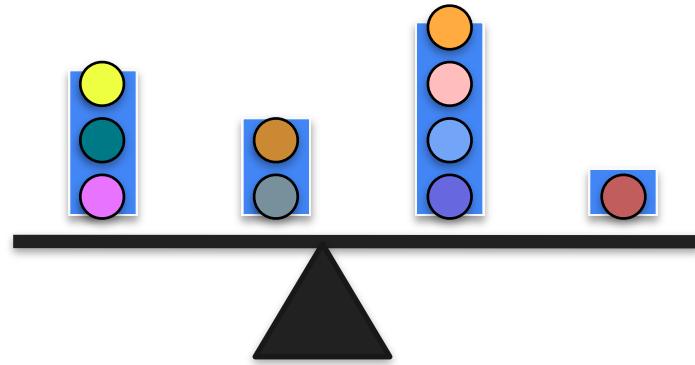
# Mean: Example

Age: 0      1      2      3       $0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 2 + 3$



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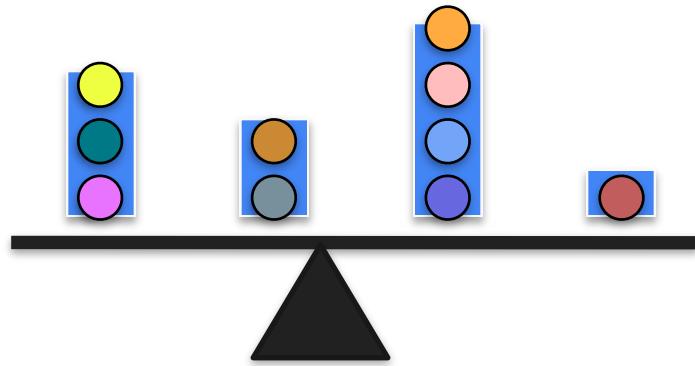
Age: 0      1      2      3



$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

# Mean: Example

Age: 0      1      2      3

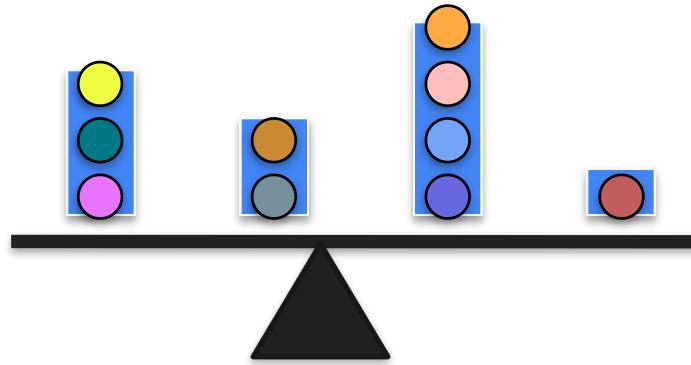


$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

$$= \frac{13}{10}$$

# Mean: Example

Age: 0      1      2      3



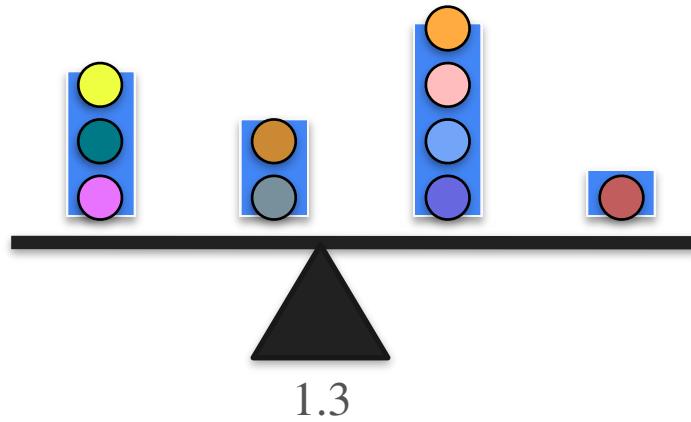
$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

$$= \frac{13}{10}$$

$$= 1.3$$

# Mean: Example

Age: 0      1      2      3

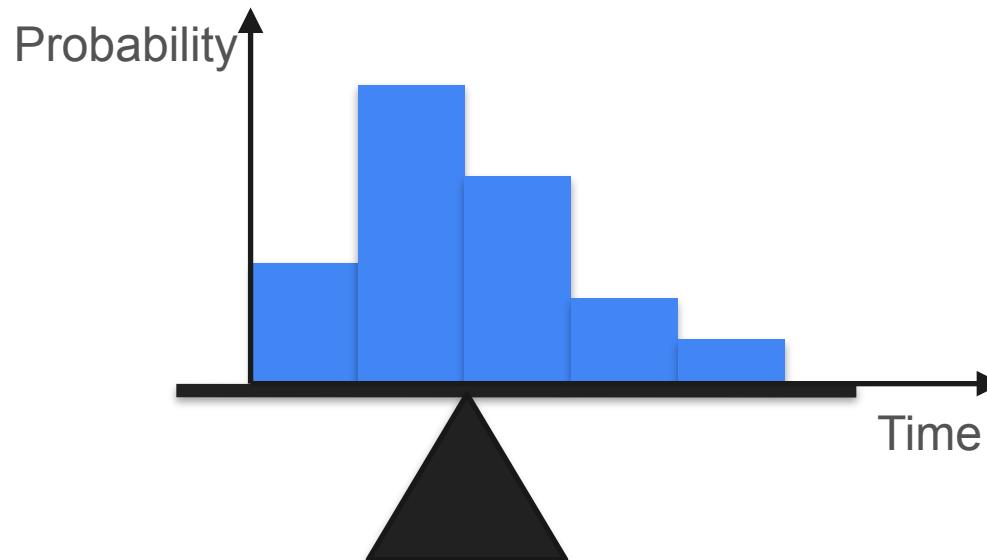
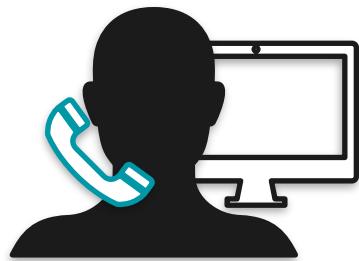


$$\begin{array}{r} 0 + 0 + 0 + 1 + 1 + 2 + 2 + 2 + 3 \\ \hline 10 \end{array}$$

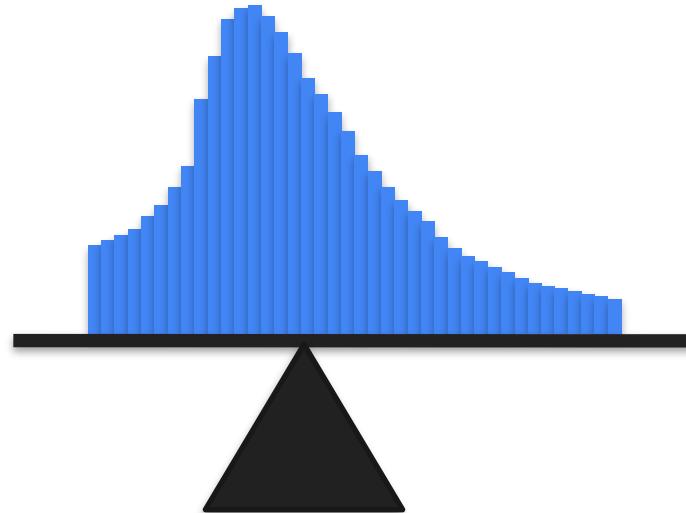
$$= \frac{13}{10}$$

$$= 1.3$$

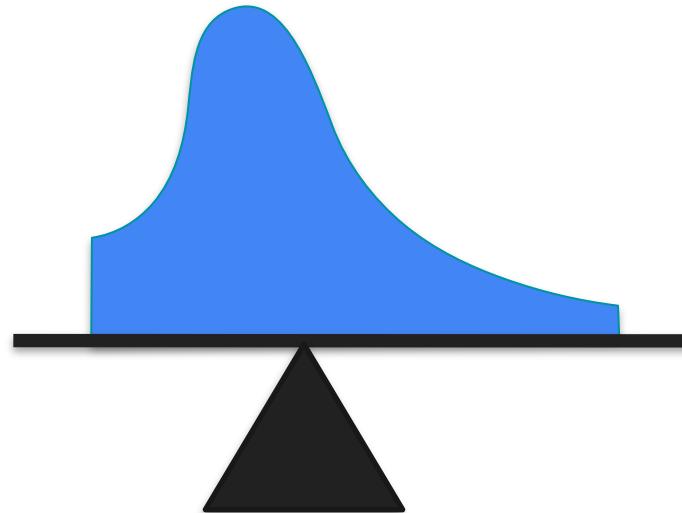
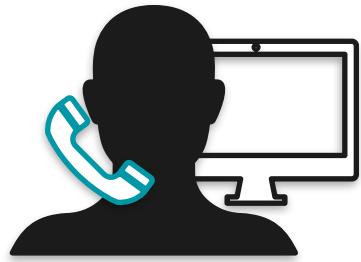
# Mean



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# Median: Motivation

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- Why?
  1. The program was really good
  2. The university had great connections

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- In the 1980s, the starting salary for a geography graduate at the University of North Carolina was \$250,000.
- For the rest of the country, the starting salary for a geography graduate was \$22,000.
- Why?
  1. The program was really good
  2. The university had great connections
  3. One student made lots of money

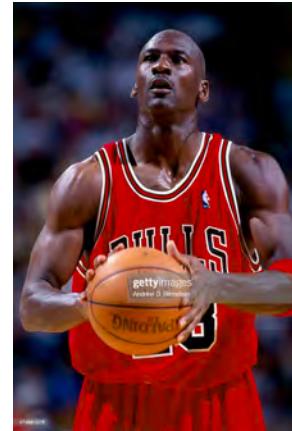
# Median: Motivation

- In the 1980s, the starting salary for a geography graduate at the University of North Carolina was \$250,000.
- For the rest of the country, the starting salary for a geography graduate was \$22,000.
- Why?
  1. The program was really good
  2. The university had great connections
  3. One student made lots of money



# Median: Motivation

- In the 1980s, the starting salary for a geography graduate at the University of North Carolina was \$250,000.
  - For the rest of the country, the starting salary for a geography graduate was \$22,000.
  - Why?
    1. The program was really good
    2. The university had great connections
    3. One student made lots of money
- 



Michael Jordan

# Outliers

# Outliers

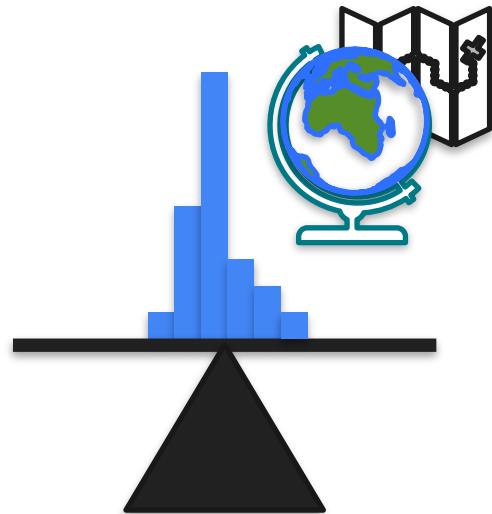


# Outliers



# Outliers

Graduates



Salary

# Outliers

Graduates



# Outliers

Graduates



# Outliers

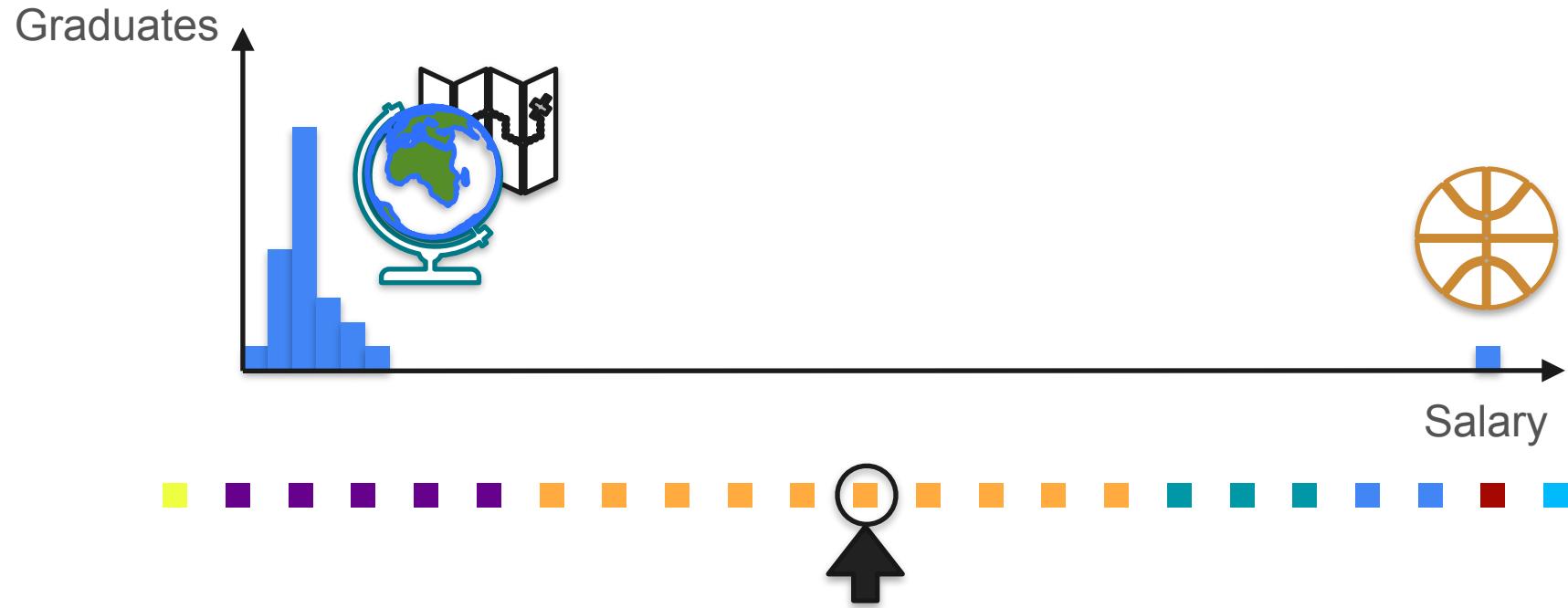


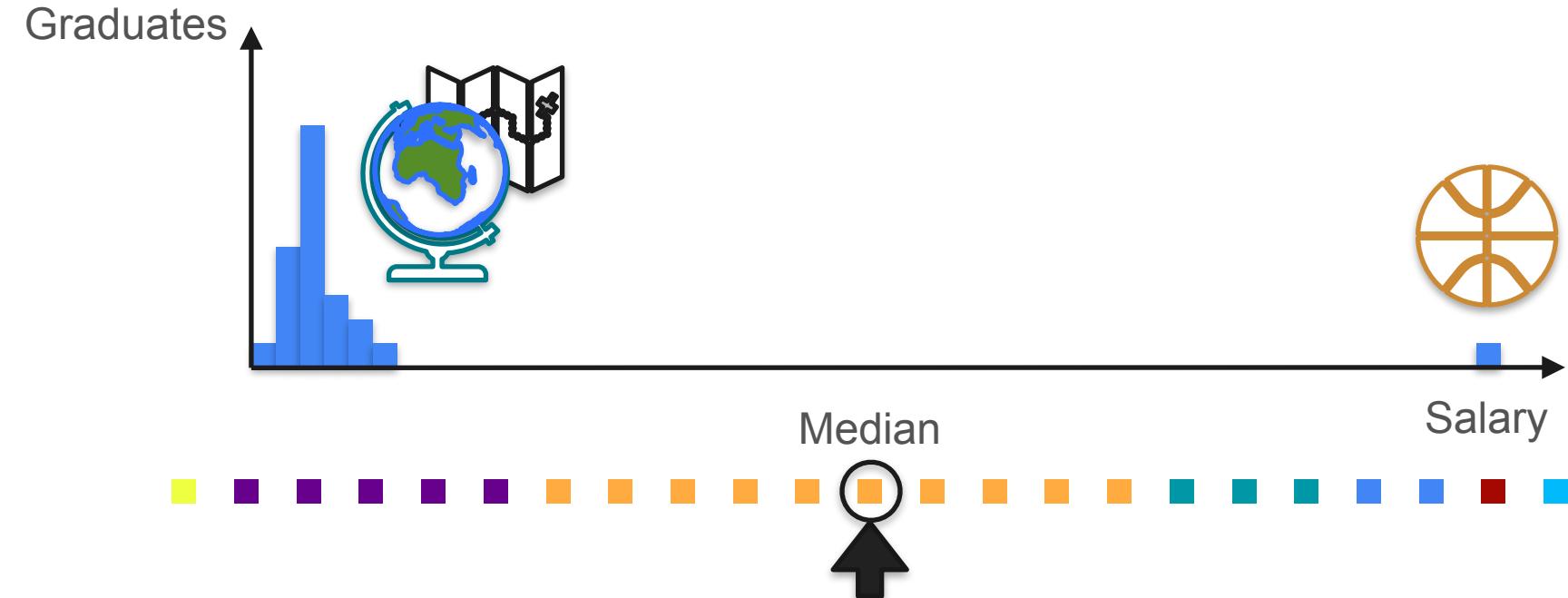
# Median

Graduates



# Median





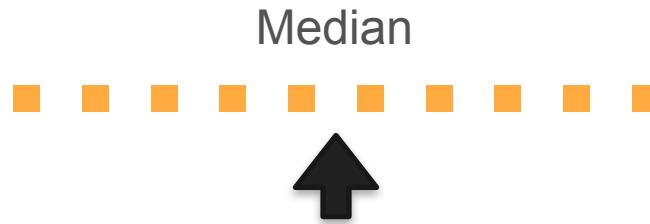
# Median



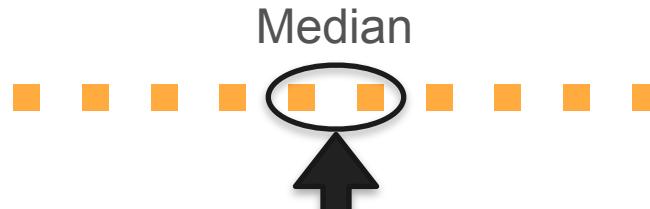
# Median



# Median

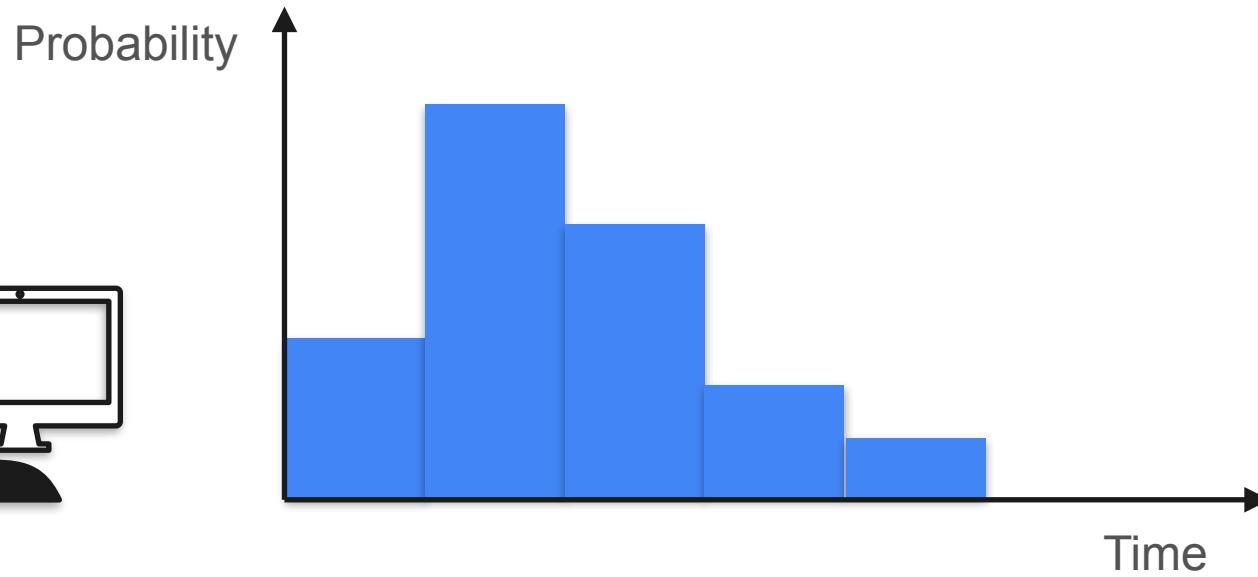


# Median

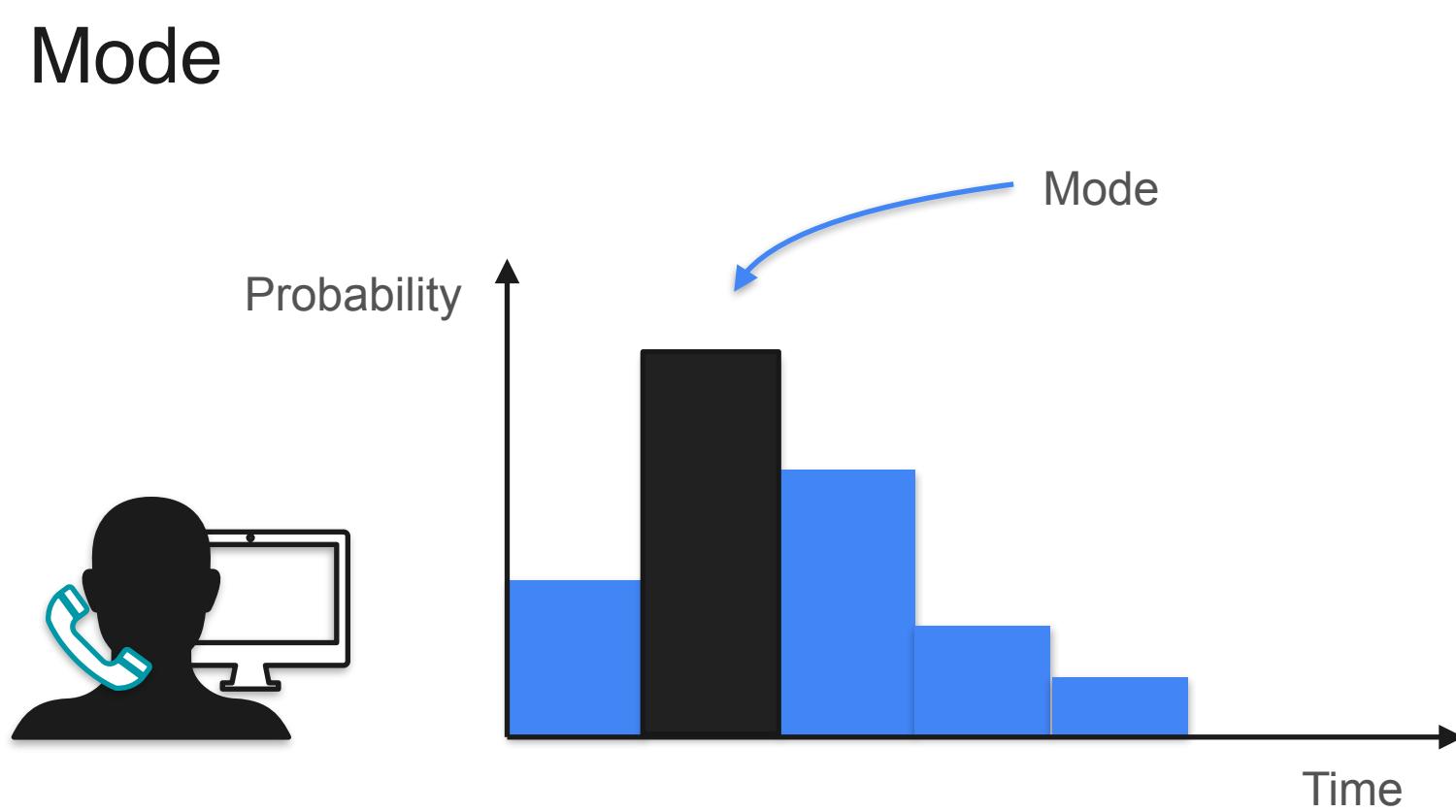


Median  
Average of the  
two middle ones

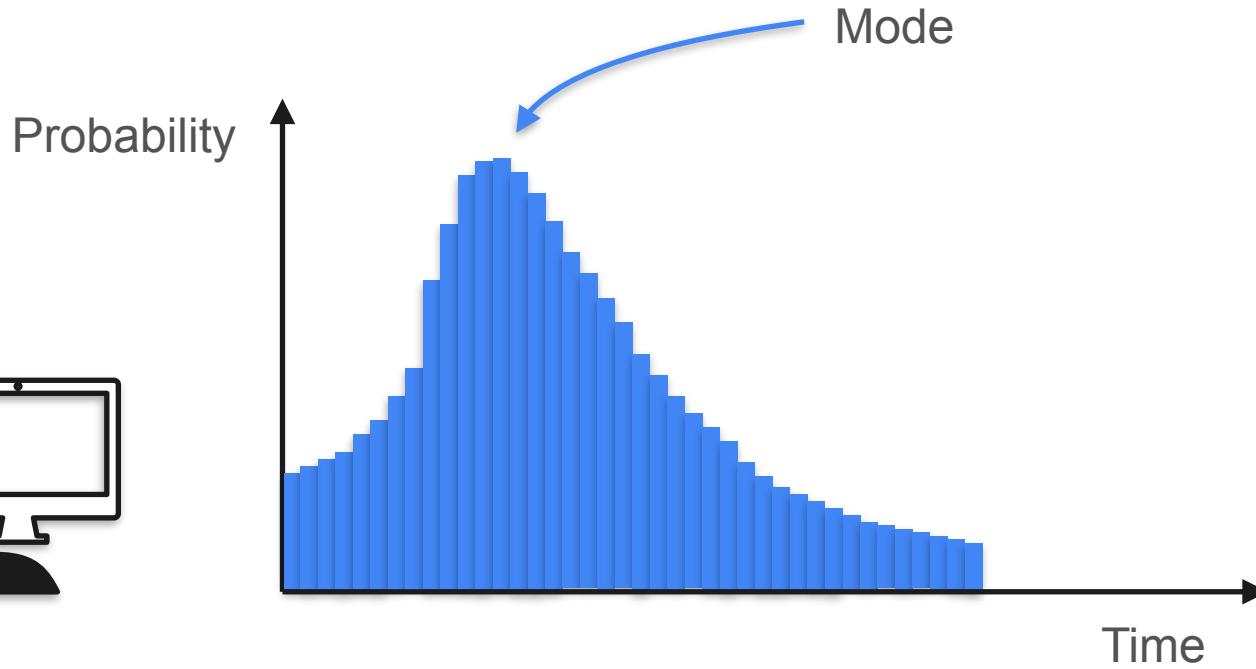
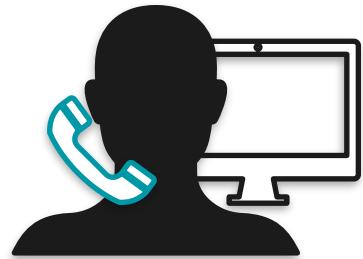
# Mode



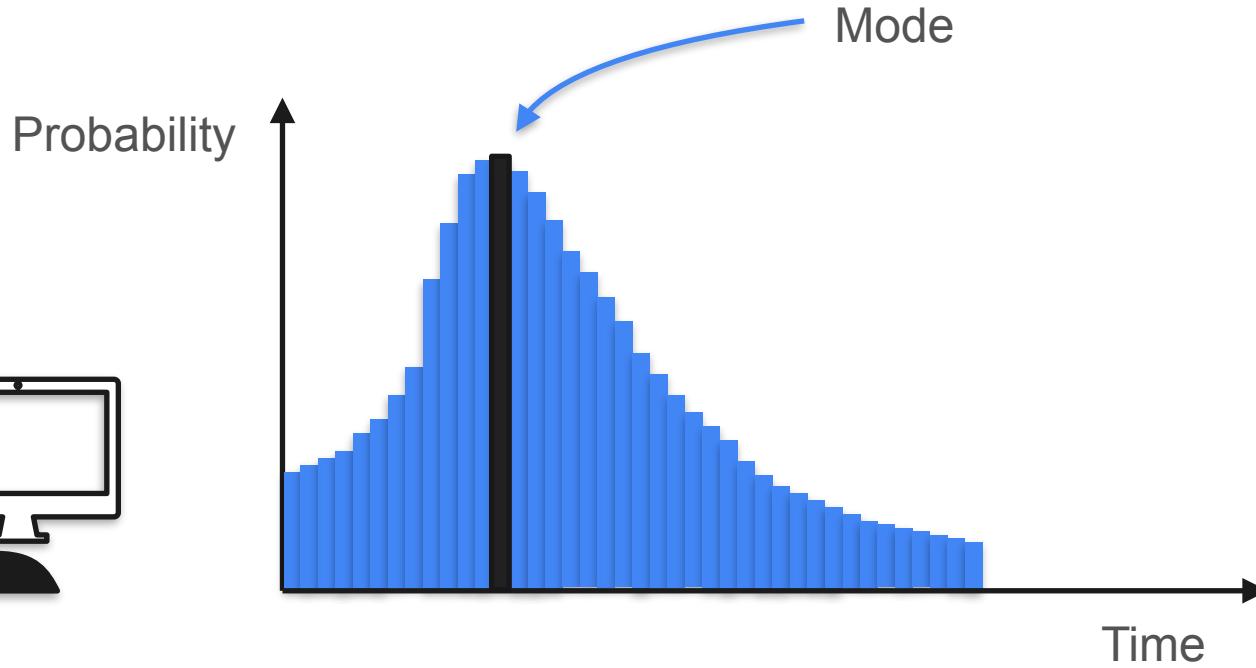
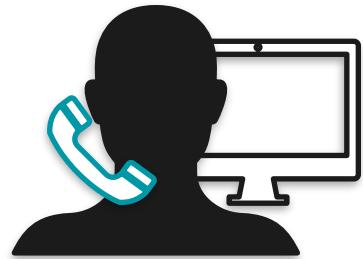
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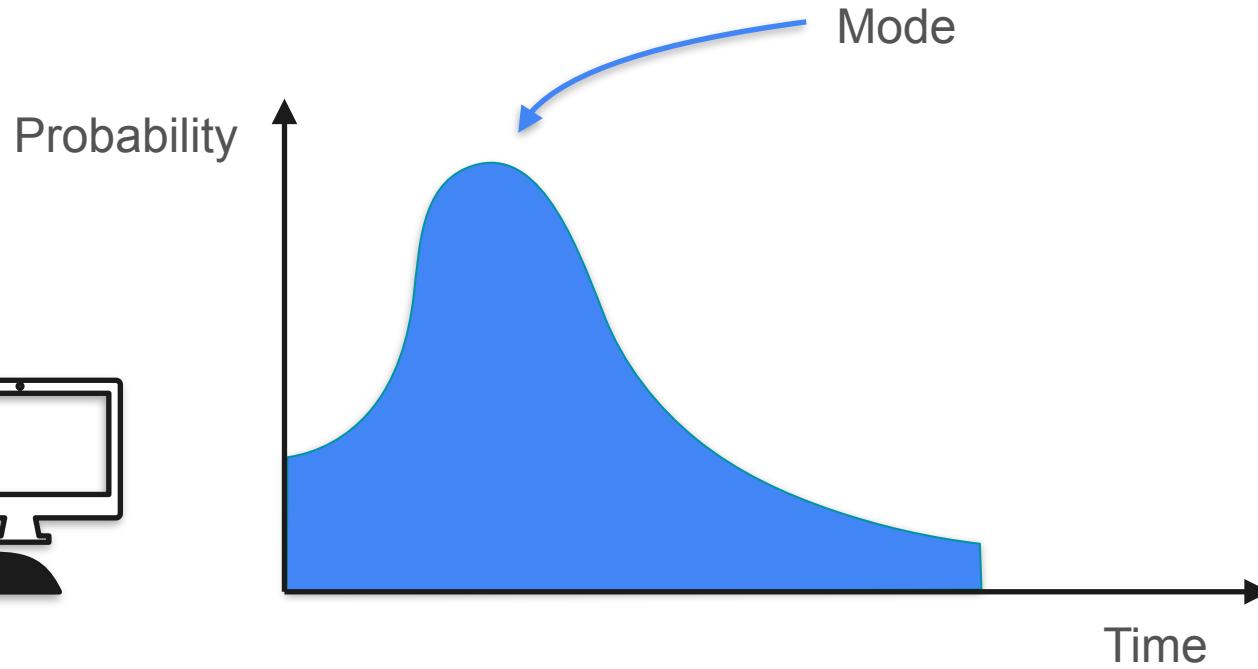
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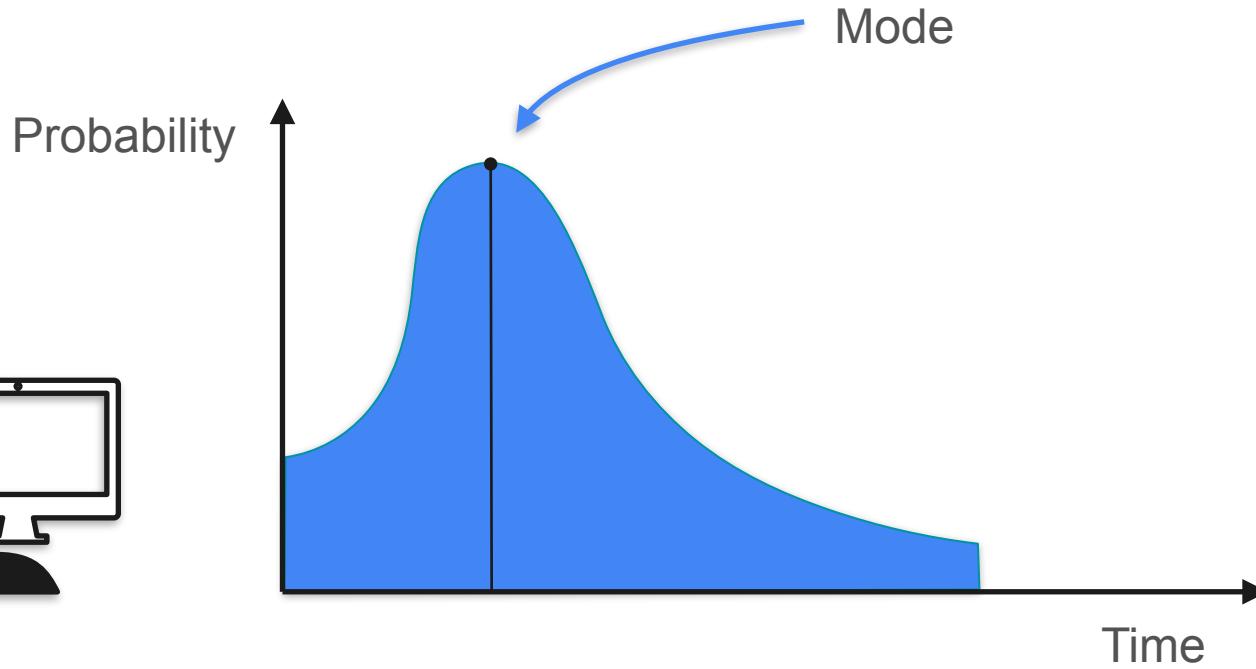
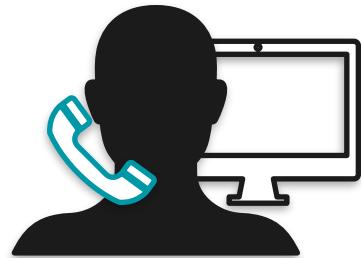
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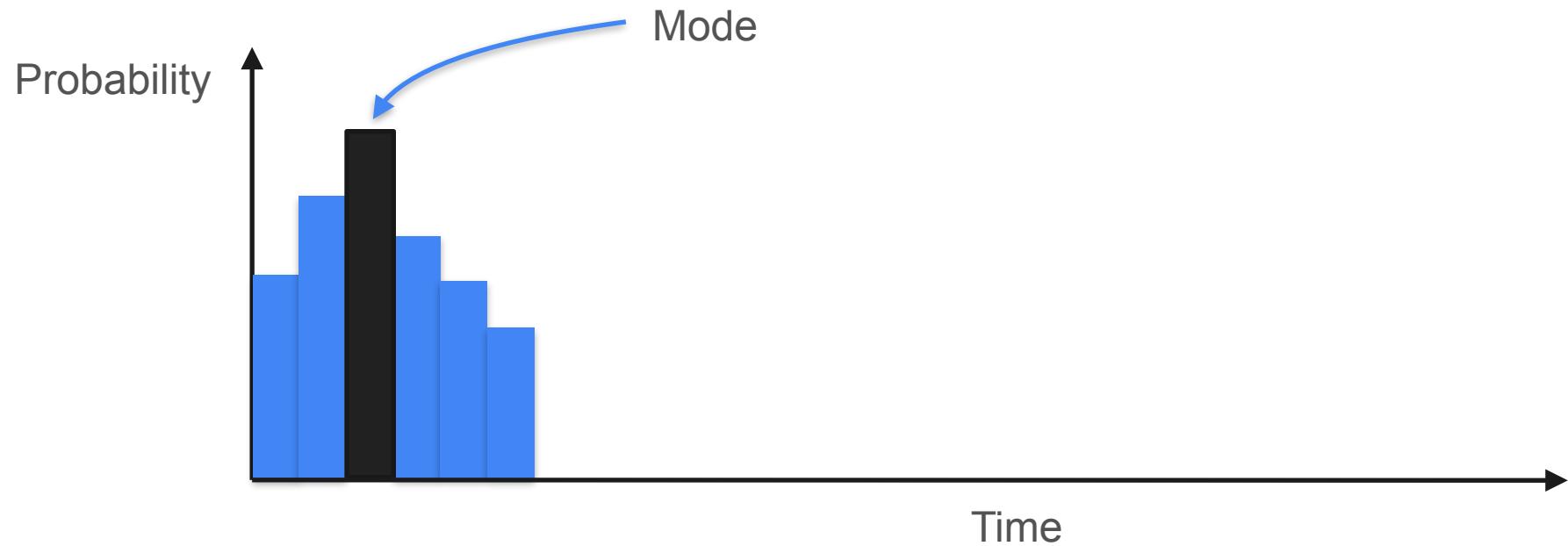
# Mode



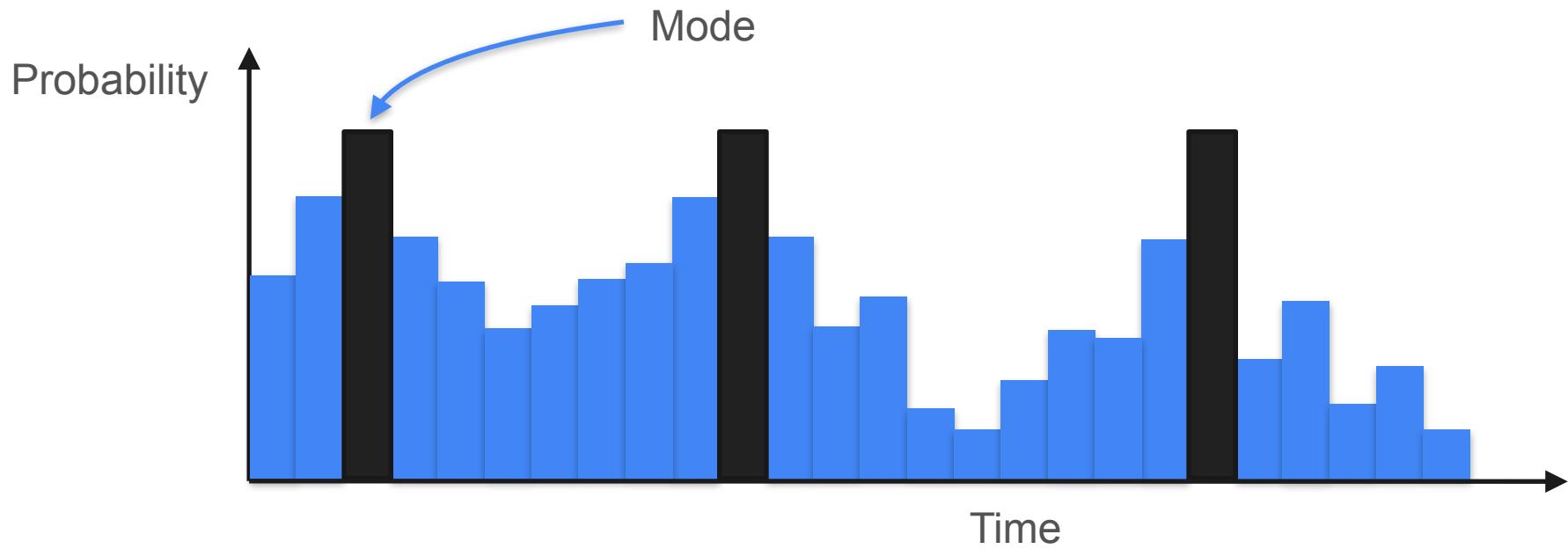
# Mode



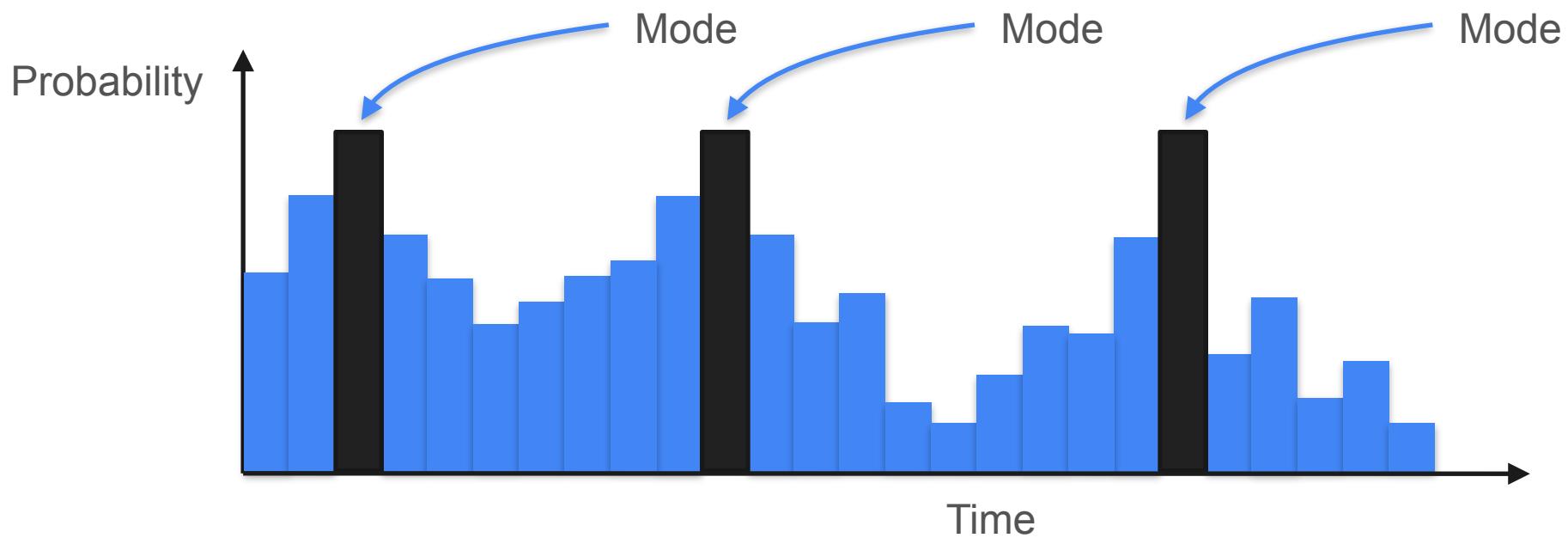
# Mode: Multimodal Distribution



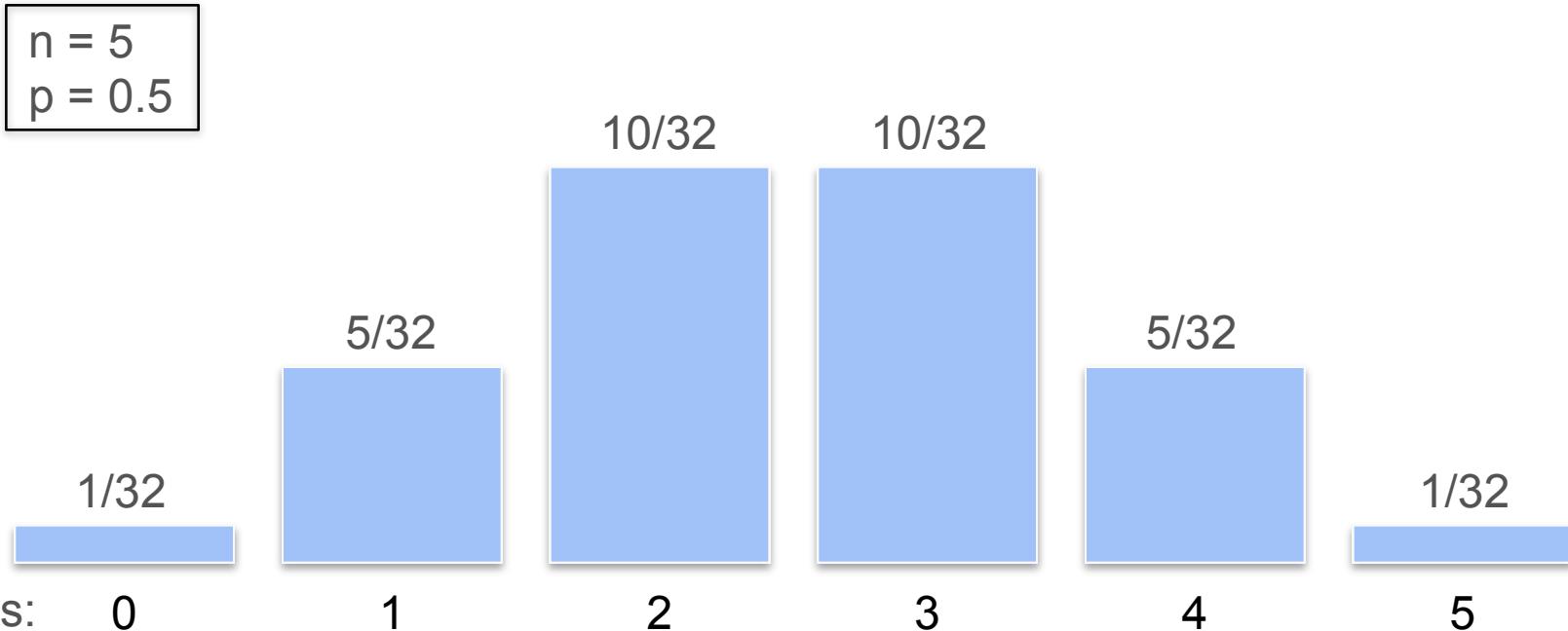
# Mode: Multimodal Distribution



# Mode: Multimodal Distribution

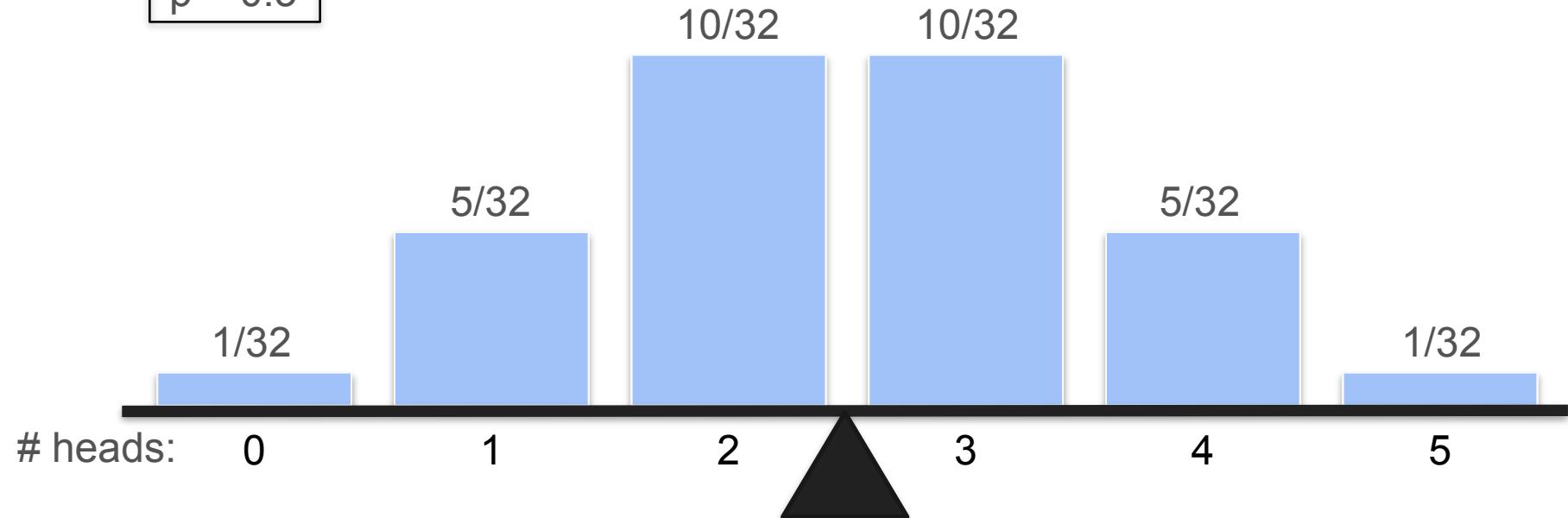


# Mean, Median and Mode in Binomial Distribution

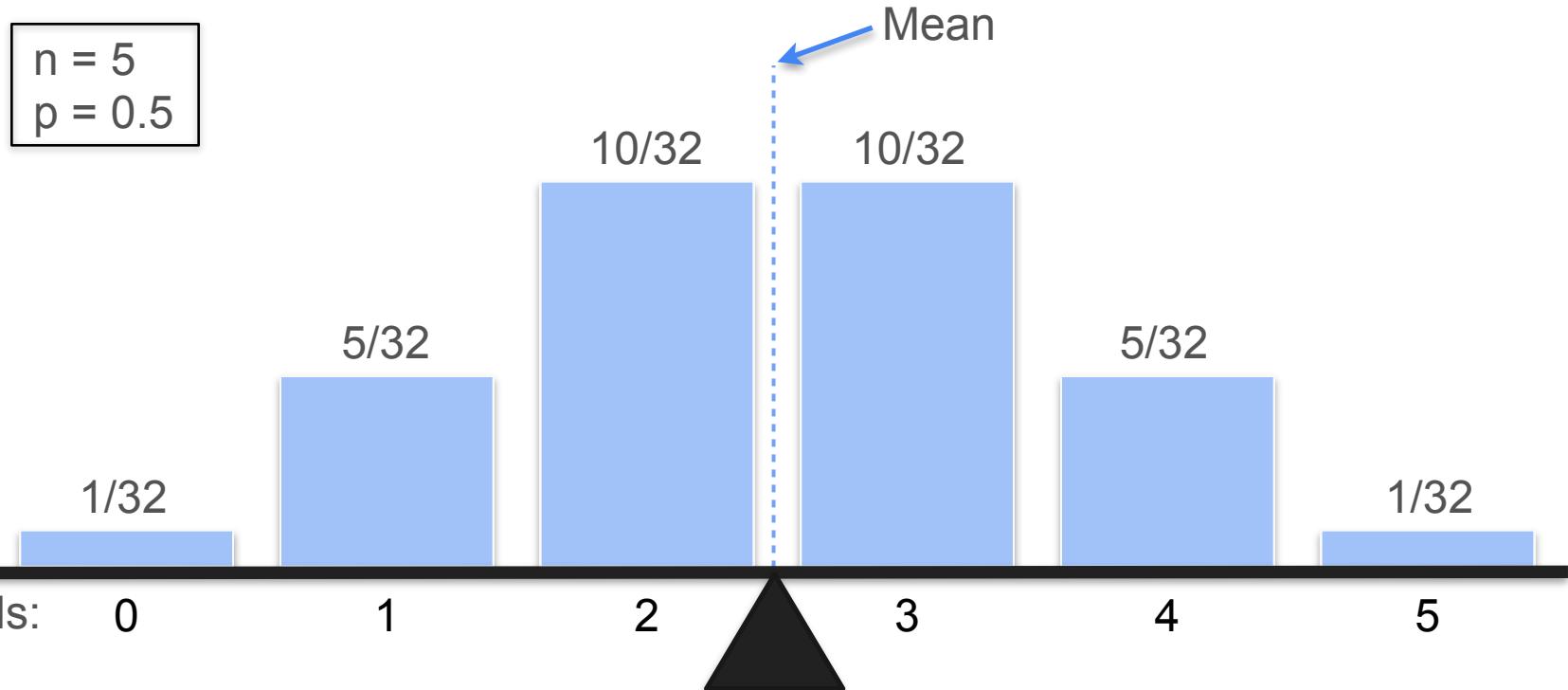


# Mean, Median and Mode in Binomial Distribution

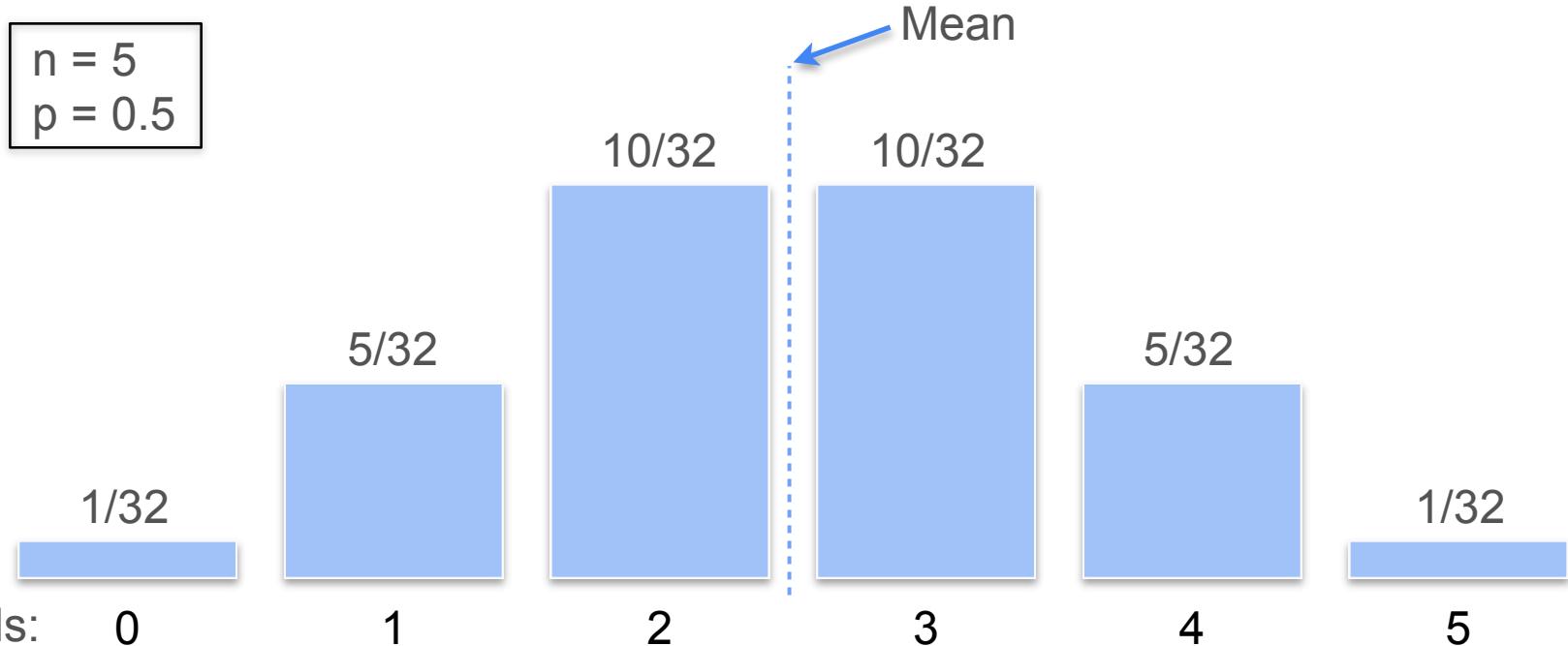
$n = 5$   
 $p = 0.5$



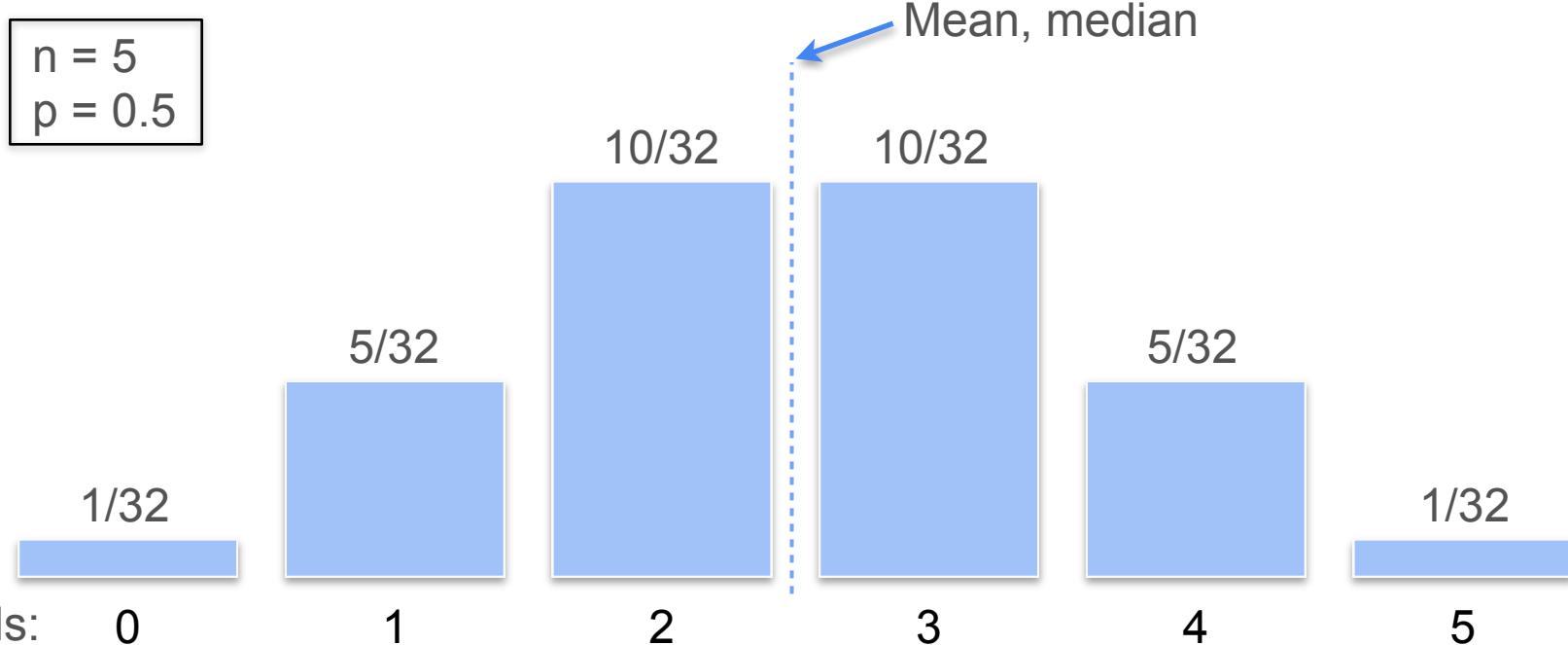
# Mean, Median and Mode in Binomial Distribution



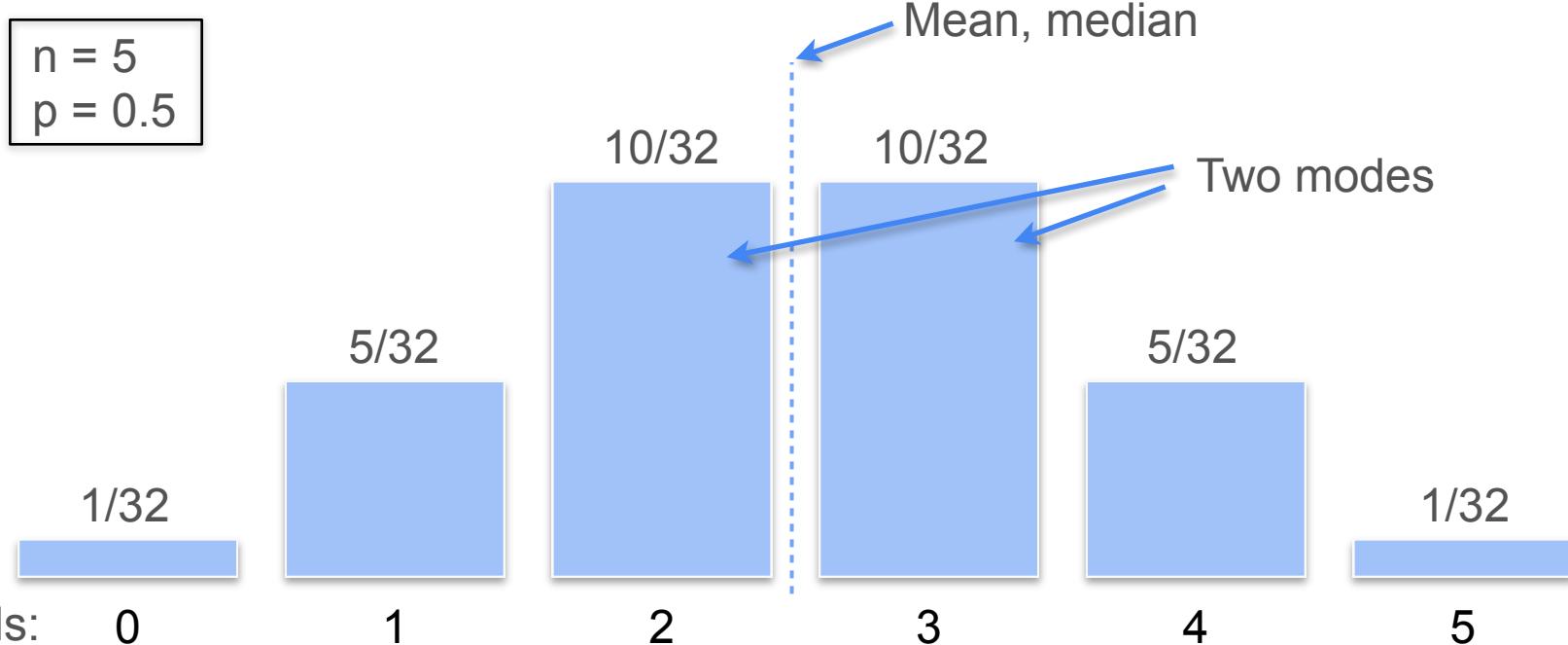
# Mean, Median and Mode in Binomial Distribution



# Mean, Median and Mode in Binomial Distribution

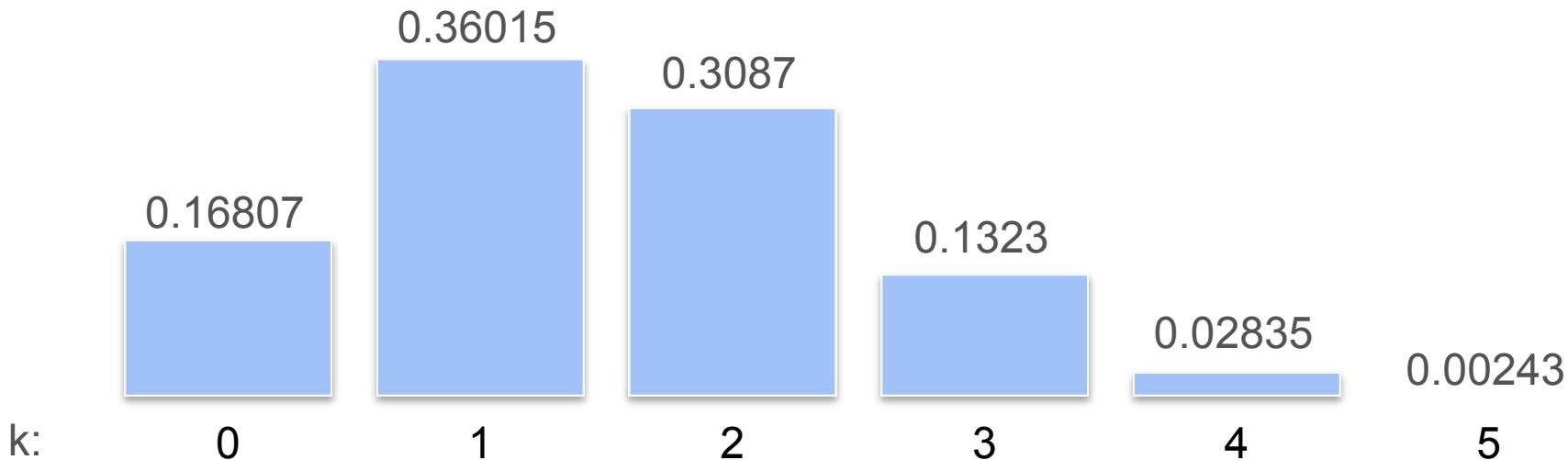


# Mean, Median and Mode in Binomial Distribution



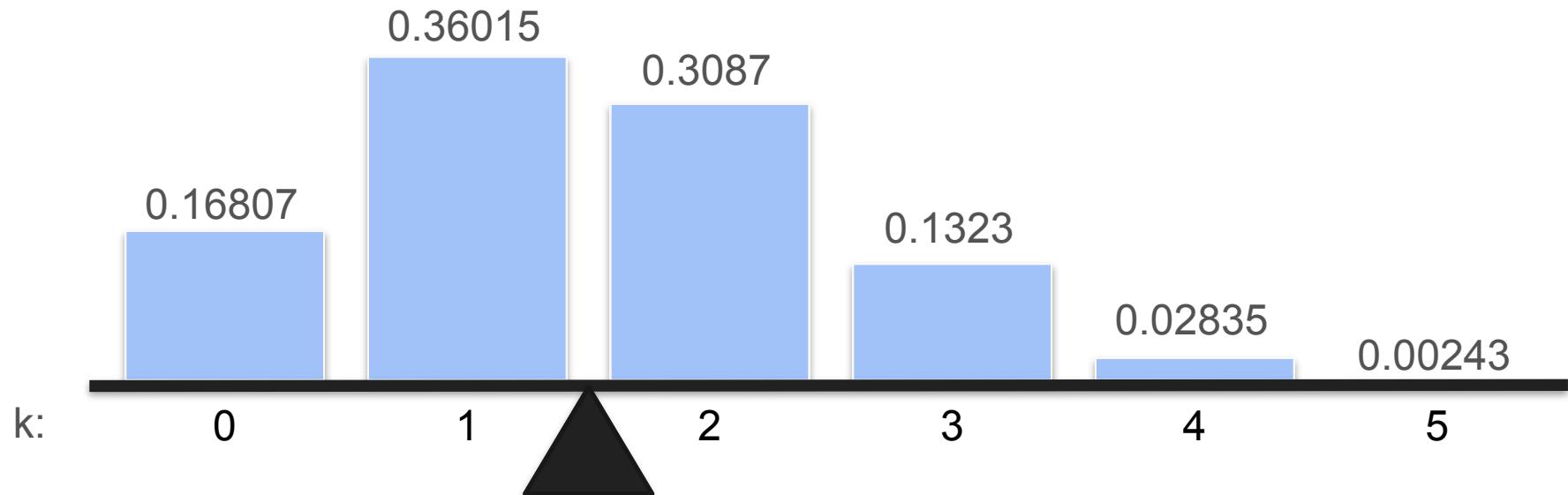
# Mean, Median and Mode in Binomial Distribution

$n = 5$   
 $p = 0.3$

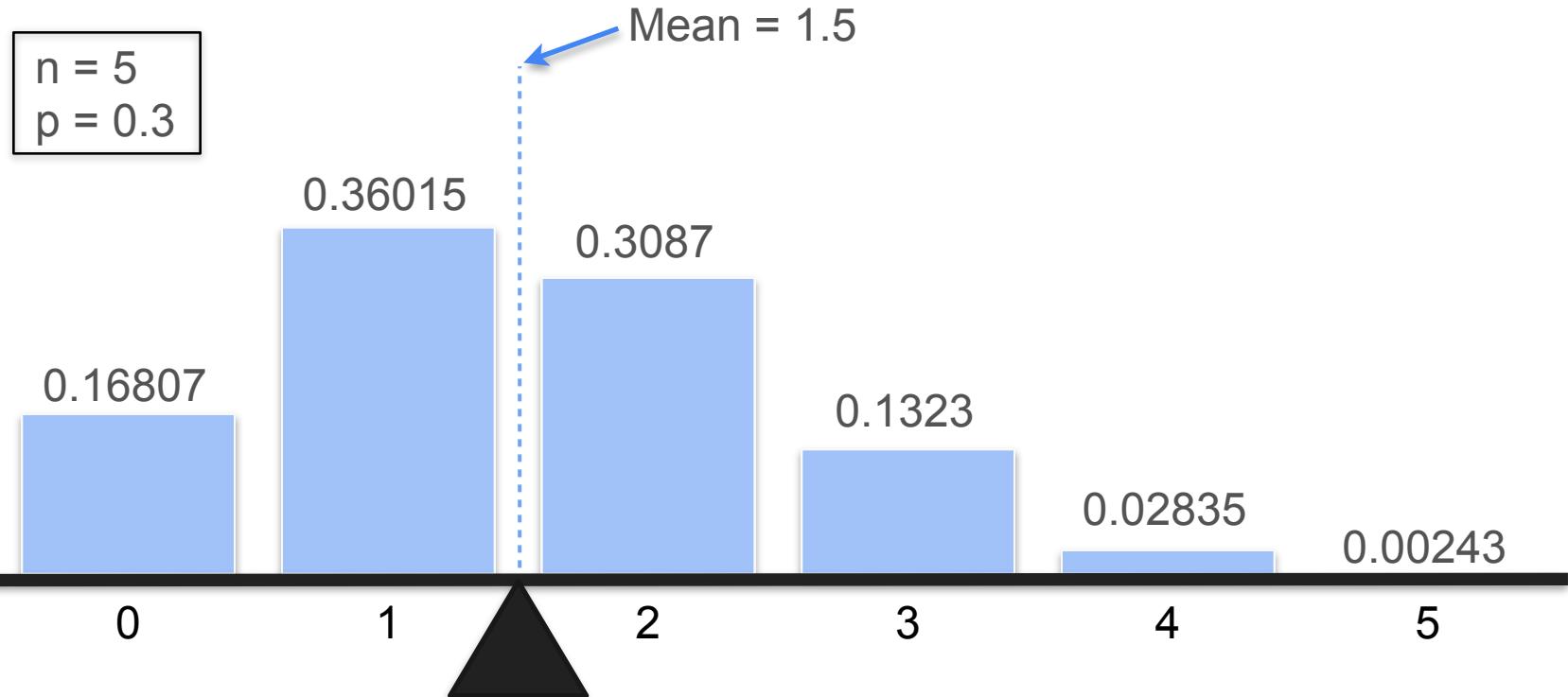


# Mean, Median and Mode in Binomial Distribution

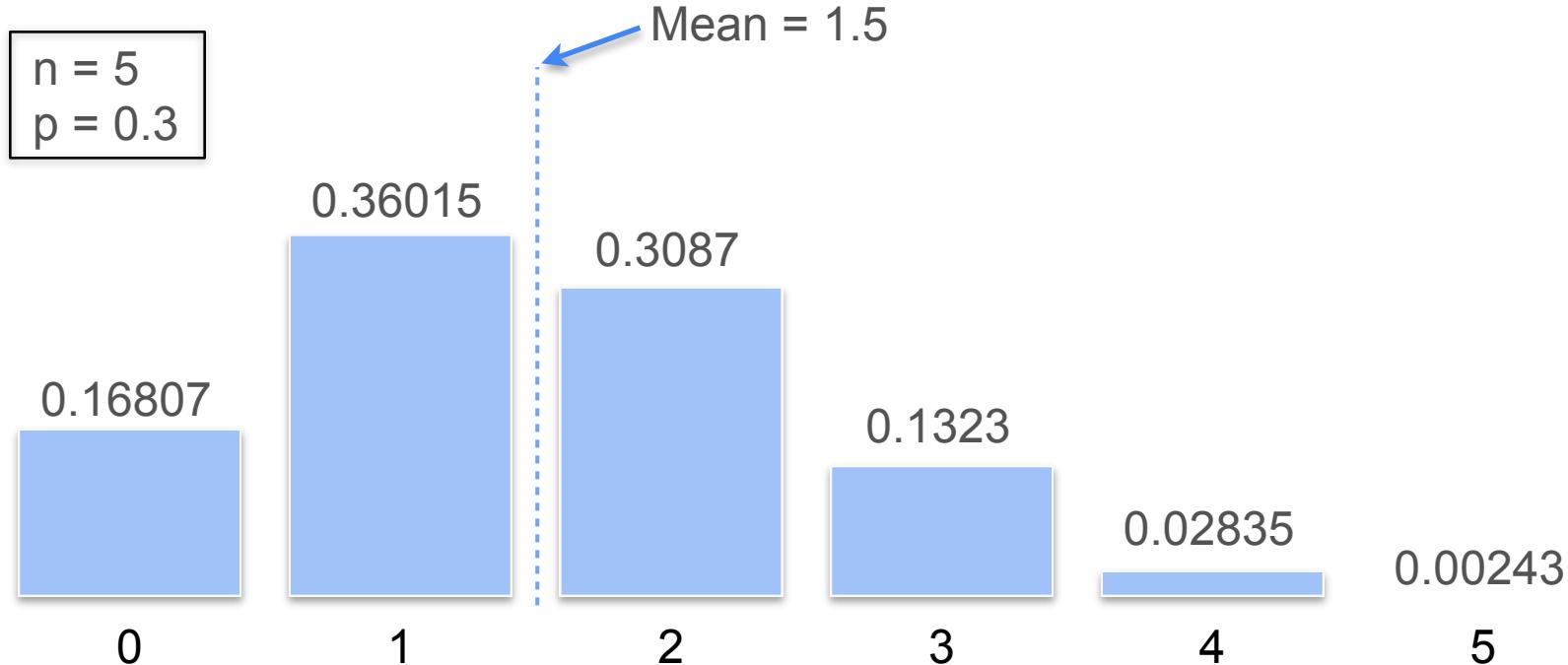
$n = 5$   
 $p = 0.3$



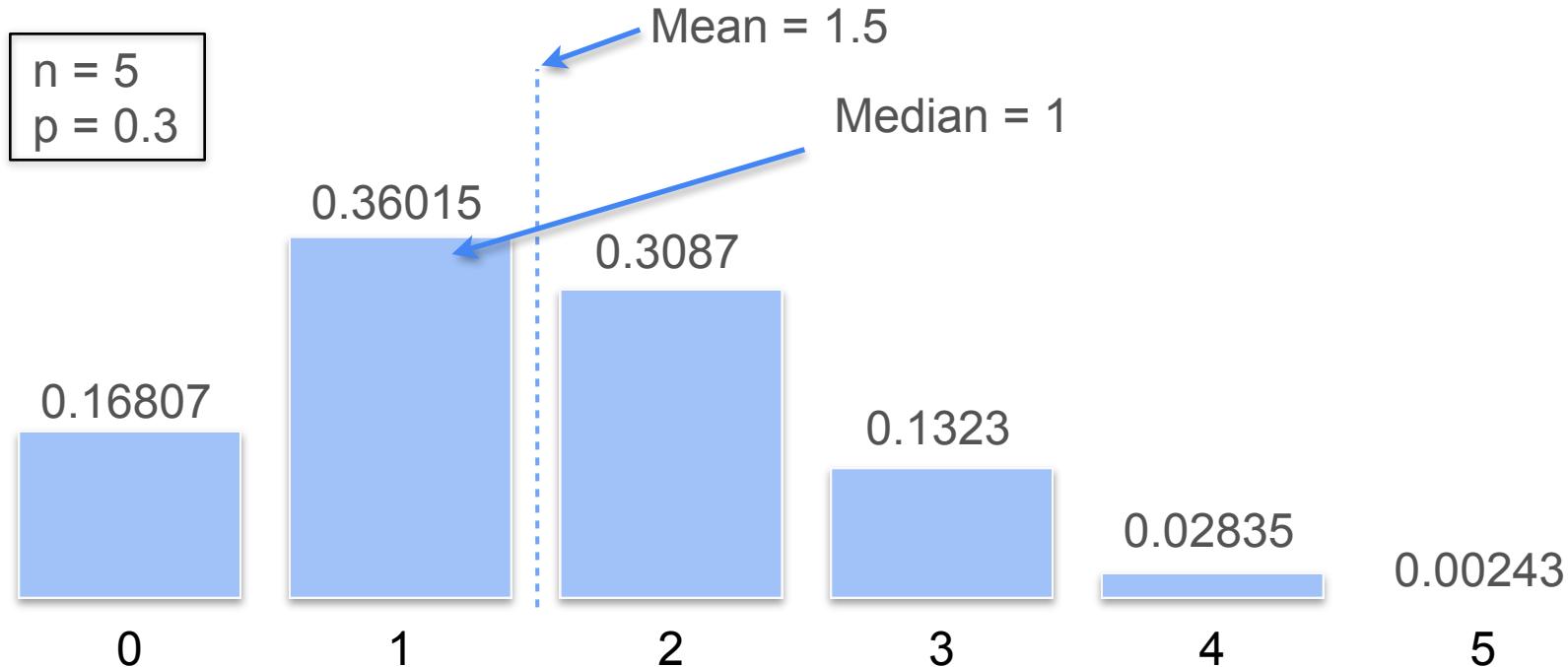
# Mean, Median and Mode in Binomial Distribution



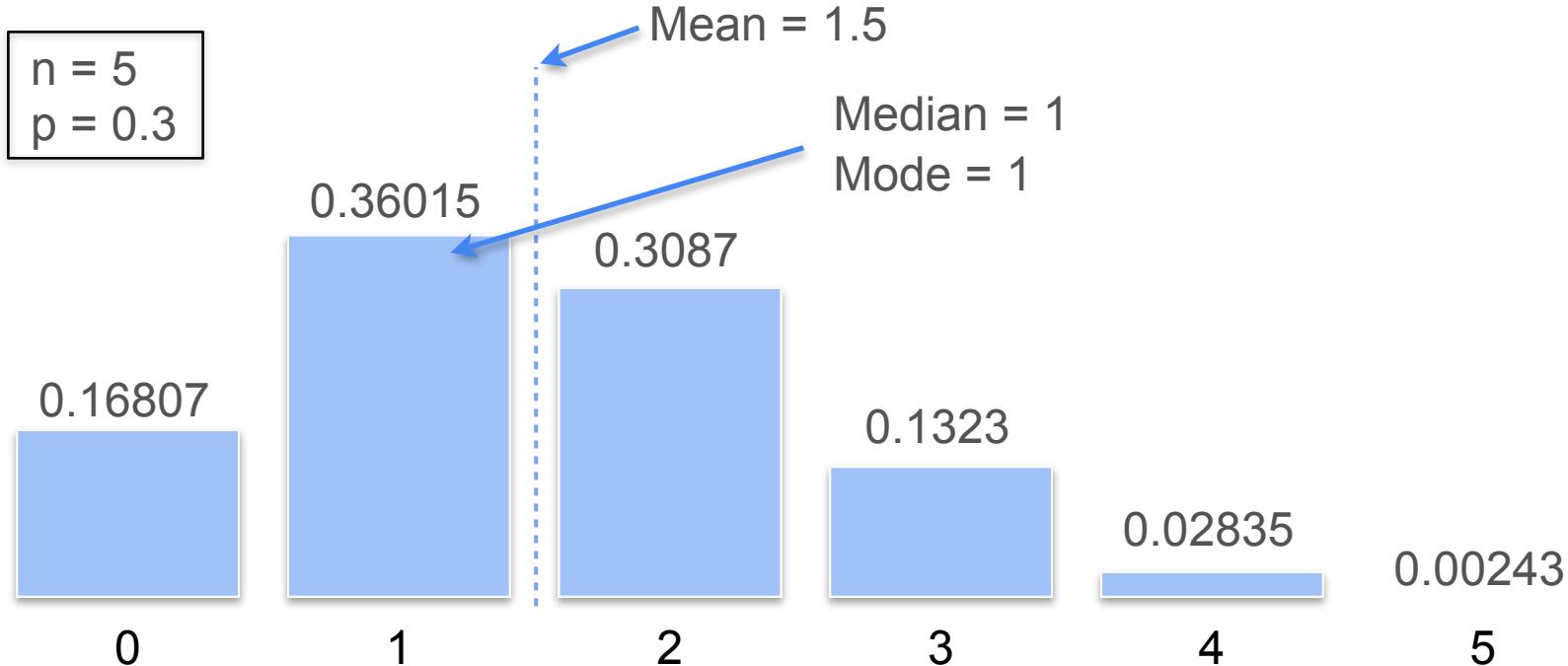
# Mean, Median and Mode in Binomial Distribution



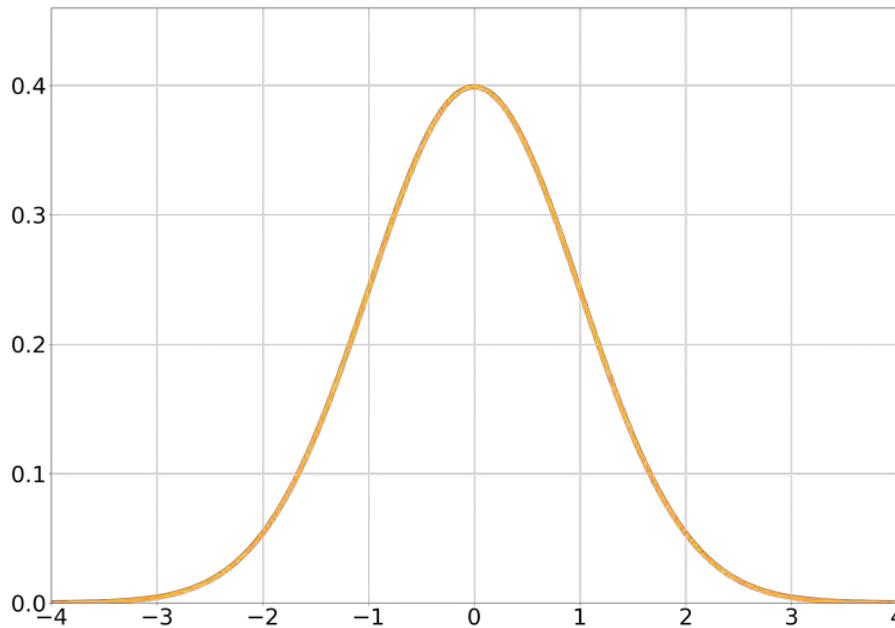
# Mean, Median and Mode in Binomial Distribution



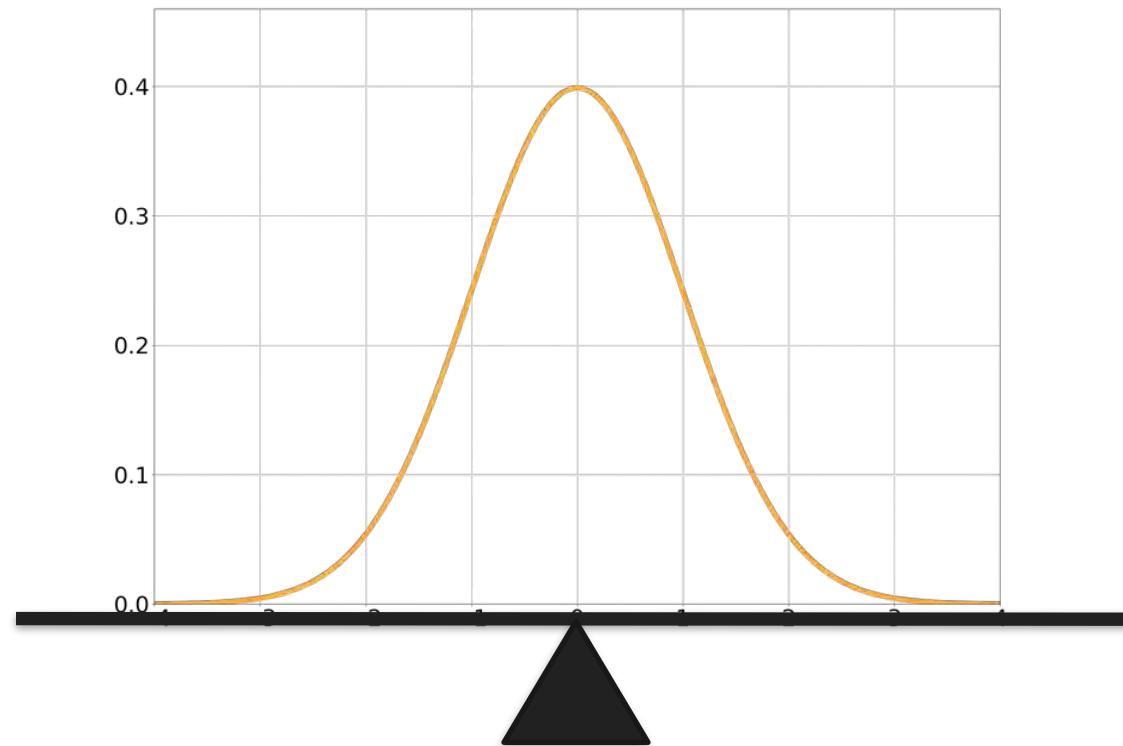
# Mean, Median and Mode in Binomial Distribution



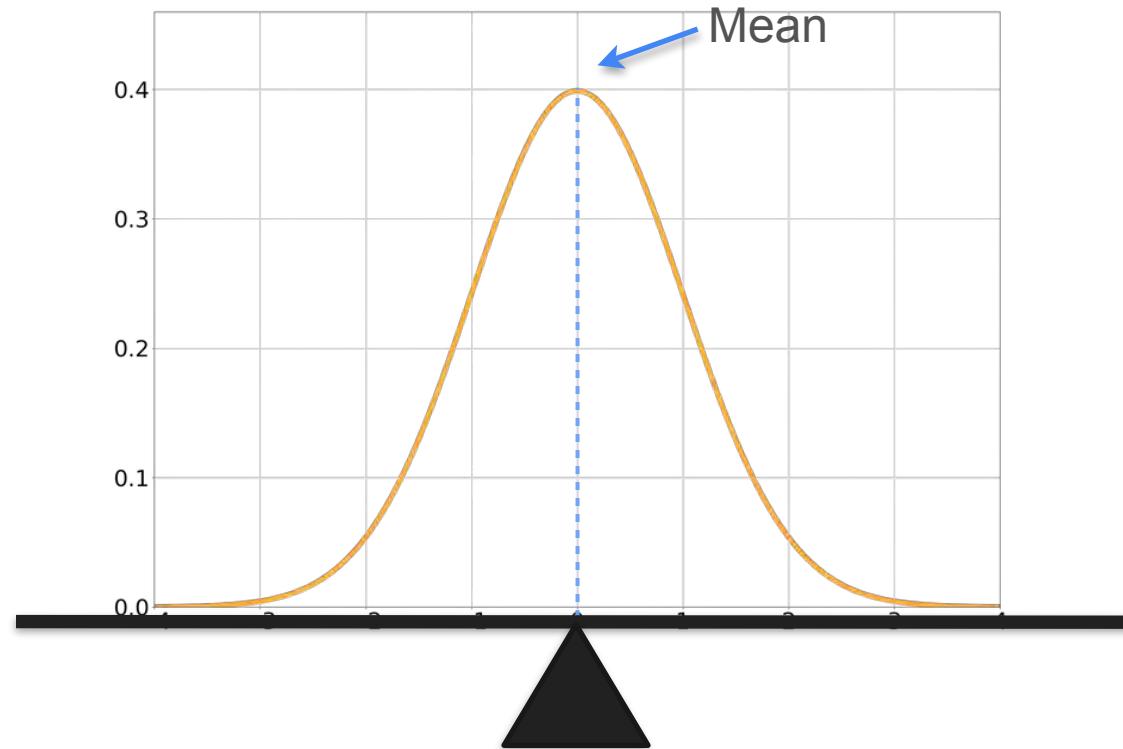
# Mean, Median and Mode in Normal Distribution



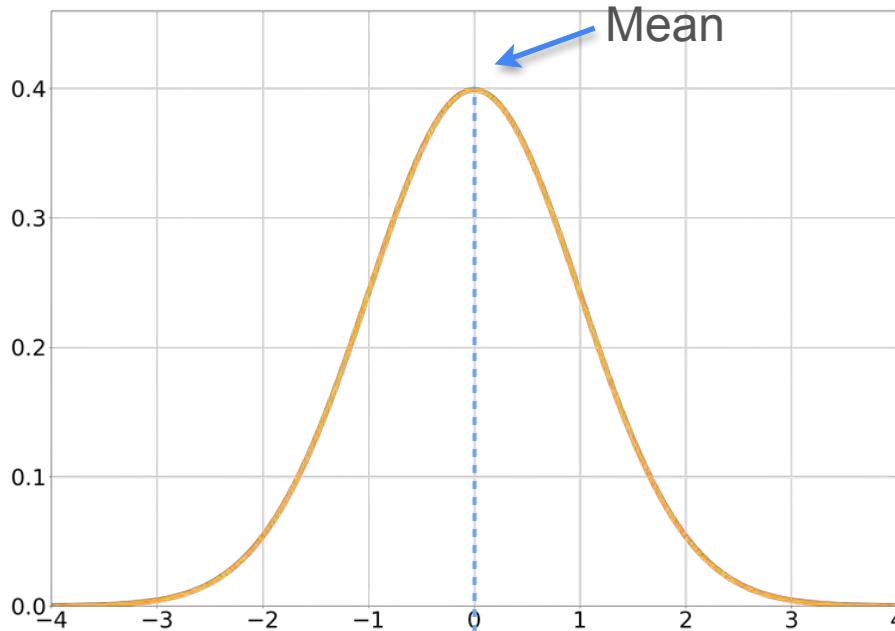
# Mean, Median and Mode in Normal Distribution



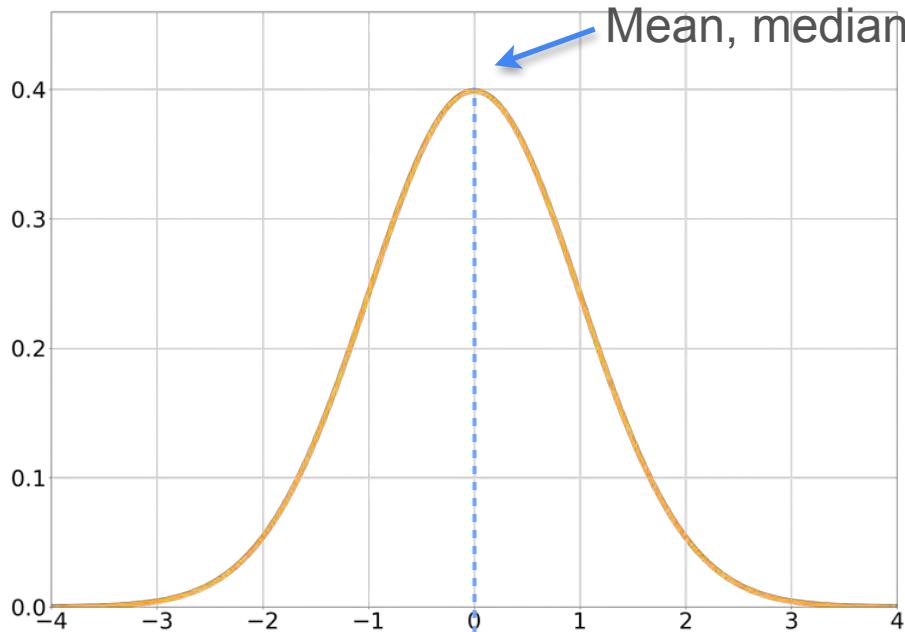
# Mean, Median and Mode in Normal Distribution



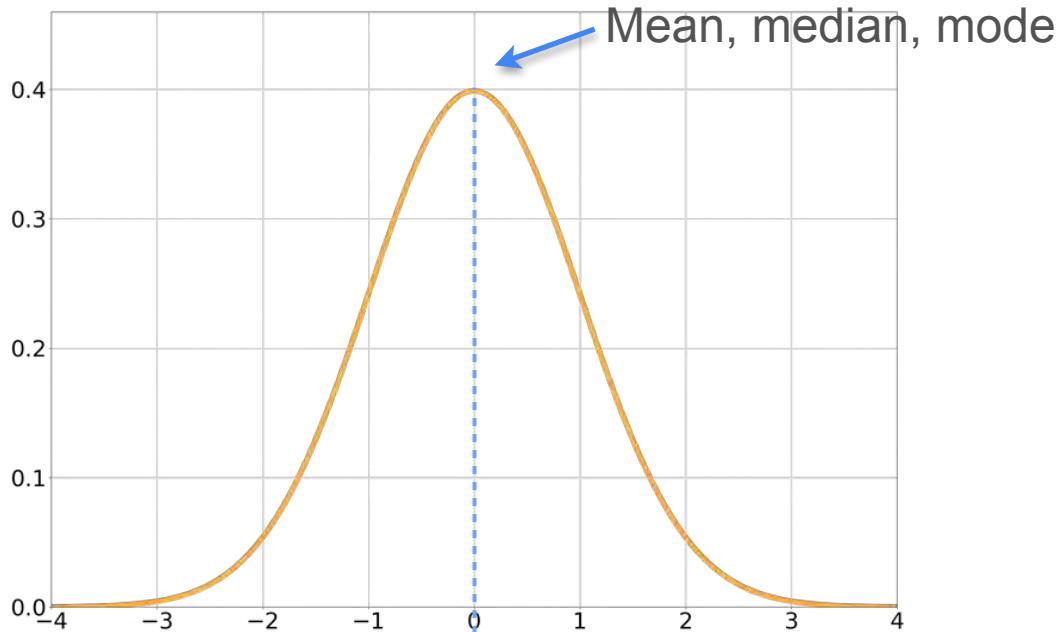
# Mean, Median and Mode in Normal Distribution



# Mean, Median and Mode in Normal Distribution



# Mean, Median and Mode in Normal Distribution





DeepLearning.AI

# Describing Distributions

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## Expected Value

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$6

Do you play the game?

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$4

Do you play the game?

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$4

Do you play the game?

What is the maximum amount of money you would pay to play this game?

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10$

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0$

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0 = \$5$

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0 = \$5 \rightarrow$  You expect to win \$5 on average  
 $\mathbb{E}[X] = 5$

# Expected Value: Motivation Example 1

You play a game with a friend



You win 10 dollars



You win nothing

Game cost:

\$5

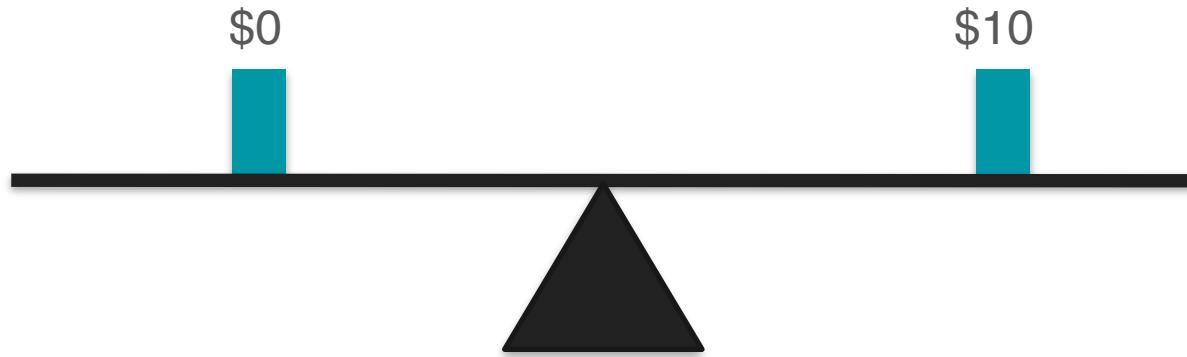
Long term:  $0.5 \cdot \$10 + 0.5 \cdot \$0 = \$5$  

You expect to win \$5 on average  
 $E[X] = 5$

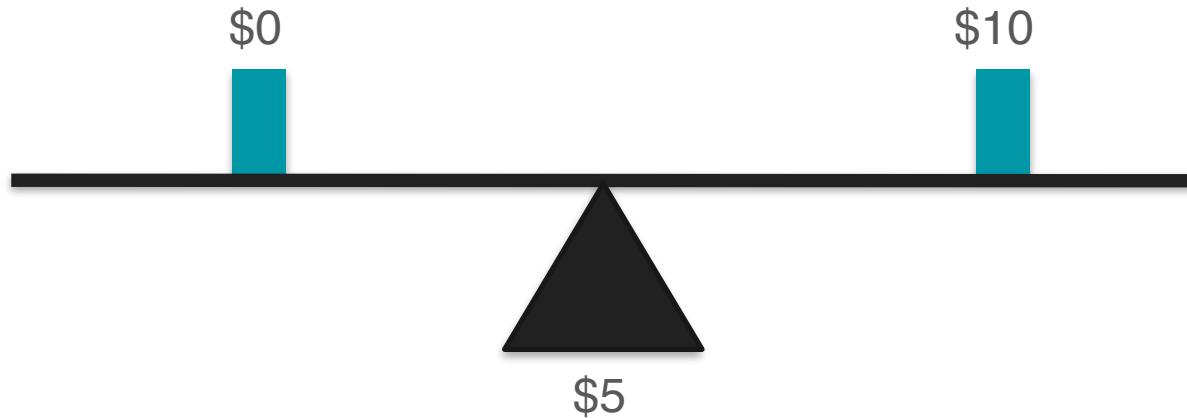
# Expected Value: Motivation Example 1



# Expected Value: Motivation Example 1



# Expected Value: Motivation Example 1



# Expected Value: Motivation Example 2

Play another game



Flip three coins. For each heads you win \$1

What is the maximum amount of money you would pay to play this game?

# Expected Value: Motivation Example 2

Number of heads:

0



1



2



3



# Expected Value: Motivation Example 2

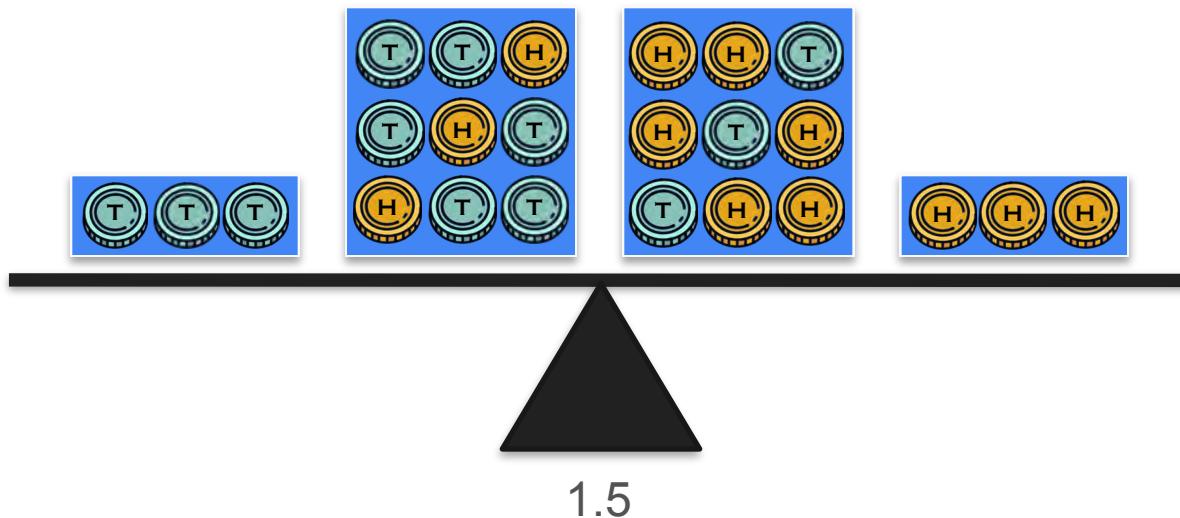
Number of heads:

0

1

2

3



# Expected Value: Motivation Example 2

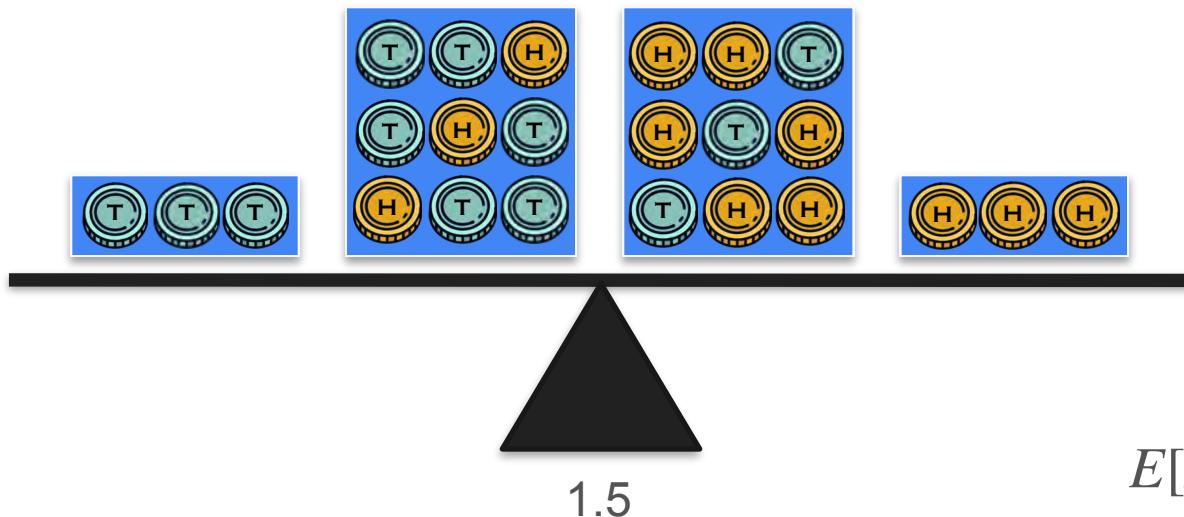
Number of heads:

0

1

2

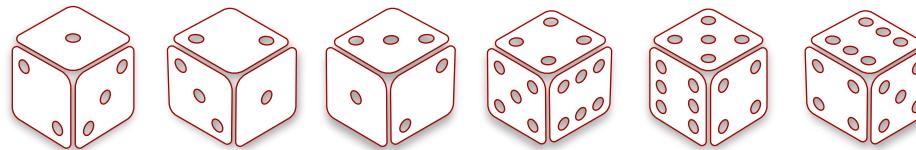
3



# Expected Value: Motivation Example 3

Probability:    1/6    1/6    1/6    1/6    1/6    1/6

Roll:        1        2        3        4        5        6

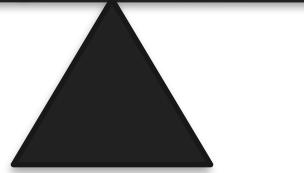
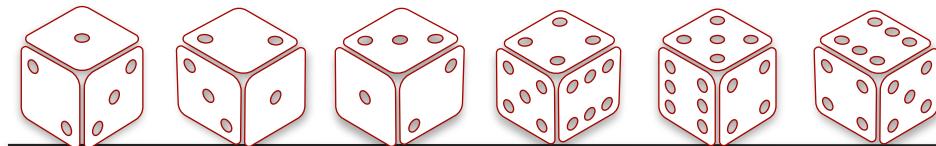


$$\frac{1 + 2 + 3 + 4 + 5 + 6}{6} = 3.5$$

# Expected Value: Motivation Example 3

Probability:     $1/6$      $1/6$      $1/6$      $1/6$      $1/6$      $1/6$

Roll:     $1$      $2$      $3$      $4$      $5$      $6$

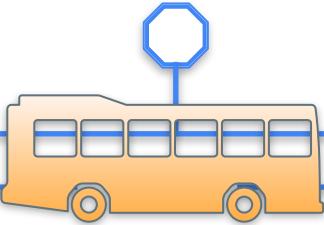


$3.5$

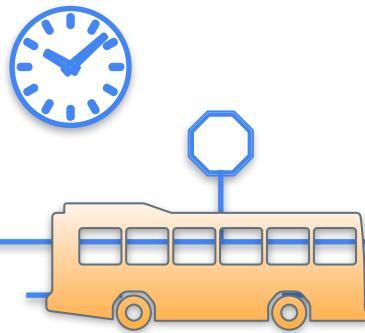
# Expected Value



# Expected Value



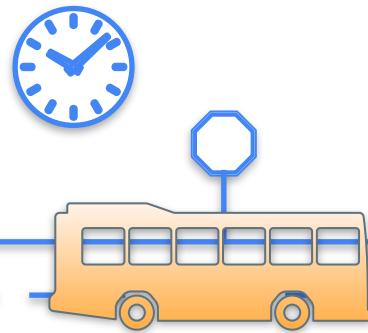
# Expected Value



# Expected Value

Waiting Time

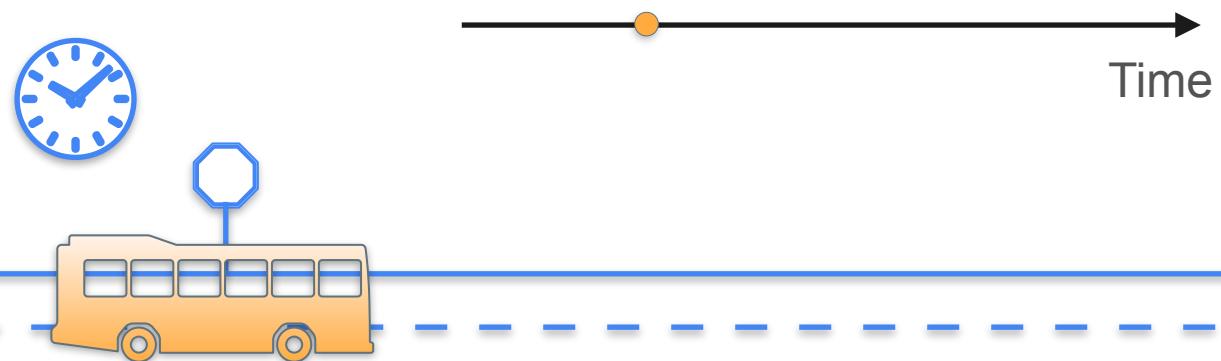
15 min



# Expected Value

Waiting Time

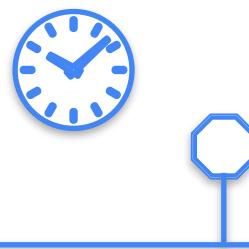
15 min



# Expected Value

Waiting Time

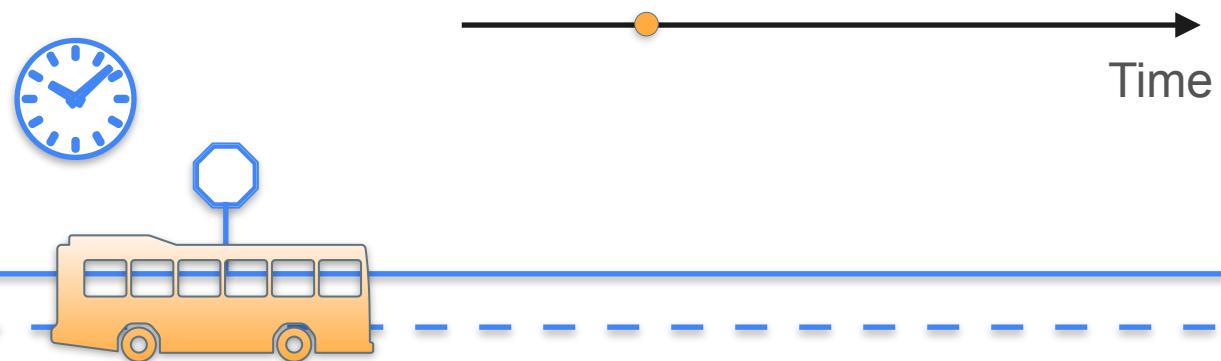
15 min



# Expected Value

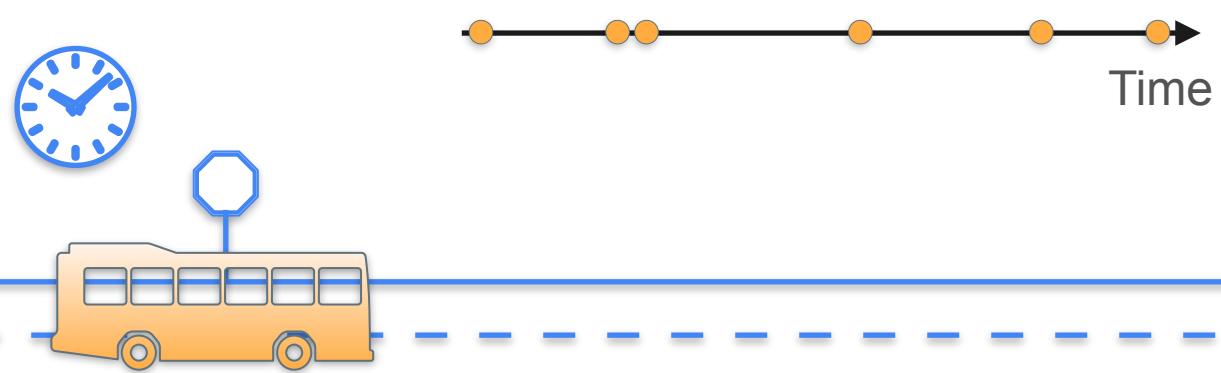
Waiting Time

15 min



# Expected Value

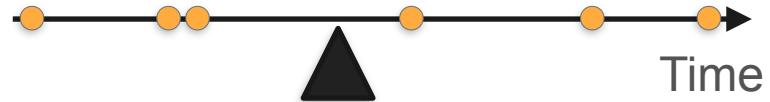
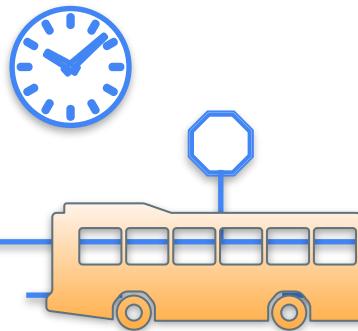
Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min



# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min

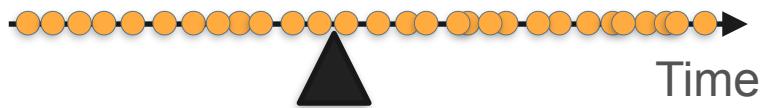
Average = 27.833



# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min
37 min
8 min
29 min
55 min
...

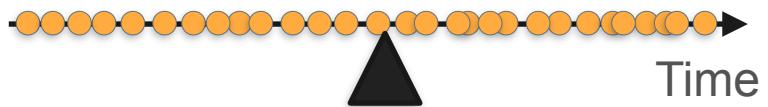
Average = 27.833



# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min
37 min
8 min
29 min
55 min
...

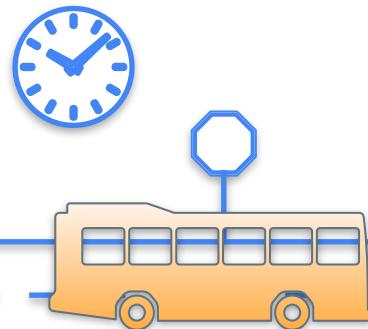
Average = 30



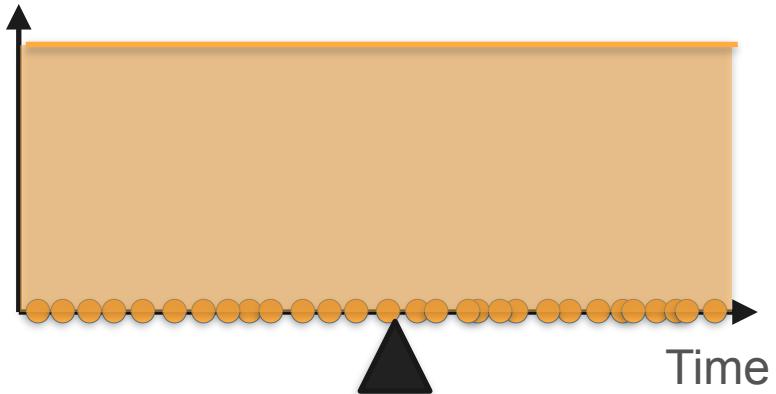
# Expected Value

Waiting Time
15 min
32 min
58 min
1 min
47 min
14 min
37 min
8 min
29 min
55 min
...

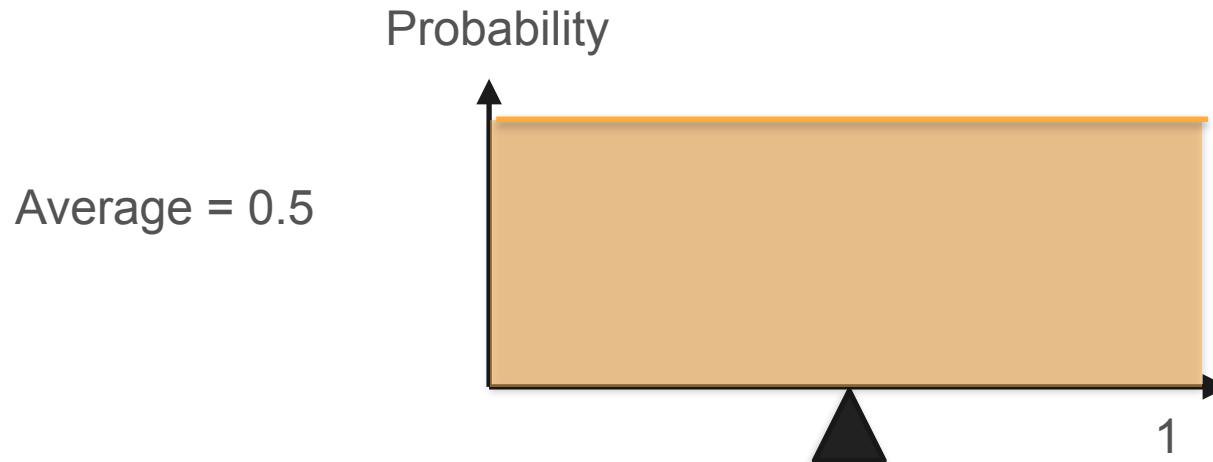
Average = 30



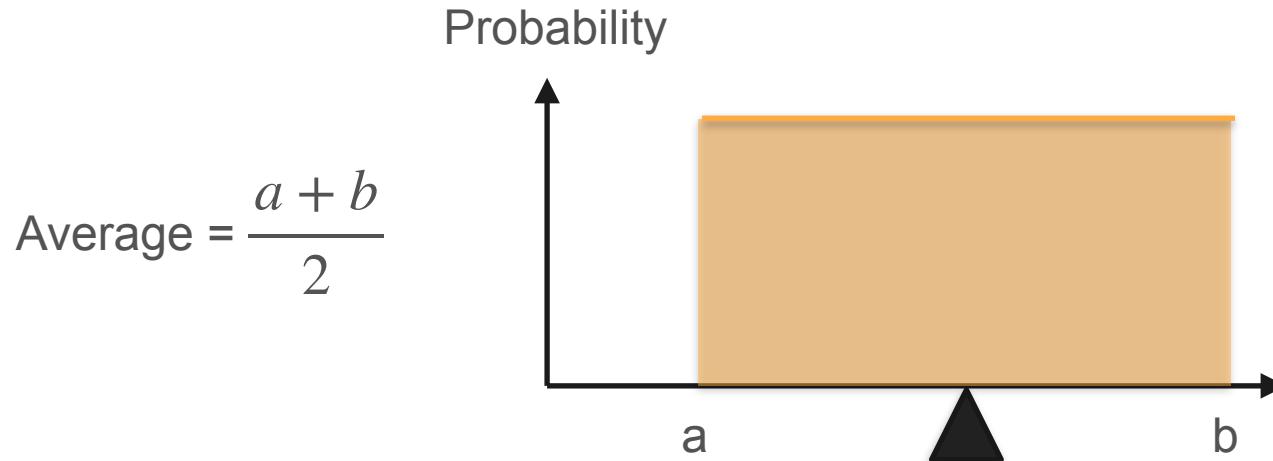
Probability



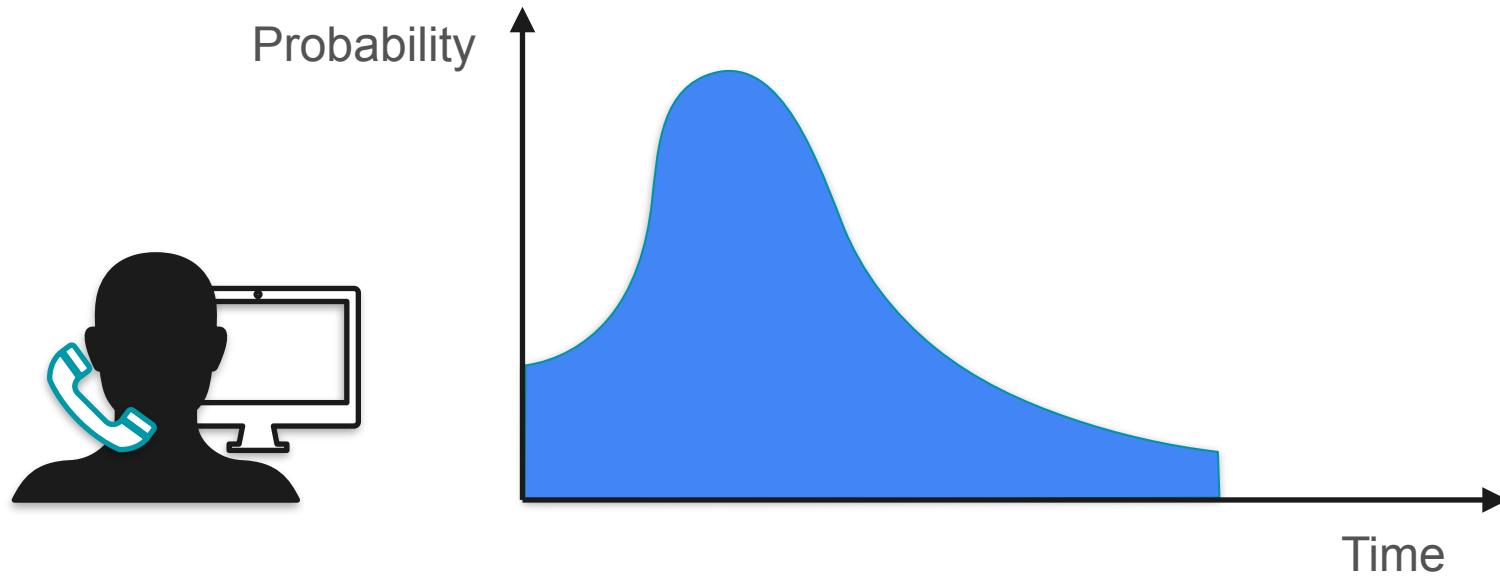
# Expected Value: Uniform Distribution



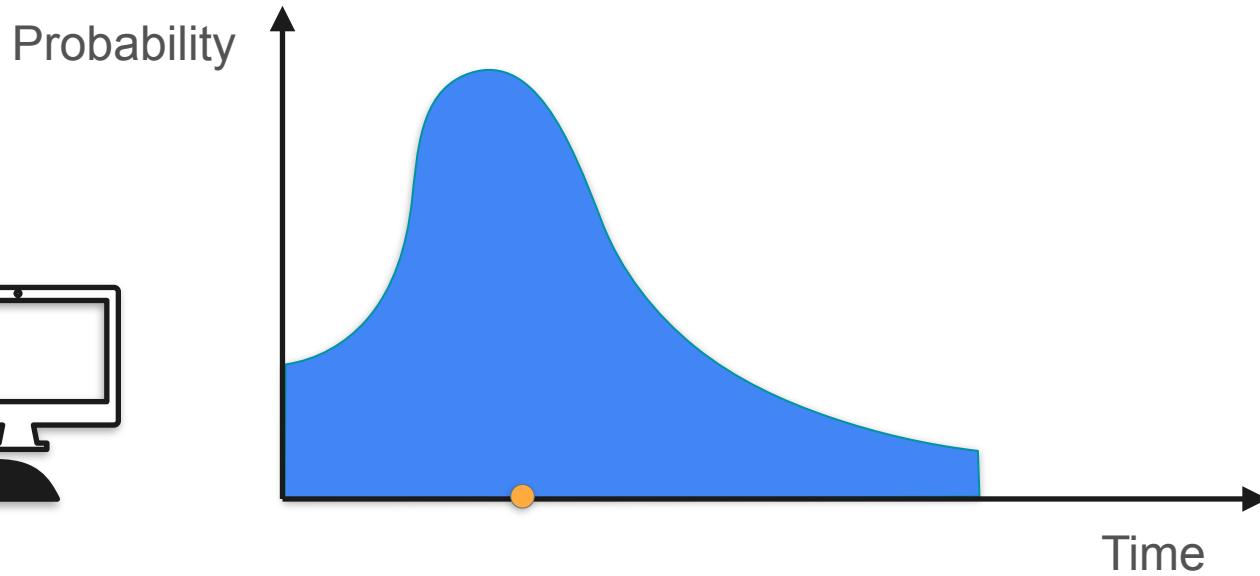
# Expected Value: Uniform Distribution



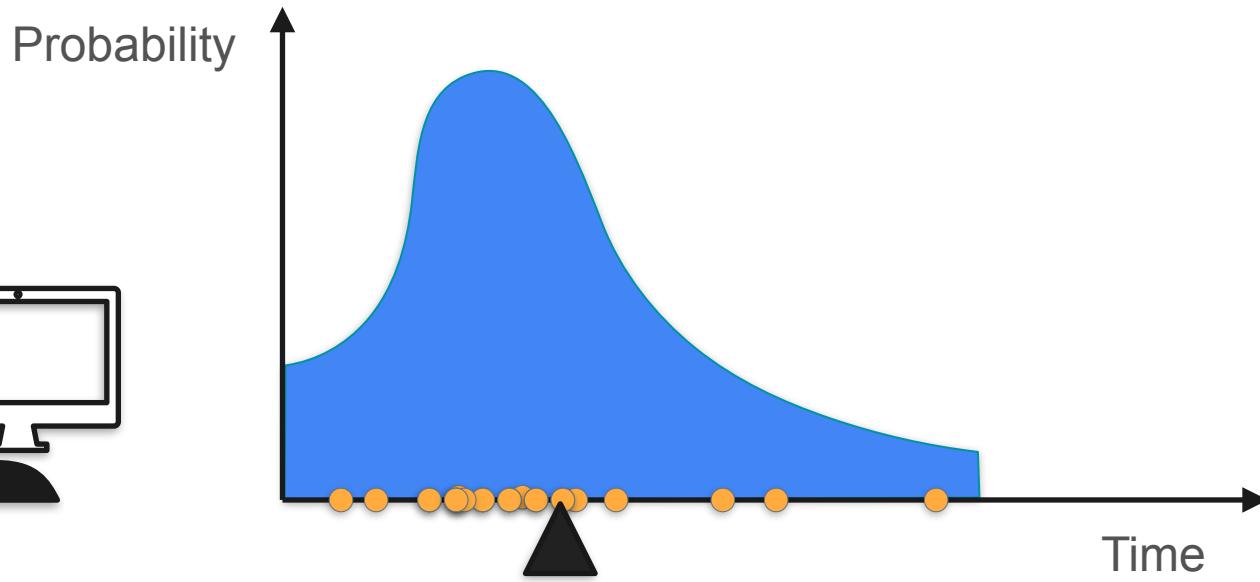
# Expected Value



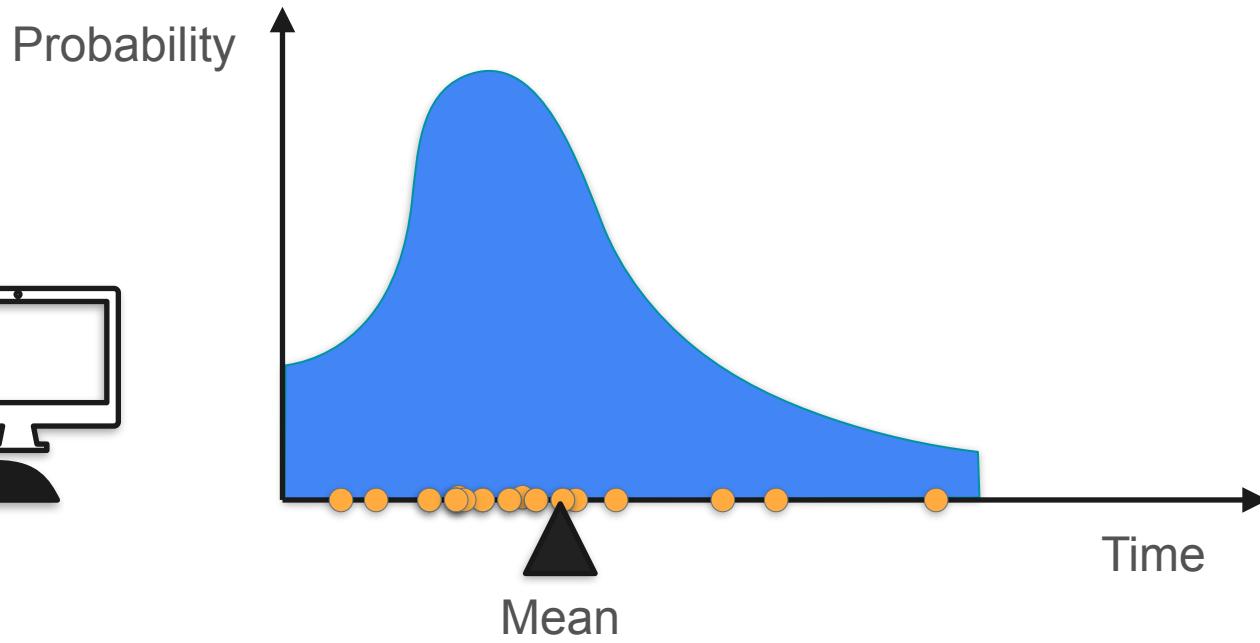
# Expected Value



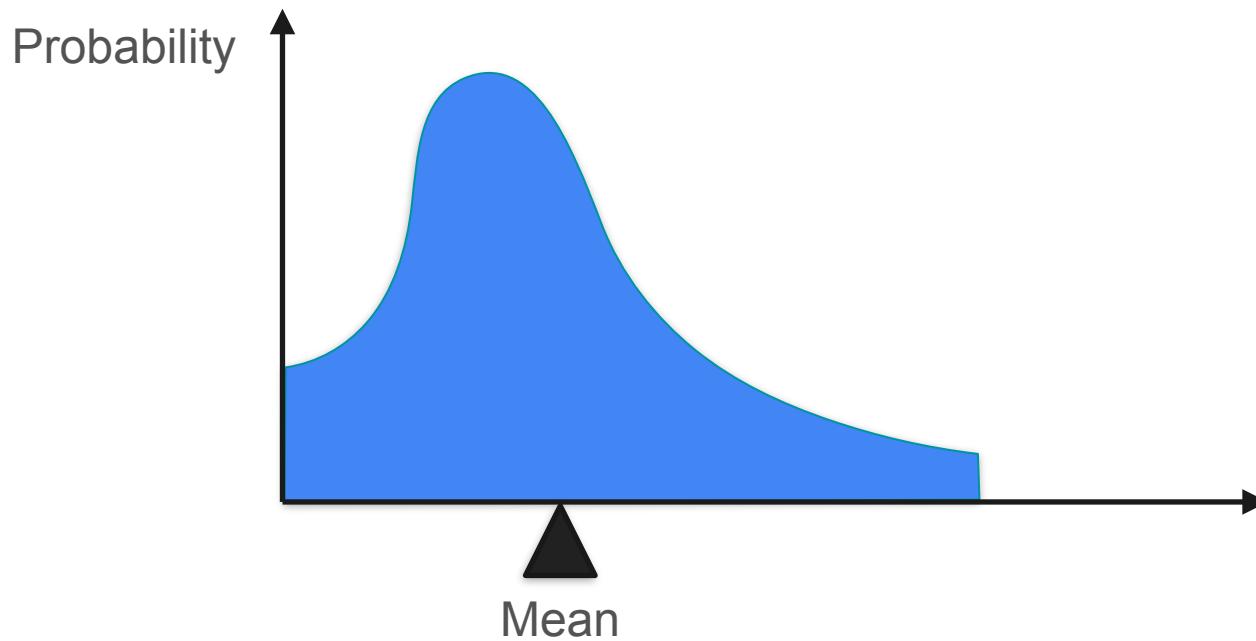
# Expected Value



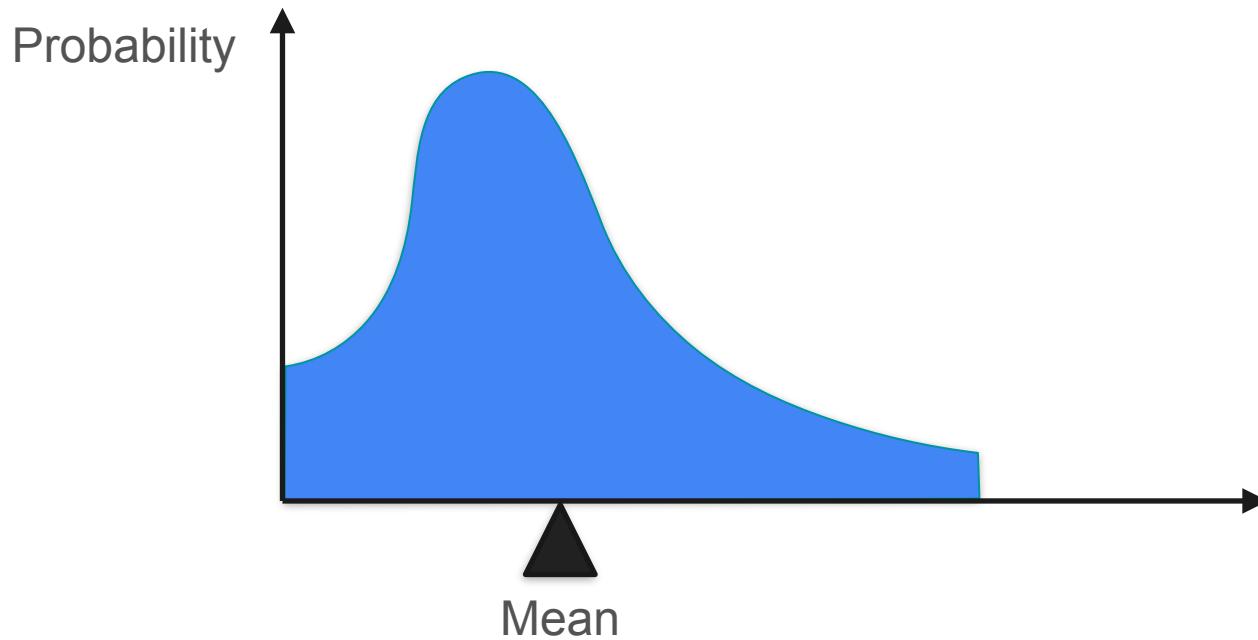
# Expected Value



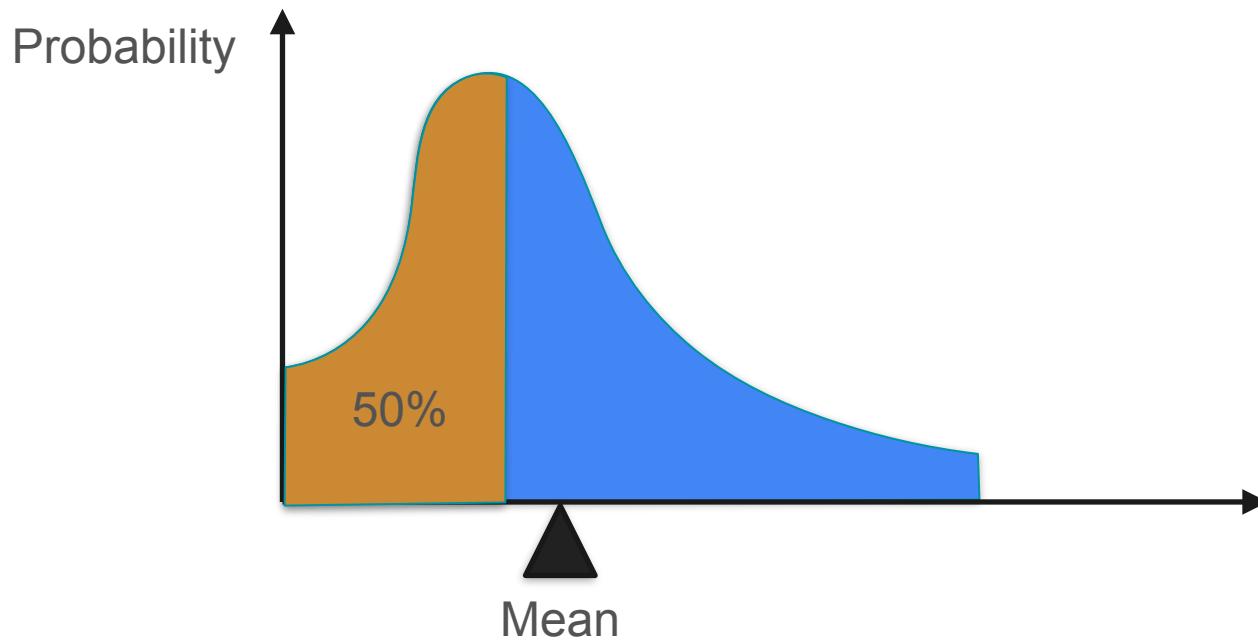
# Expected Value: General Case



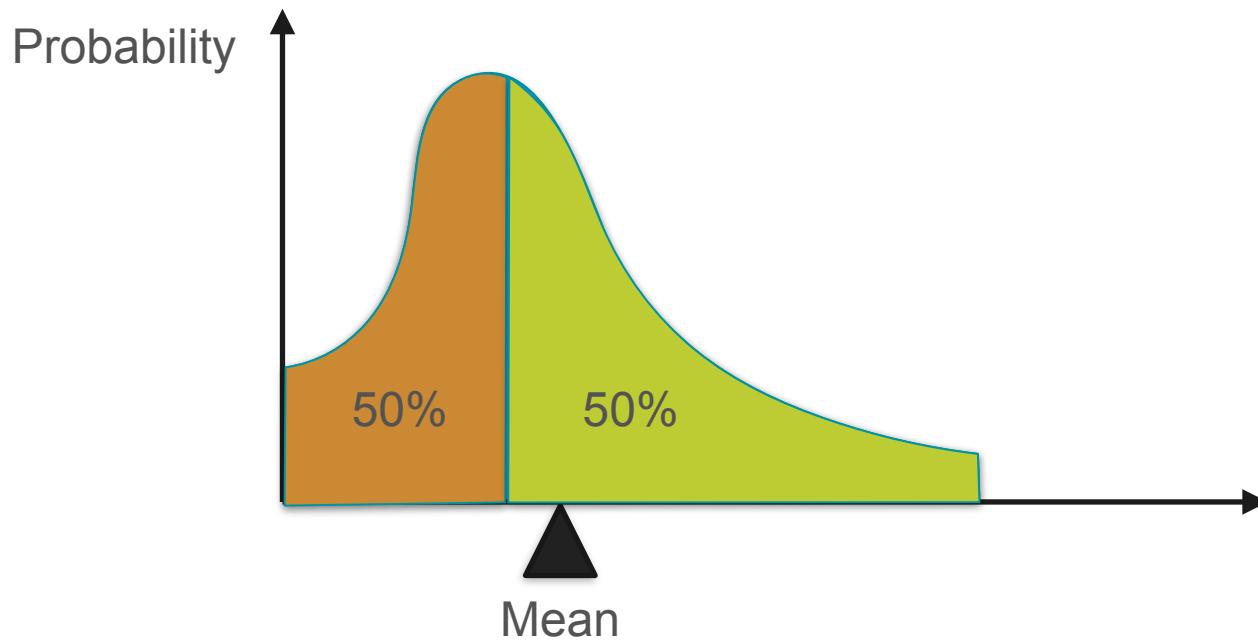
# Expected Value: Common Misconception



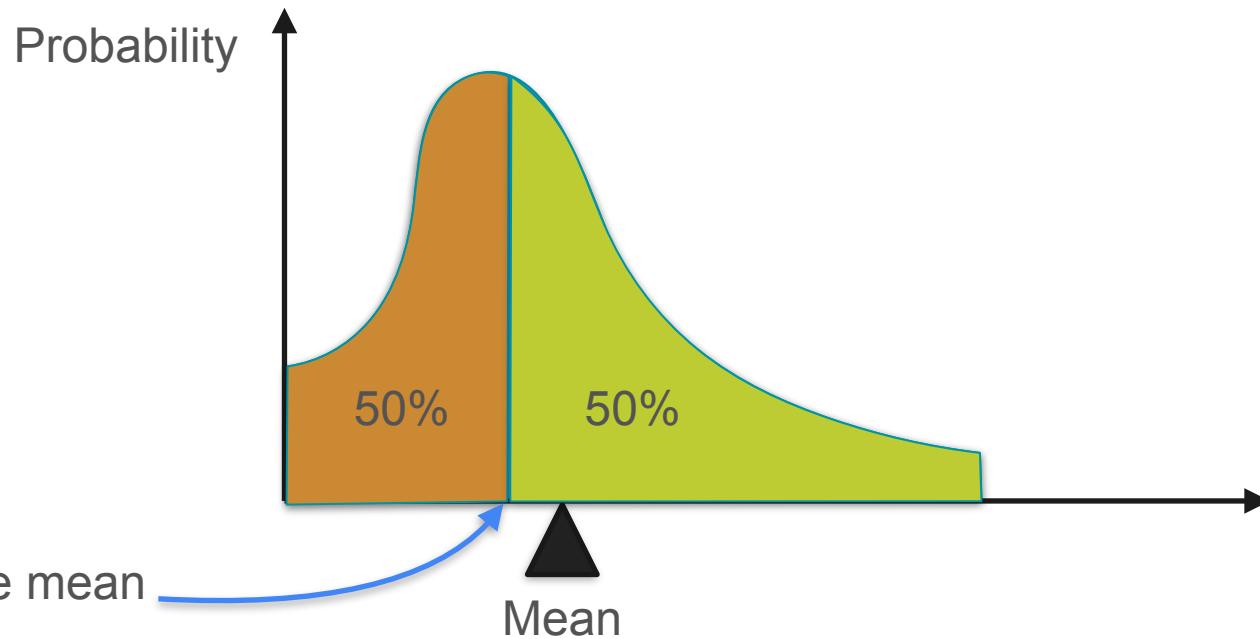
# Expected Value: Common Misconception



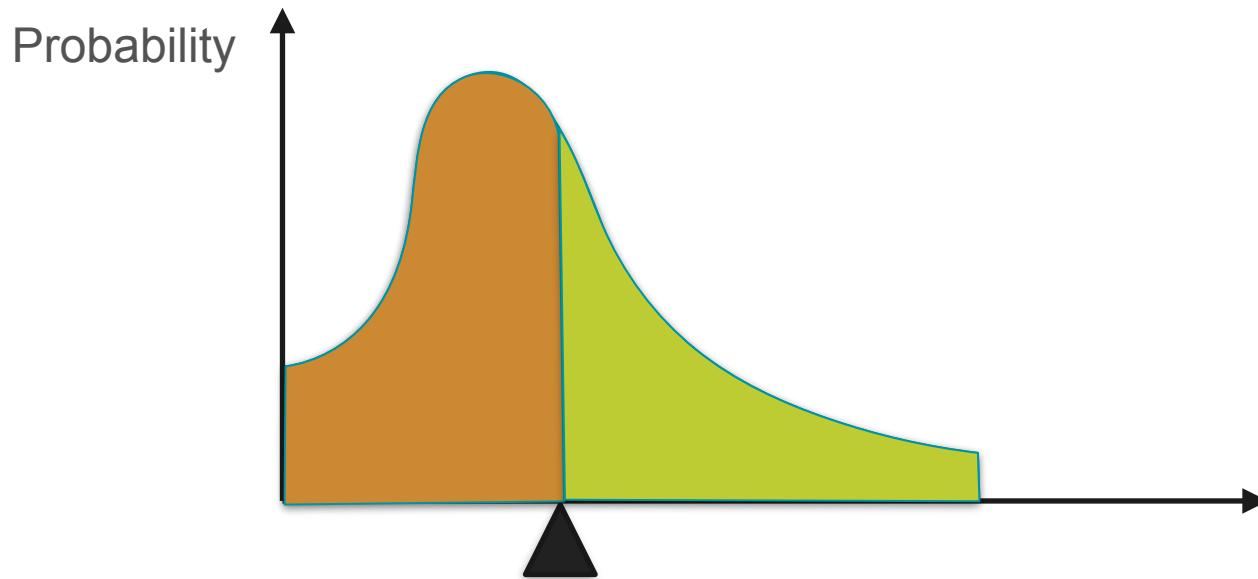
# Expected Value: Common Misconception



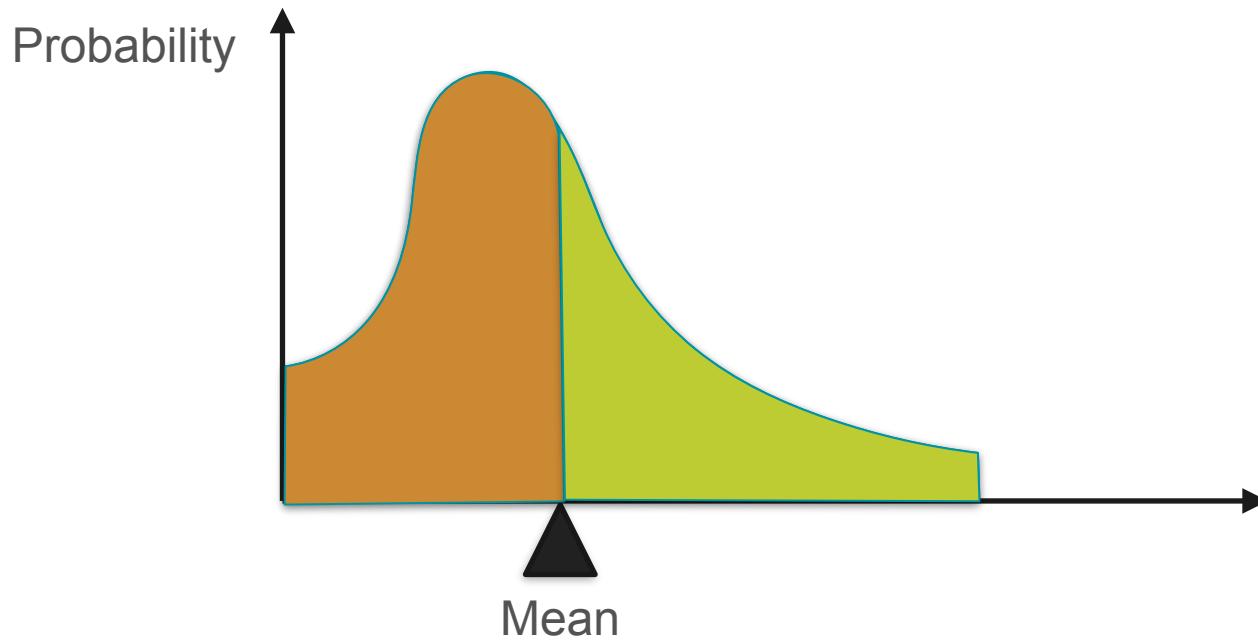
# Expected Value: Common Misconception



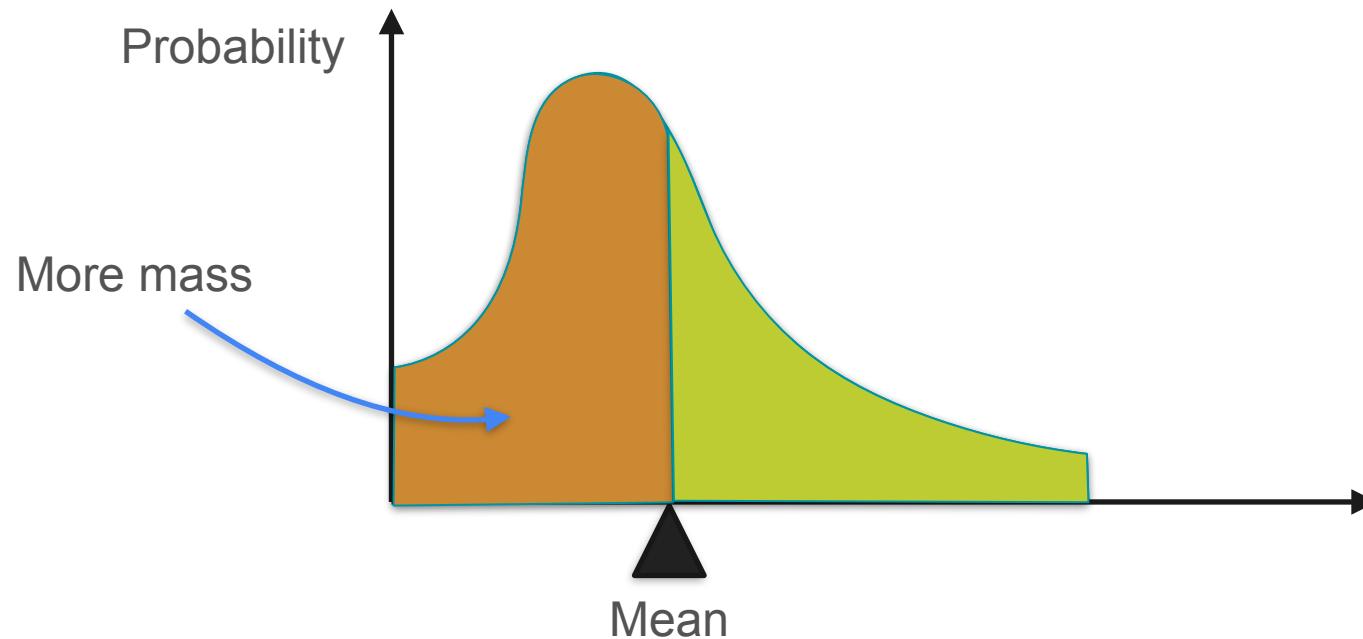
# Expected Value: Common Misconception



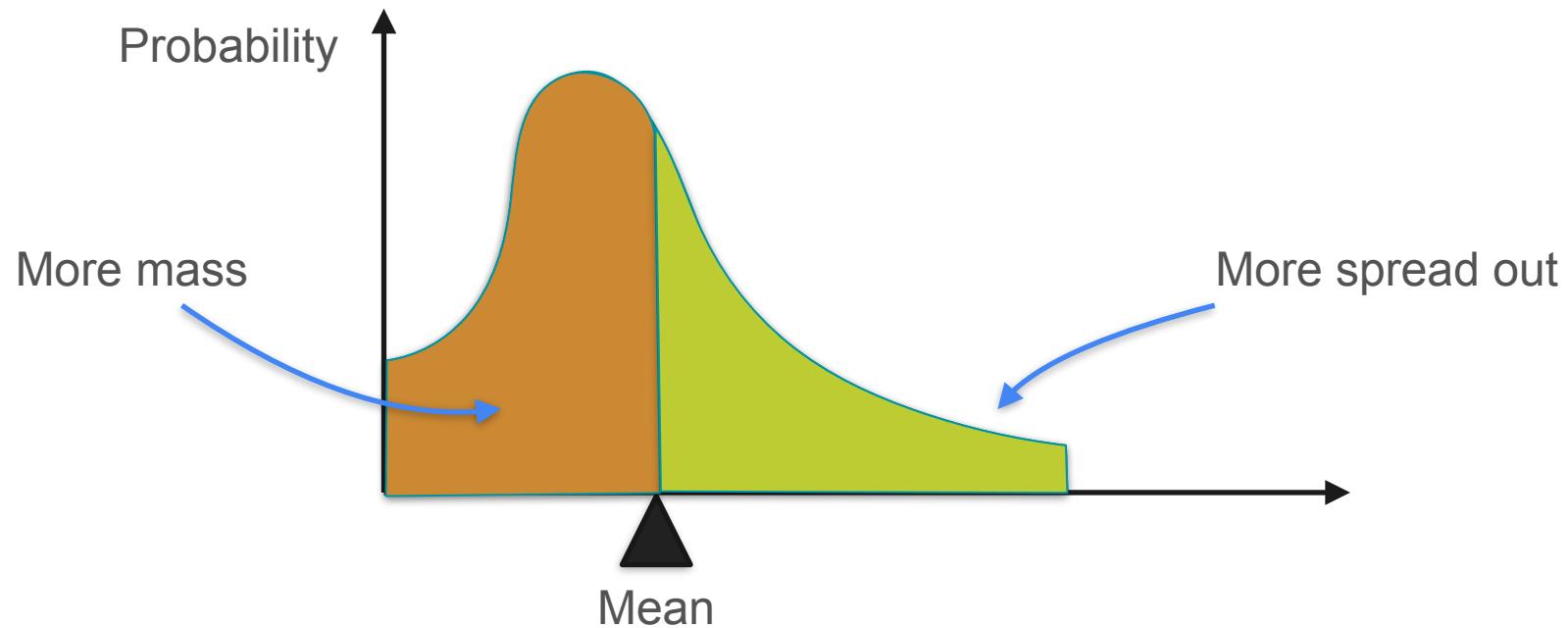
# Expected Value: Common Misconception



# Expected Value: Common Misconception



# Expected Value: Common Misconception



# Expected Value: Common Misconception

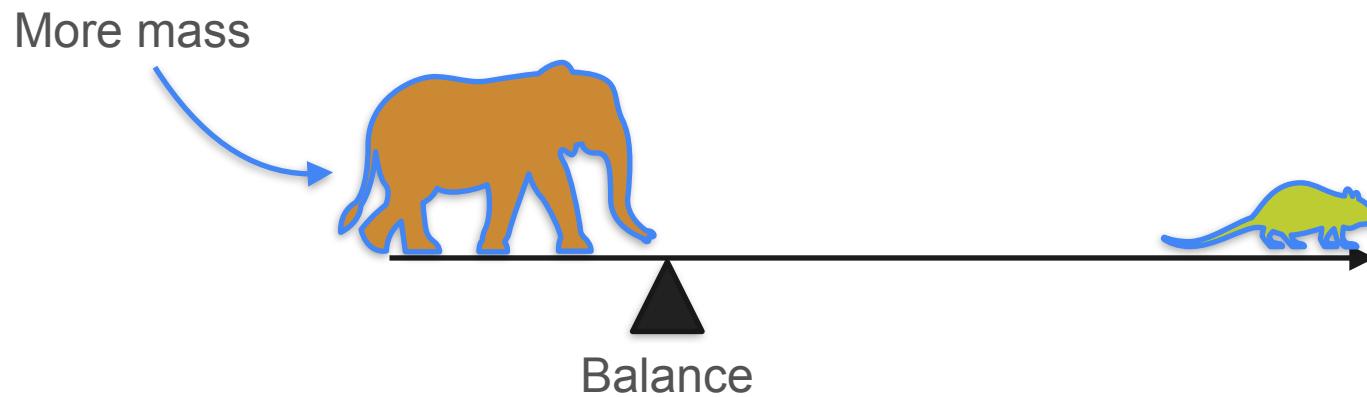


Balance

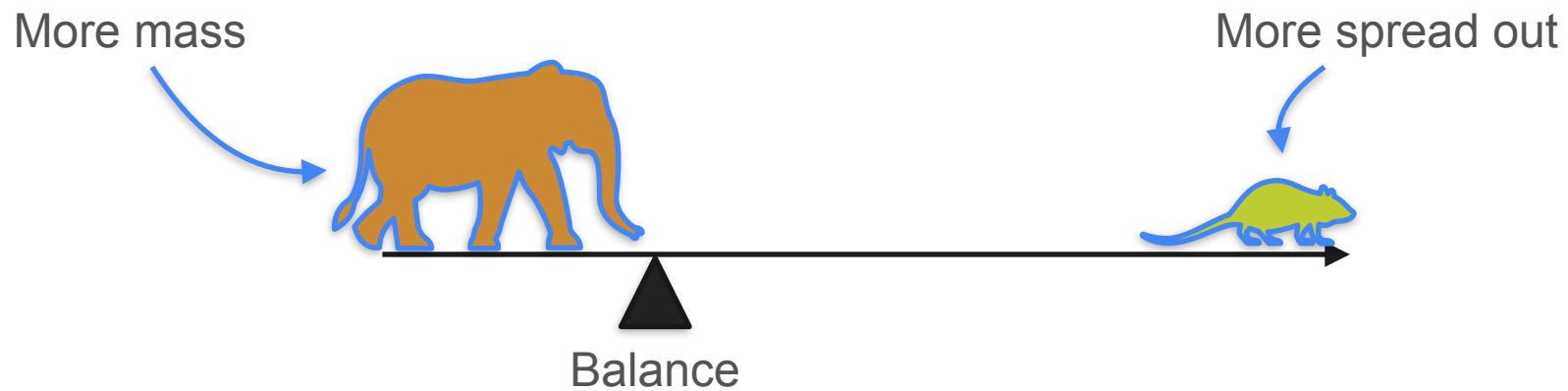
# Expected Value: Common Misconception



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# Expected Value: Common Misconception





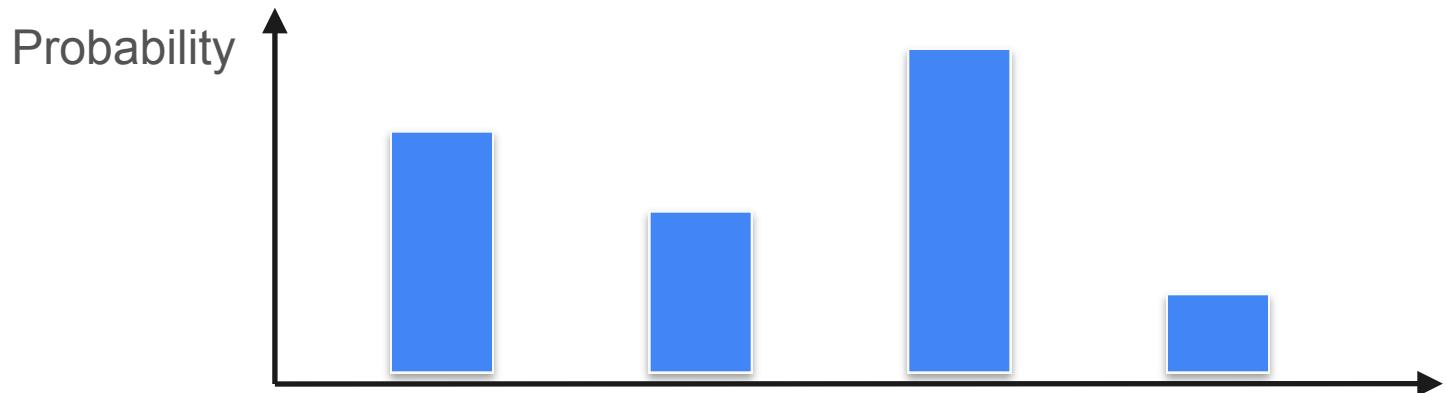
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# Describing Distributions

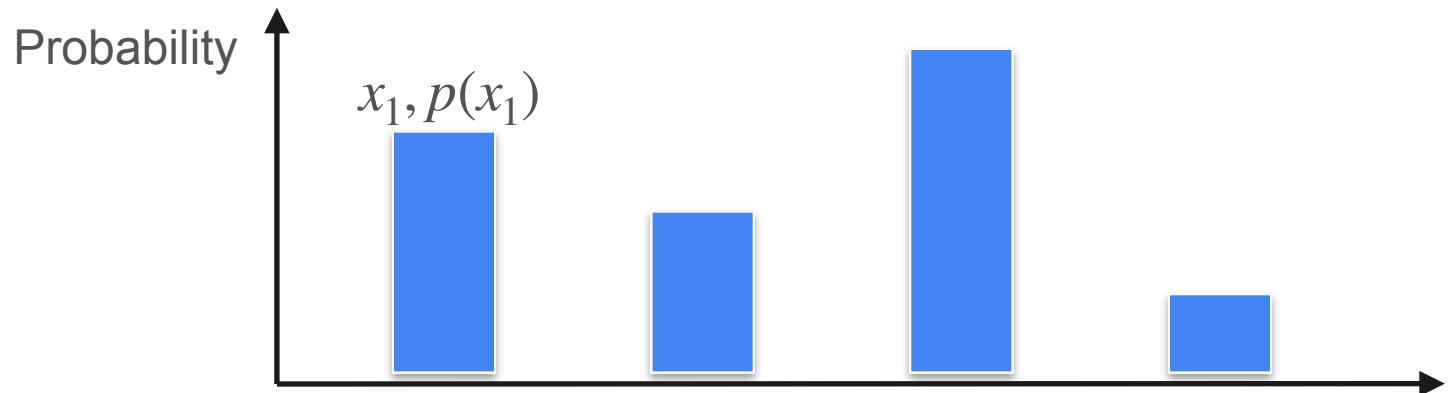
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## Expected value of a function

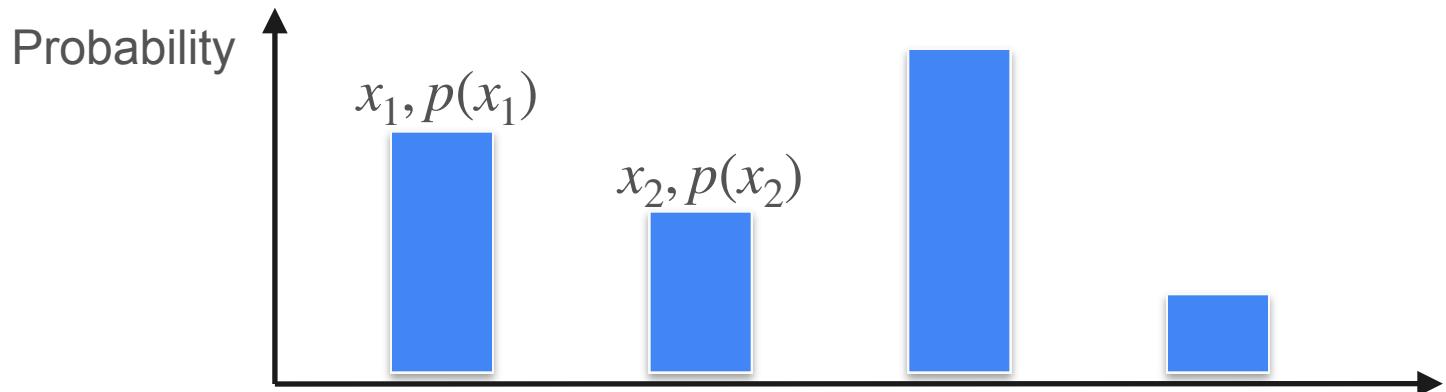
# Expected Value of a Function



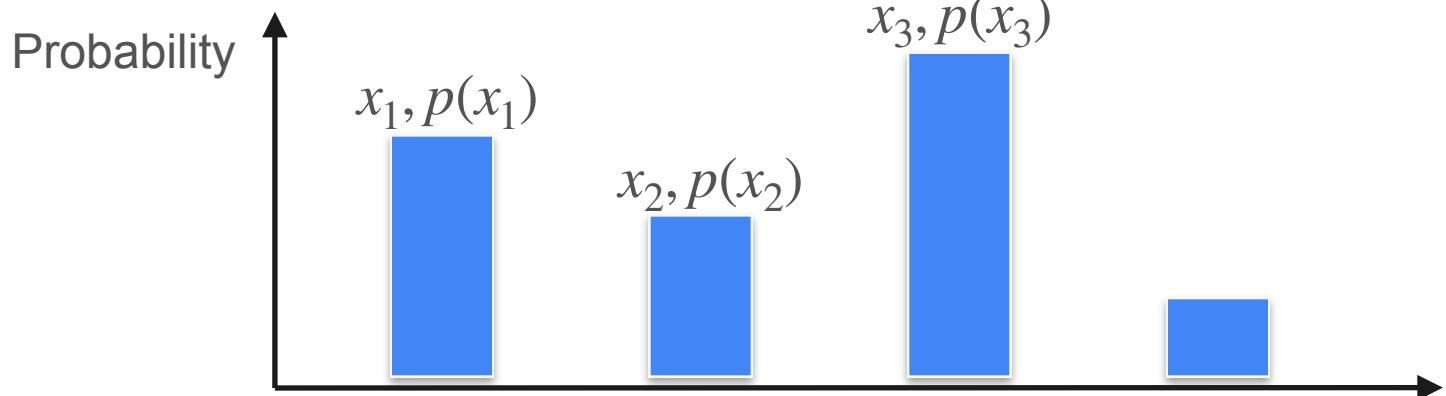
# Expected Value of a Function



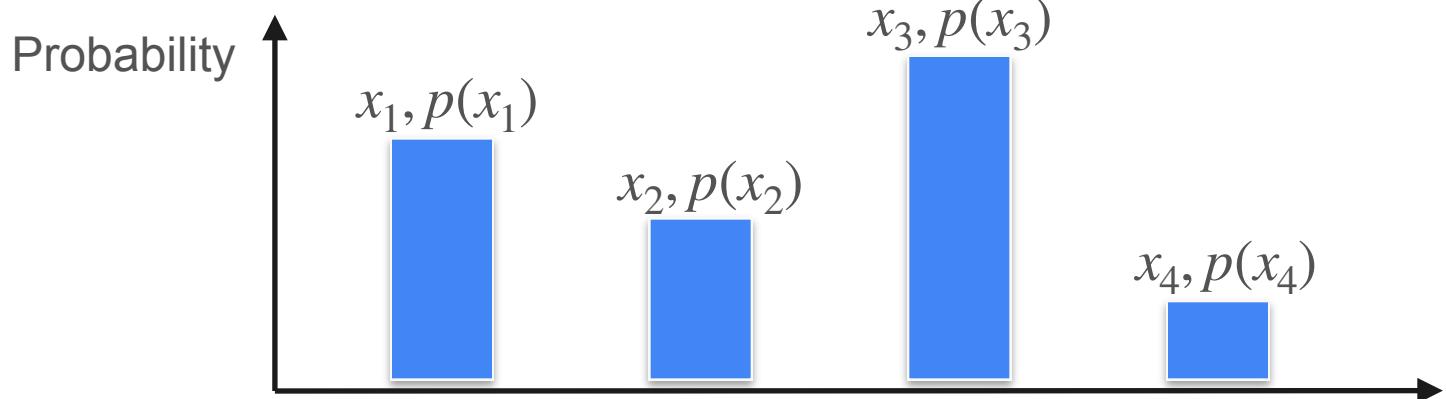
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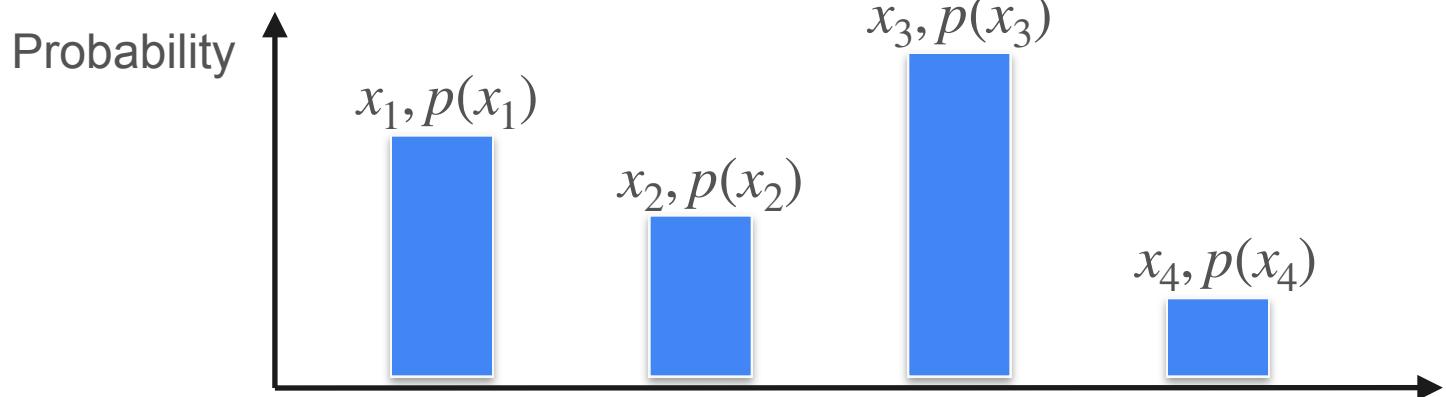
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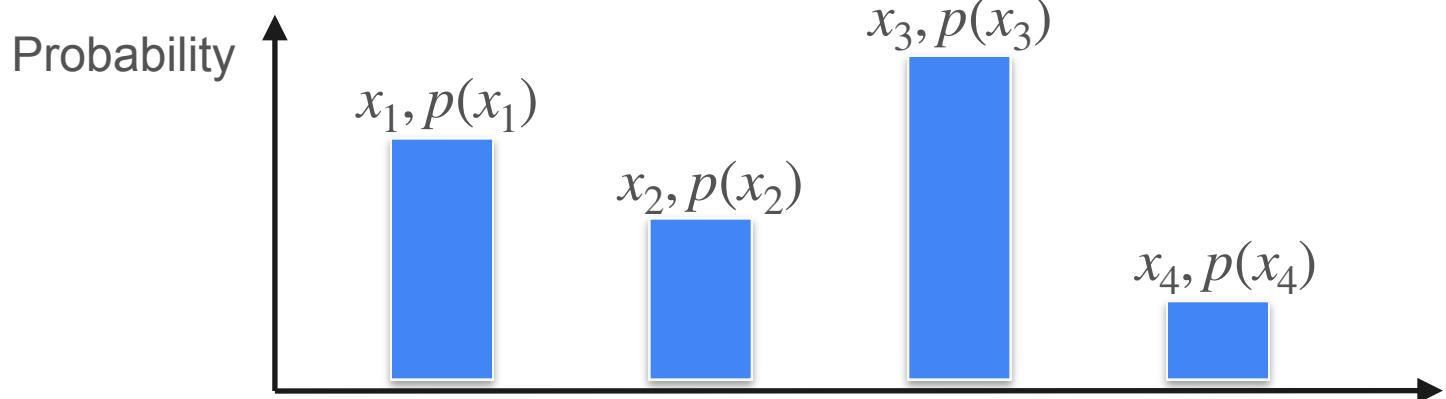


# Expected Value of a Function



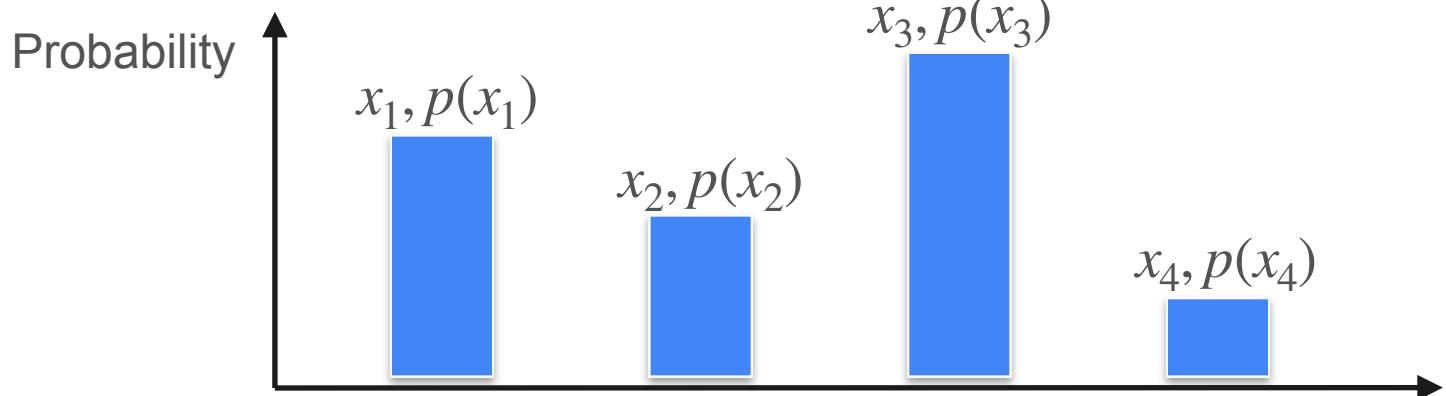
$$\mathbb{E}[X] =$$

# Expected Value of a Function



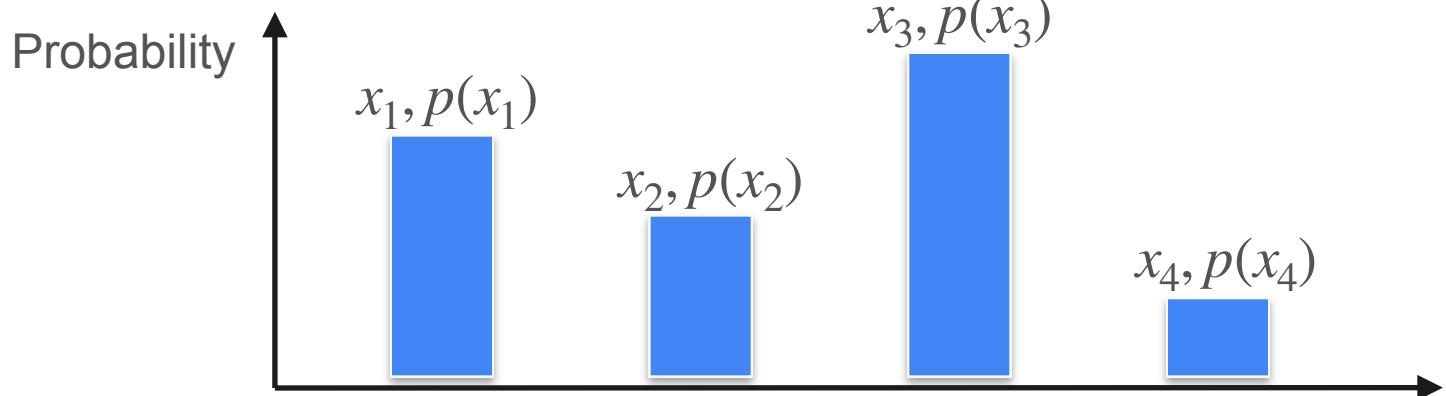
$$\mathbb{E}[X] = x_1 p(x_1)$$

# Expected Value of a Function



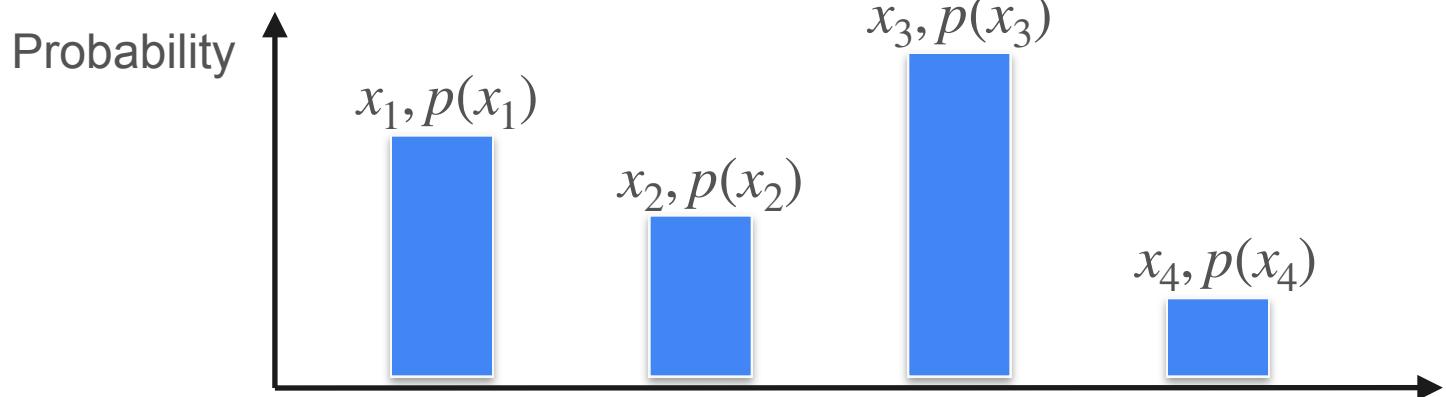
$$\mathbb{E}[X] = x_1 p(x_1) + x_2 p(x_2)$$

# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

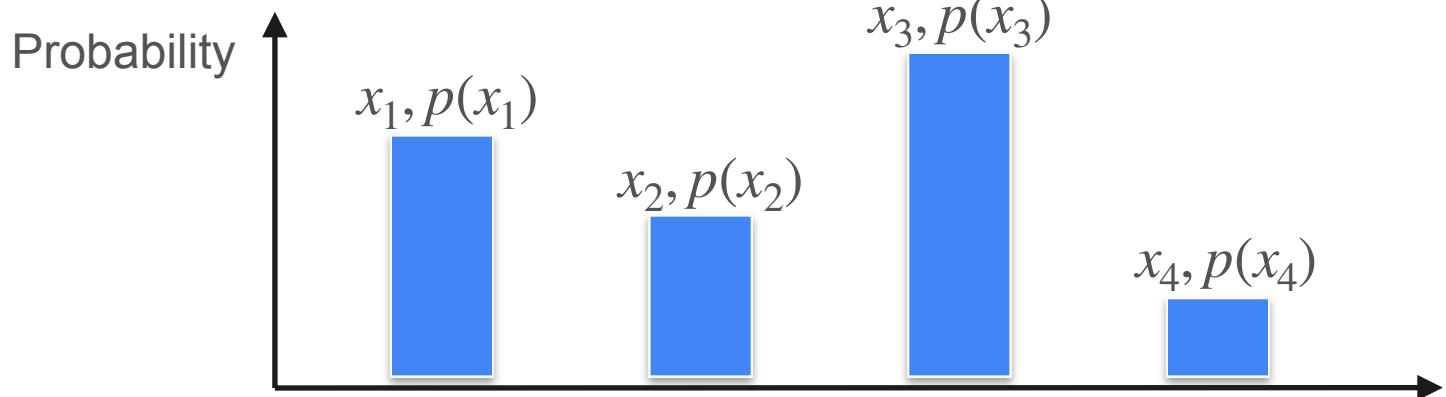
# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] =$$

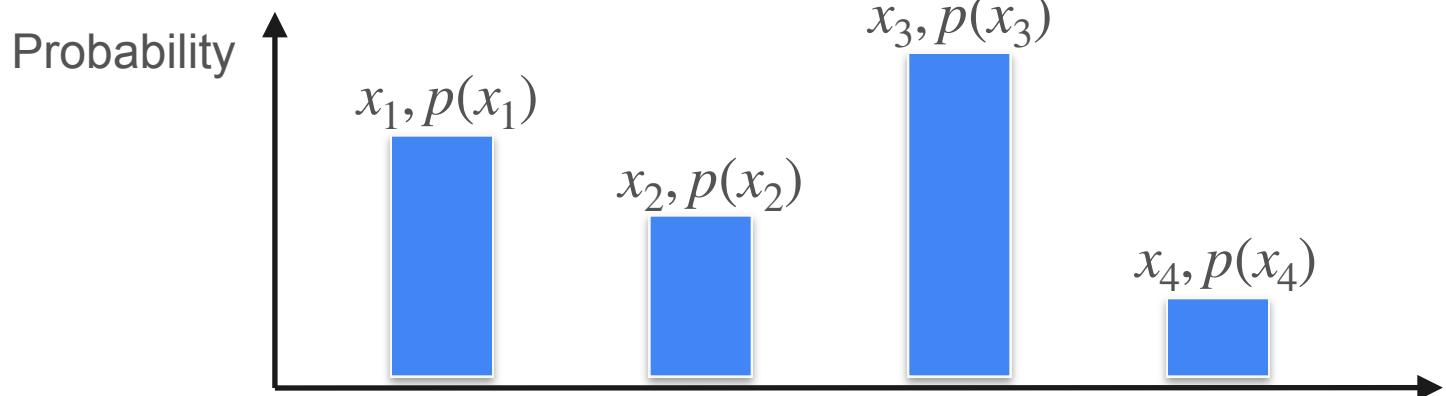
# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] = f(x_1)p(x_1)$$

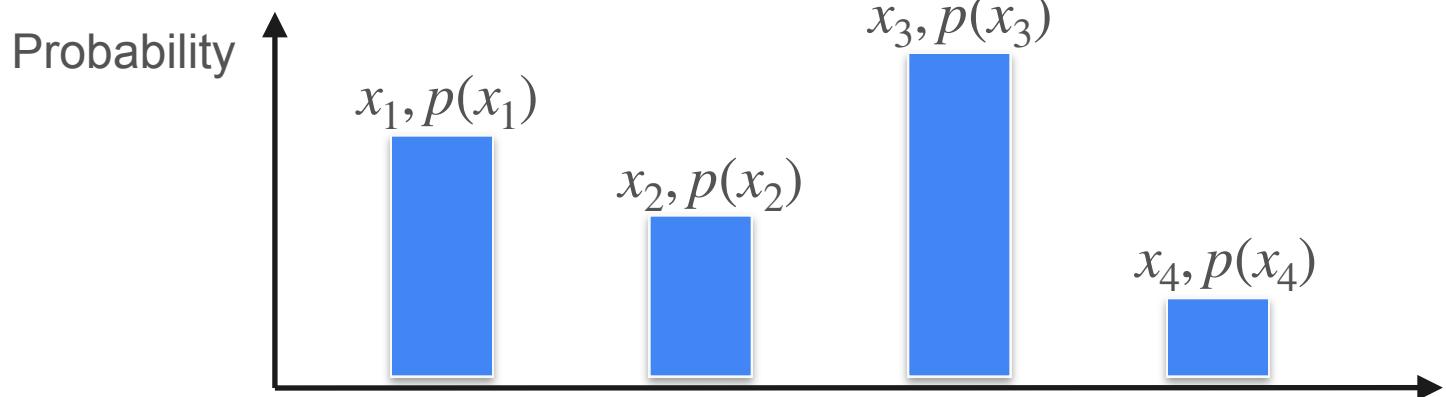
# Expected Value of a Function



$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] = f(x_1)p(x_1) + f(x_2)p(x_2)$$

# Expected Value of a Function



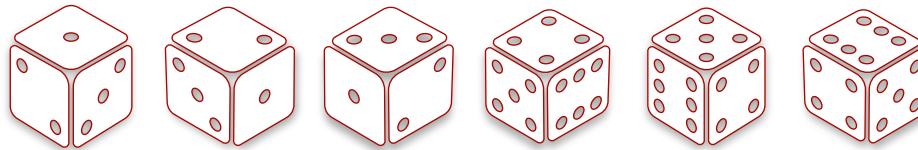
$$\mathbb{E}[X] = x_1p(x_1) + x_2p(x_2) + x_3p(x_3) + x_4p(x_4)$$

$$E[f(X)] = f(x_1)p(x_1) + f(x_2)p(x_2) + f(x_3)p(x_3) + f(x_4)p(x_4)$$

# Expected Value of a Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

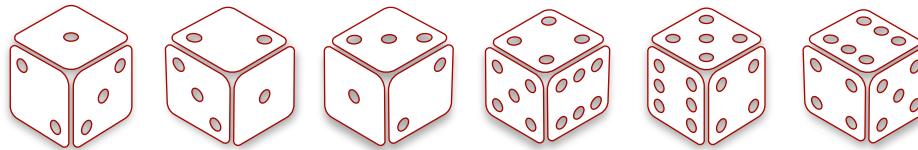
Roll:    1            2            3            4            5            6



# Expected Value of a Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

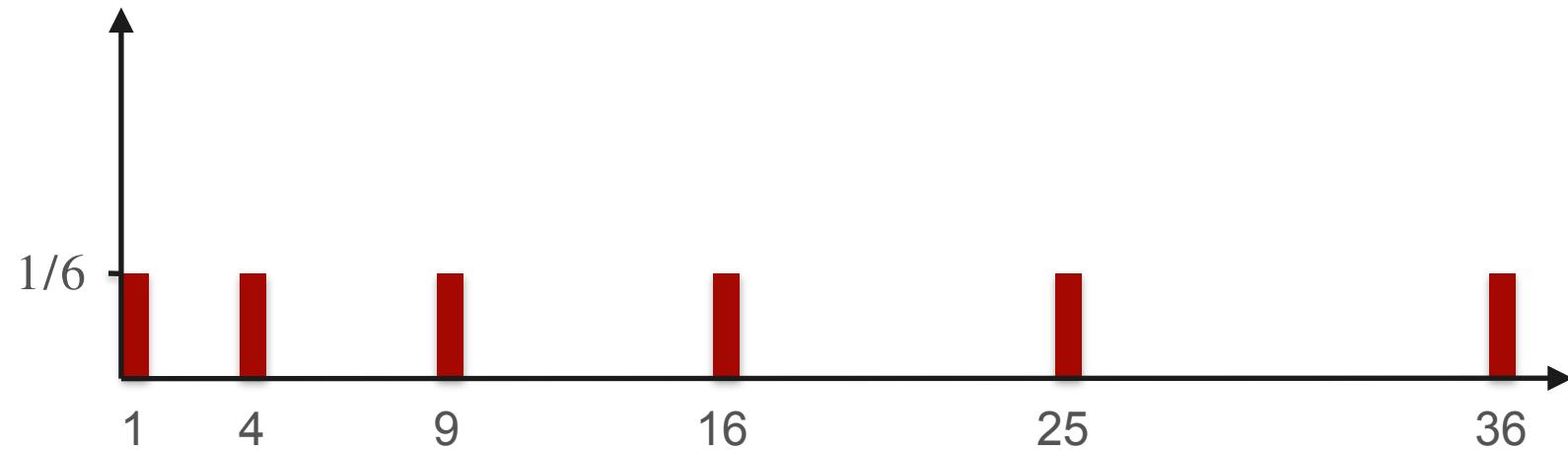
Roll:      1      2      3      4      5      6



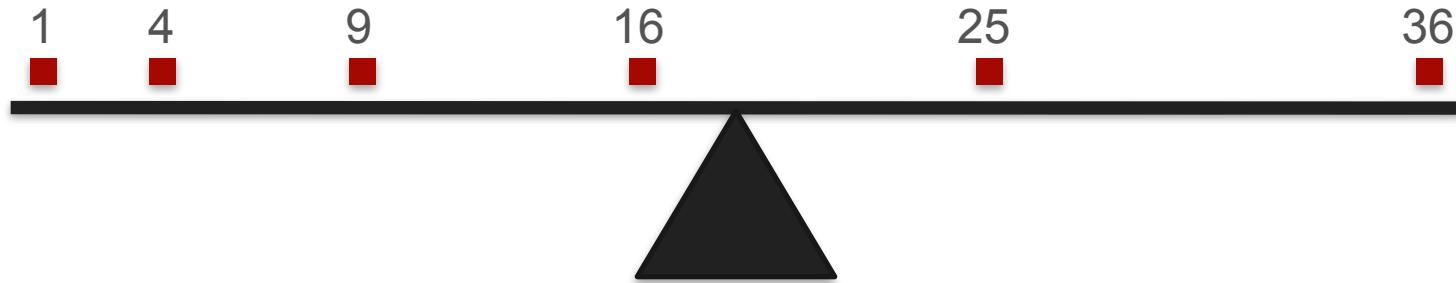
Square:      1      4      9      16      25      36

# Expected Value of a Function

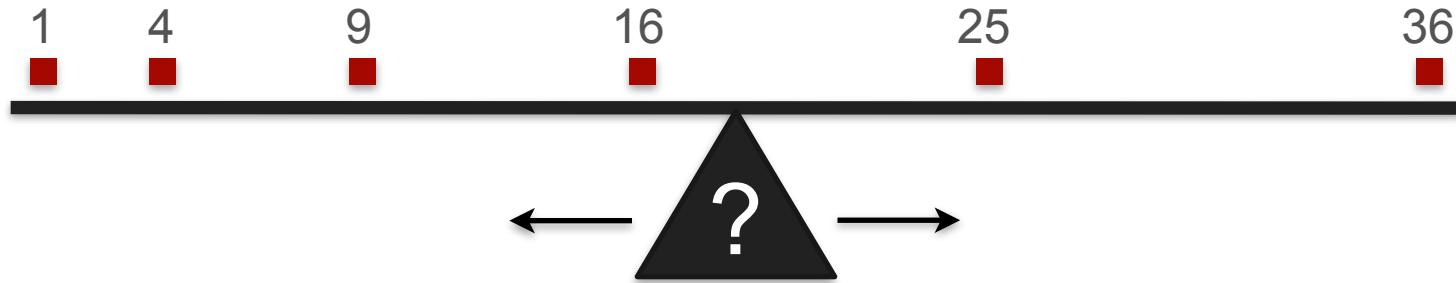
Probability



# Expected Value of a Function

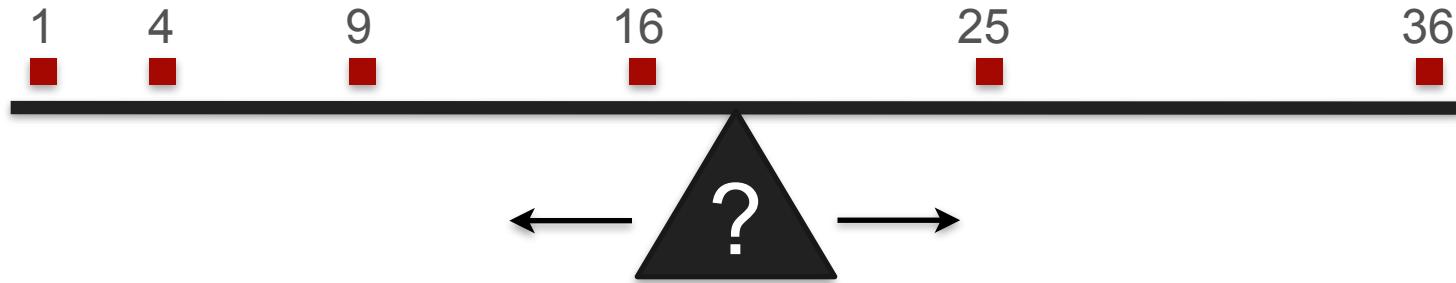


# Expected Value of a Function



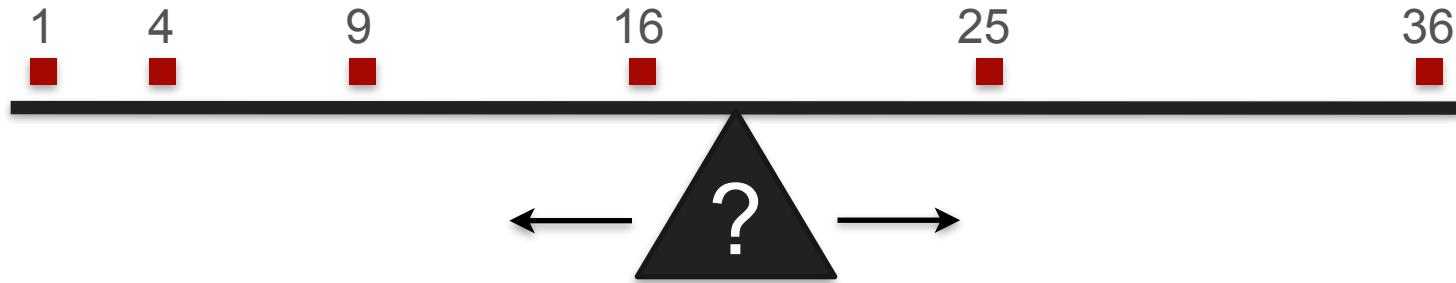
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6}$$



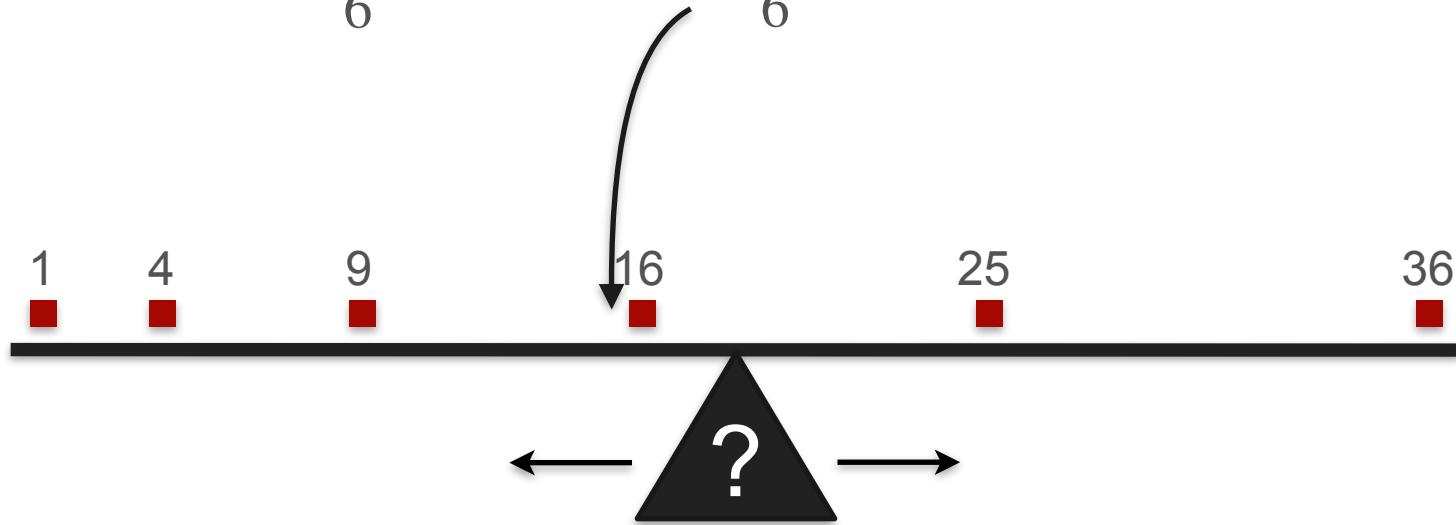
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6}$$



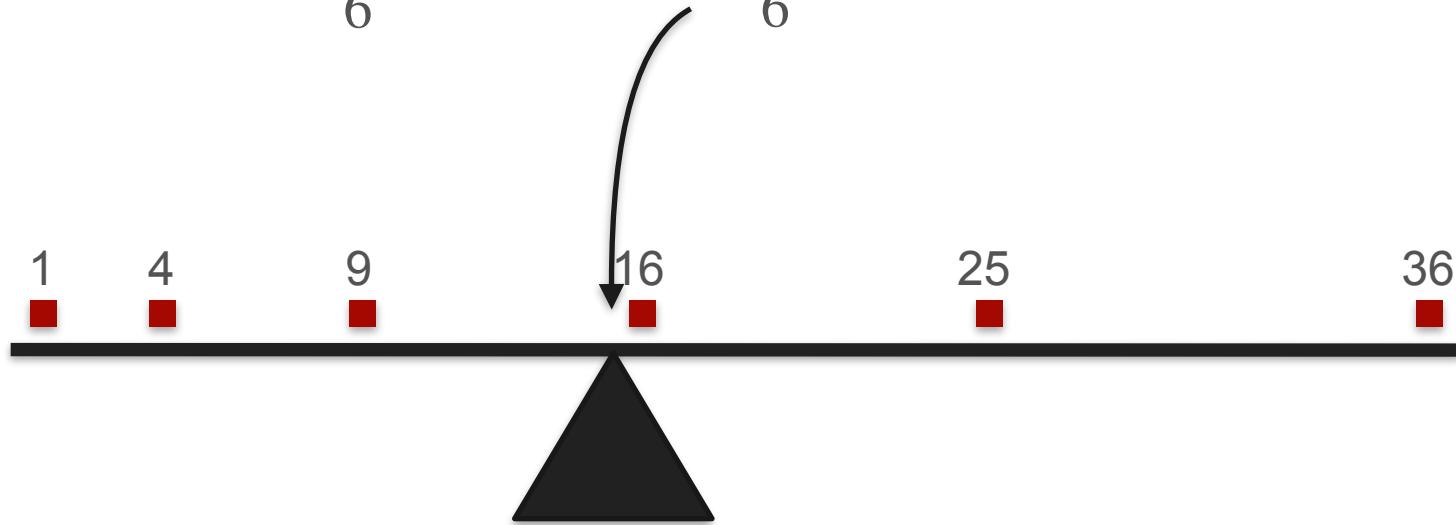
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6}$$



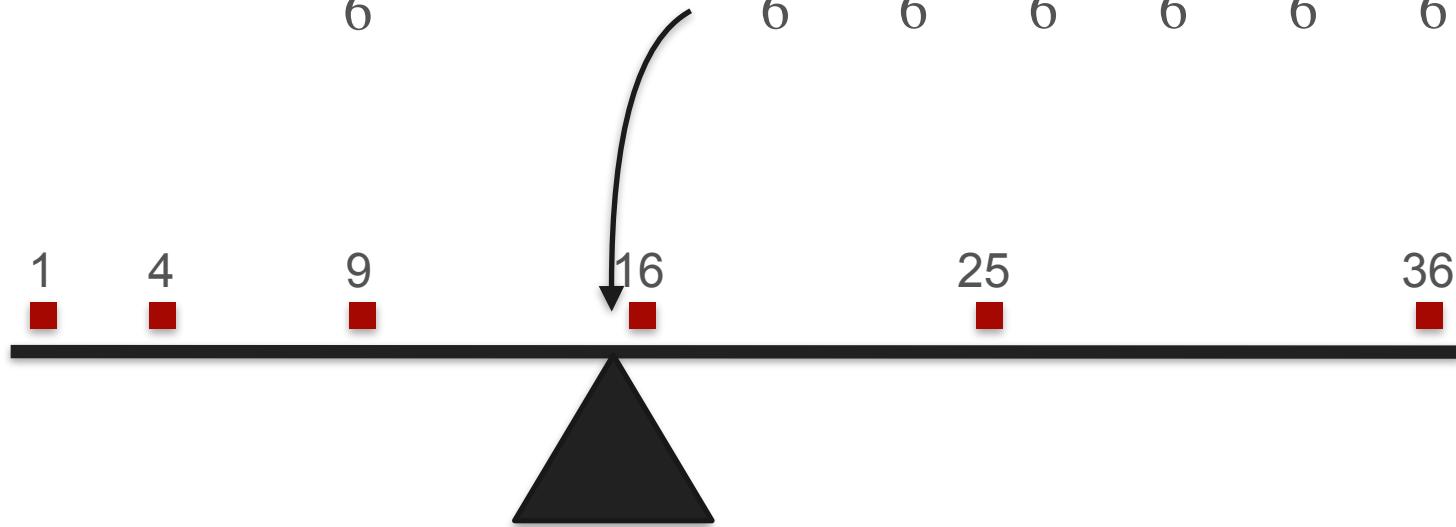
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6}$$



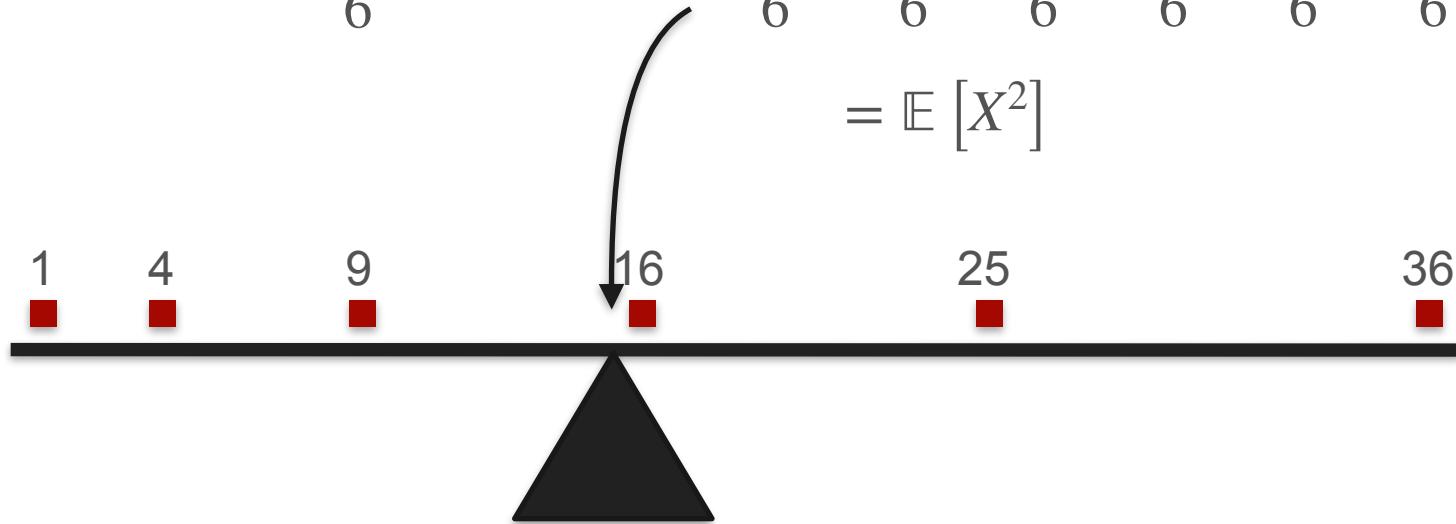
# Expected Value of a Function

$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6} = \frac{1^2}{6} + \frac{2^2}{6} + \frac{3^2}{6} + \frac{4^2}{6} + \frac{5^2}{6} + \frac{6^2}{6}$$



# Expected Value of a Function

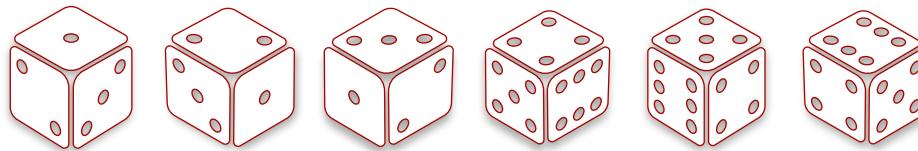
$$\frac{1 + 4 + 9 + 16 + 25 + 36}{6} = \frac{91}{6} = \frac{1^2}{6} + \frac{2^2}{6} + \frac{3^2}{6} + \frac{4^2}{6} + \frac{5^2}{6} + \frac{6^2}{6}$$
$$= \mathbb{E}[X^2]$$



# Expectation of Linear Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

Roll:    1            2            3            4            5            6

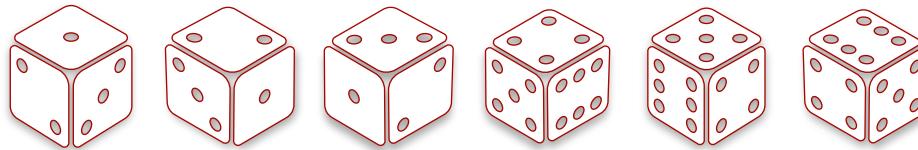


Wins

# Expectation of Linear Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

Roll:      1      2      3      4      5      6



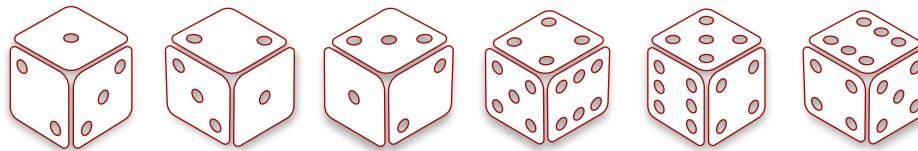
Double:      2      4      6      8      10      12

Wins      2 - 5      4 - 5      6 - 5      8 - 5      10 - 5      12 - 5

# Expectation of Linear Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

Roll:    1            2            3            4            5            6

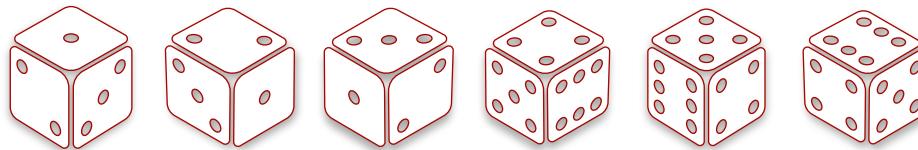


Wins

# Expectation of Linear Function

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

Roll:    1            2            3            4            5            6

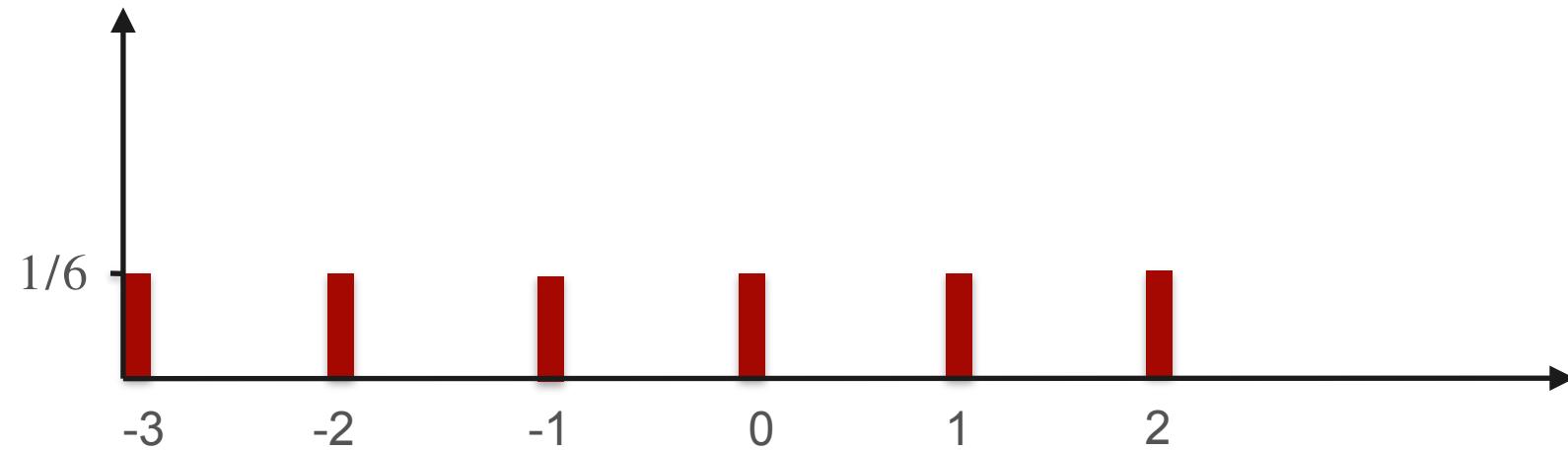


Double:    2            4            6            8            10            12

Wins        -3            -2            -1            0            1            2

# Expected Value of a Function

Probability



# Expected Value of a Function



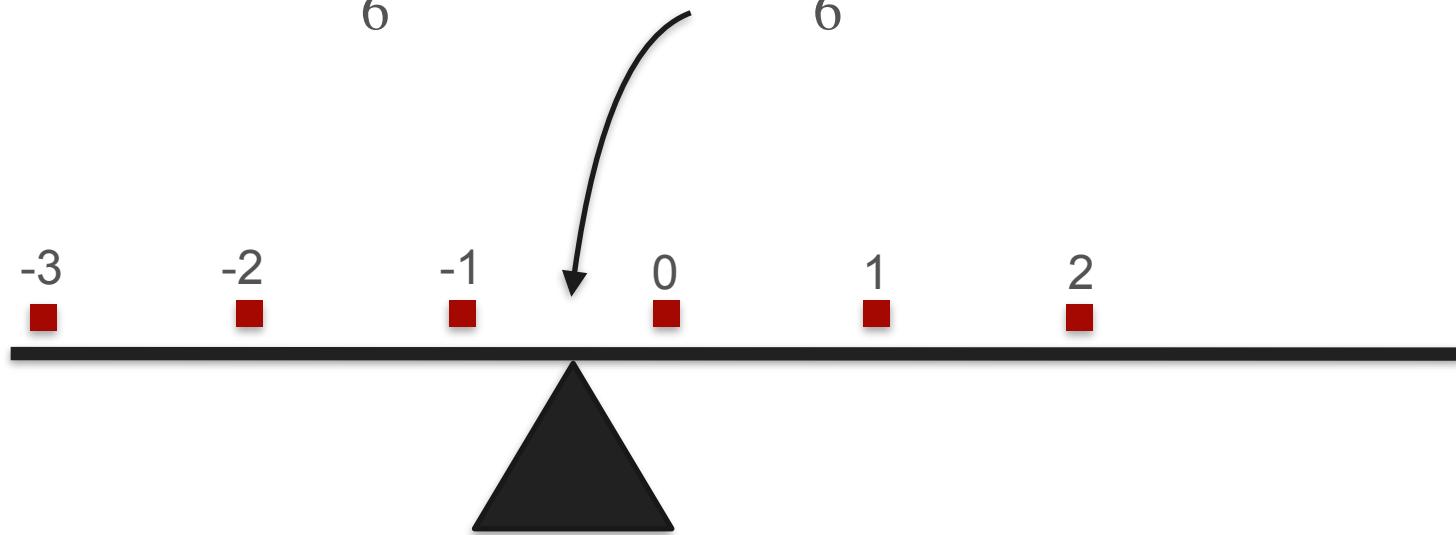
# Expected Value of a Function

$$\frac{-3 + -2 + -1 + 0 + 1 + 2}{6}$$



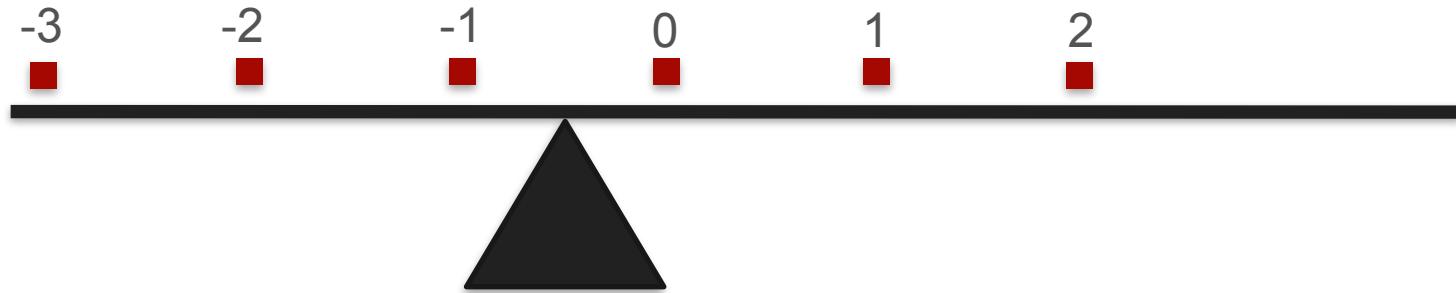
# Expected Value of a Function

$$\frac{-3 + -2 + -1 + 0 + 1 + 2}{6} = \frac{-3}{6} = -0.5$$



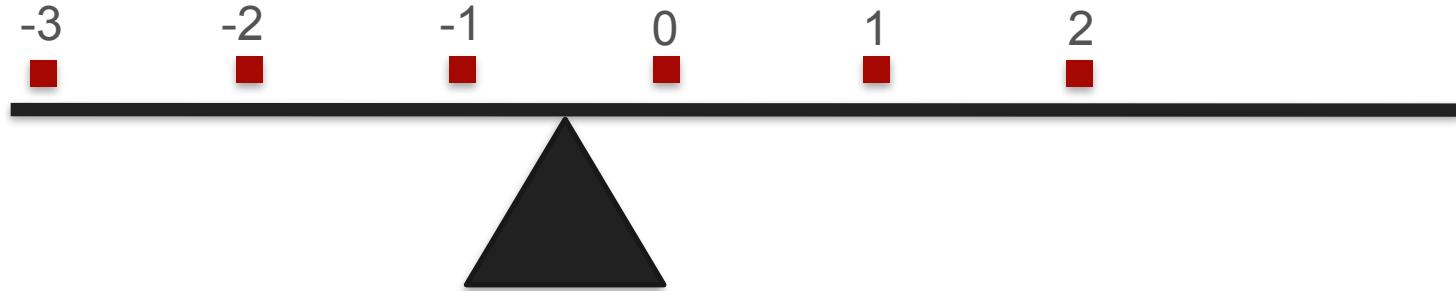
# Expected Value of a Function

$$\frac{(2 \cdot 1 - 5) + (2 \cdot 2 - 5) + (2 \cdot 3 - 5) + (2 \cdot 4 - 5) + (2 \cdot 5 - 5) + (2 \cdot 6 - 5)}{6} = \frac{-3}{6} = -0.5$$



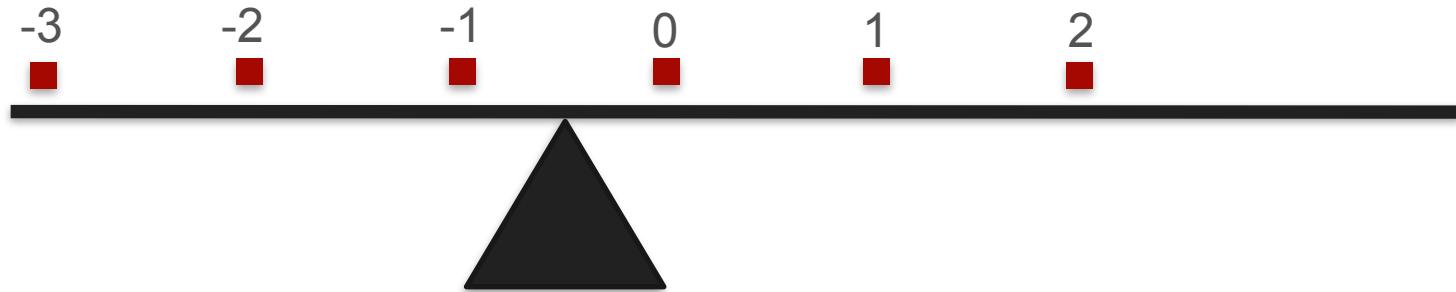
# Expected Value of a Function

$$\frac{(2 \cdot 1) + (2 \cdot 2) + (2 \cdot 3) + (2 \cdot 4) + (2 \cdot 5) + (2 \cdot 6) + 6 \cdot (-5)}{6} = \frac{-3}{6} = -0.5$$



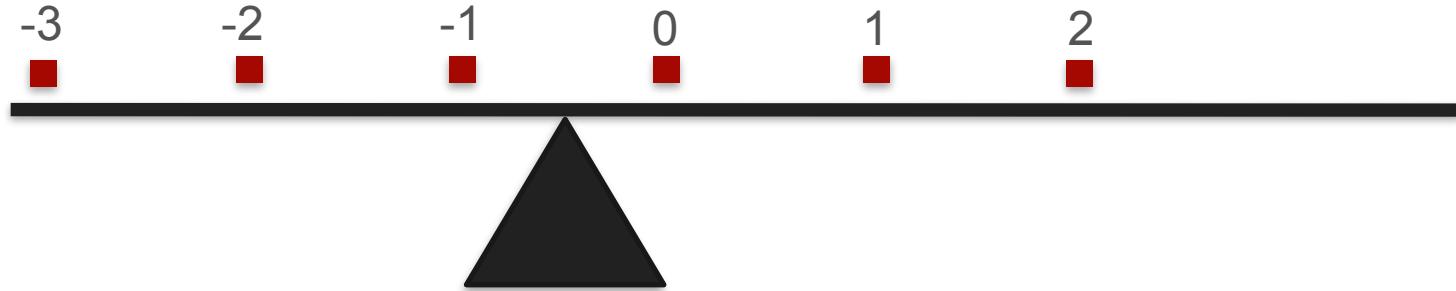
# Expected Value of a Function

$$\frac{(2 \cdot 1) + (2 \cdot 2) + (2 \cdot 3) + (2 \cdot 4) + (2 \cdot 5) + (2 \cdot 6)}{6} + (-5) = \frac{-3}{6} = -0.5$$

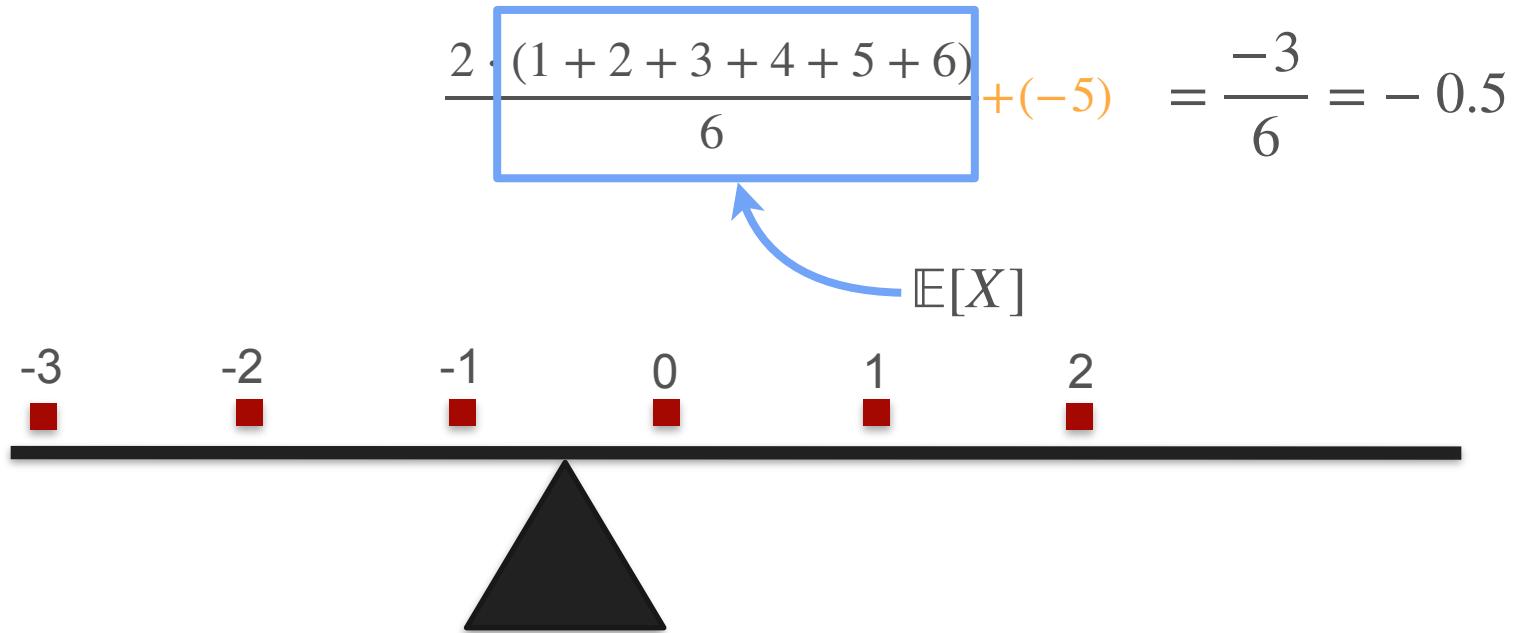


# Expected Value of a Function

$$\frac{2 \cdot (1 + 2 + 3 + 4 + 5 + 6)}{6} + (-5) = \frac{-3}{6} = -0.5$$



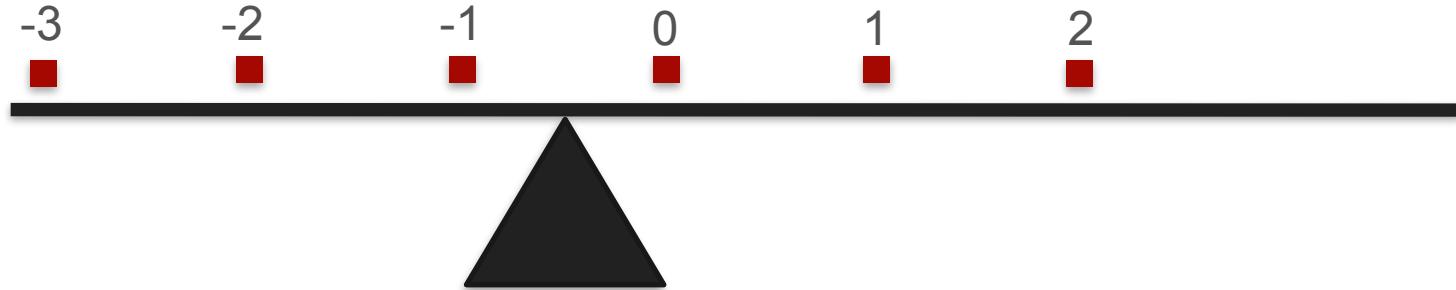
# Expected Value of a Function



# Expected Value of a Function

$$\mathbb{E}[2 \cdot X + (-5)] = \frac{2 \cdot (1 + 2 + 3 + 4 + 5 + 6)}{6} + (-5) = \frac{-3}{6} = -0.5$$

$= 2 \cdot \mathbb{E}[X] + (-5)$



# Expected Value of a Function

$$\mathbb{E}[2 \cdot X + (-5)] = \frac{2 \cdot (1 + 2 + 3 + 4 + 5 + 6)}{6} + (-5) = \frac{-3}{6} = -0.5$$

$= 2 \cdot \mathbb{E}[X] + (-5)$



In general:  
 $\mathbb{E}[aX + b] = a\mathbb{E}[X] + b$

# Expected Value of a Function

$$\mathbb{E}[2 \cdot X + (-5)] = \frac{2 \cdot (1 + 2 + 3 + 4 + 5 + 6)}{6} + (-5) = \frac{-3}{6} = -0.5$$

$= 2 \cdot \mathbb{E}[X] + (-5)$



In general:

$$\mathbb{E}[aX + b] = a\mathbb{E}[X] + b$$

$$\mathbb{E}[aX] = a\mathbb{E}[X]$$

# Expected Value of a Function

$$\mathbb{E}[2 \cdot X + (-5)] = \frac{2 \cdot (1 + 2 + 3 + 4 + 5 + 6)}{6} + (-5) = \frac{-3}{6} = -0.5$$

$= 2 \cdot \mathbb{E}[X] + (-5)$



In general:

$$\mathbb{E}[aX + b] = a\mathbb{E}[X] + b$$

$$\mathbb{E}[aX] = a\mathbb{E}[X]$$

$$\mathbb{E}[b] = b$$



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# Describing Distributions

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## Sum of expectations

# Sum of Expectation: Expected Winnings

You play a game:

# Sum of Expectation: Expected Winnings

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

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Win \$1



Win nothing

# Sum of Expectation: Expected Winnings

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

Then throw a dice. You win the amount you roll.



Win \$1



Win nothing

# Sum of Expectation: Expected Winnings

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

Then throw a dice. You win the amount you roll.

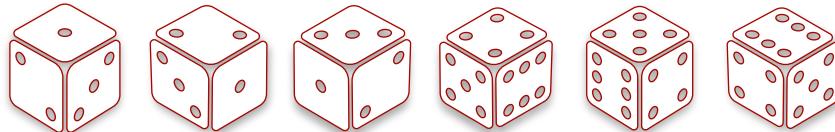


Win \$1



Win nothing

Win      \$1      \$2      \$3      \$4      \$5      \$6



# Sum of Expectation: Expected Winnings

You play a game:

Flip a coin. If heads you win \$ 1, else you win nothing.

Then throw a dice. You win the amount you roll.

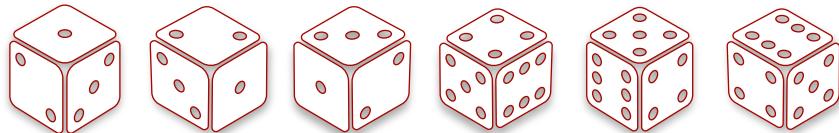


Win \$1



Win nothing

Win      \$1      \$2      \$3      \$4      \$5      \$6



What are your expected winnings for the game?

# Sum of Expectations: Expected Winnings



Win \$1



Win nothing

Win

\$1

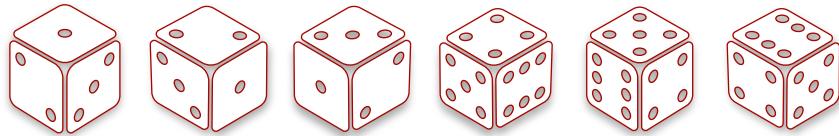
\$2

\$3

\$4

\$5

\$6



# Sum of Expectations: Expected Winnings

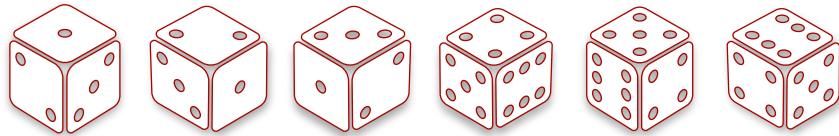


Win \$1



Win nothing

Win    \$1    \$2    \$3    \$4    \$5    \$6



$$\mathbb{E} [X_{coin}] = \$0.5$$

# Sum of Expectations: Expected Winnings



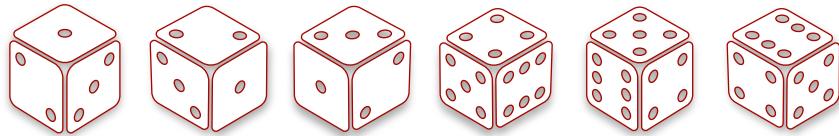
Win \$1



Win nothing

$$\mathbb{E}[X_{coin}] = \$0.5$$

Win    \$1    \$2    \$3    \$4    \$5    \$6



$$\mathbb{E}[X_{dice}] = \$3.5$$

# Sum of Expectations: Expected Winnings

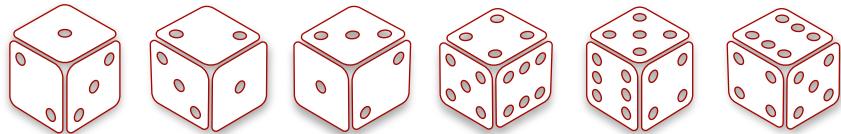


Win \$1



Win nothing

Win \$1 \$2 \$3 \$4 \$5 \$6



$$\mathbb{E}[X_{coin}] = \$0.5$$

$$\mathbb{E}[X_{dice}] = \$3.5$$

$$\mathbb{E}[X] = \mathbb{E}[X_{coin}] + \mathbb{E}[X_{dice}] = \$0.5 + \$3.5 = \$4$$

# Sum of Expectations: Expected Winnings

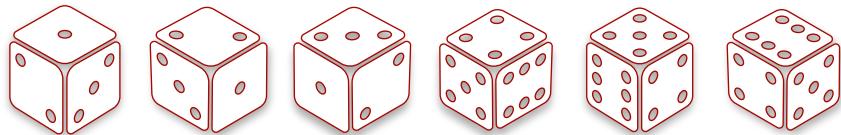


Win \$1



Win nothing

Win \$1 \$2 \$3 \$4 \$5 \$6



$$\mathbb{E}[X_{coin}] = \$0.5$$

$$\mathbb{E}[X_{dice}] = \$3.5$$

$$\mathbb{E}[X] = \mathbb{E}[X_{coin}] + \mathbb{E}[X_{dice}] = \$0.5 + \$3.5 = \$4$$

In general:  $\mathbb{E}[X_1 + X_2] = \mathbb{E}[X_1] + \mathbb{E}[X_2]$

# Sum of Expectations: Bag With Names



8 billion people

# Sum of Expectations: Bag With Names



8 billion people

# Sum of Expectations: Bag With Names



8 billion people

# Sum of Expectations: Bag With Names



Expected number of  
correct assignments?



8 billion people

# Sum of Expectations: Bag With Names



1

Expected number of  
correct assignments?



8 billion people

# Sum of Expectations: Bag With Names



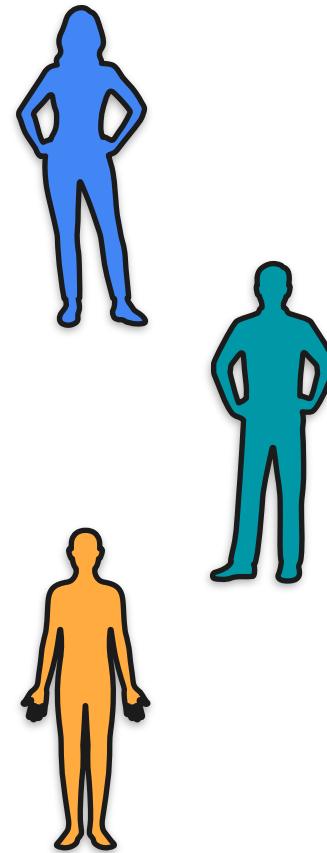
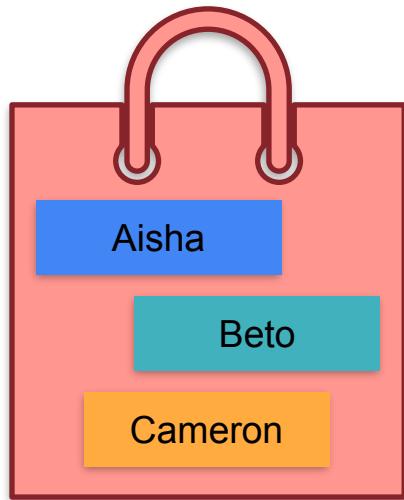
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Expected number of  
correct assignments?

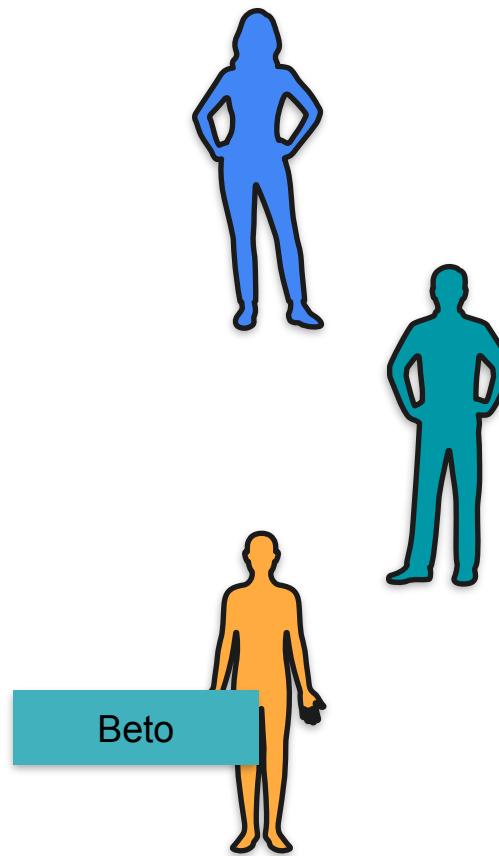
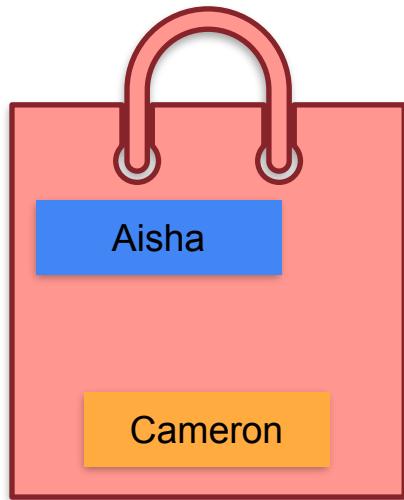


8 billion people

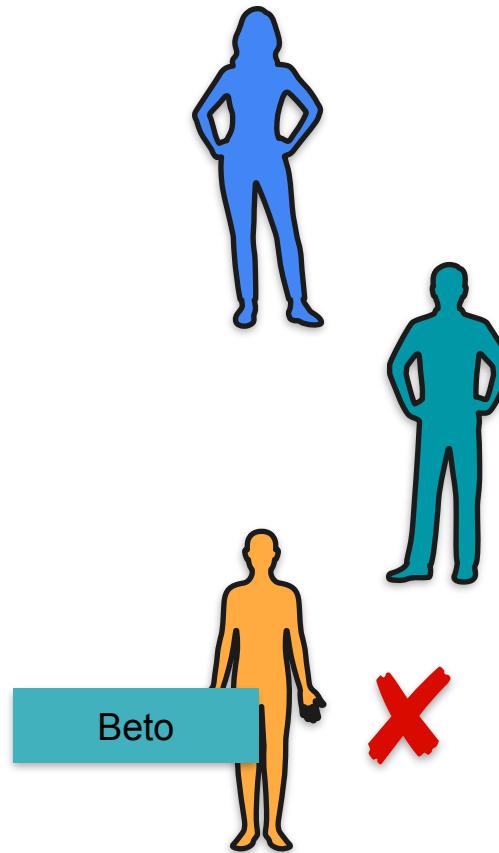
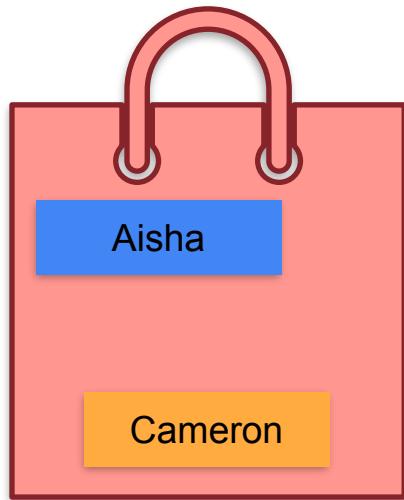
# Bag With 3 Names



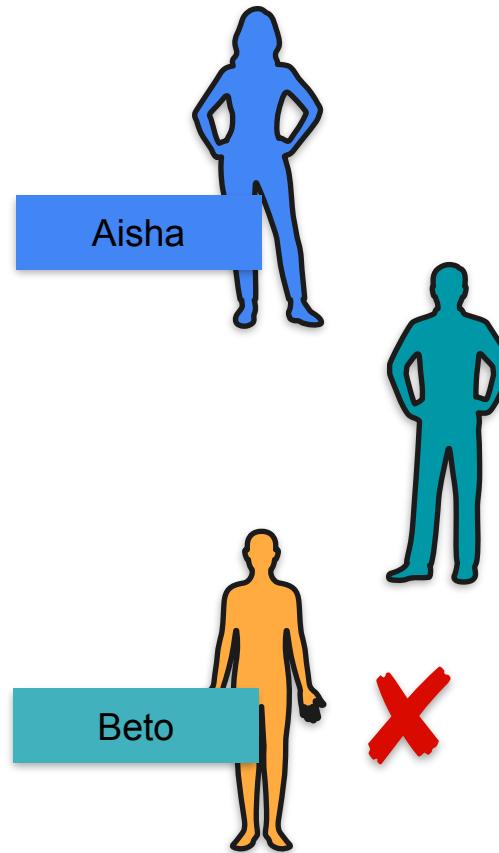
# Bag With 3 Names



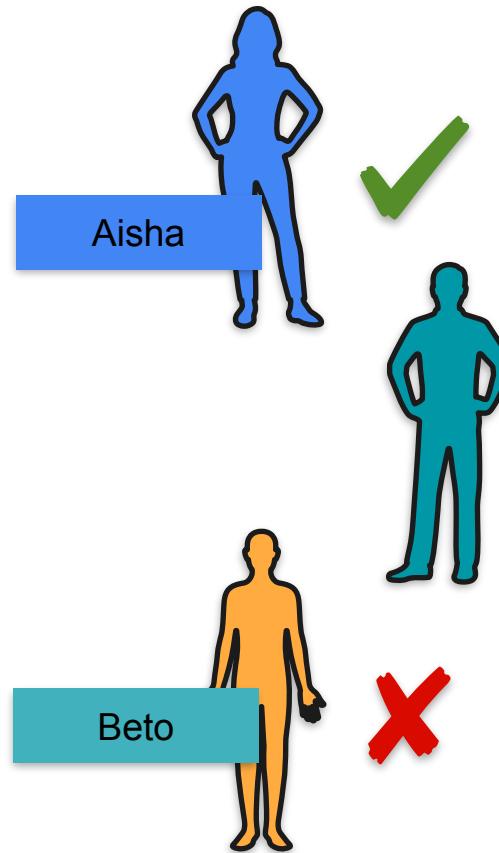
# Bag With 3 Names



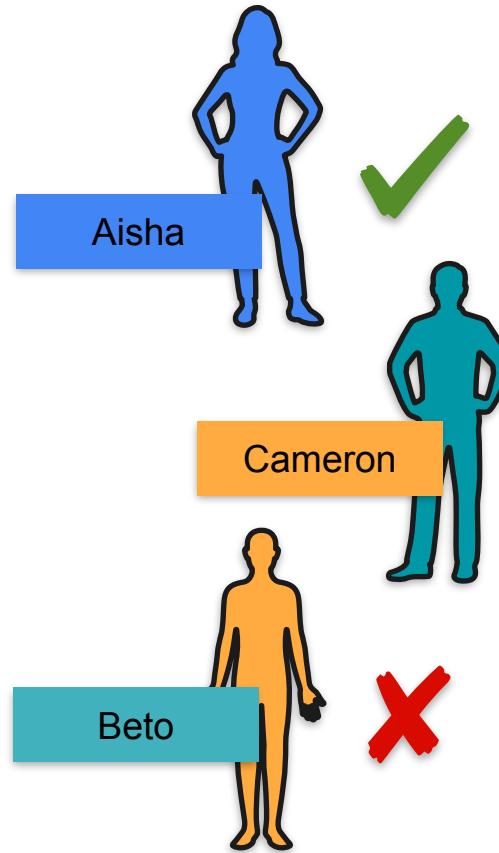
# Bag With 3 Names



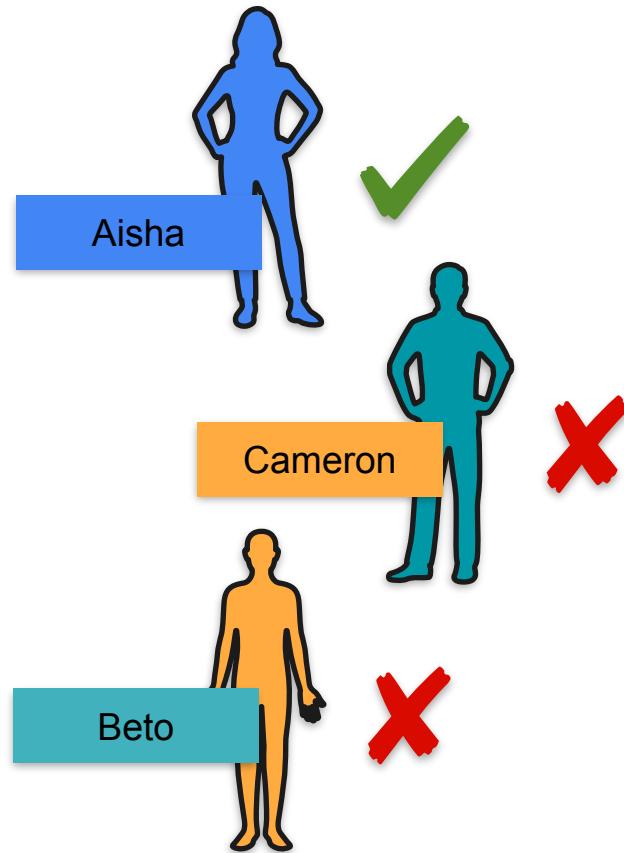
# Bag With 3 Names



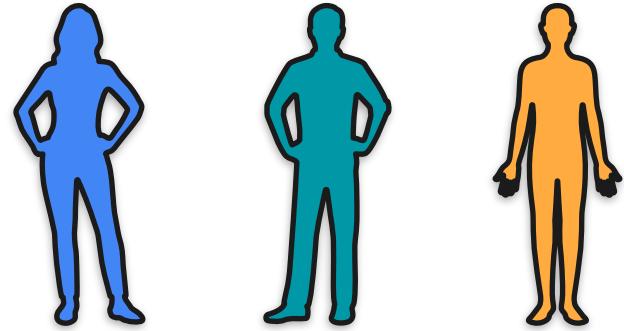
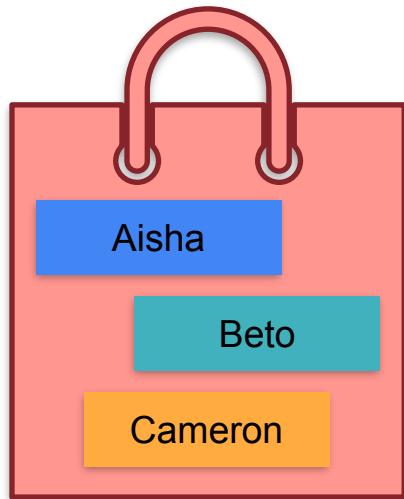
# Bag With 3 Names



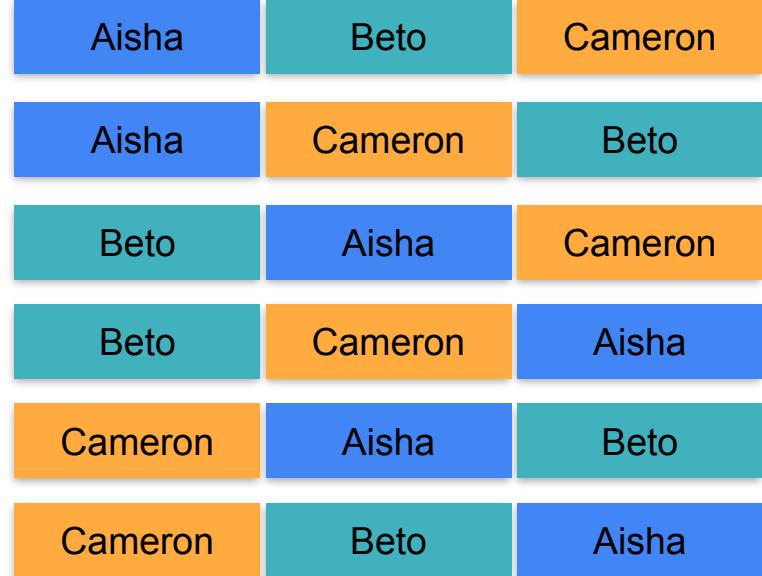
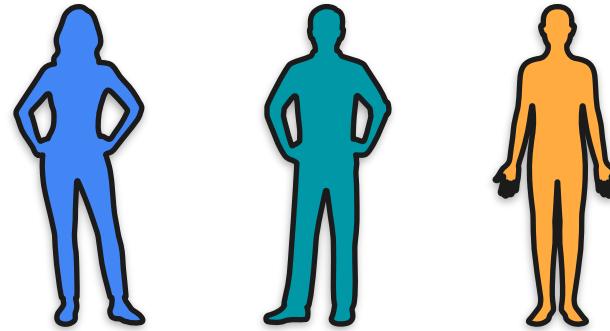
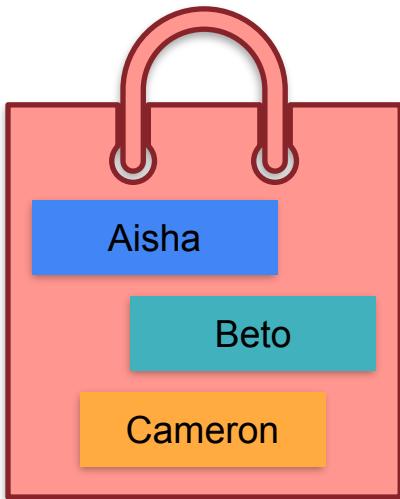
# Bag With 3 Names



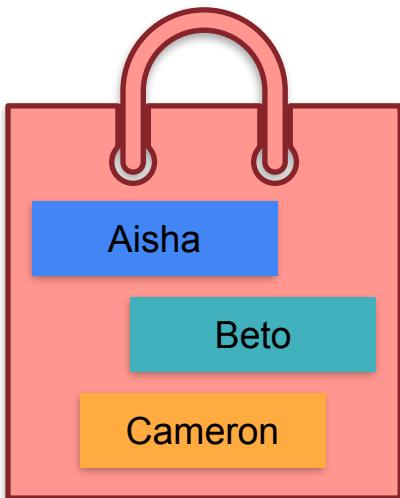
# Bag With 3 Names



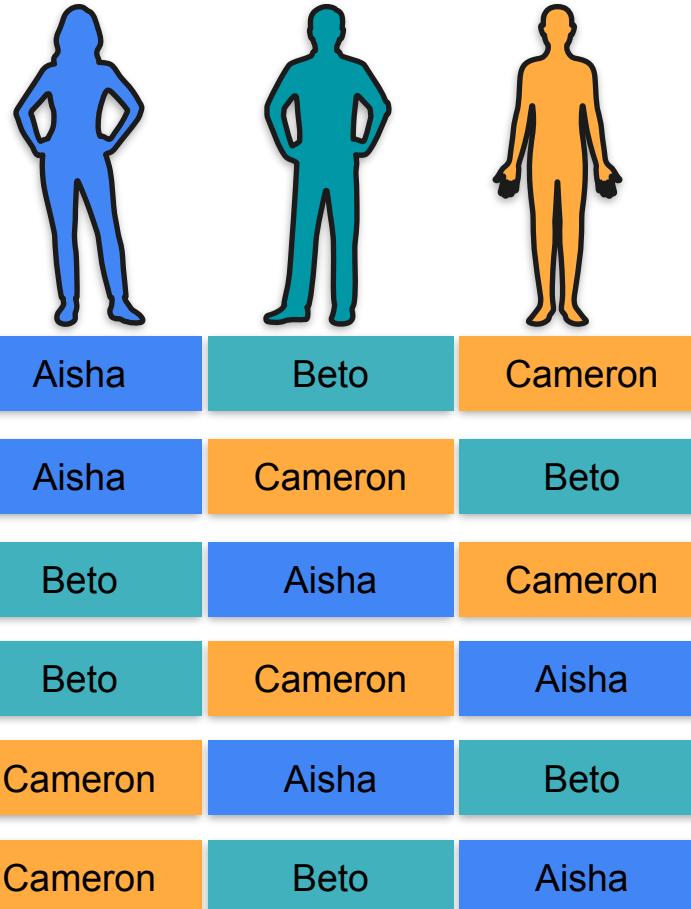
# Bag With 3 Names



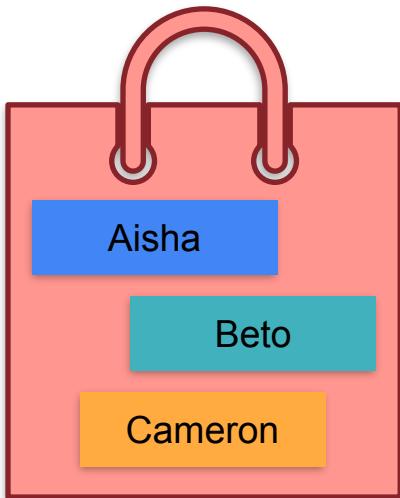
# Bag With 3 Names



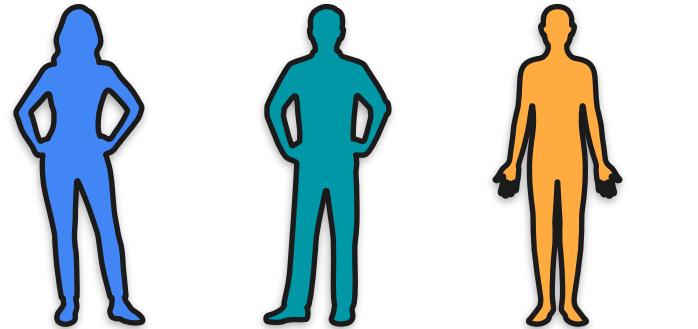
Correct



# Bag With 3 Names

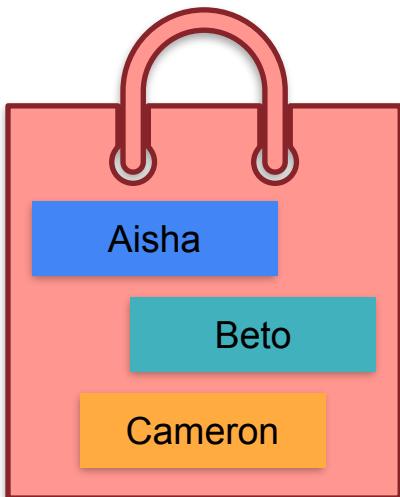


Correct



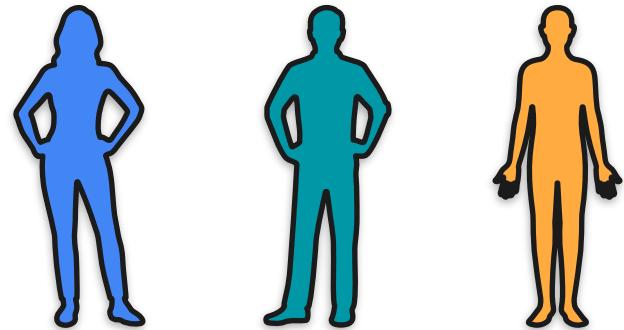
Aisha	Beto	Cameron
Aisha	Cameron	Beto
Beto	Aisha	Cameron
Beto	Cameron	Aisha
Cameron	Aisha	Beto
Cameron	Beto	Aisha

# Bag With 3 Names

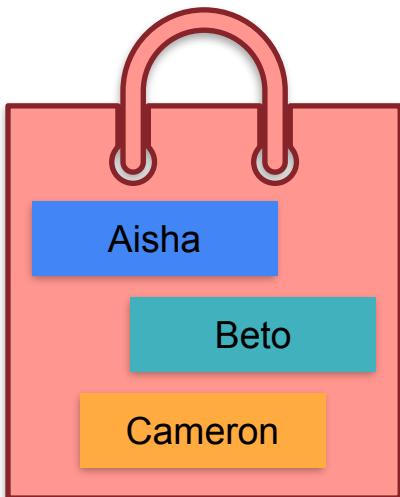


Correct

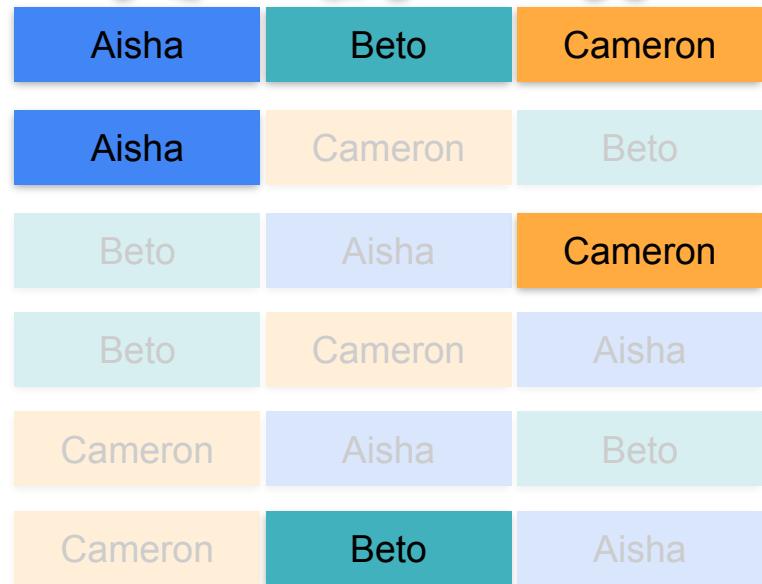
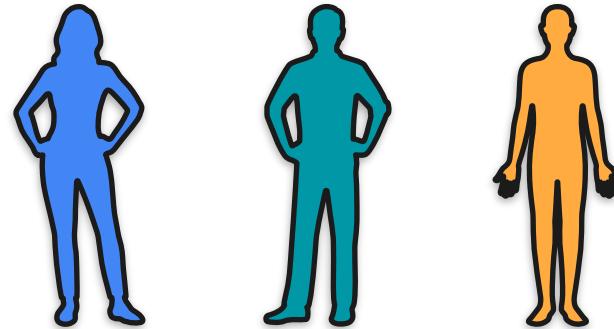
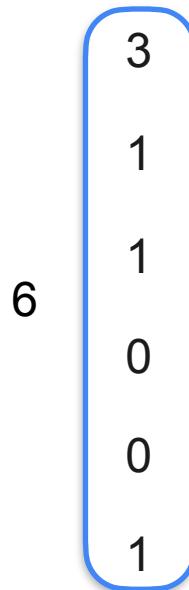
3	Aisha	Beto	Cameron
1	Aisha	Cameron	Beto
1	Beto	Aisha	Cameron
0	Beto	Cameron	Aisha
0	Cameron	Aisha	Beto
1	Cameron	Beto	Aisha



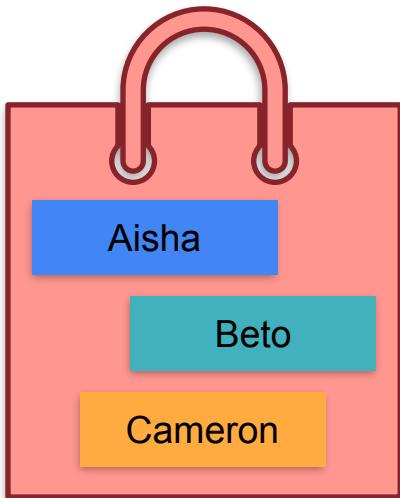
# Bag With 3 Names



Correct



# Bag With 3 Names

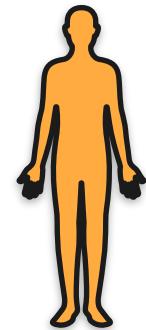
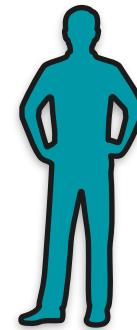
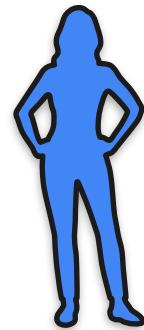
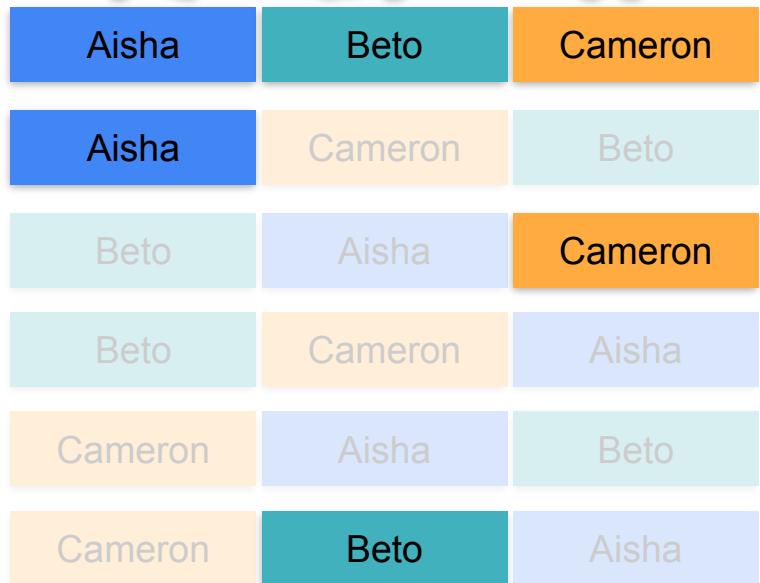


Average  
1

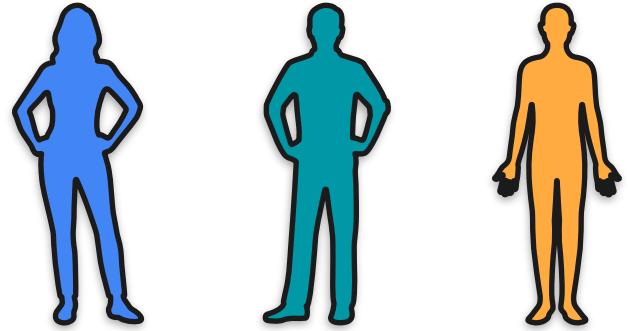
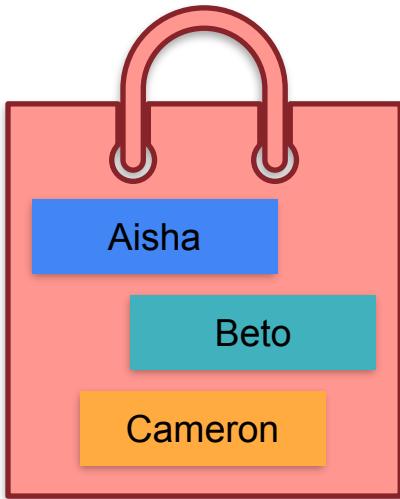
Correct

3  
1  
1  
0  
0  
1

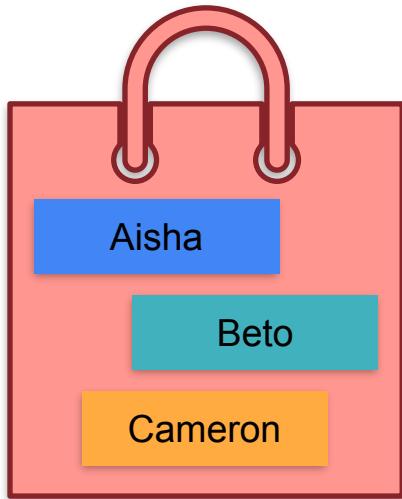
6



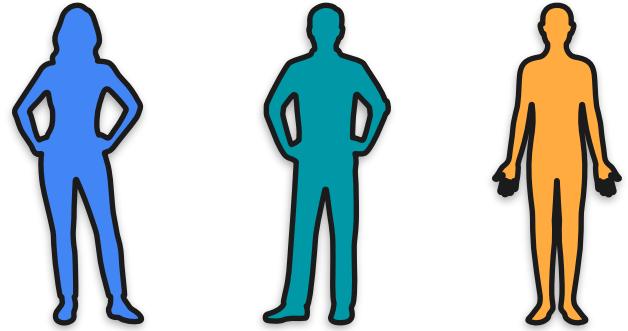
# Adding Expectations



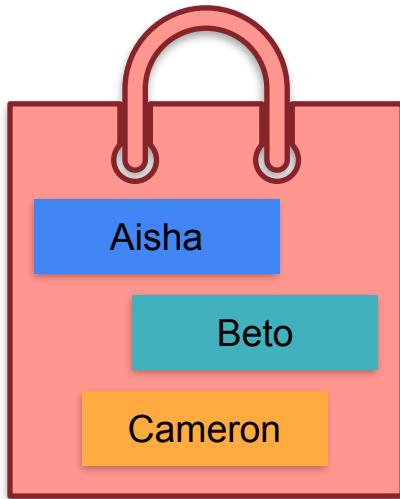
# Adding Expectations



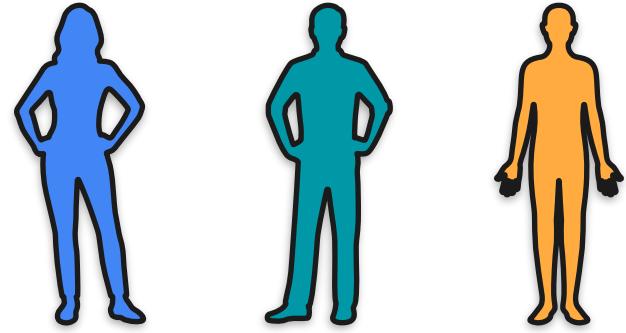
$\mathbb{E}[\text{Matches}]$



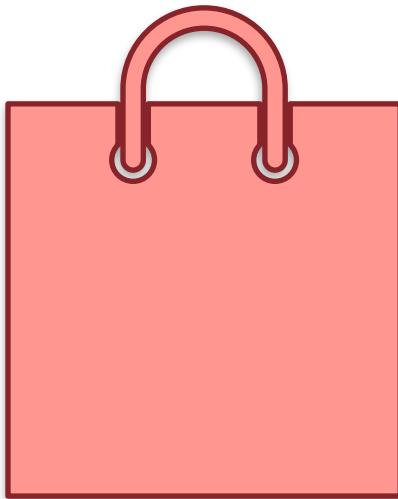
# Adding Expectations



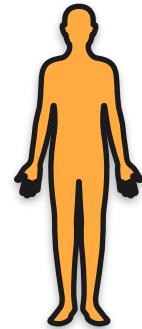
$$\mathbb{E}[\text{Matches}] = \mathbb{E}[A]$$



# Adding Expectations



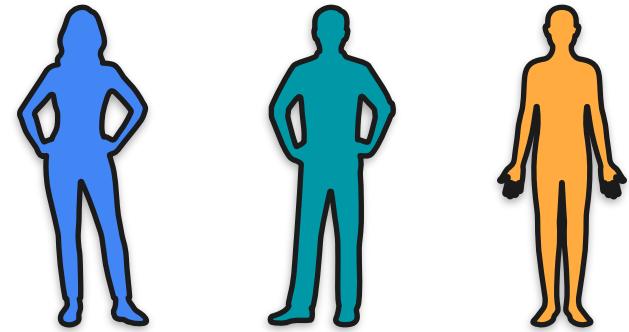
$$\mathbb{E}[\text{Matches}] = \mathbb{E}[A]$$



# Adding Expectations



$\mathbb{E}[\text{Matches}]$



$= \mathbb{E}[A]$

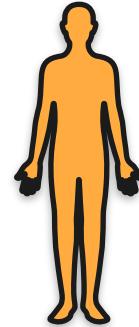
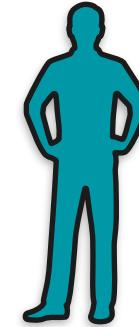
# Adding Expectations



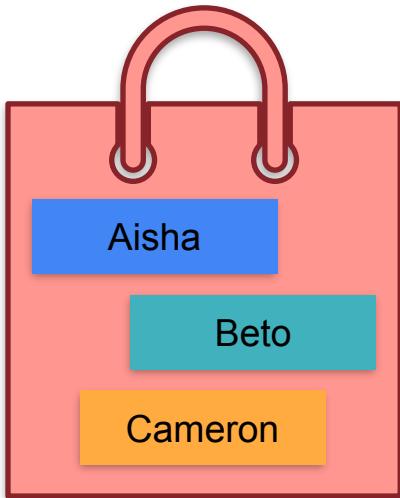
$\mathbb{E}[\text{Matches}]$

$= \mathbb{E}[A]$

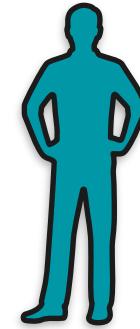
$$= 1/3$$



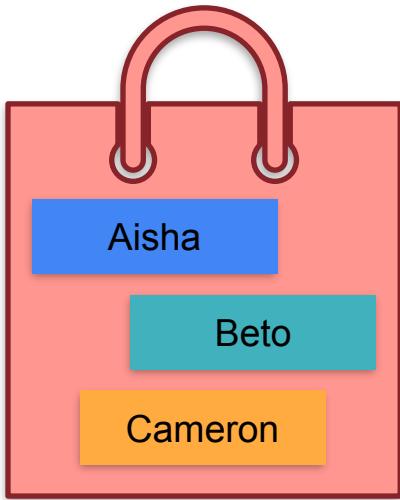
# Adding Expectations



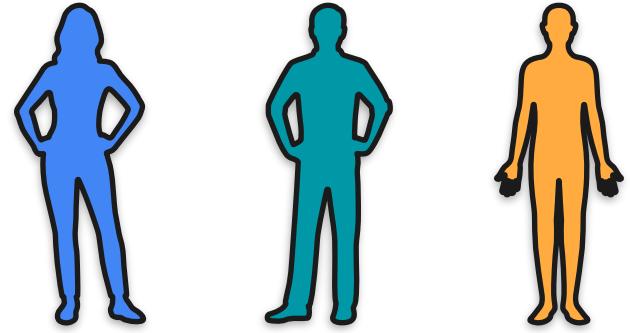
$$\mathbb{E}[\text{Matches}] = \mathbb{E}[A] = 1/3$$



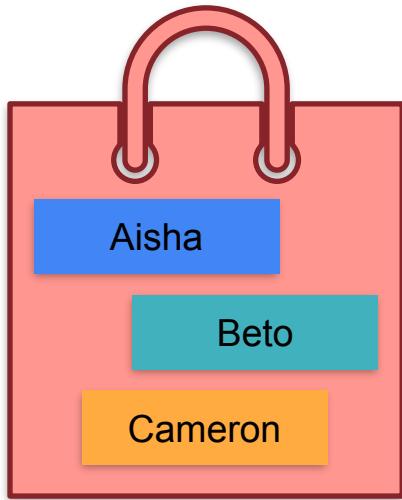
# Adding Expectations



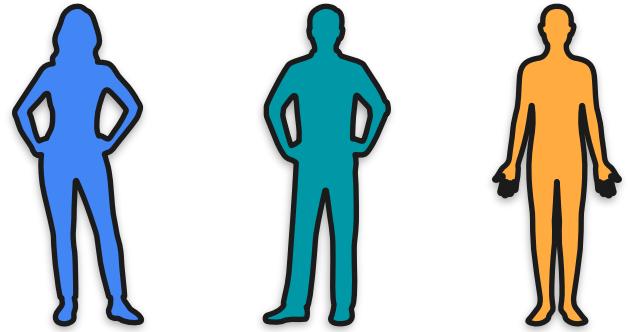
$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] \\ &= 1/3 + 1/3\end{aligned}$$



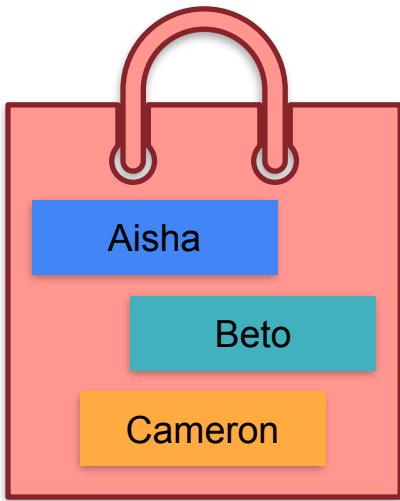
# Adding Expectations



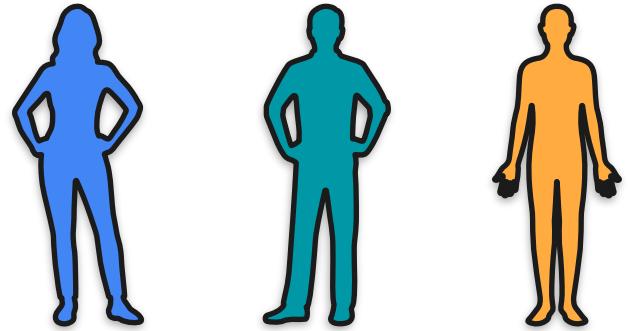
$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] + \mathbb{E}[C] \\ &= 1/3 + 1/3 + 1/3\end{aligned}$$



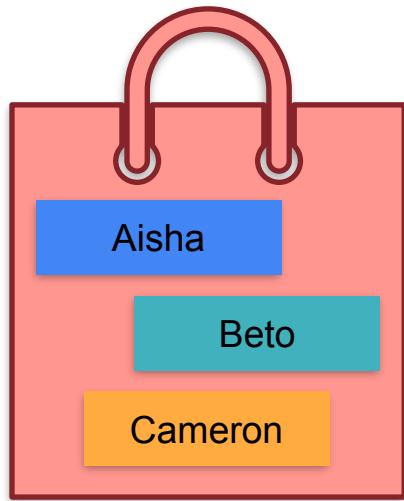
# Adding Expectations



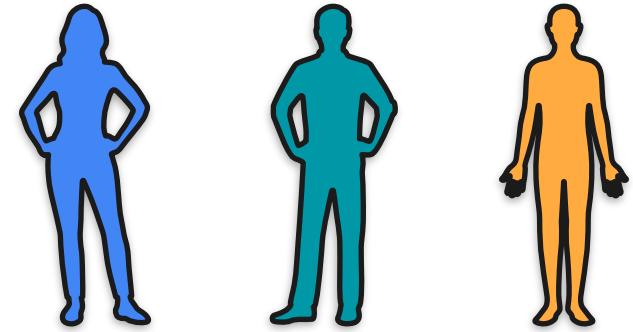
$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] + \mathbb{E}[C] \\ &= 1/3 + 1/3 + 1/3 \\ &= 1\end{aligned}$$



# Adding Expectations



$$\begin{aligned}\mathbb{E}[\text{Matches}] &= \mathbb{E}[A] + \mathbb{E}[B] + \mathbb{E}[C] \\ &= 1/3 + 1/3 + 1/3 \\ &= 1\end{aligned}$$



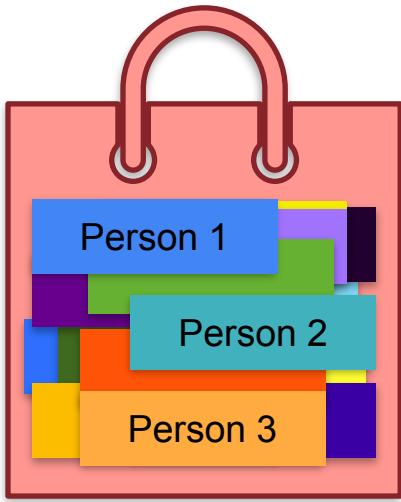
Average  
1

# Adding Expectations



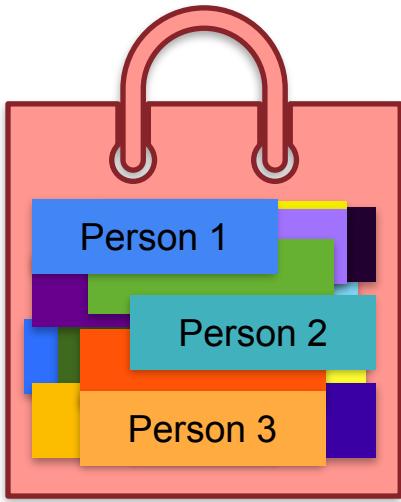
8 billion people

# Adding Expectations



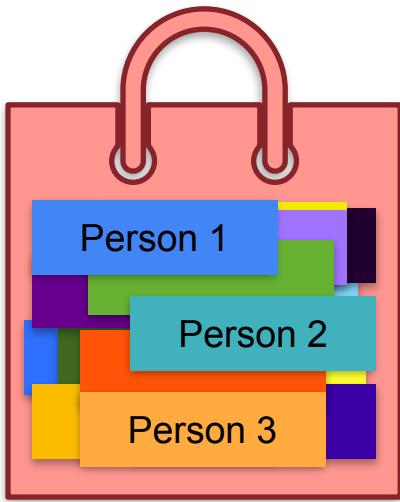
8 billion people

# Adding Expectations



8 billion people

# Adding Expectations



Expected number = ?



# Adding Expectations



# Adding Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}]$$

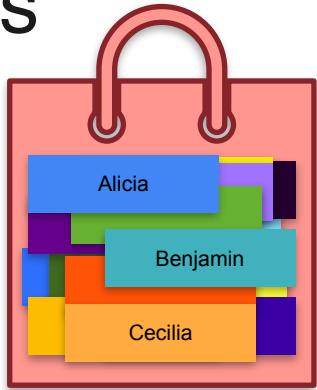
# Adding Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}]$$

$n$  people ( $n = 8$  billion)

# Adding Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}] \quad \overbrace{\qquad \qquad \qquad}^{\text{n people (n = 8 billion)}} = \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n}$$

# Adding Expectations



$$\begin{aligned}\mathbb{E} [\text{Matches}] &= \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}] \\ &= \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n} \\ &= n \cdot \frac{1}{n}\end{aligned}$$

$n$  people ( $n = 8$  billion)

# Adding Expectations



$$\begin{aligned}\mathbb{E} [\text{Matches}] &= \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}] \\ &\quad \overbrace{\hspace{10em}}^{\text{n people (n = 8 billion)}} \\ &= \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n} \\ &= n \cdot \frac{1}{n} = 1\end{aligned}$$

# Adding Expectations



$$\mathbb{E} [\text{Matches}] = \mathbb{E} [X_{\text{person}_1}] + \mathbb{E} [X_{\text{person}_2}] + \dots + \mathbb{E} [X_{\text{person}_n}] = \frac{1}{n} + \frac{1}{n} + \dots + \frac{1}{n}$$

$n \text{ people } (n = 8 \text{ billion})$

In general:

$$\mathbb{E} [X_1 + X_2 + \dots + X_n] = \mathbb{E} [X_1] + \mathbb{E} [X_2] + \dots + \mathbb{E} [X_n]$$

$$= n \cdot \frac{1}{n} = 1$$



DeepLearning.AI

# Describing Distributions

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## Variance

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 1 dollar



You lose 1 dollar

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 1 dollar



You lose 1 dollar

\$0

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

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What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend

Game cost:



You win 1 dollar



You lose 1 dollar

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 1 dollar



You lose 1 dollar

Game cost:

\$0

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 100 dollars



You lose 100 dollars

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 100 dollars



You lose 100 dollars

\$0

What is the fair amount of money to pay to play this game?

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You lose 100 dollars

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You play a game with a friend

Game cost:



You win 100 dollars



You lose 100 dollars

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

You play a game with a friend



You win 100 dollars



You lose 100 dollars

Game cost:

\$0

What is the fair amount of money to pay to play this game?

# Variance Motivation: Fair Price To Play the Game

How do you tell these two games apart?

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 100 dollars



You lose 100 dollars

# Variance Motivation: Fair Price To Play the Game

How do you tell these two games apart?

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



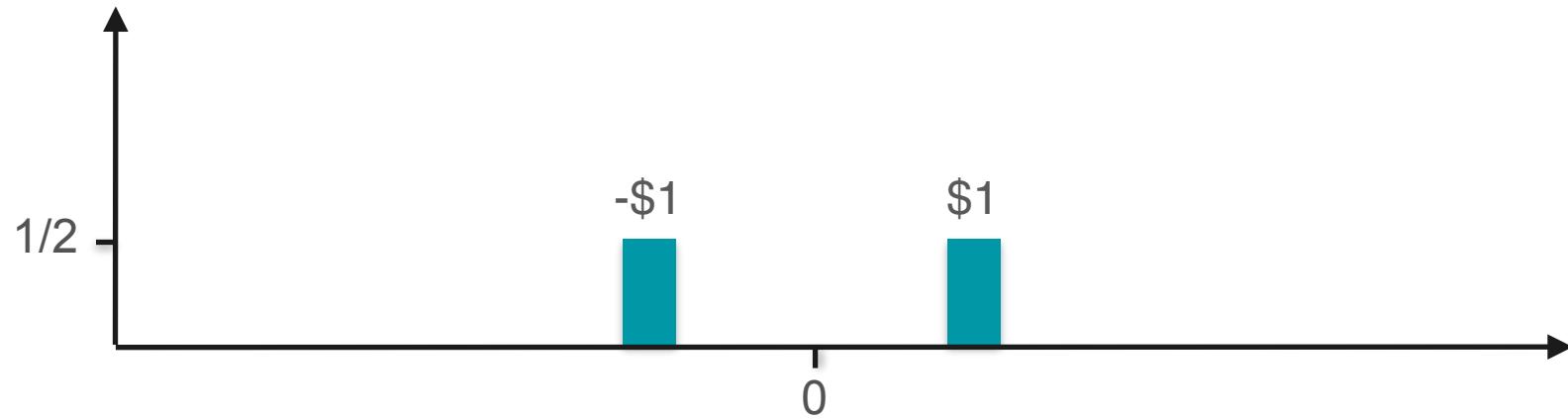
You win 100 dollars

You lose 100 dollars

Variance!

# Variance Motivation: Measuring Spread

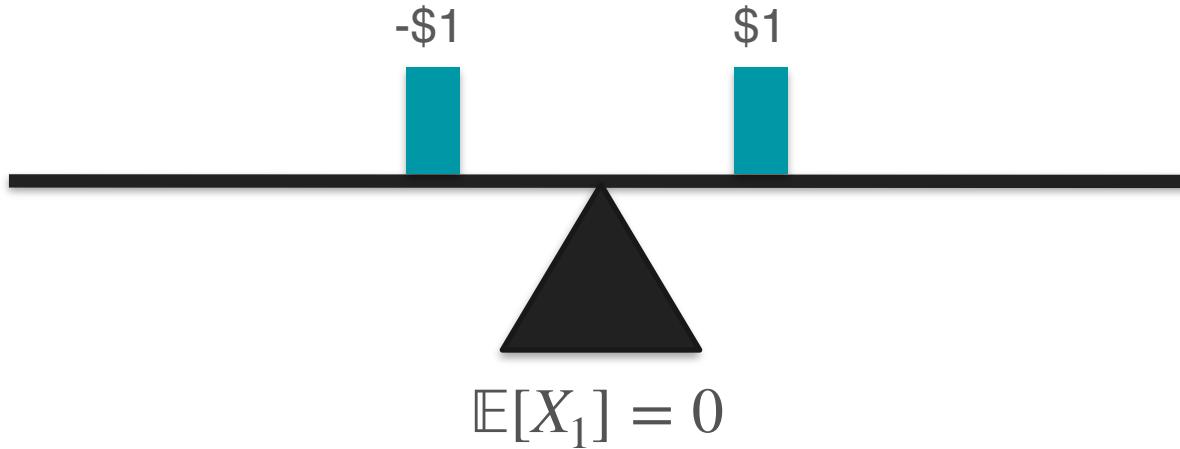
Probability



# Variance Motivation: Measuring Spread

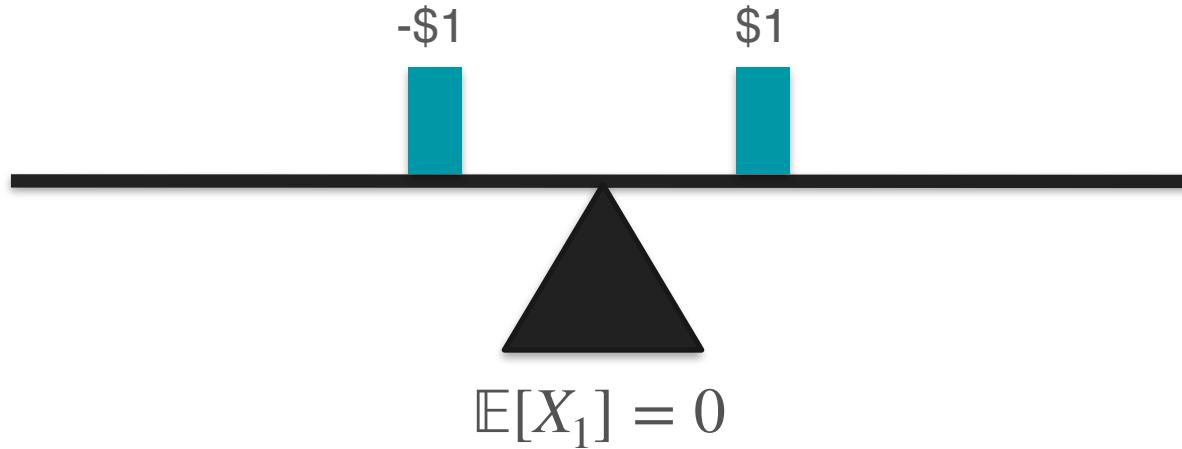


# Variance Motivation: Measuring Spread

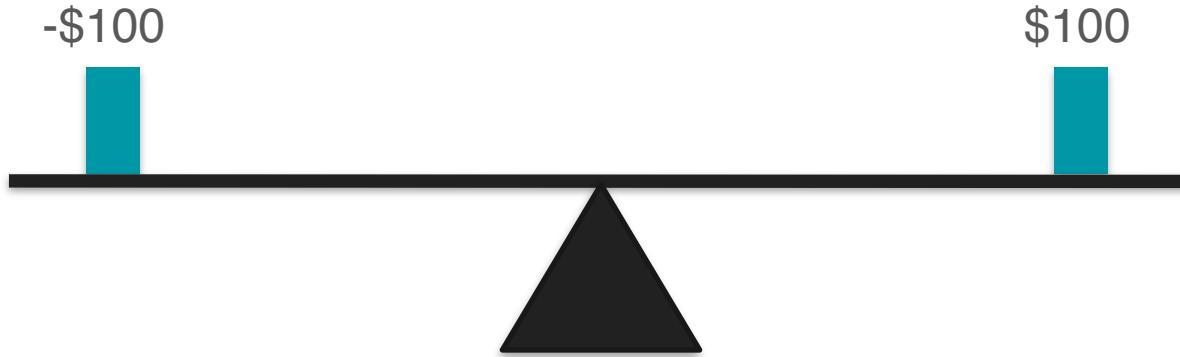


# Variance Motivation: Measuring Spread

$X_1$  = expected amount of money gained in game 1

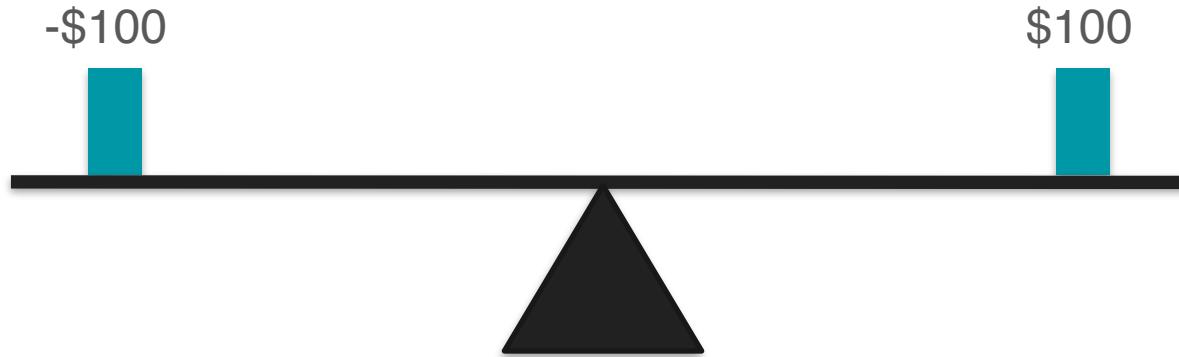


# Variance Motivation: Measuring Spread



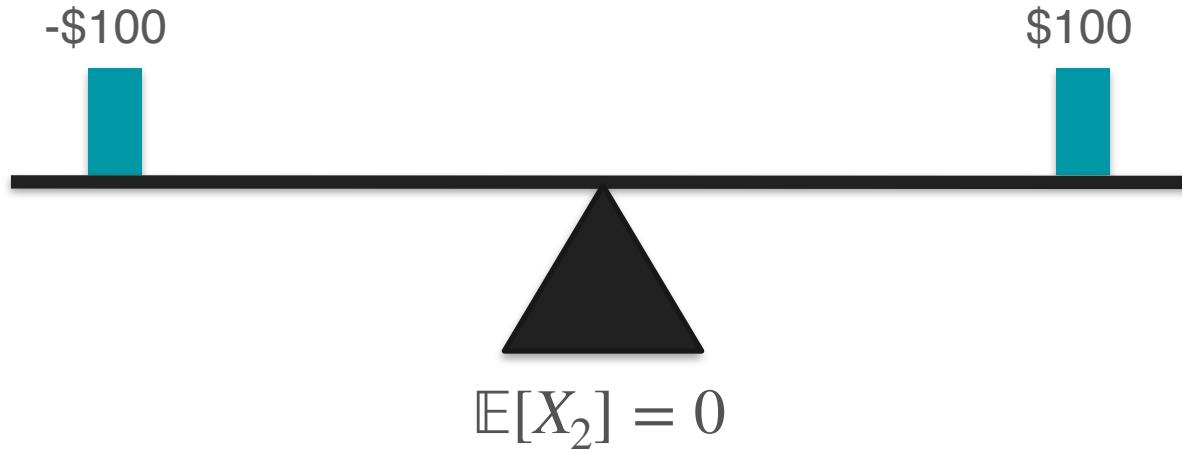
# Variance Motivation: Measuring Spread

$X_2$  = expected amount of money gained in game 2

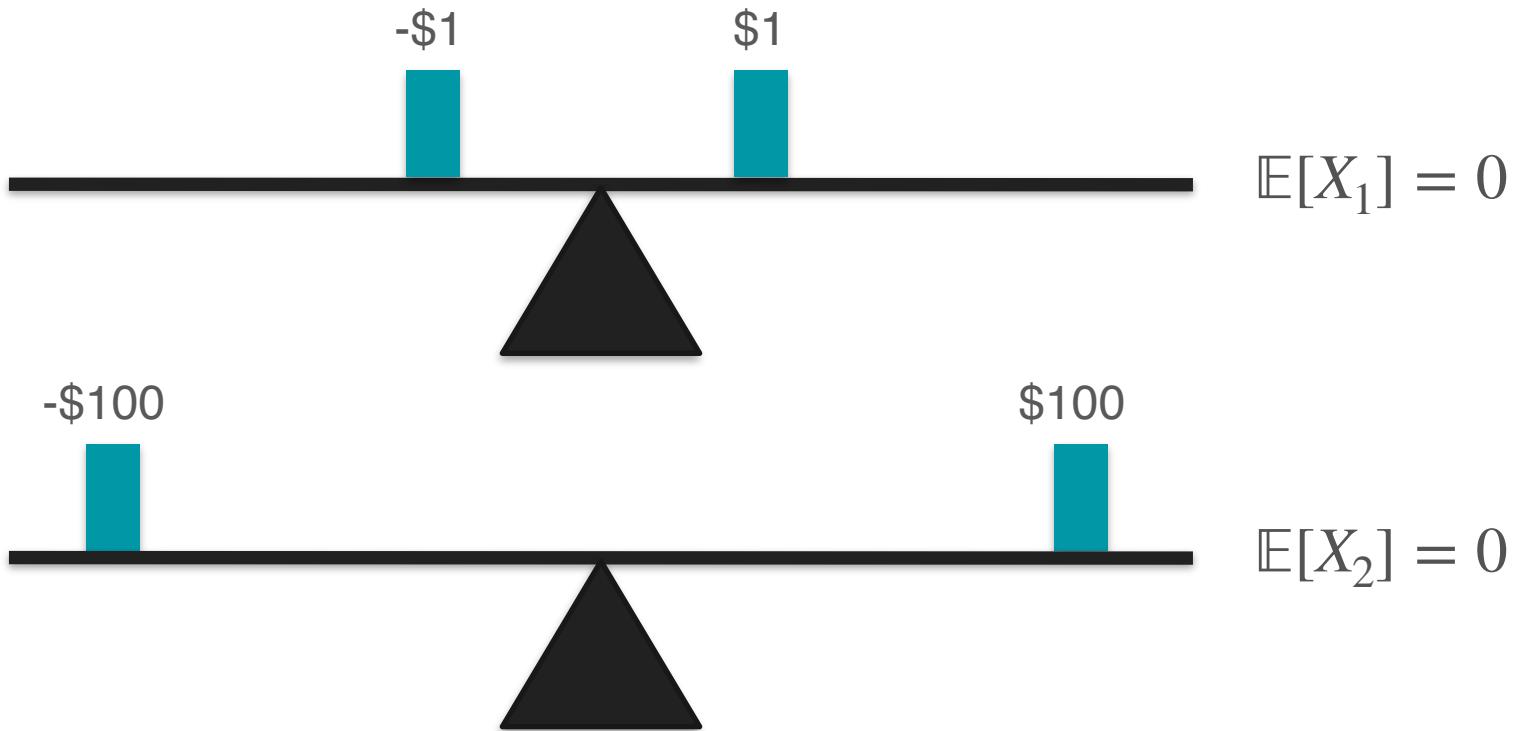


# Variance Motivation: Measuring Spread

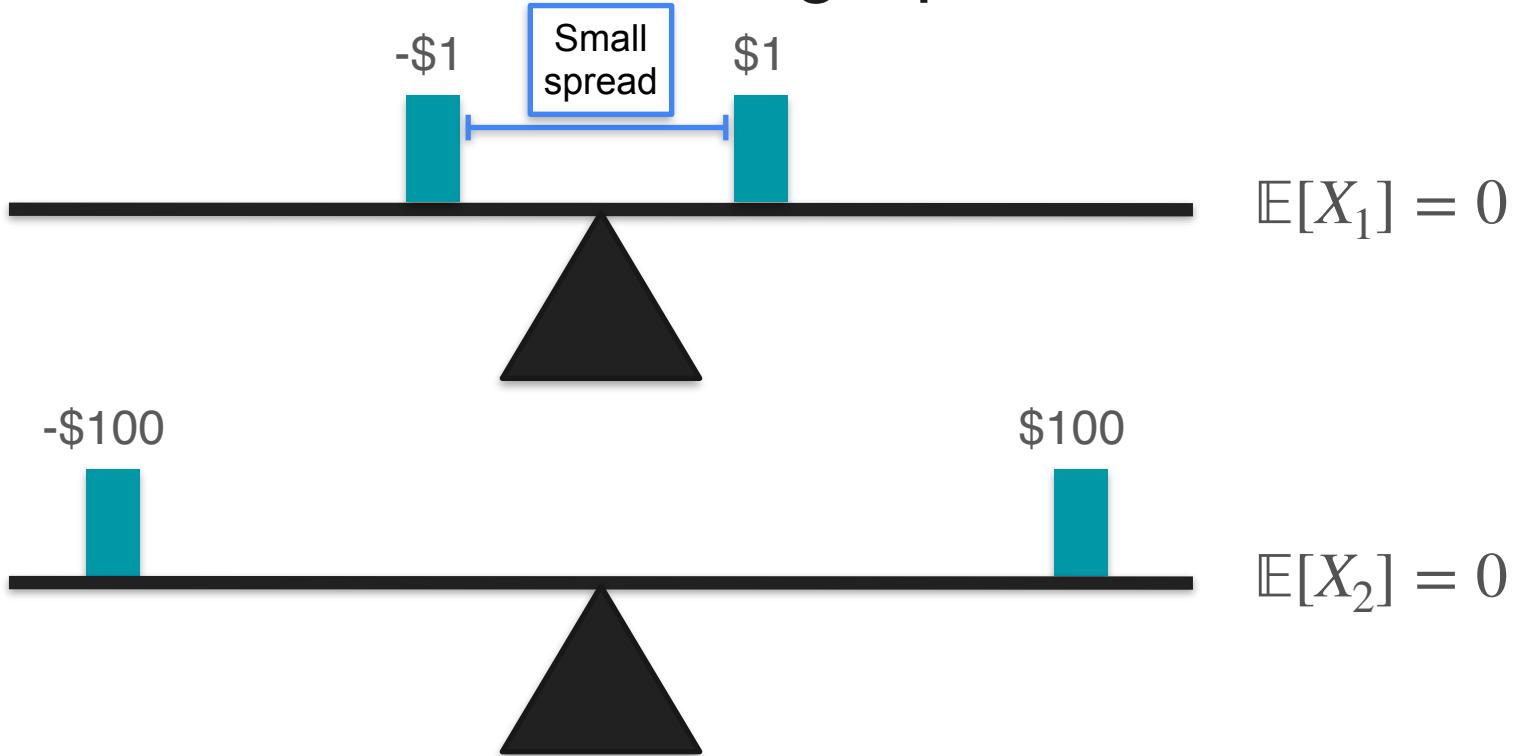
$X_2$  = expected amount of money gained in game 2



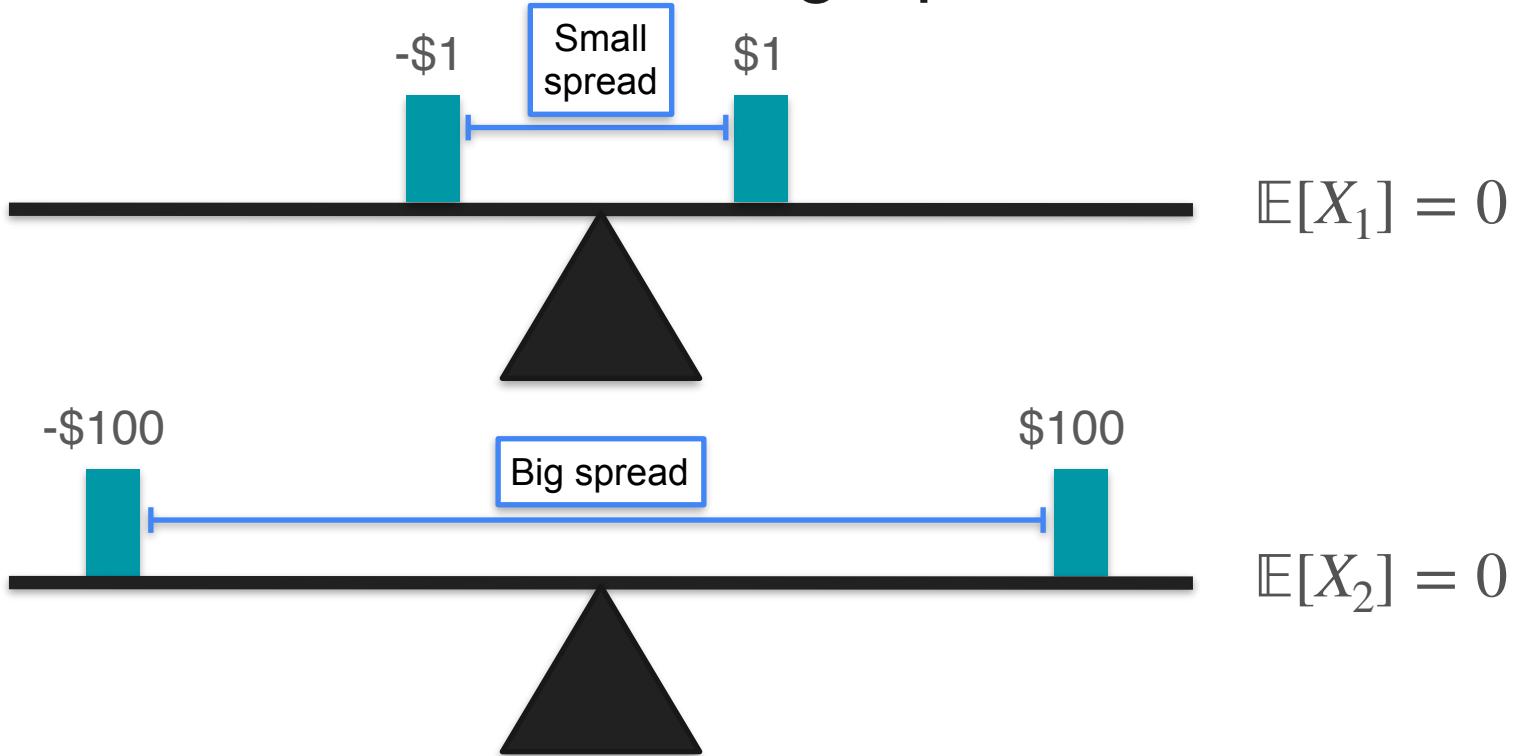
# Variance Motivation: Measuring Spread



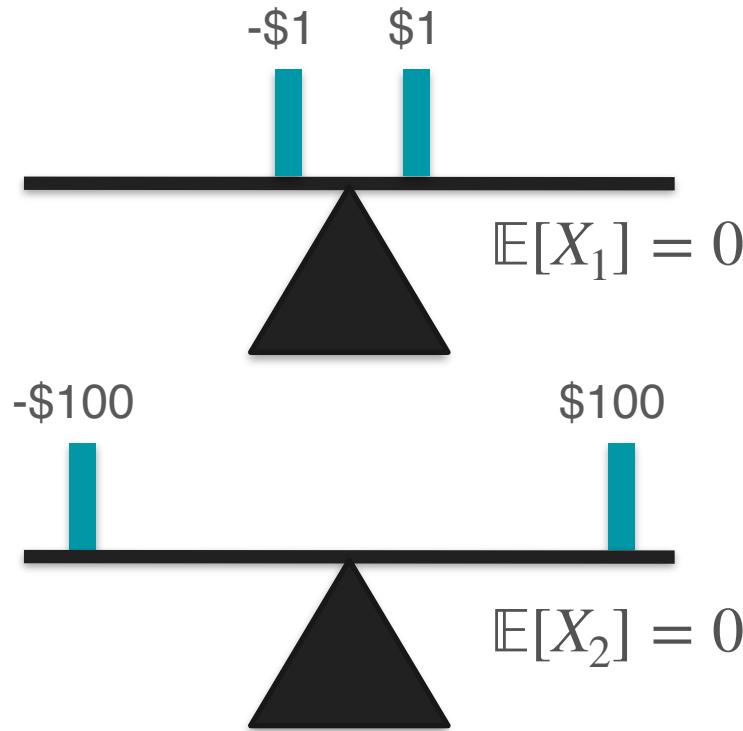
# Variance Motivation: Measuring Spread



# Variance Motivation: Measuring Spread



# Variance Motivation: Measuring Spread



# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1) + (-1)}{2} = 0$$



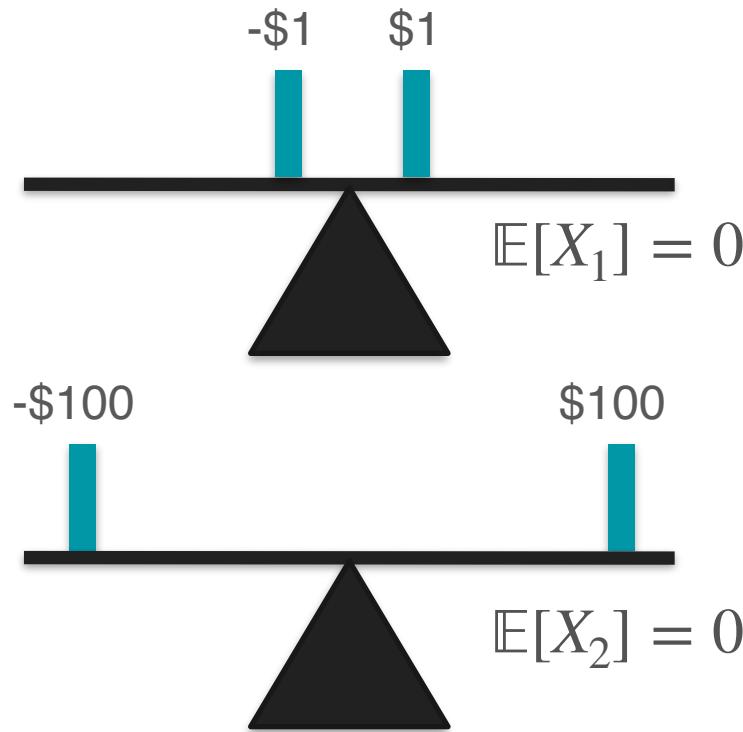
# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1) + (-1)}{2} = 0$$

$$\mathbb{E}[X_2] = \frac{(100) + (-100)}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1) + (-1)}{2} = 0$$

Turn into positive?

$$\mathbb{E}[X_2] = \frac{(100) + (-100)}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1)^2 + (-1)^2}{2} = 0$$

$$\mathbb{E}[X_2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1] = \frac{(1)^2 + (-1)^2}{2} = 0$$



$$\mathbb{E}[X_2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 0$$



$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$



$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 0$$

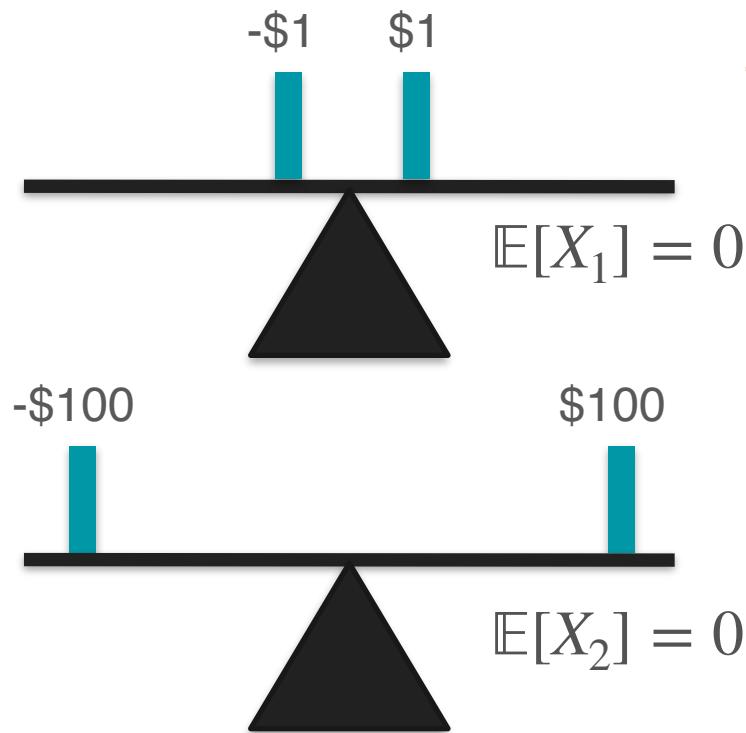
# Variance Motivation: Measuring Spread



$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$

$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 10,000$$

# Variance Motivation: Measuring Spread

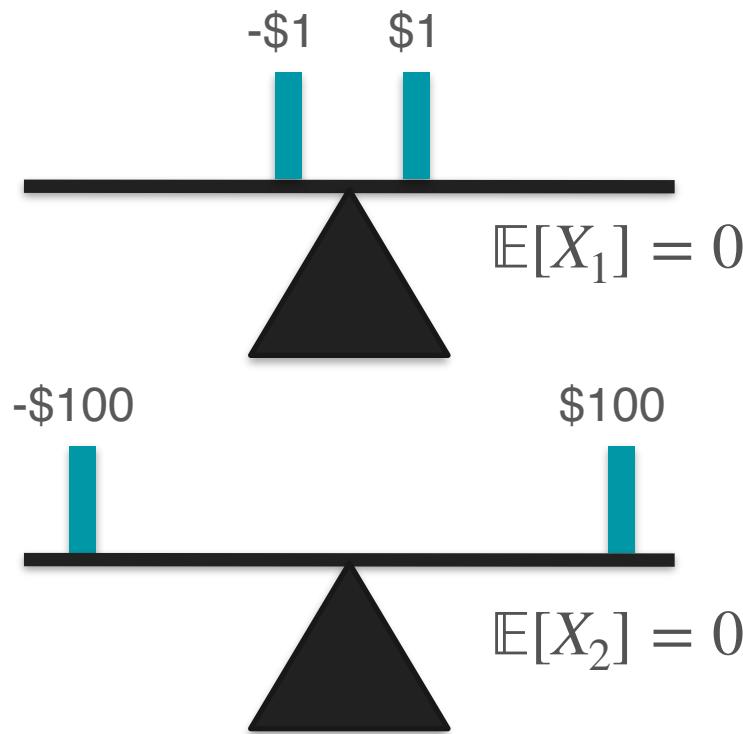


Key for telling game  
1 and game 2 apart!

$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$

$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 10,000$$

# Variance Motivation: Measuring Spread



Key for telling game  
1 and game 2 apart!

$$\mathbb{E}[X_1^2] = \frac{(1)^2 + (-1)^2}{2} = 1$$

$$\mathbb{E}[X_2^2] = \frac{(100)^2 + (-100)^2}{2} = 10,000$$

Measure of spread

# Variance Motivation: Measuring Spread

$$\mathbb{E}[X^2]$$

# Variance Motivation: Measuring Spread

$$\mathbb{E}[X^2]$$

Almost...

# Variance Motivation: Centering With Mean

# Variance Motivation: Centering With Mean

## Game 1



You win 1 dollar



You lose 1 dollar

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

How risky are these two games in comparison?

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

How risky are these two games in comparison?

**Hint:** Think of the spread

# Variance Motivation: Centering With Mean

Game 1



You win 1 dollar



You lose 1 dollar

Game 2



You win 6 dollars



You win 4 dollars

They are equally risky

# Variance Motivation: Centering With Mean

## Game 1



You win 1 dollar



You lose 1 dollar

$$\mathbb{E}[X_1]^2 = \frac{(-1)^2 + (1)^2}{2} = 1$$

## Game 2



You win 6 dollars



You win 4 dollars

$$\mathbb{E}[X_2]^2 = \frac{(4)^2 + (6)^2}{2} = 26$$

# Variance Motivation: Centering With Mean

## Game 1



You win 1 dollar



You lose 1 dollar

$$\mathbb{E}[X_1]^2 = \frac{(-1)^2 + (1)^2}{2} = 1$$



Same risk?

$$\mathbb{E}[X_2]^2 = \frac{(4)^2 + (6)^2}{2} = 26$$



## Game 2



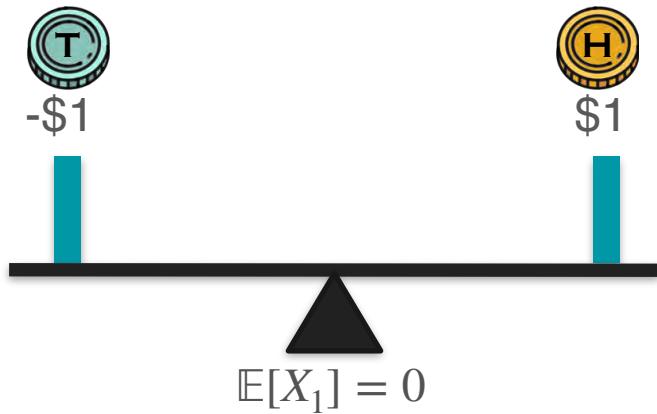
You win 6 dollars



You win 4 dollars

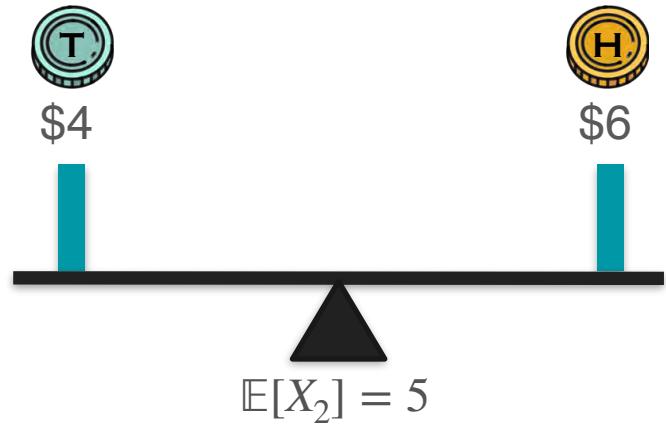
# Variance Motivation: Centering With Mean

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Game 1

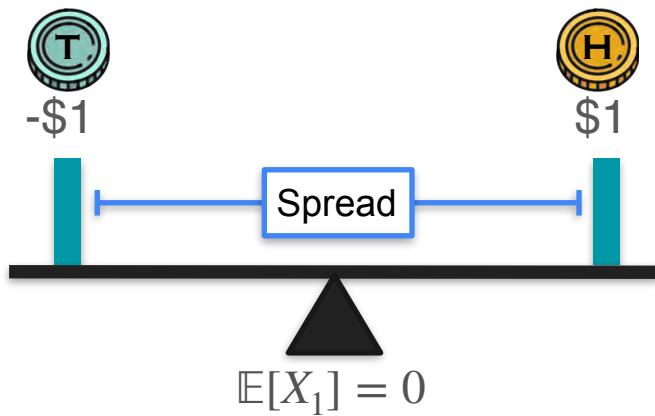
$$\mathbb{E}[X_2]^2 = \frac{(4)^2 + (6)^2}{2} = 26$$



Game 2

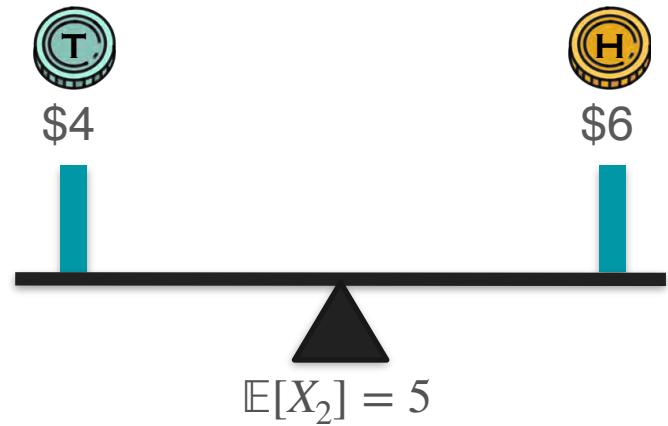
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Game 1

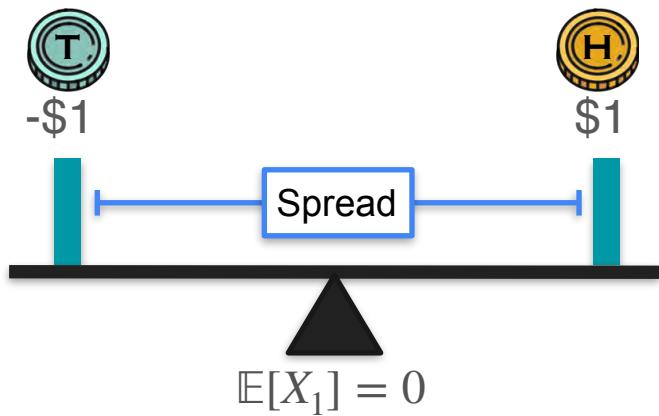
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Game 2

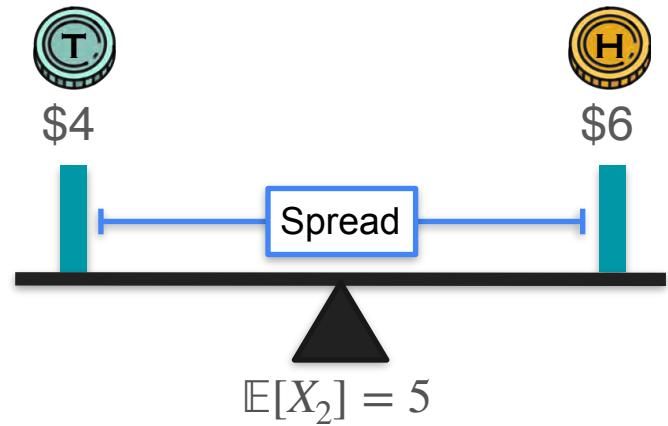
# Variance Motivation: Centering With Mean

$$\mathbb{E}[X_1]^2 = \frac{(-1)^2 + (1)^2}{2} = 1$$



Game 1

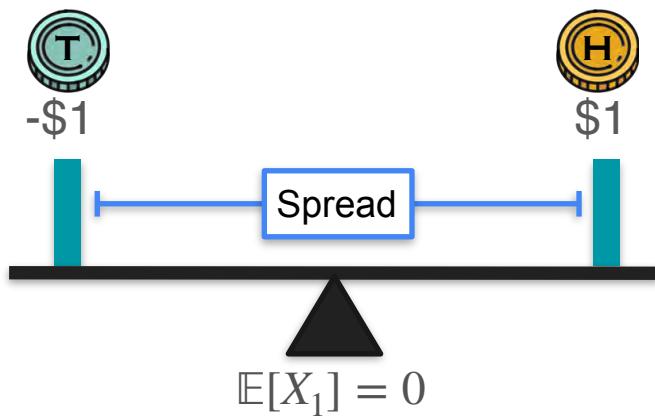
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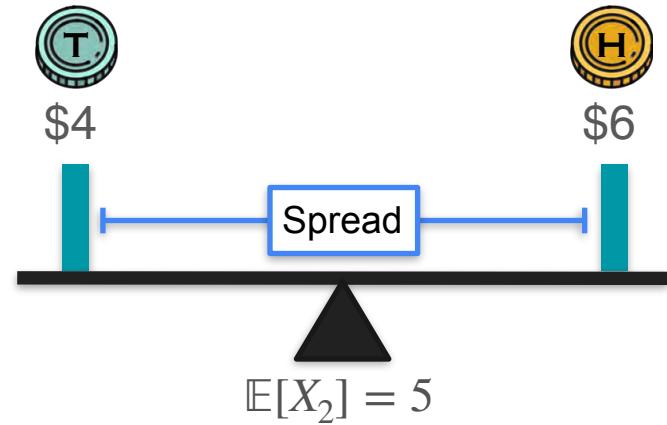
Game 2

# Variance Motivation: Centering With Mean

$$\mathbb{E}[X_1]^2 = \frac{(-1)^2 + (1)^2}{2} = 1 \quad \leftarrow \text{Same spread?} \rightarrow \quad \mathbb{E}[X_2]^2 = \frac{(4)^2 + (6)^2}{2} = 26$$



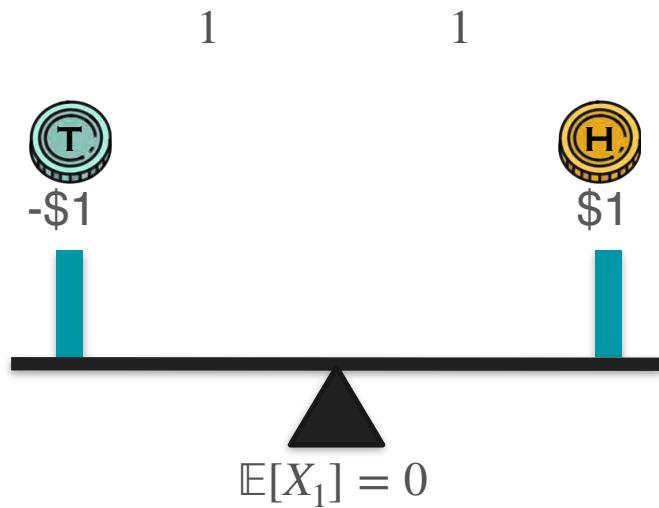
Game 1



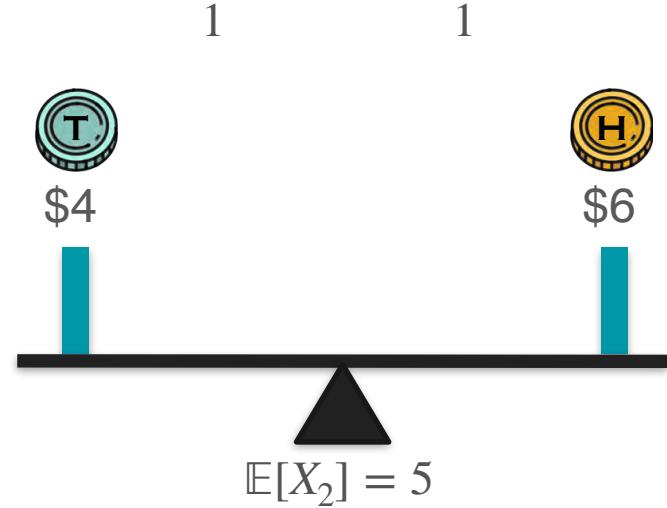
Game 2

# Variance: Spread and Shift

$$\mathbb{E}[X_1^2] = 1$$



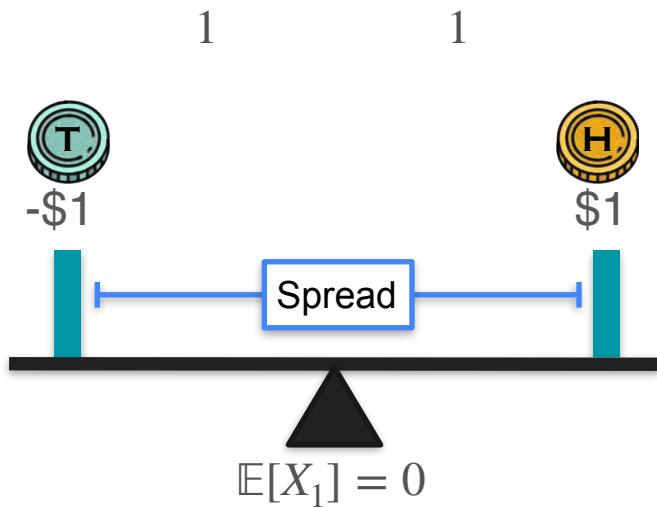
Game 1



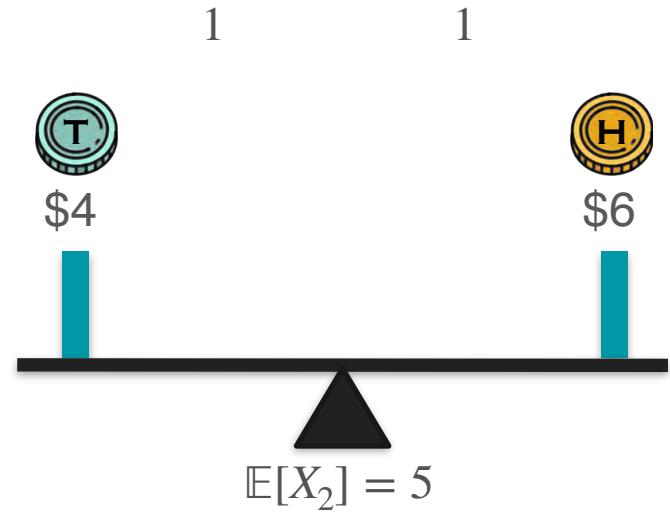
Game 2

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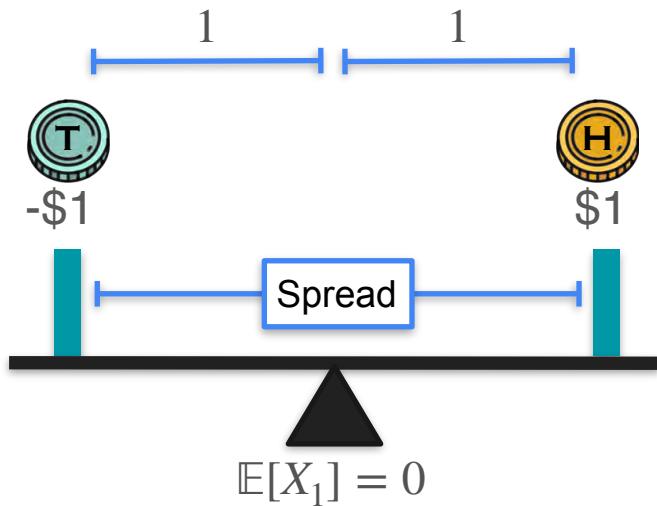
Game 1



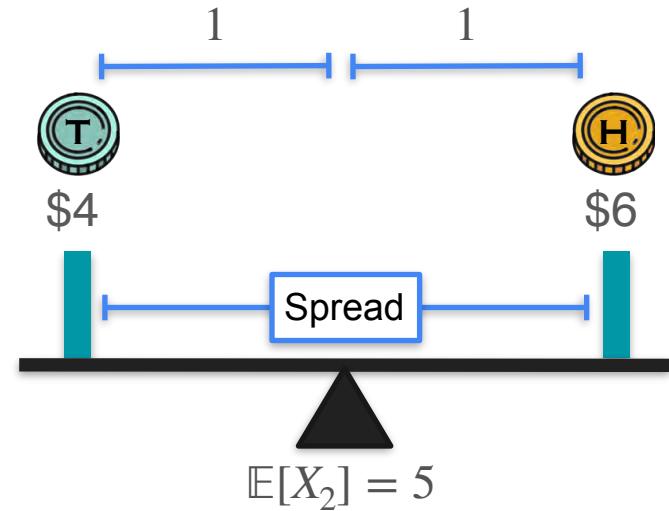
Game 2

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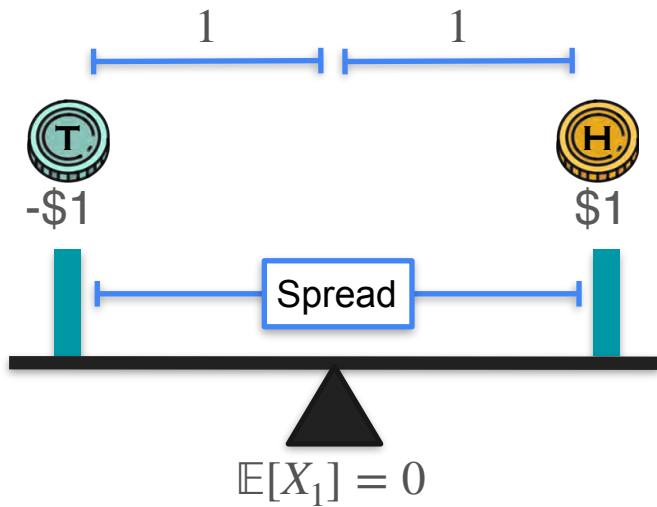
Game 1



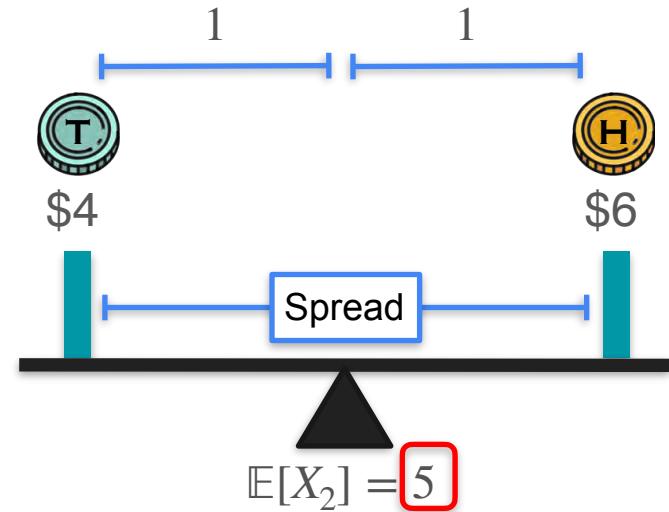
Game 2

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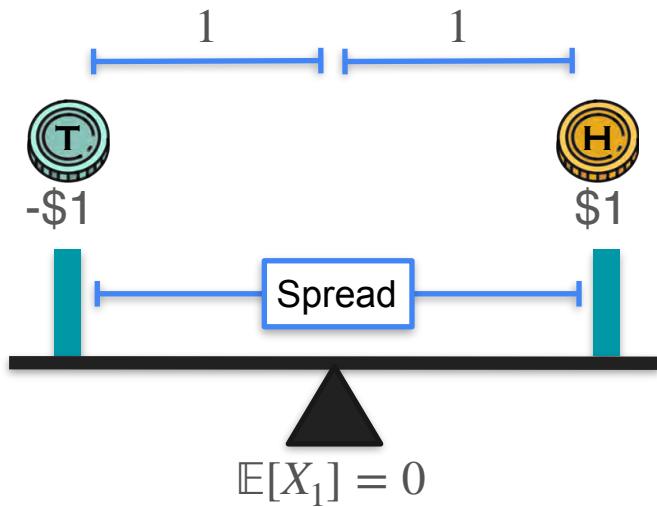
Game 1



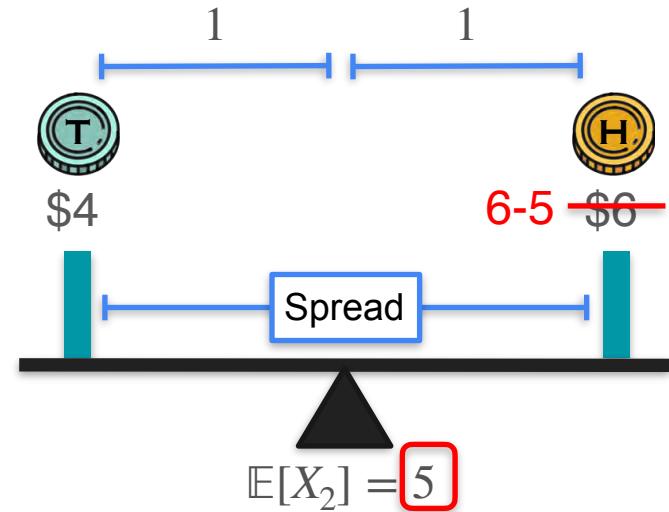
Game 2

# Variance: Spread and Shift

$$\mathbb{E}[X_1^2] = 1$$



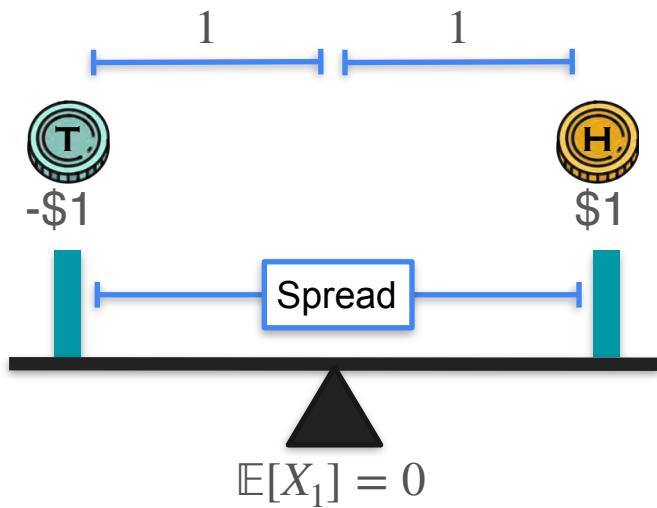
Game 1



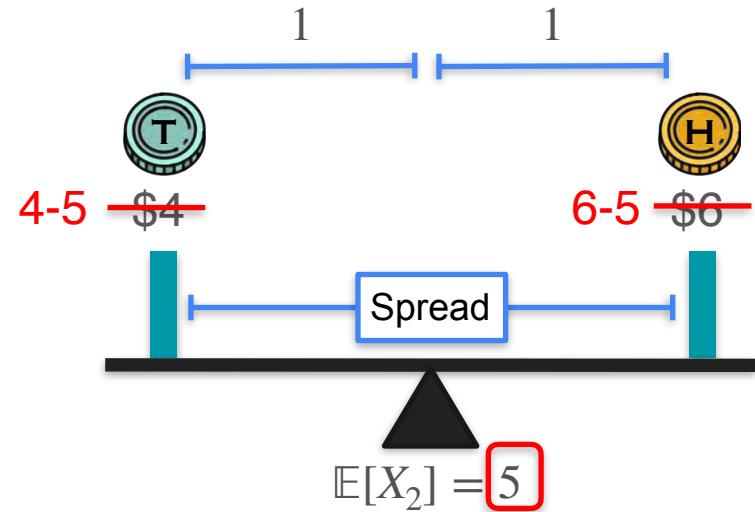
Game 2

# Variance: Spread and Shift

$$\mathbb{E}[X_1^2] = 1$$



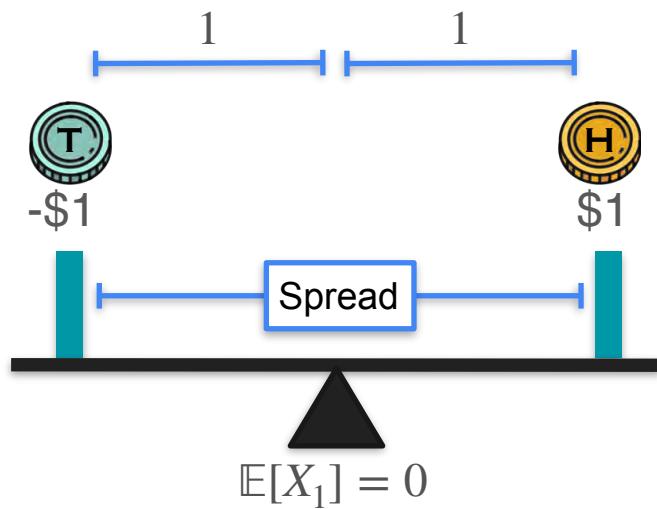
Game 1



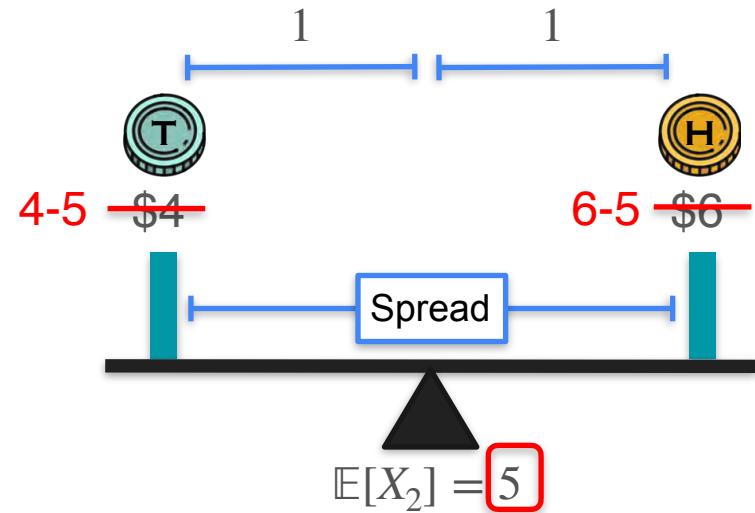
Game 2

# Variance: Spread and Shift

$$\mathbb{E}[X_1^2] = 1$$

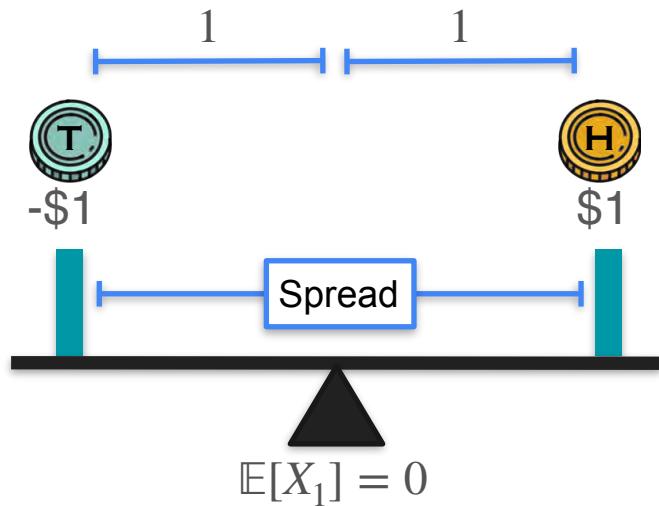


$$\mathbb{E}[(X_2 - 5)^2]$$



# Variance: Spread and Shift

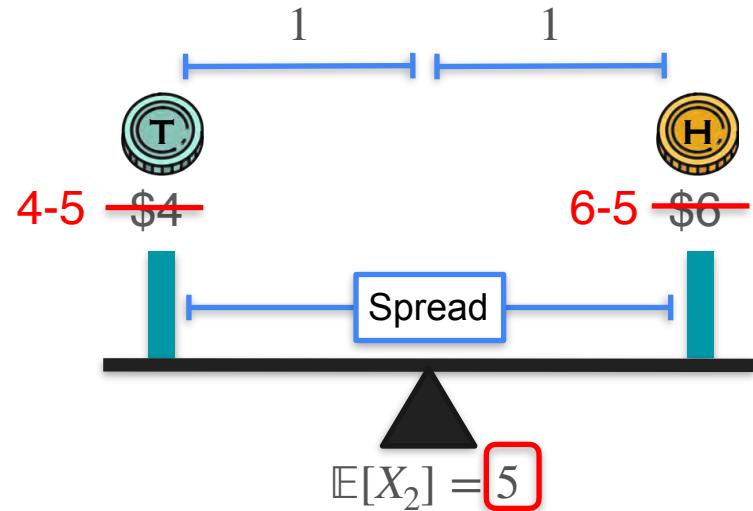
$$\mathbb{E}[X_1^2] = 1$$



Game 1

$$\text{Mean: } \mu$$

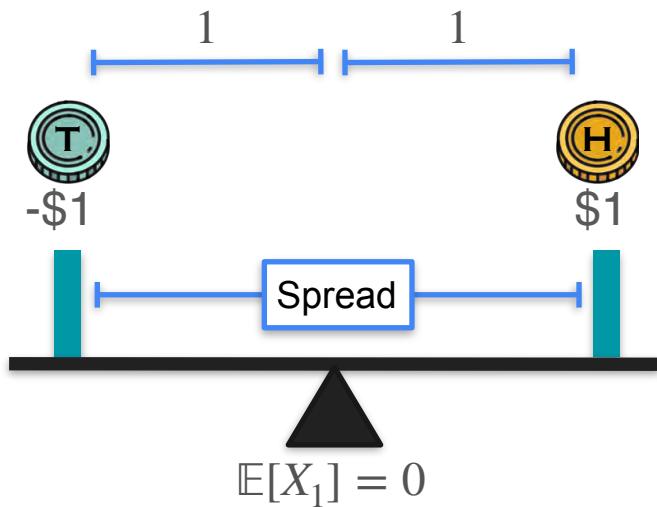
$$\mathbb{E}[(X_2 - 5)^2]$$



Game 2

# Variance: Spread and Shift

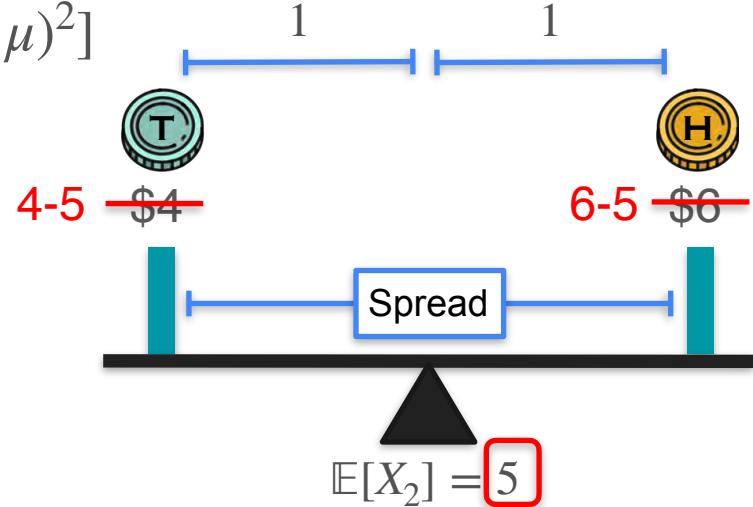
$$\mathbb{E}[X_1^2] = 1$$



Game 1

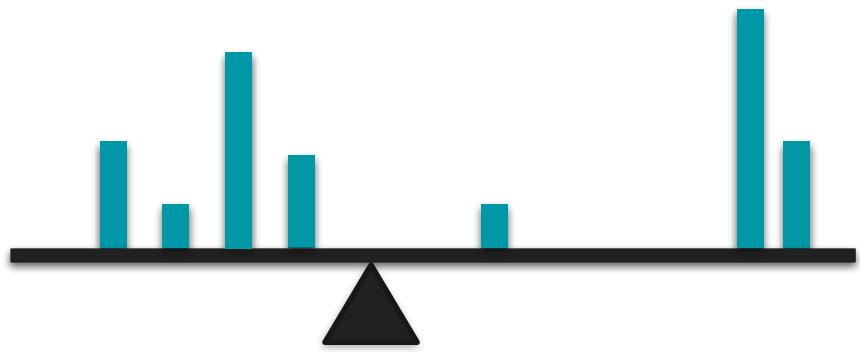
Mean:  $\mu$

$$\mathbb{E}[(X_2 - 5)^2]$$

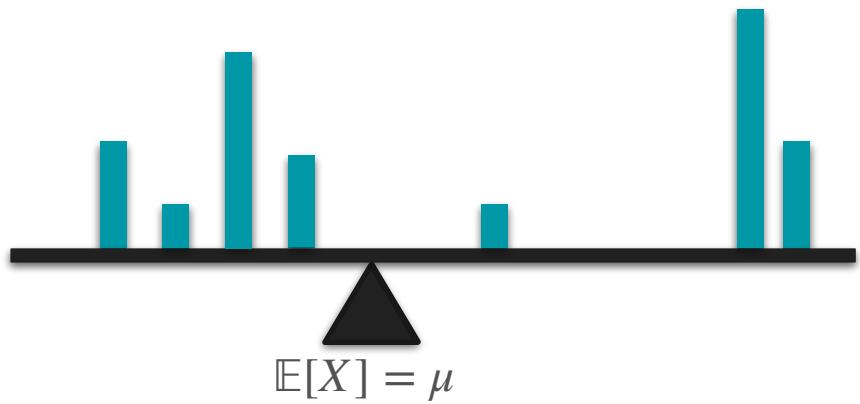


Game 2

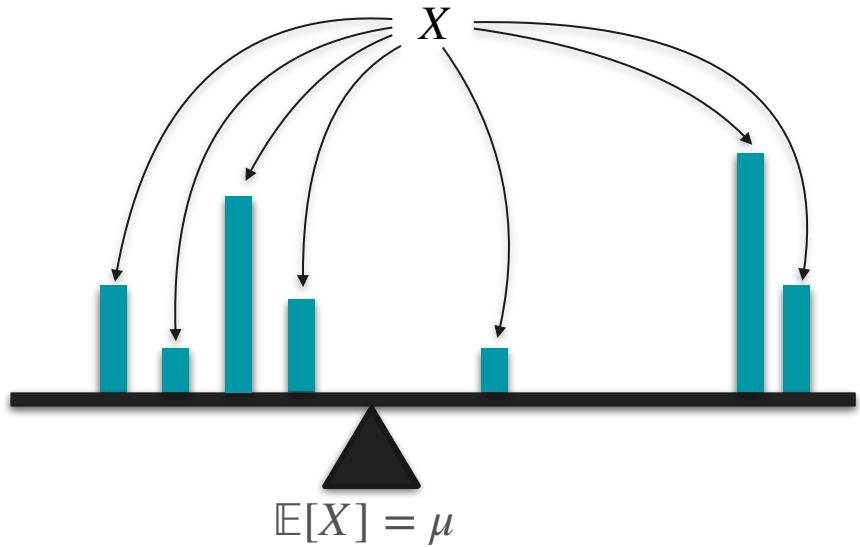
# Variance Formula



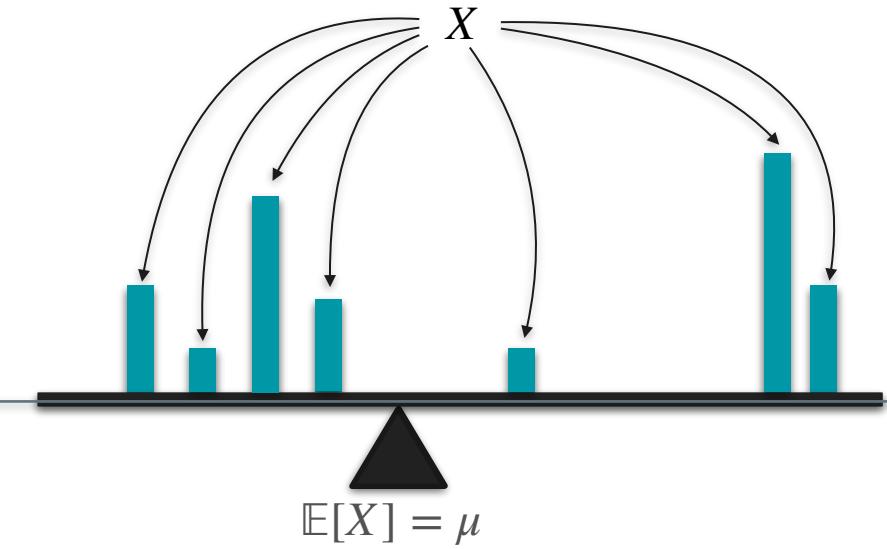
# Variance Formula



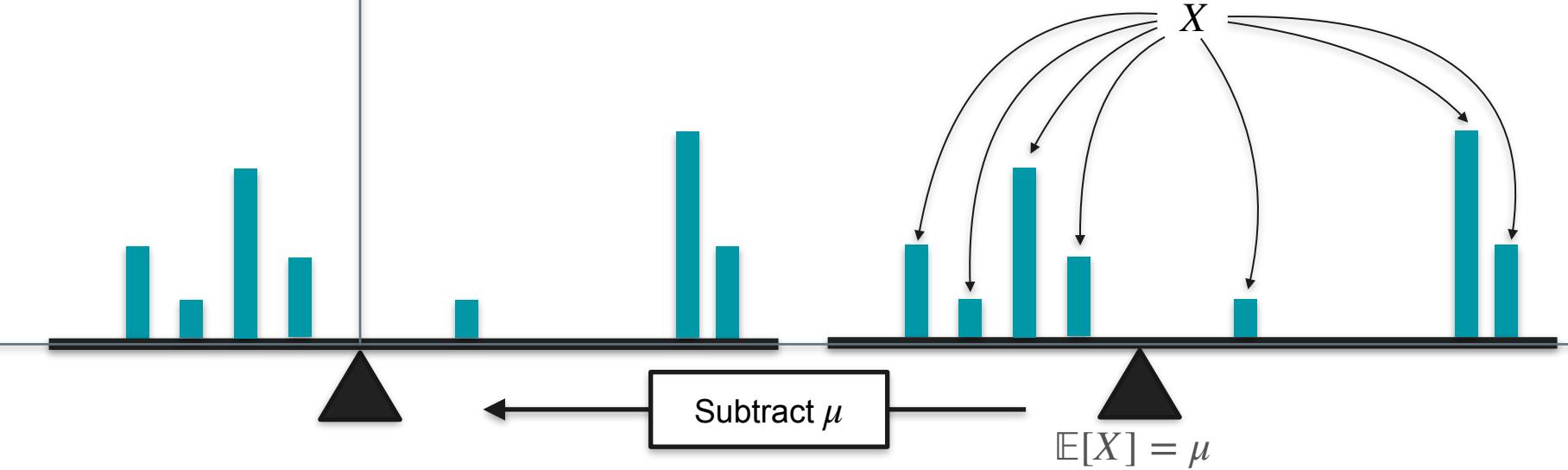
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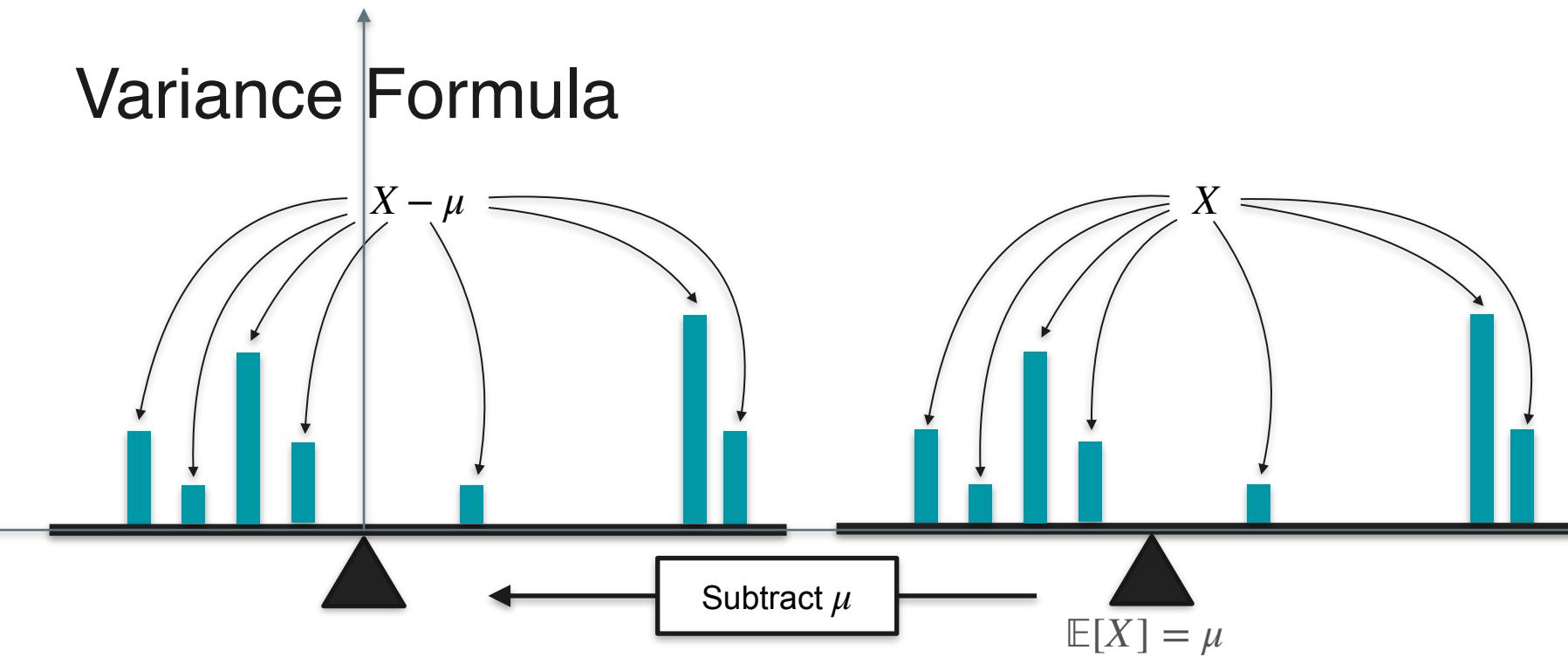
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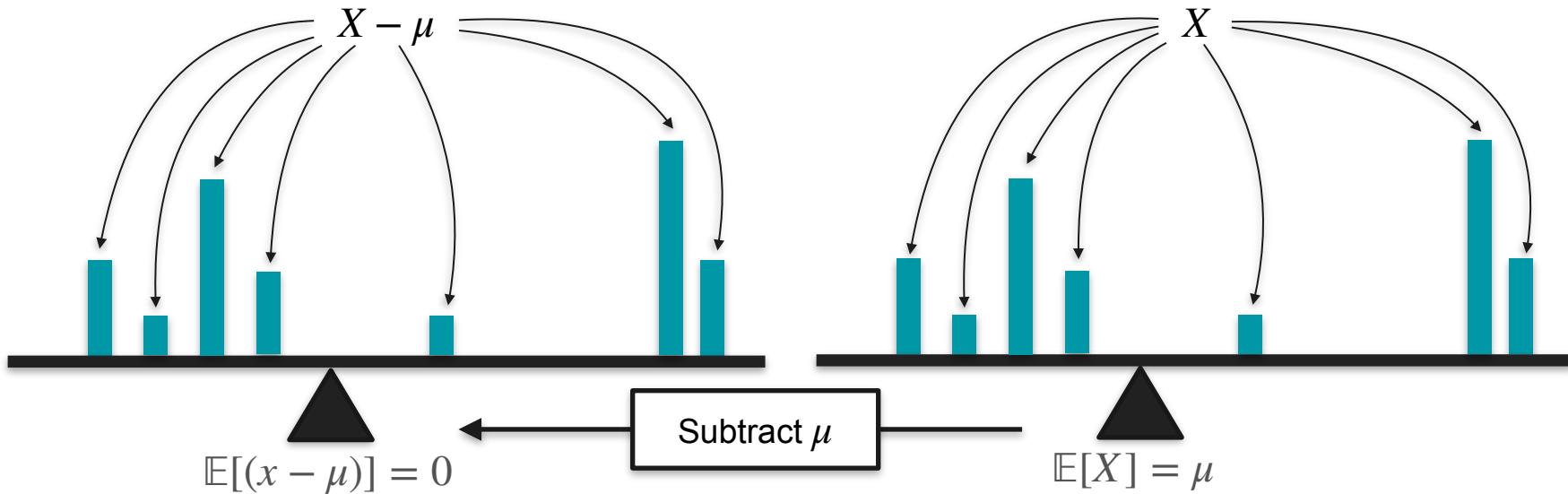
# Variance Formula



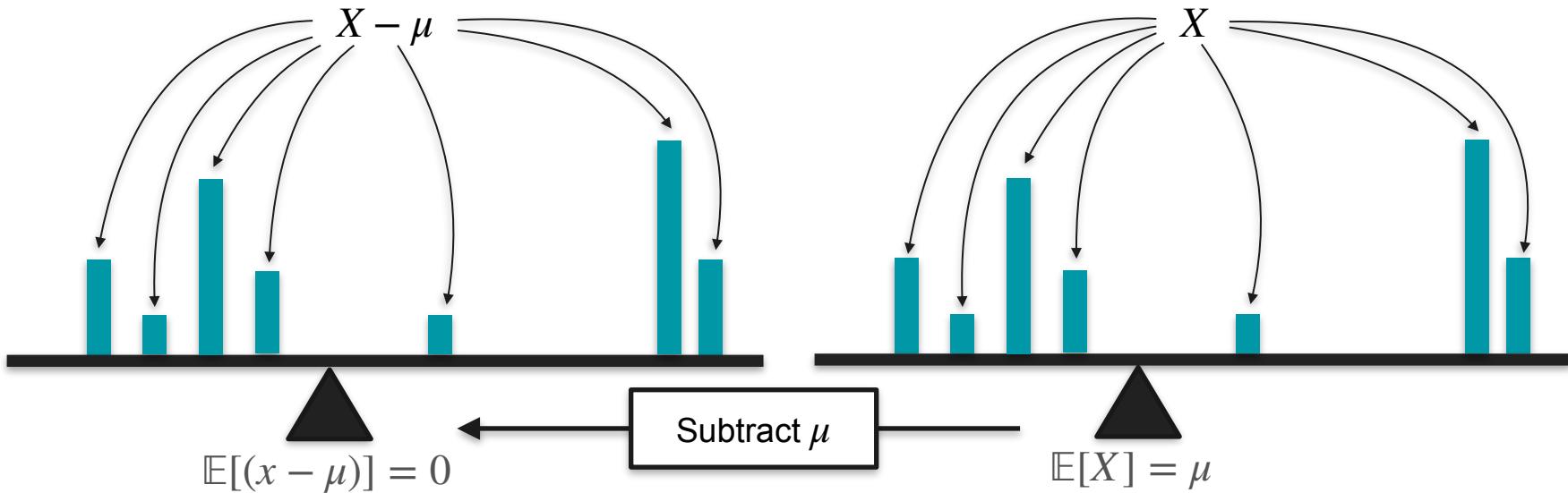
# Variance Formula



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# Variance Formula



$$Var(X) = \mathbb{E}[(X - \mu)^2]$$

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# Variance Formula

$$\begin{aligned} \text{Var}(X) = \mathbb{E}[(X - \mu)^2] &= \mathbb{E}[X^2 - 2\mu X + \mu^2] \\ &= \mathbb{E}[X^2] - \mathbb{E}[2\mu X] + \mathbb{E}[\mu^2] \end{aligned}$$

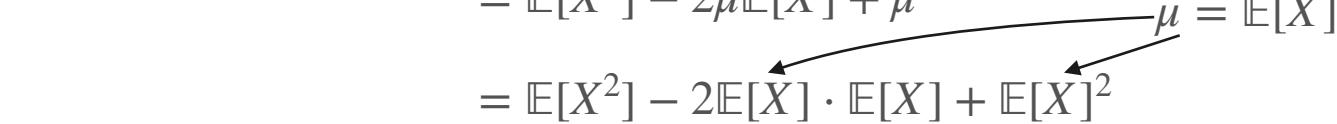

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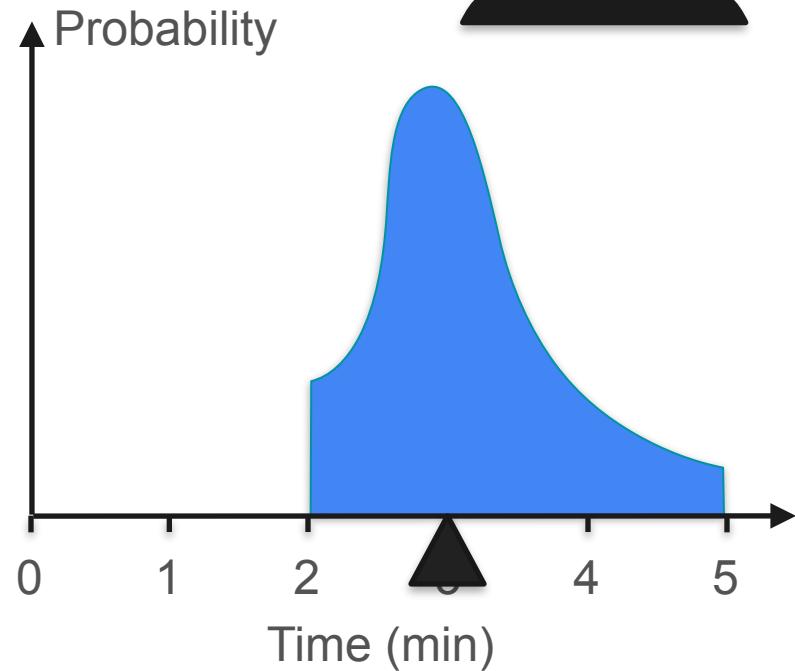
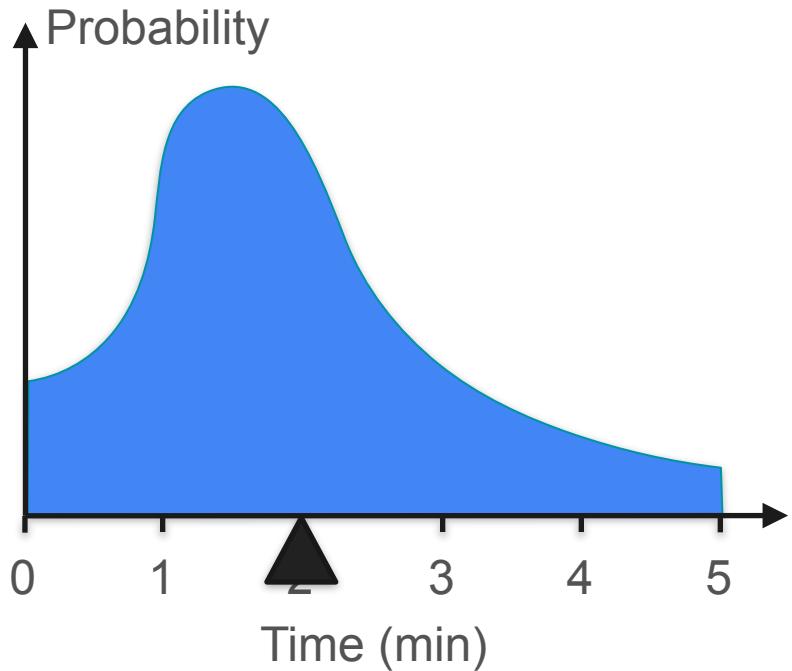
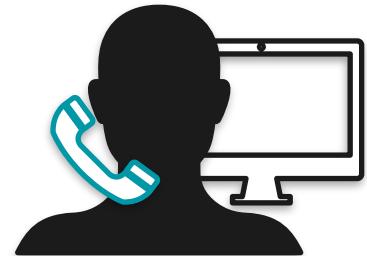
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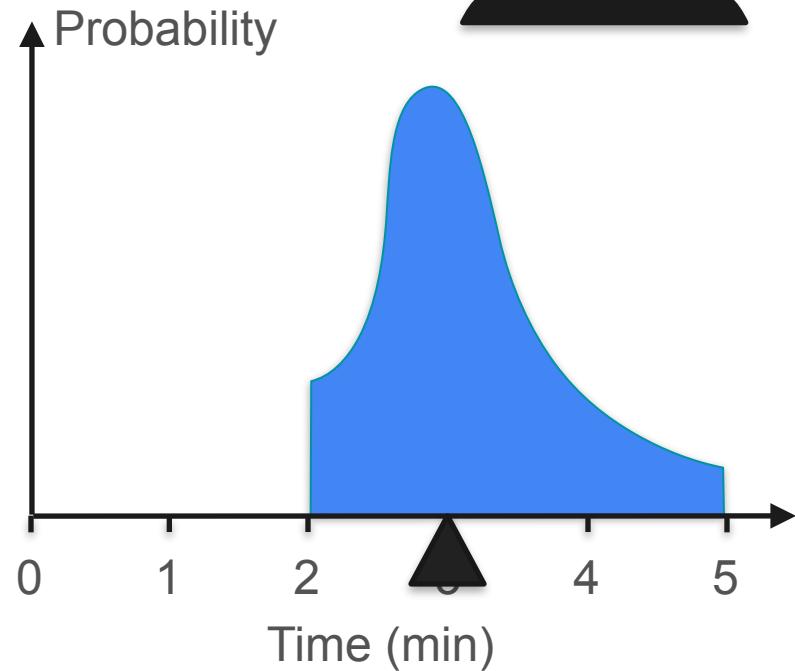
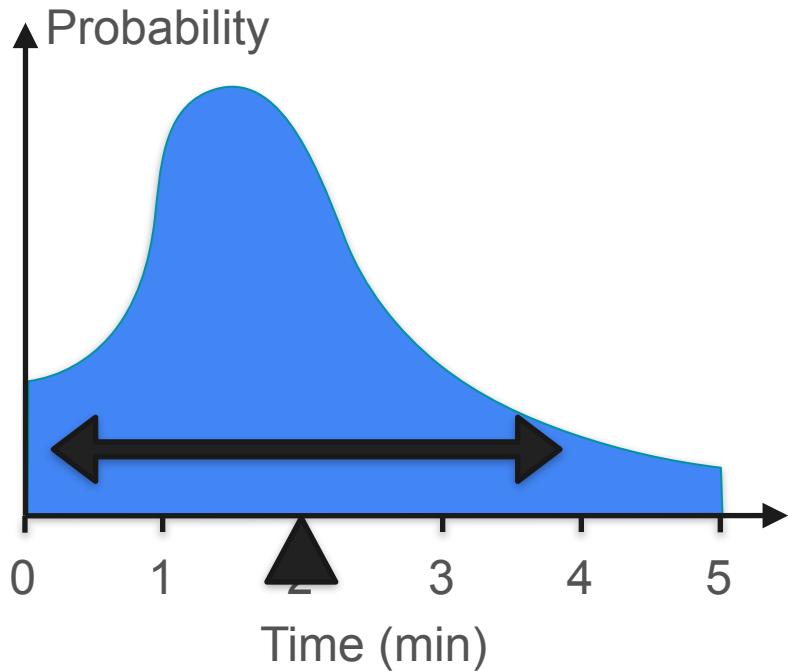
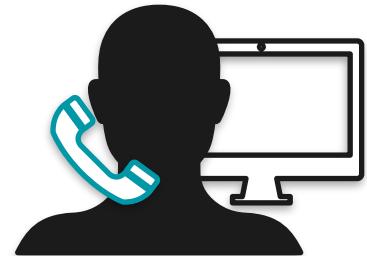
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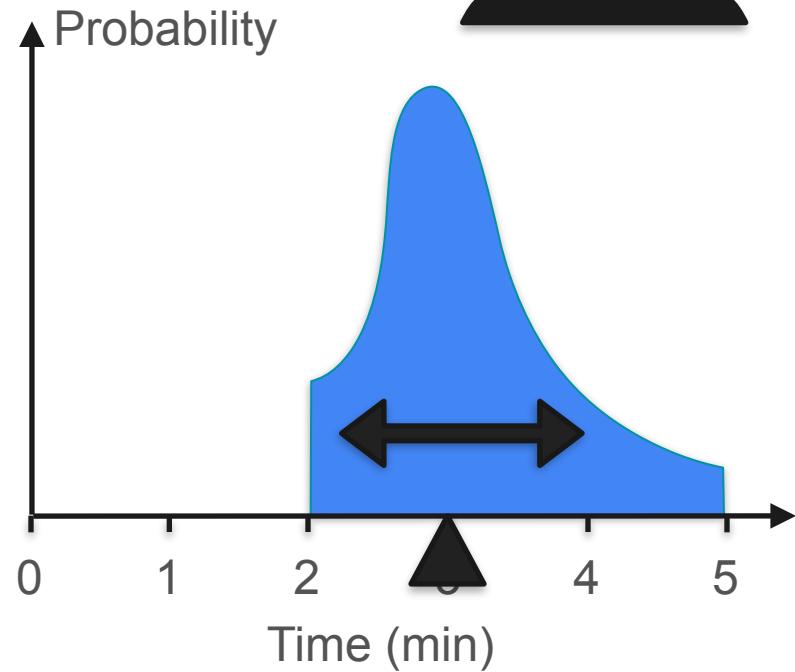
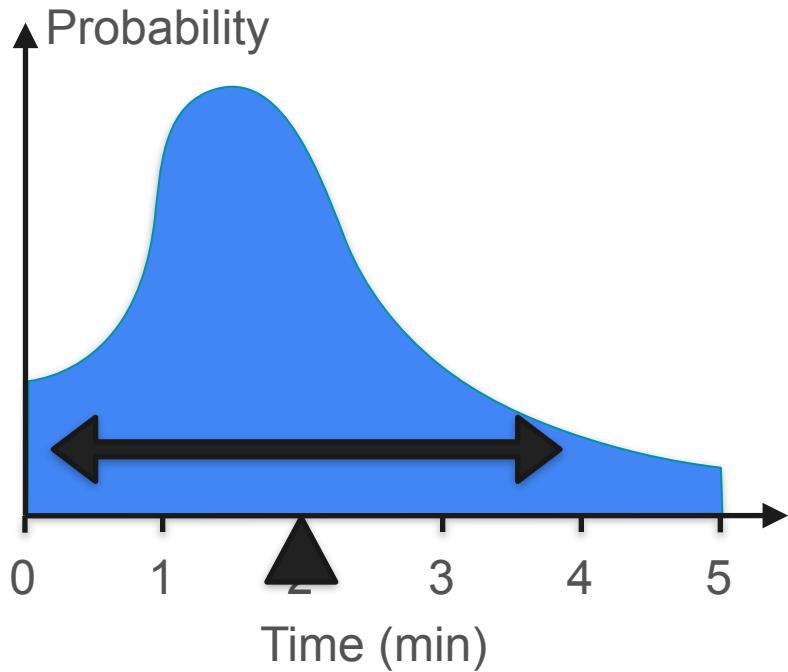
# Variance for Continuous Distributions



# Variance for Continuous Distributions

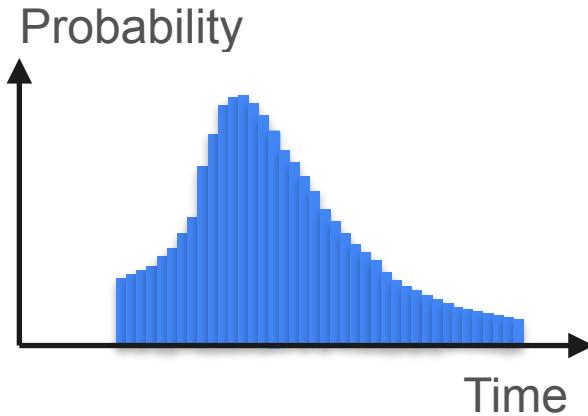


# Variance for Continuous Distributions



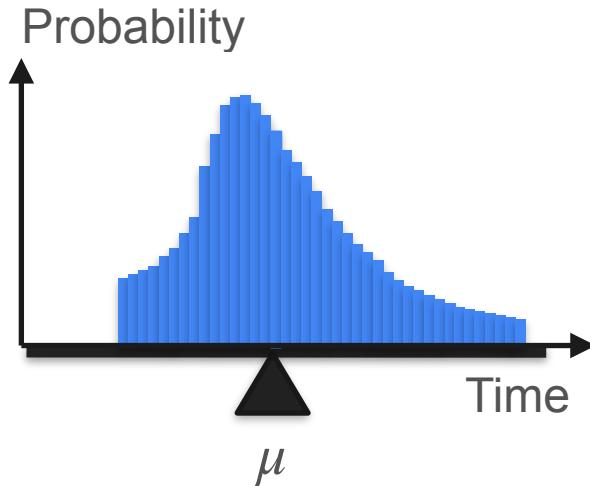
# Variance

$$\text{Var}(X) = \mathbb{E}[(X - \mu)^2] = \mathbb{E}[X^2] - \mathbb{E}[X]^2$$



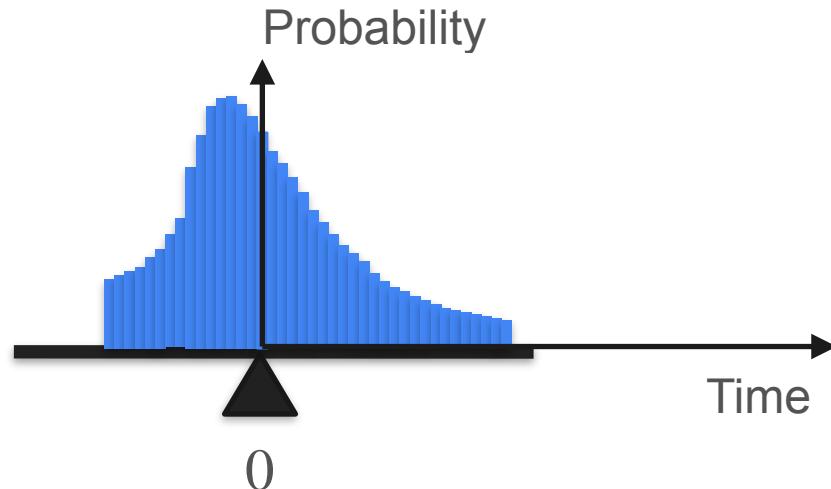
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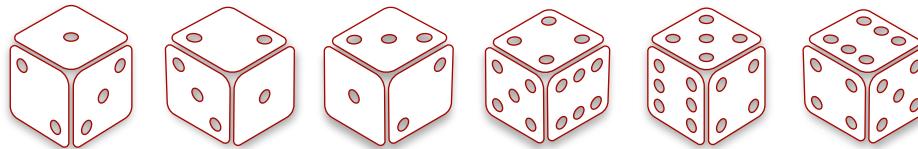


# Properties of the Variance

# Properties of the Variance

Probability:  $1/6$     $1/6$     $1/6$     $1/6$     $1/6$     $1/6$

Roll:      1      2      3      4      5      6



Double:      2      4      6      8      10      12

Wins      -3      -2      -1      0      1      2

# Properties of the Variance

$$= 2.92$$

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$$= 2.92$$



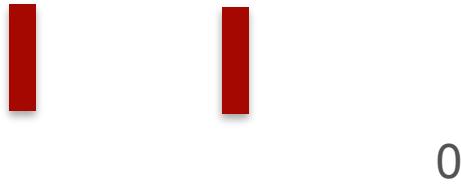
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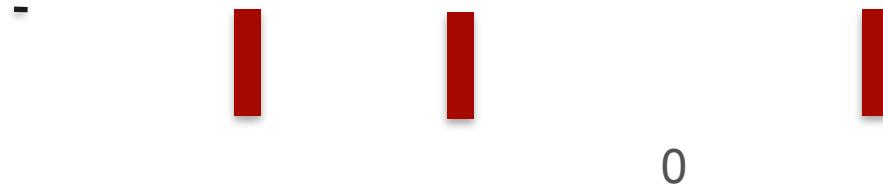
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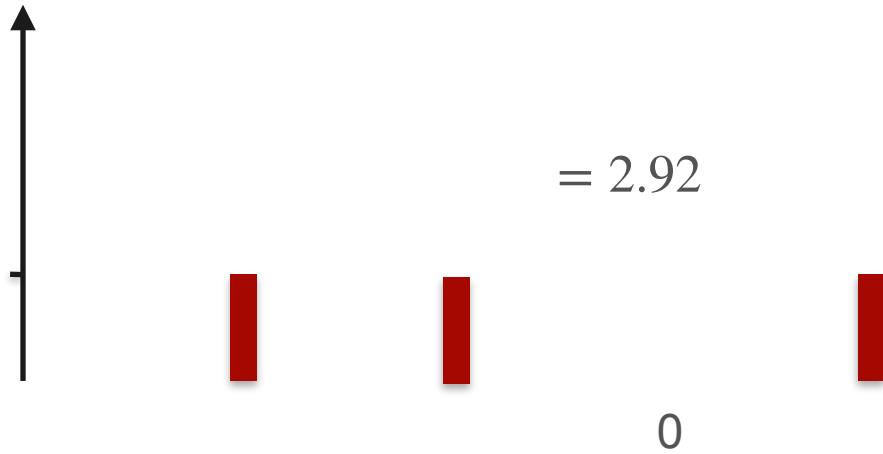


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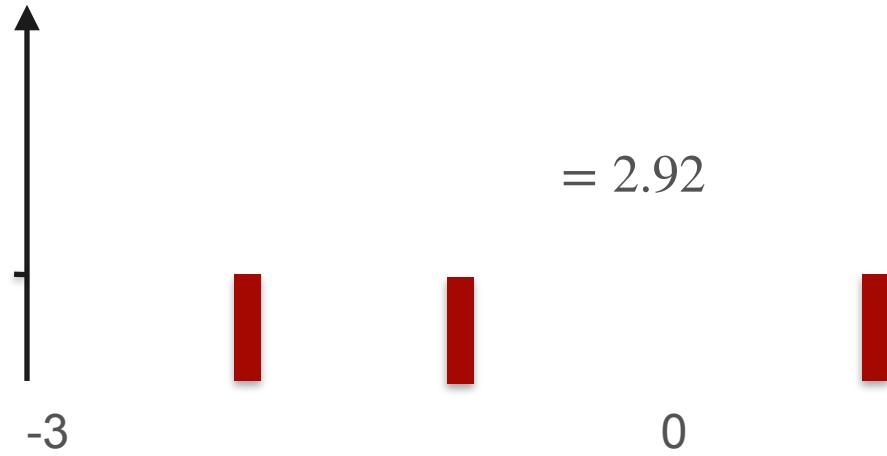
$$= 2.92$$



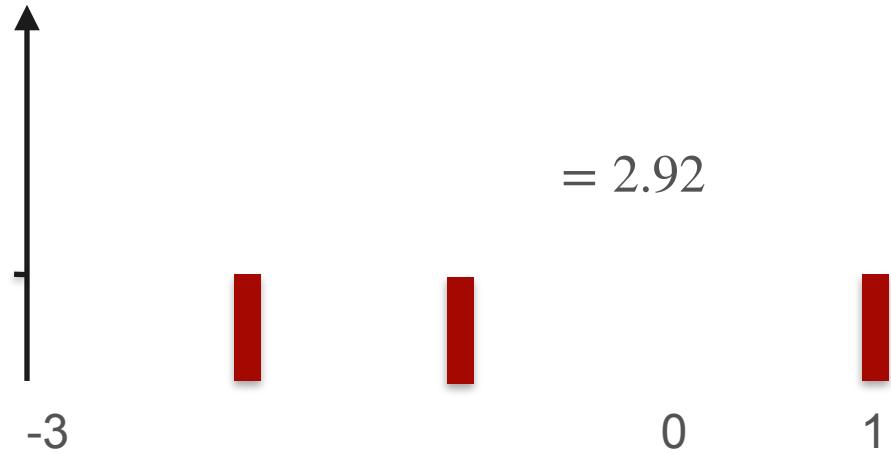
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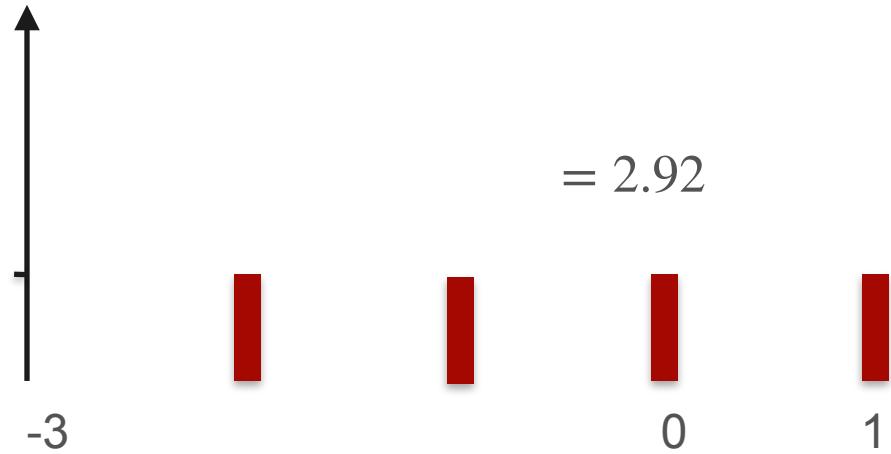
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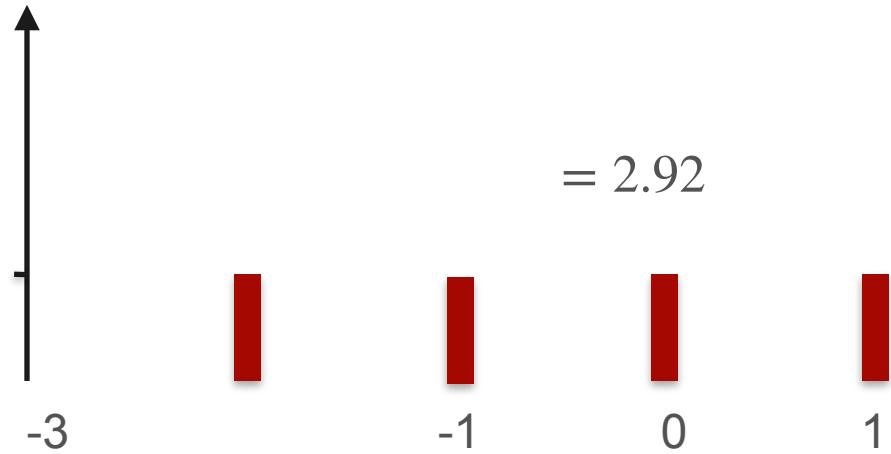
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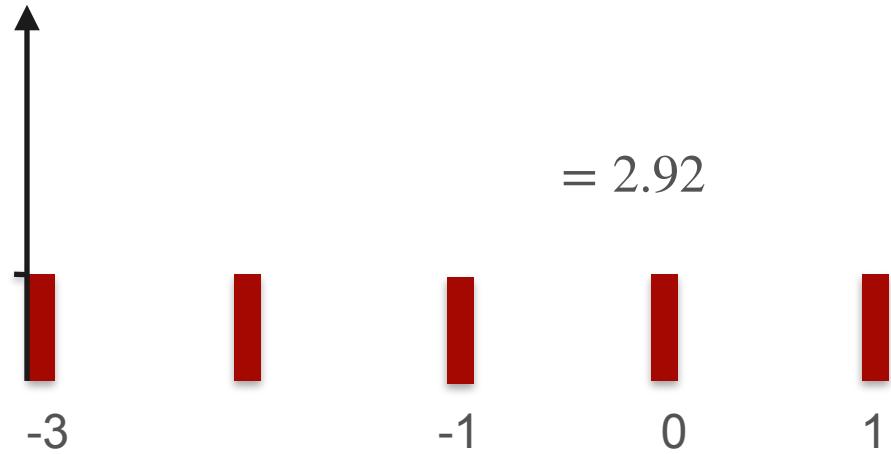
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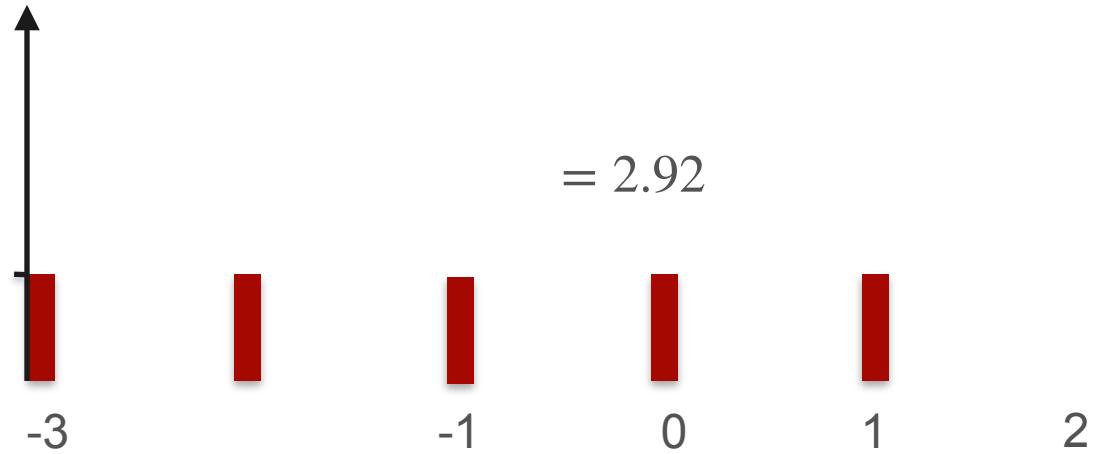
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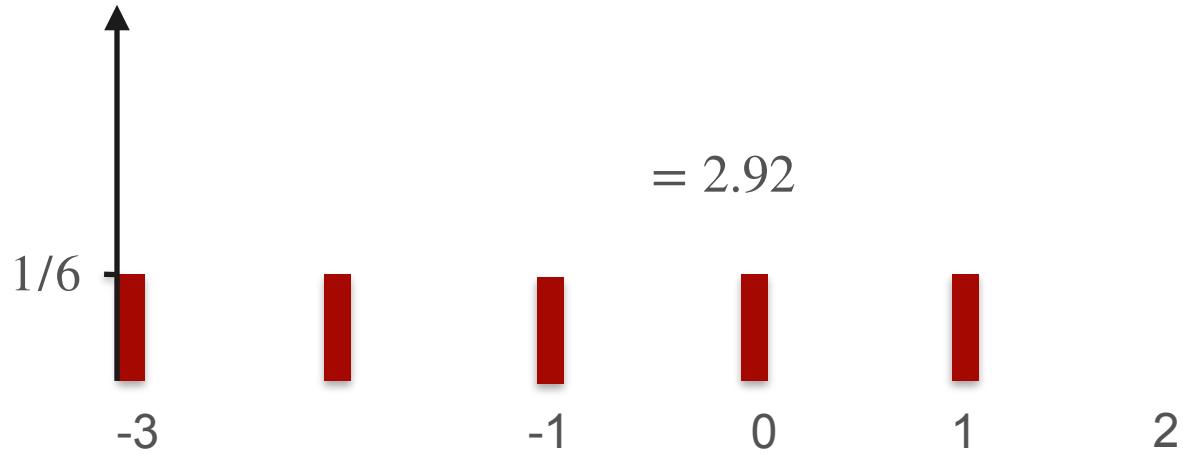
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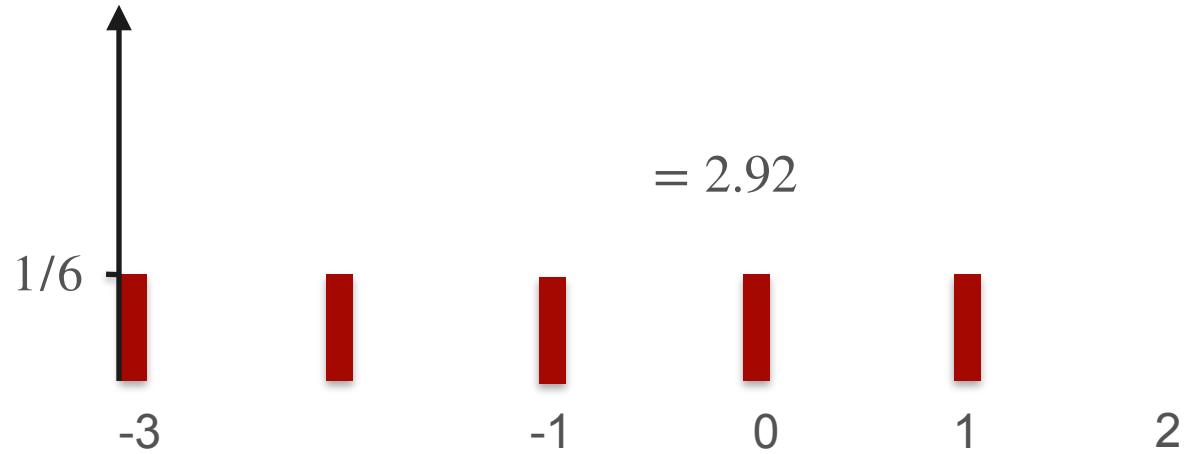


# Properties of the Variance



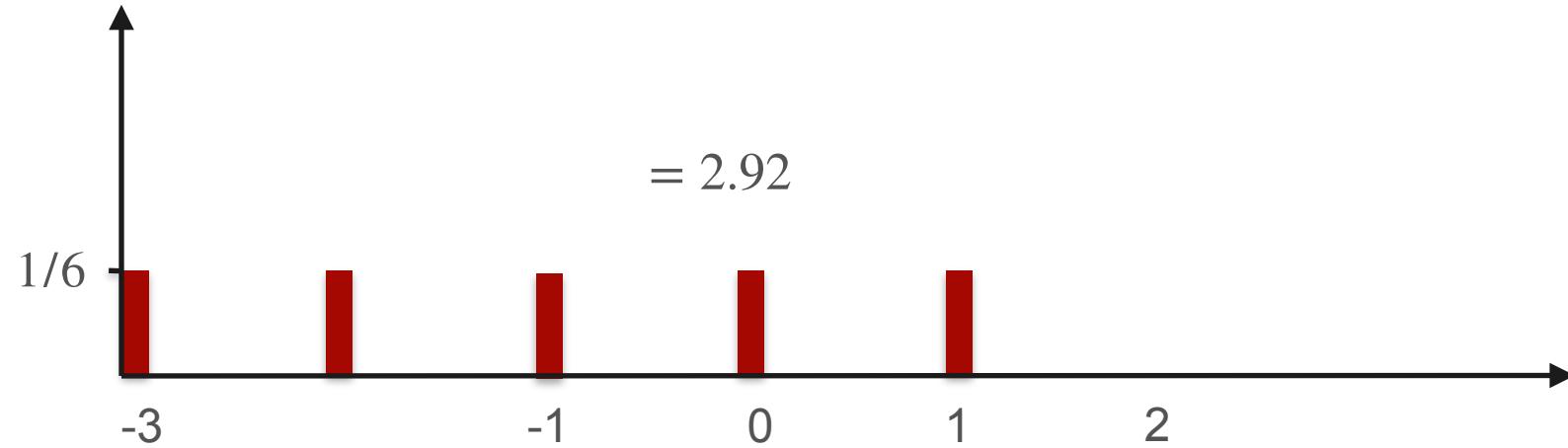
# Properties of the Variance

Probability



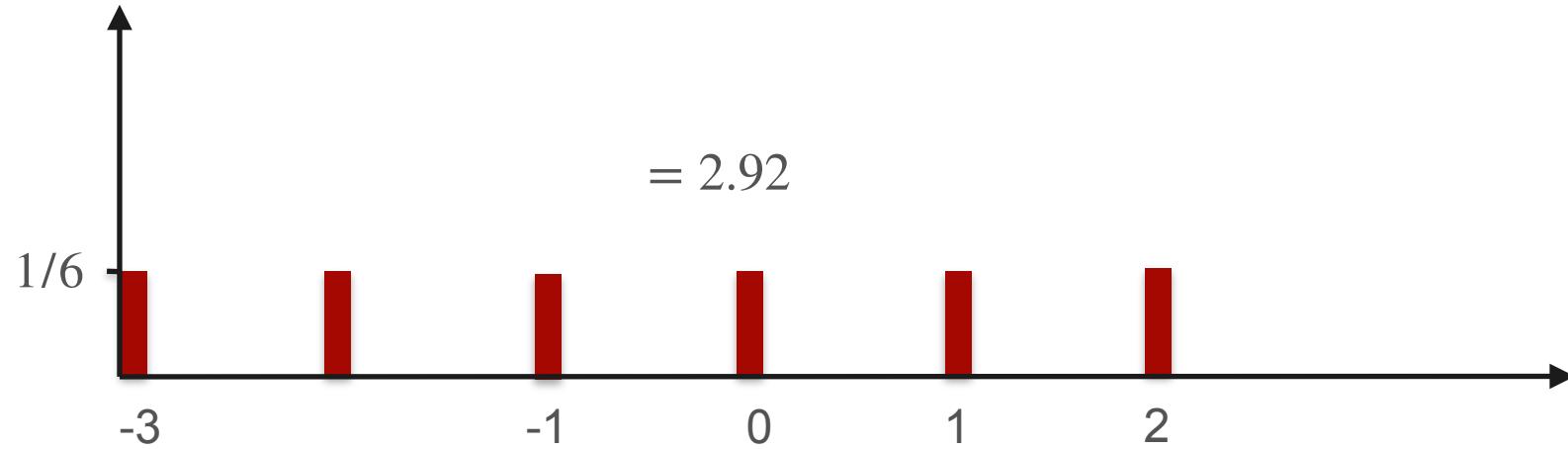
# Properties of the Variance

Probability



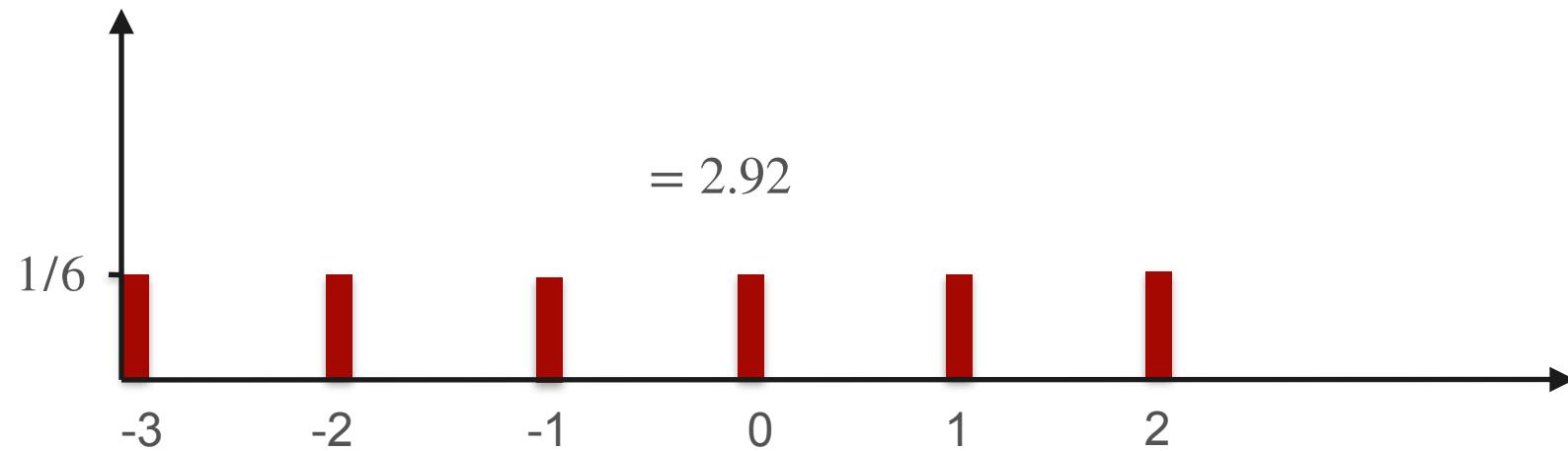
# Properties of the Variance

Probability



# Properties of the Variance

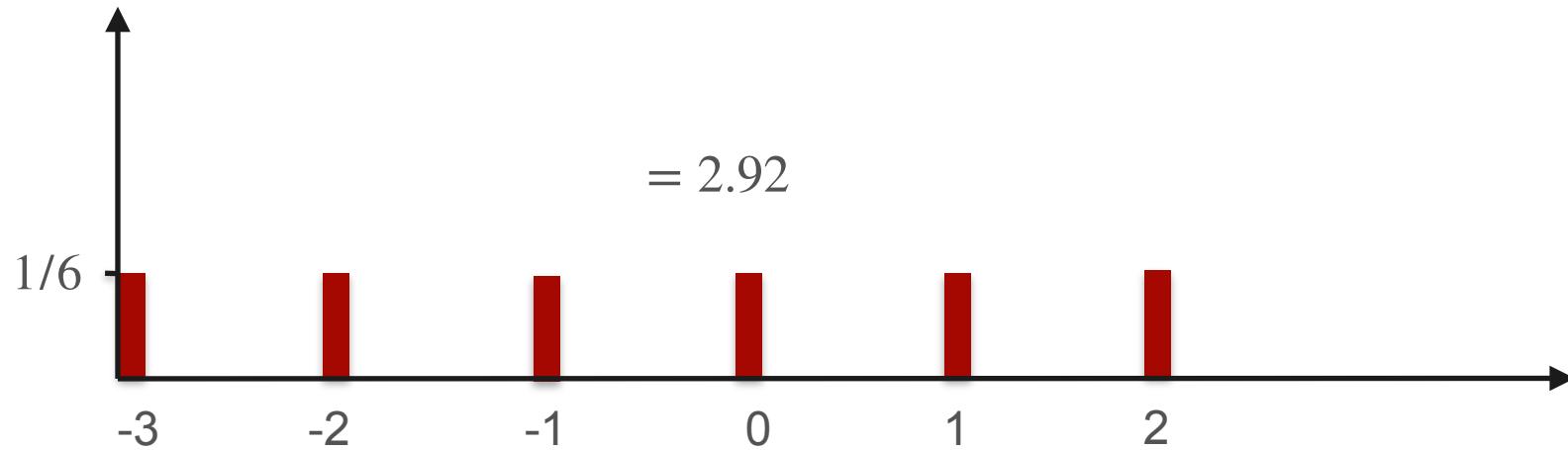
Probability



# Properties of the Variance

$$\text{Var}(2X - 5) = \mathbb{E} \left[ (2X - 5 - \mathbb{E}[2X - 5])^2 \right]$$

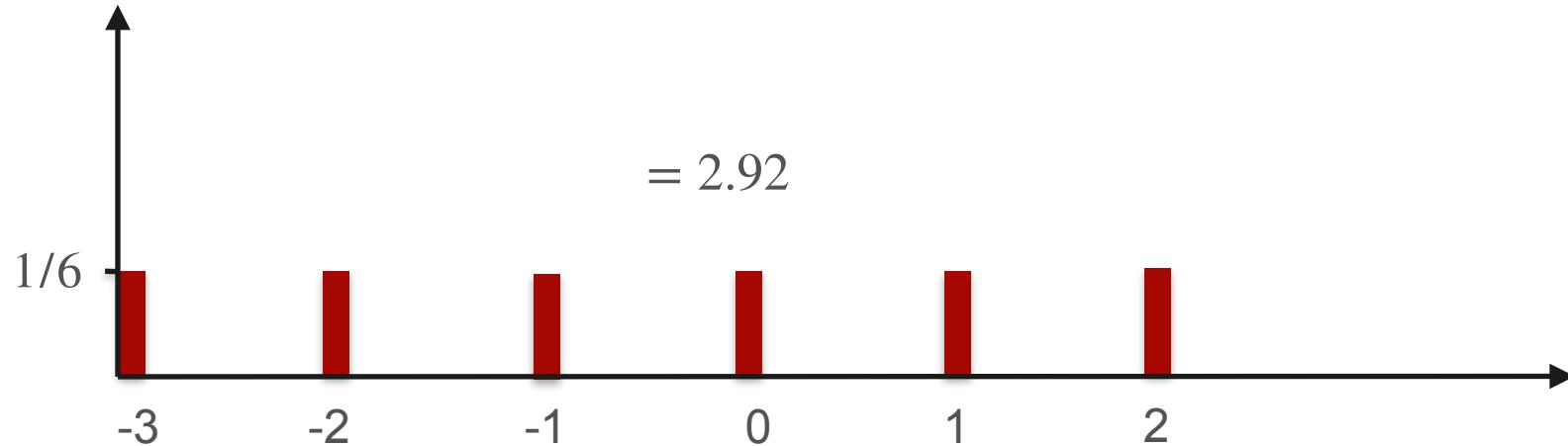
Probability



# Properties of the Variance

$$\begin{aligned} \text{Var}(2X - 5) &= \mathbb{E} \left[ (2X - 5 - \mathbb{E}[2X - 5])^2 \right] \\ &= \mathbb{E} \left[ (2X - 5)^2 \right] - \mathbb{E}[2X - 5]^2 \end{aligned}$$

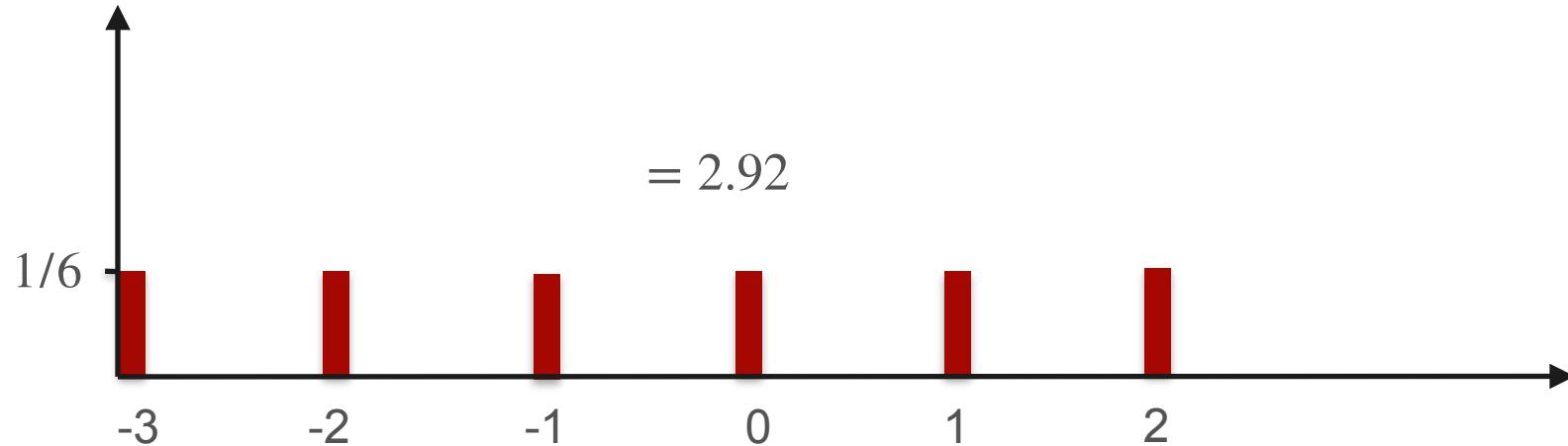
Probability



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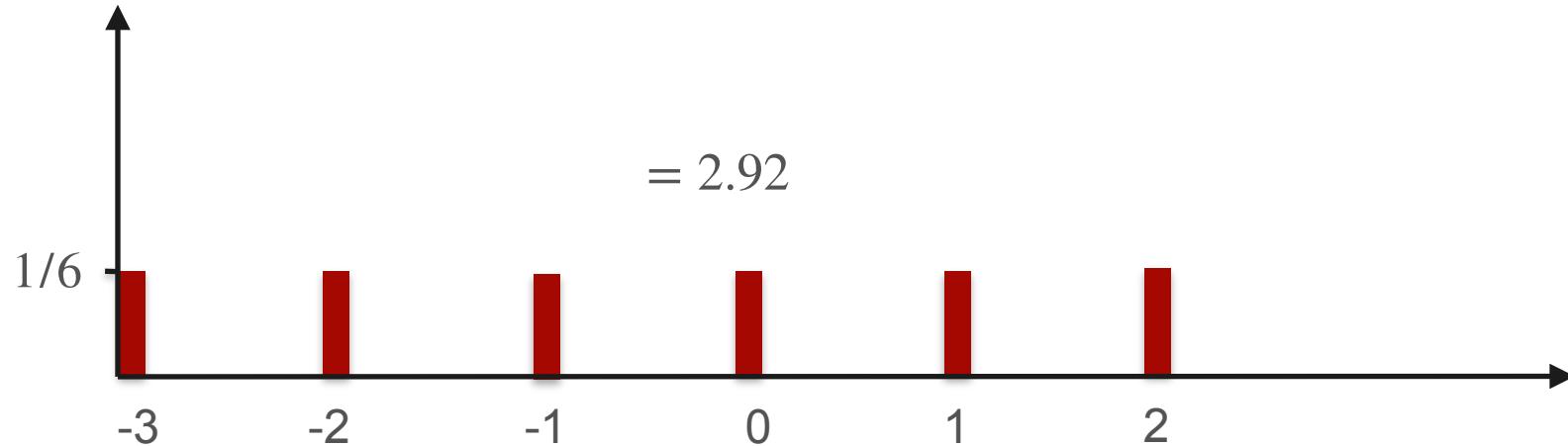
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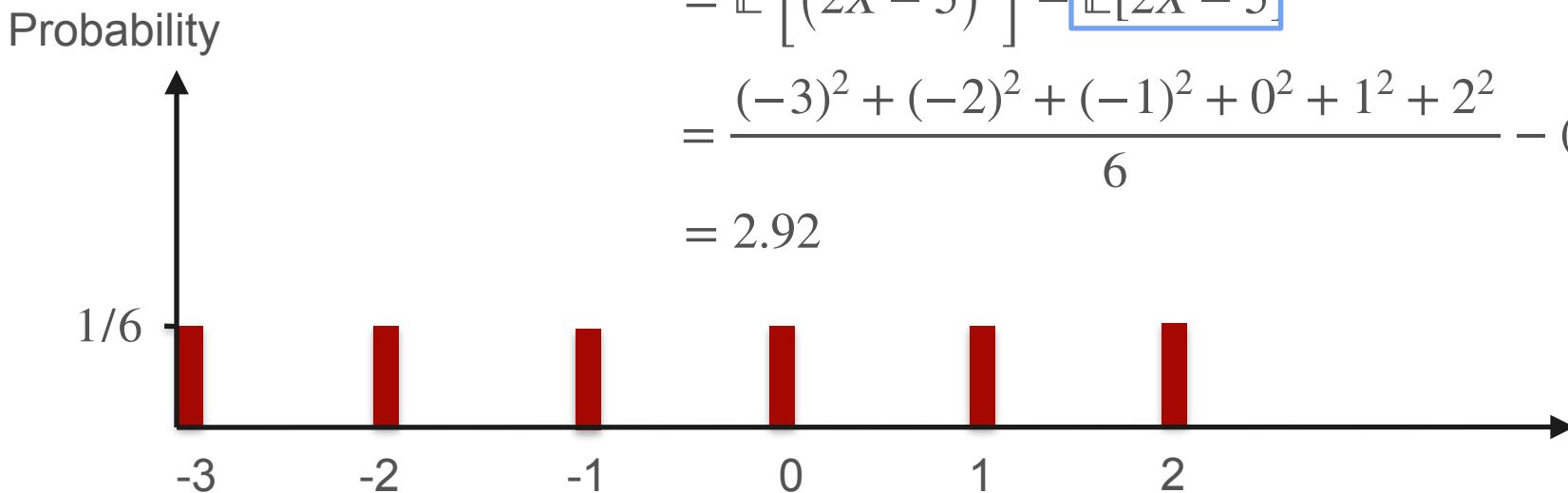
# Properties of the Variance

$$Var(2X - 5) = \mathbb{E} \left[ (2X - 5 - \mathbb{E}[2X - 5])^2 \right]$$

$$= \mathbb{E} \left[ (2X - 5)^2 \right] - \boxed{\mathbb{E}[2X - 5]}^2$$

$$= \frac{(-3)^2 + (-2)^2 + (-1)^2 + 0^2 + 1^2 + 2^2}{6} - (-0.5)^2$$

$$= 2.92$$



# Properties of the Variance

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$$\mathbb{E} [(2X - 5)^2]$$

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$$\mathbb{E} [(2X - 5)^2] = \mathbb{E} [2^2 X^2 + (-5)^2 - 2(-5)X]$$

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*2 $\mathbb{E}[X]$  - 5*



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# Properties of the Variance

$$Var(2X - 5) = \boxed{2^2\mathbb{E}[X^2]} + (-5)^2 - 2(-5)\mathbb{E}[X] - (\boxed{2^2\mathbb{E}[X]^2} + (-5)^2 - 2(-5)\mathbb{E}[X])$$

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In general:  $\text{Var}(aX + b) = a^2 \text{Var}(X)$



DeepLearning.AI

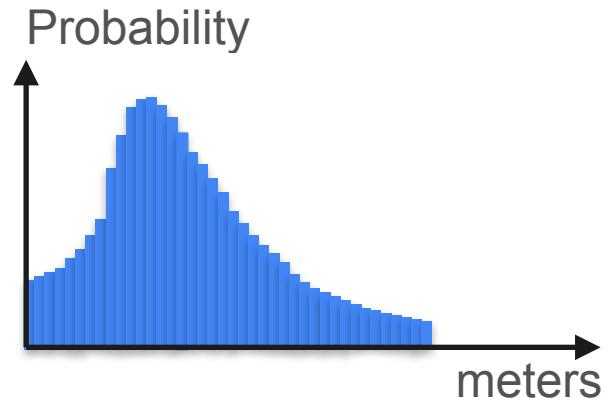
# Describing Distributions

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## Standard deviation

# Standard Deviation

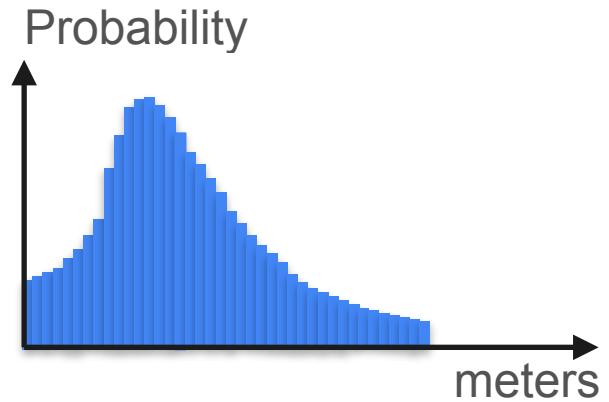
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# Standard Deviation

$$\text{Var}(X) = \mathbb{E}[(X - \mu)^2] = \mathbb{E}[X^2] - \mathbb{E}[X]^2$$

Say  $X$  is measured in meters.

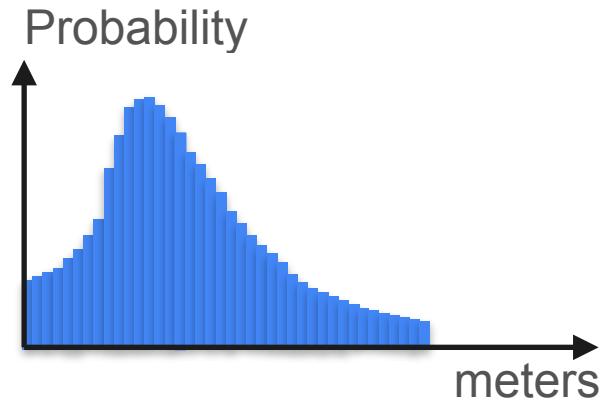


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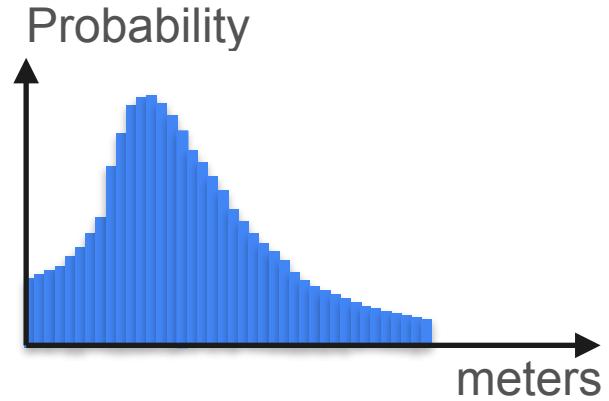


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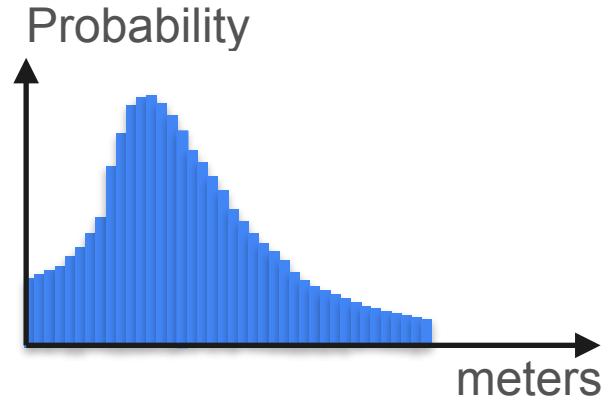


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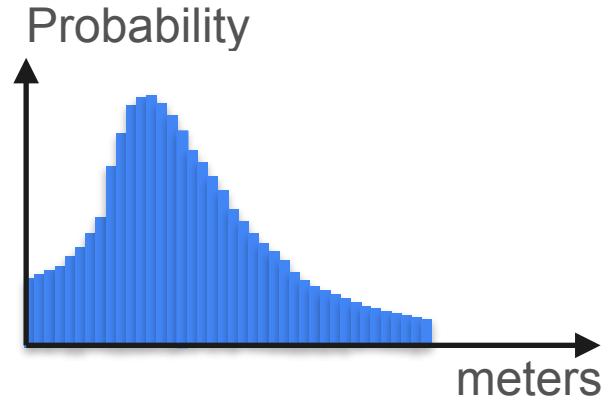
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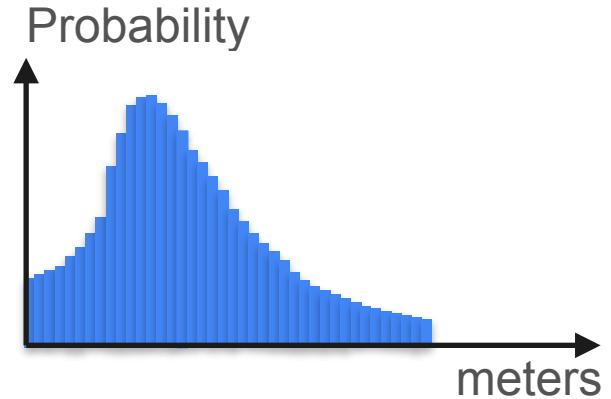
$$\text{Var}(X) = \mathbb{E}[(X - \mu)^2] = \mathbb{E}[X^2] - \mathbb{E}[X]^2$$

Say  $X$  is measured in meters.

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Then  $\text{Var}(X)$  is measured in meters<sup>2</sup>.

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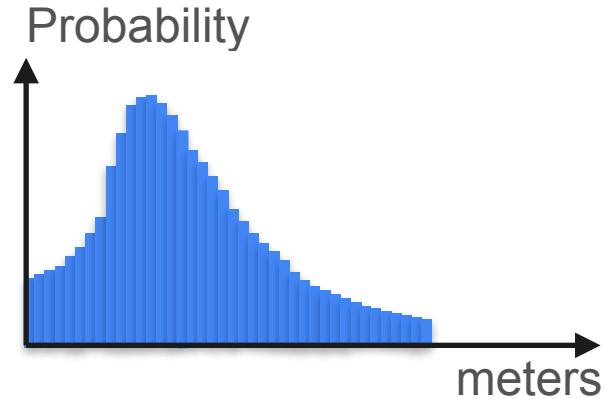
Say  $X$  is measured in meters.

Then  $\mathbb{E}[X]$  is measured in meters.

Then  $\text{Var}(X)$  is measured in meters<sup>2</sup>.

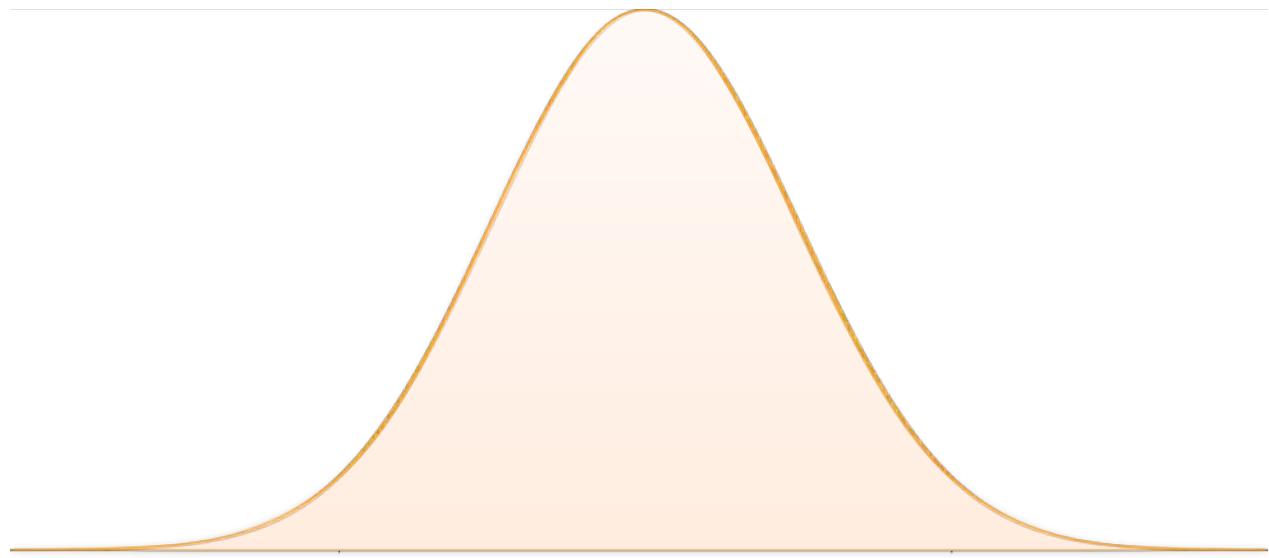
Then  $\sqrt{\text{Var}(X)}$  is measured in meters.

Let's call  $std(X) = \sqrt{\text{Var}(X)}$ , the *standard deviation* of  $X$



# Normal Distribution: 68-95-99.7 Rule

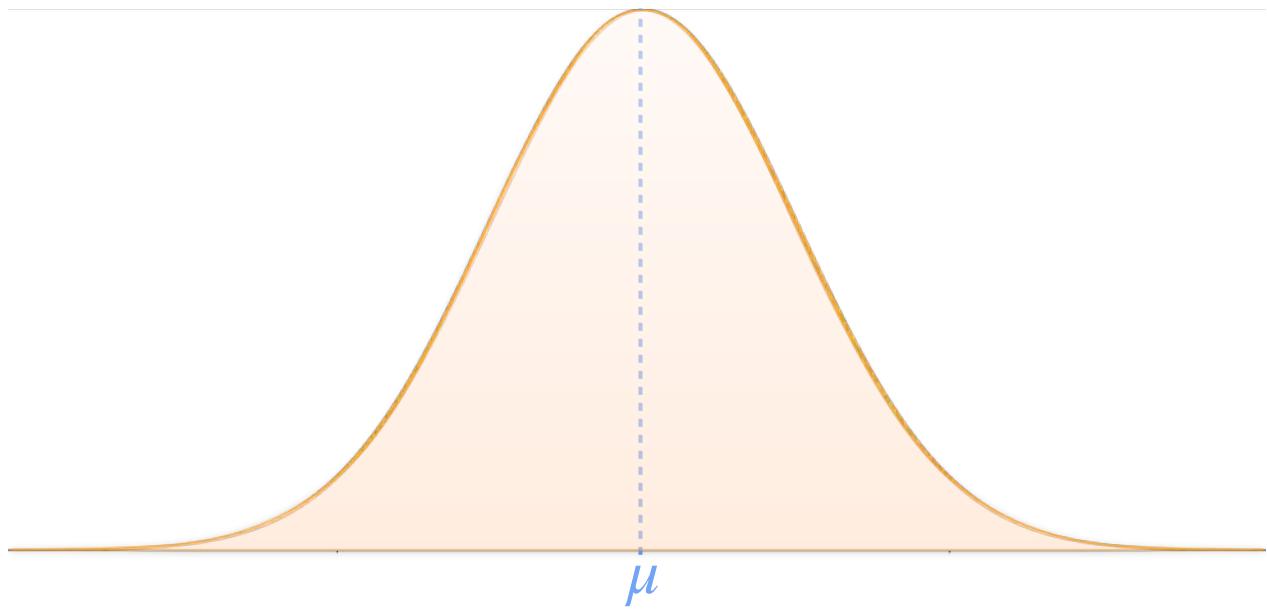
# Normal Distribution: 68-95-99.7 Rule



# Normal Distribution: 68-95-99.7 Rule

Parameters:

- $\mu$ : center of the bell

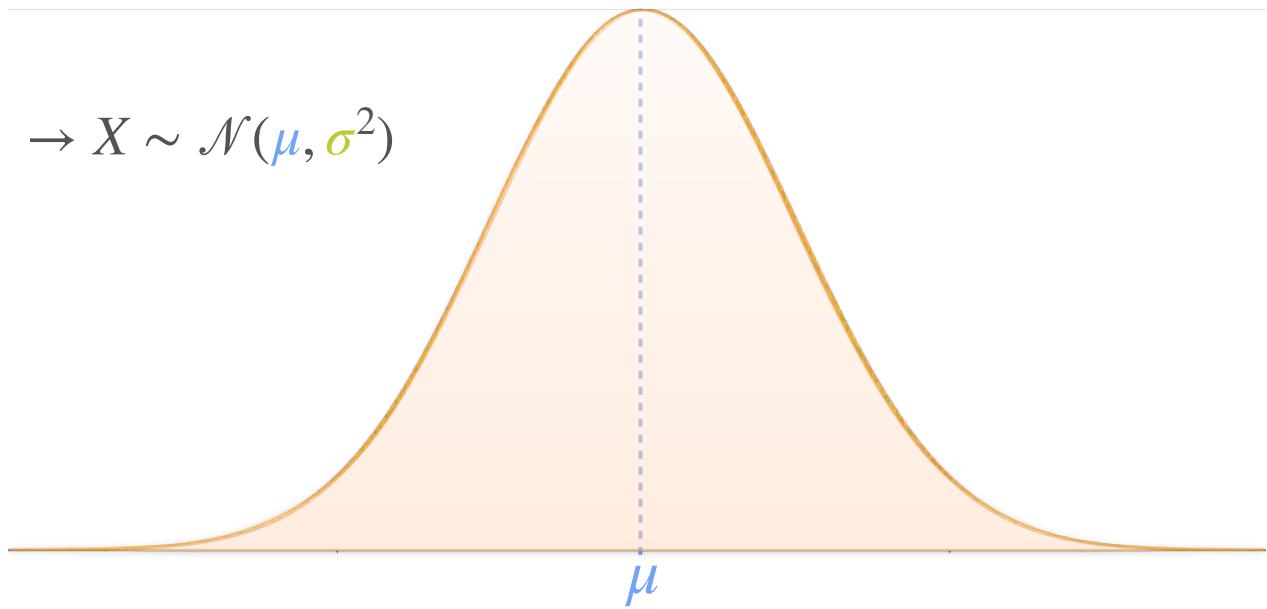


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Parameters:

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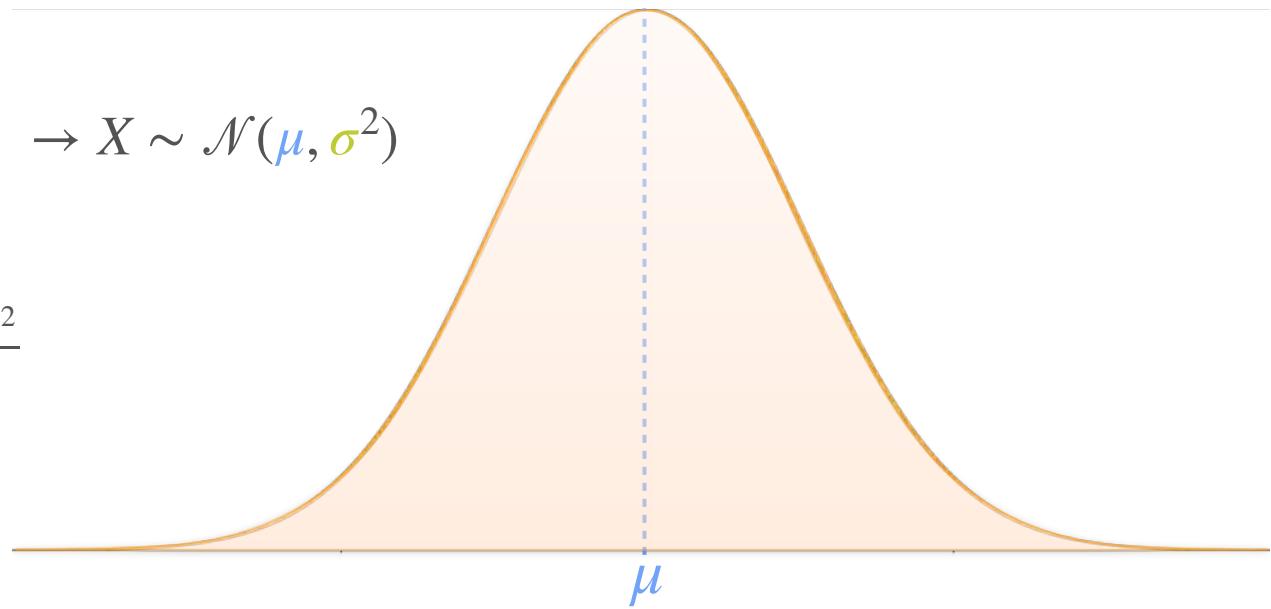
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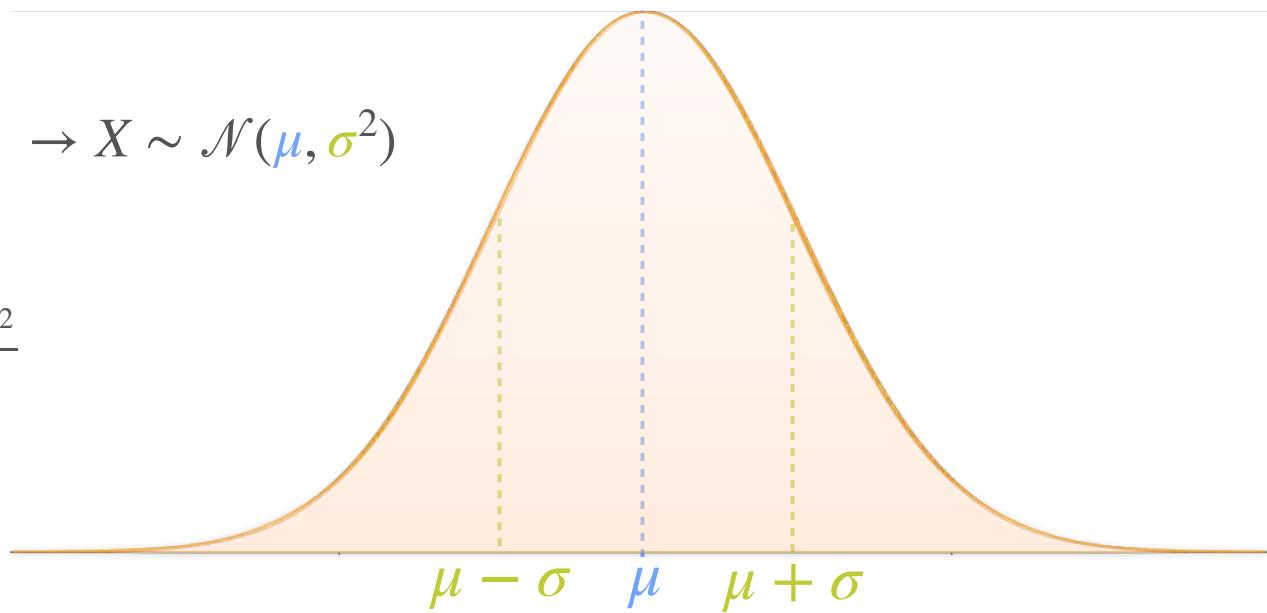
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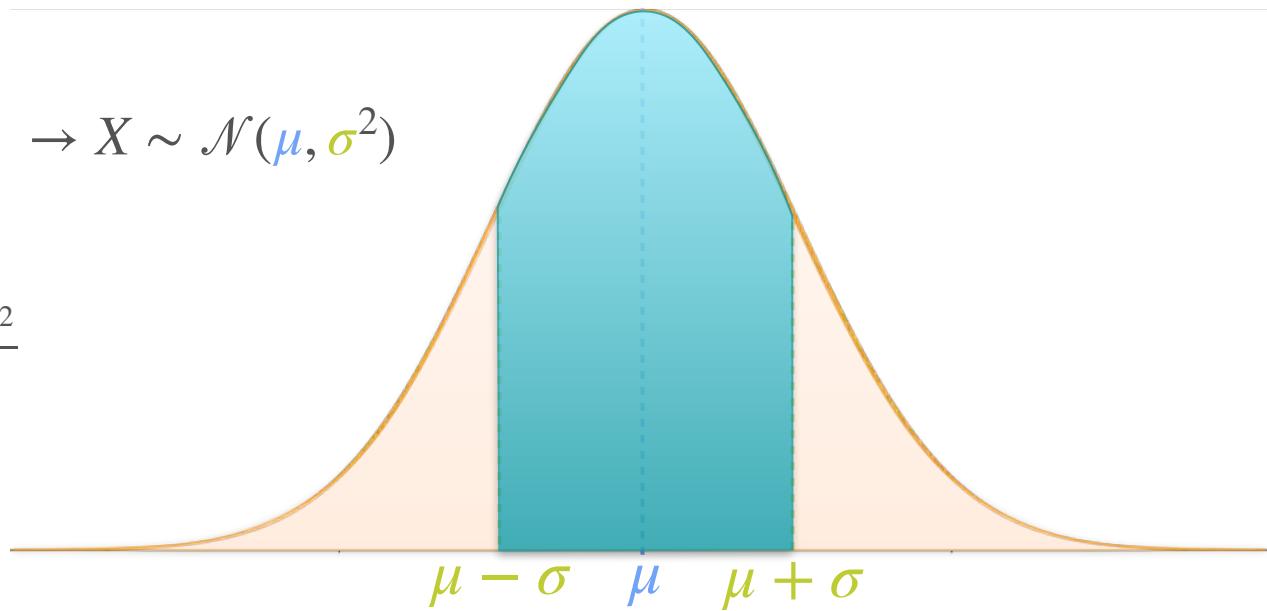
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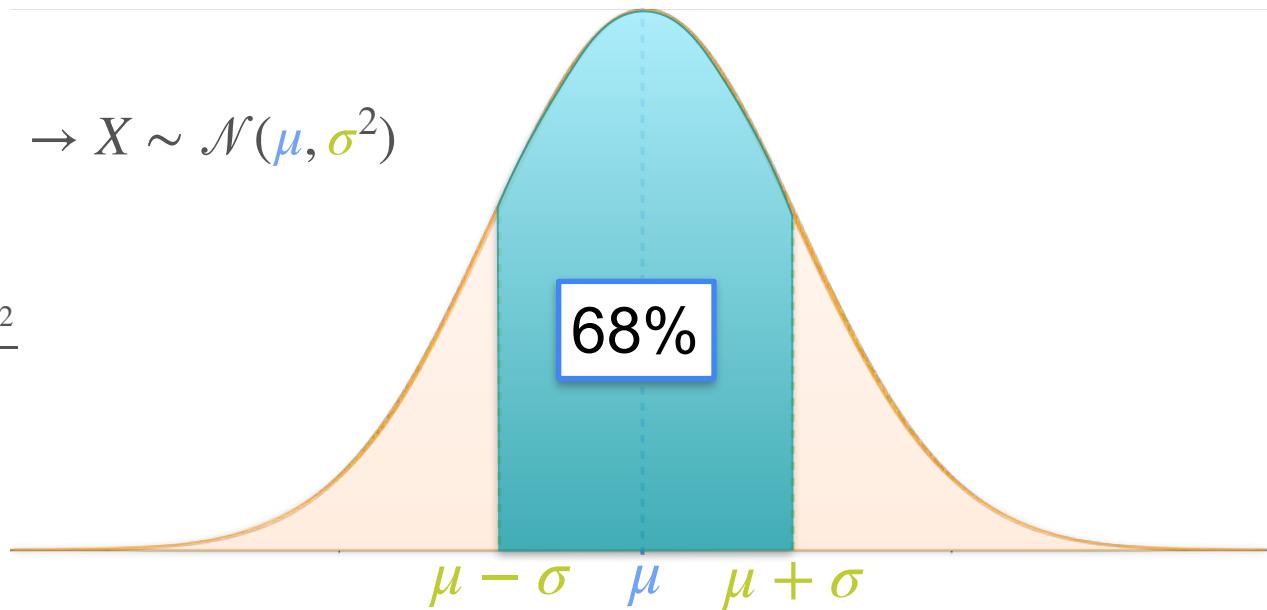
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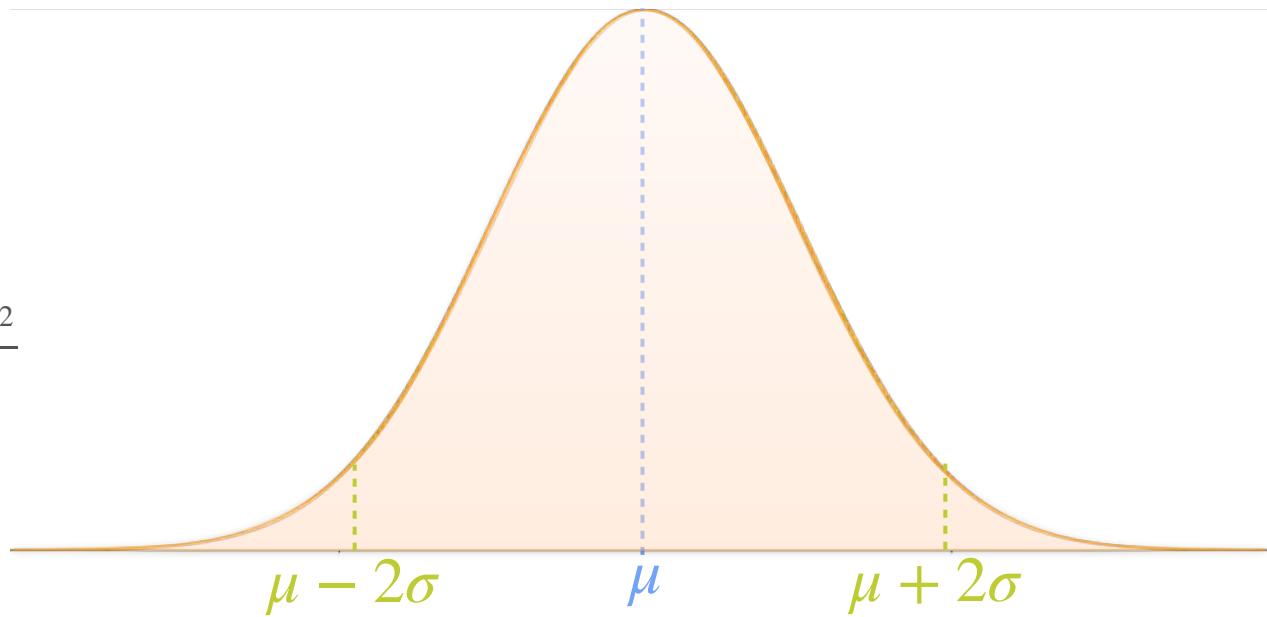


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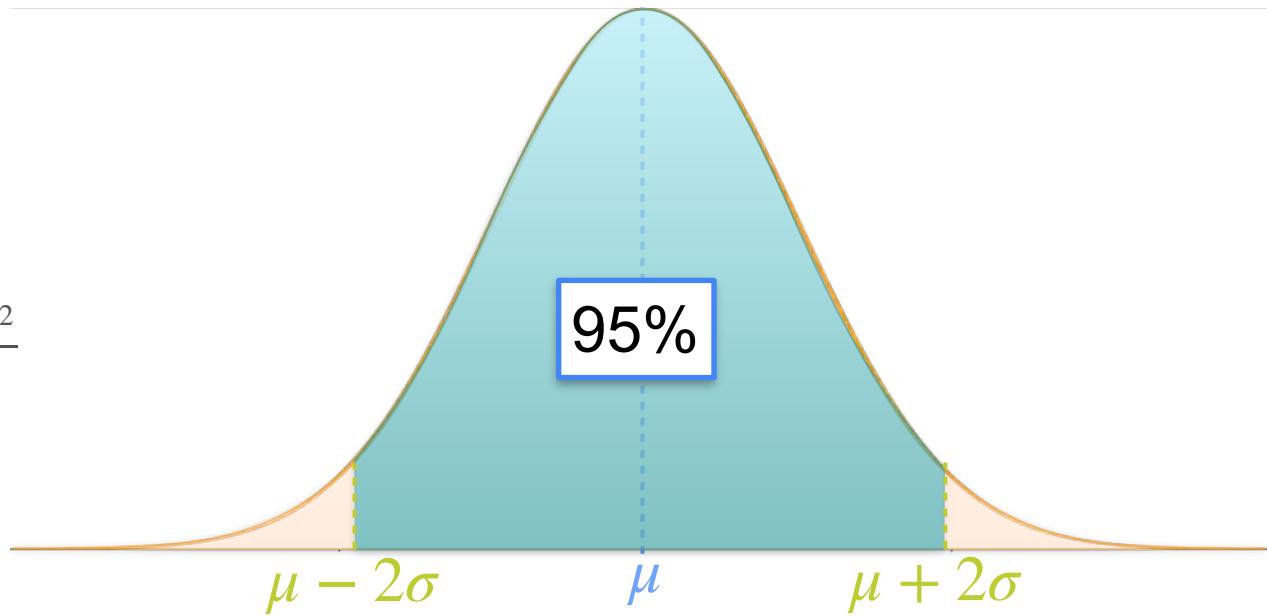


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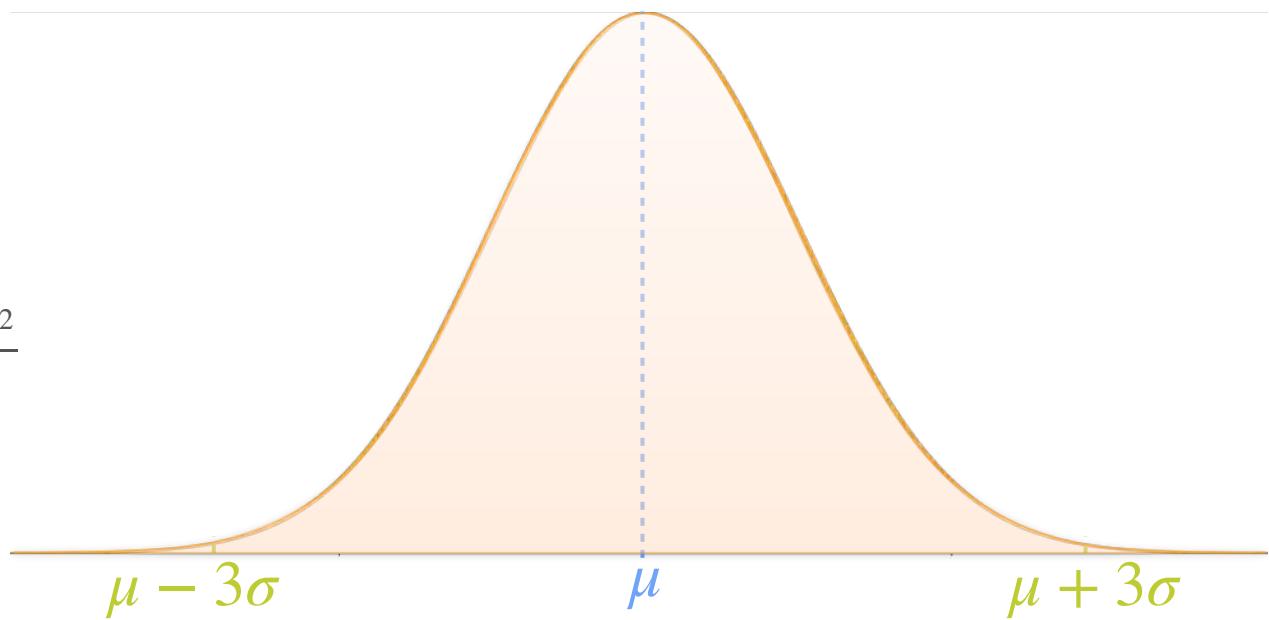


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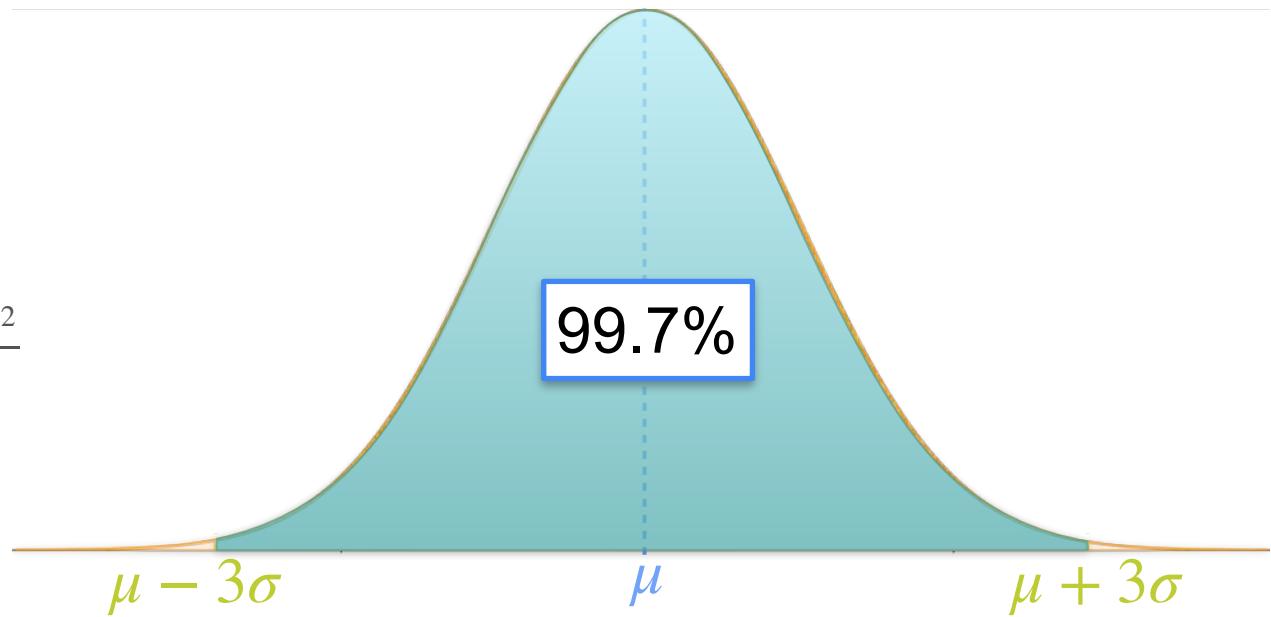


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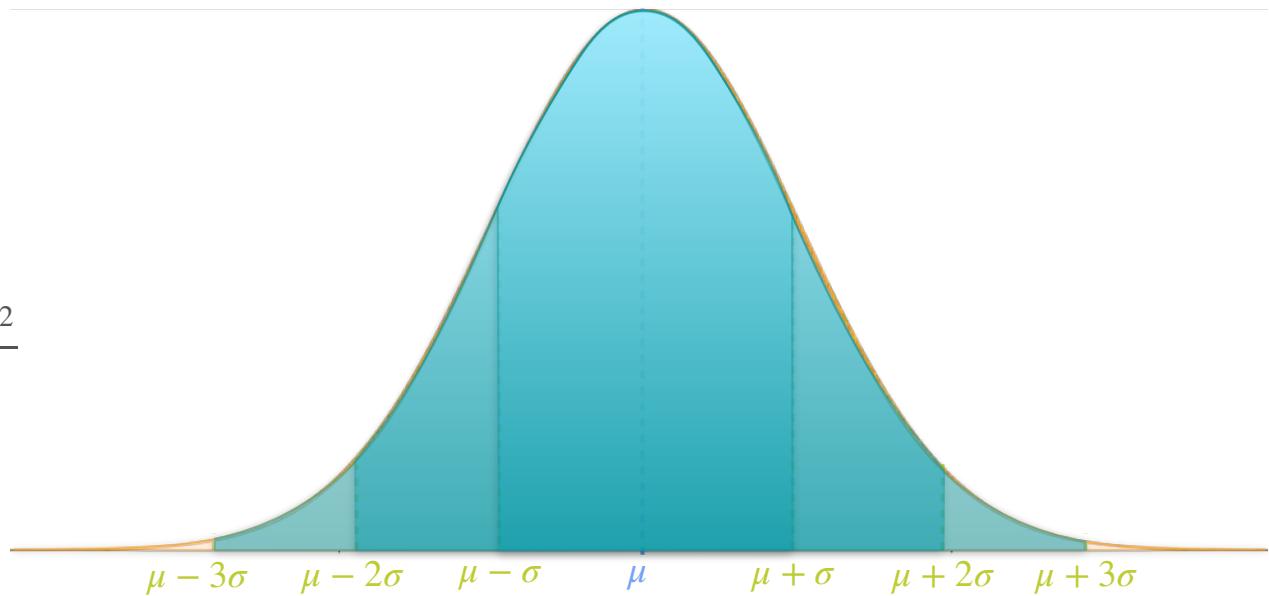


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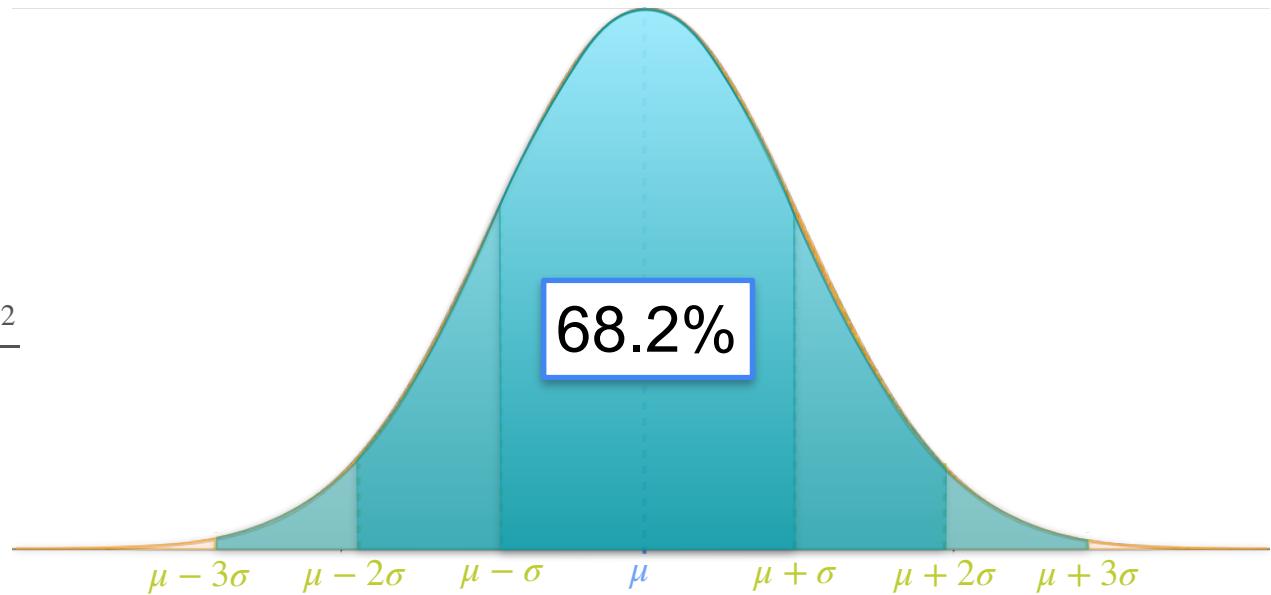


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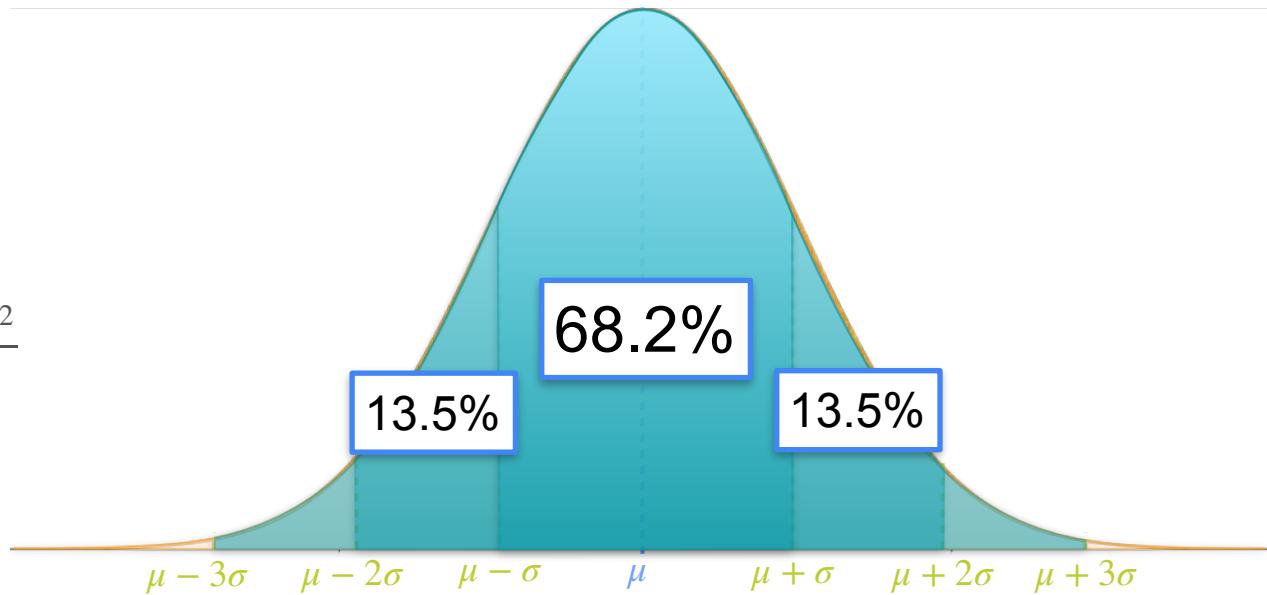


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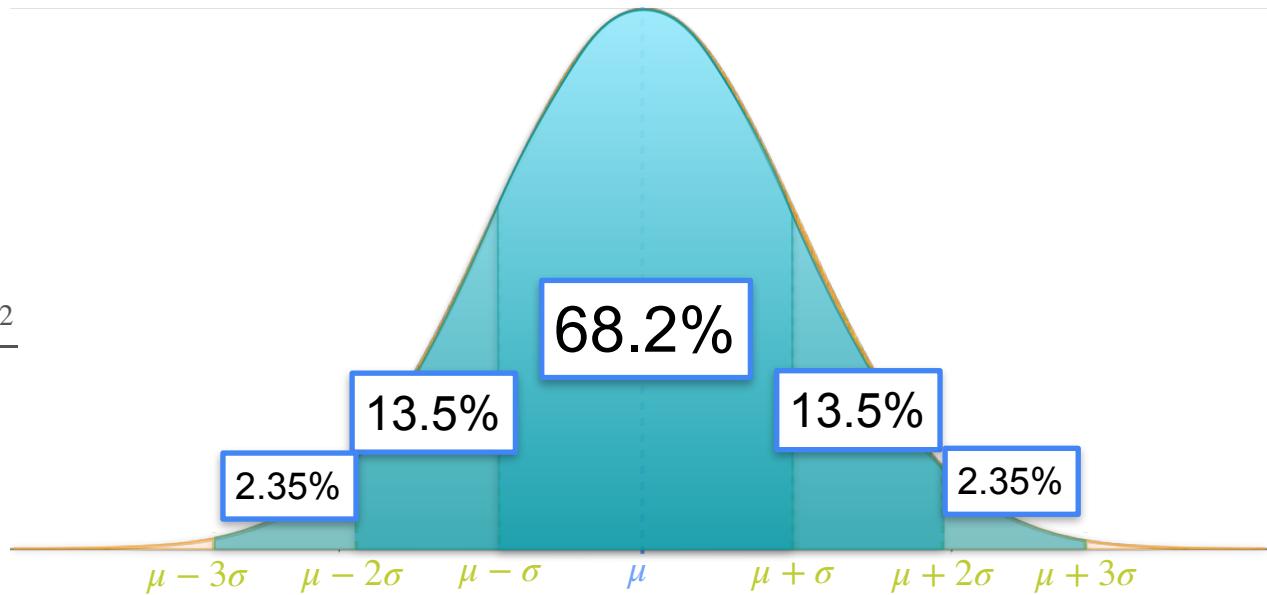


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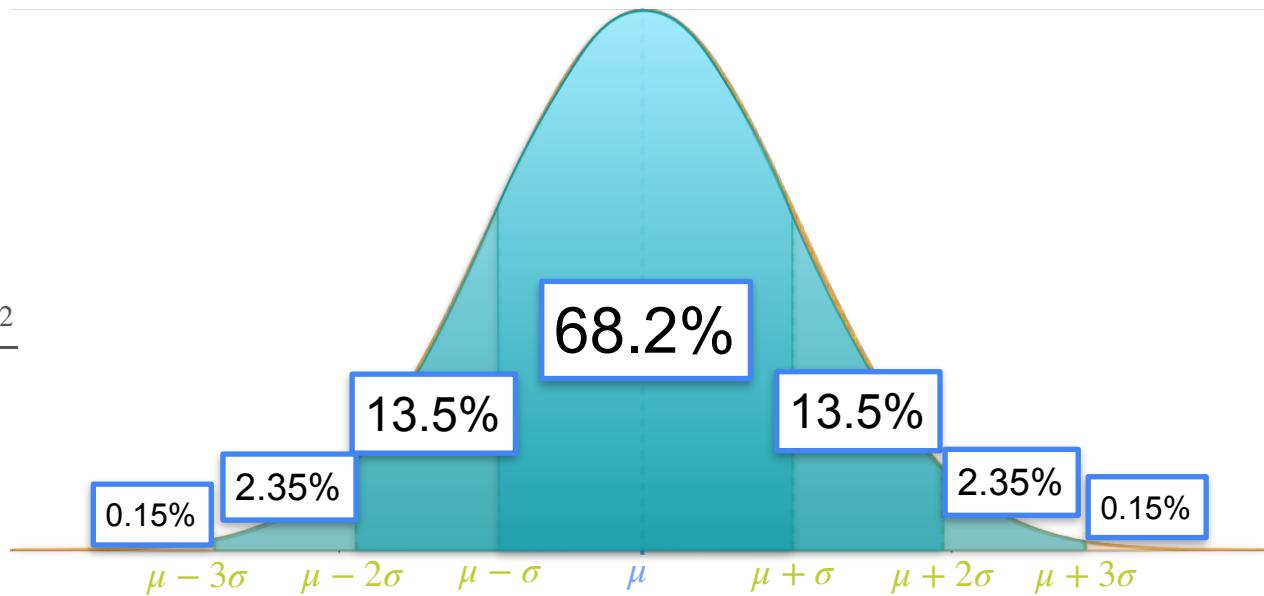


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# Sum of Gaussians: an Example

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Total response time of a computer system

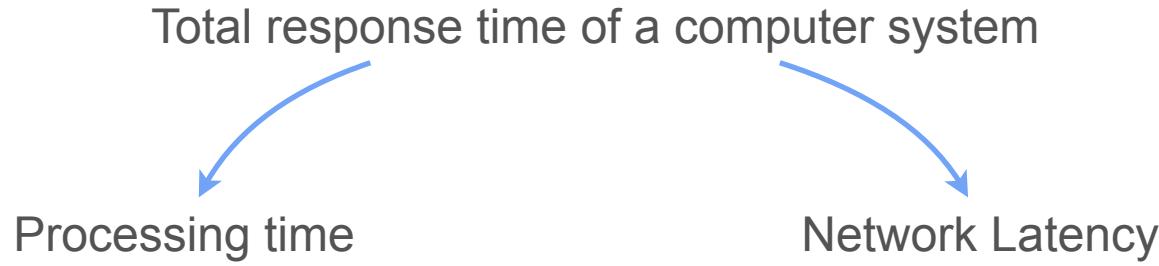
# Sum of Gaussians: an Example

Total response time of a computer system



Processing time

# Sum of Gaussians: an Example



# Sum of Gaussians: an Example

$R$  : Total response time of a computer system

$T$  : Processing time

$L$  : Network Latency



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$$R = T + L$$

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$$T \sim \mathcal{N}(10, 2^2)$$

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# Sum of Gaussians: an Example

$R$  : Total response time of a computer system

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$$T \sim \mathcal{N}(10, 2^2)$$

$L$  : Network Latency

$$L \sim \mathcal{N}(5, 1^2)$$

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# Sum of Gaussians: an Example



$$T \sim \mathcal{N}(10, 2^2)$$

$$L \sim \mathcal{N}(5, 1^2)$$

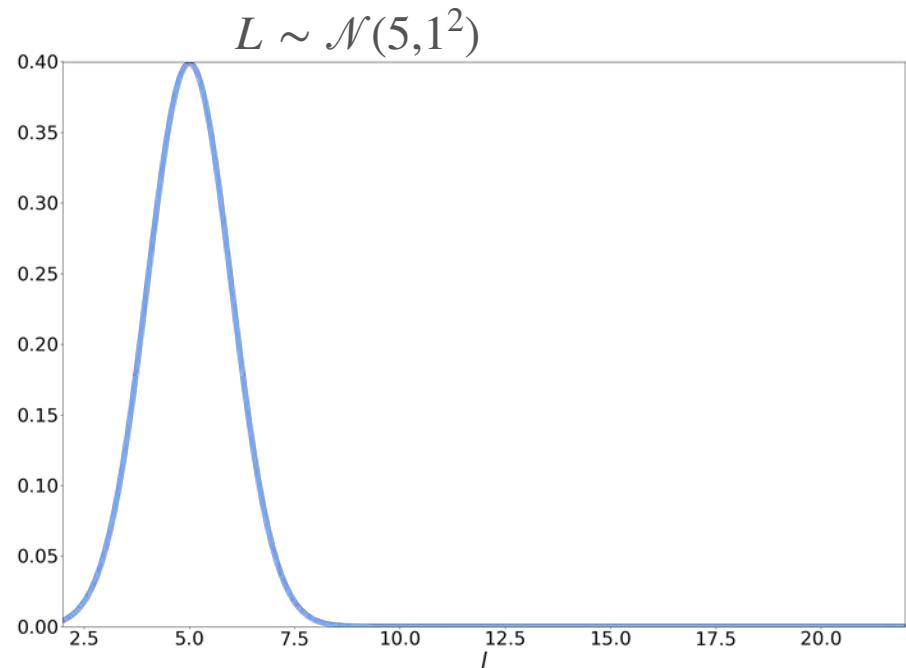
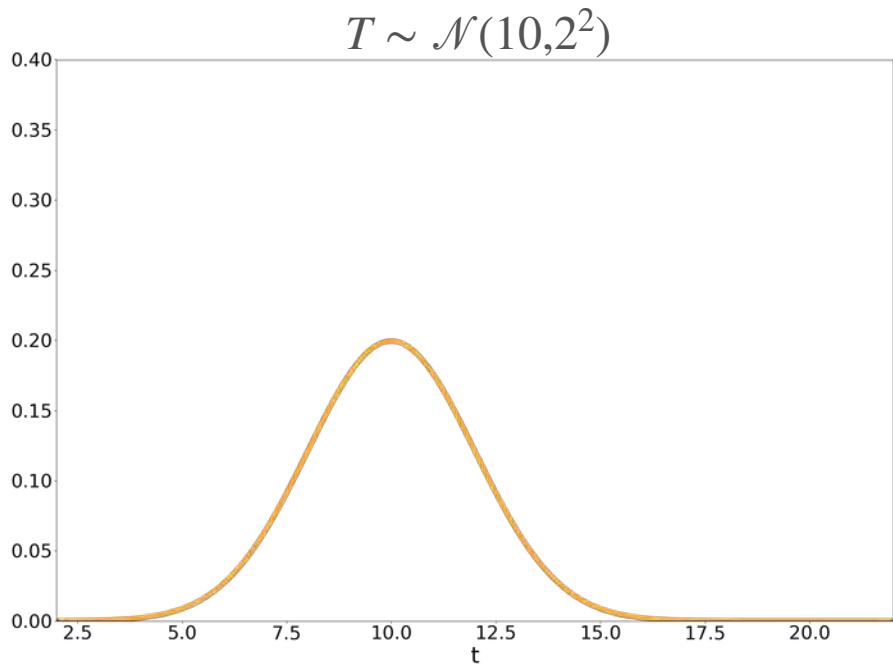
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# Sum Of Gaussians

$$T \sim \mathcal{N}(10, 2^2)$$

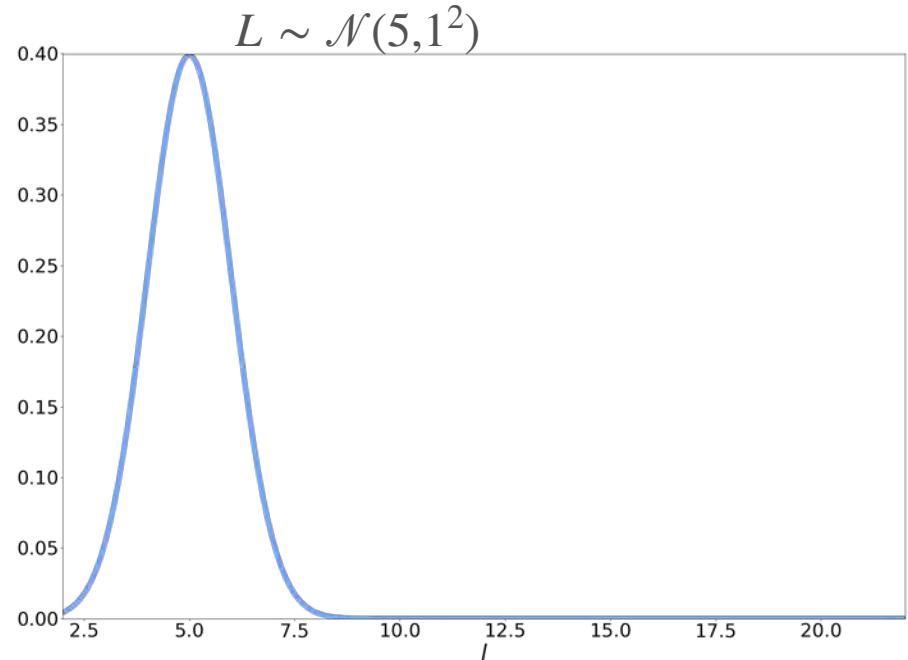
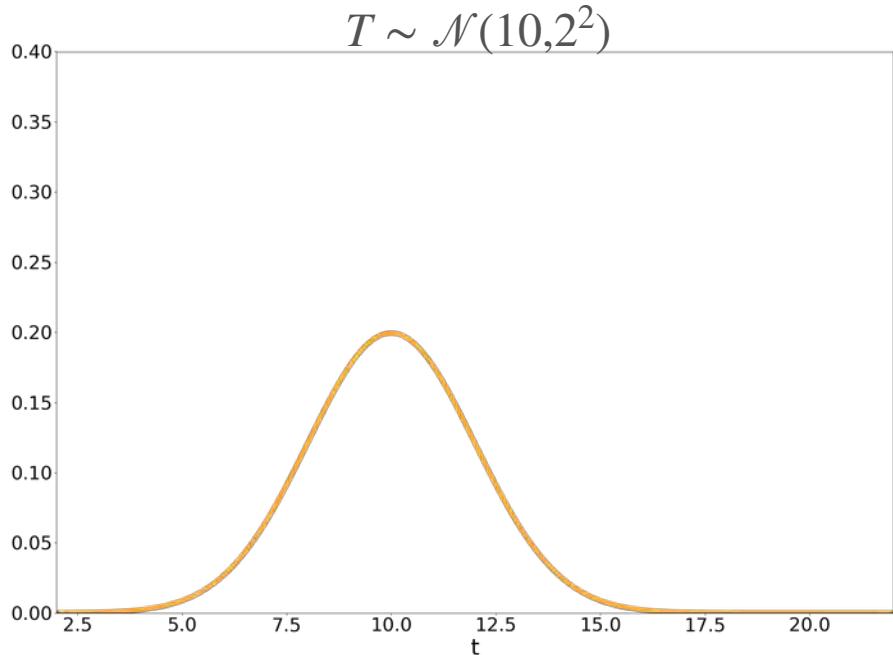
$$L \sim \mathcal{N}(5, 1^2)$$

# Sum Of Gaussians



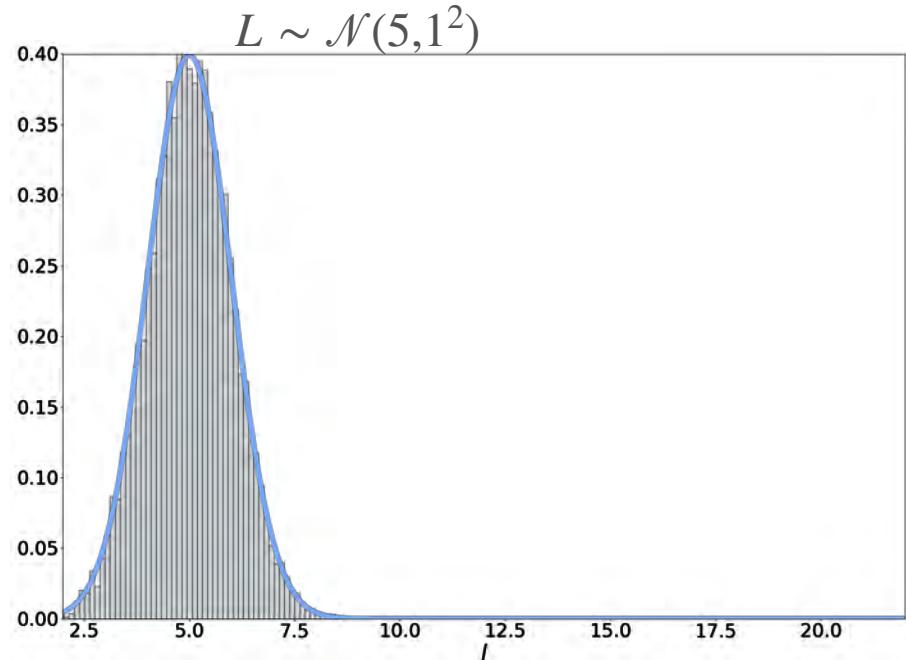
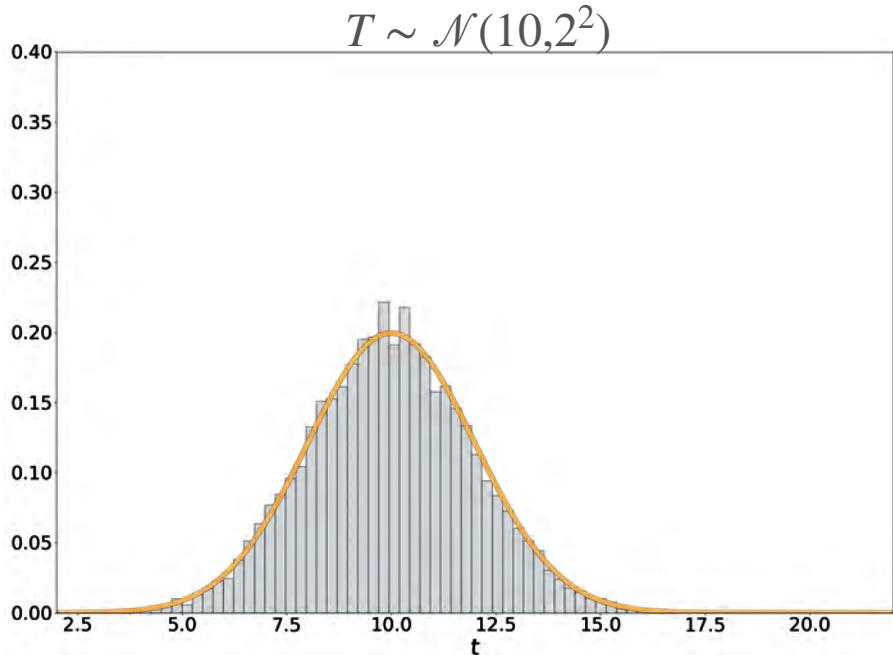
# Sum Of Gaussians

Sample each variable 10000 times



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Sample each variable 10000 times

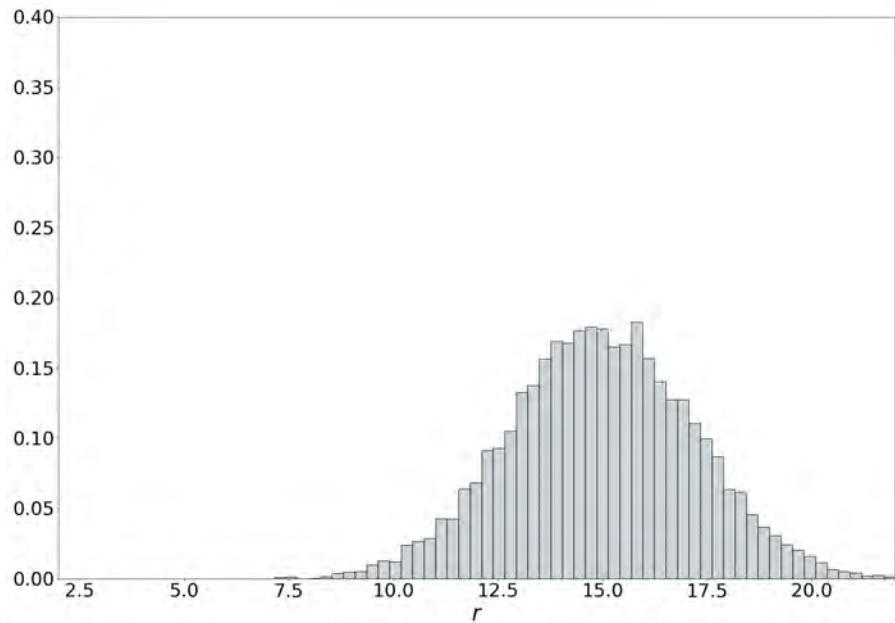


# Sum Of Gaussians

$$R = T + L$$

# Sum Of Gaussians

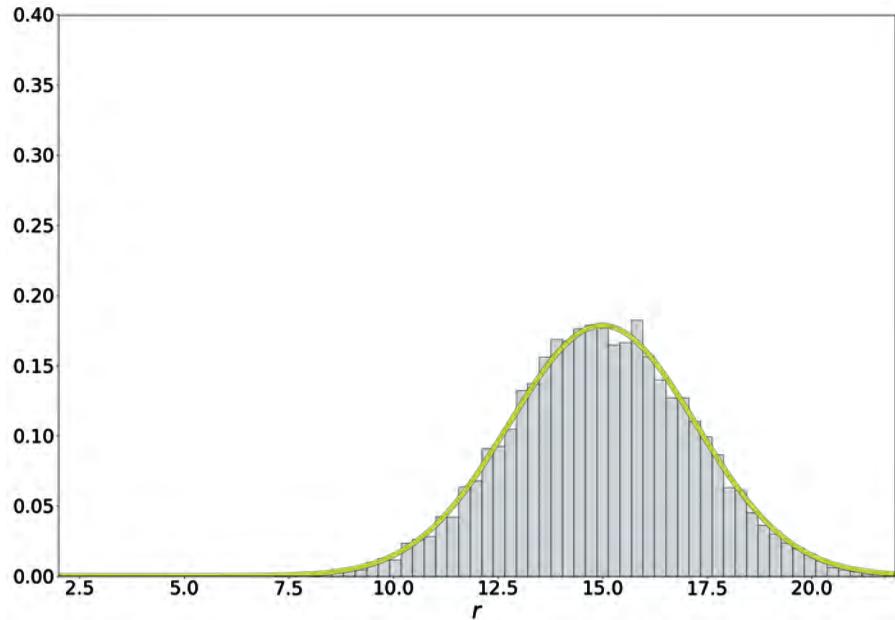
$$R = T + L$$



# Sum Of Gaussians

$$R = T + L$$

$R$  is still Gaussian!

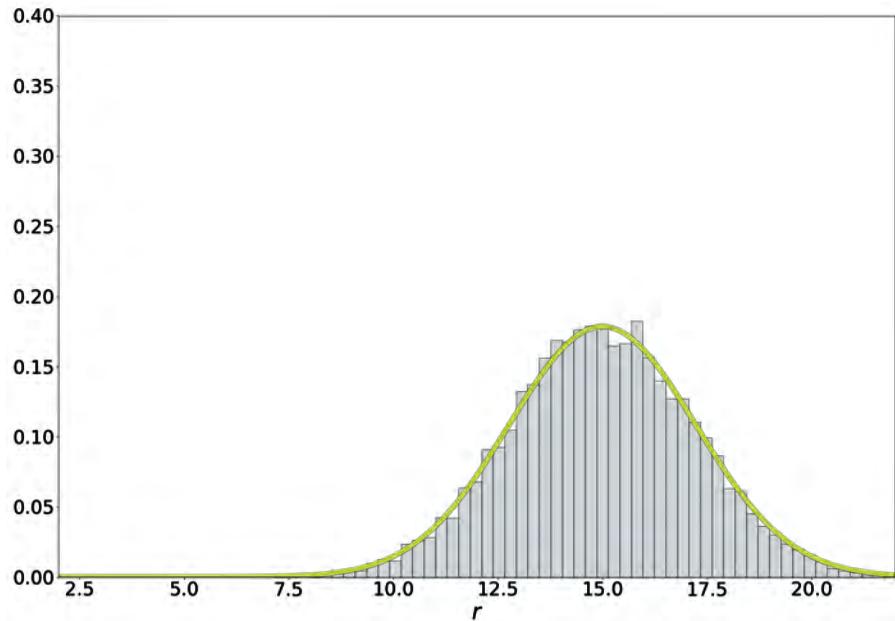


# Sum Of Gaussians

$$R = T + L$$

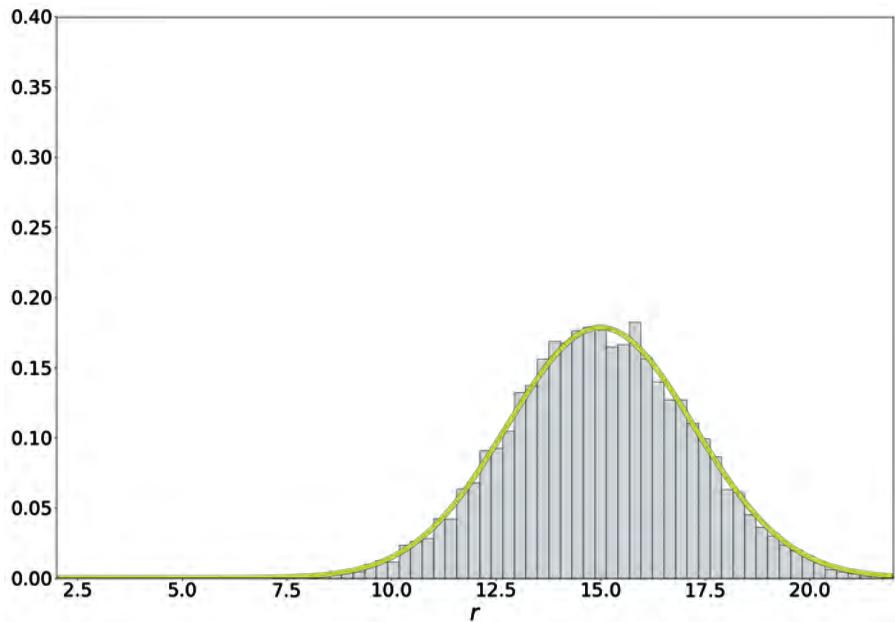
$R$  is still Gaussian!

$$\mu_R = \mathbb{E}[R]$$



# Sum Of Gaussians

$$R = T + L$$

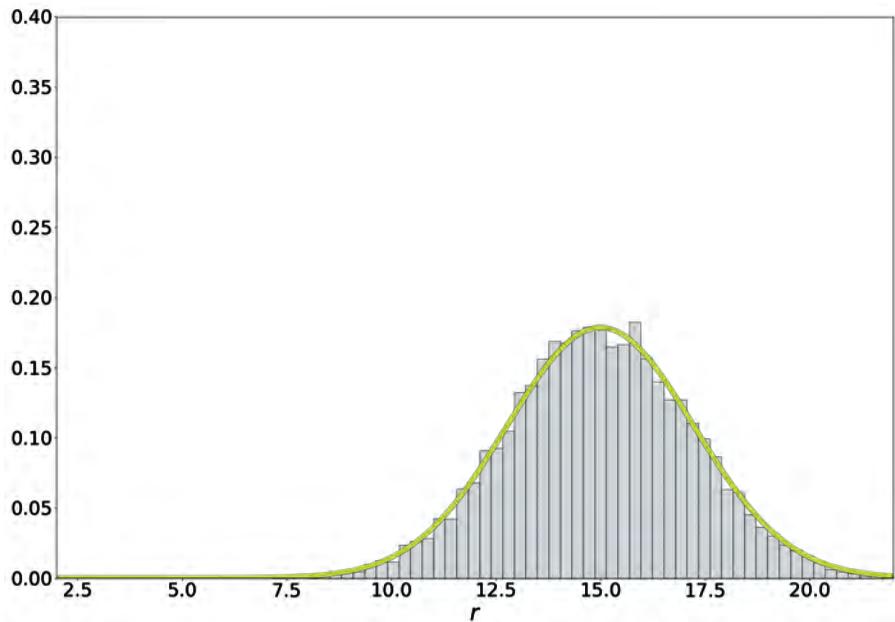


$R$  is still Gaussian!

$$\mu_R = \mathbb{E}[R] = \mathbb{E}[T + L]$$

# Sum Of Gaussians

$$R = T + L$$



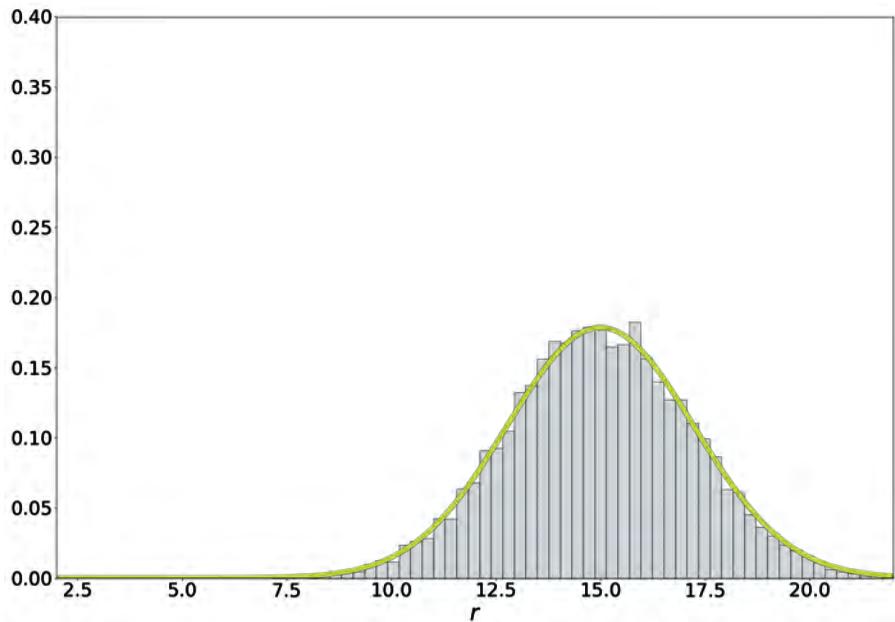
$R$  is still Gaussian!

Expectation is linear

$$\mu_R = \mathbb{E}[R] = \mathbb{E}[T + L] = \mathbb{E}[T] + \mathbb{E}[L]$$

# Sum Of Gaussians

$$R = T + L$$



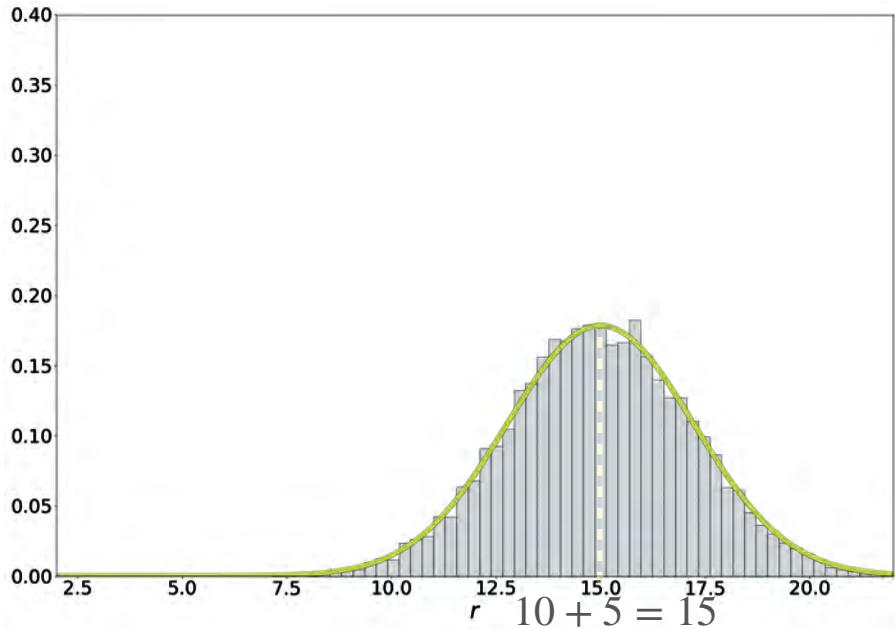
$R$  is still Gaussian!

Expectation is linear

$$\begin{aligned}\mu_R &= \mathbb{E}[R] = \mathbb{E}[T + L] = \mathbb{E}[T] + \mathbb{E}[L] \\ &= \mu_T + \mu_L\end{aligned}$$

# Sum Of Gaussians

$$R = T + L$$



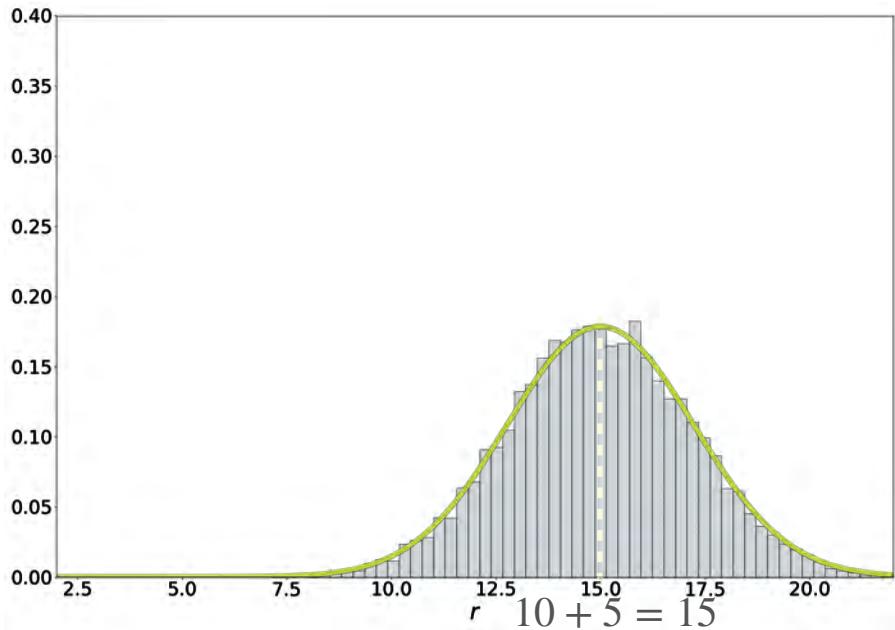
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$$\begin{aligned}\mu_R &= \mathbb{E}[R] = \mathbb{E}[T + L] = \mathbb{E}[T] + \mathbb{E}[L] \\ &= \mu_T + \mu_L = 10 + 5 = 15\end{aligned}$$

# Sum Of Gaussians

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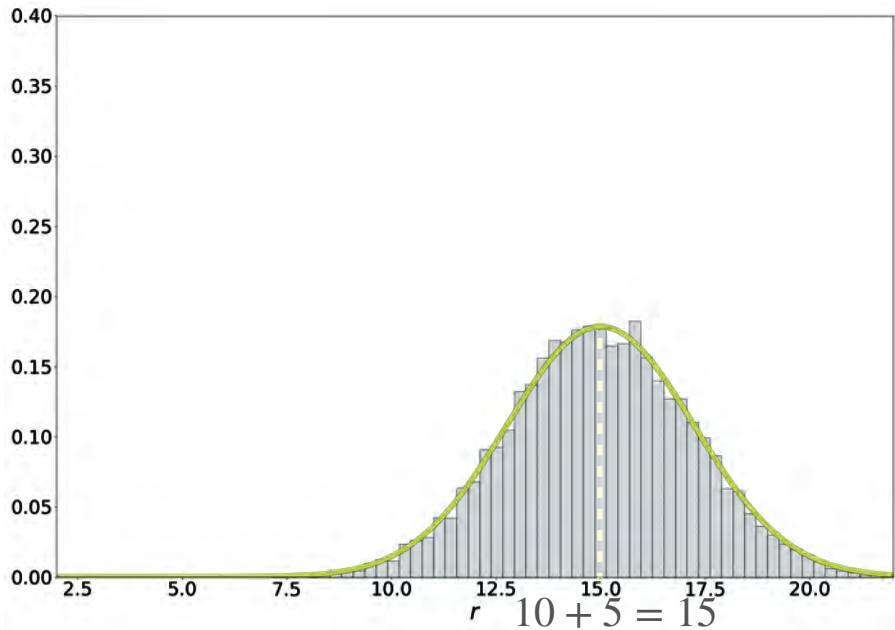
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$$\sigma_R^2 = Var(R)$$

# Sum Of Gaussians

$$R = T + L$$



$R$  is still Gaussian!

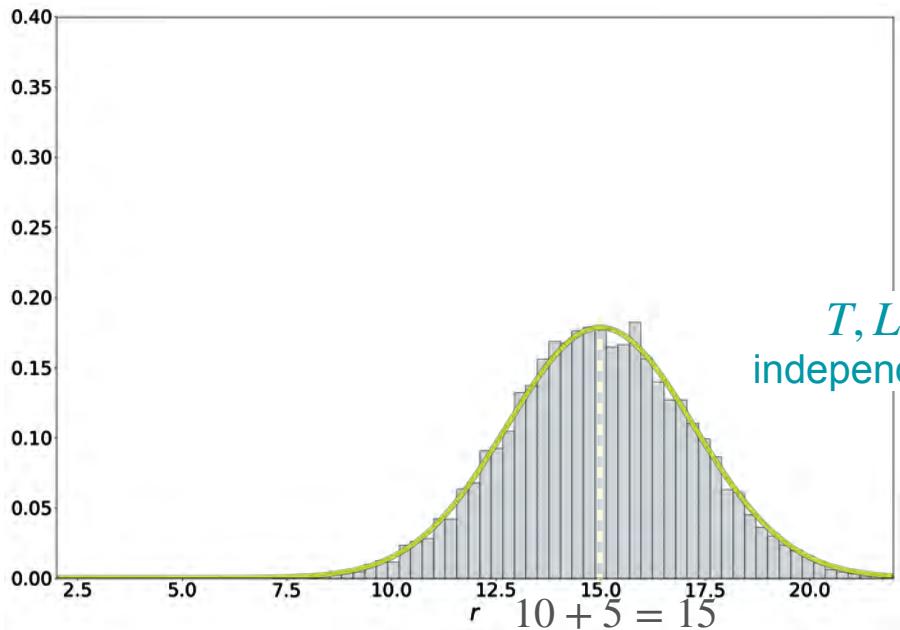
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$$\sigma_R^2 = \text{Var}(R) = \text{Var}(T + L)$$

# Sum Of Gaussians

$$R = T + L$$



$R$  is still Gaussian!

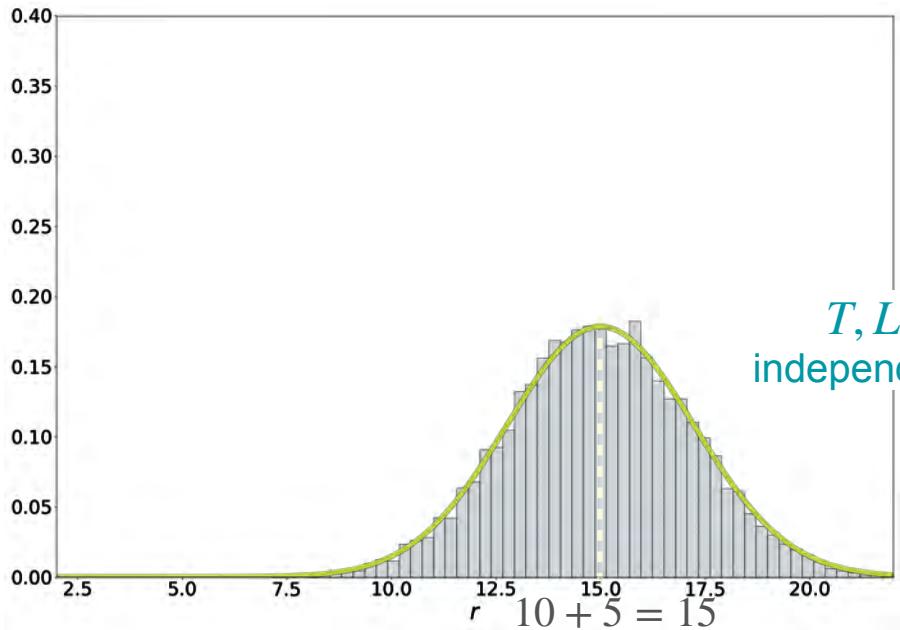
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$R$  is still Gaussian!

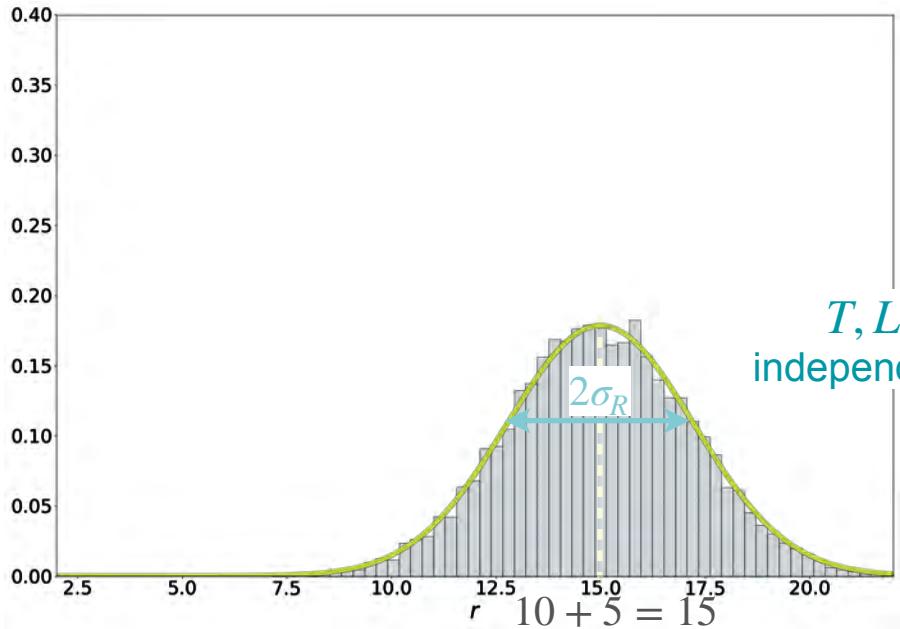
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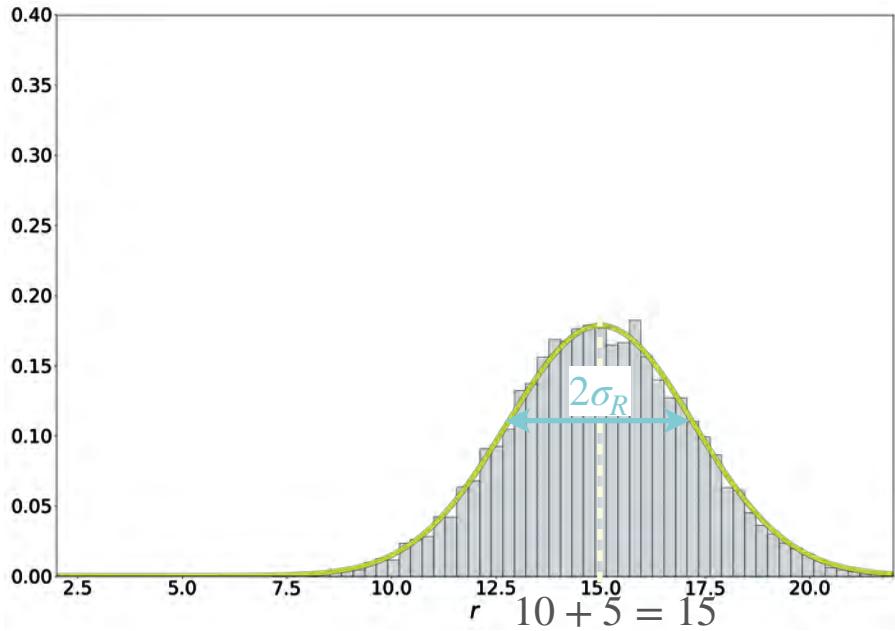
$$= 4 + 1 = 5$$

# Sum Of Gaussians

$$R = T + L$$

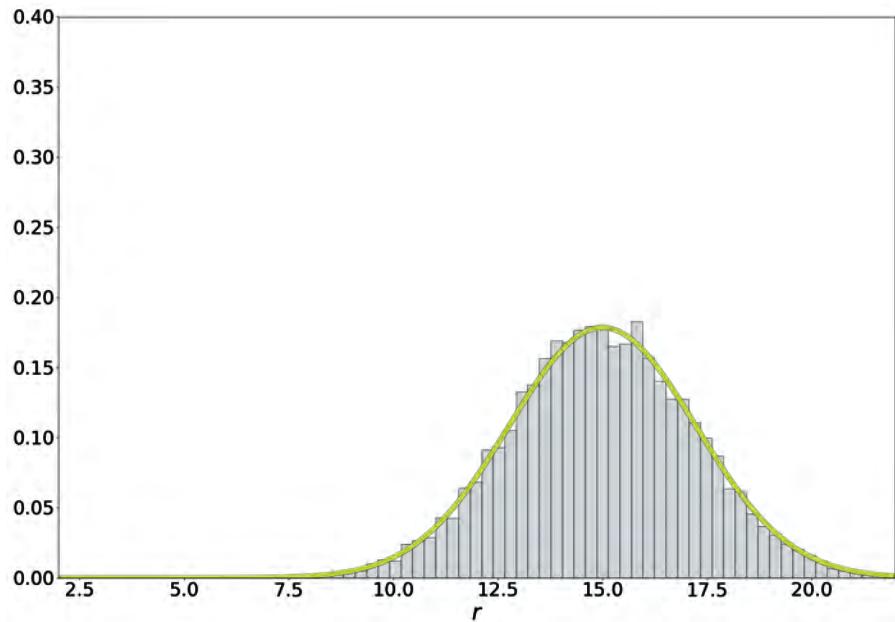
$R$  is still Gaussian!

$$R = (T + L) \sim \mathcal{N} \left( 10 + 5, \quad 4 + 1 \quad \right)$$



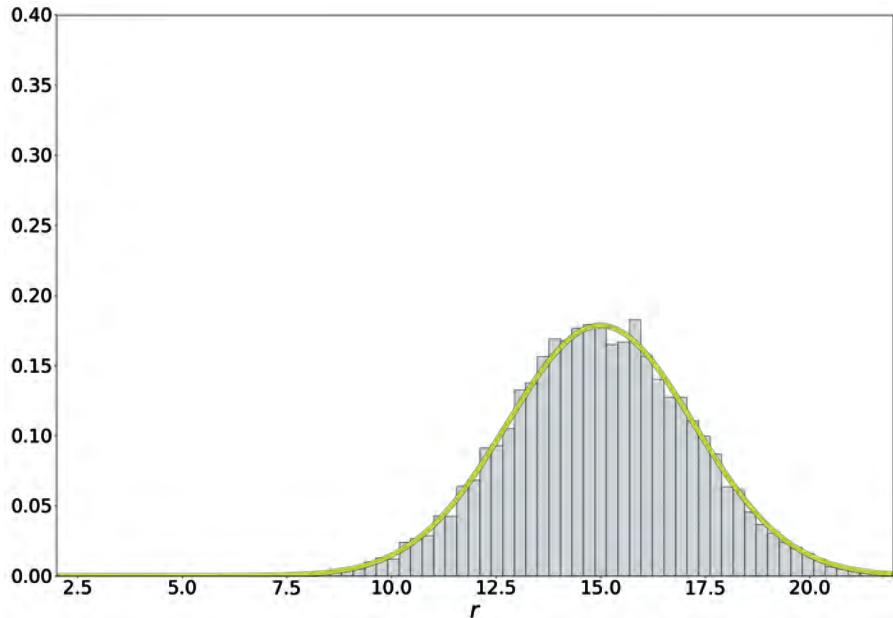
# Sum Of Gaussians

$$R = T + L$$



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$$R = T + L$$

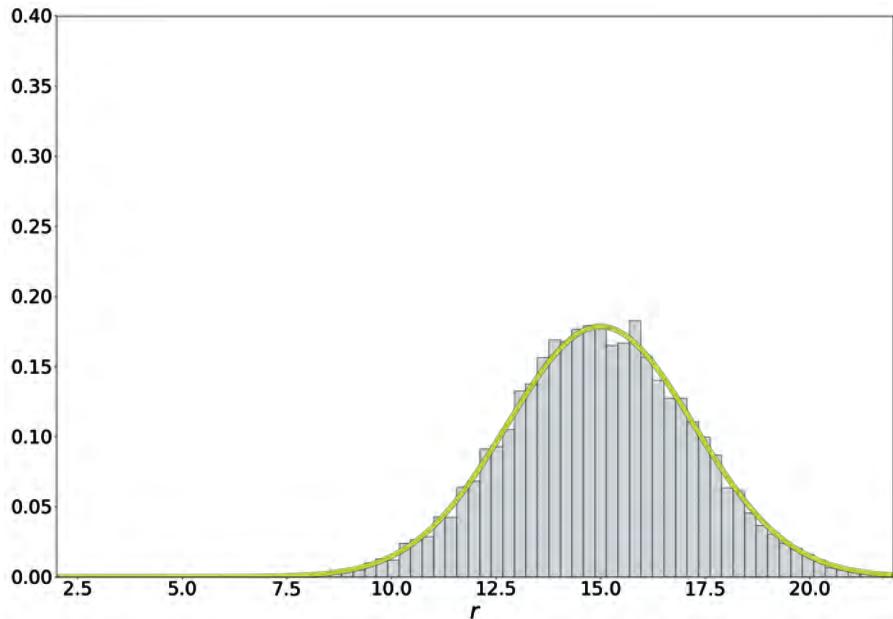


In general:  $W = aX + bY$

Independent  $\begin{cases} X \sim \mathcal{N}(\mu_X, \sigma_X^2) \\ Y \sim \mathcal{N}(\mu_Y, \sigma_Y^2) \end{cases}$

# Sum Of Gaussians

$$R = T + L$$



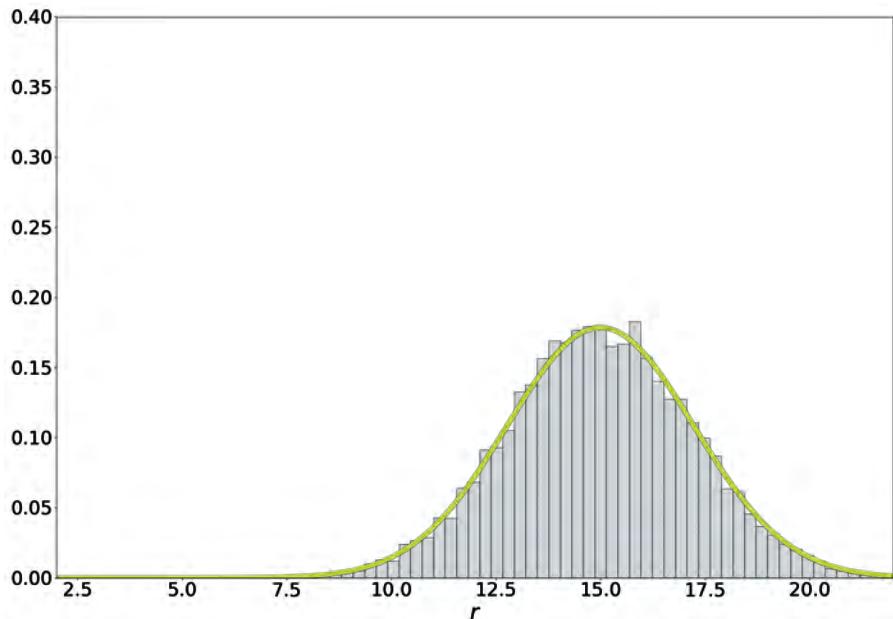
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$$\rightarrow W \sim \mathcal{N} \left( \quad , \quad \right)$$

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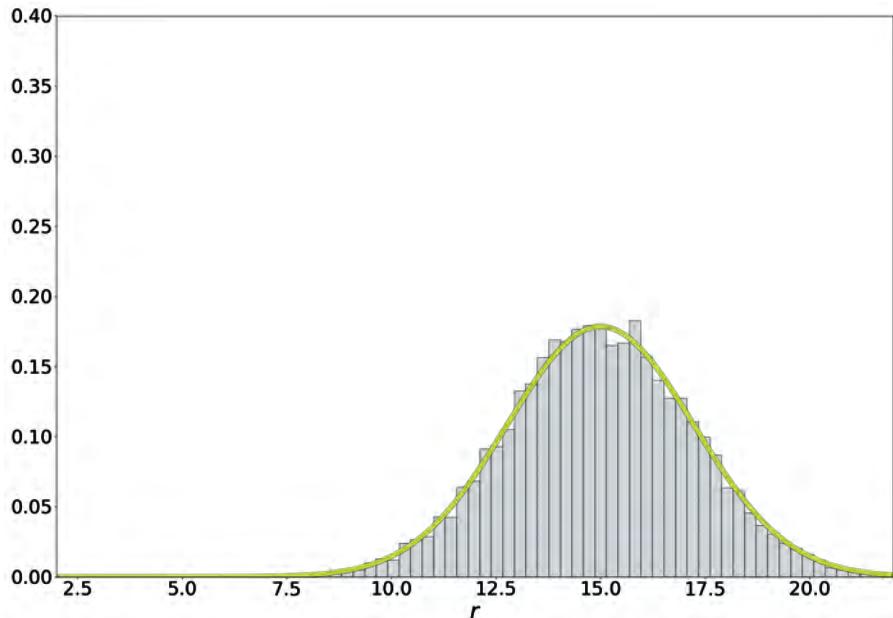
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$$R = T + L$$



In general:  $W = aX + bY$

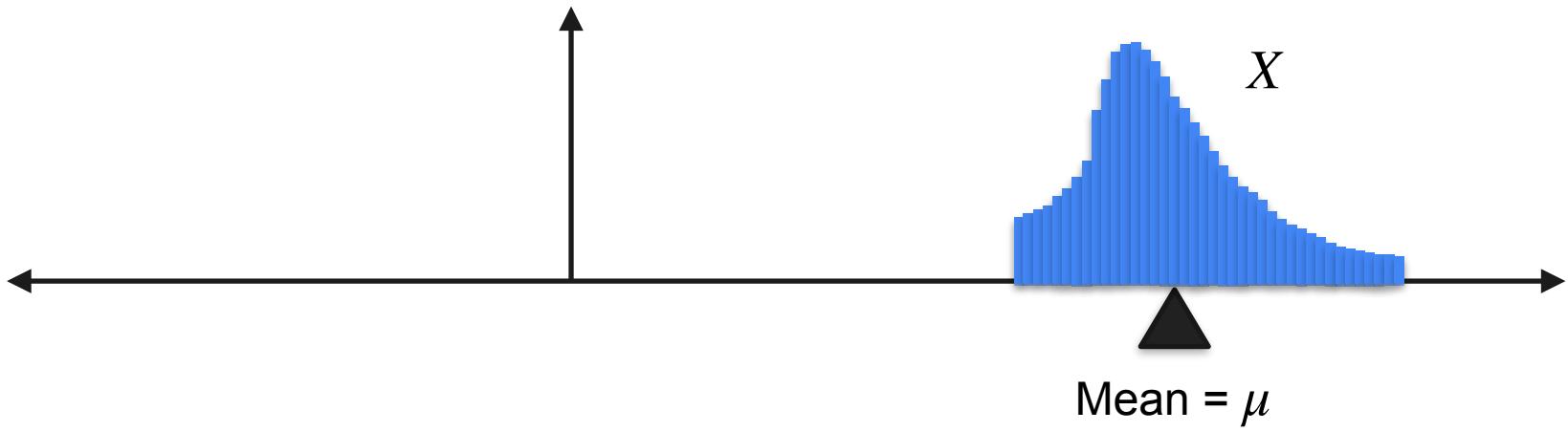
Independent  $\begin{cases} X \sim \mathcal{N}(\mu_X, \sigma_X^2) \\ Y \sim \mathcal{N}(\mu_Y, \sigma_Y^2) \end{cases}$

$$\rightarrow W \sim \mathcal{N} \left( a\mu_x + b\mu_y, a^2\sigma_x^2 + b^2\sigma_y^2 \right)$$

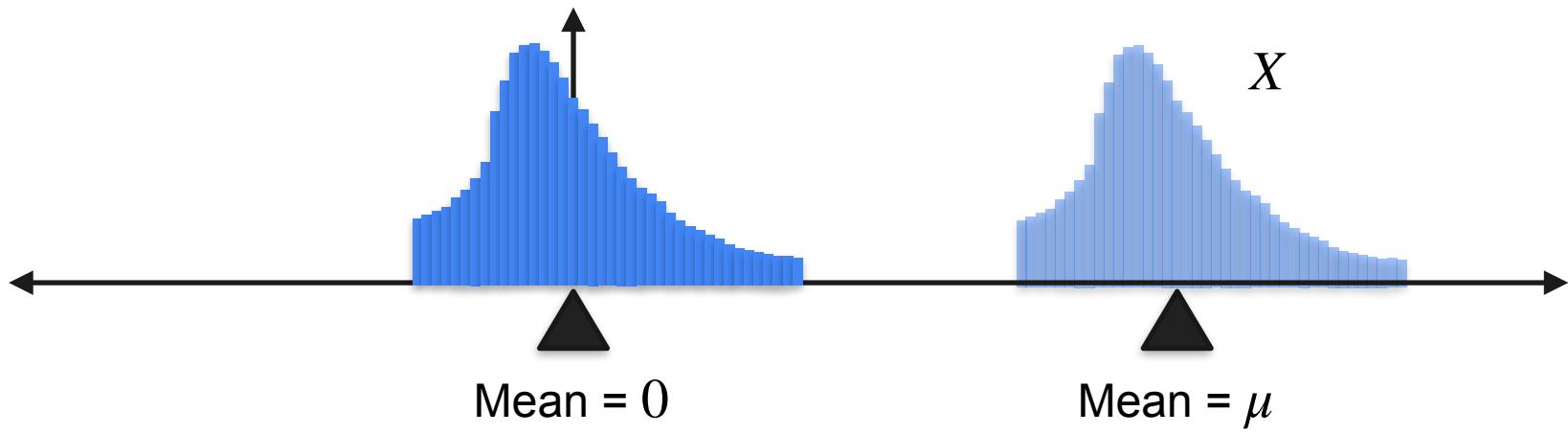
# Everything Is Nicer When the Mean Is 0



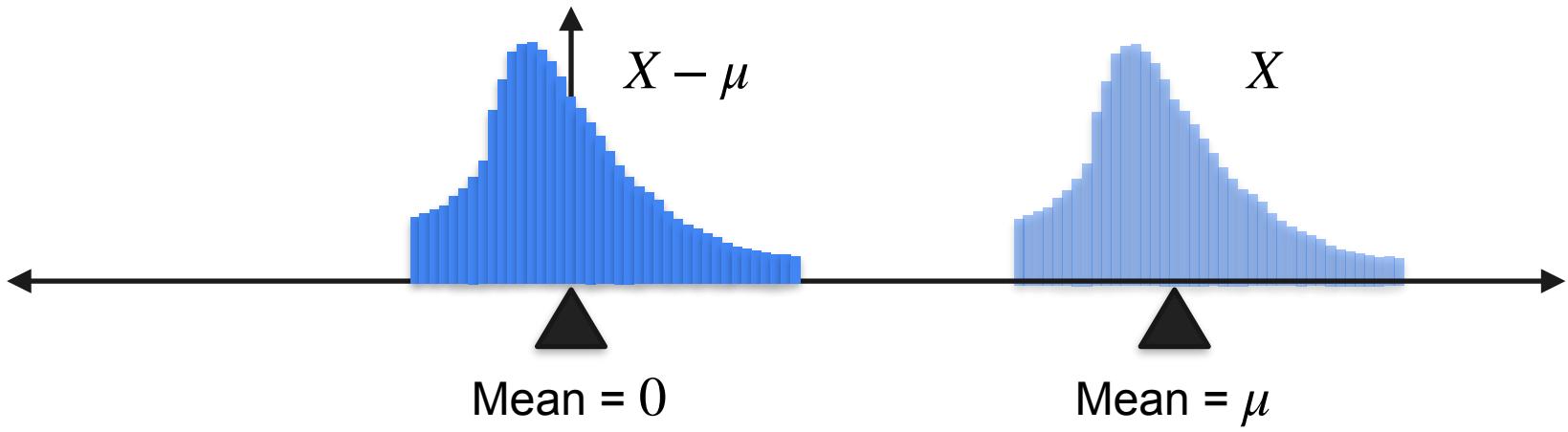
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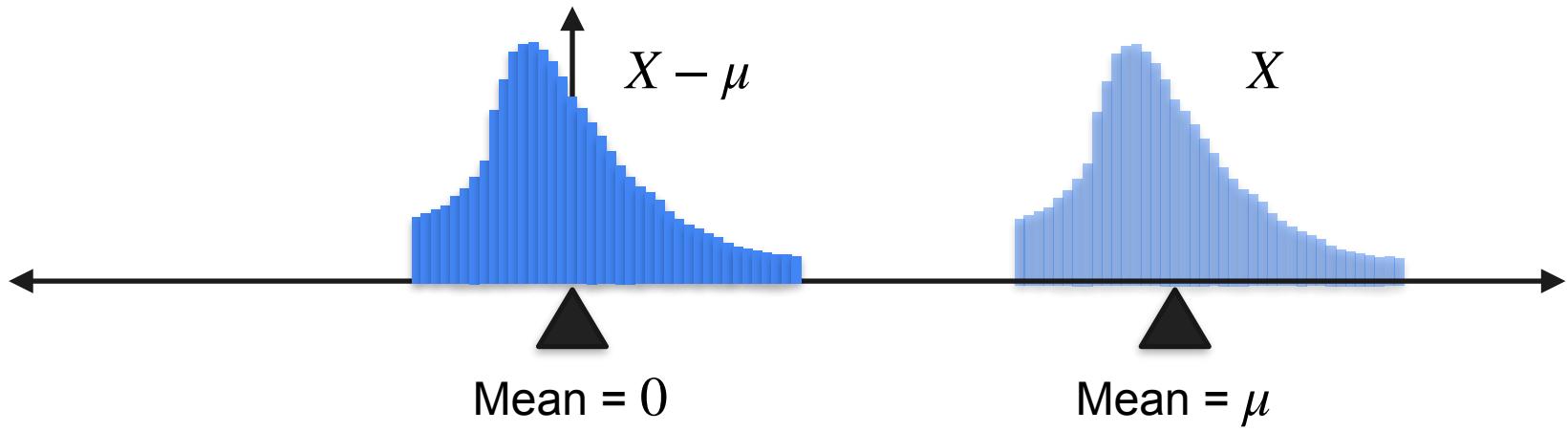
# Everything Is Nicer When the Mean Is 0



# Everything Is Nicer When the Mean Is 0



# Everything Is Nicer When the Mean Is 0



$$X \rightarrow X - \mu$$

# Everything Is Nicer When the Mean Is 0

Why?

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Why?

$$\mathbb{E}[X + Y] = \mathbb{E}[X] + \mathbb{E}[Y]$$

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$$\mathbb{E}[X - \mu]$$

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# Everything Is Nicer When the Mean Is 0

Why?

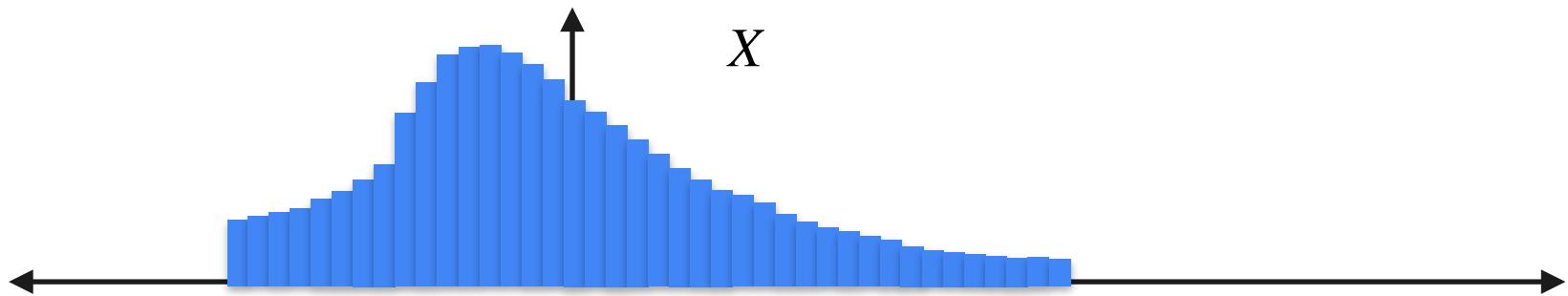
$$\mathbb{E}[X + Y] = \mathbb{E}[X] + \mathbb{E}[Y]$$

$$\mathbb{E}[X - \mu] = \mathbb{E}[X] - \mathbb{E}[\mu]$$

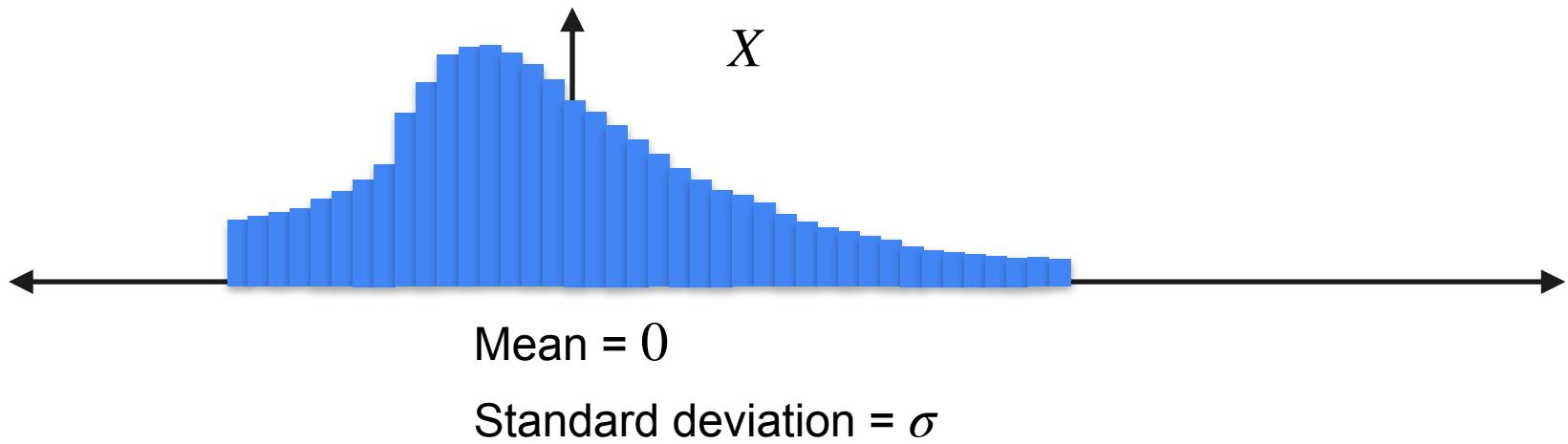
$$= \mathbb{E}[X] - \mu$$

$$= 0$$

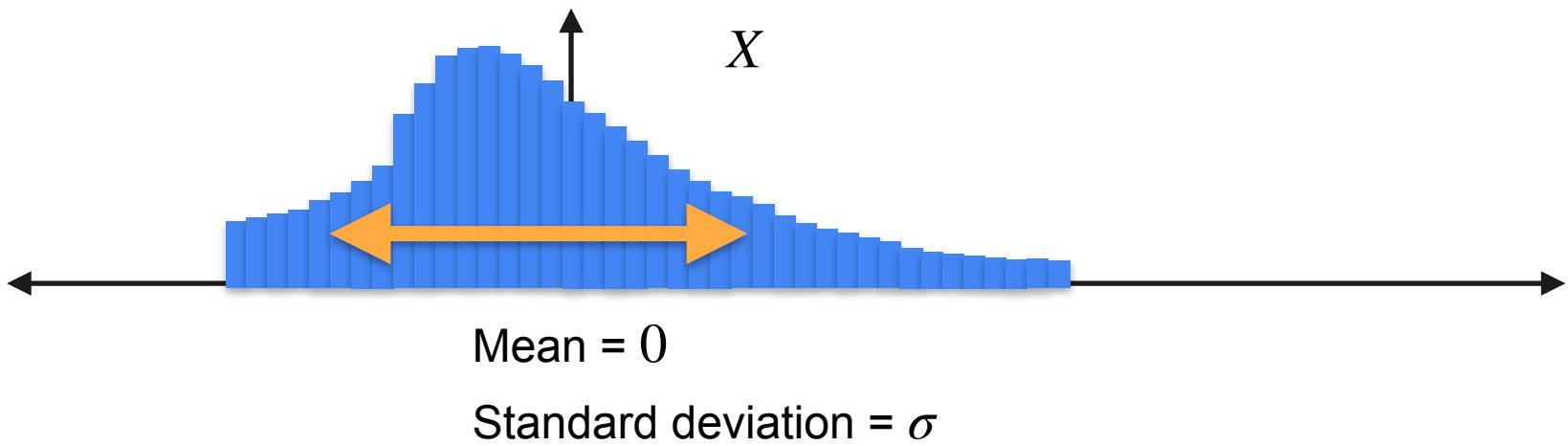
# Everything Is Nicer When the Standard Deviation Is 1



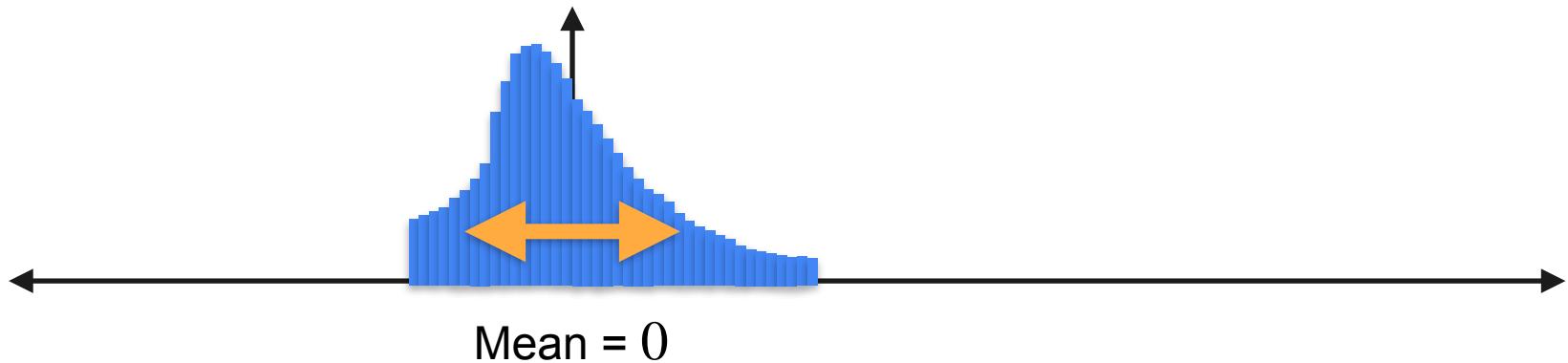
# Everything Is Nicer When the Standard Deviation Is 1



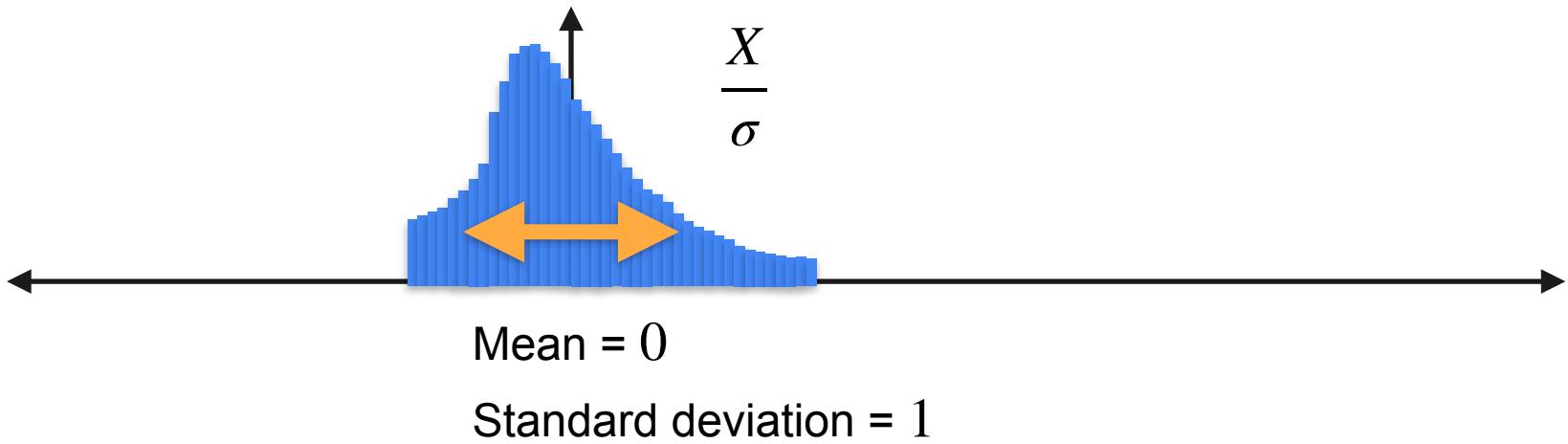
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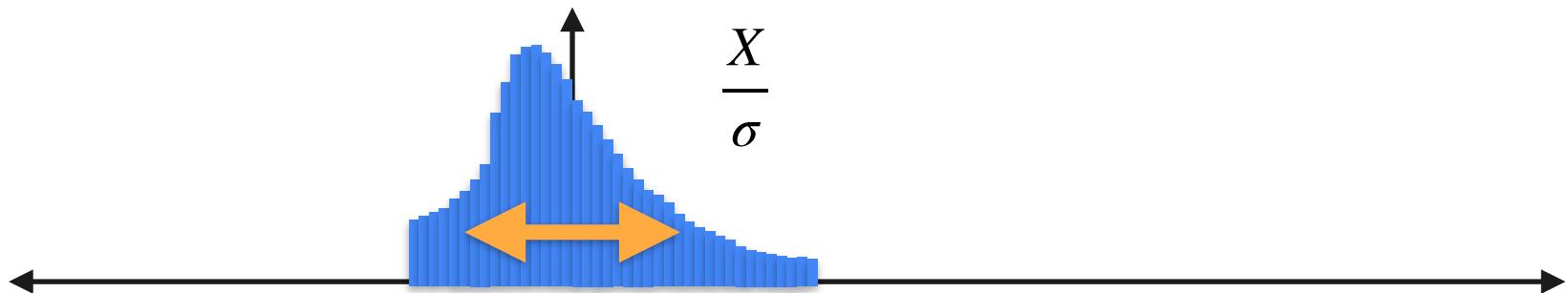
# Everything Is Nicer When the Standard Deviation Is 1



# Everything Is Nicer When the Standard Deviation Is 1



# Everything Is Nicer When the Standard Deviation Is 1



Mean = 0

Standard deviation = 1

$$X \rightarrow \frac{X}{\sigma}$$

# Everything Is Nicer When the Standard Deviation Is 1

Why?

$$Var\left(\frac{X}{\sigma}\right)$$

# Everything Is Nicer When the Standard Deviation Is 1

Why?

$$Var\left(\frac{X}{\sigma}\right)$$

$$Var(cX)$$

# Everything Is Nicer When the Standard Deviation Is 1

Why?

$$Var\left(\frac{X}{\sigma}\right)$$

$$Var(cX) = \mathbb{E}[(cX)^2] - \mathbb{E}[cX]^2$$

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$$Var\left(\frac{X}{\sigma}\right)$$

$$Var(cX) = \mathbb{E}[(cX)^2] - \mathbb{E}[cX]^2$$

$$= \mathbb{E}[c^2X^2] - (c\mathbb{E}[X])^2$$

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$$= c^2Var(X)$$

# Everything Is Nicer When the Standard Deviation Is 1

Why?

$$Var\left(\frac{X}{\sigma}\right) = \frac{1}{\sigma^2}Var(X)$$

$$Var(cX) = \mathbb{E}[(cX)^2] - \mathbb{E}[cX]^2$$

$$= \mathbb{E}[c^2X^2] - (c\mathbb{E}[X])^2$$

$$= c^2\mathbb{E}[X^2] - c^2\mathbb{E}[X]^2$$

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$$= c^2Var(X)$$

$$Var\left(\frac{X}{\sigma}\right) = \frac{1}{\sigma^2}Var(X)$$

$$std\left(\frac{X}{\sigma}\right) = \frac{1}{\sigma}std(X)$$

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$$= \mathbb{E}[c^2X^2] - (c\mathbb{E}[X])^2$$

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$$Var\left(\frac{X}{\sigma}\right) = \frac{1}{\sigma^2}Var(X)$$

$$std\left(\frac{X}{\sigma}\right) = \frac{1}{\sigma}std(X)$$

$$= \frac{\sigma}{\sigma}$$

# Everything Is Nicer When the Standard Deviation Is 1

Why?

$$Var(cX) = \mathbb{E}[(cX)^2] - \mathbb{E}[cX]^2$$

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$$Var\left(\frac{X}{\sigma}\right) = \frac{1}{\sigma^2}Var(X)$$

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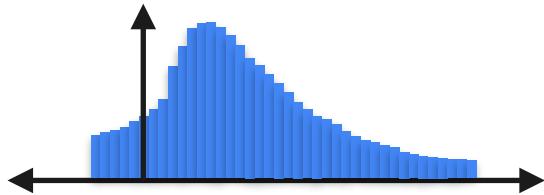
$$= \frac{\sigma}{\sigma}$$

$$= 1$$

# Standardize a Distribution

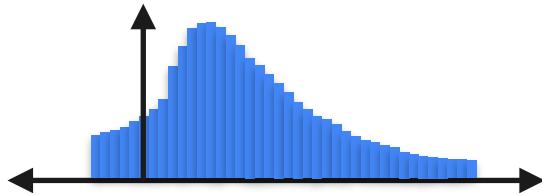
# Standardize a Distribution

$X$

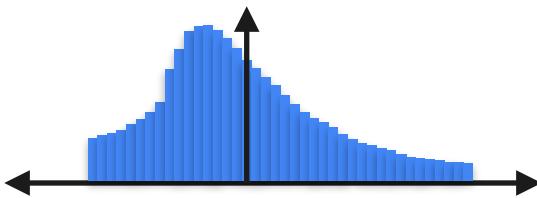


$$\begin{aligned}\text{Mean} &= \mu \\ \text{std} &= \sigma\end{aligned}$$

# Standardize a Distribution

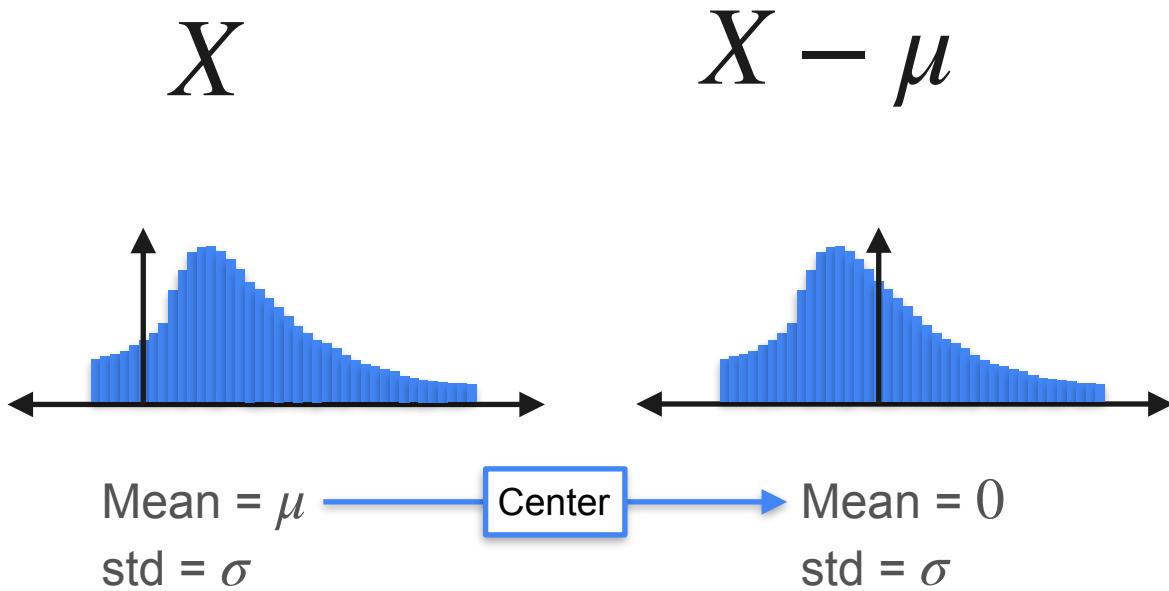
$$X$$
$$X - \mu$$


Mean =  $\mu$   
std =  $\sigma$

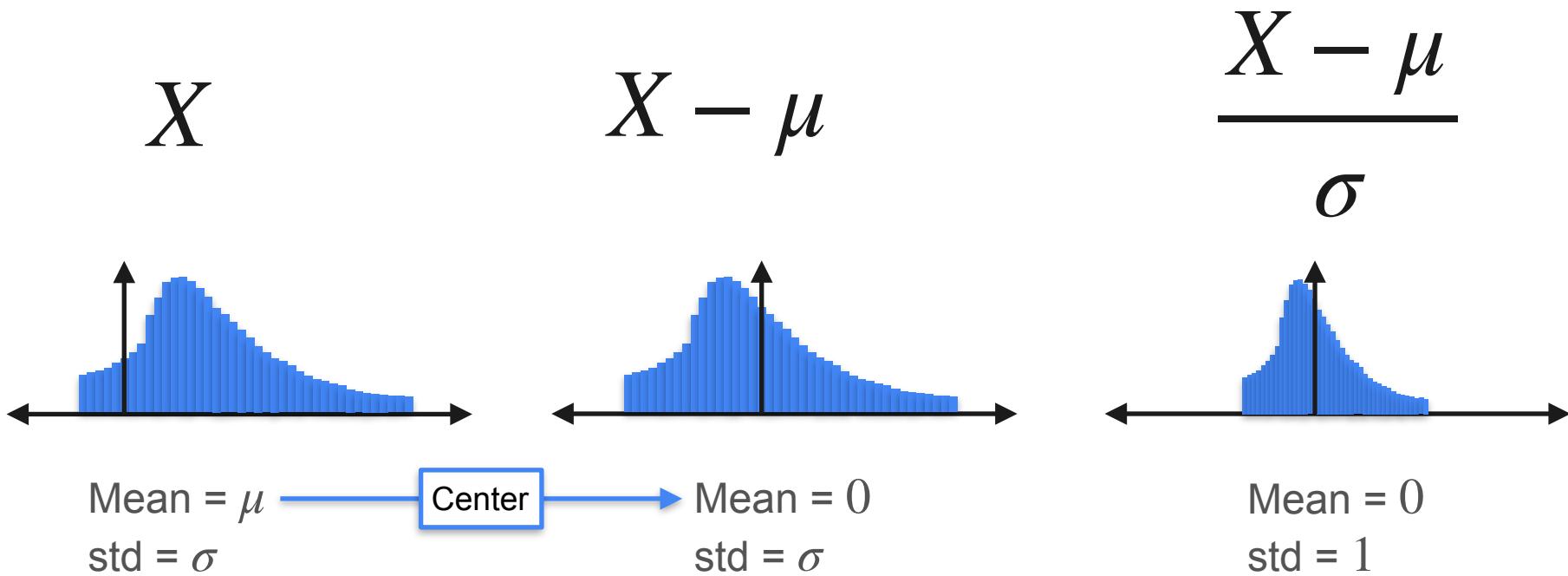


Mean = 0  
std =  $\sigma$

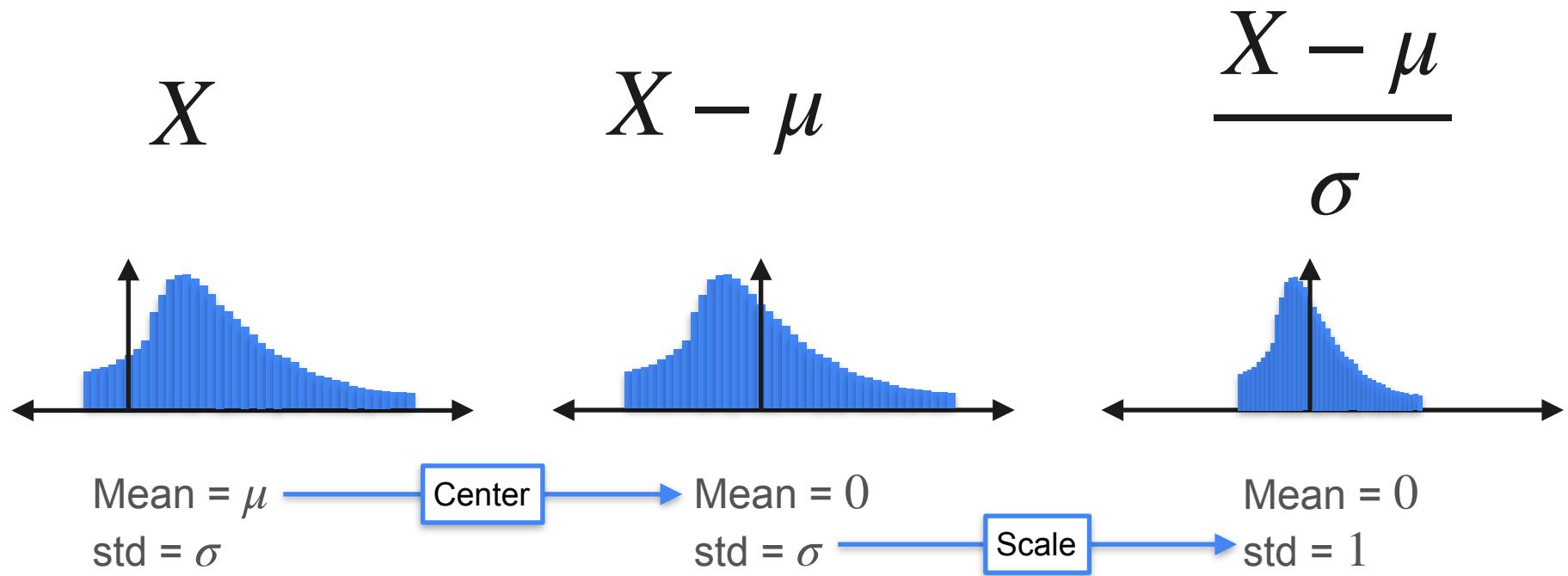
# Standardize a Distribution



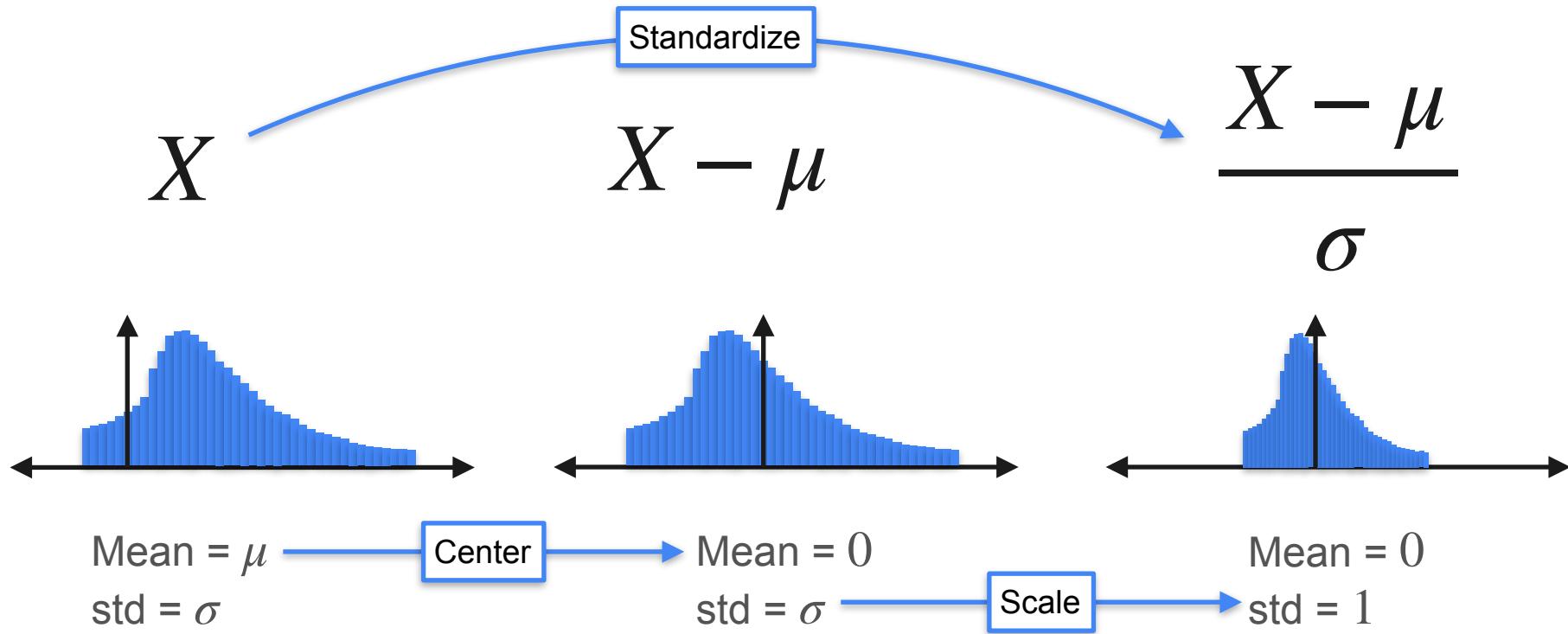
# Standardize a Distribution



# Standardize a Distribution



# Standardize a Distribution





DeepLearning.AI

# Describing Distributions

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## Skewness and Kurtosis

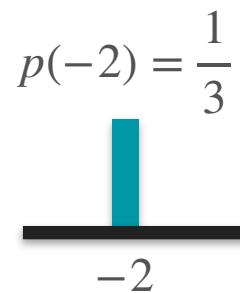
# Moments of a Distribution

Random variable  $X$



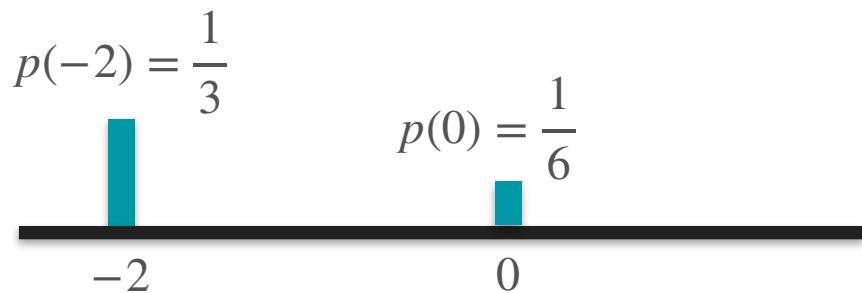
# Moments of a Distribution

Random variable  $X$

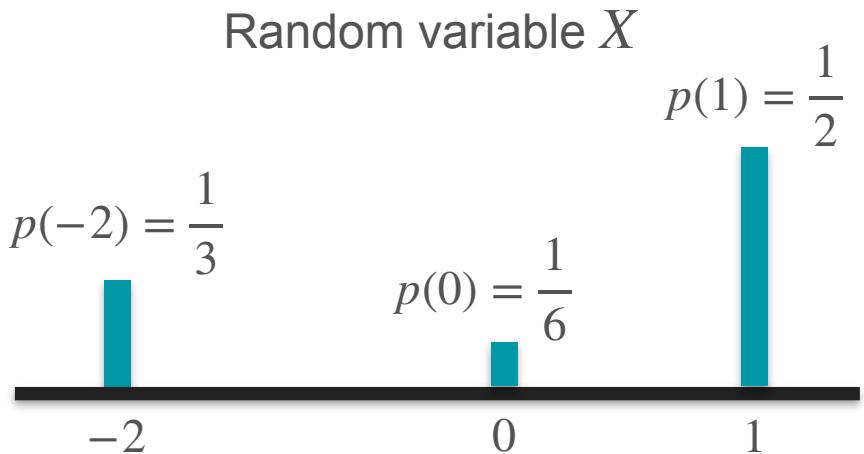


# Moments of a Distribution

Random variable  $X$



# Moments of a Distribution



# Moments of a Distribution

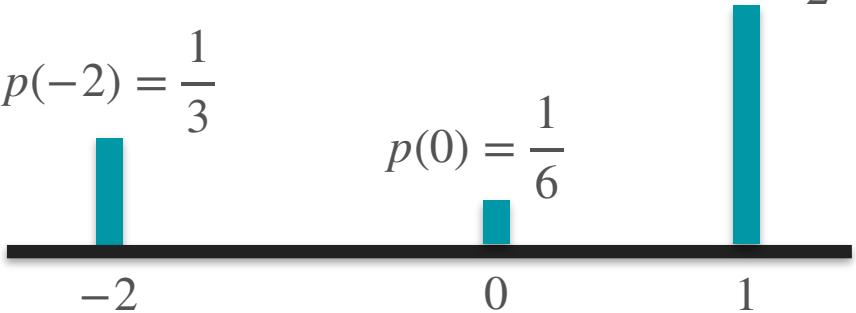
$$\mathbb{E}[X] = \frac{1}{3}(-2) + \frac{1}{6}(0) + \frac{1}{2}(1)$$

Random variable  $X$

$$p(1) = \frac{1}{2}$$

$$p(-2) = \frac{1}{3}$$

$$p(0) = \frac{1}{6}$$



# Moments of a Distribution

$$\mathbb{E}[X] = \frac{1}{3}(-2) + \frac{1}{6}(0) + \frac{1}{2}(1)$$

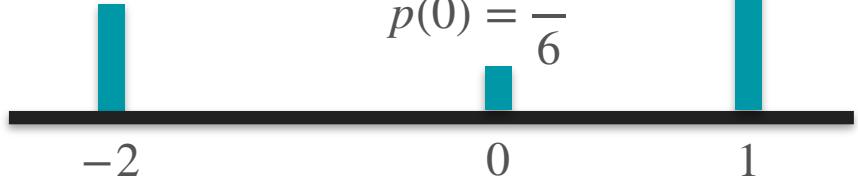
$$\mathbb{E}[X^2] = \frac{1}{3}(-2)^2 + \frac{1}{6}(0)^2 + \frac{1}{2}(1)^2$$

Random variable  $X$

$$p(1) = \frac{1}{2}$$

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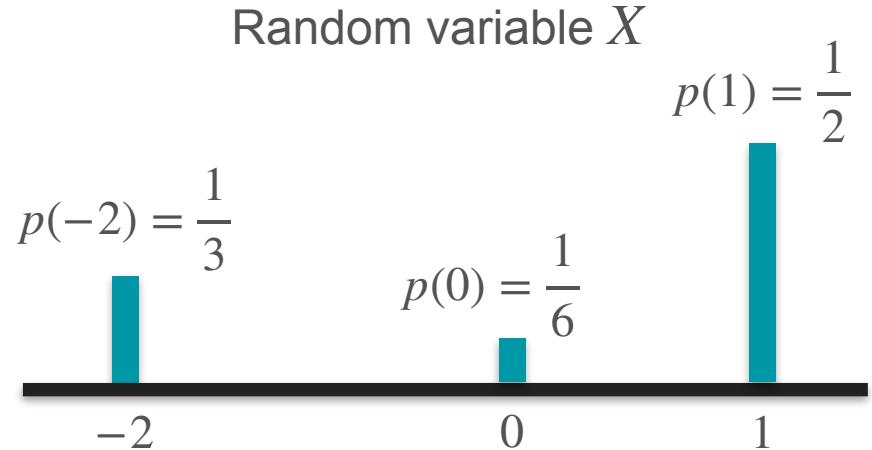


# Moments of a Distribution

$$\mathbb{E}[X] = \frac{1}{3}(-2) + \frac{1}{6}(0) + \frac{1}{2}(1)$$

$$\mathbb{E}[X^2] = \frac{1}{3}(-2)^2 + \frac{1}{6}(0)^2 + \frac{1}{2}(1)^2$$

$$\mathbb{E}[X^3] = \frac{1}{3}(-2)^3 + \frac{1}{6}(0)^3 + \frac{1}{2}(1)^3$$



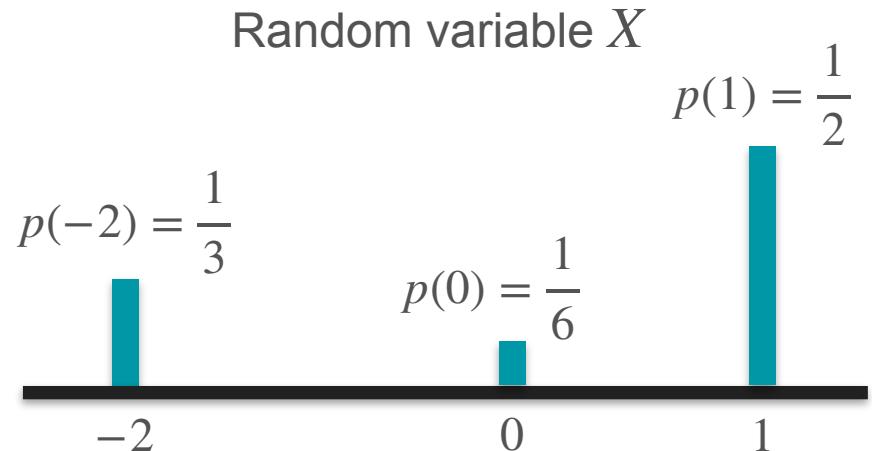
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...



# Moments of a Distribution

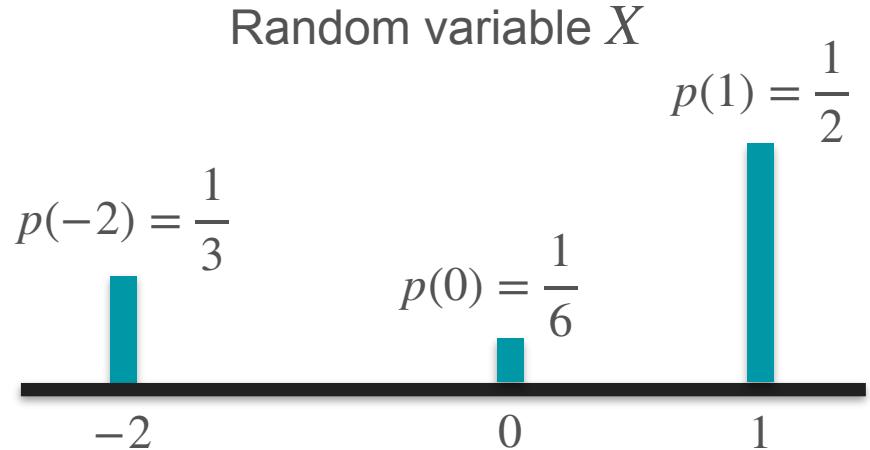
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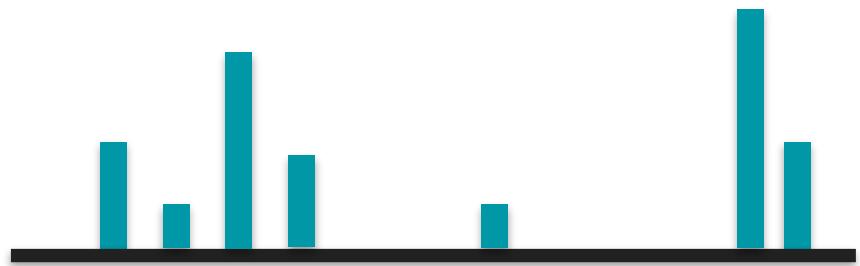
...

$$\mathbb{E}[X^k] = \frac{1}{3}(-2)^k + \frac{1}{6}(0)^k + \frac{1}{2}(1)^k$$



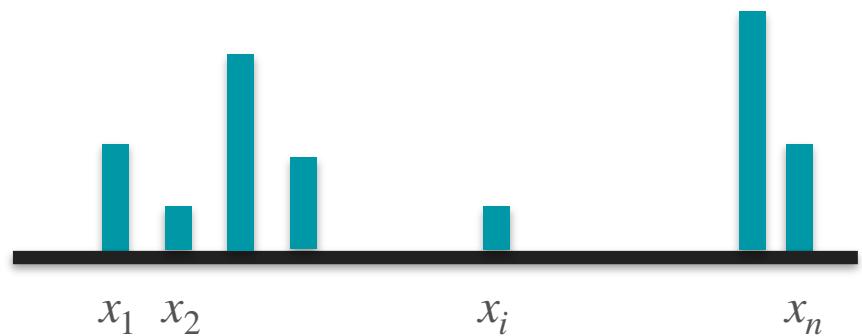
# Moments of a Distribution

Random variable  $X$



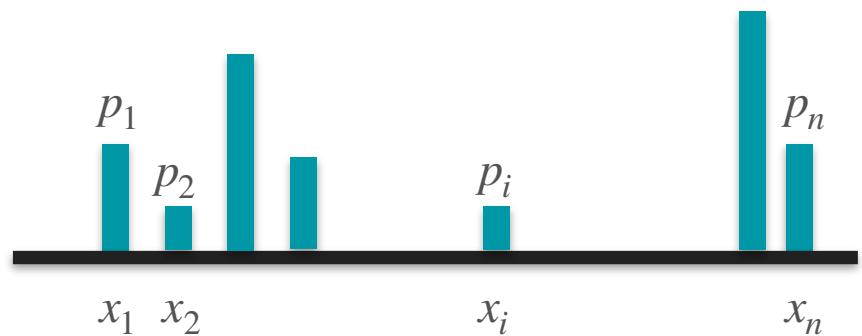
# Moments of a Distribution

Random variable  $X$



# Moments of a Distribution

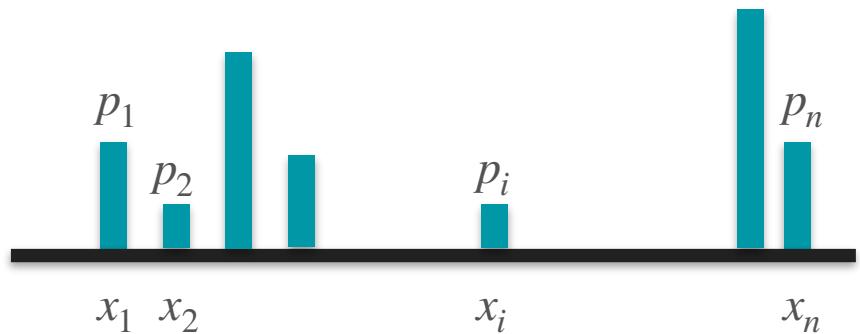
Random variable  $X$



# Moments of a Distribution

$$\mathbb{E}[X] = p_1x_1 + p_2x_2 + \cdots + p_nx_n$$

Random variable  $X$

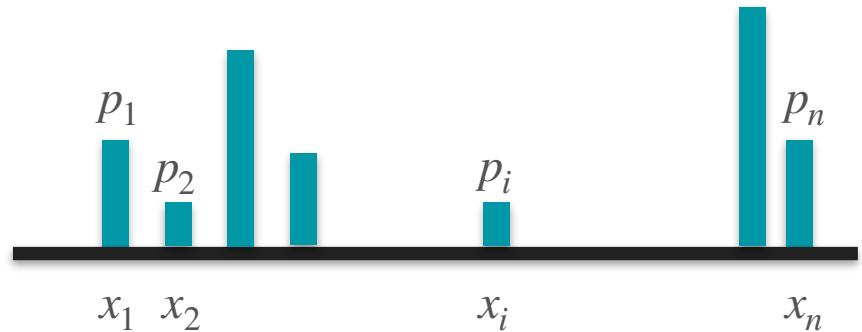


# Moments of a Distribution

$$\mathbb{E}[X] = p_1x_1 + p_2x_2 + \cdots + p_nx_n$$

$$\mathbb{E}[X^2] = p_1x_1^2 + p_2x_2^2 + \cdots + p_nx_n^2$$

Random variable  $X$



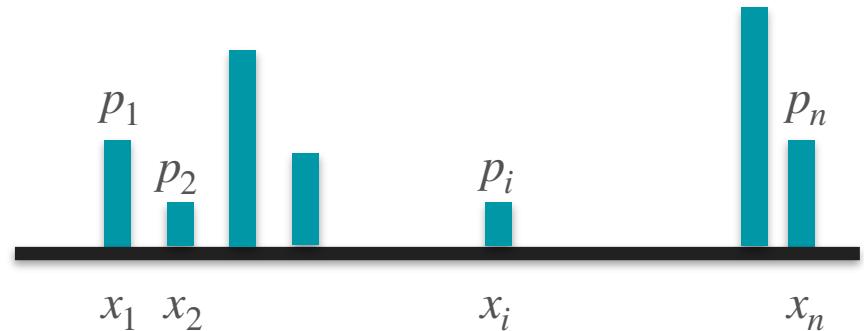
# Moments of a Distribution

$$\mathbb{E}[X] = p_1x_1 + p_2x_2 + \cdots + p_nx_n$$

$$\mathbb{E}[X^2] = p_1x_1^2 + p_2x_2^2 + \cdots + p_nx_n^2$$

$$\mathbb{E}[X^3] = p_1x_1^3 + p_2x_2^3 + \cdots + p_nx_n^3$$

Random variable  $X$



# Moments of a Distribution

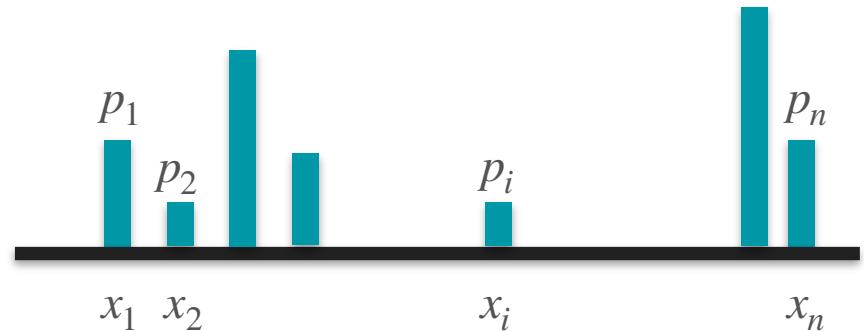
$$\mathbb{E}[X] = p_1x_1 + p_2x_2 + \dots + p_nx_n$$

$$\mathbb{E}[X^2] = p_1x_1^2 + p_2x_2^2 + \dots + p_nx_n^2$$

$$\mathbb{E}[X^3] = p_1x_1^3 + p_2x_2^3 + \dots + p_nx_n^3$$

$$\mathbb{E}[X^4] = p_1x_1^4 + p_2x_2^4 + \dots + p_nx_n^4$$

Random variable  $X$



# Moments of a Distribution

$$\mathbb{E}[X] = p_1x_1 + p_2x_2 + \dots + p_nx_n$$

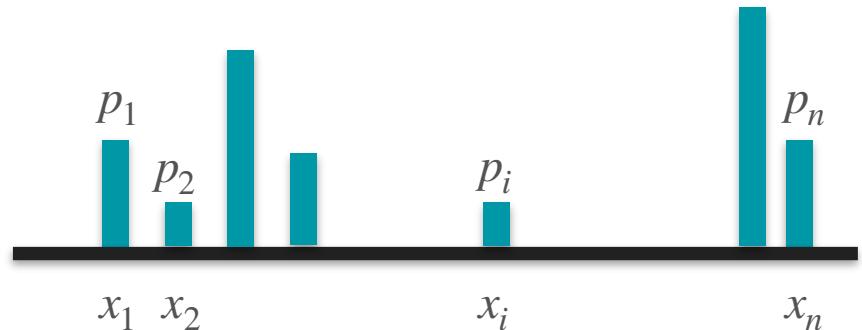
$$\mathbb{E}[X^2] = p_1x_1^2 + p_2x_2^2 + \dots + p_nx_n^2$$

$$\mathbb{E}[X^3] = p_1x_1^3 + p_2x_2^3 + \dots + p_nx_n^3$$

$$\mathbb{E}[X^4] = p_1x_1^4 + p_2x_2^4 + \dots + p_nx_n^4$$

...

Random variable  $X$



# Moments of a Distribution

$$\mathbb{E}[X] = p_1x_1 + p_2x_2 + \cdots + p_nx_n$$

$$\mathbb{E}[X^2] = p_1x_1^2 + p_2x_2^2 + \cdots + p_nx_n^2$$

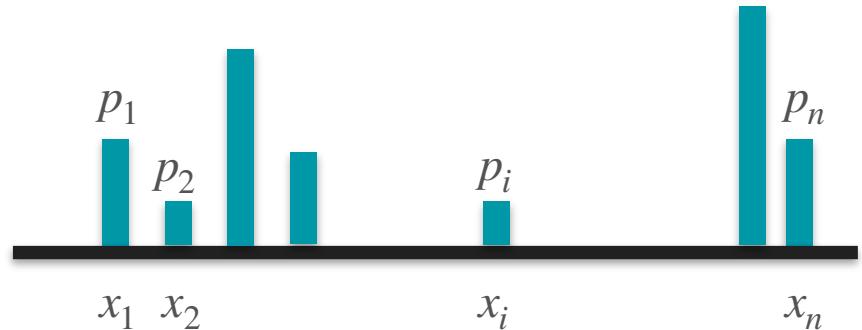
$$\mathbb{E}[X^3] = p_1x_1^3 + p_2x_2^3 + \cdots + p_nx_n^3$$

$$\mathbb{E}[X^4] = p_1x_1^4 + p_2x_2^4 + \cdots + p_nx_n^4$$

...

$$\mathbb{E}[X^k] = p_1x_1^k + p_2x_2^k + \cdots + p_nx_n^k$$

Random variable  $X$

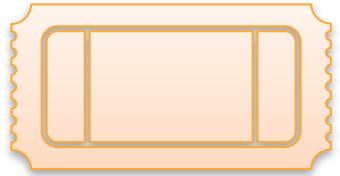


# Video 7b:

- Skewness

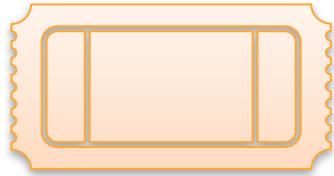
# Lottery vs Insurance

# Lottery vs Insurance



Lottery

# Lottery vs Insurance



Lottery



Car insurance

# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery



Car insurance

# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery



Car insurance

You **win** \$99 with 1% probability

You **lose** \$1 with 99% probability

# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance

You **win** \$99 with 1% probability

You **lose** \$1 with 99% probability

# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery

You **win** \$99 with 1% probability

You **lose** \$1 with 99% probability



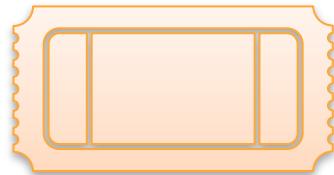
Cost: \$1  
Crash Reparation: \$100

Car insurance

You **win** \$1 with 99% probability

You **lose** \$99 with 1% probability

# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance



# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance



# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance



# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance

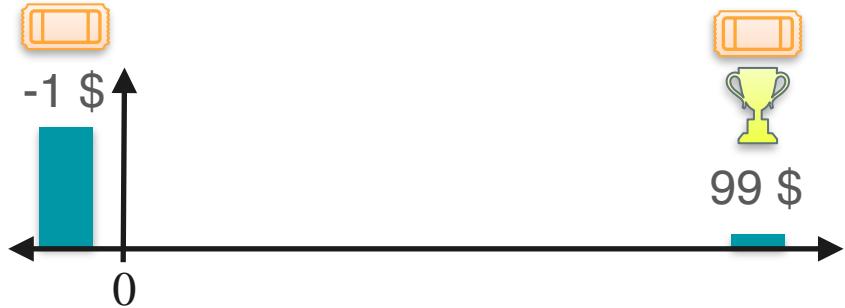


# Lottery vs Insurance



Ticket: \$1  
Jackpot: \$100

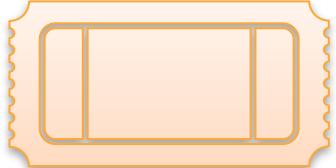
Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance





Ticket: \$1  
Jackpot: \$100

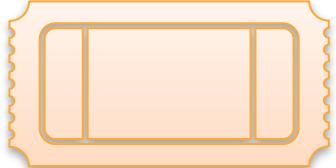
Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance





Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance





Ticket: \$1  
Jackpot: \$100

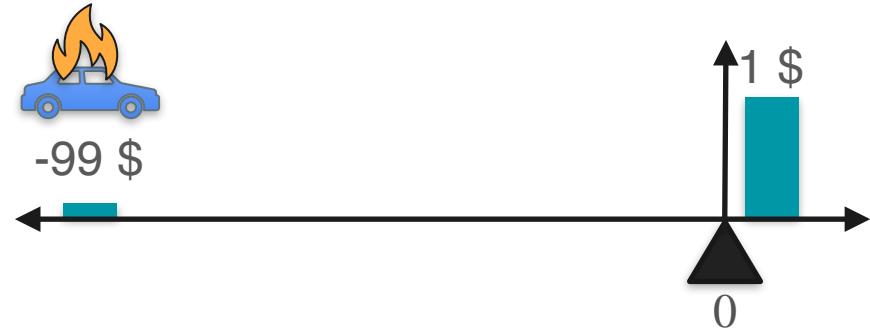
Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$





Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance

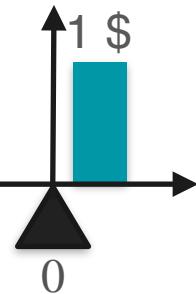
$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$

Lose 1  
With probability 0.99

Win 99  
With probability 0.01



-99 \$





Ticket: \$1  
Jackpot: \$100

Lottery

$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$

Lose 1  
With probability 0.99

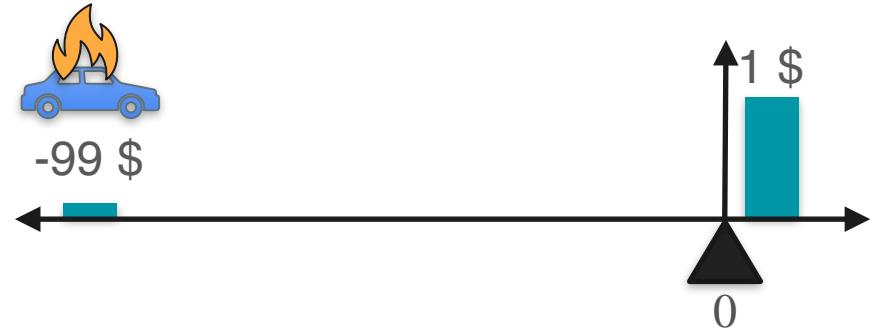
Win 99  
With probability 0.01



Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_2] = -99 \cdot 0.01 + 1 \cdot 0.99 = 0$$





Ticket: \$1  
Jackpot: \$100

## Lottery

$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$

Lose 1  
With probability 0.99

Win 99  
With probability 0.01



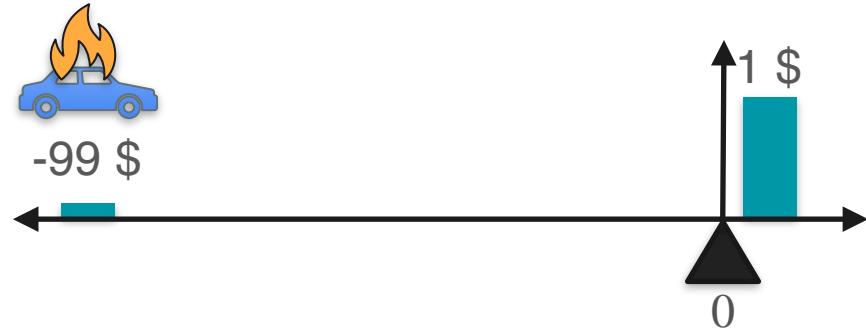
Cost: \$1  
Crash Reparation: \$100

## Car insurance

$$\mathbb{E}[X_2] = -99 \cdot 0.01 + 1 \cdot 0.99 = 0$$

Lose 99  
With probability 0.01

Win 1  
With probability 0.99





Ticket: \$1  
Jackpot: \$100

Lottery



Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$

$$\mathbb{E}[X_2] = -99 \cdot 0.01 + 1 \cdot 0.99 = 0$$





Ticket: \$1  
Jackpot: \$100

Lottery

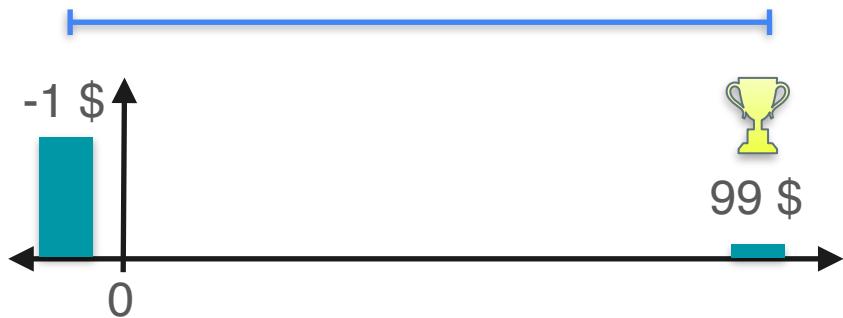
$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$



Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_2] = -99 \cdot 0.01 + 1 \cdot 0.99 = 0$$





Ticket: \$1  
Jackpot: \$100

Lottery

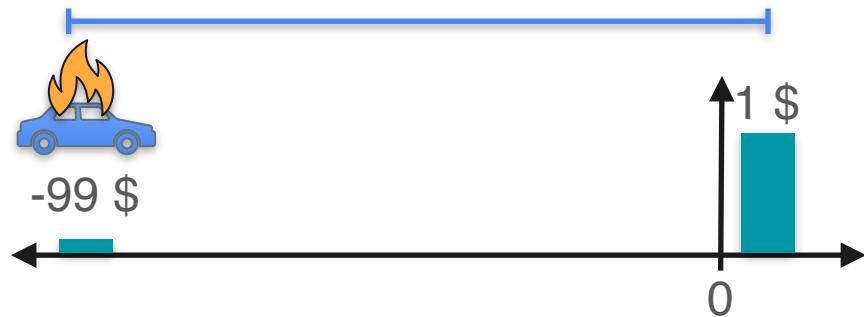
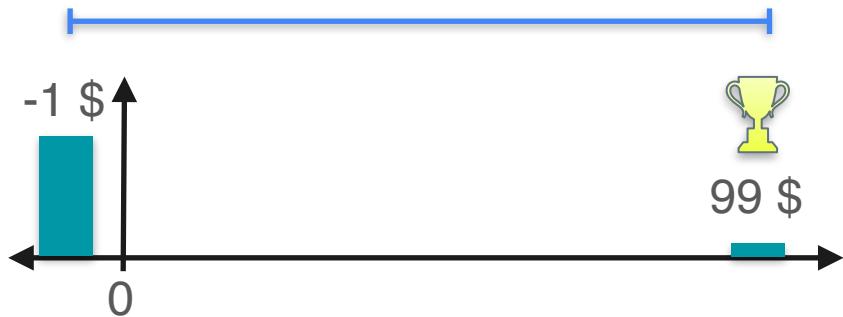
$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$



Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_2] = -99 \cdot 0.01 + 1 \cdot 0.99 = 0$$



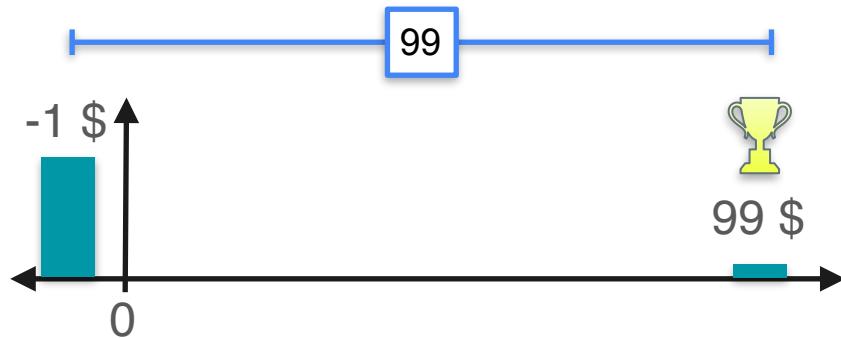


Ticket: \$1  
Jackpot: \$100

Lottery

$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$

$$Var(X_1) = (-1)^2 \cdot 0.99 + (99)^2 \cdot 0.01 = 99$$



Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_2] = -99 \cdot 0.01 + 1 \cdot 0.99 = 0$$



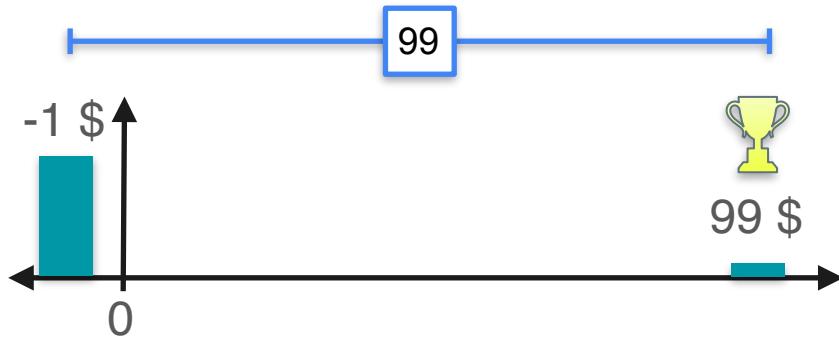


Ticket: \$1  
Jackpot: \$100

Lottery

$$\mathbb{E}[X_1] = -1 \cdot 0.99 + 99 \cdot 0.01 = 0$$

$$Var(X_1) = (-1)^2 \cdot 0.99 + (99)^2 \cdot 0.01 = 99$$

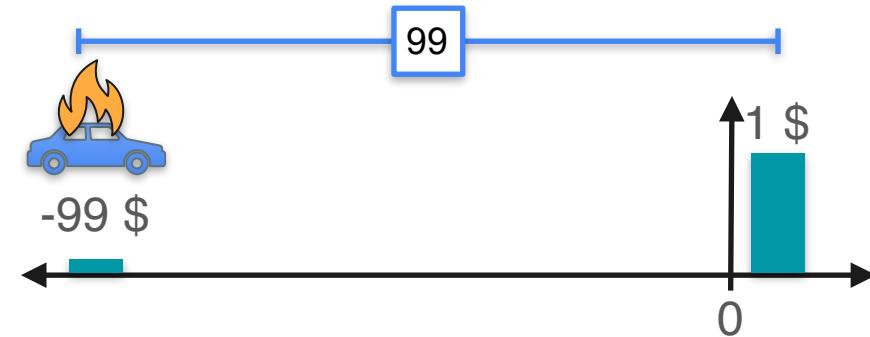


Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_2] = -99 \cdot 0.01 + 1 \cdot 0.99 = 0$$

$$Var(X_2) = (-99)^2 \cdot 0.01 + (1)^2 \cdot 0.99 = 99$$



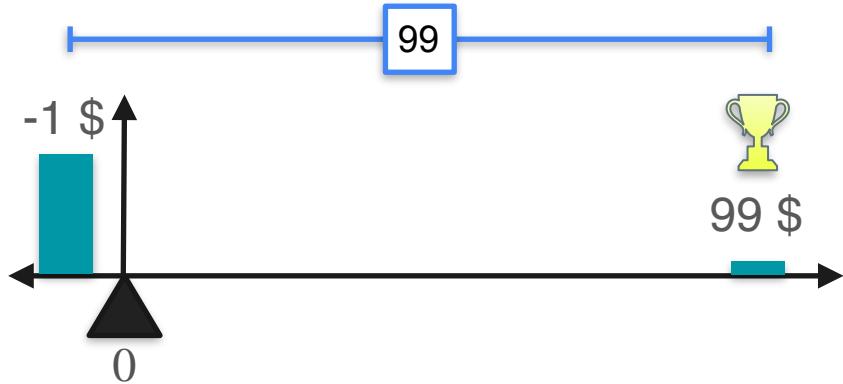


Ticket: \$1  
Jackpot: \$100

Lottery

$$\mathbb{E}[X_1] = 0$$

$$Var(X_1) = 99$$

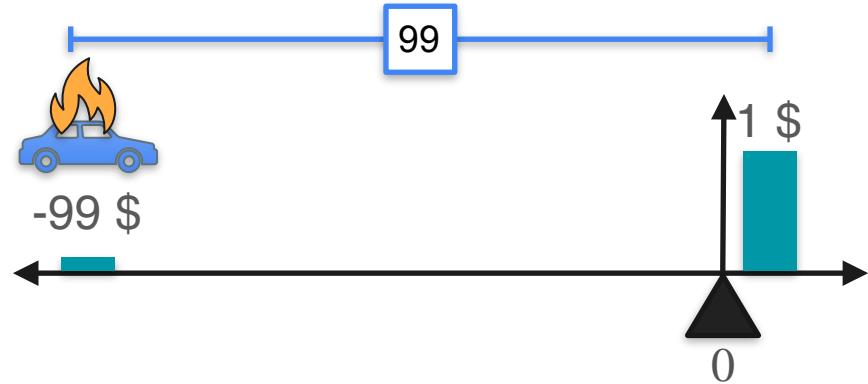


Cost: \$1  
Crash Reparation: \$100

Car insurance

$$\mathbb{E}[X_2] = 0$$

$$Var(X_2) = 99$$





Ticket: \$1  
Jackpot: \$100

Lottery

$$\mathbb{E}[X_1] = 0$$

$$Var(X_1) = 99$$



Cost: \$1  
Crash Reparation: \$100

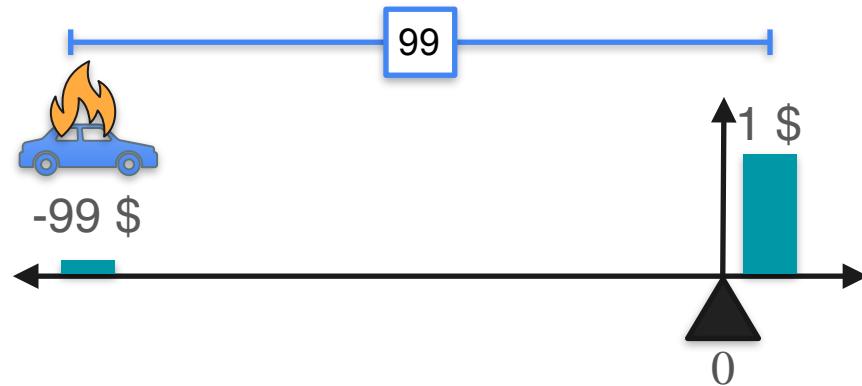
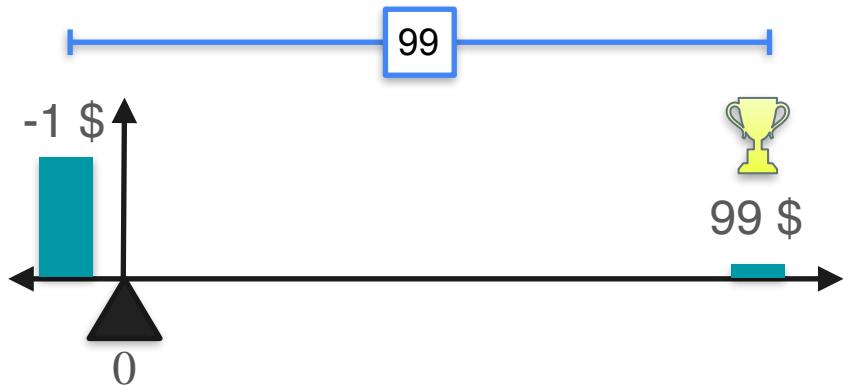
Car insurance

Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$Var(X_2) = 99$$





Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$Var(X_1) = 99$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$Var(X_2) = 99$$





Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$Var(X_1) = 99$$

$$\mathbb{E}[X_1^2] - \mathbb{E}[X_1]^2 = 99$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$Var(X_2) = 99$$

$$\mathbb{E}[X_2^2] - \mathbb{E}[X_2]^2 = 99$$





Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$Var(X_1) = 99$$

$$\mathbb{E}[X_1^2] - \mathbb{E}[X_1]^2 = 99$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$Var(X_2) = 99$$

$$\mathbb{E}[X_2^2] - \mathbb{E}[X_2]^2 = 99$$





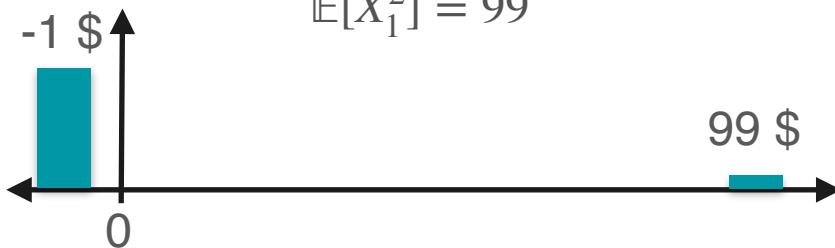
Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$Var(X_1) = 99$$

$$\mathbb{E}[X_1^2] - \mathbb{E}[X_1]^2 = 99$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

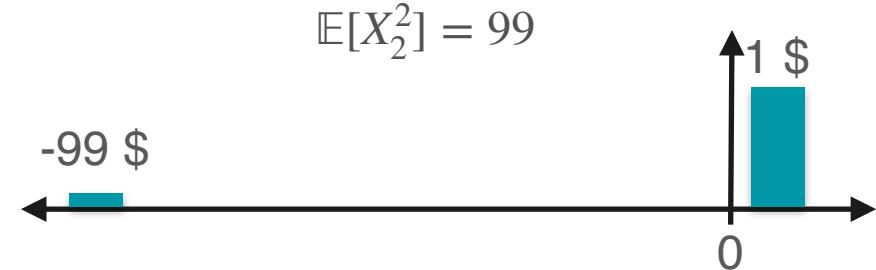
Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$Var(X_2) = 99$$

$$\mathbb{E}[X_2^2] - \mathbb{E}[X_2]^2 = 99$$





Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$





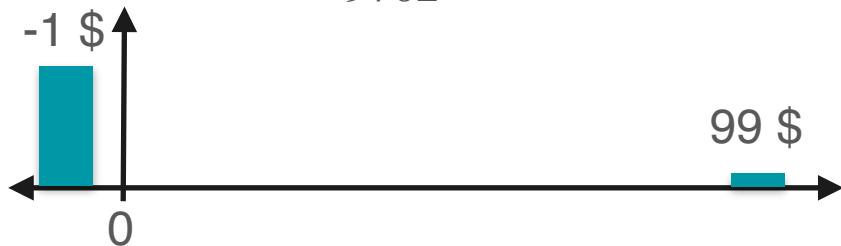
Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$

$$\begin{aligned}\mathbb{E}[X_1^3] &= (-1)^3 \cdot 0.99 + (99)^3 \cdot 0.01 \\ &= 9702\end{aligned}$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$





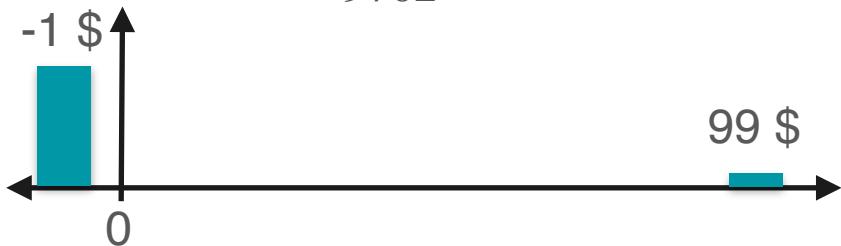
Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$

$$\begin{aligned}\mathbb{E}[X_1^3] &= (-1)^3 \cdot 0.99 + (99)^3 \cdot 0.01 \\ &= 9702\end{aligned}$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

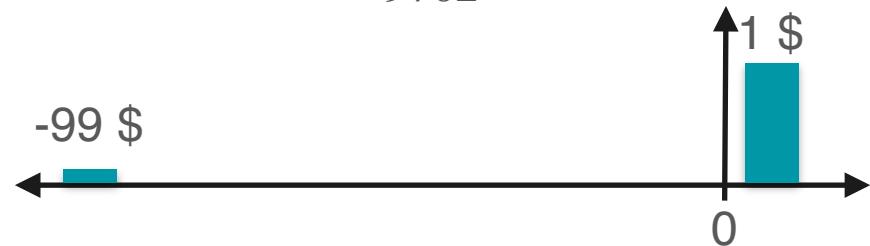
Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$

$$\begin{aligned}\mathbb{E}[X_2^3] &= (1)^3 \cdot 0.99 + (-99)^3 \cdot 0.01 \\ &= -9702\end{aligned}$$





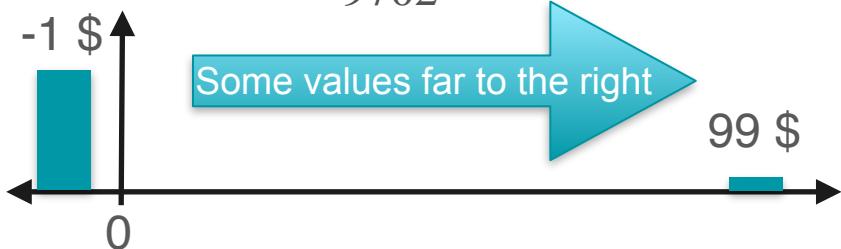
Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$

$$\begin{aligned}\mathbb{E}[X_1^3] &= (-1)^3 \cdot 0.99 + (99)^3 \cdot 0.01 \\ &= 9702\end{aligned}$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

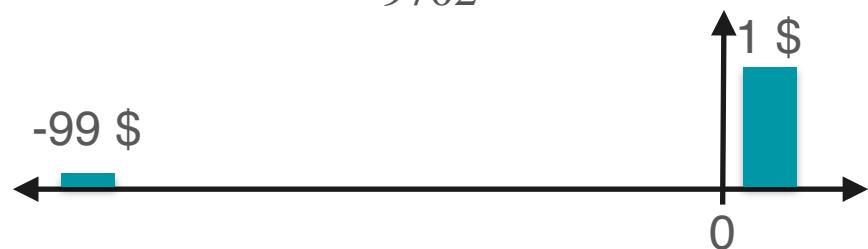
Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$

$$\begin{aligned}\mathbb{E}[X_2^3] &= (1)^3 \cdot 0.99 + (-99)^3 \cdot 0.01 \\ &= -9702\end{aligned}$$





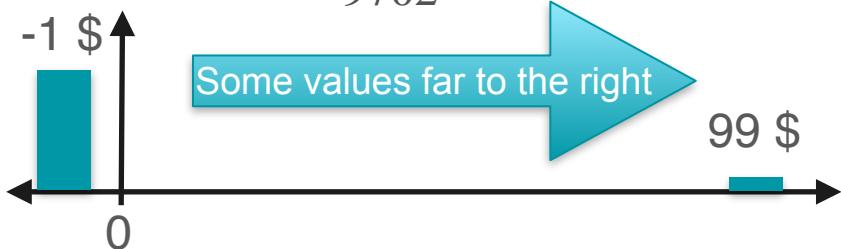
Ticket: \$1  
Jackpot: \$99

## Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$

$$\begin{aligned}\mathbb{E}[X_1^3] &= (-1)^3 \cdot 0.99 + (99)^3 \cdot 0.01 \\ &= 9702\end{aligned}$$



Cost: \$1  
Crash Reparation: \$99

## Car insurance

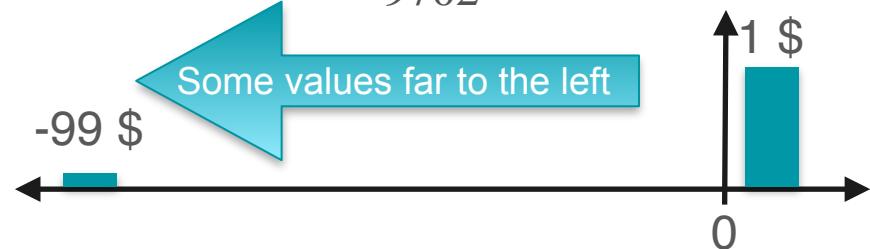
Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$

$$\begin{aligned}\mathbb{E}[X_2^3] &= (1)^3 \cdot 0.99 + (-99)^3 \cdot 0.01 \\ &= -9702\end{aligned}$$





Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$

$$\mathbb{E}[X_1^3] = \text{Large positive value}$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$

$$\mathbb{E}[X_2^3] = \text{Large negative value}$$





Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$

$$\mathbb{E}[X_1^3] = \text{Large positive value}$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

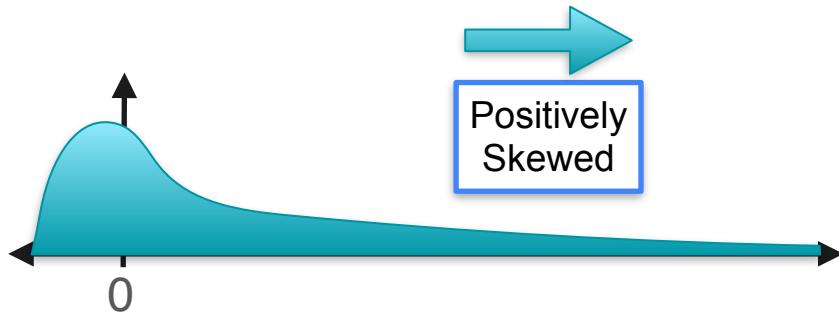
Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$

$$\mathbb{E}[X_2^3] = \text{Large negative value}$$





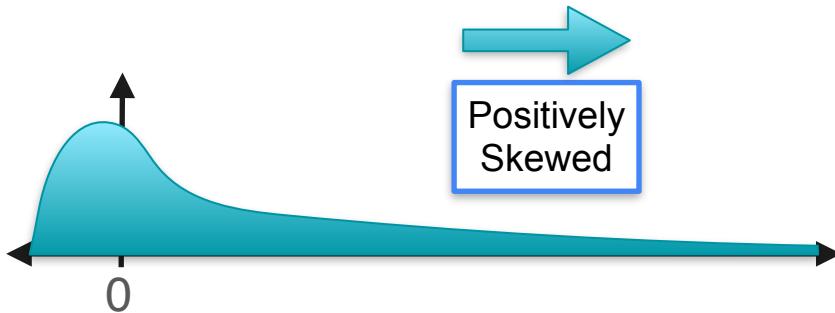
Ticket: \$1  
Jackpot: \$99

Lottery

$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[X_1^2] = 99$$

$$\mathbb{E}[X_1^3] = \text{Large positive value}$$



Cost: \$1  
Crash Reparation: \$99

Car insurance

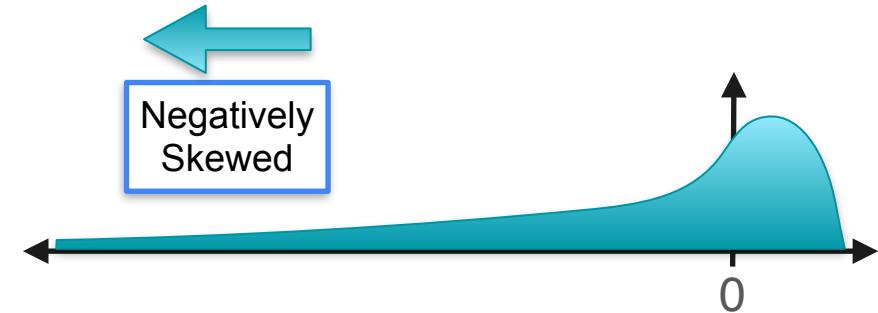
Same expectation  
Same variance

How to tell them apart?

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[X_2^2] = 99$$

$$\mathbb{E}[X_2^3] = \text{Large negative value}$$



# Skewness

$$\mathbb{E}[X^3]$$

# Skewness

$$\mathbb{E}[X^3]$$

Almost...

# Skewness

$$\mathbb{E}[X^3]$$

Almost...

Need to standardize...

# Skewness

# Skewness

$$\text{Skewness} = \mathbb{E} \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right]$$

# Skewness

# Skewness



Positively  
Skewed



$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] > 0$$

# Skewness



Positively  
Skewed



Not  
Skewed



$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] > 0$$

$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] = 0$$

# Skewness



Positively  
Skewed



Not  
Skewed



Negatively  
Skewed



$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] > 0$$

$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] = 0$$

$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] < 0$$

# Video 7c:

- Kurtosis

# Kurtosis: Example

Game 1

Game 2

# Kurtosis: Example

Game 1

probability  $\frac{1}{2}$ : You win 1 dollar

Game 2

# Kurtosis: Example

Game 1

**probability**  $\frac{1}{2}$ : You win 1 dollar

**probability**  $\frac{1}{2}$ : You lose 1 dollar

Game 2

# Kurtosis: Example

## Game 1

**probability**  $\frac{1}{2}$ : You win 1 dollar

**probability**  $\frac{1}{2}$ : You lose 1 dollar

## Game 2

**probability**  $\frac{100}{202}$ : You win 10 cents

# Kurtosis: Example

## Game 1

**probability**  $\frac{1}{2}$ : You win 1 dollar

**probability**  $\frac{1}{2}$ : You lose 1 dollar

## Game 2

**probability**  $\frac{100}{202}$ : You win 10 cents

**probability**  $\frac{100}{202}$ : You lose 10 cents

# Kurtosis: Example

## Game 1

**probability**  $\frac{1}{2}$ : You win 1 dollar

**probability**  $\frac{1}{2}$ : You lose 1 dollar

## Game 2

**probability**  $\frac{100}{202}$ : You win 10 cents

**probability**  $\frac{100}{202}$ : You lose 10 cents

**probability**  $\frac{1}{202}$ : You win 10 dollars

# Kurtosis: Example

## Game 1

**probability**  $\frac{1}{2}$ : You win 1 dollar

**probability**  $\frac{1}{2}$ : You lose 1 dollar

## Game 2

**probability**  $\frac{100}{202}$ : You win 10 cents

**probability**  $\frac{100}{202}$ : You lose 10 cents

**probability**  $\frac{1}{202}$ : You win 10 dollars

**probability**  $\frac{1}{202}$ : You lose 10 dollars

# Kurtosis: Example

## Game 1

Which one  
is riskier?

**probability**  $\frac{1}{2}$ : You win 1 dollar

**probability**  $\frac{1}{2}$ : You lose 1 dollar

## Game 2

**probability**  $\frac{100}{202}$ : You win 10 cents

**probability**  $\frac{100}{202}$ : You lose 10 cents

**probability**  $\frac{1}{202}$ : You win 10 dollars

**probability**  $\frac{1}{202}$ : You lose 10 dollars

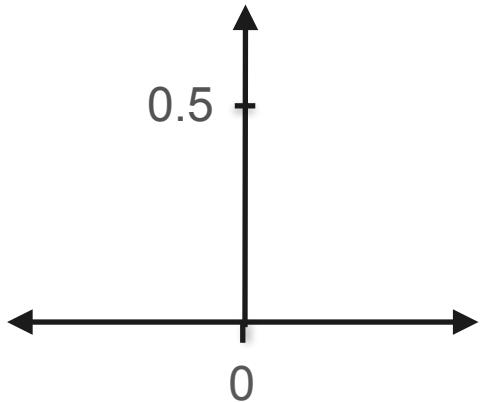
# Kurtosis: Example

Game 1

Game 2

# Kurtosis: Example

Game 1

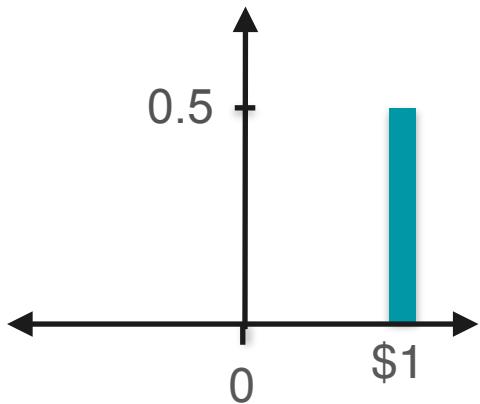


Game 2



# Kurtosis: Example

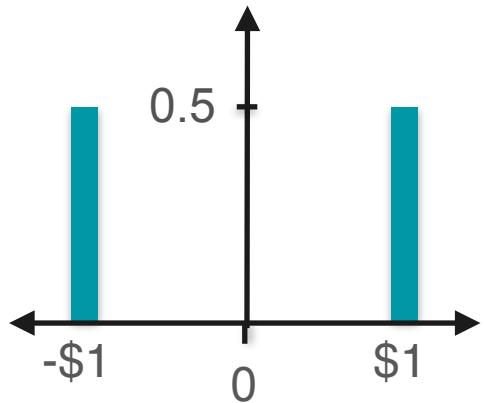
Game 1



Game 2

# Kurtosis: Example

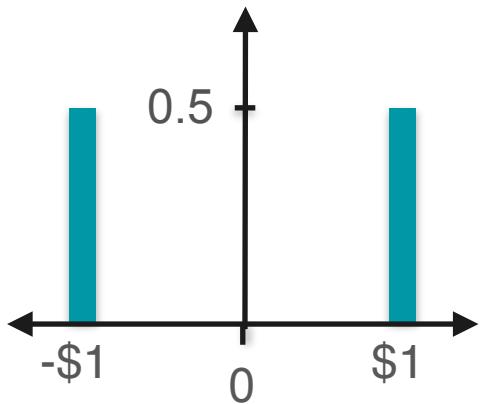
Game 1



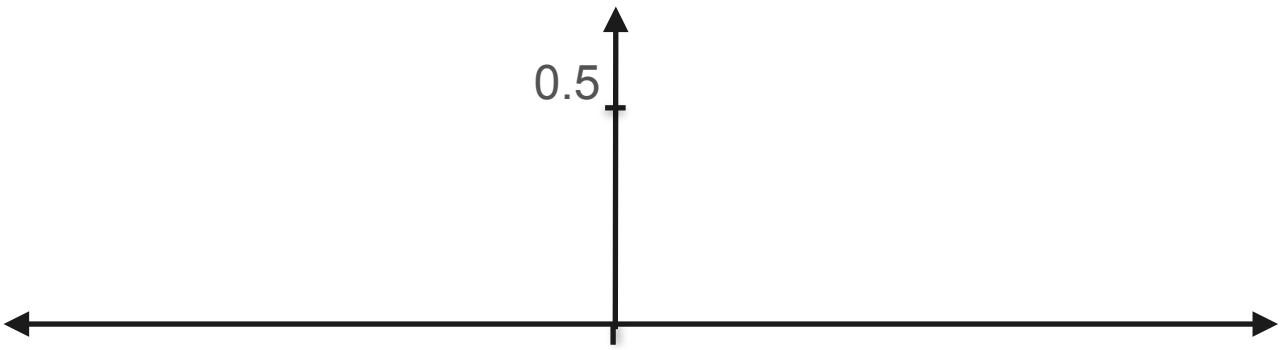
Game 2

# Kurtosis: Example

Game 1



Game 2

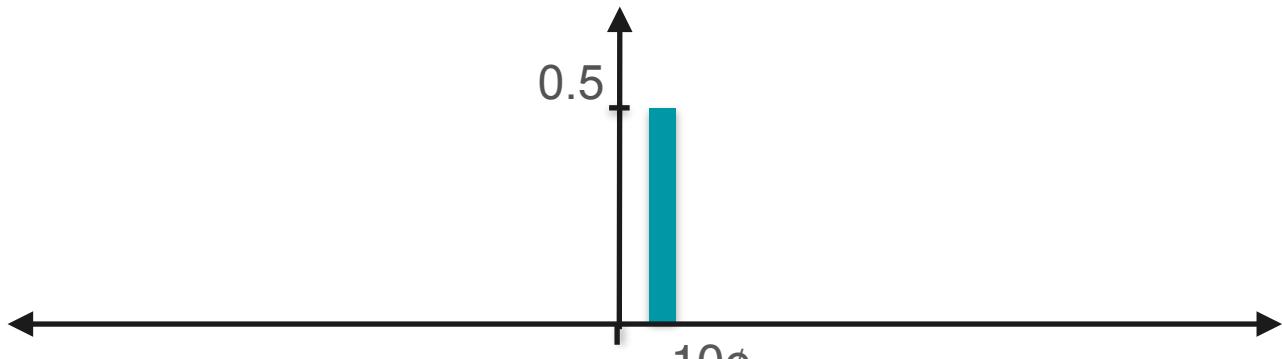


# Kurtosis: Example

Game 1

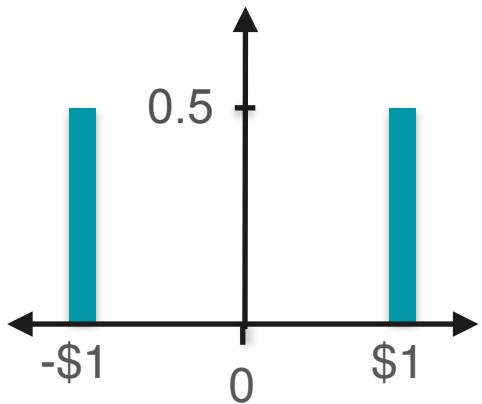


Game 2

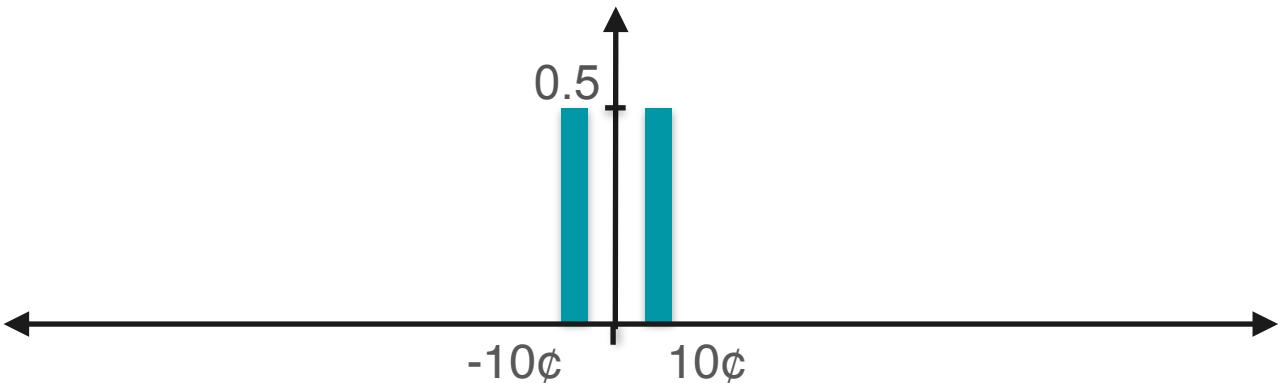


# Kurtosis: Example

Game 1

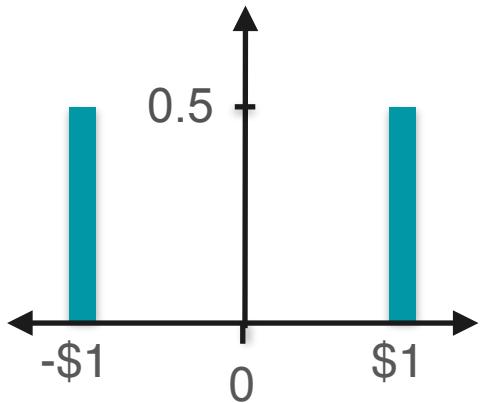


Game 2

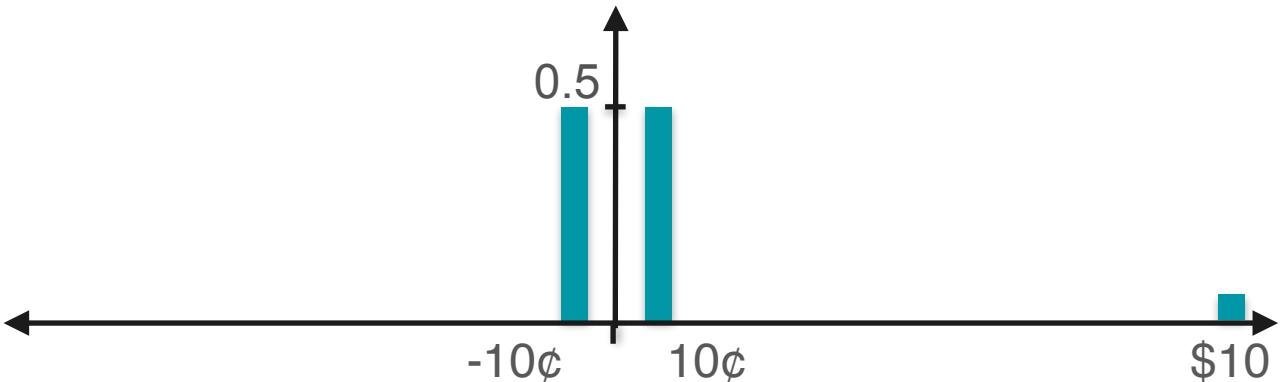


# Kurtosis: Example

Game 1



Game 2

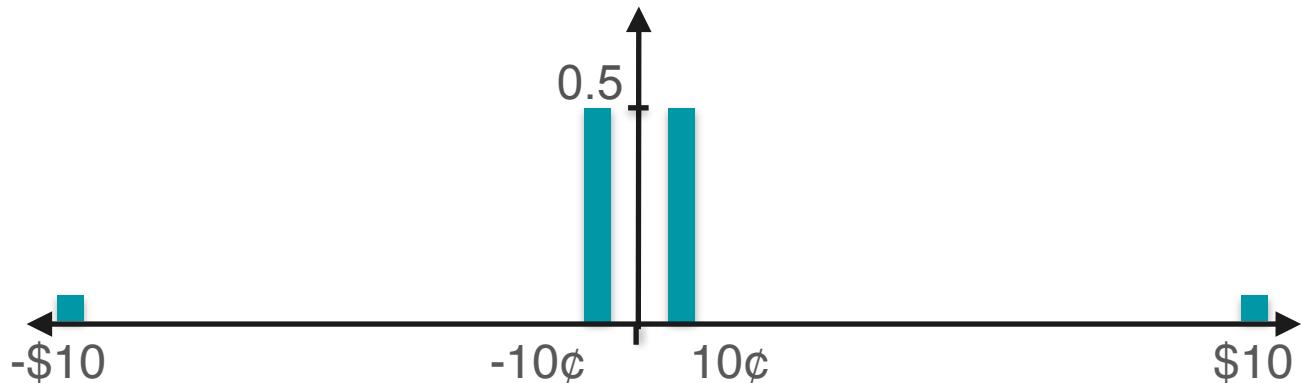


# Kurtosis: Example

Game 1

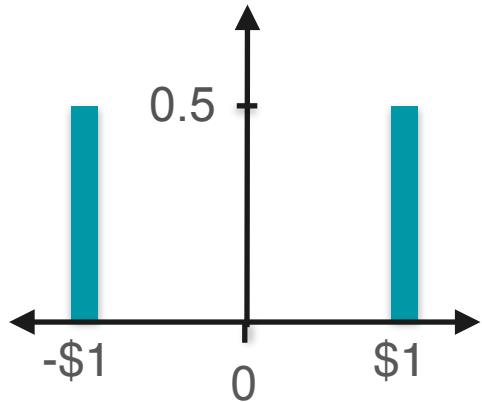


Game 2



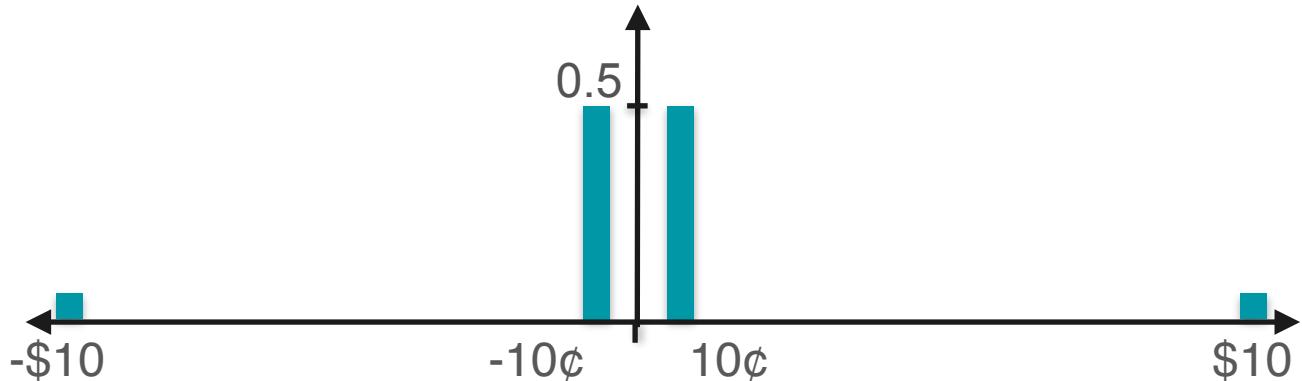
# Kurtosis: Example

Game 1



Expected value?

Game 2



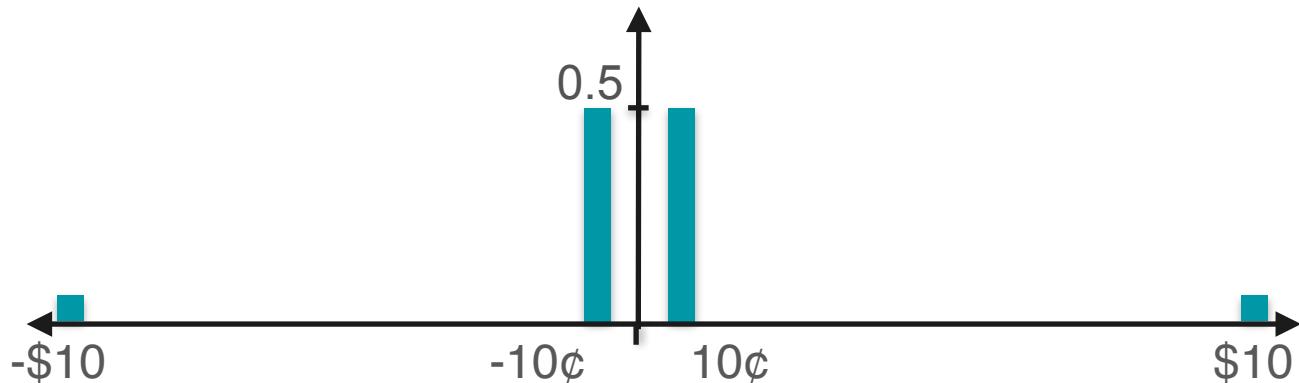
# Kurtosis: Example

Game 1



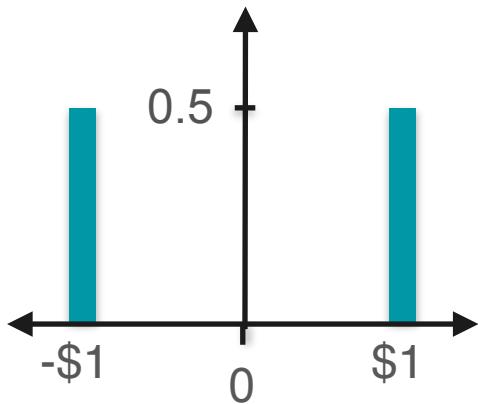
Expected value?  
Standard deviation?

Game 2



# Kurtosis: Example

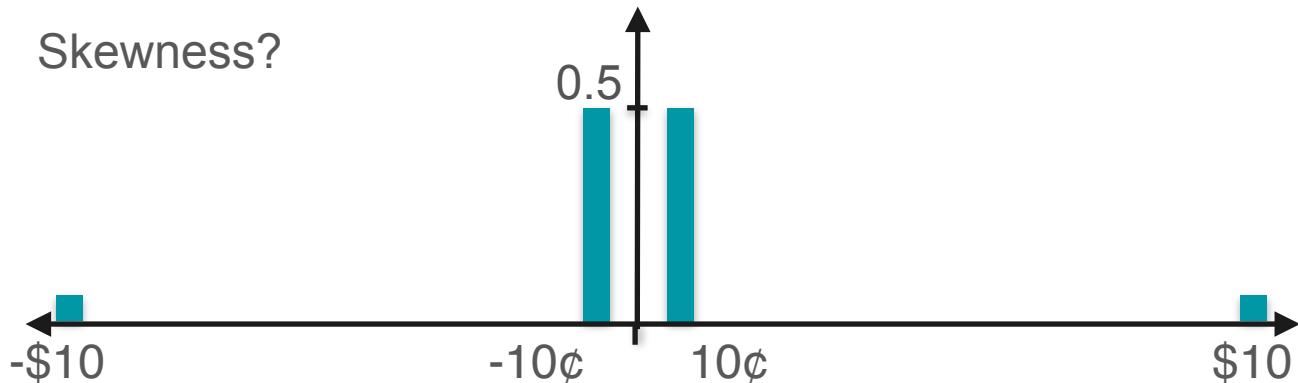
Game 1



Expected value?  
Standard deviation?

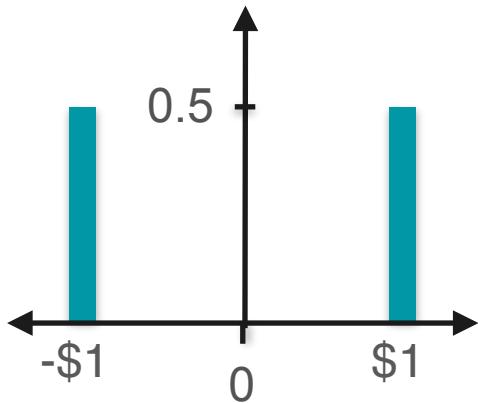
Skewness?

Game 2

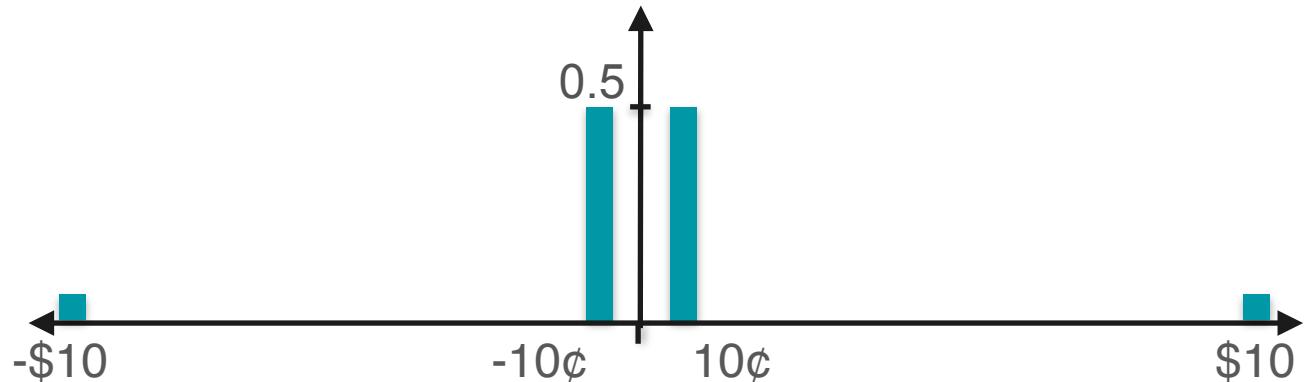


# Kurtosis: Example Expected Value

Game 1

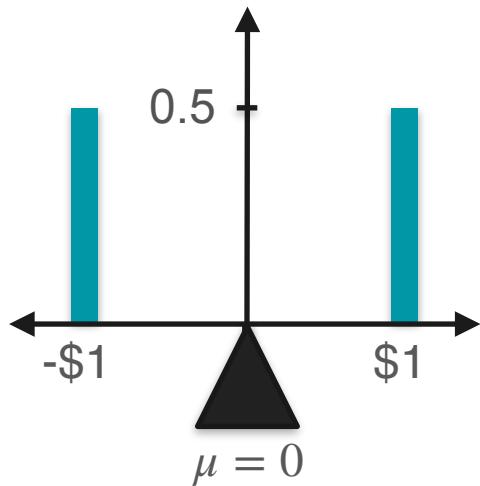


Game 2

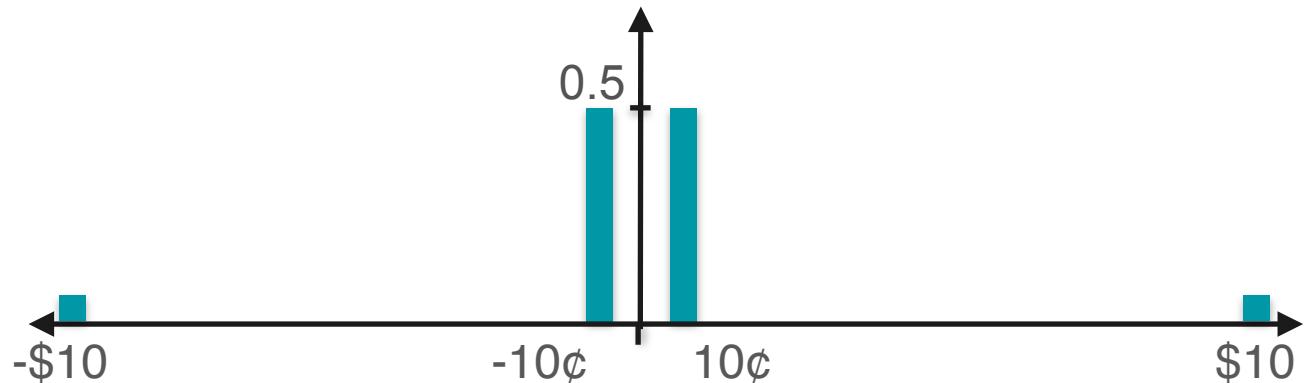


# Kurtosis: Example Expected Value

Game 1

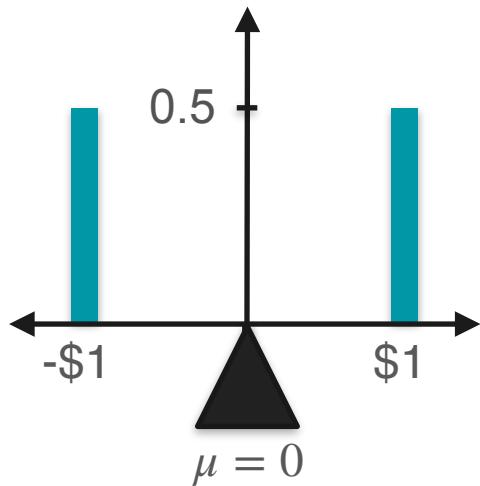


Game 2

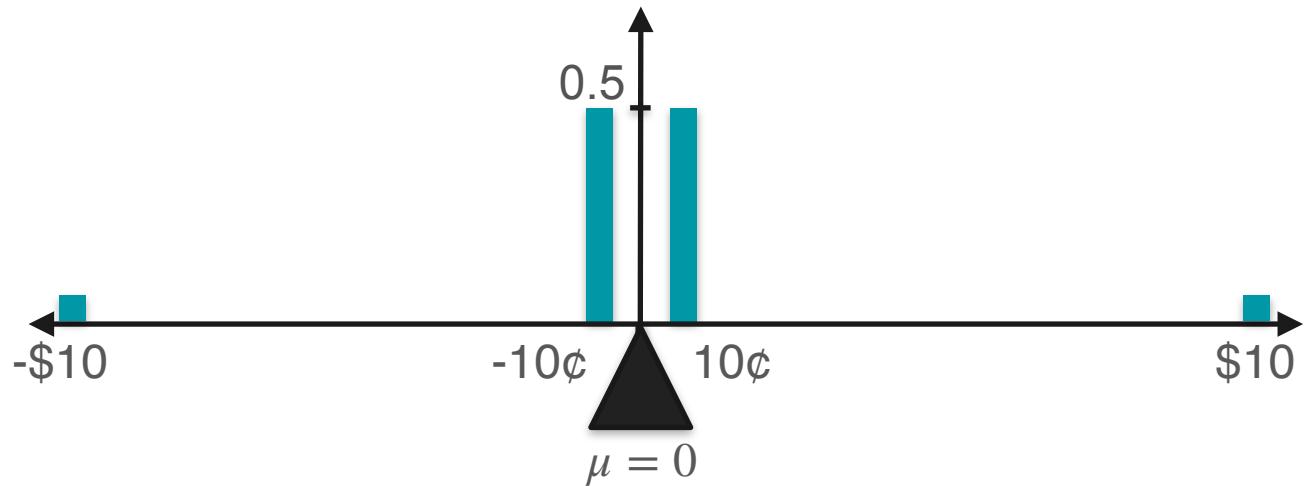


# Kurtosis: Example Expected Value

Game 1



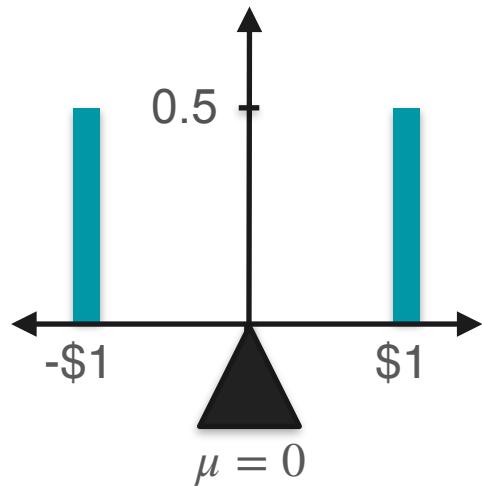
Game 2



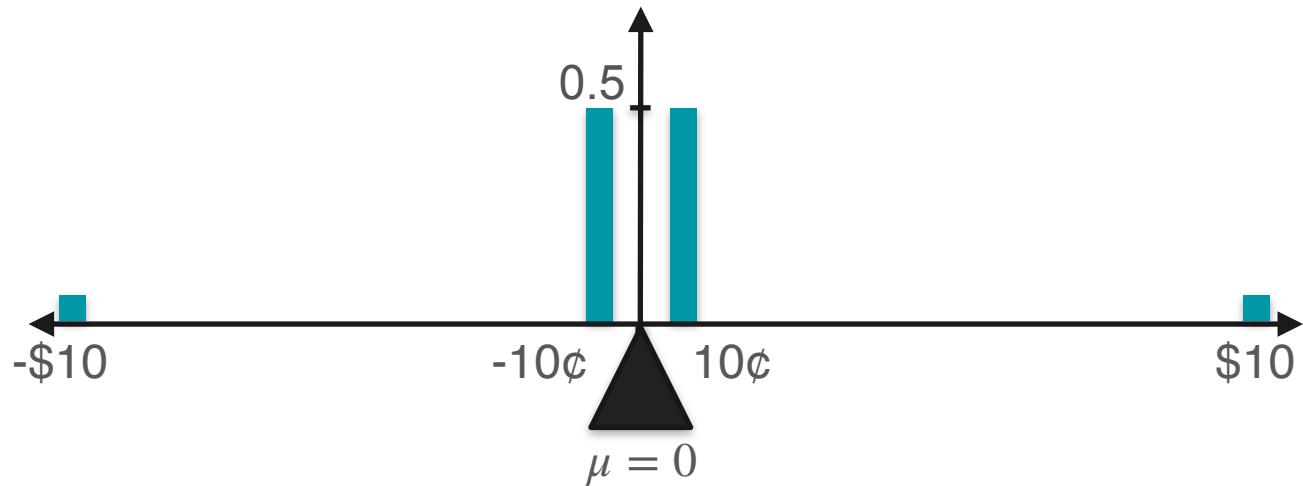
# Kurtosis: Example Expected Value

Game 1

$$\mathbb{E}[X_1] = 0$$



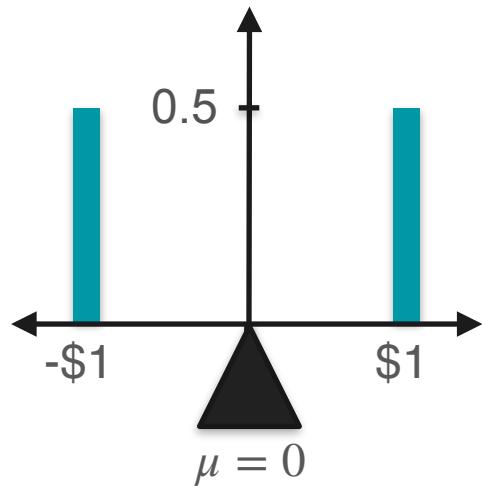
Game 2



# Kurtosis: Example Expected Value

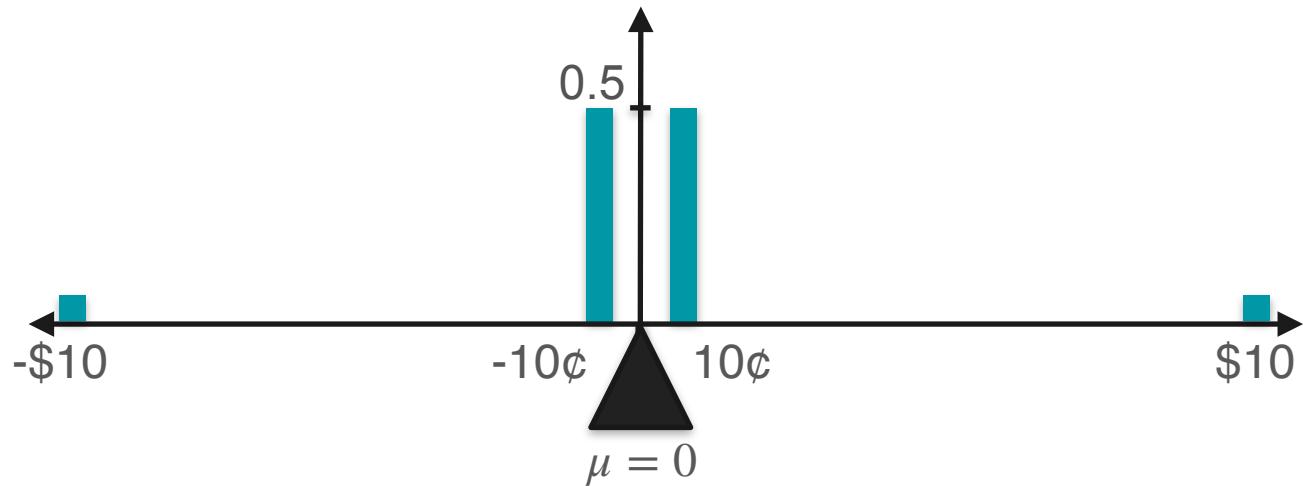
Game 1

$$\mathbb{E}[X_1] = 0$$

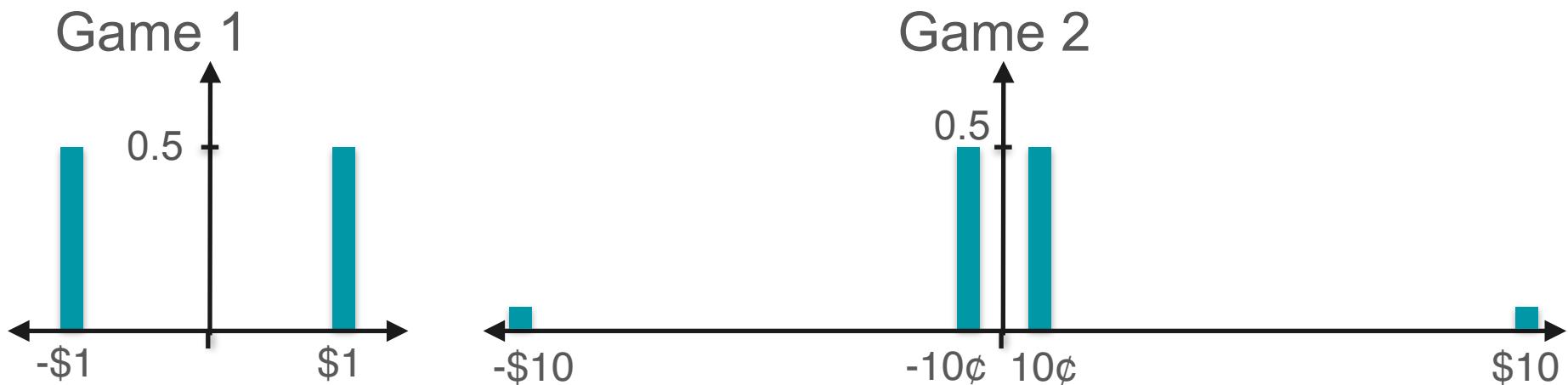


Game 2

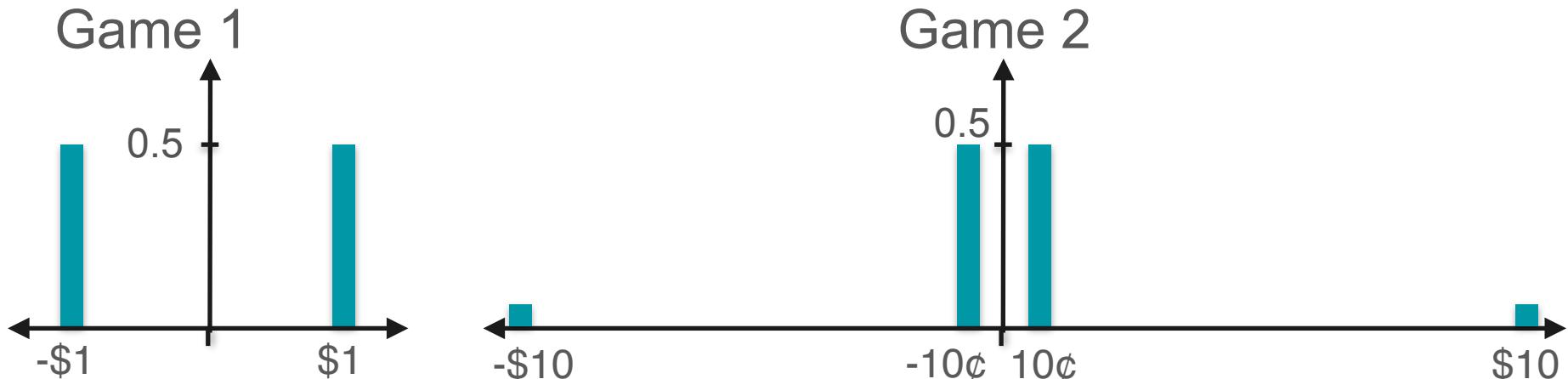
$$\mathbb{E}[X_2] = 0$$



# Kurtosis: Example Variance

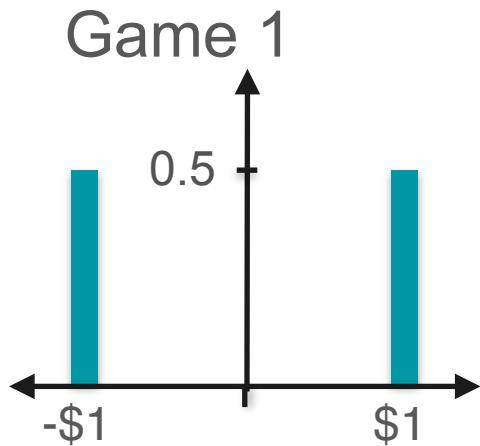


# Kurtosis: Example Variance

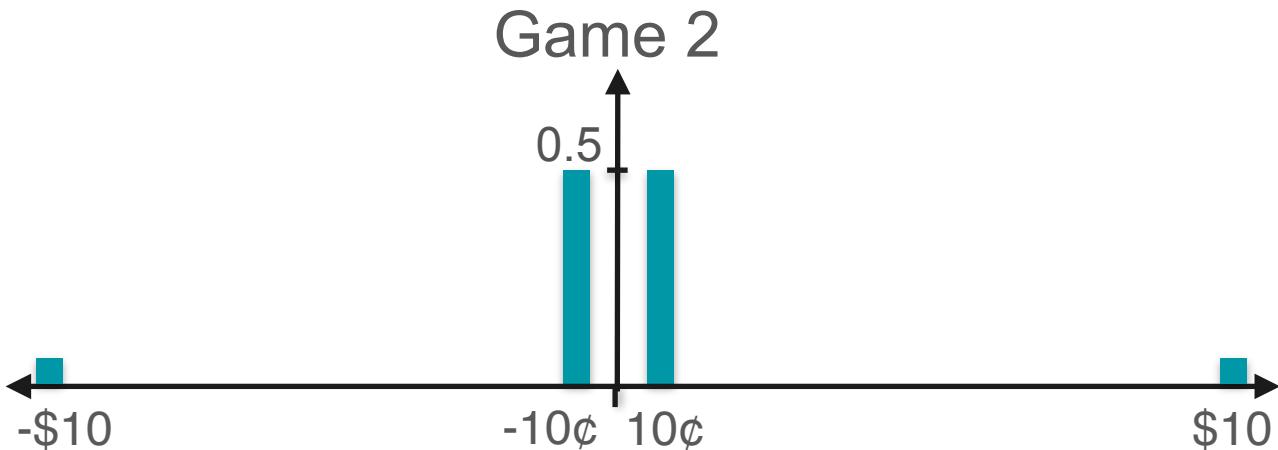


$$\mathbb{E}[X_1^2]$$

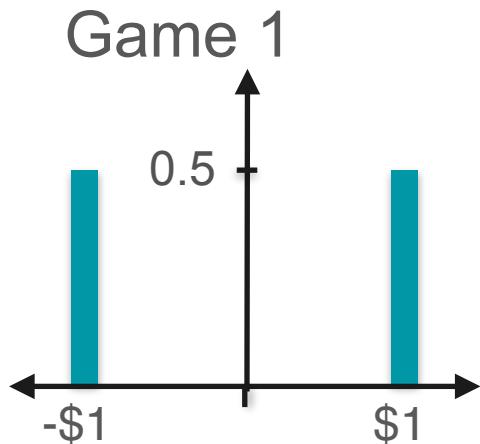
# Kurtosis: Example Variance



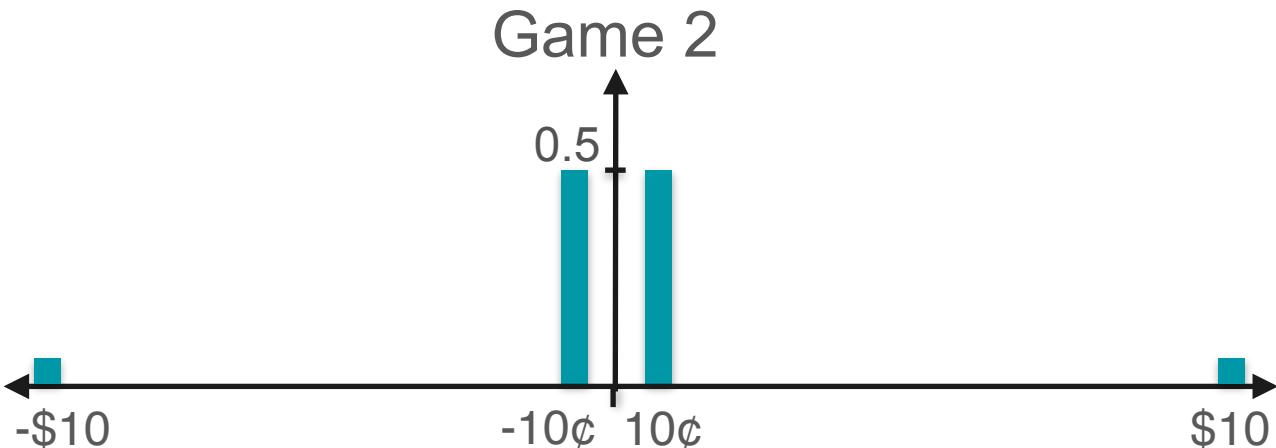
$$\mathbb{E}[X_1^2] = \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2$$



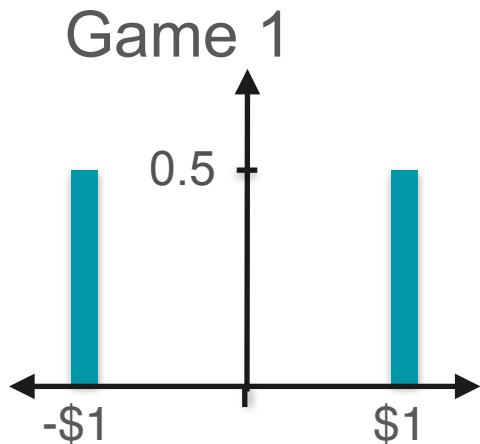
# Kurtosis: Example Variance



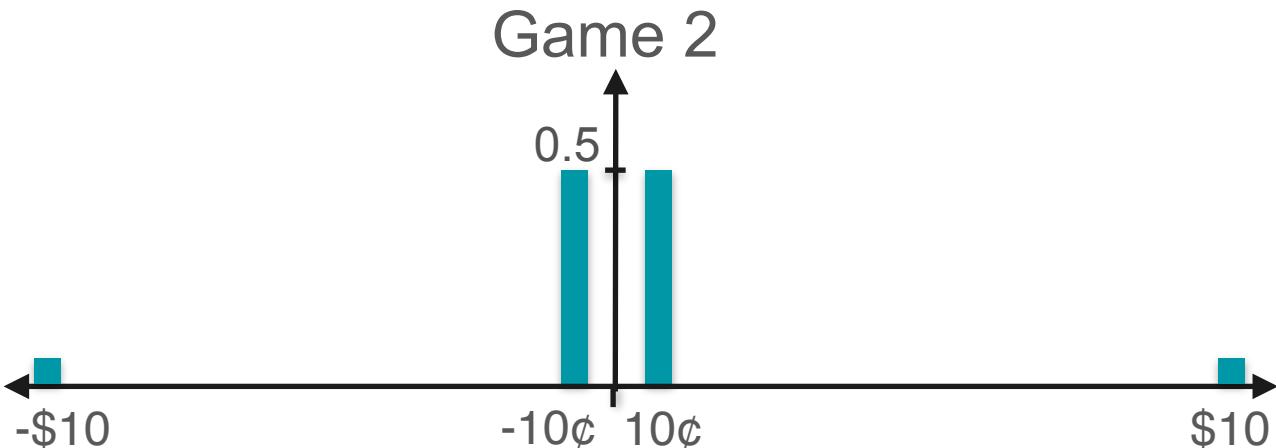
$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$



# Kurtosis: Example Variance

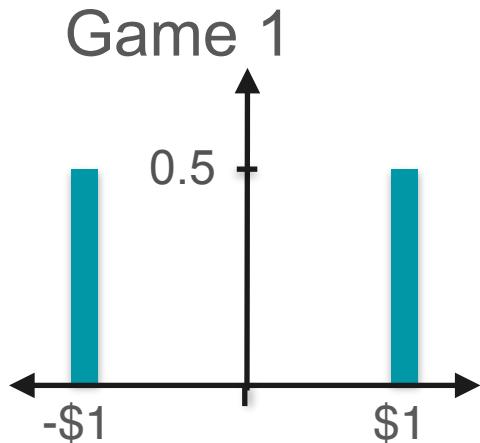


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

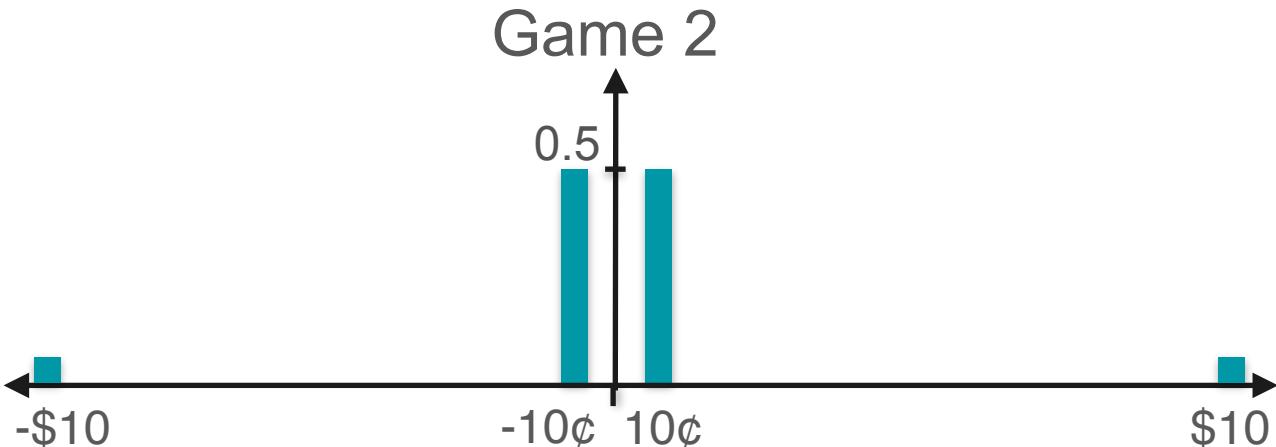


$$\mathbb{E}[X_2^2]$$

# Kurtosis: Example Variance

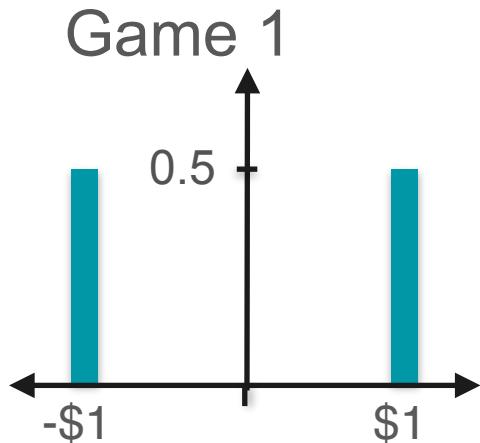


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

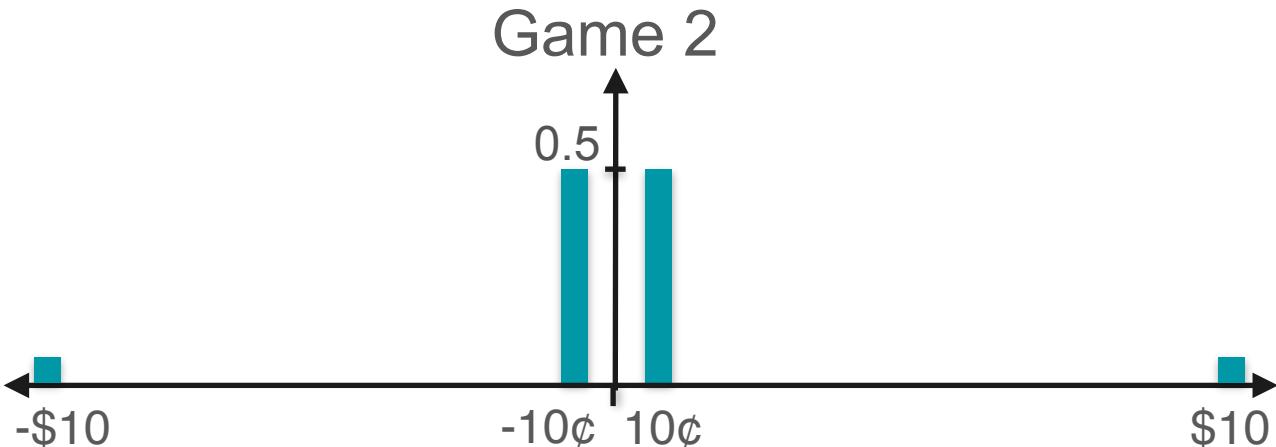


$$\mathbb{E}[X_2^2] = \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2$$

# Kurtosis: Example Variance

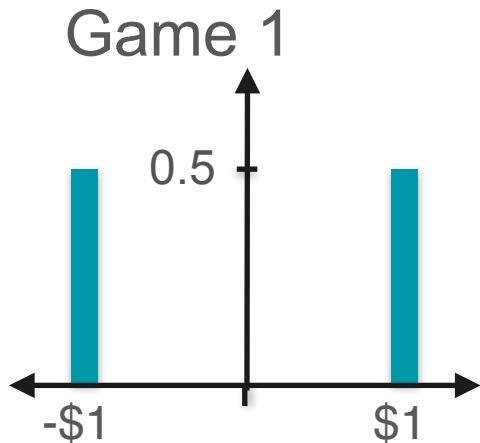


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

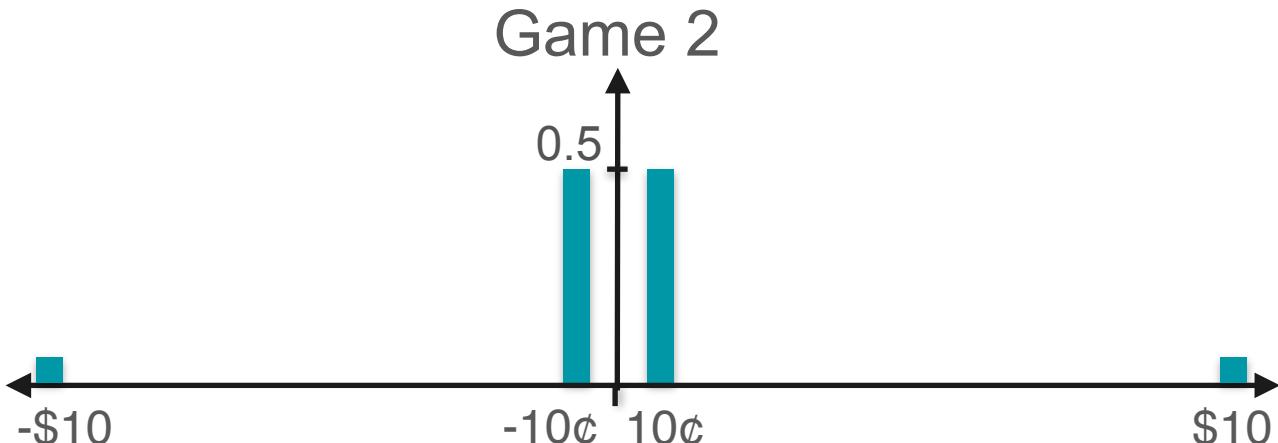


$$\begin{aligned}\mathbb{E}[X_2^2] &= \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2 \\ &= \frac{100}{202} \cdot \frac{1}{100} + \frac{100}{202} \cdot \frac{1}{100} + \frac{1}{202} \cdot 100 + \frac{1}{202} \cdot 100\end{aligned}$$

# Kurtosis: Example Variance

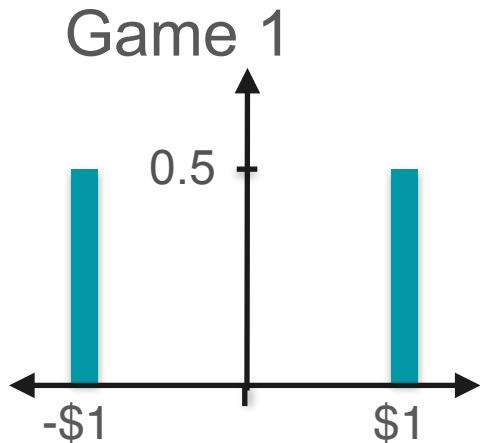


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

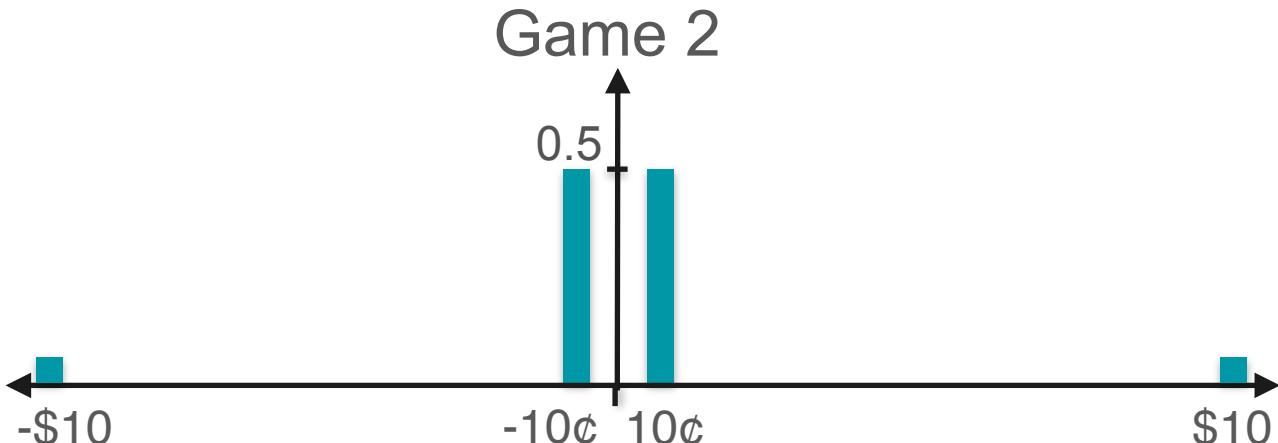


$$\begin{aligned}\mathbb{E}[X_2^2] &= \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2 \\ &= \frac{100}{202} \cdot \frac{1}{100} + \frac{100}{202} \cdot \frac{1}{100} + \frac{1}{202} \cdot 100 + \frac{1}{202} \cdot 100 \\ &= \frac{1}{202} + \frac{1}{202} + \frac{100}{202} + \frac{100}{202}\end{aligned}$$

# Kurtosis: Example Variance

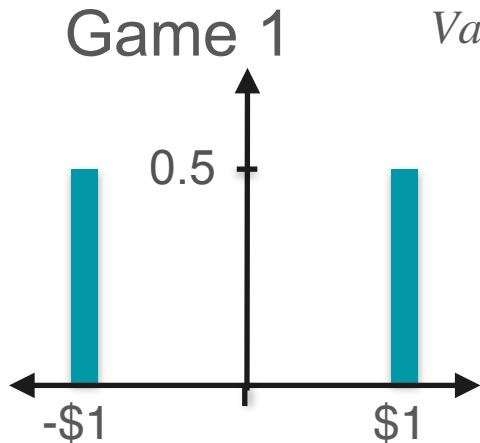


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

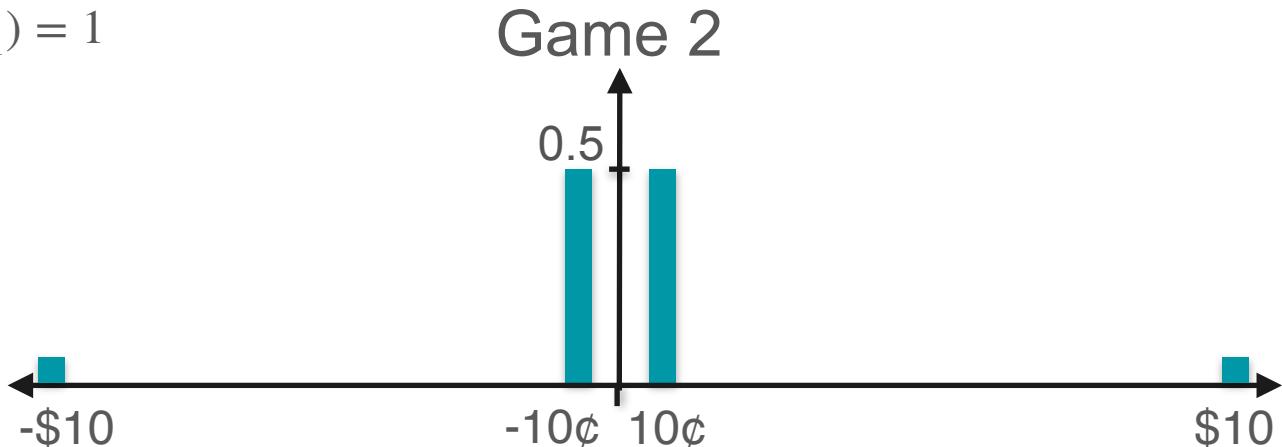


$$\begin{aligned}\mathbb{E}[X_2^2] &= \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2 \\ &= \frac{100}{202} \cdot \frac{1}{100} + \frac{100}{202} \cdot \frac{1}{100} + \frac{1}{202} \cdot 100 + \frac{1}{202} \cdot 100 \\ &= \frac{1}{202} + \frac{1}{202} + \frac{100}{202} + \frac{100}{202} = 1\end{aligned}$$

# Kurtosis: Example Variance

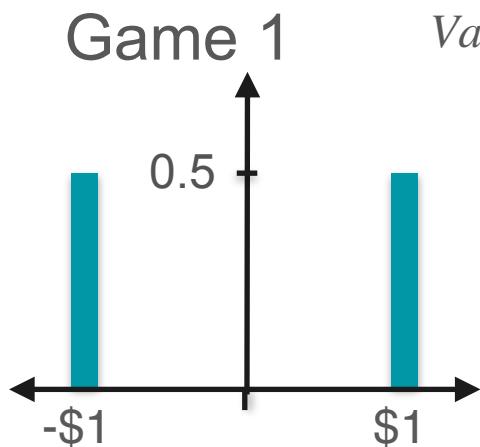


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

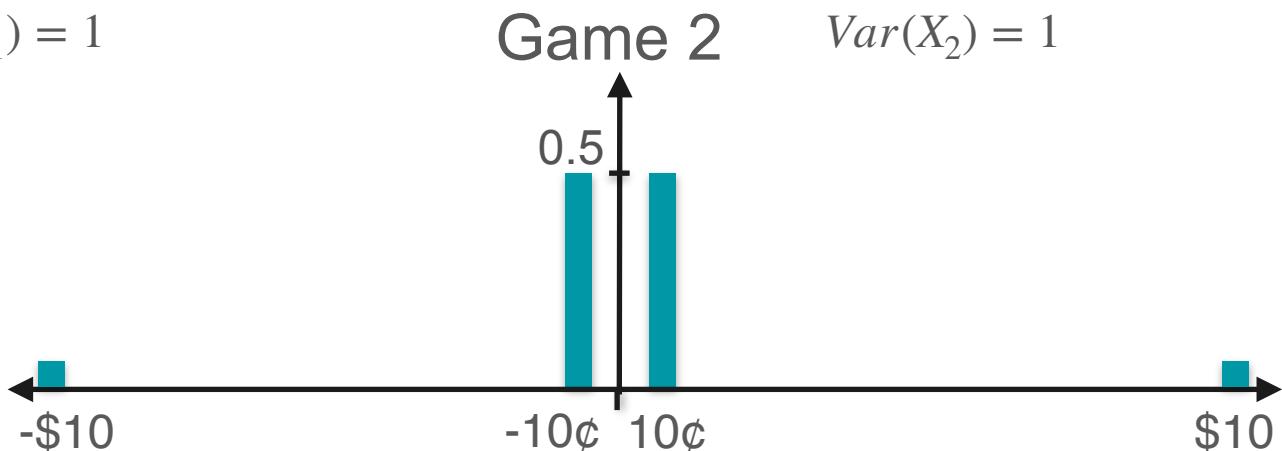


$$\begin{aligned}\mathbb{E}[X_2^2] &= \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2 \\ &= \frac{100}{202} \cdot \frac{1}{100} + \frac{100}{202} \cdot \frac{1}{100} + \frac{1}{202} \cdot 100 + \frac{1}{202} \cdot 100 \\ &= \frac{1}{202} + \frac{1}{202} + \frac{100}{202} + \frac{100}{202} = 1\end{aligned}$$

# Kurtosis: Example Variance

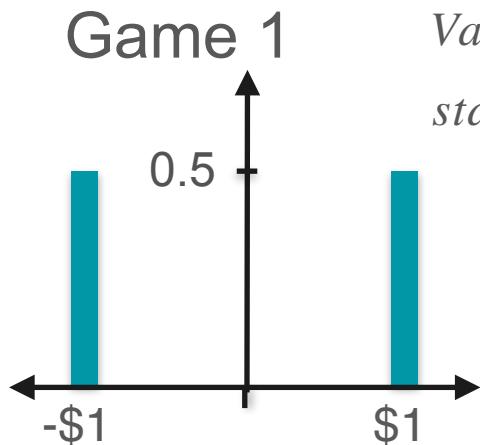


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

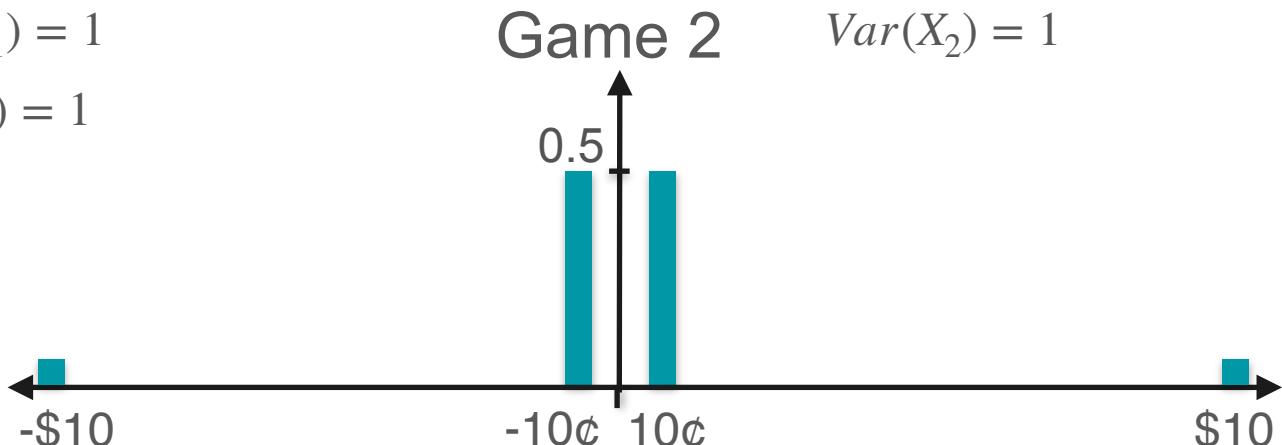


$$\begin{aligned}\mathbb{E}[X_2^2] &= \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2 \\ &= \frac{100}{202} \cdot \frac{1}{100} + \frac{100}{202} \cdot \frac{1}{100} + \frac{1}{202} \cdot 100 + \frac{1}{202} \cdot 100 \\ &= \frac{1}{202} + \frac{1}{202} + \frac{100}{202} + \frac{100}{202} = 1\end{aligned}$$

# Kurtosis: Example Variance

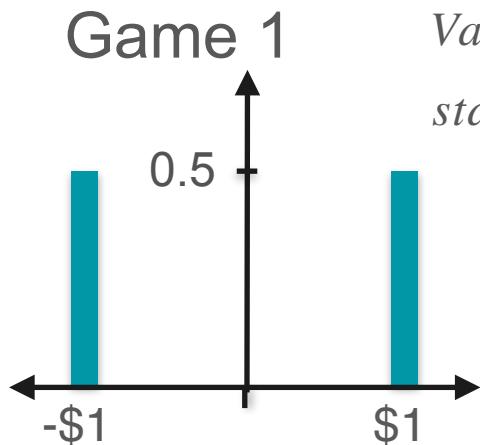


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$

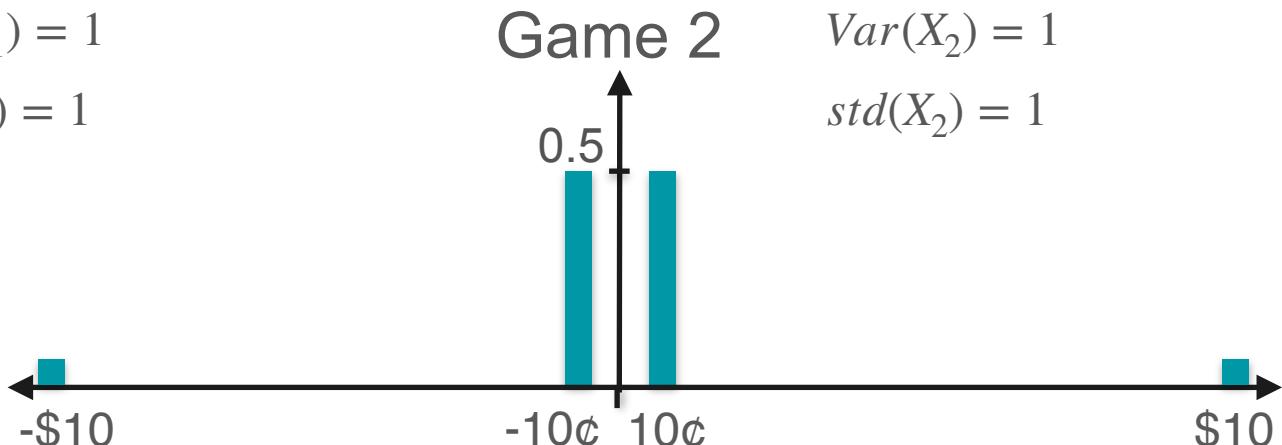


$$\begin{aligned}\mathbb{E}[X_2^2] &= \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2 \\ &= \frac{100}{202} \cdot \frac{1}{100} + \frac{100}{202} \cdot \frac{1}{100} + \frac{1}{202} \cdot 100 + \frac{1}{202} \cdot 100 \\ &= \frac{1}{202} + \frac{1}{202} + \frac{100}{202} + \frac{100}{202} = 1\end{aligned}$$

# Kurtosis: Example Variance

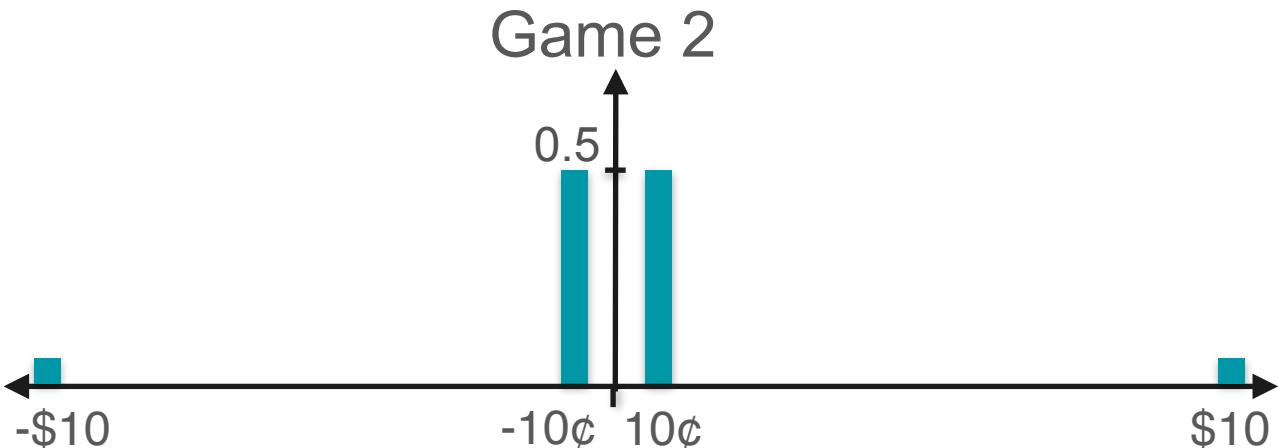
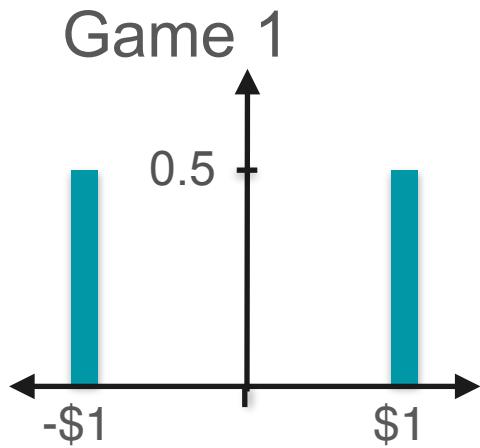


$$\begin{aligned}\mathbb{E}[X_1^2] &= \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 \\ &= 1\end{aligned}$$



$$\begin{aligned}\mathbb{E}[X_2^2] &= \frac{100}{202}(-0.1)^2 + \frac{100}{202}(0.1)^2 + \frac{1}{202}(-10)^2 + \frac{1}{202}(10)^2 \\ &= \frac{100}{202} \cdot \frac{1}{100} + \frac{100}{202} \cdot \frac{1}{100} + \frac{1}{202} \cdot 100 + \frac{1}{202} \cdot 100 \\ &= \frac{1}{202} + \frac{1}{202} + \frac{100}{202} + \frac{100}{202} = 1\end{aligned}$$

# Kurtosis: Example Skewness



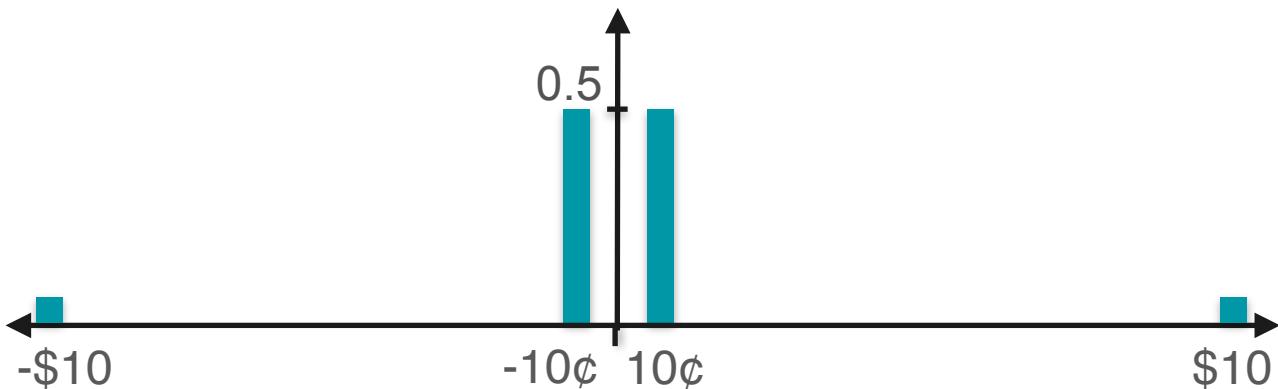
# Kurtosis: Example Skewness

Game 1

$$Skew(X_1) = 0$$



Game 2



# Kurtosis: Example Skewness

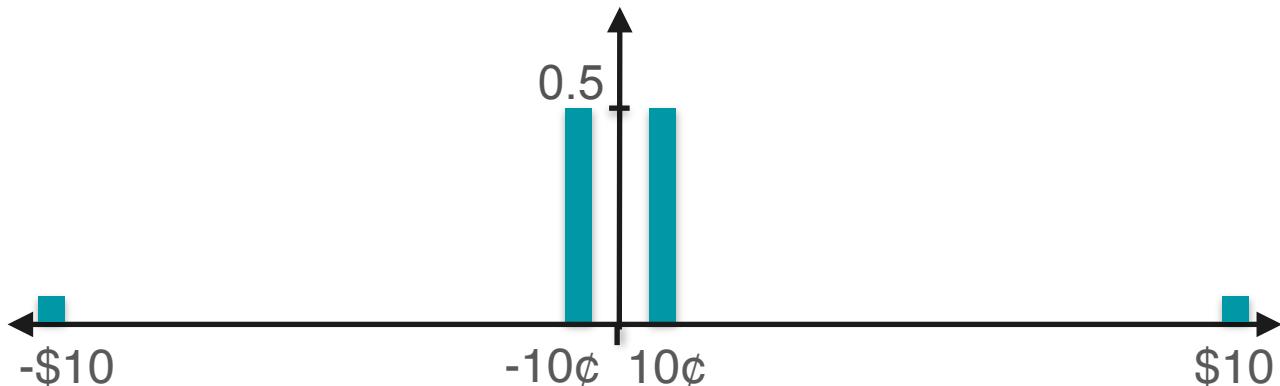
Game 1

$$Skew(X_1) = 0$$



Game 2

$$Skew(X_2) = 0$$

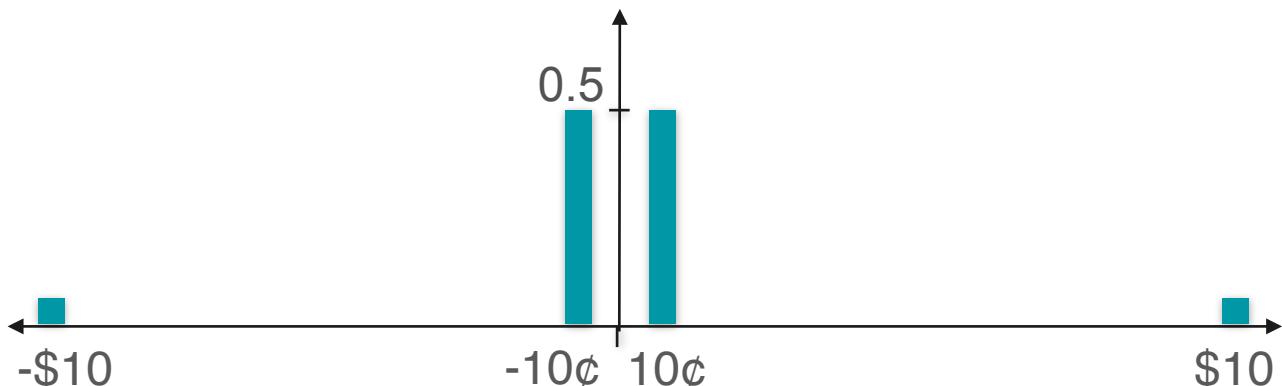


# Kurtosis

Game 1



Game 2

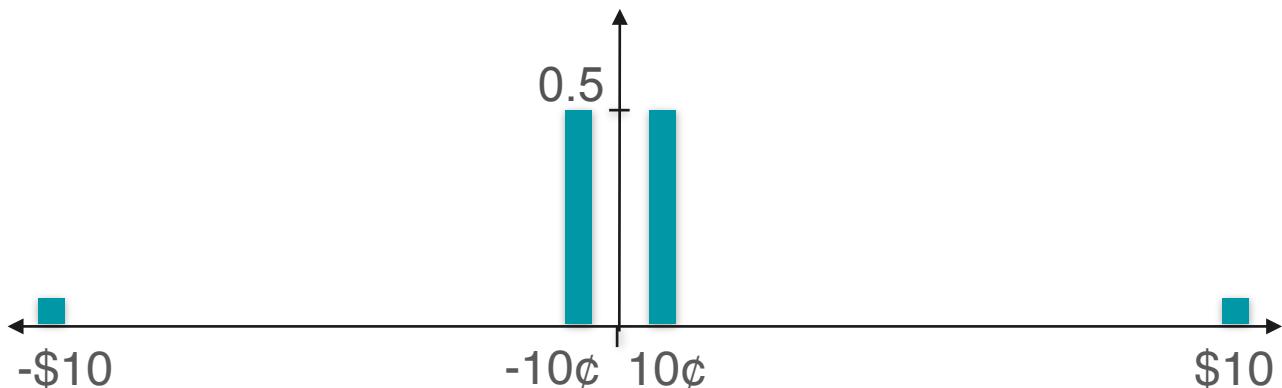


# Kurtosis

Game 1



Game 2



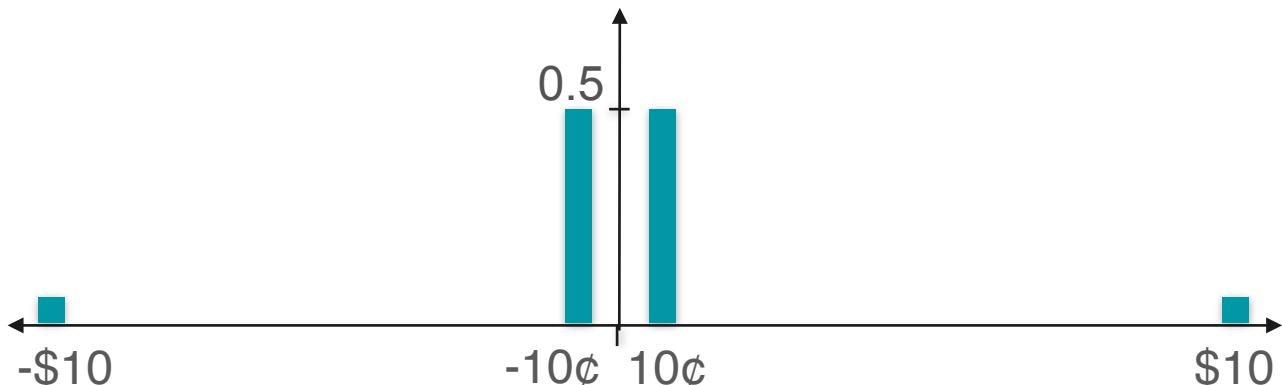
$$Skew(X_1) = 0$$

# Kurtosis

Game 1



Game 2



$$Skew(X_1) = 0$$

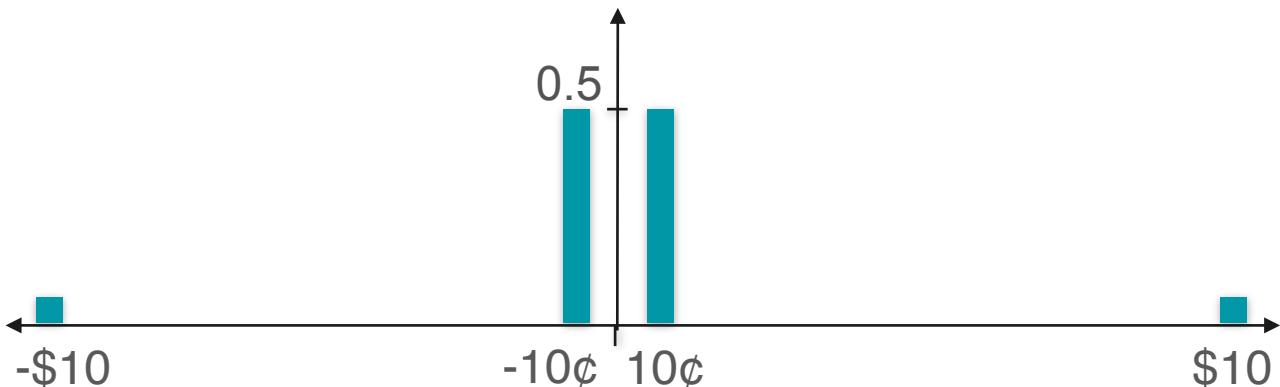
$$Skew(X_2) = 0$$

# Kurtosis

Game 1



Game 2



$$Var(X_1) = 1$$

$$Skew(X_1) = 0$$

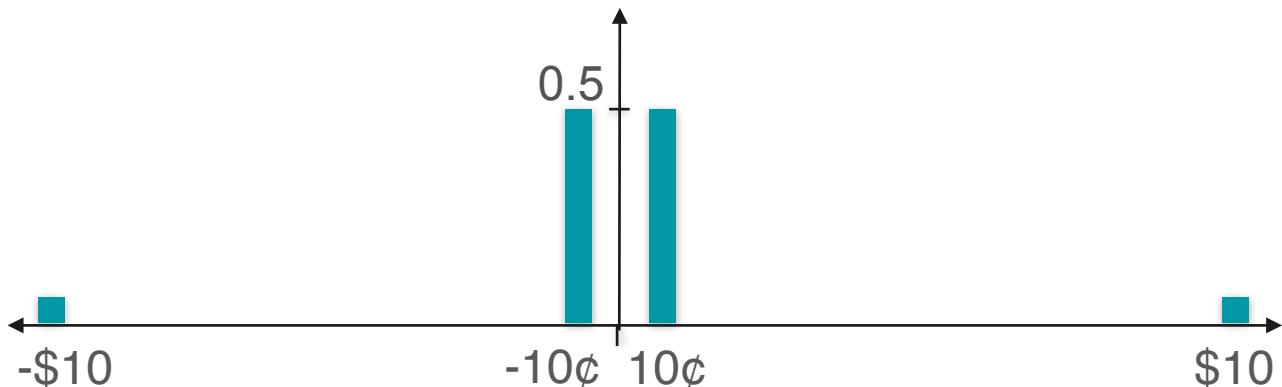
$$Skew(X_2) = 0$$

# Kurtosis

Game 1



Game 2



$$Var(X_1) = 1$$

$$Skew(X_1) = 0$$

$$Var(X_2) = 1$$

$$Skew(X_2) = 0$$

# Kurtosis

Game 1

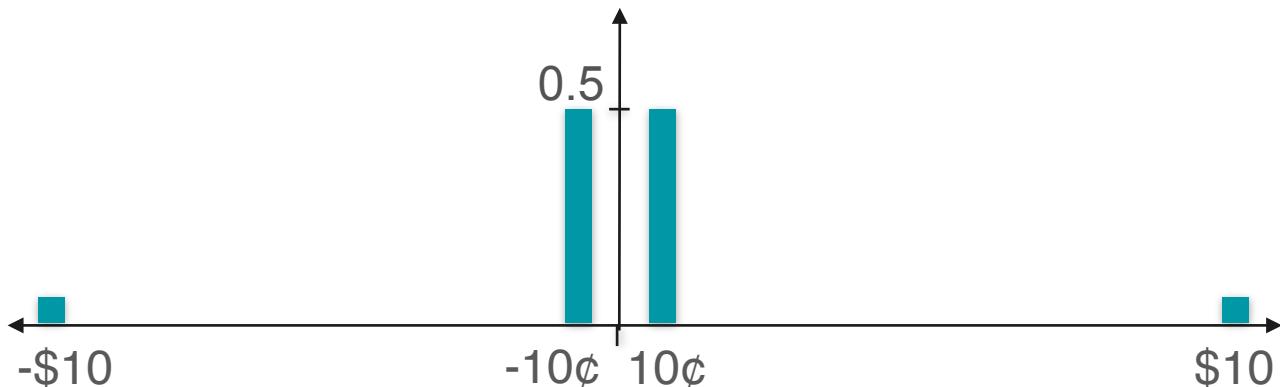


$$E[X_1] = 0$$

$$Var(X_1) = 1$$

$$Skew(X_1) = 0$$

Game 2



$$Var(X_2) = 1$$

$$Skew(X_2) = 0$$

# Kurtosis

Game 1

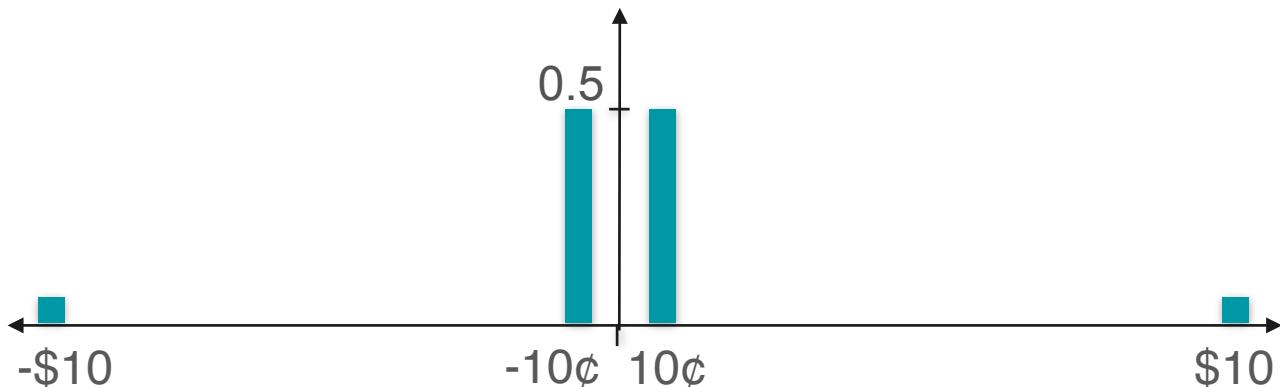


$$E[X_1] = 0$$

$$Var(X_1) = 1$$

$$Skew(X_1) = 0$$

Game 2



$$E[X_2] = 0$$

$$Var(X_2) = 1$$

$$Skew(X_2) = 0$$

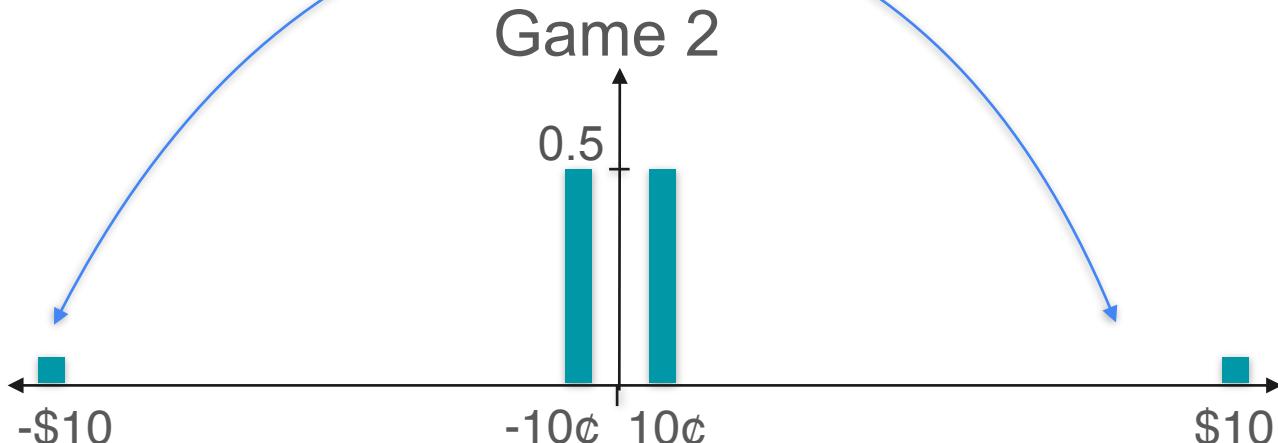
# Kurtosis



$$E[X_1] = 0$$

$$Var(X_1) = 1$$

$$Skew(X_1) = 0$$



$$E[X_2] = 0$$

$$Var(X_2) = 1$$

$$Skew(X_2) = 0$$

Has values way  
farther from 0

# Kurtosis

Game 1



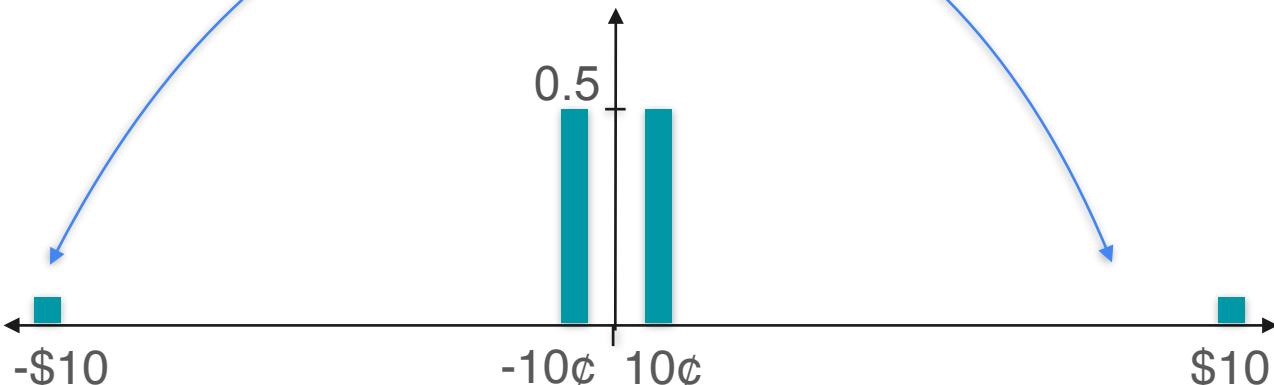
$$E[X_1] = 0$$

$$E[X_1] = 0$$

$$Var(X_1) = 1$$

$$Skew(X_1) = 0$$

Game 2



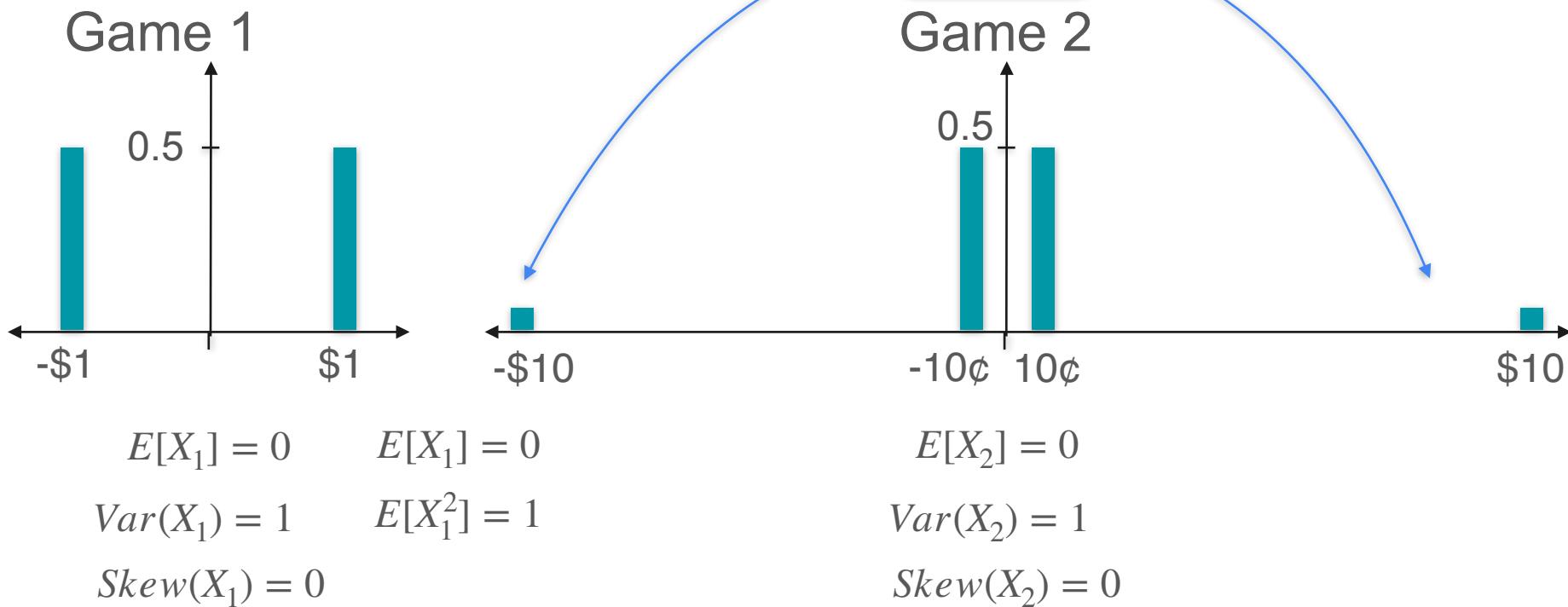
$$E[X_2] = 0$$

$$Var(X_2) = 1$$

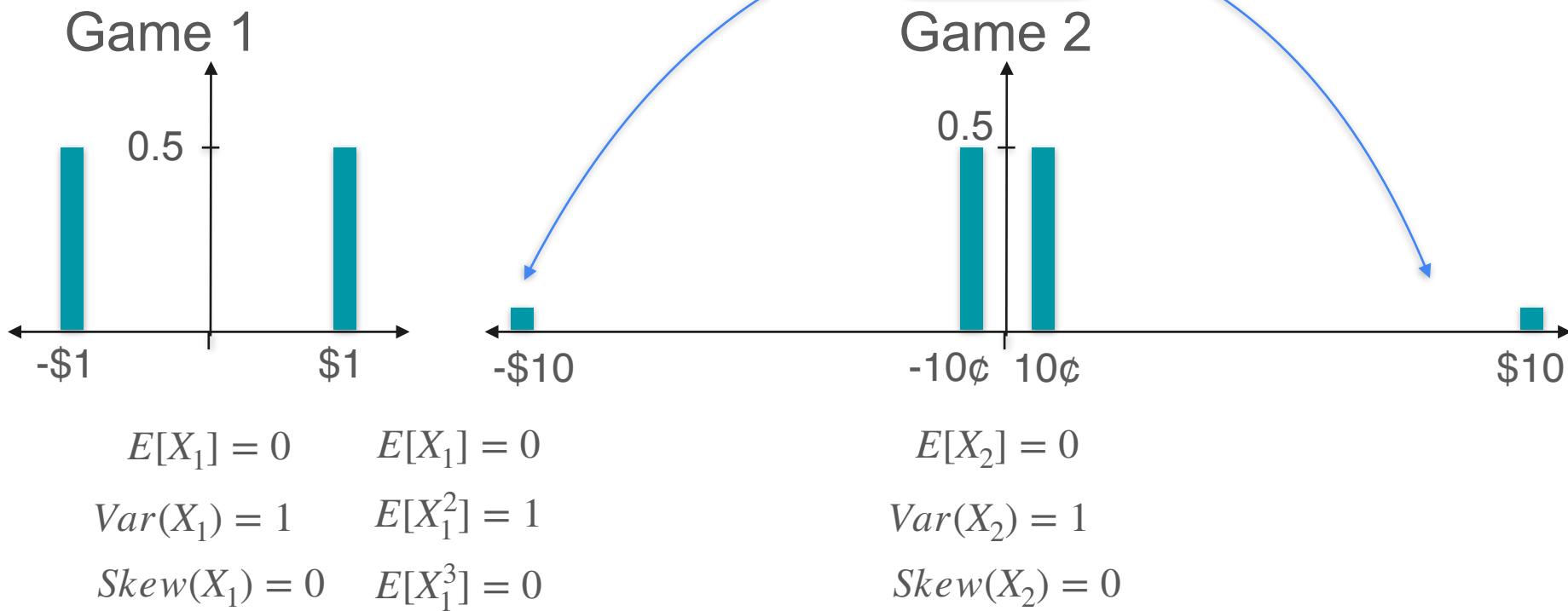
$$Skew(X_2) = 0$$

Has values way  
farther from 0

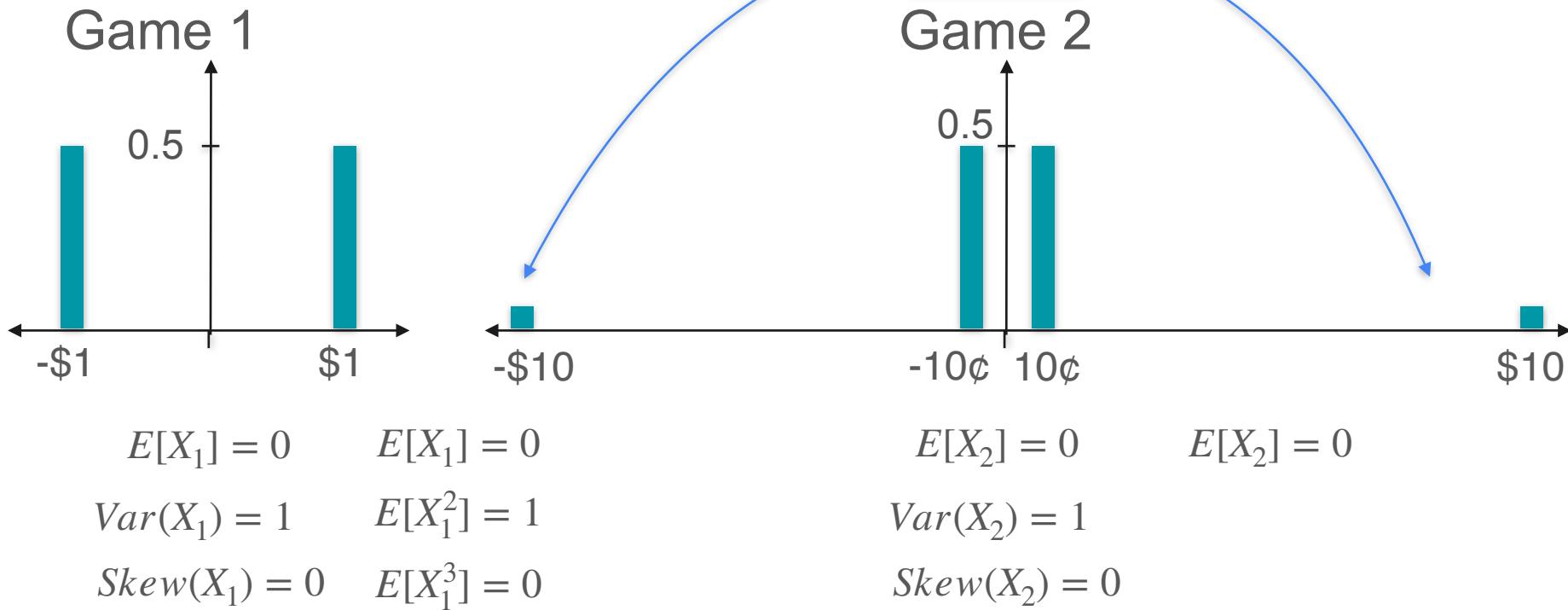
# Kurtosis



# Kurtosis



# Kurtosis



# Kurtosis

Game 1



$$E[X_1] = 0$$

$$E[X_1] = 0$$

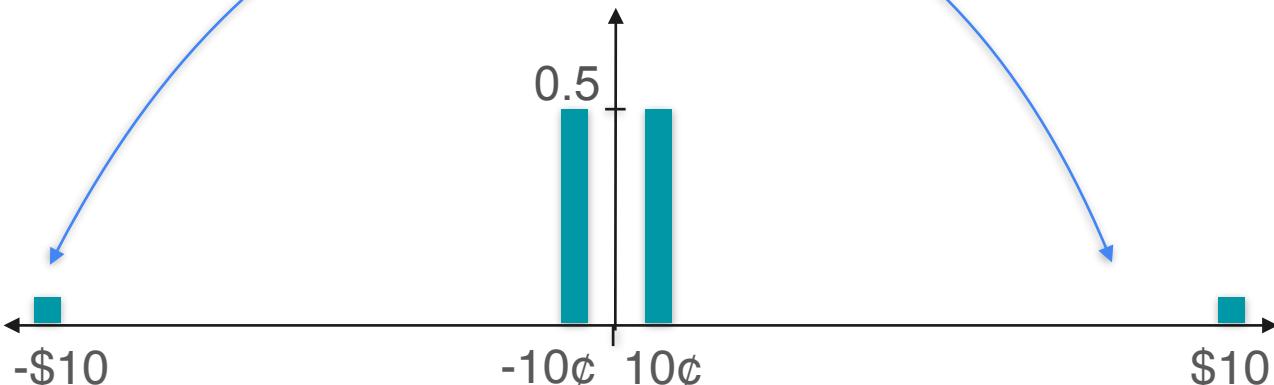
$$Var(X_1) = 1$$

$$E[X_1^2] = 1$$

$$Skew(X_1) = 0$$

$$E[X_1^3] = 0$$

Game 2



$$E[X_2] = 0$$

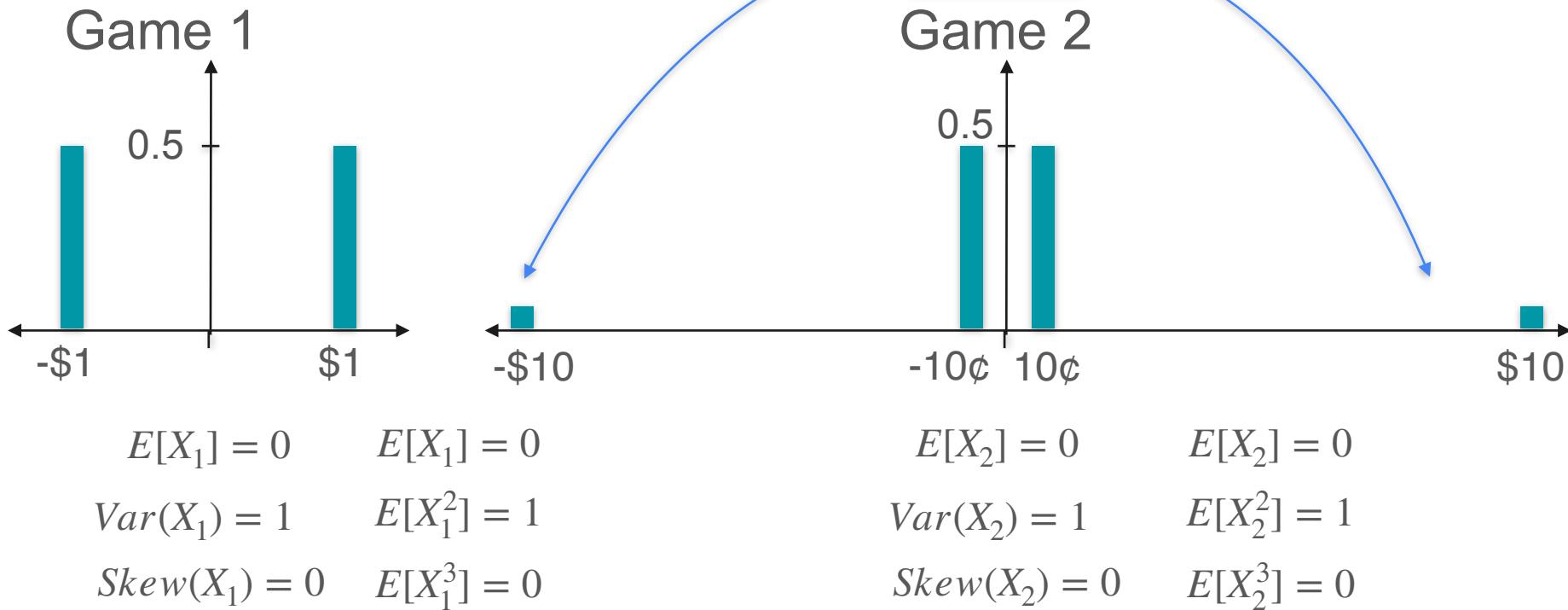
$$E[X_2] = 0$$

$$Var(X_2) = 1$$

$$E[X_2^2] = 1$$

$$Skew(X_2) = 0$$

# Kurtosis



# Kurtosis

Game 1



$$E[X_1] = 0$$

$$E[X_1] = 0$$

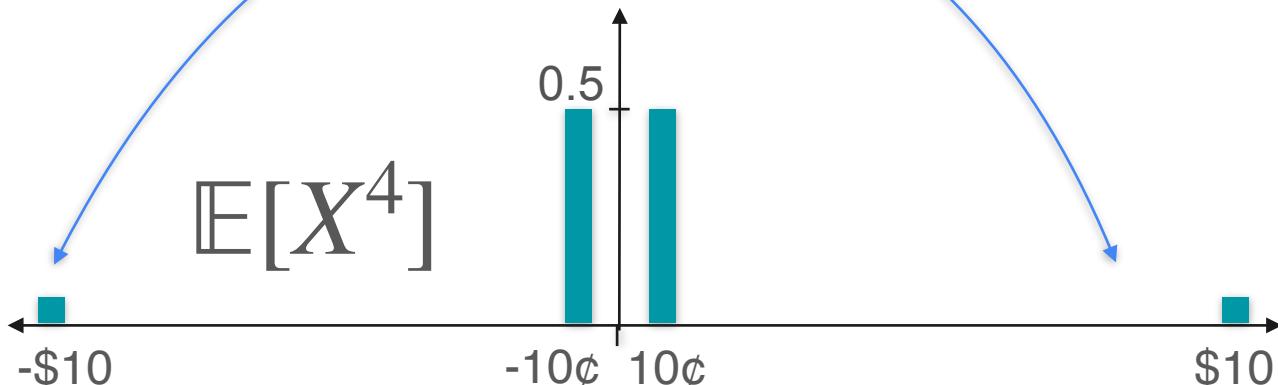
$$Var(X_1) = 1$$

$$E[X_1^2] = 1$$

$$Skew(X_1) = 0$$

$$E[X_1^3] = 0$$

Game 2



$$E[X_2] = 0$$

$$E[X_2] = 0$$

$$Var(X_2) = 1$$

$$E[X_2^2] = 1$$

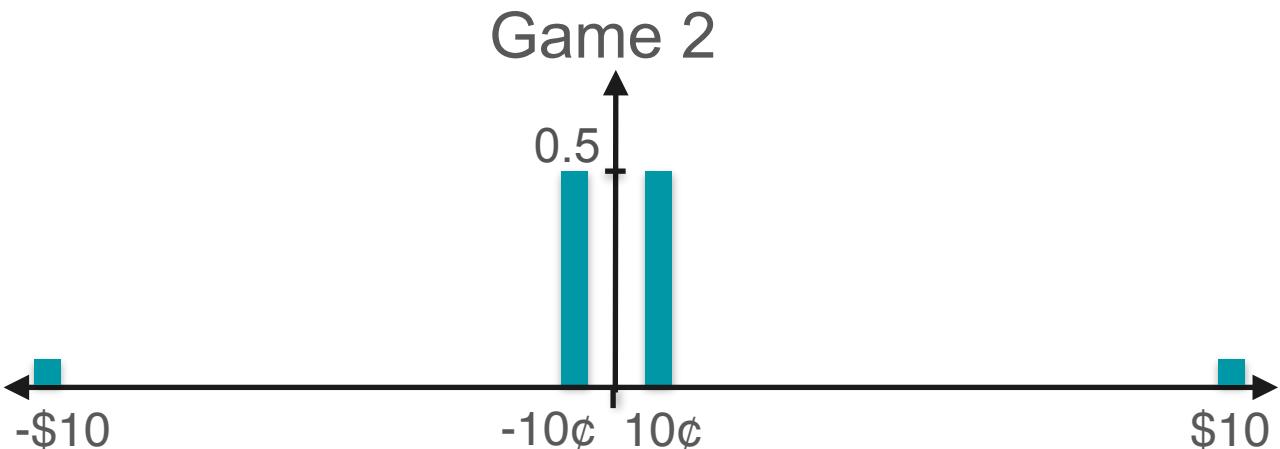
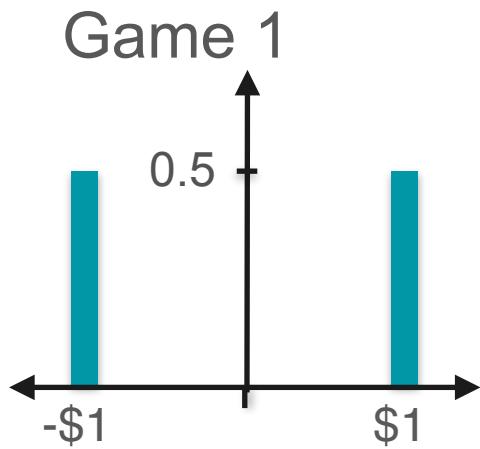
$$Skew(X_2) = 0$$

$$E[X_2^3] = 0$$

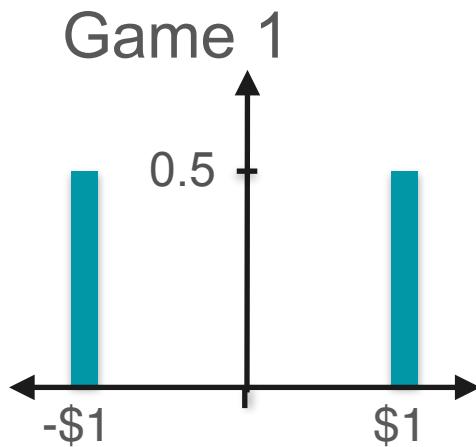
Has values way  
farther from 0

$$\mathbb{E}[X^4]$$

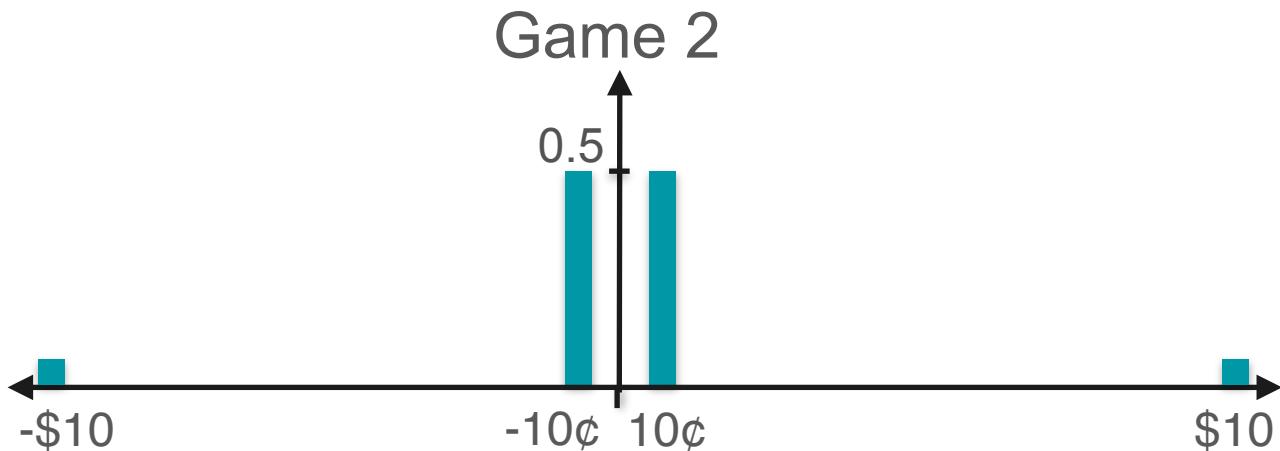
# Kurtosis



# Kurtosis



$$\mathbb{E}[X_1^4]$$



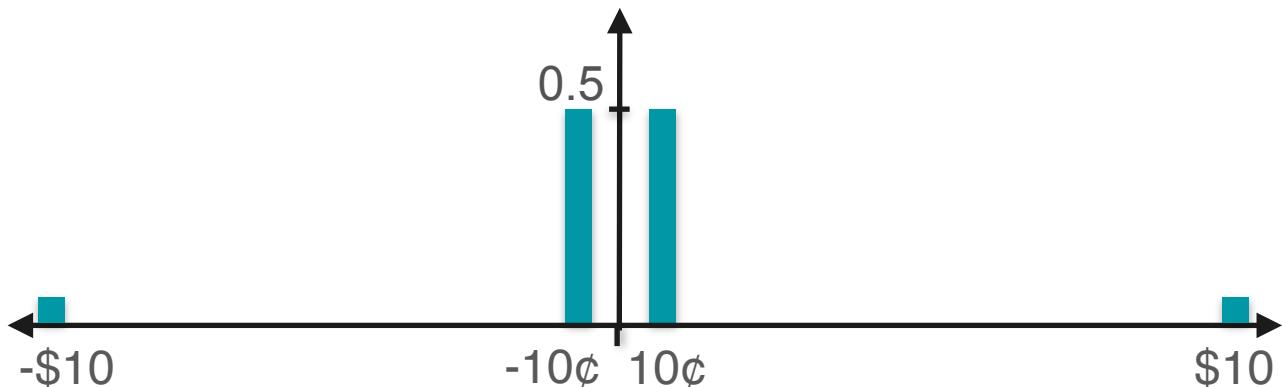
# Kurtosis

Game 1



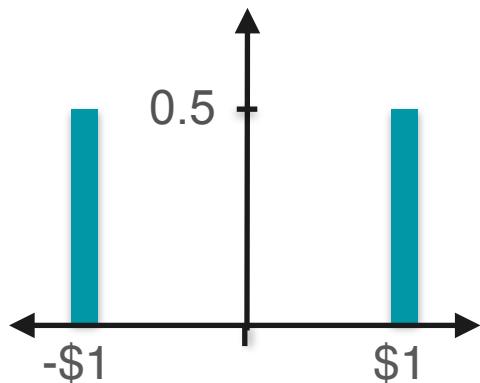
$$\mathbb{E}[X_1^4] = \frac{1}{2}(-1)^4 + \frac{1}{2}(1)^4$$

Game 2



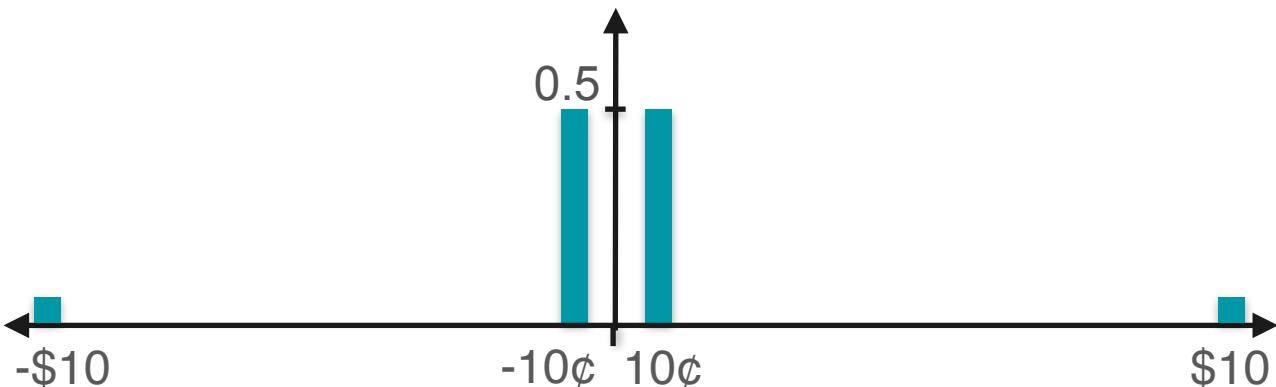
# Kurtosis

Game 1



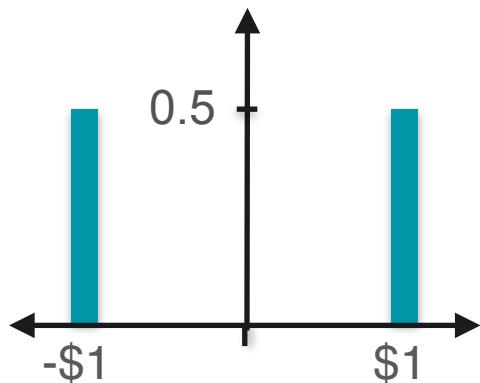
$$\begin{aligned}\mathbb{E}[X_1^4] &= \frac{1}{2}(-1)^4 + \frac{1}{2}(1)^4 \\ &= 1\end{aligned}$$

Game 2



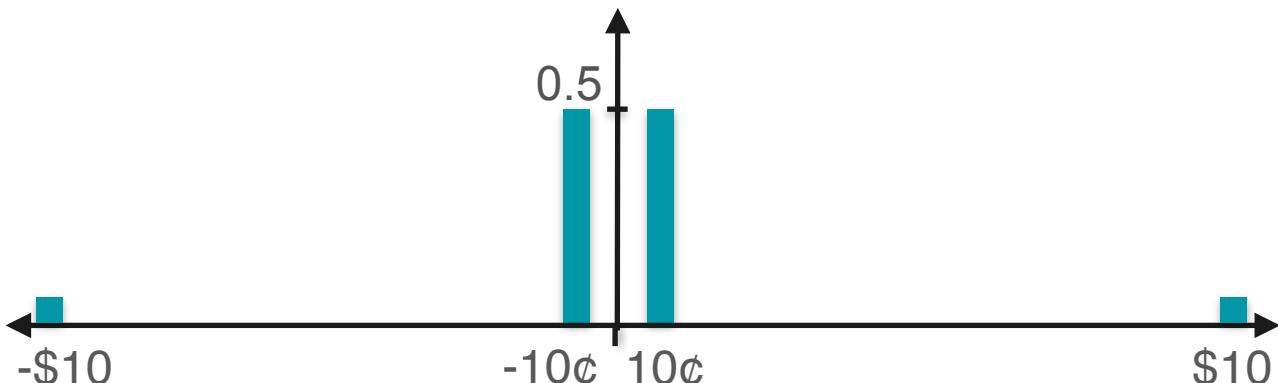
# Kurtosis

Game 1



$$\begin{aligned}\mathbb{E}[X_1^4] &= \frac{1}{2}(-1)^4 + \frac{1}{2}(1)^4 \\ &= 1\end{aligned}$$

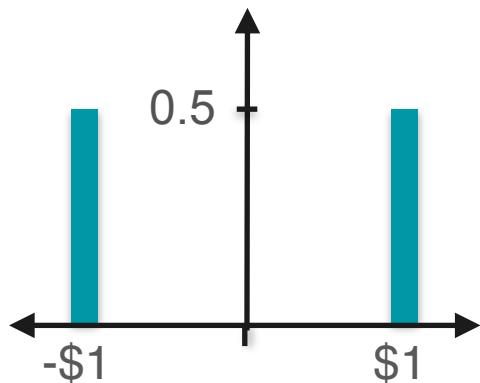
Game 2



$$\mathbb{E}[X_2^4]$$

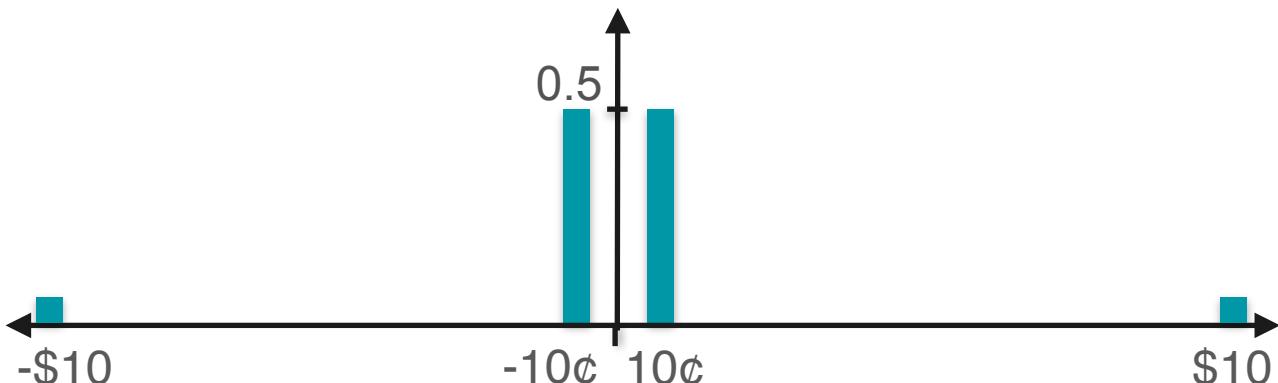
# Kurtosis

Game 1



$$\begin{aligned}\mathbb{E}[X_1^4] &= \frac{1}{2}(-1)^4 + \frac{1}{2}(1)^4 \\ &= 1\end{aligned}$$

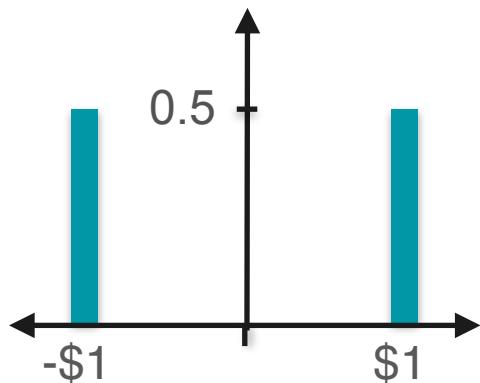
Game 2



$$\mathbb{E}[X_2^4] = \frac{100}{202}(-0.1)^4 + \frac{100}{202}(0.1)^4 + \frac{1}{202}(-10)^4 + \frac{1}{202}(10)^4$$

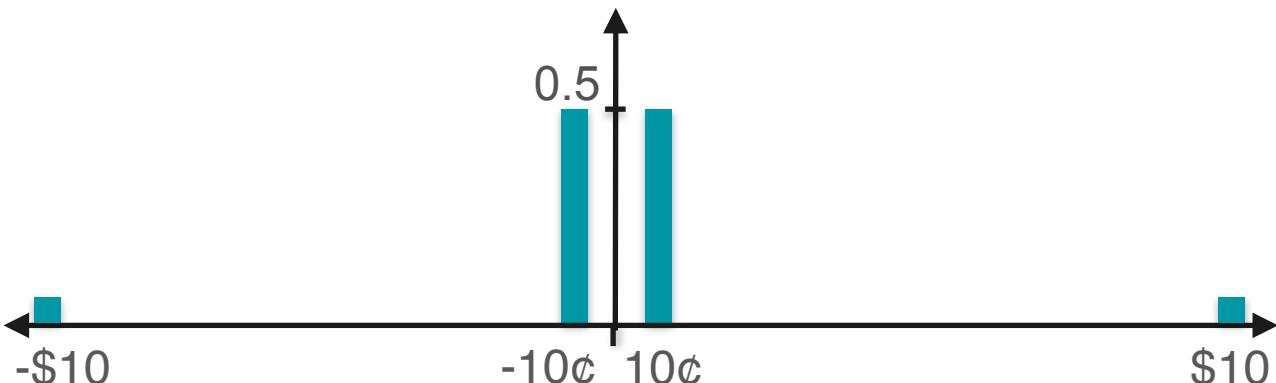
# Kurtosis

Game 1



$$\begin{aligned}\mathbb{E}[X_1^4] &= \frac{1}{2}(-1)^4 + \frac{1}{2}(1)^4 \\ &= 1\end{aligned}$$

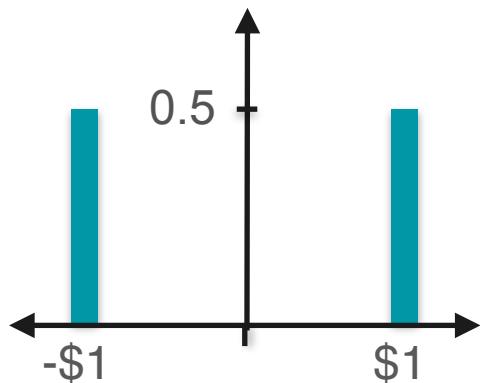
Game 2



$$\begin{aligned}\mathbb{E}[X_2^4] &= \frac{100}{202}(-0.1)^4 + \frac{100}{202}(0.1)^4 + \frac{1}{202}(-10)^4 + \frac{1}{202}(10)^4 \\ &= 99.01\end{aligned}$$

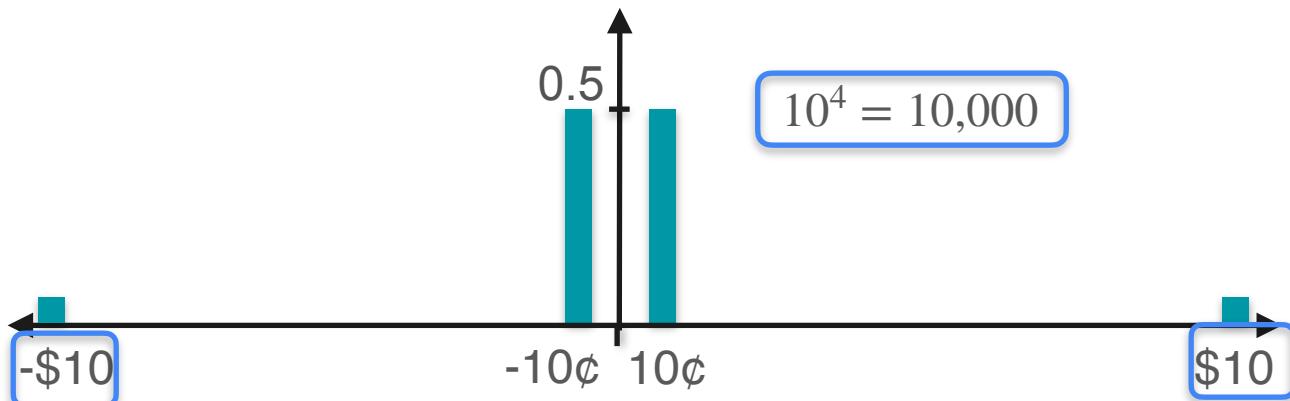
# Kurtosis

Game 1



$$\begin{aligned}\mathbb{E}[X_1^4] &= \frac{1}{2}(-1)^4 + \frac{1}{2}(1)^4 \\ &= 1\end{aligned}$$

Game 2



$$\begin{aligned}\mathbb{E}[X_2^4] &= \frac{100}{202}(-0.1)^4 + \frac{100}{202}(0.1)^4 + \frac{1}{202}(-10)^4 + \frac{1}{202}(10)^4 \\ &= 99.01\end{aligned}$$

# Kurtosis

$$\mathbb{E}[X^4]$$

# Kurtosis

$$\mathbb{E}[X^4]$$

Almost...

# Kurtosis

$$\mathbb{E}[X^4]$$

Almost...

Need to standardize...

# Kurtosis

# Kurtosis

$$\text{Kurtosis} = E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right]$$

# Kurtosis: High and Low

# Kurtosis: High and Low



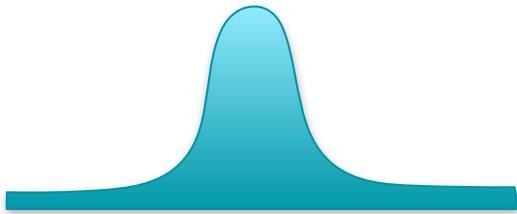
$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{small}$$

$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{large}$$

# Kurtosis: High and Low



$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{small}$$

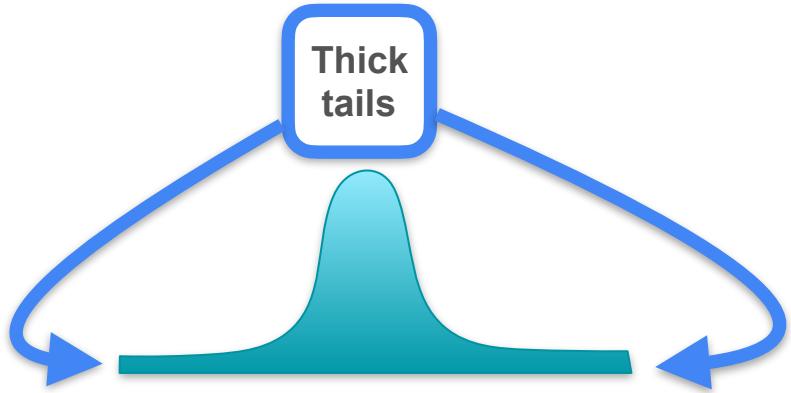


$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{large}$$

# Kurtosis: High and Low

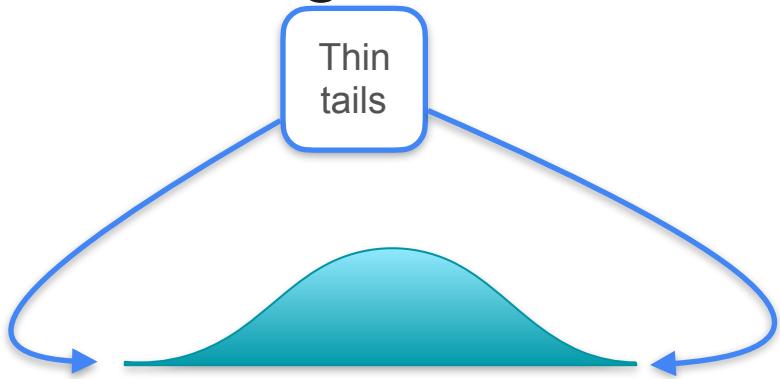


$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{small}$$

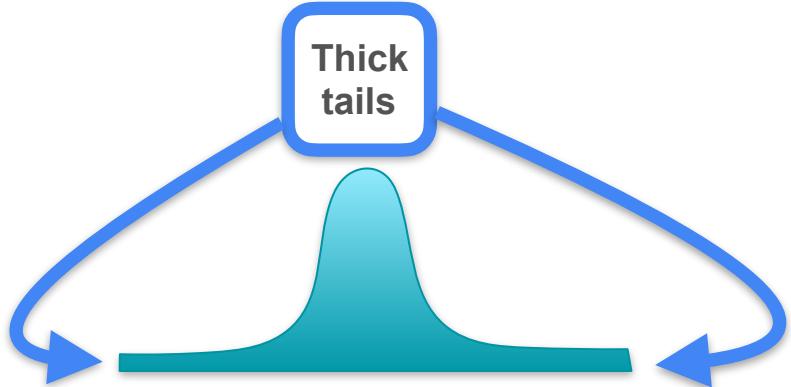


$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{large}$$

# Kurtosis: High and Low

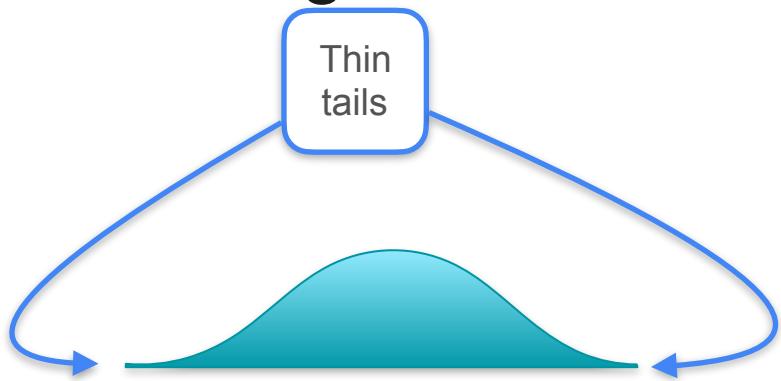


$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{small}$$

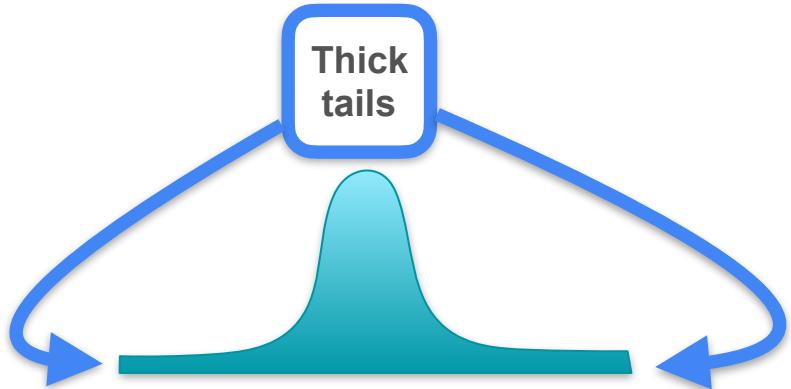


$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{large}$$

# Kurtosis: High and Low



$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{small}$$



$$E \left[ \left( \frac{X - \mu}{\sigma} \right)^4 \right] = \text{large}$$

Even if they have the same variance!



DeepLearning.AI

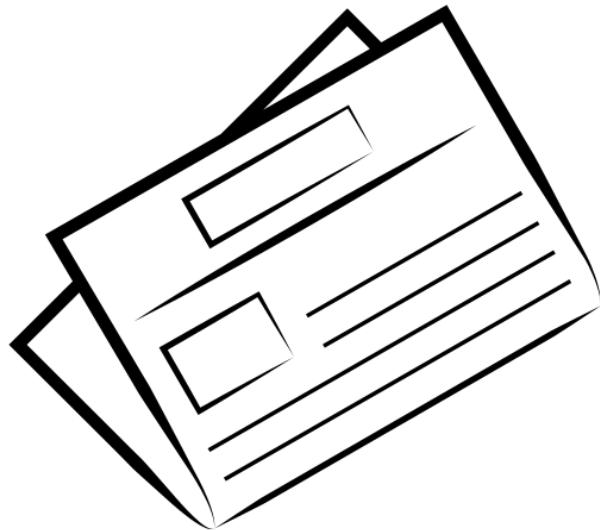
# Describing Distributions

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## Quantiles and box-plots

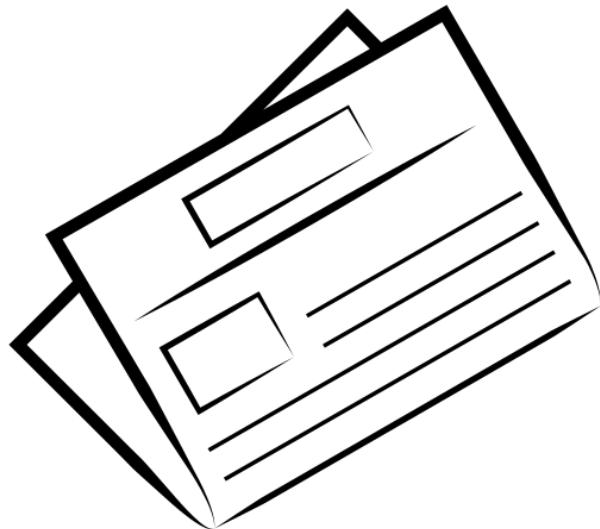
# Quantiles: Example

# Quantiles: Example



Newspaper advertisement

# Quantiles: Example



Newspaper advertisement

Newspaper Advertisement (X)			
18.3	18.4	23.2	51.2
35.2	29.7	75	8.7
65.9	14.2	54.7	25.9

# Quantiles: Example

Newspaper Advertisement (X)			
18.3	18.4	23.2	51.2
35.2	29.7	75	8.7
65.9	14.2	54.7	25.9

# Quantiles: Example

What is the median here?

Newspaper Advertisement (X)			
18.3	18.4	23.2	51.2
35.2	29.7	75	8.7
65.9	14.2	54.7	25.9

# Quantiles: Example

What is the median here?

The point that splits your data in half

Newspaper Advertisement (X)			
18.3	18.4	23.2	51.2
35.2	29.7	75	8.7
65.9	14.2	54.7	25.9

# Quantiles: Example

What is the median here?

The point that splits your data in half

Newspaper Advertisement (X)			
8.7	14.2	18.3	18.4
23.2	25.9	29.7	35.2
51.2	54.7	65.9	75

# Quantiles: Example

What is the median here?

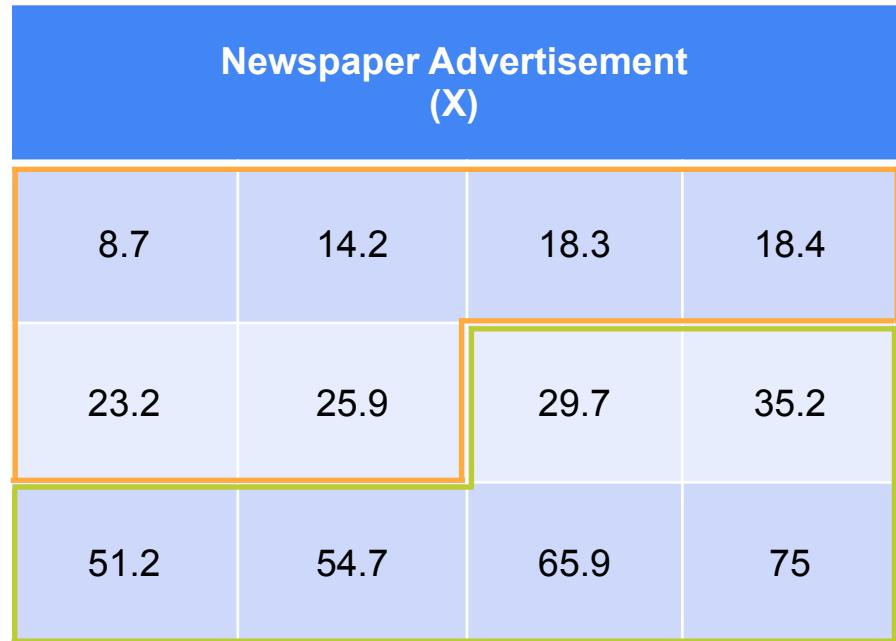
The point that splits your data in half

Newspaper Advertisement (X)			
8.7	14.2	18.3	18.4
23.2	25.9	29.7	35.2
51.2	54.7	65.9	75

# Quantiles: Example

What is the median here?

The point that splits your data in half



# Quantiles: Example

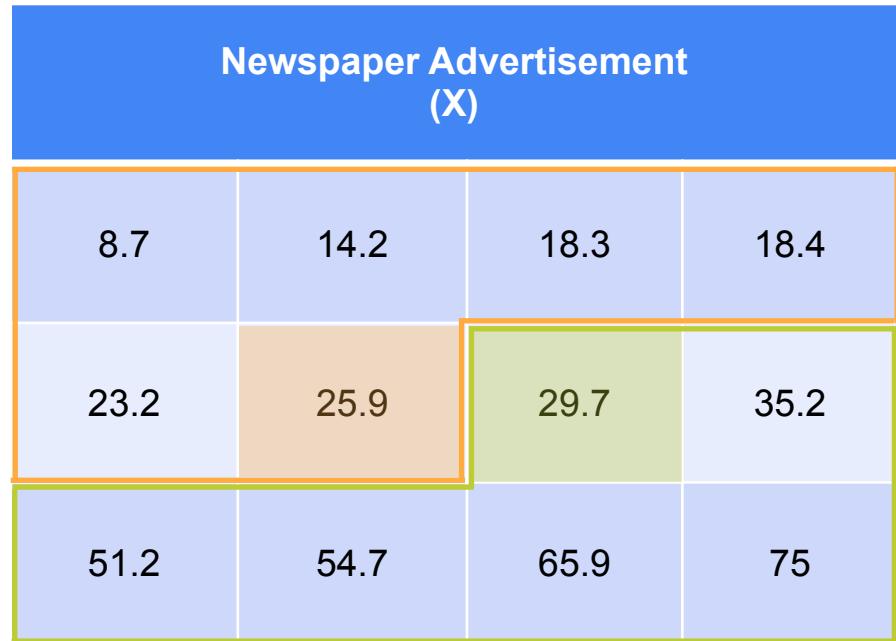
What is the median here?

The point that splits your data in half

$$\text{Median} = \frac{25.9 + 29.7}{2} = 27.8$$

50% quantile

Second quartile

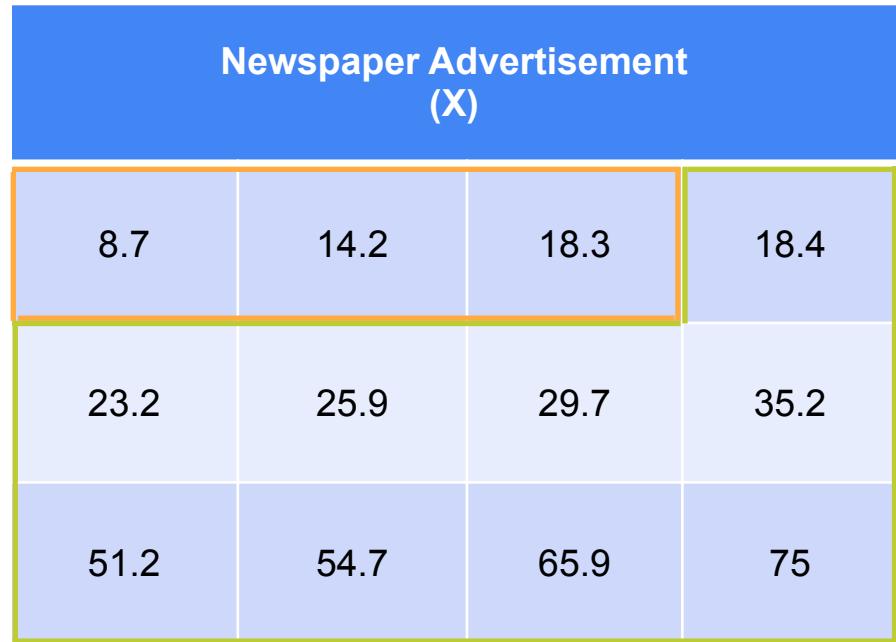


# Quantiles: Example

Newspaper Advertisement (X)			
8.7	14.2	18.3	18.4
23.2	25.9	29.7	35.2
51.2	54.7	65.9	75

# Quantiles: Example

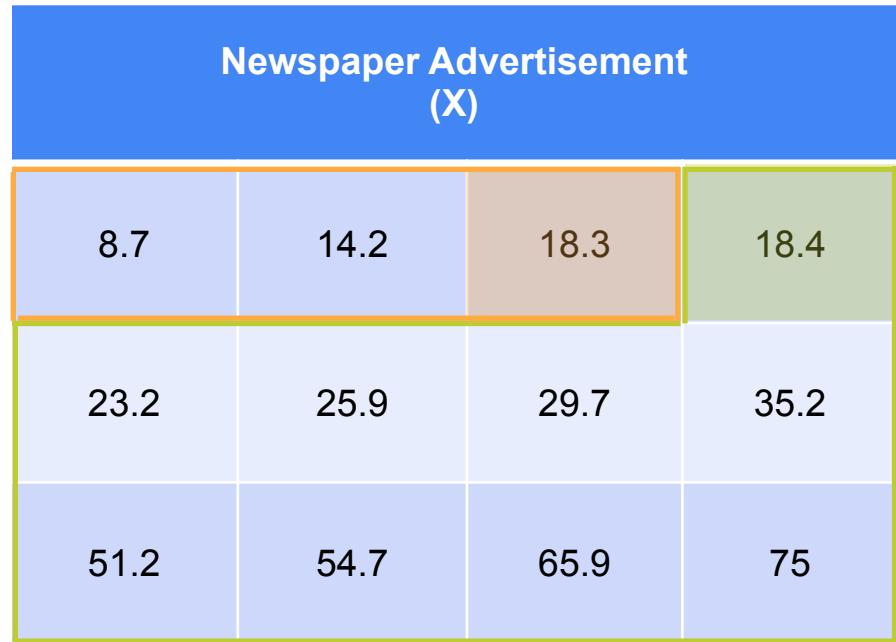
What about the point that leaves 1/4 of your data to the left and 3/4 to the right?



# Quantiles: Example

What about the point that leaves 1/4 of your data to the left and 3/4 to the right?

$$\frac{18.3 + 18.4}{2} = 18.35$$



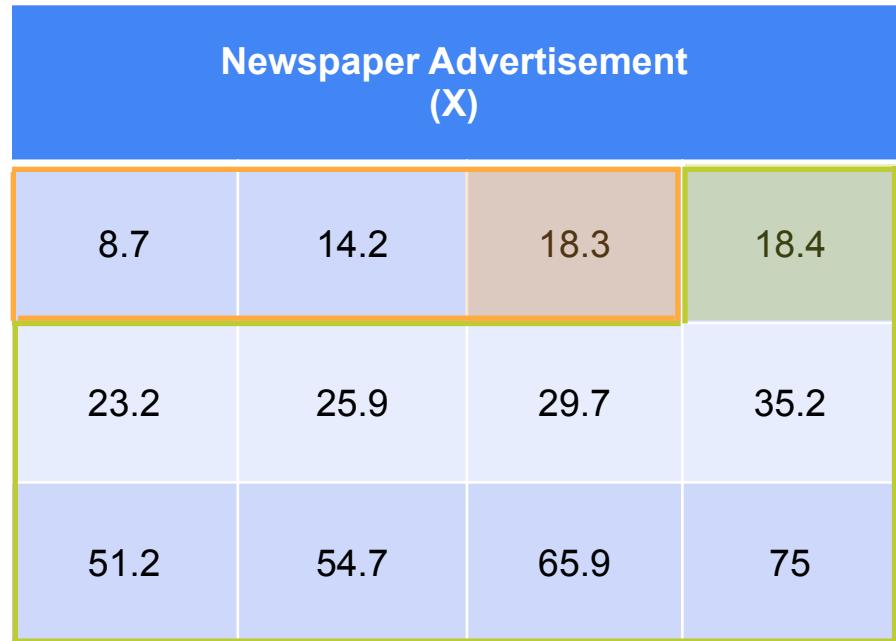
# Quantiles: Example

What about the point that leaves 1/4 of your data to the left and 3/4 to the right?

$$\frac{18.3 + 18.4}{2} = 18.35$$

25% quantile

First quartile



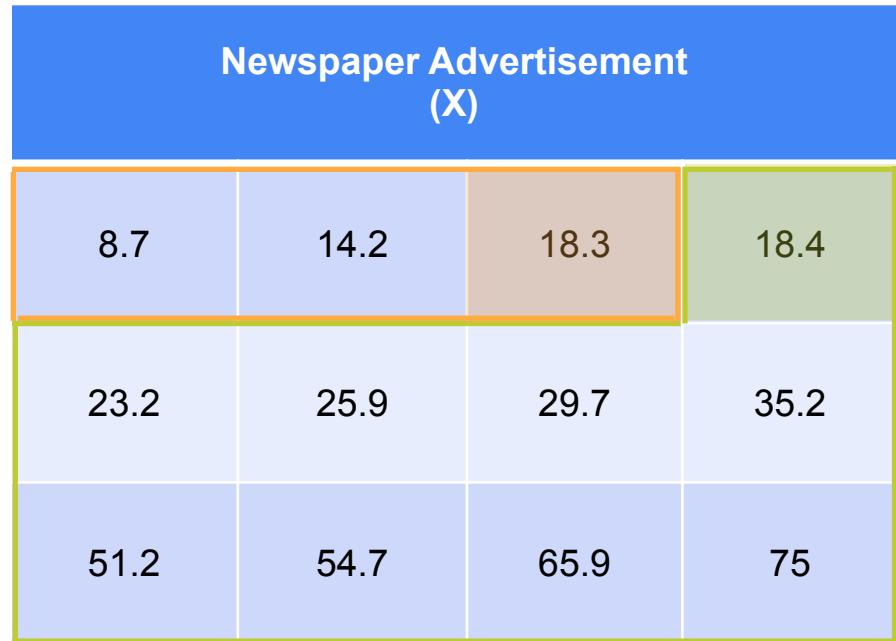
# Quantiles: Example

What about the point that leaves 1/4 of your data to the left and 3/4 to the right?

$$q_{0.25} = Q1 = \frac{18.3 + 18.4}{2} = 18.35$$

25% quantile

First quartile



# Quantiles

# Quantiles

In general:

The **k%** quantile ( $q_{k/100}$ ) is the value that leaves k% of your data to the left and (100-k)% of your data to the right

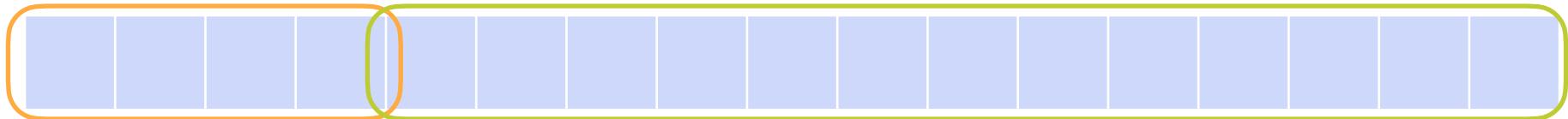
# Quantiles

In general:

The **k%** quantile ( $q_{k/100}$ ) is the value that leaves k% of your data to the left and  $(100 - k)\%$  of your data to the right

$k\%$

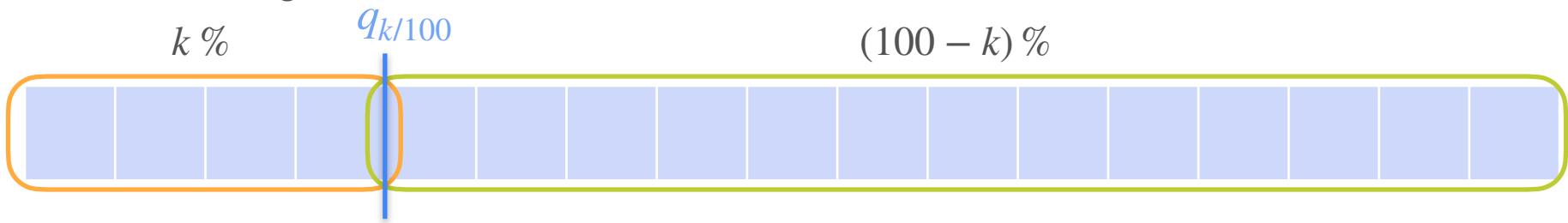
$(100 - k)\%$



# Quantiles

In general:

The **k%** quantile ( $q_{k/100}$ ) is the value that leaves k% of your data to the left and  $(100 - k)\%$  of your data to the right



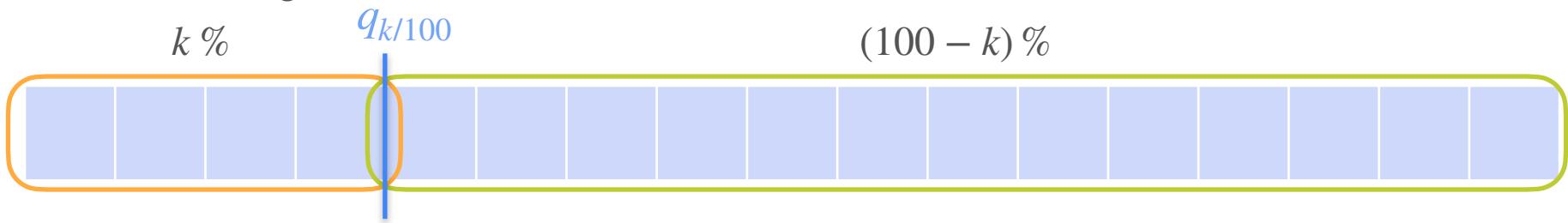
# Quantiles

In general:

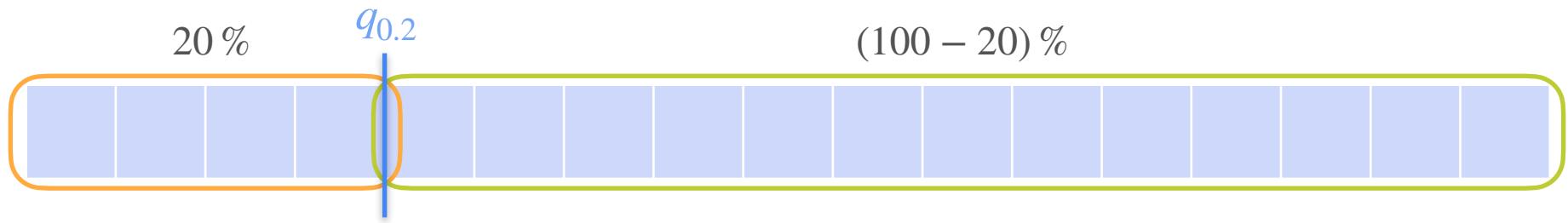
The **k%** quantile ( $q_{k/100}$ ) is the value that leaves k% of your data to the left and  $(100-k)\%$  of your data to the right

Some common quantiles:

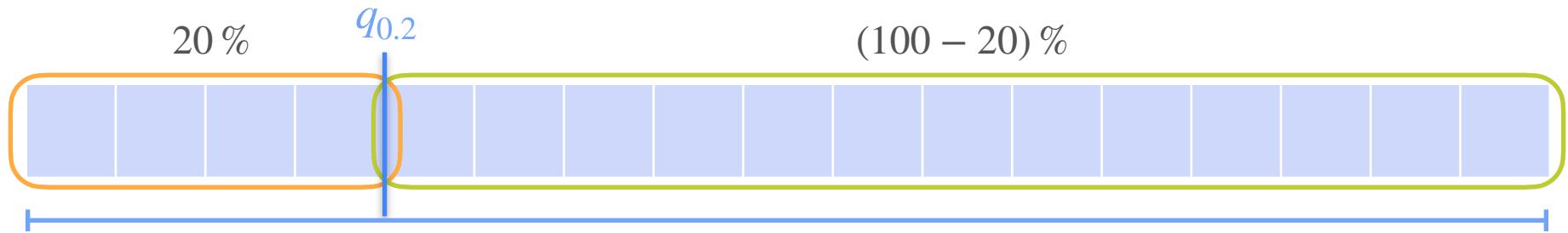
- 25% quantile (first quartile - Q1)
- 50% quantile (median - Q2)
- 75% quantile (third quartile - Q3)



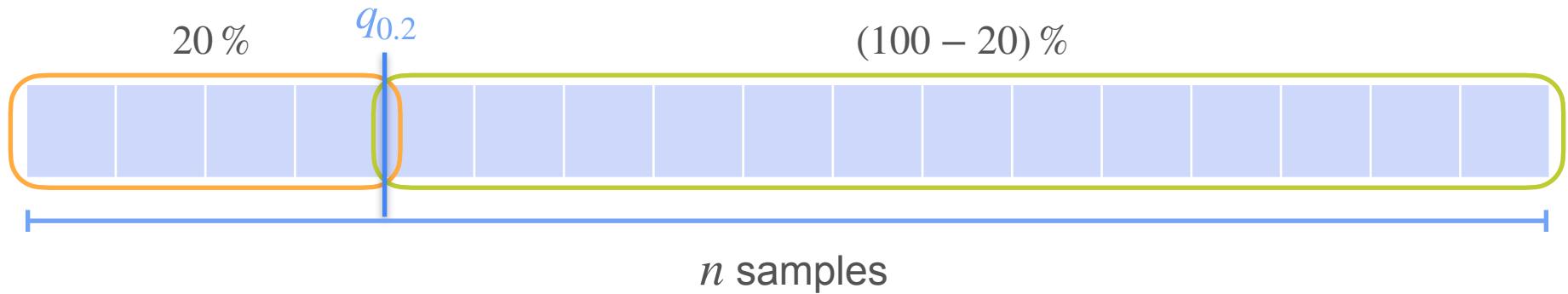
# Quantiles



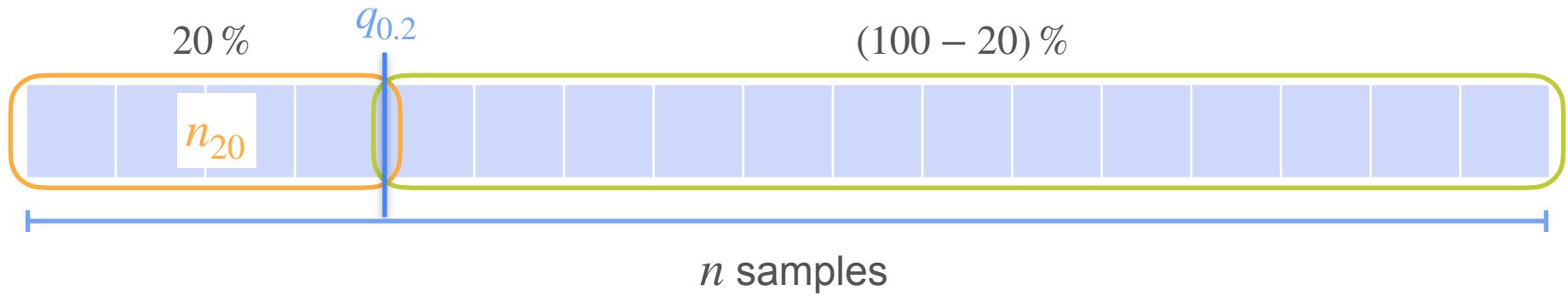
# Quantiles



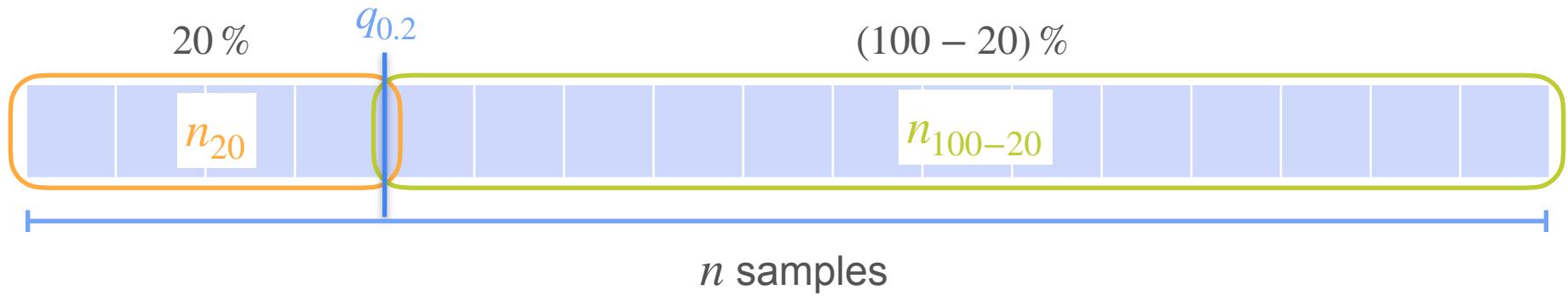
# Quantiles



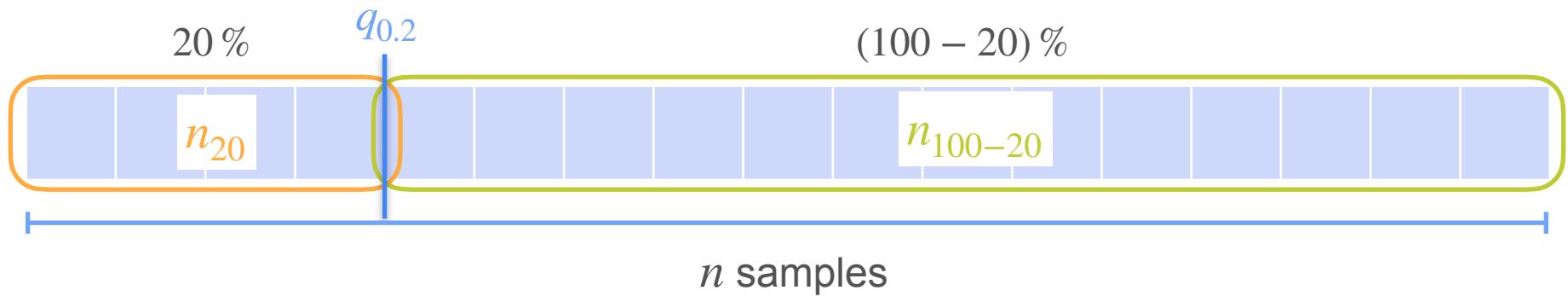
# Quantiles



# Quantiles

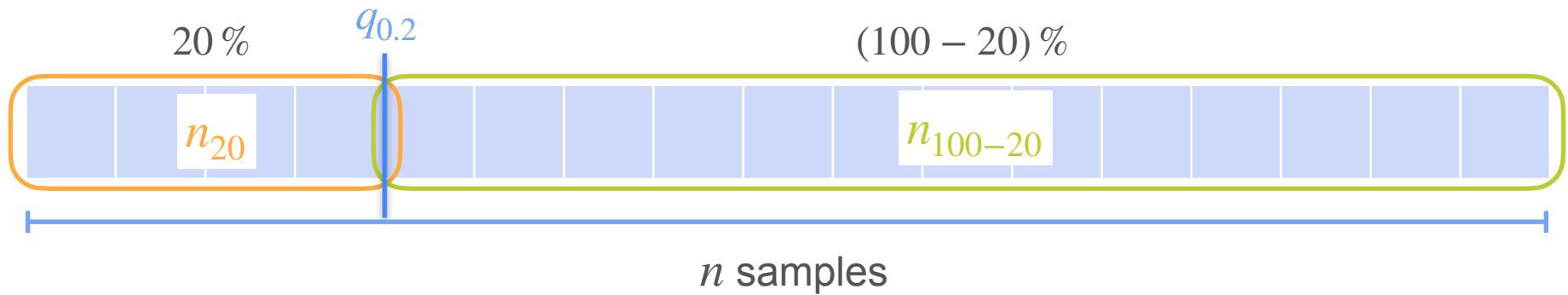


# Quantiles



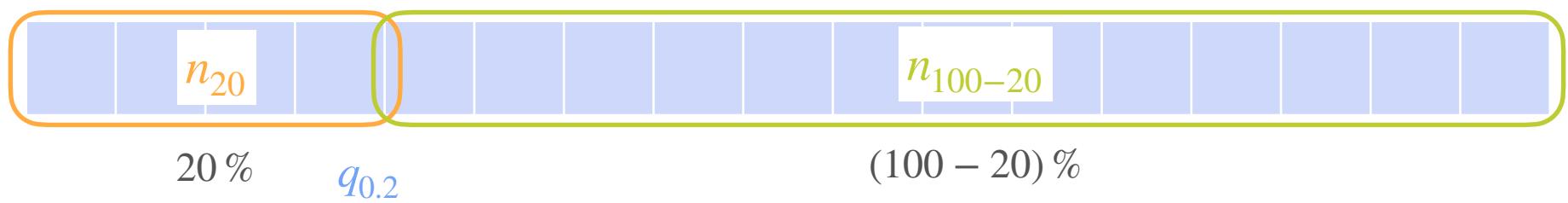
$$\frac{20}{100} = \frac{n_{20}}{n}$$

# Quantiles

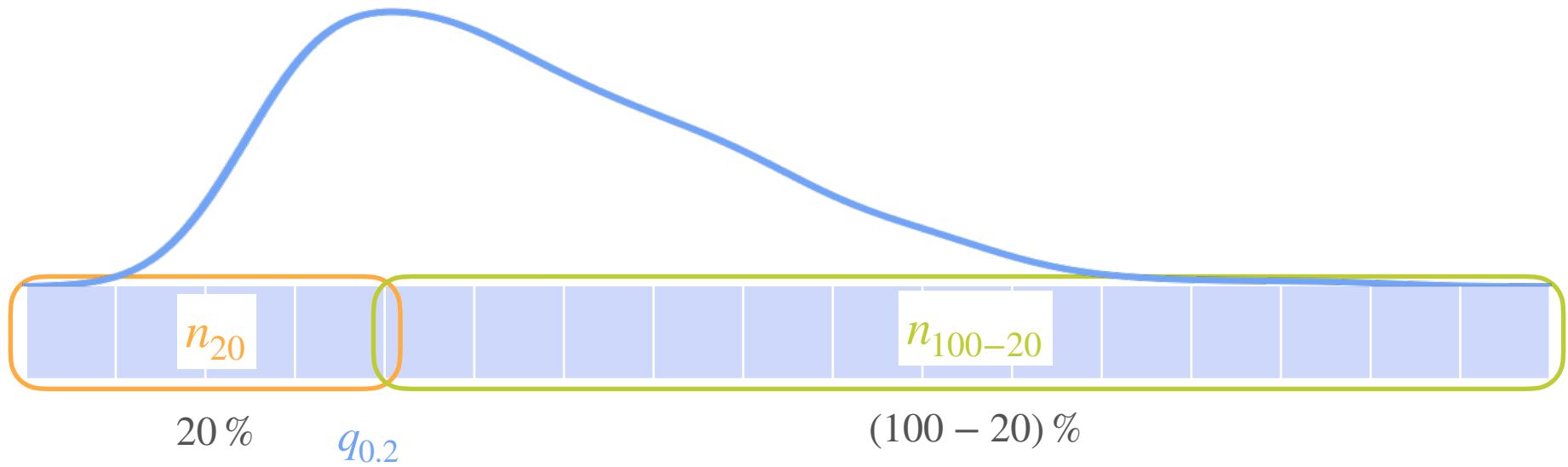


$$\frac{20}{100} = \frac{n_{20}}{n} \approx \mathbf{P}(X \leq q_{0.2})$$

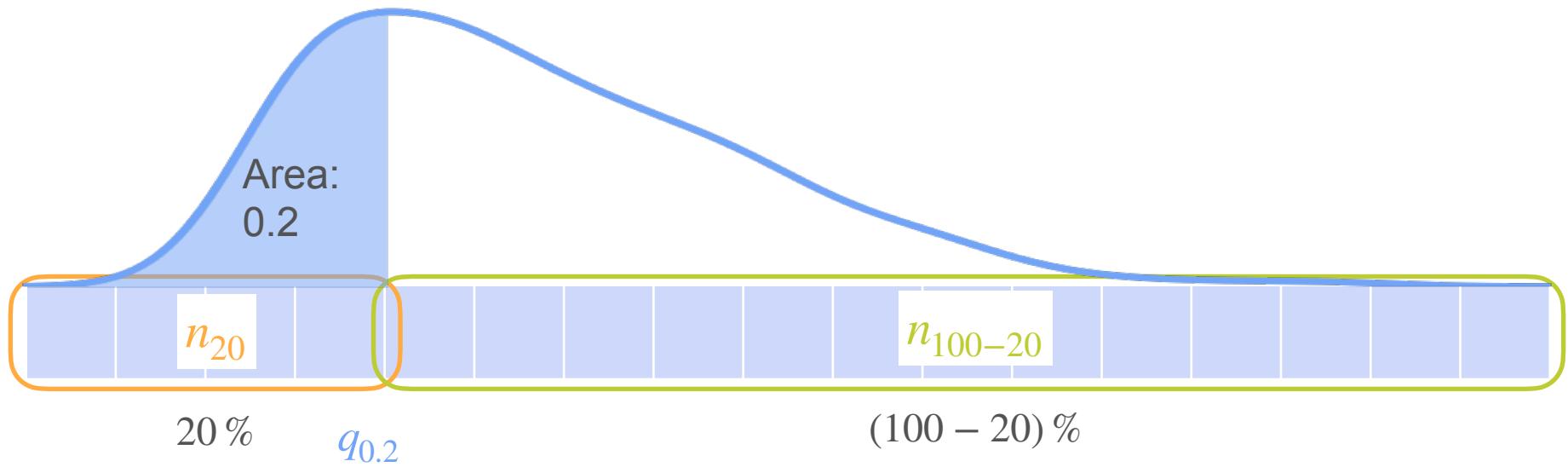
# Quantiles



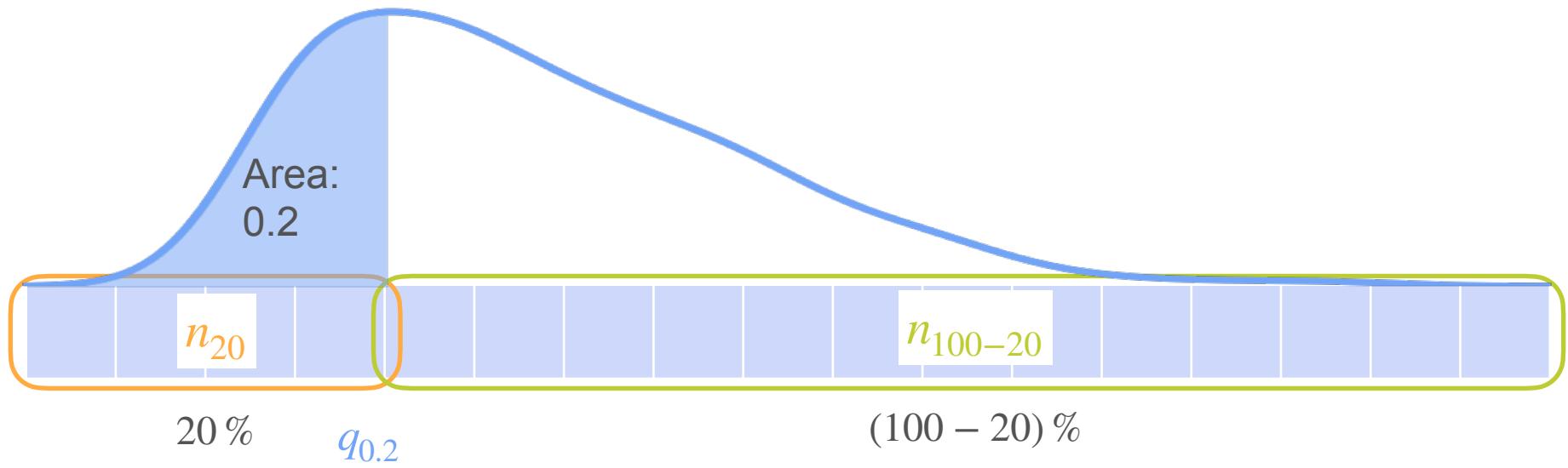
# Quantiles



# Quantiles



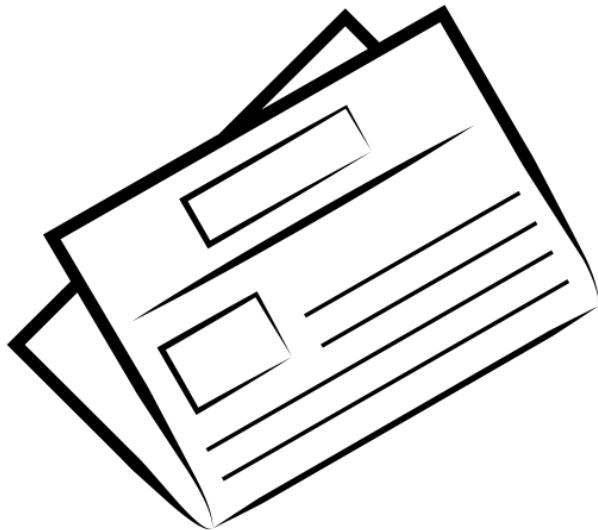
# Quantiles



**k% quantile** ( $q_{k/100}$ ) is the value such that  $\mathbf{P}(X \leq q_{k/100}) = \frac{k}{100}$

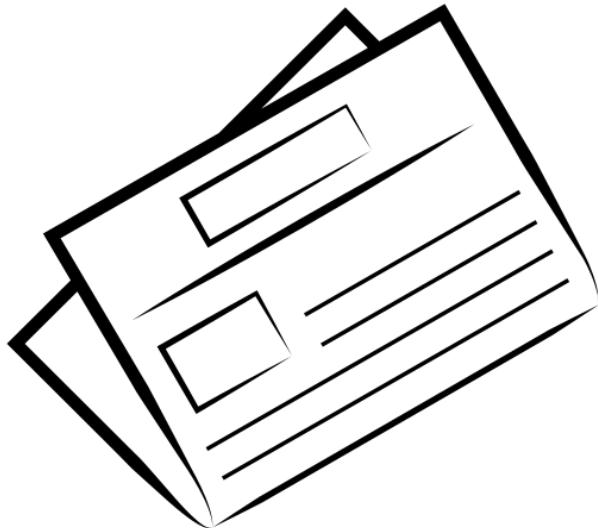
# Box-Plots

# Box-Plots



Newspaper advertisement

# Box-Plots



Newspaper advertisement

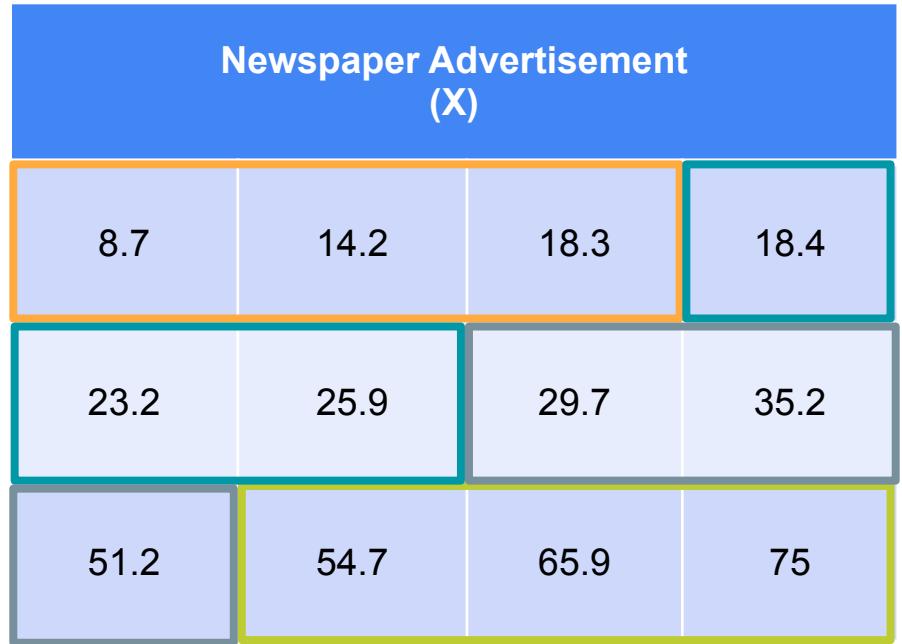
Newspaper Advertisement (X)			
8.7	14.2	18.3	18.4
23.2	25.9	29.7	35.2
51.2	54.7	65.9	75

# Box-Plots

Newspaper Advertisement  
(X)

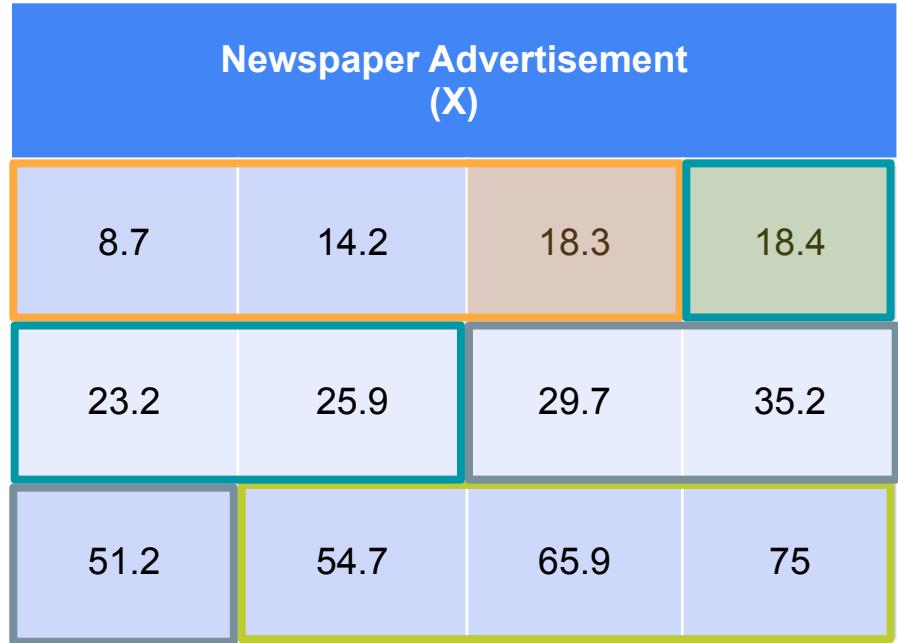
8.7	14.2	18.3	18.4
23.2	25.9	29.7	35.2
51.2	54.7	65.9	75

# Box-Plots



# Box-Plots

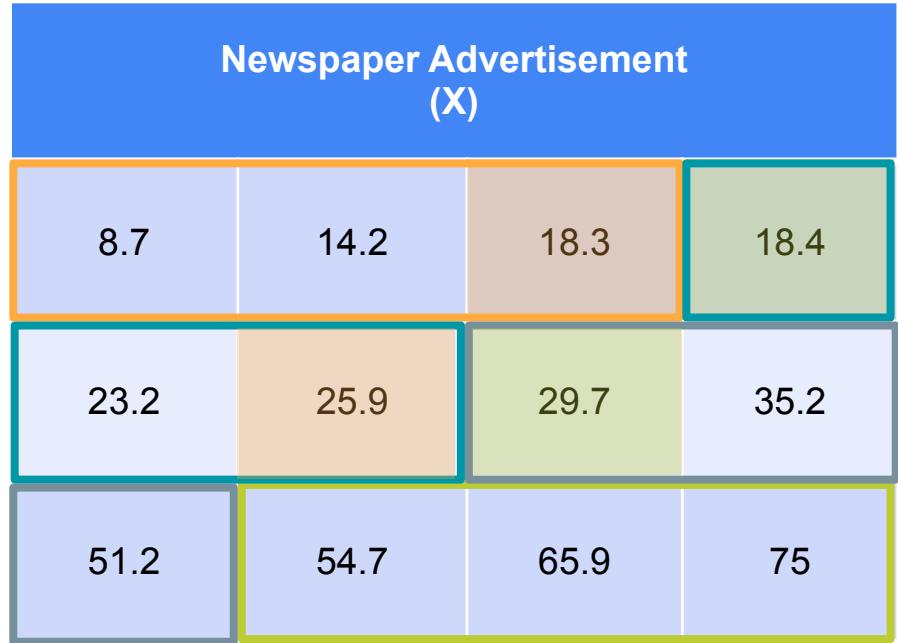
$$Q1 = q_{0.25} = \frac{18.3 + 18.4}{2} = 18.35$$



# Box-Plots

$$Q1 = q_{0.25} = \frac{18.3 + 18.4}{2} = 18.35$$

$$Q2 = q_{0.50} = \frac{25.9 + 29.7}{2} = 27.8$$

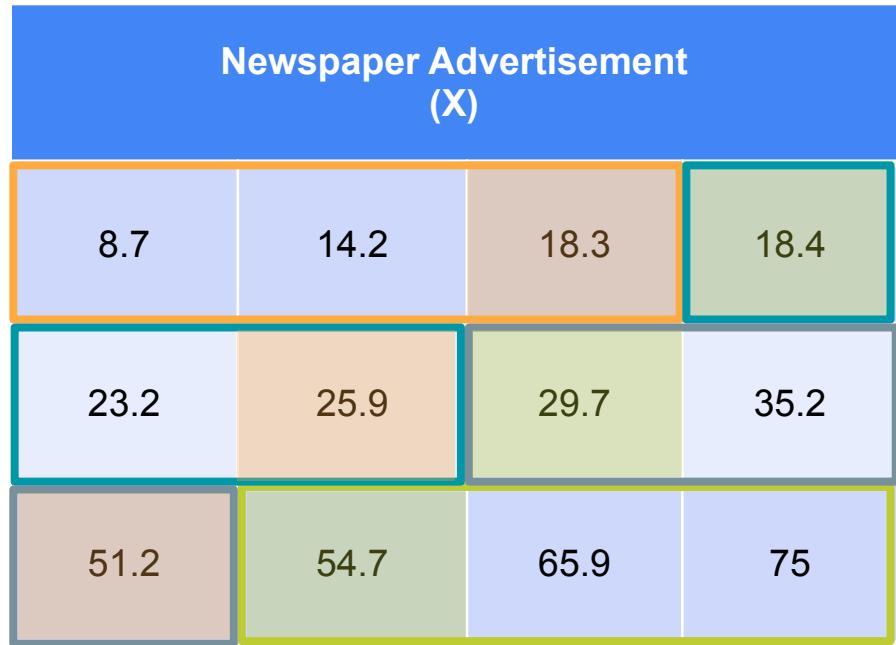


# Box-Plots

$$Q1 = q_{0.25} = \frac{18.3 + 18.4}{2} = 18.35$$

$$Q2 = q_{0.50} = \frac{25.9 + 29.7}{2} = 27.8$$

$$Q3 = q_{0.75} = \frac{51.2 + 54.7}{2} = 52.95$$

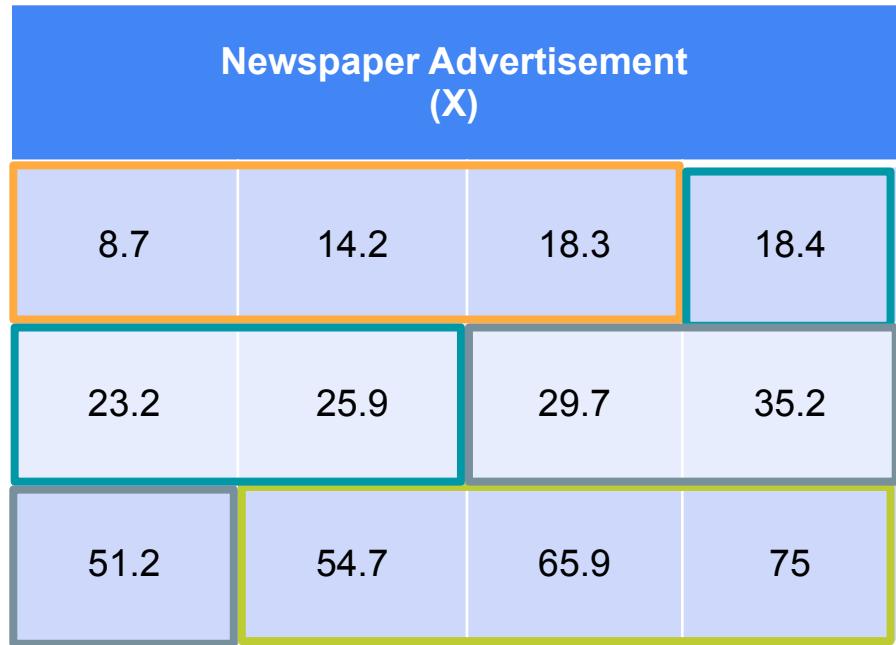


# Box-Plots

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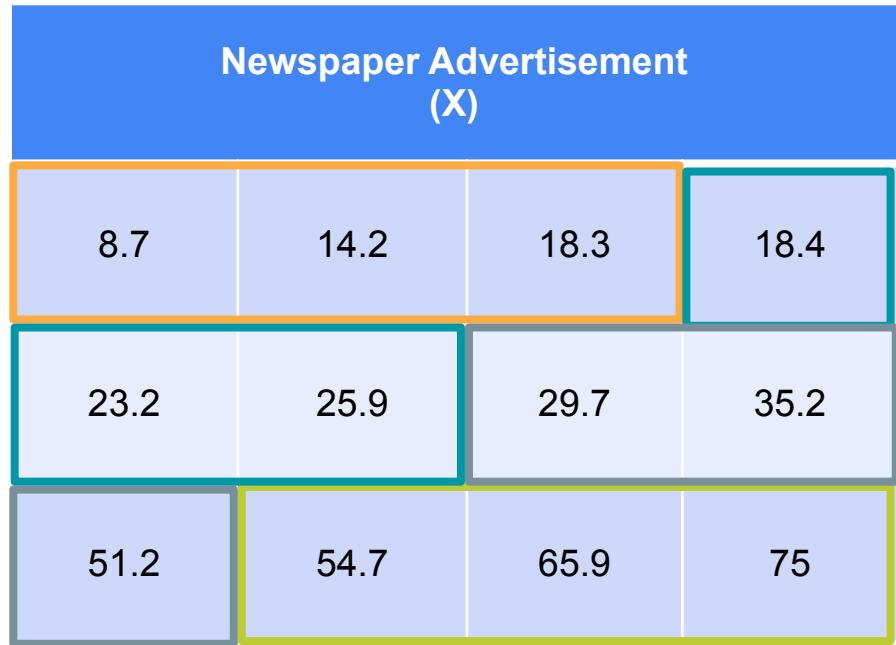
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Interquartile range (IQR)

$$IQR = Q3 - Q1$$



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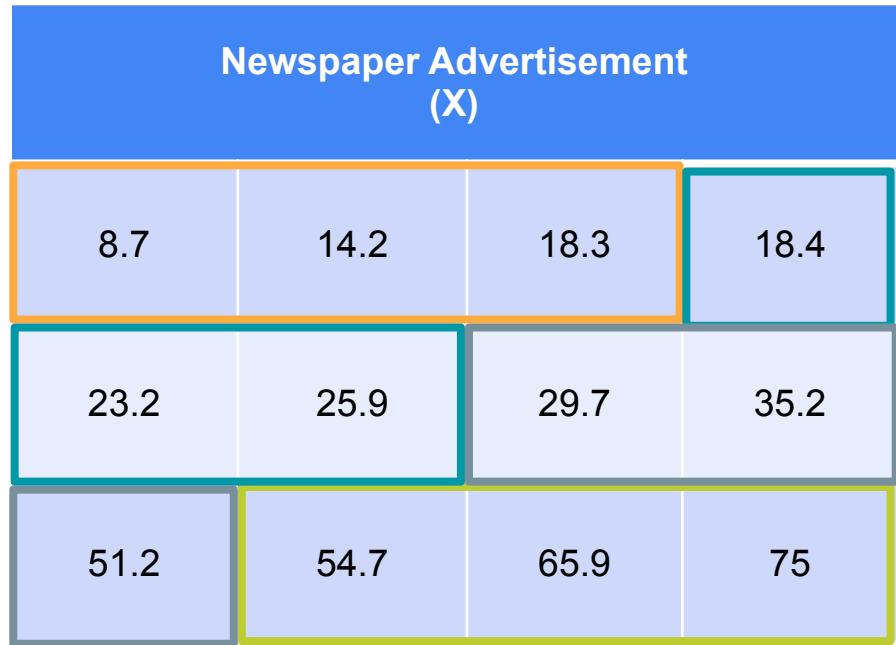
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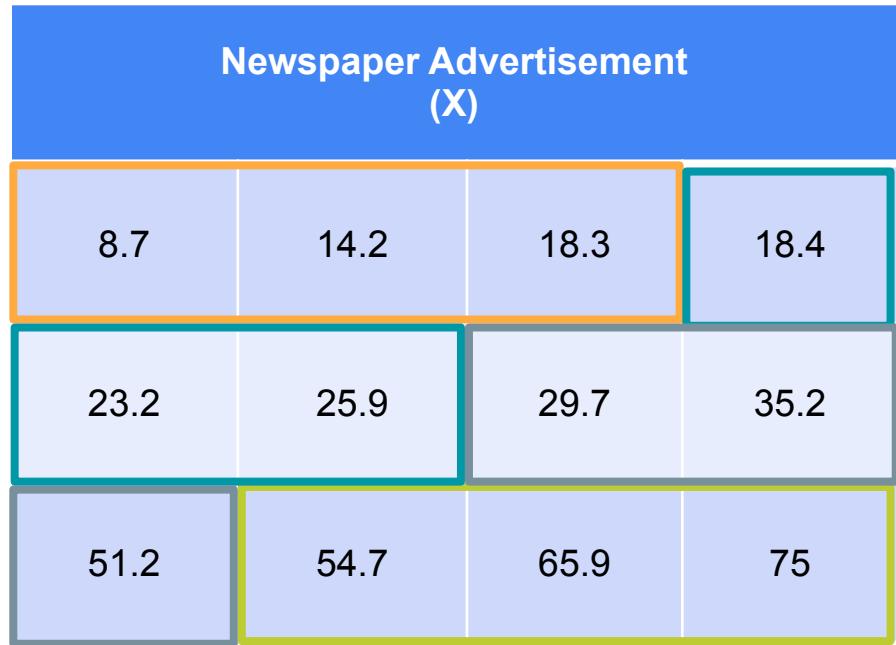
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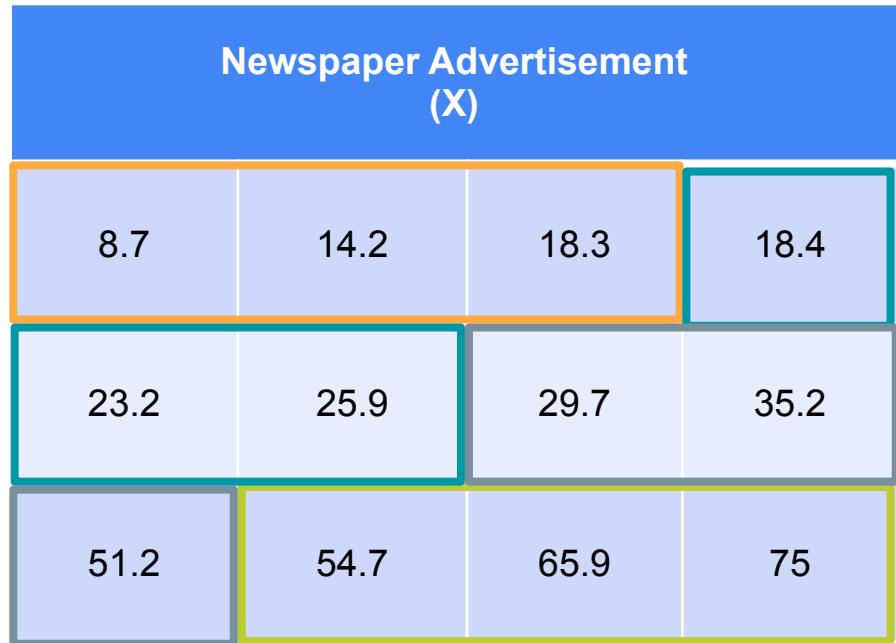
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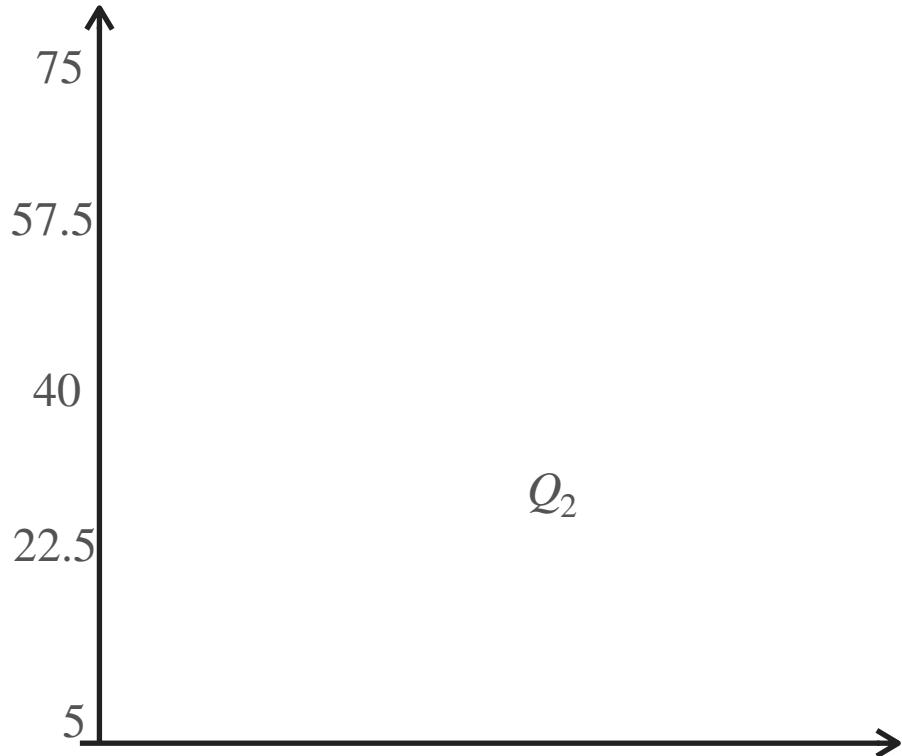
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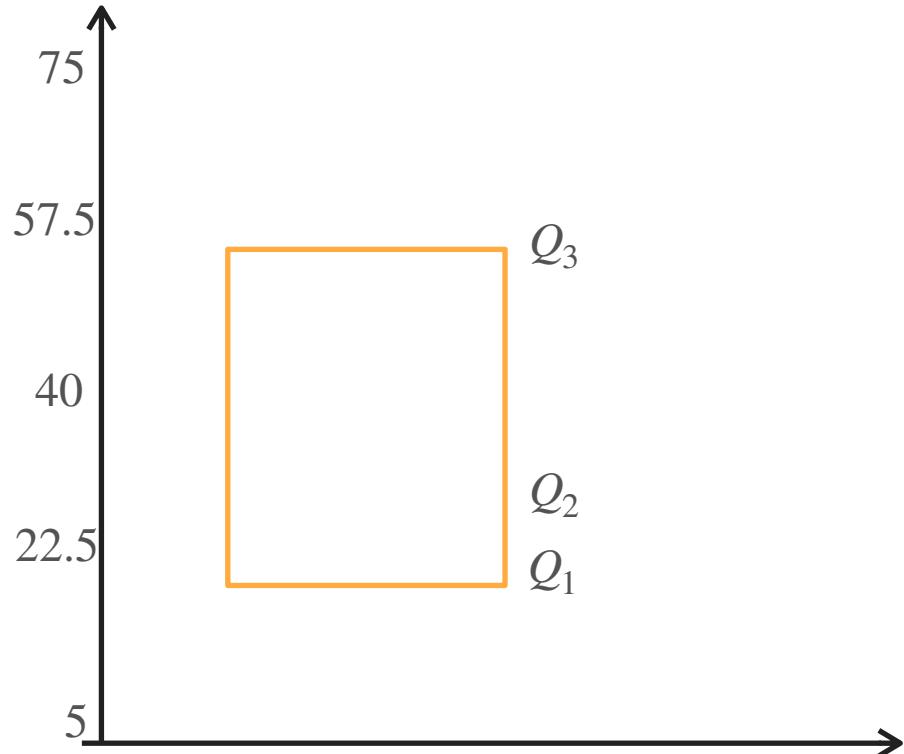
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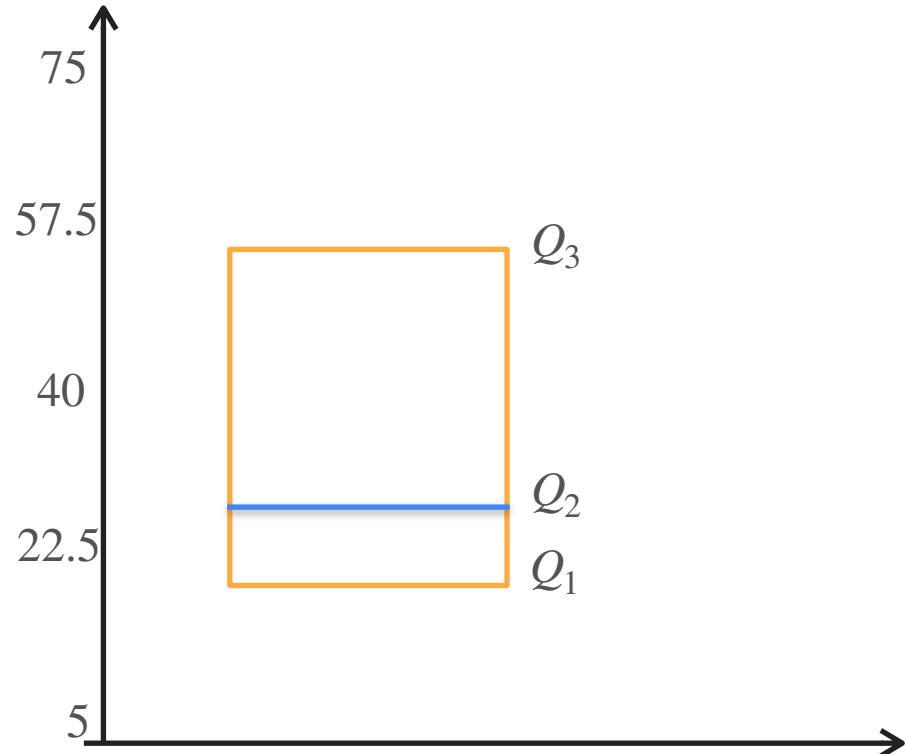
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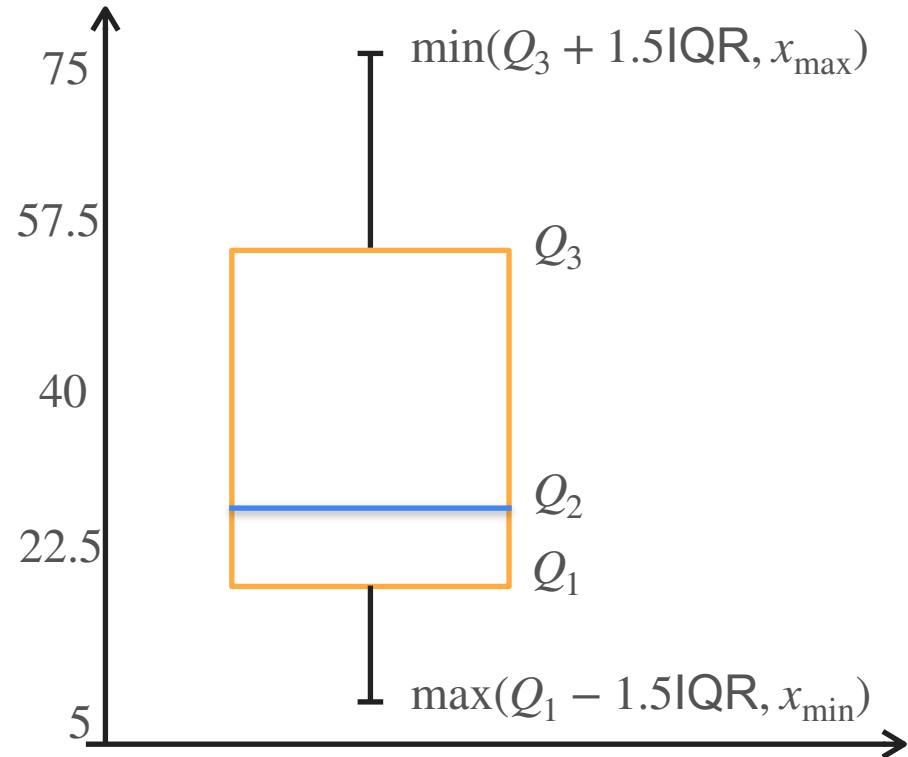
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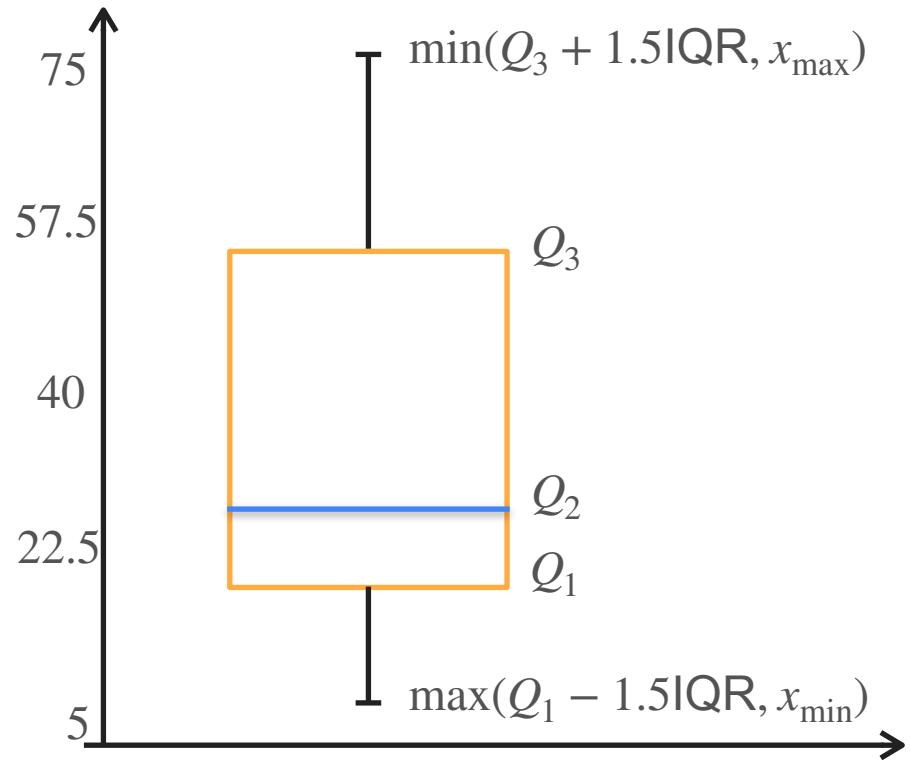
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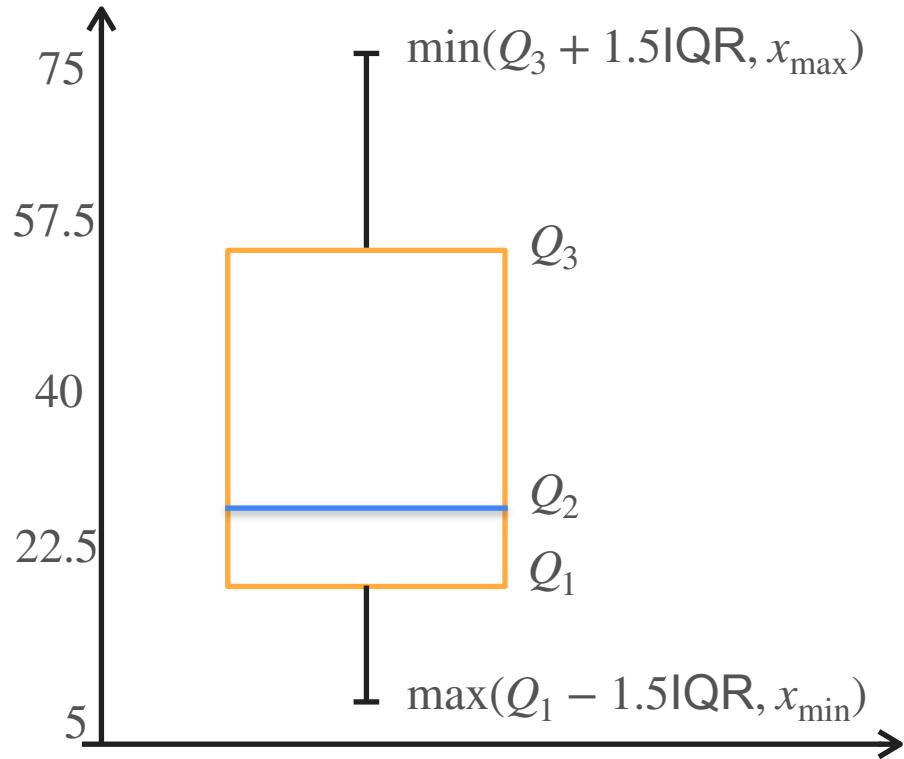
# Box-Plots



# Box-Plots

What can you tell from this plot?

- Data is skewed
- No outliers (whiskers were cut at max and min value)
- Analyze dispersion



# Box-Plots

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Let's see how the box-plot looks for the whole dataset

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$$Q_1 = 12.75 \quad Q_2 = 25.75 \quad Q_3 = 45.1$$

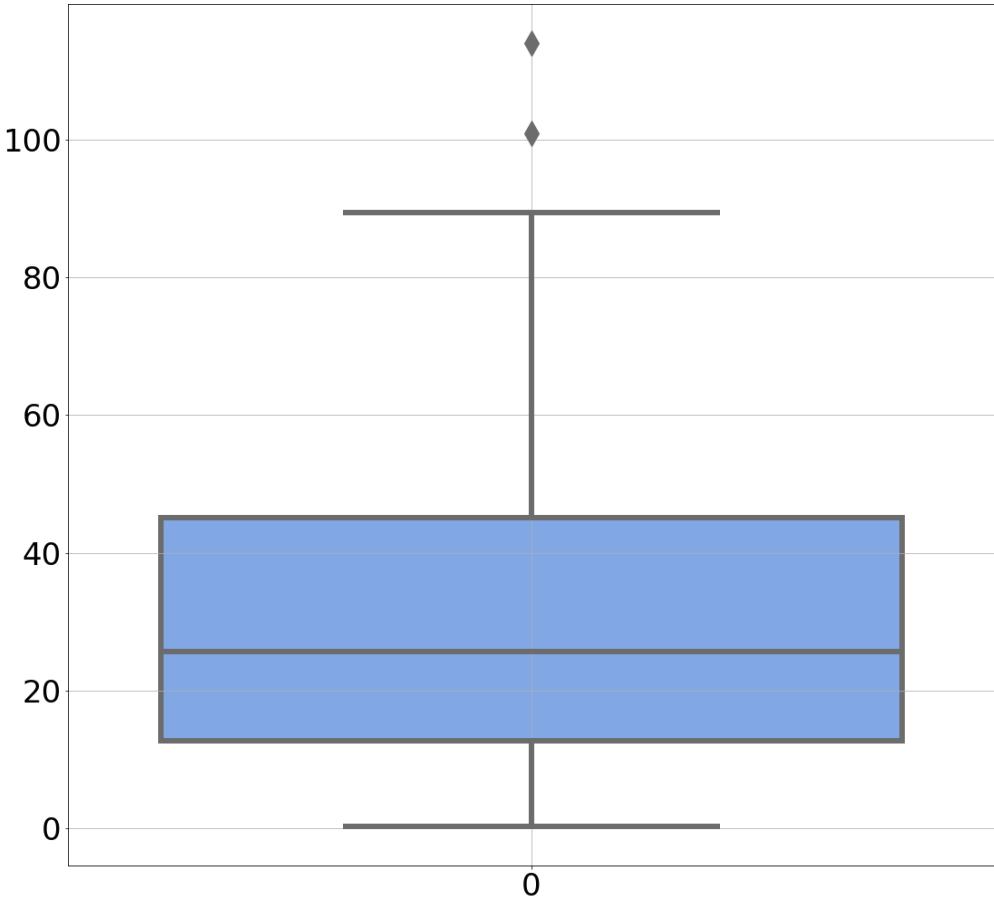
$$\text{IQR} = 32.35 \quad x_{\min} = 0.3 \quad x_{\max} = 114$$

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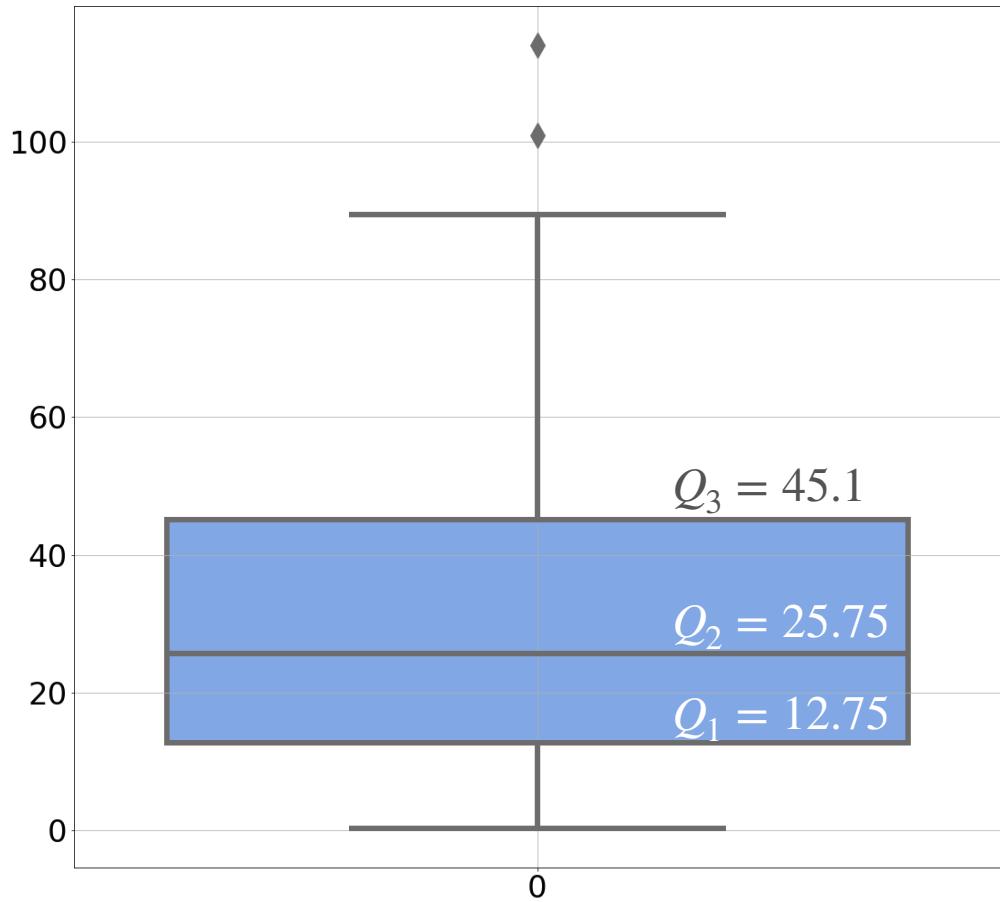


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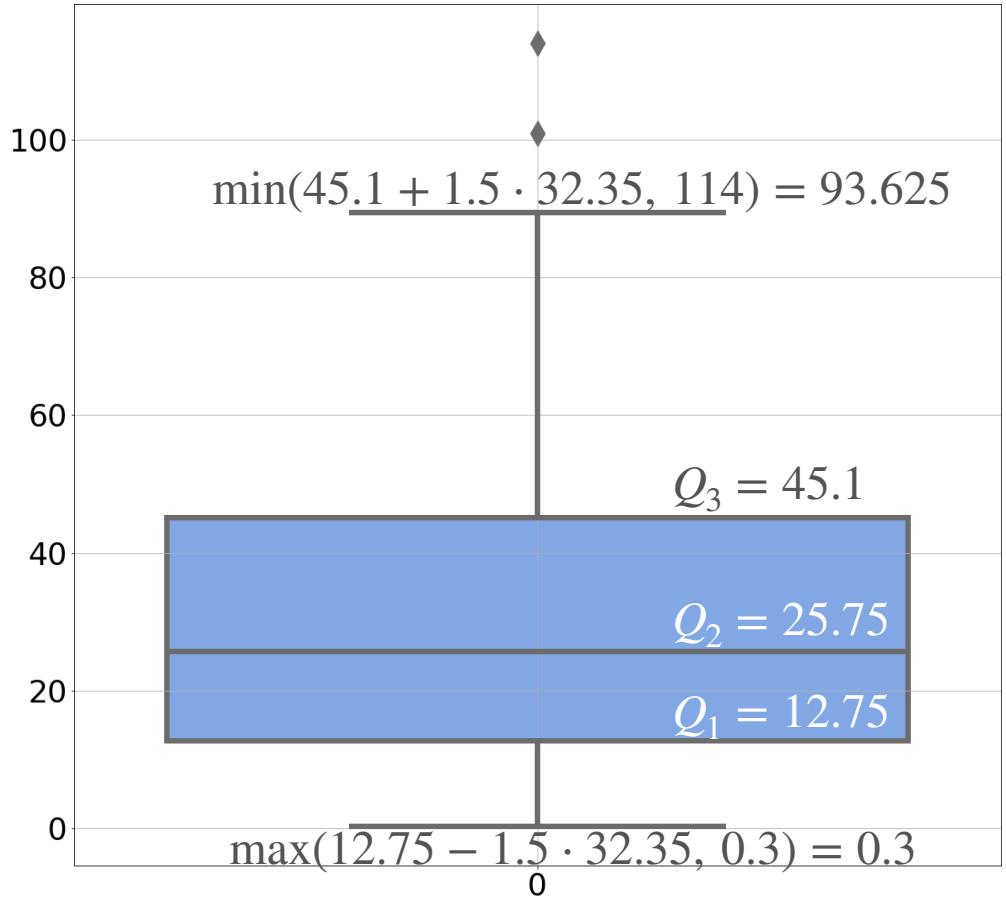


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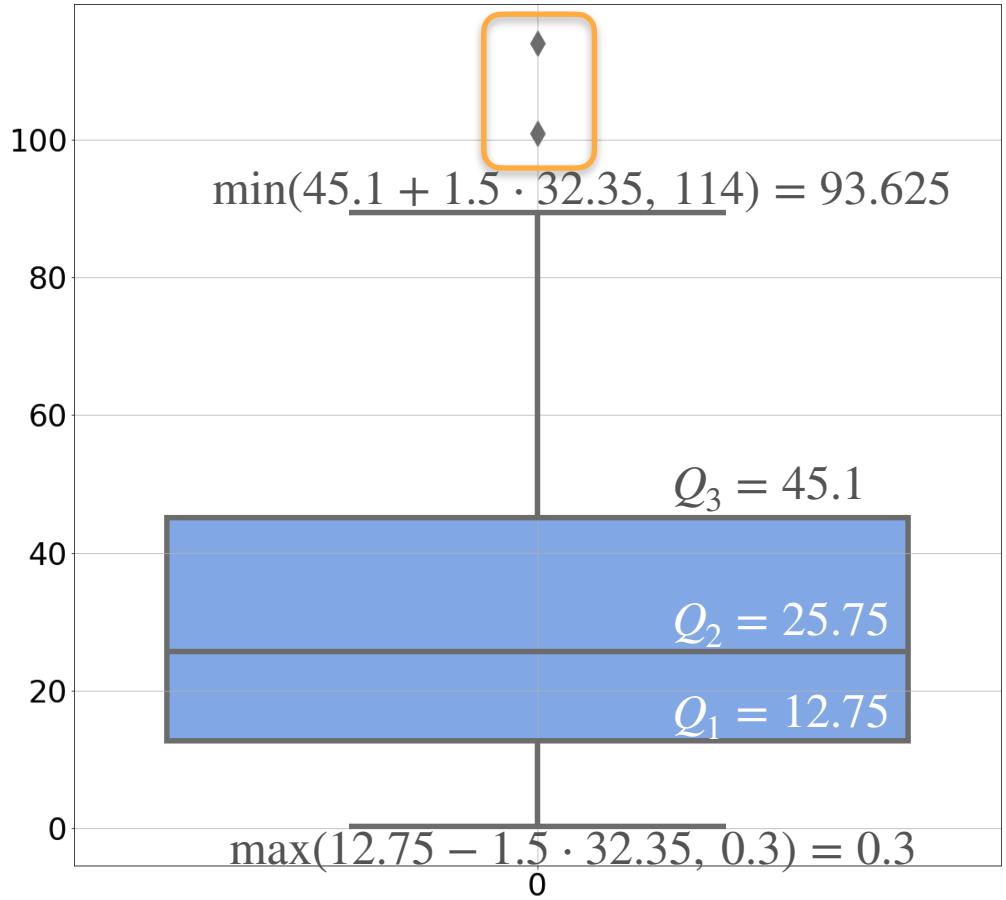
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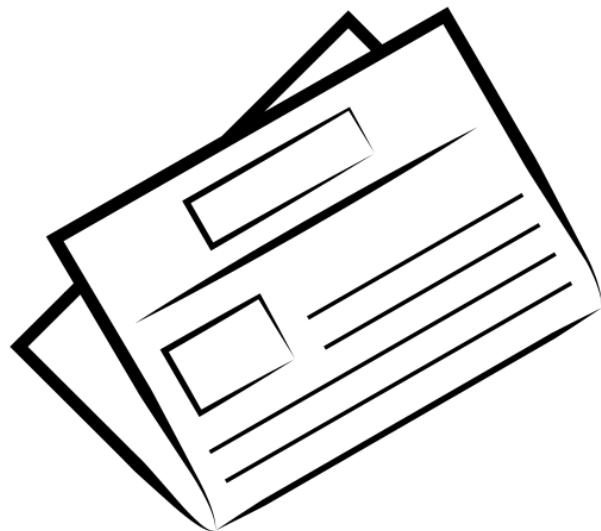
$$\text{IQR} = 32.35 \quad x_{\min} = 0.3 \quad x_{\max} = 114$$

Now you can see two outliers



# Density Estimation

# Density Estimation

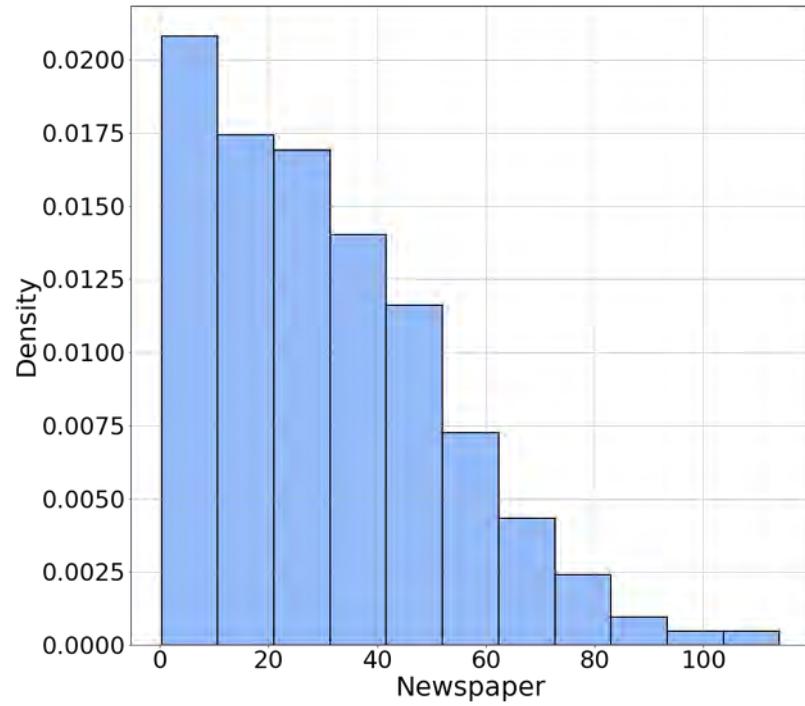


Newspaper advertisement

Newspaper Advertisement (X)			
8.7	14.2	18.3	18.4
23.2	25.9	29.7	35.2
51.2	54.7	65.9	75

# Histograms

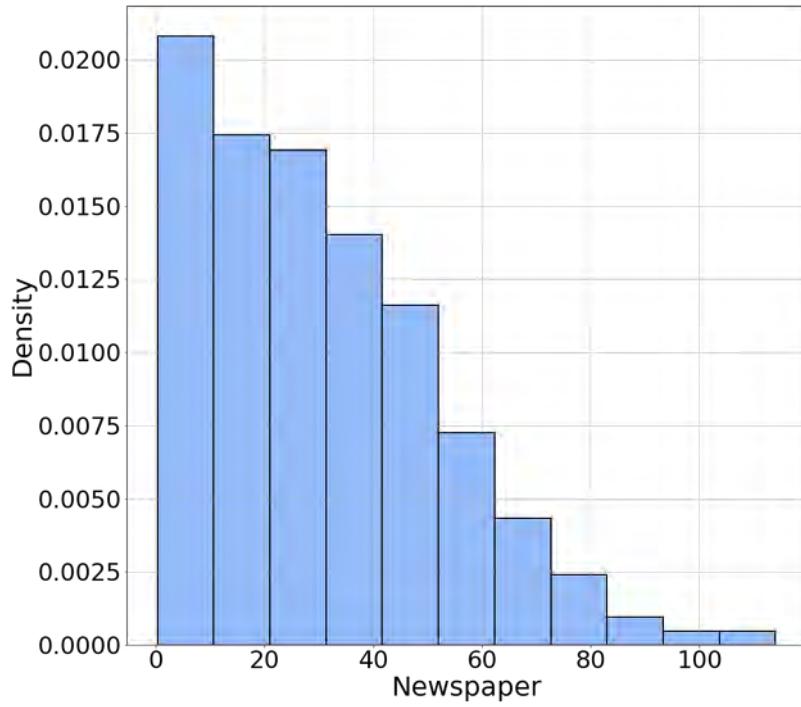
# Histograms



# Histograms

It represents a density function

- It is positive
- Area under the curve is 1



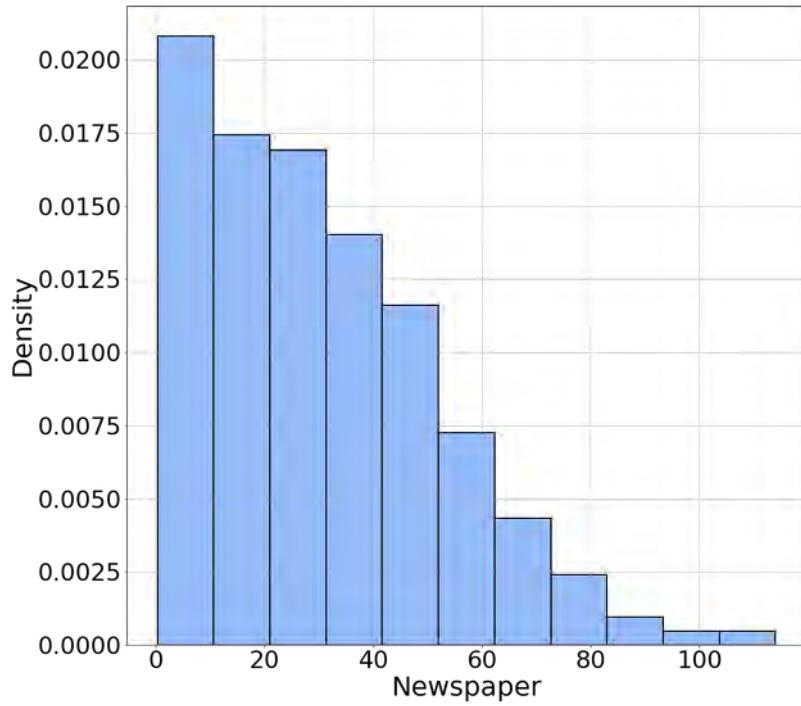
# Histograms

It represents a density function

- It is positive
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But...

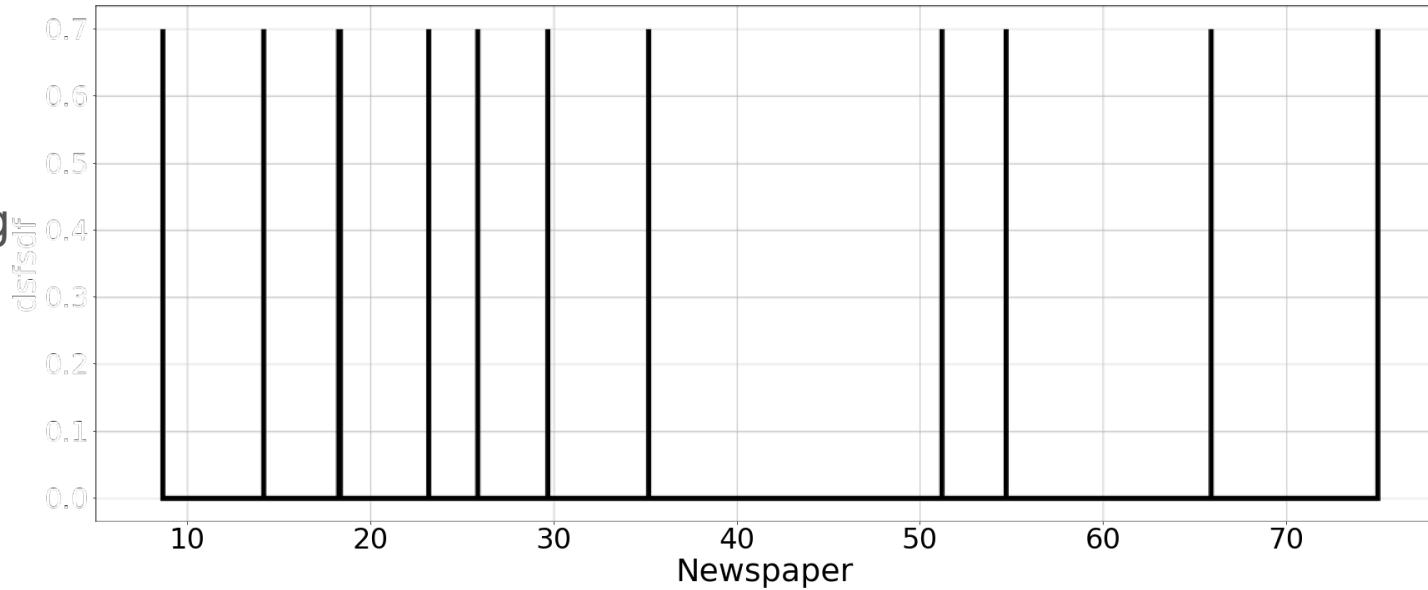
- PDFs are usually smooth function
- The discontinuities come from the method and not the data



# Kernel Density Estimation

# Kernel Density Estimation

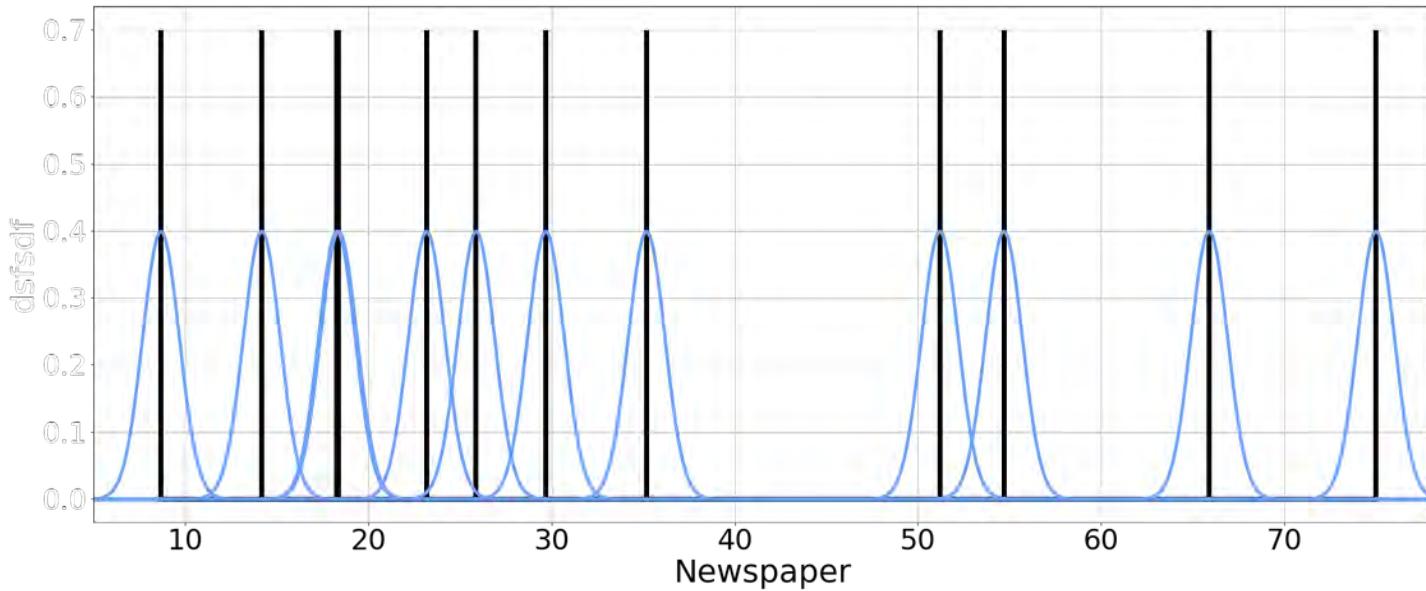
**First:** draw your observations along the x axis



# Kernel Density Estimation

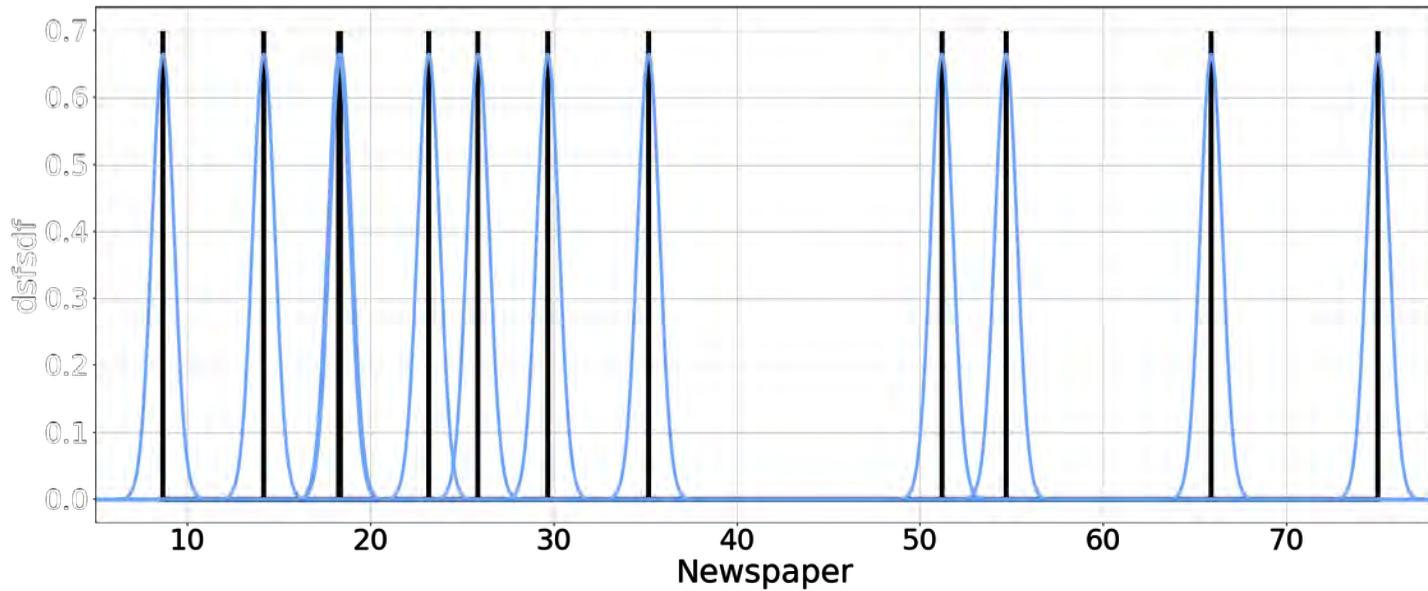
# Kernel Density Estimation

**Second:** draw a gaussian centered at each observation



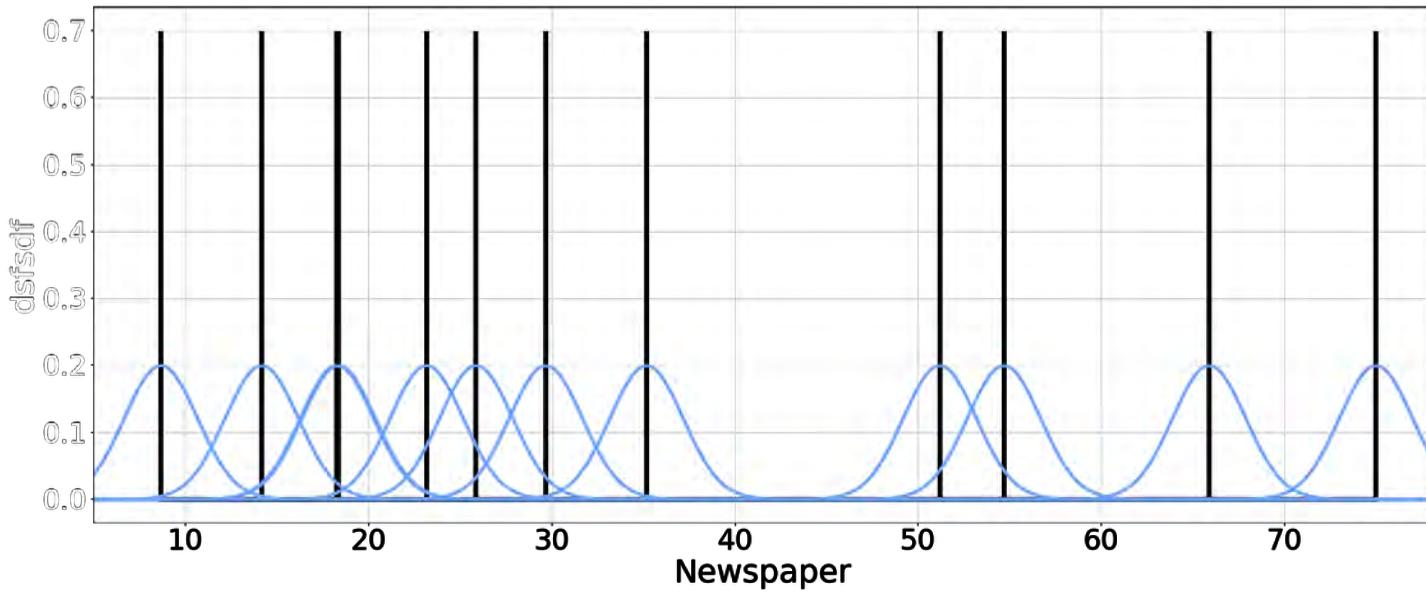
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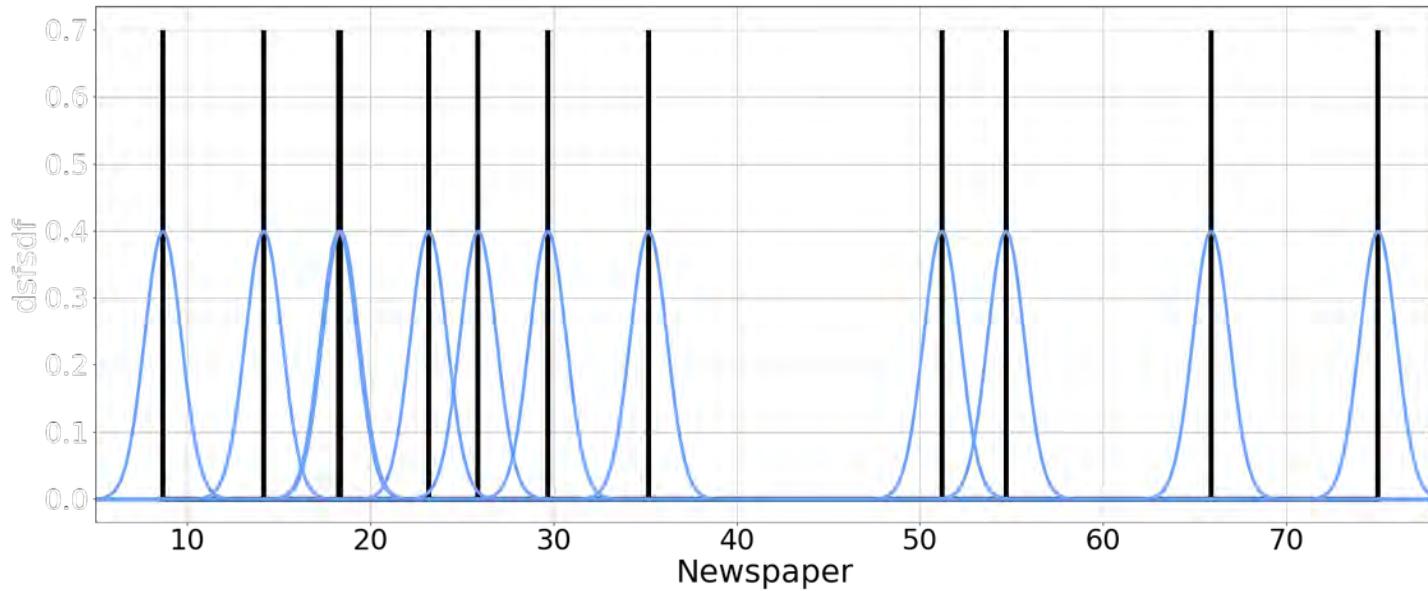
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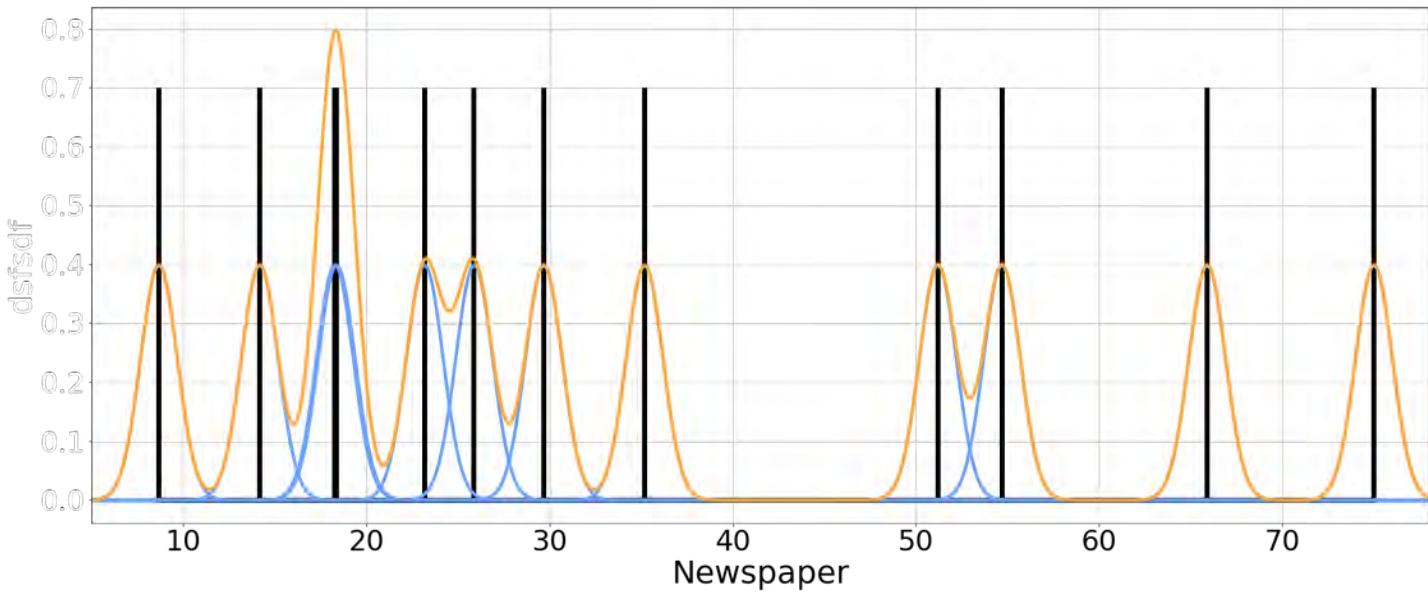


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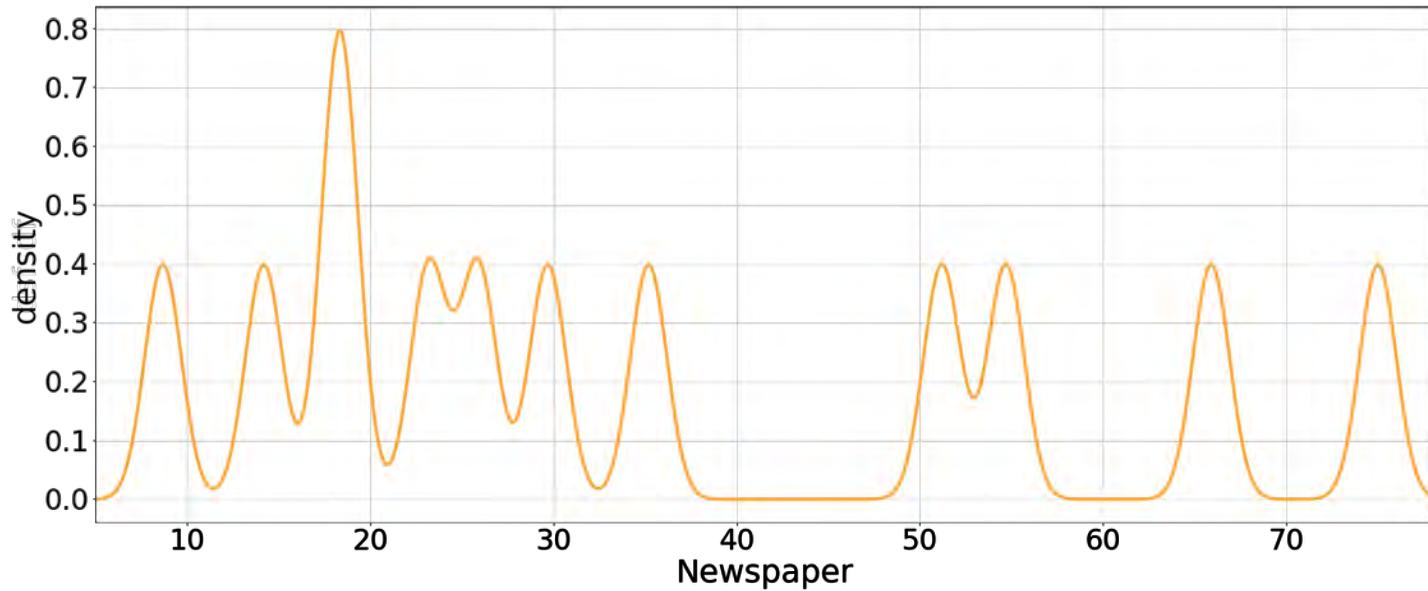


# Kernel Density Estimation



# Kernel Density Estimation

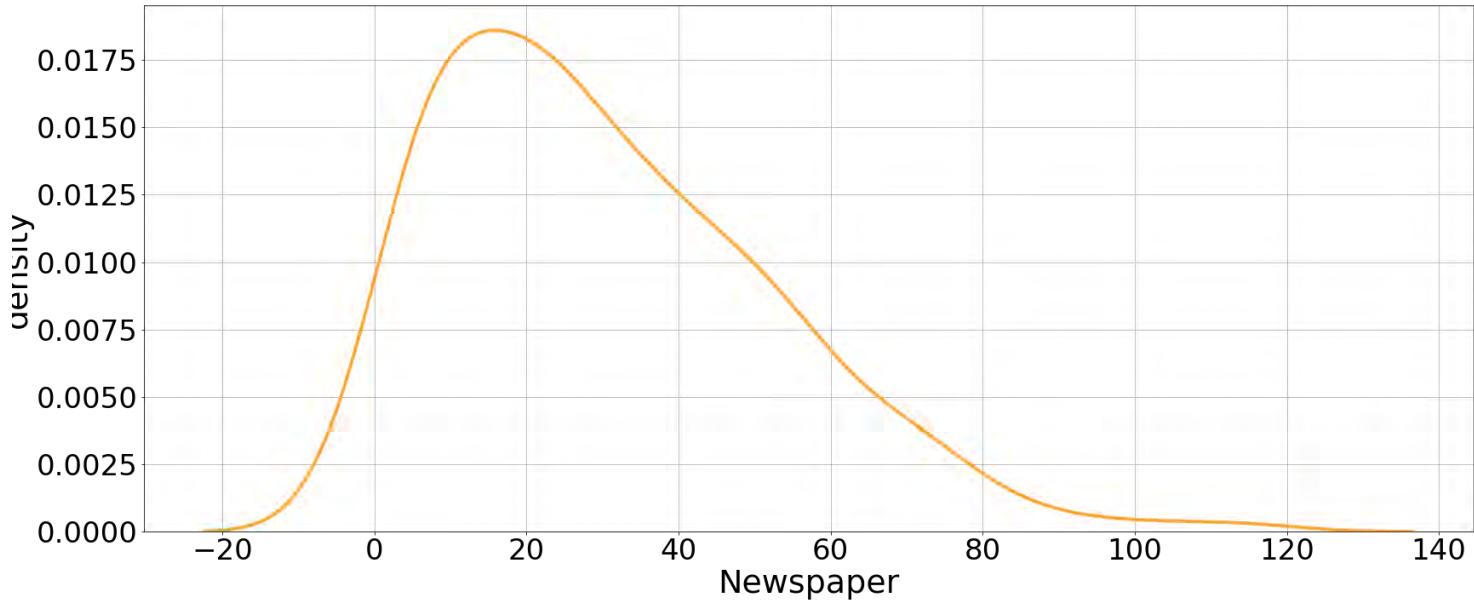
**Third:** multiply everything by  $1/n$  and sum the curves



# Kernel Density Estimation

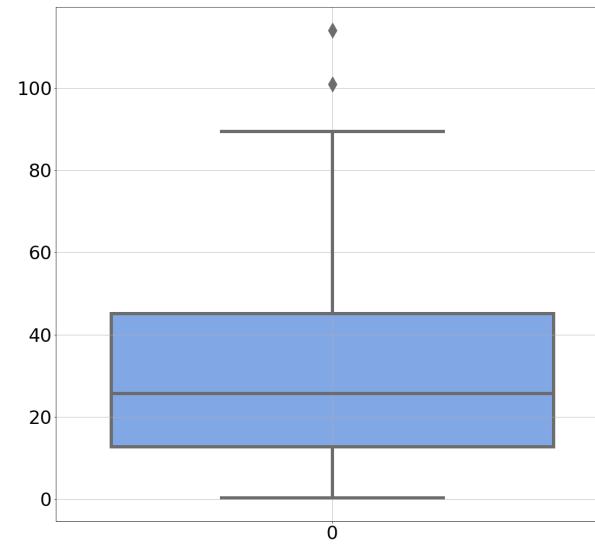
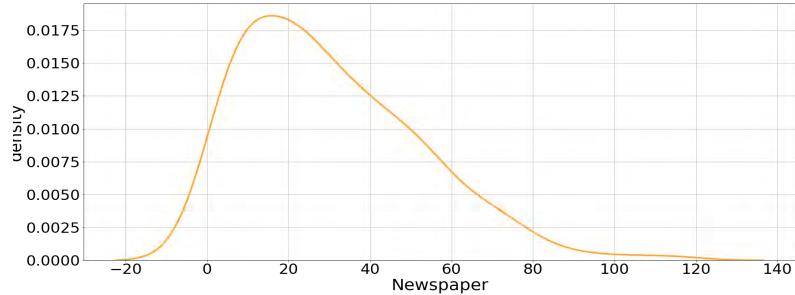
# Kernel Density Estimation

What if  
you used  
all the  
dataset?

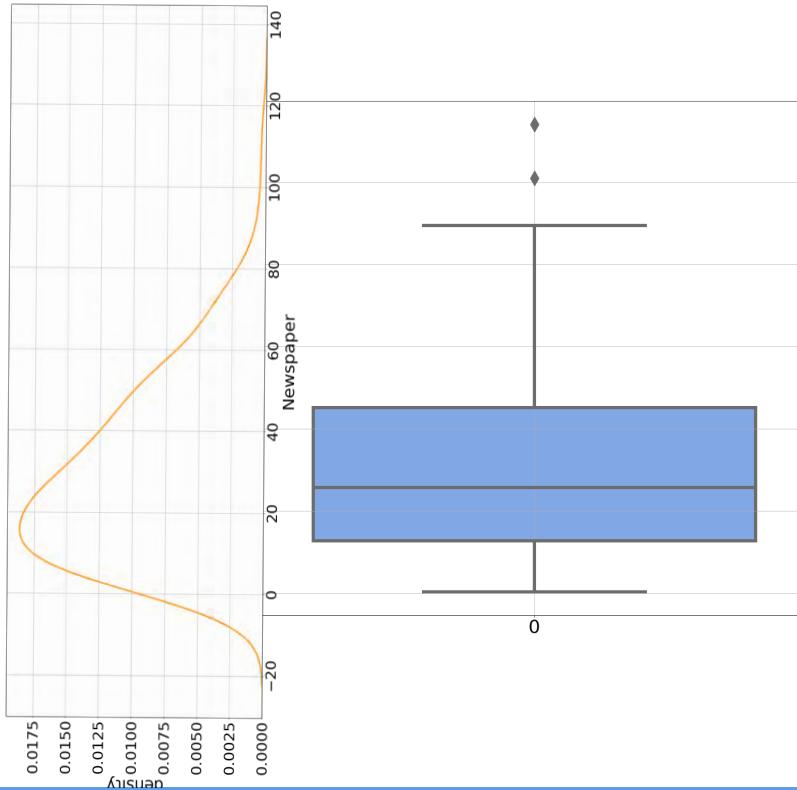


# Violin Plots

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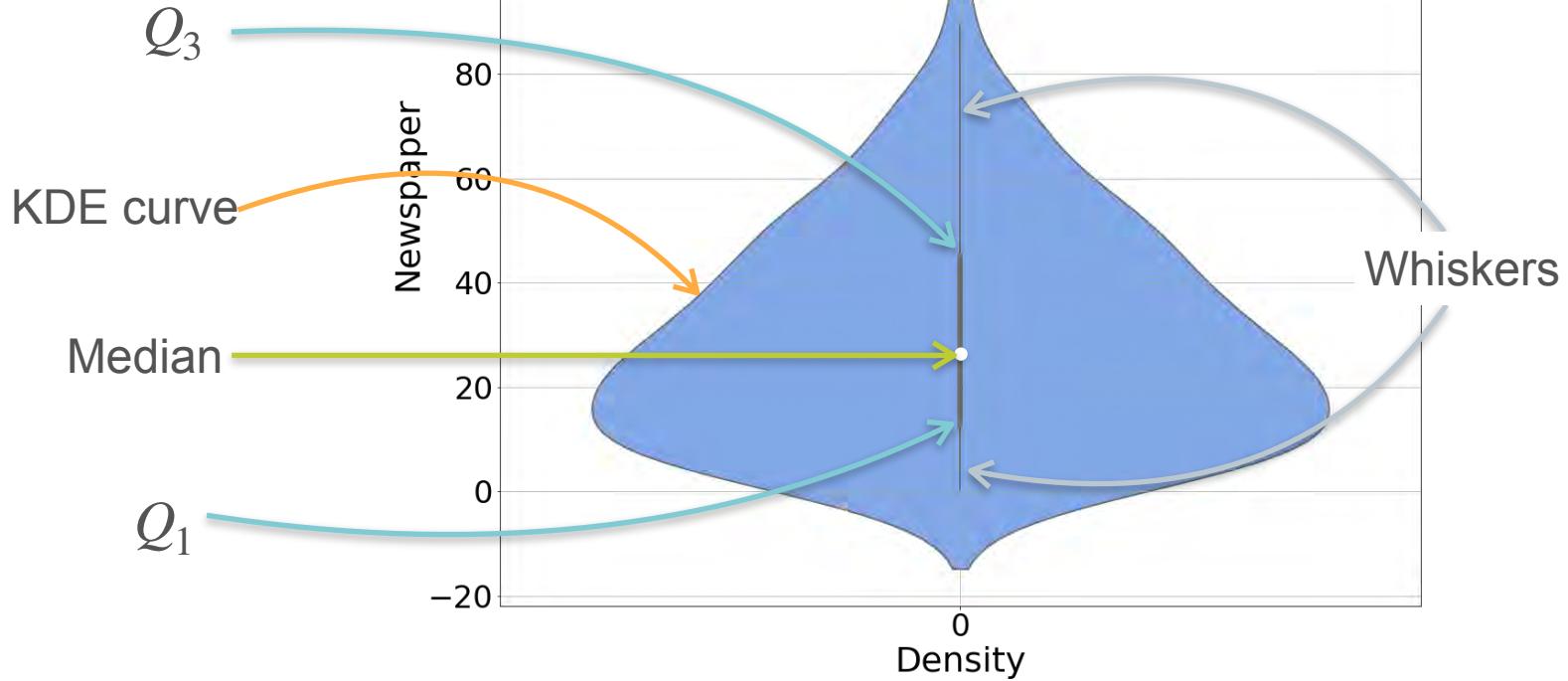


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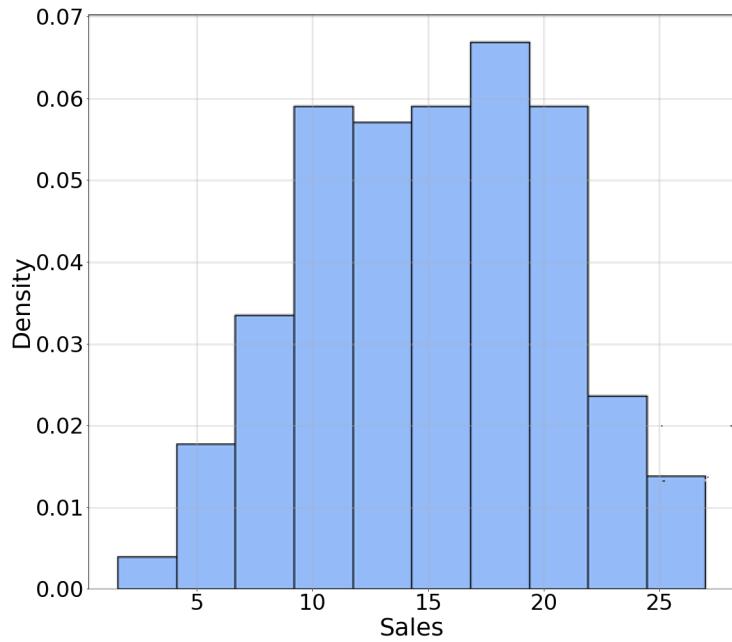
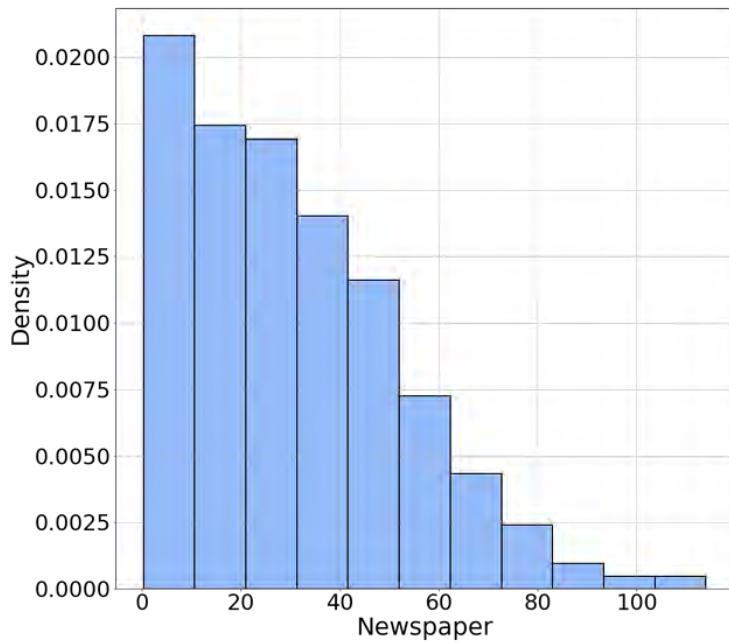
# Assessing Normality of Data

Some models assume normally distributed data

- Linear regression
- Logistic regression
- Gaussian Naive Bayes
- Others

Some tests used in Data Science also assume normality.

# Assessing Normality of Data



Newspaper

# QQ Plots

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Quantile-Quantile plots (QQ Plots) compare quantiles

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$$\left( \frac{x - \mu}{\sigma} \right)$$

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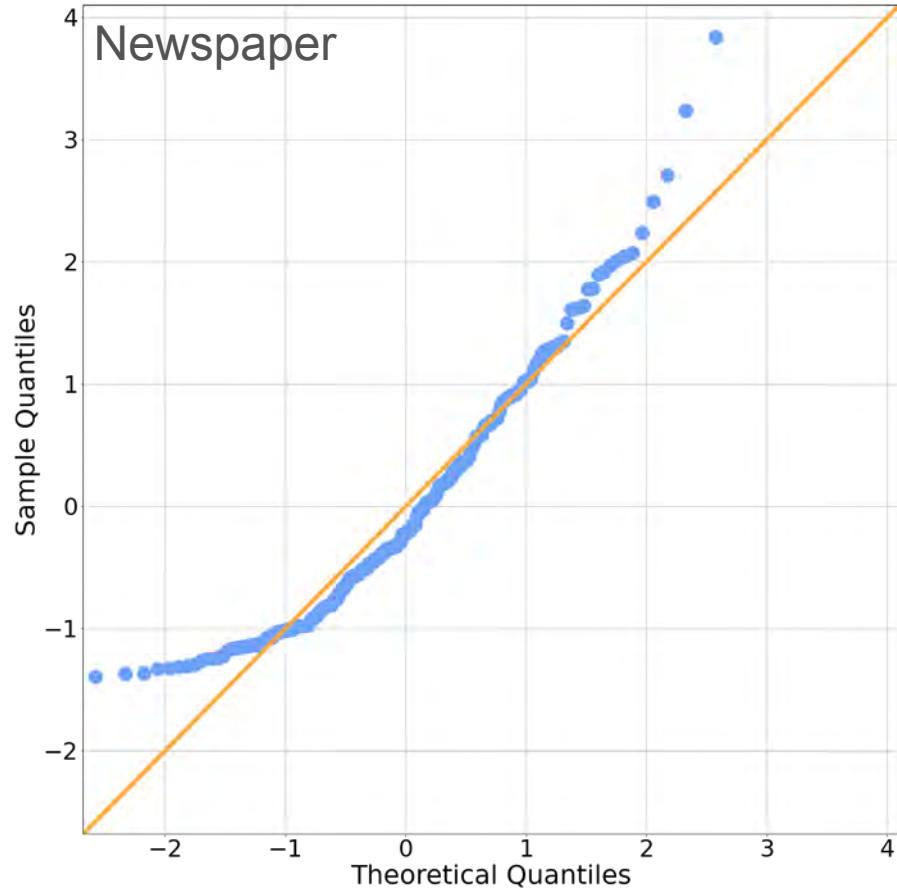
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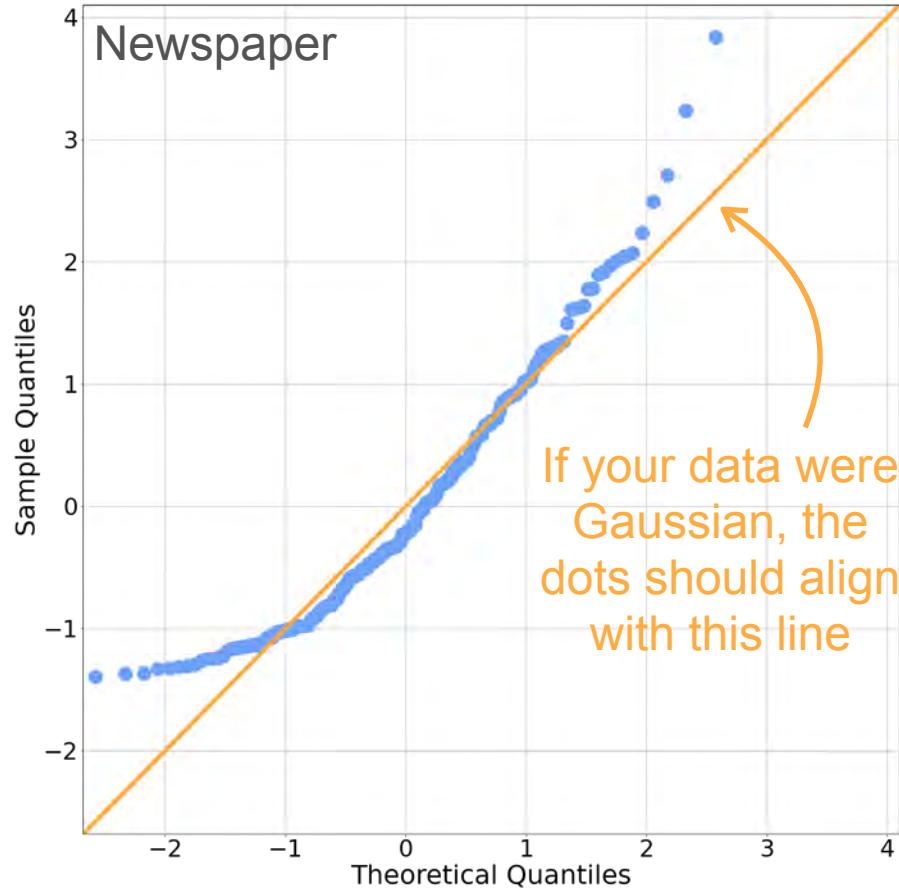
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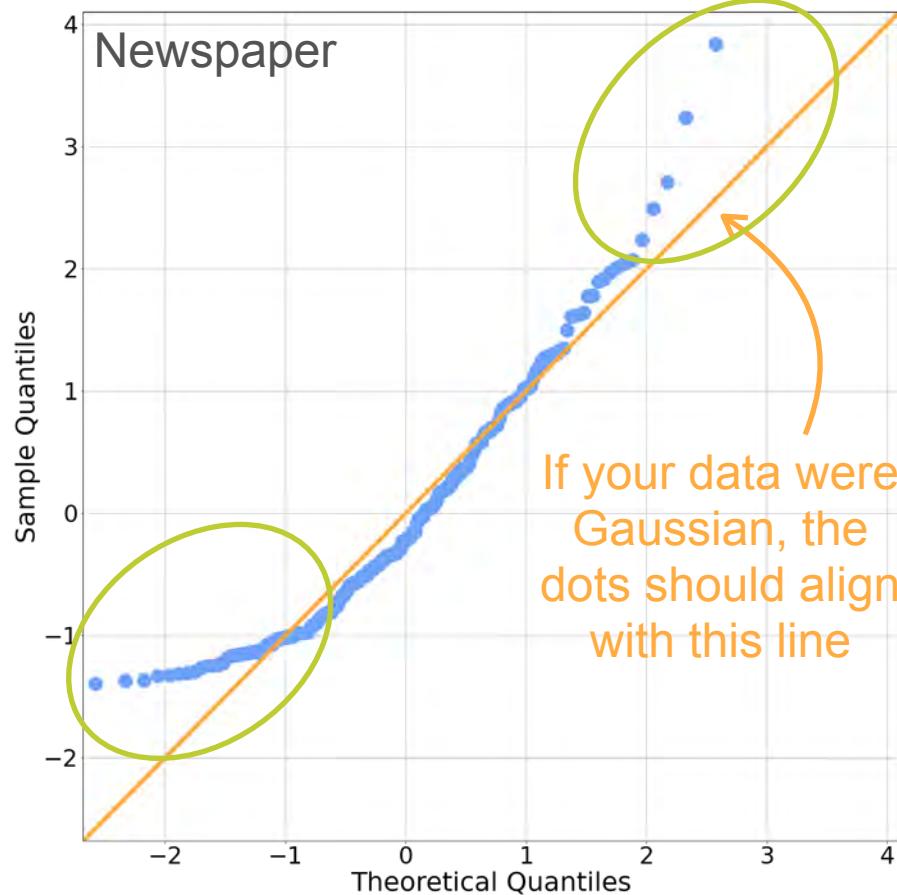
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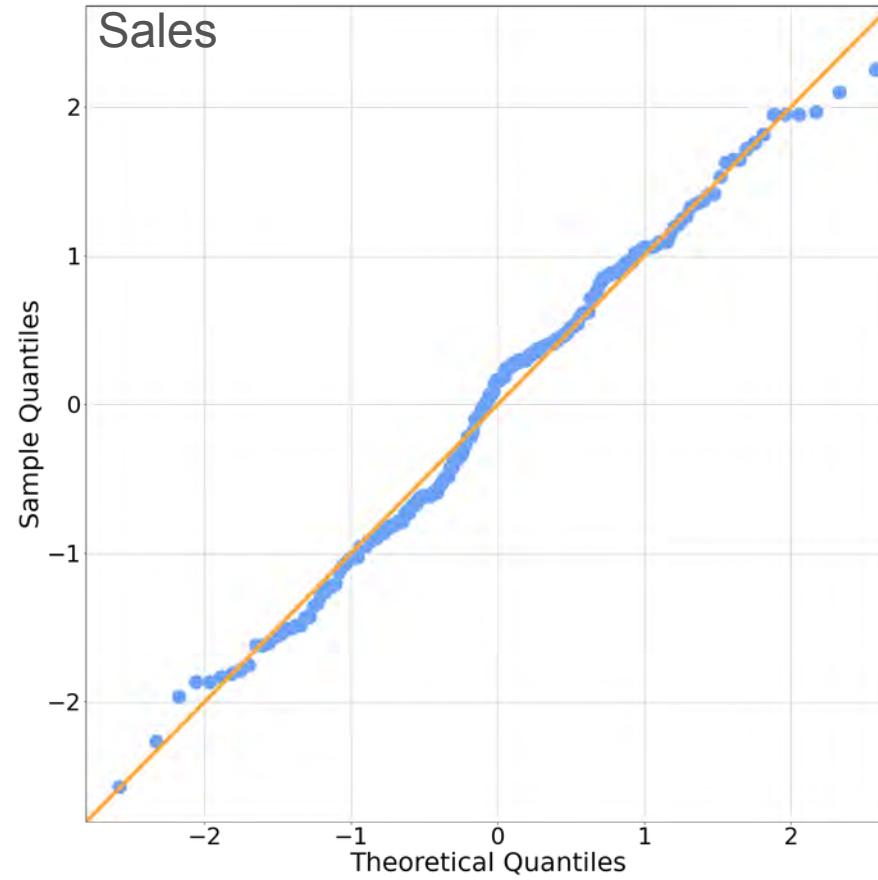
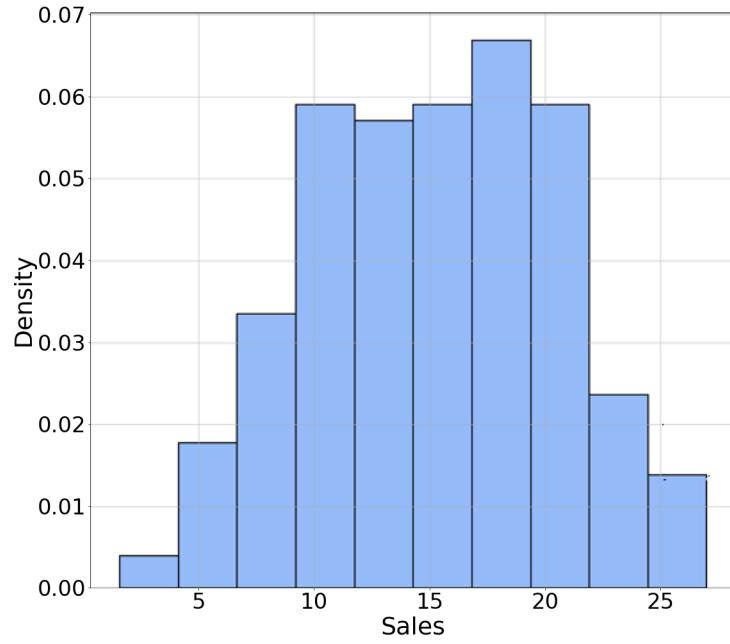
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# QQ Plots



# W2 Lesson 2



DeepLearning.AI

# Probability Distributions with Multiple Variables

---

## Joint Distribution (Discrete)

# Joint Distributions (Discrete): Example 1

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Age (Year)	Count
7	3
8	2
9	4
10	1

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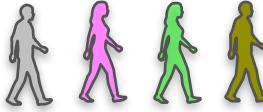


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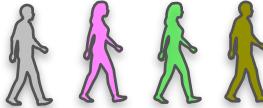
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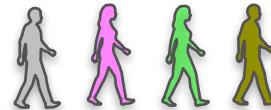
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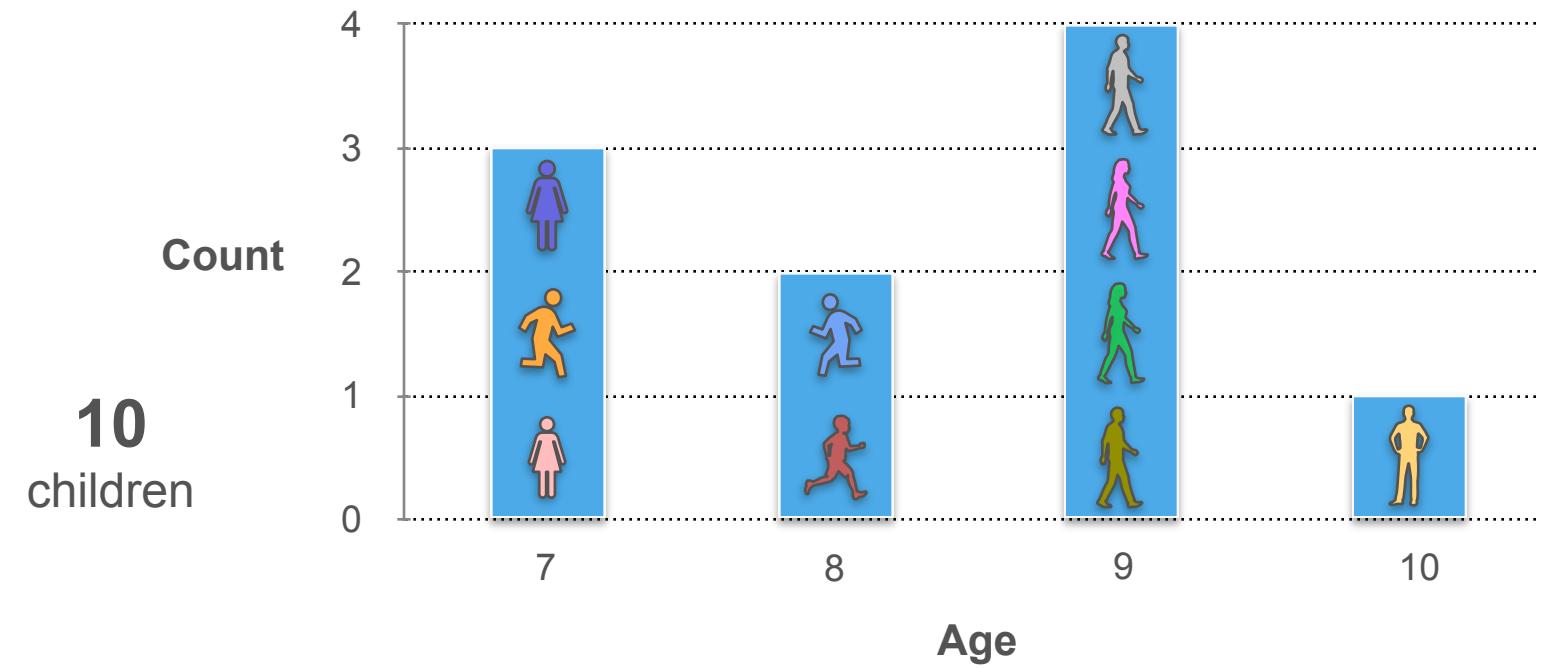
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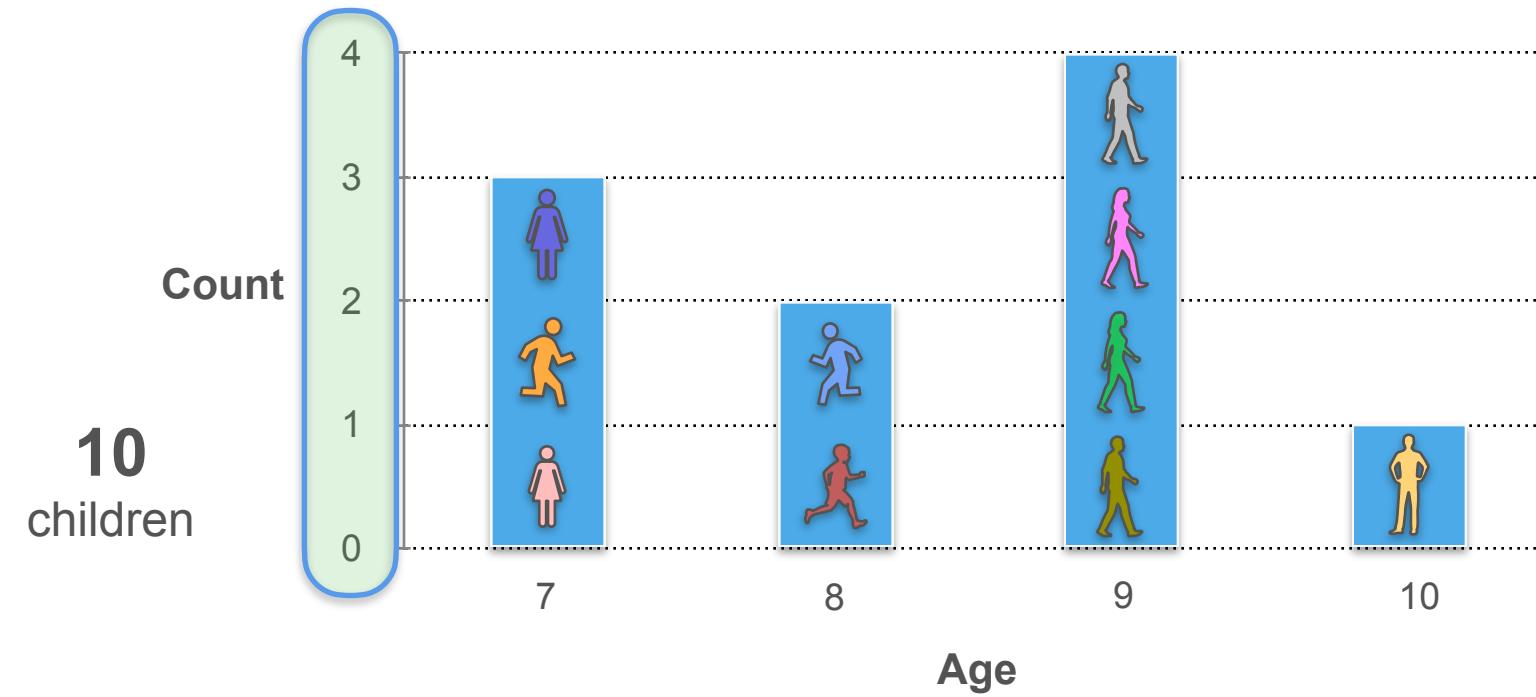
10

children

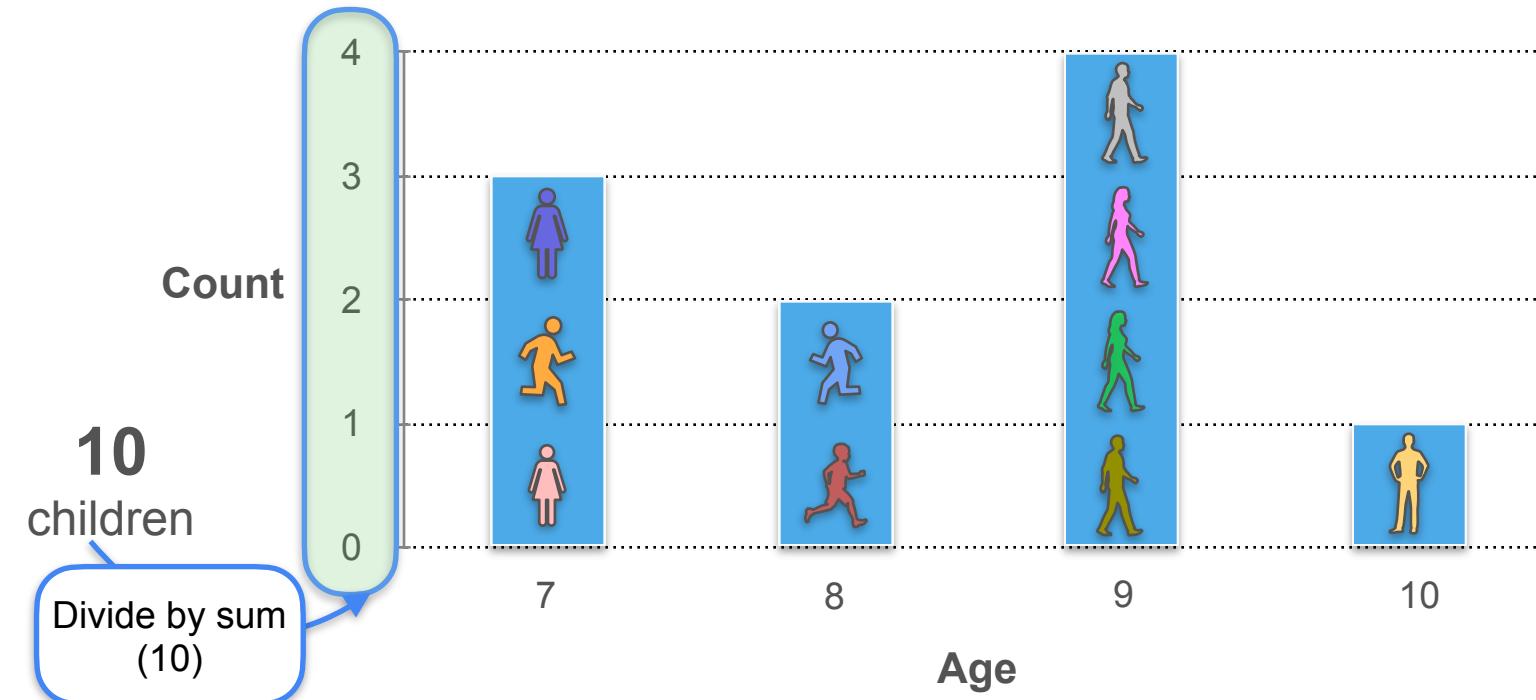
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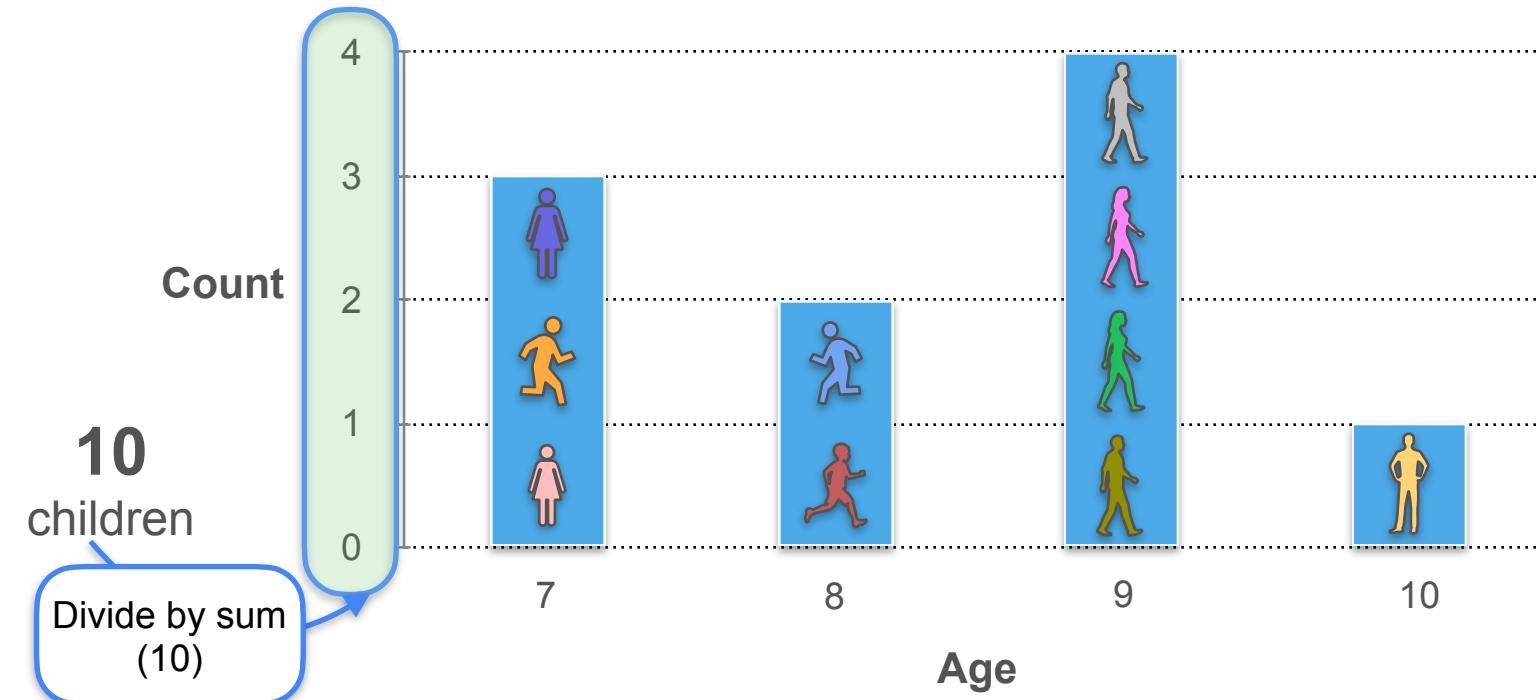
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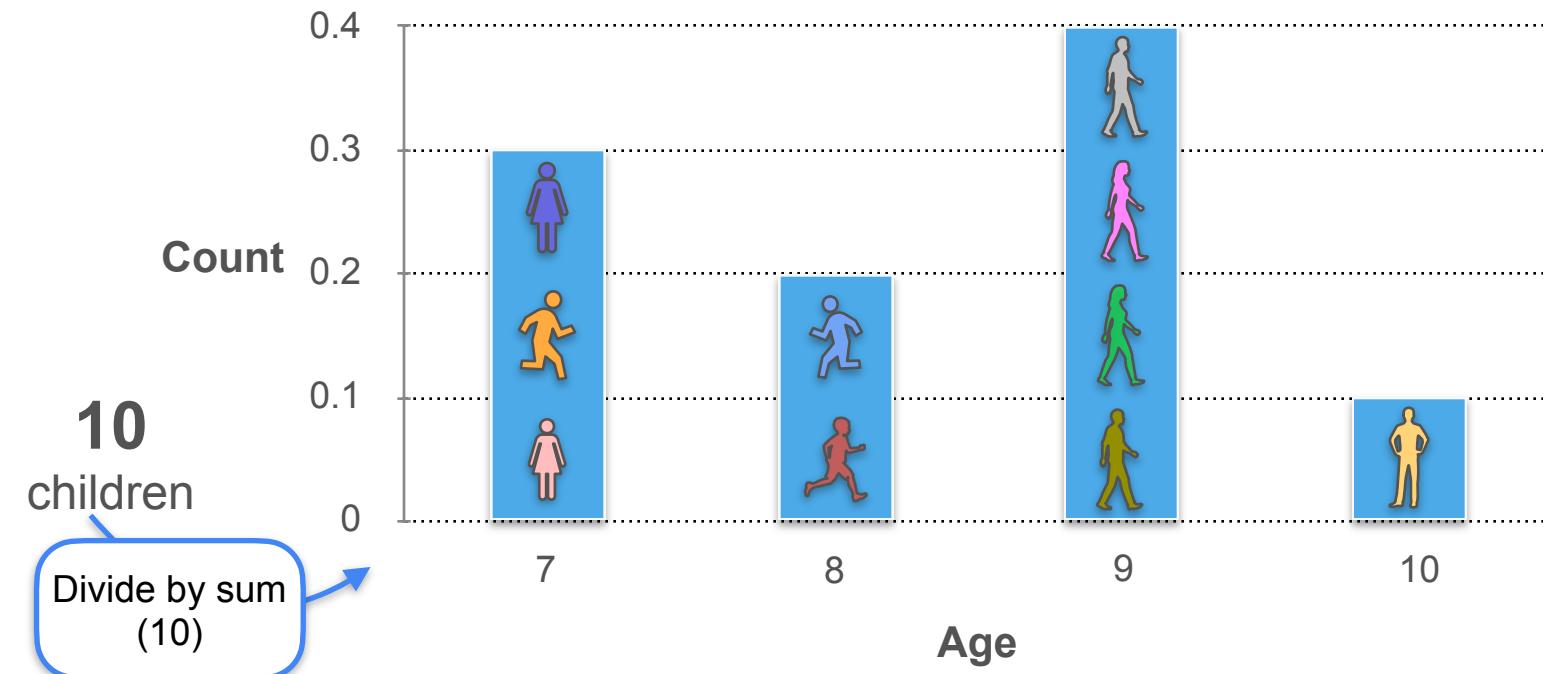
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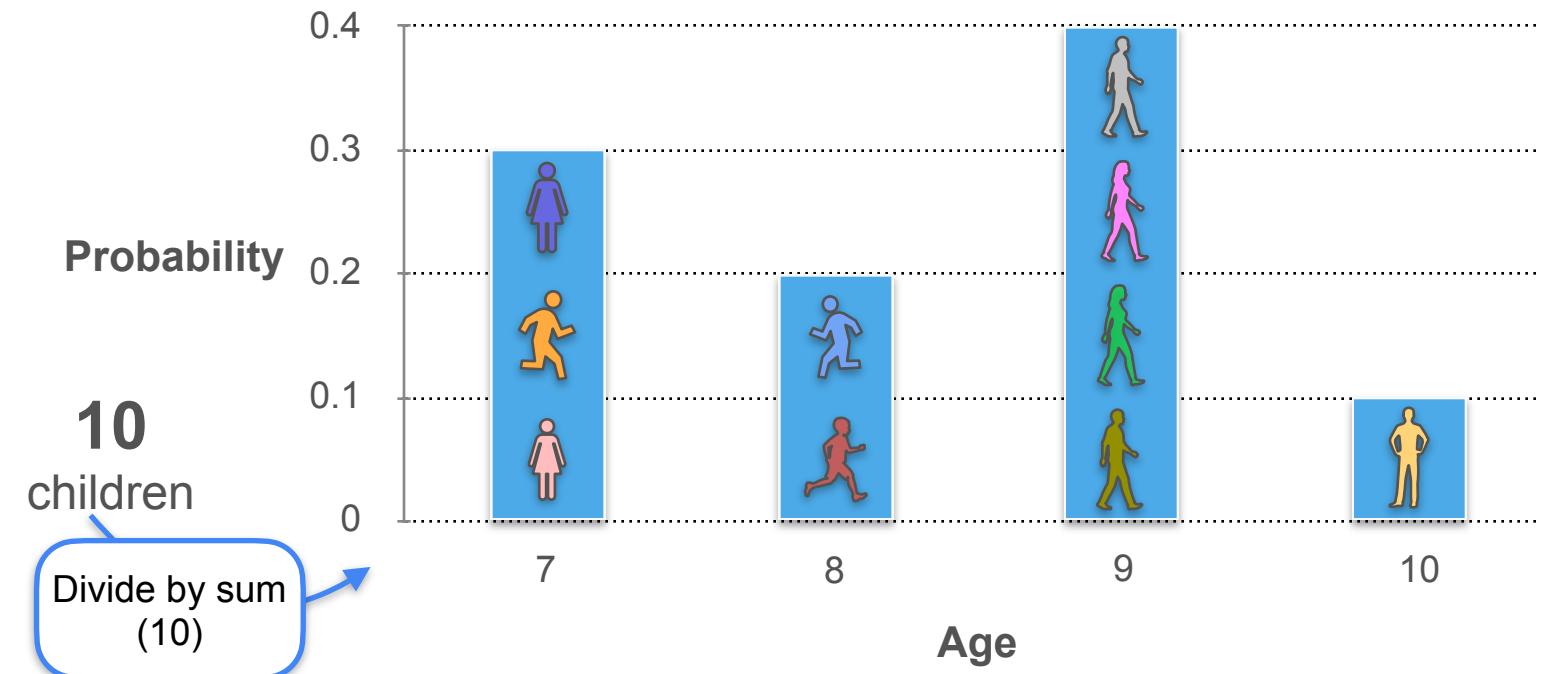
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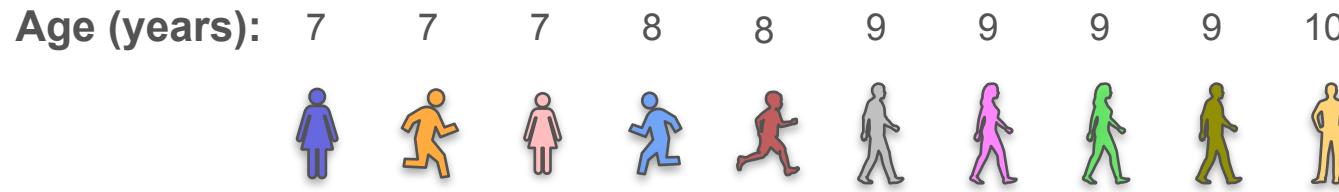
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# Joint Distributions (Discrete): Example 1

Age (years): 7    7    7    8    8    9    9    9    9    10



Height (in):

# Joint Distributions (Discrete): Example 1

Age (years):	7	7	7	8	8	9	9	9	9	10
										
Height (in):	45	46	46	47	47	49	49	49	49	50

# Joint Distributions (Discrete): Example 1

Age (years):

7      7      7      8      8      9      9      9      9      10

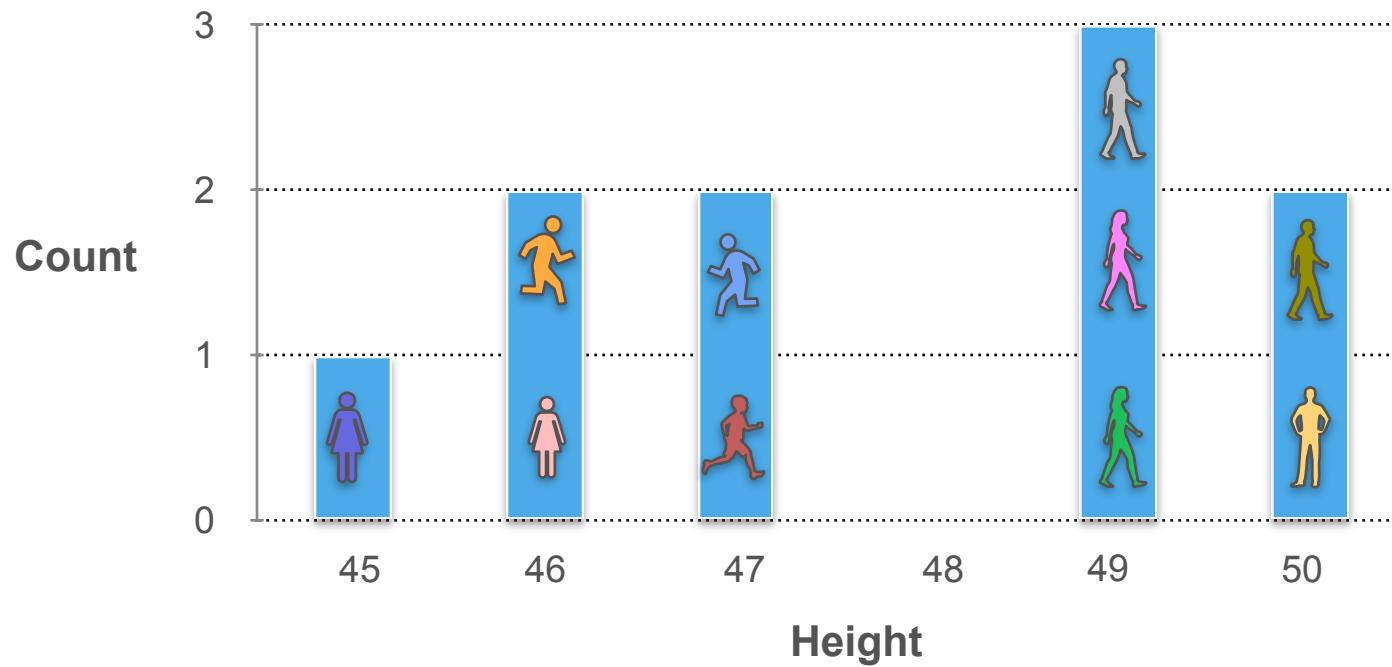


Height (in):

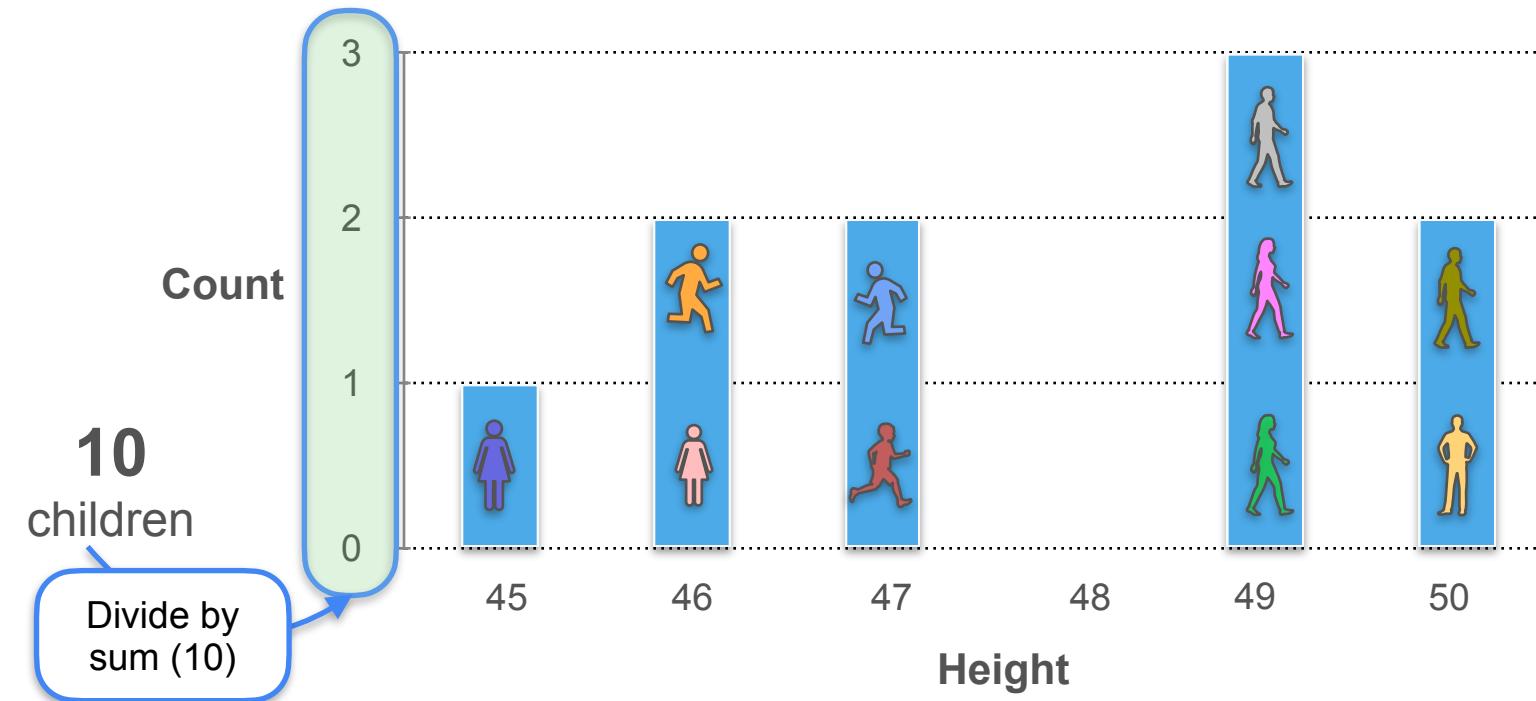
45      46      46      47      47      49      49      49      49      50

Height (in)	Count
45	1
46	2
47	2
48	0
49	4
50	1

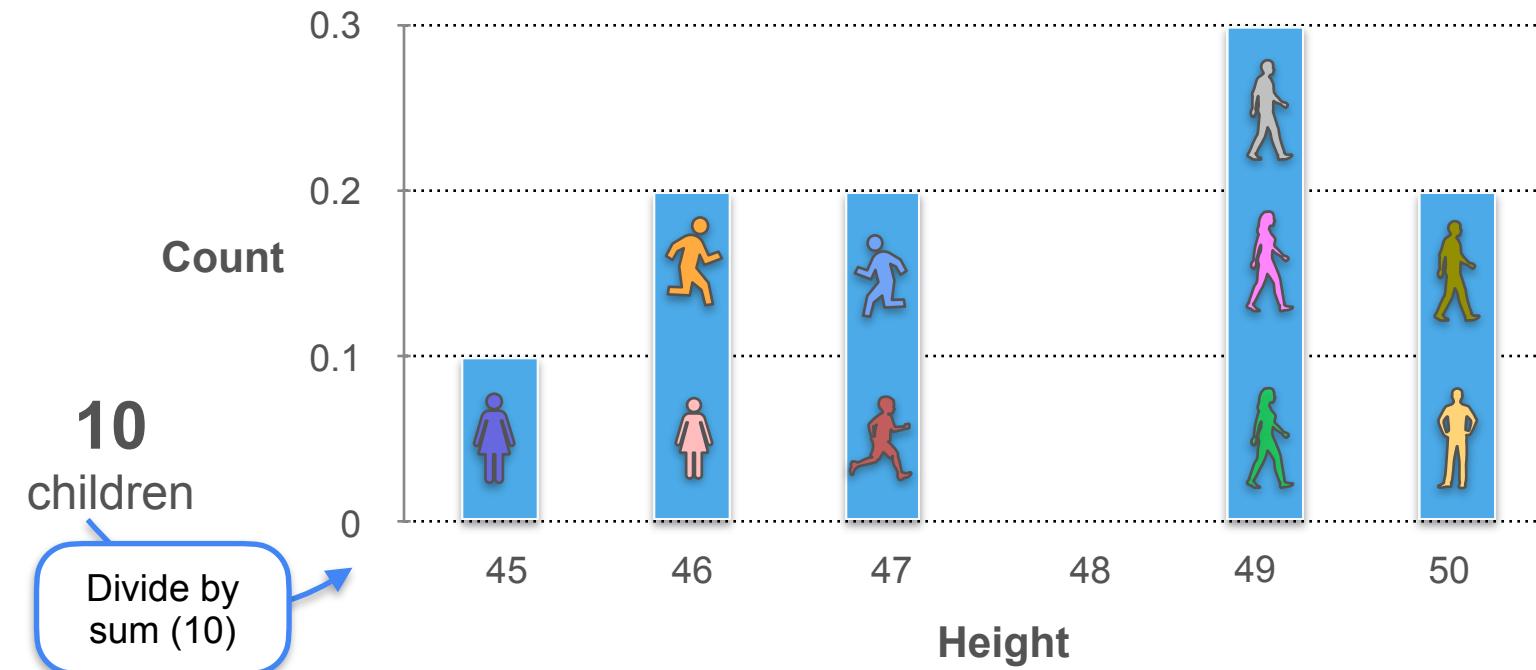
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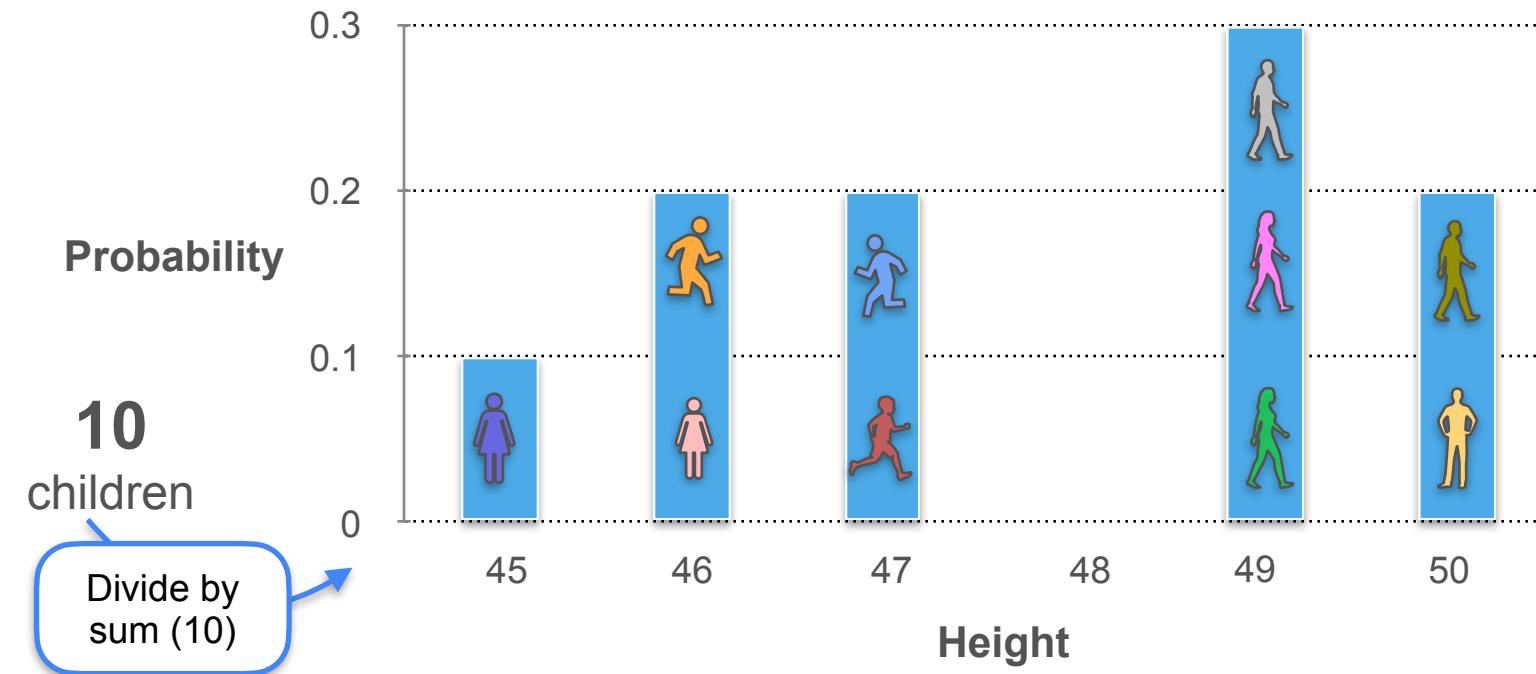
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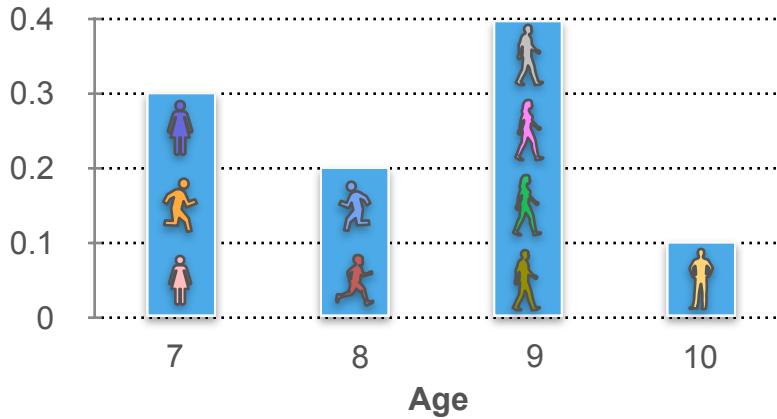


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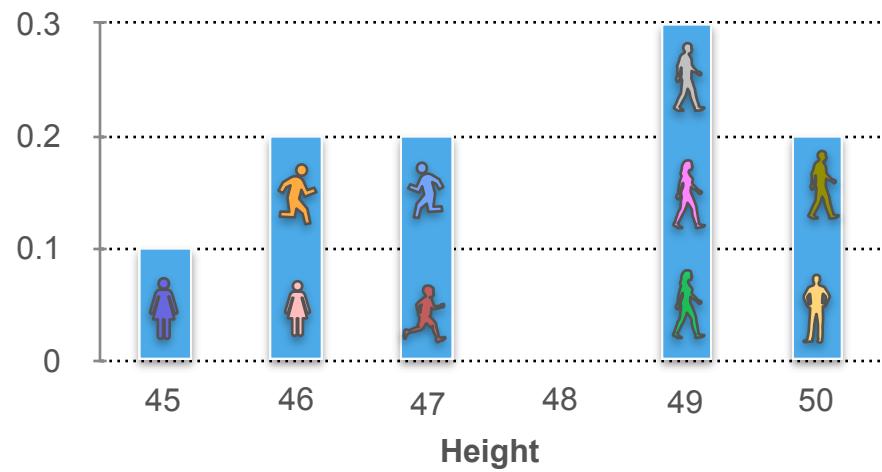
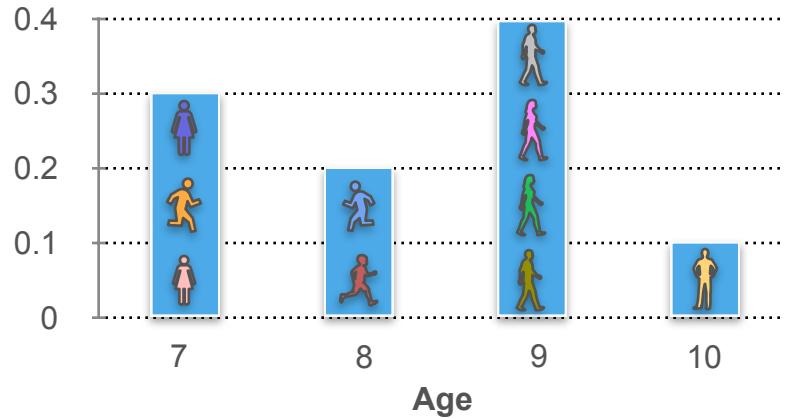


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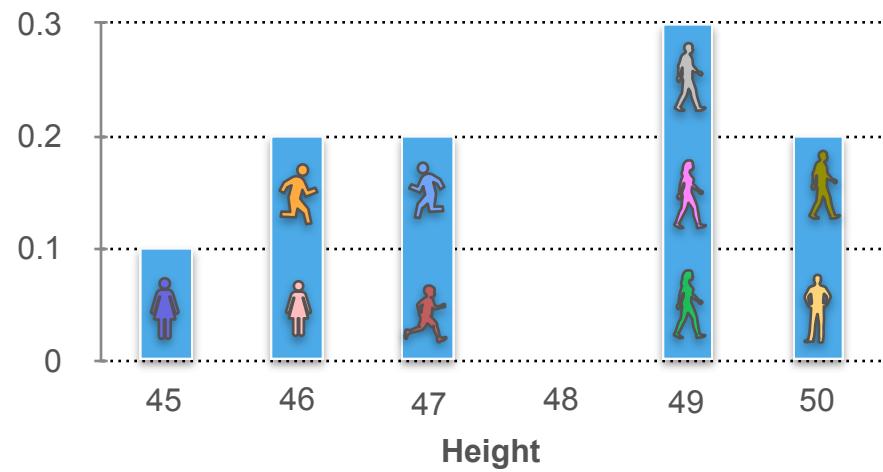
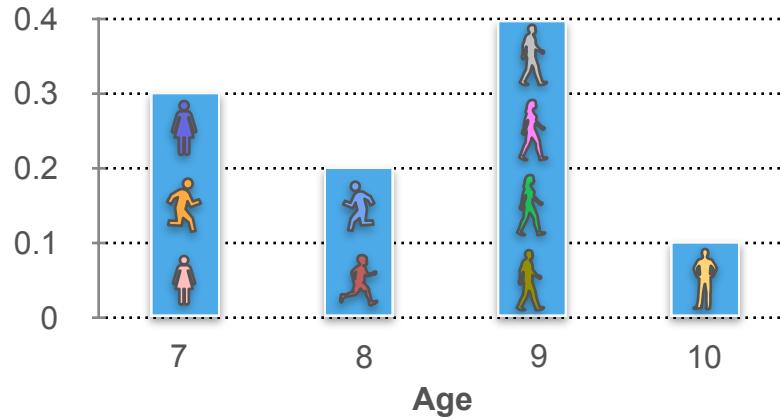
# Joint Distributions (Discrete): Example 1



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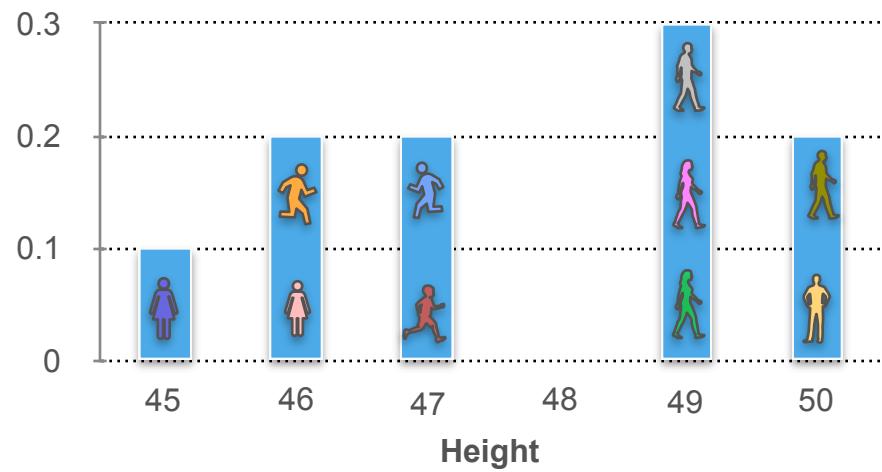
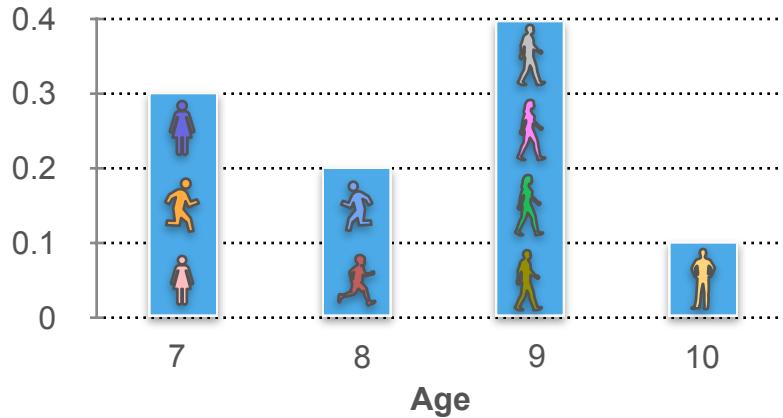


# Joint Distributions (Discrete): Example 1



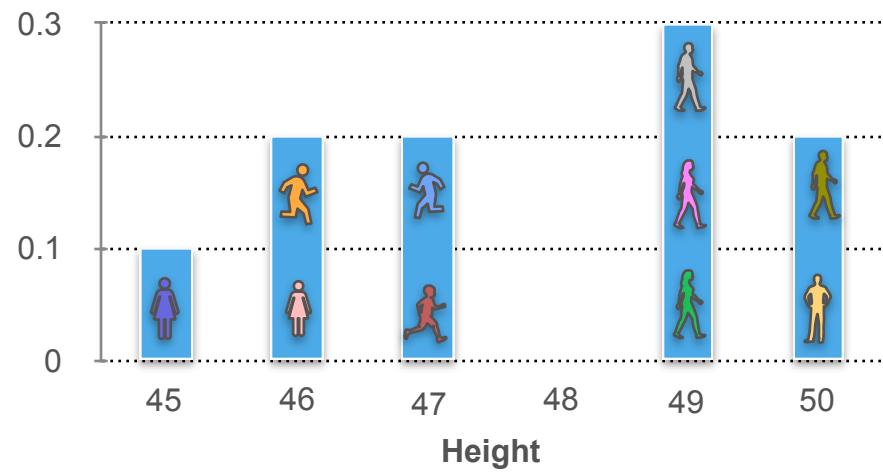
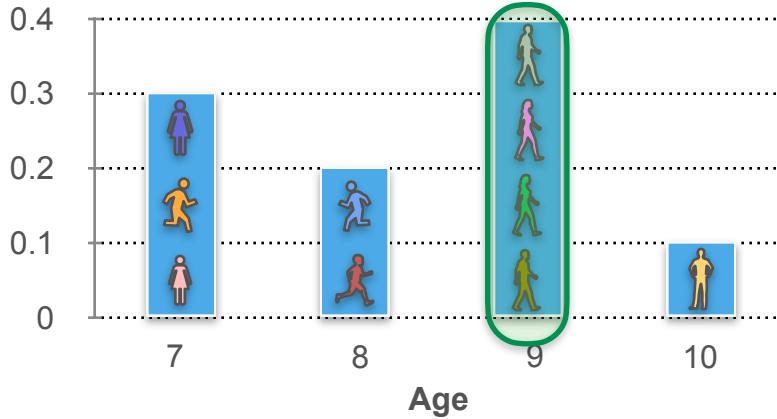
What is the probability that a child is **9 years** old and **49 inches** tall?

# Joint Distributions (Discrete): Example 1



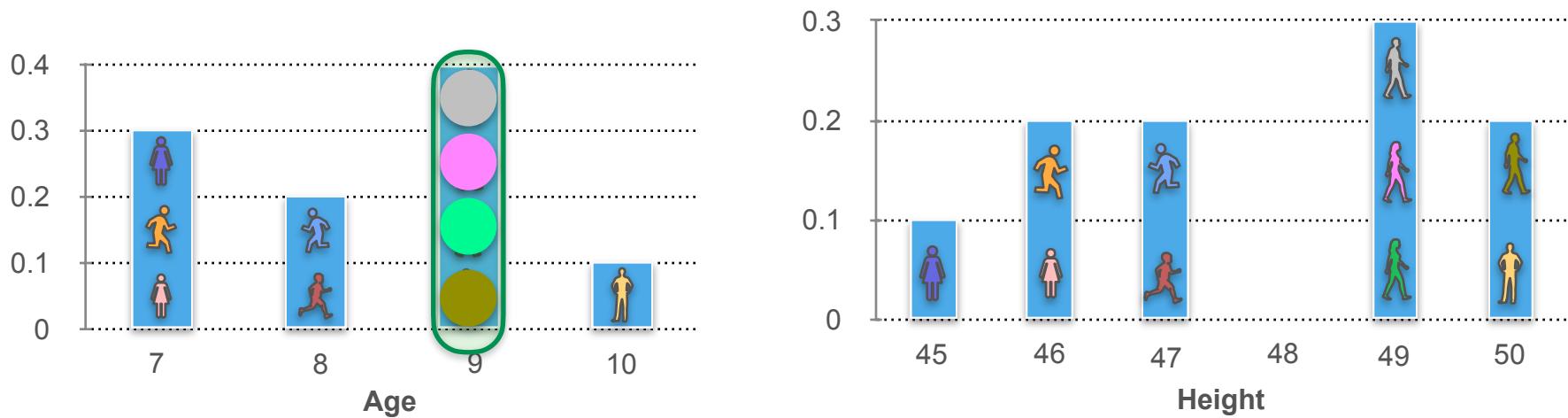
What is the probability that a child is **9 years** old and **49 inches** tall?

# Joint Distributions (Discrete): Example 1



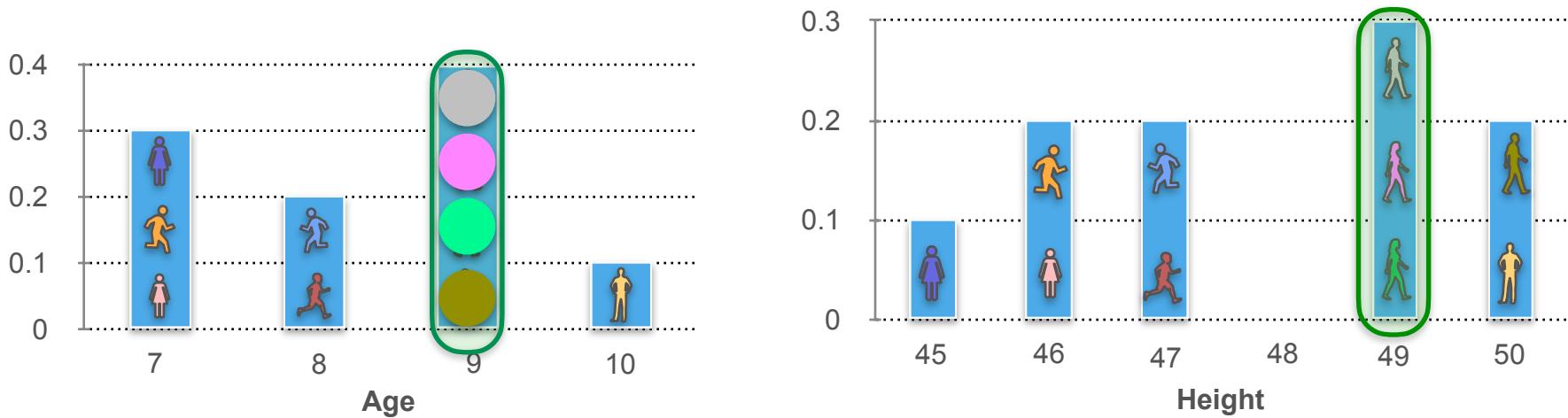
What is the probability that a child is **9 years** old and **49 inches** tall?

# Joint Distributions (Discrete): Example 1



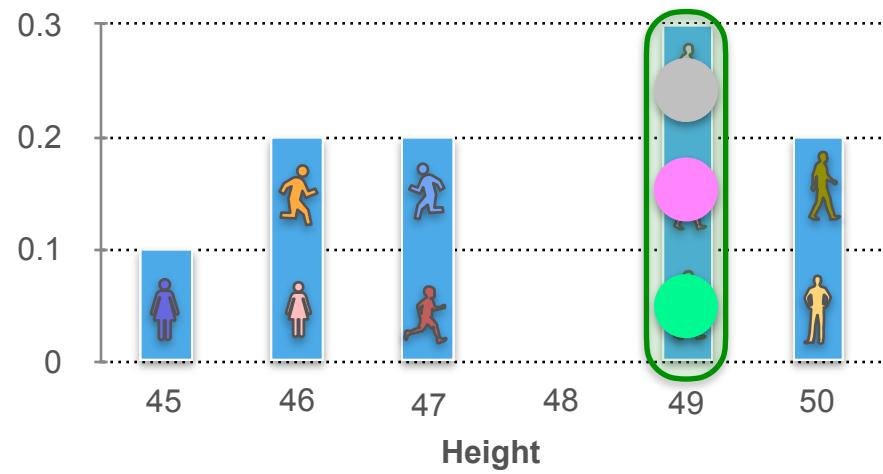
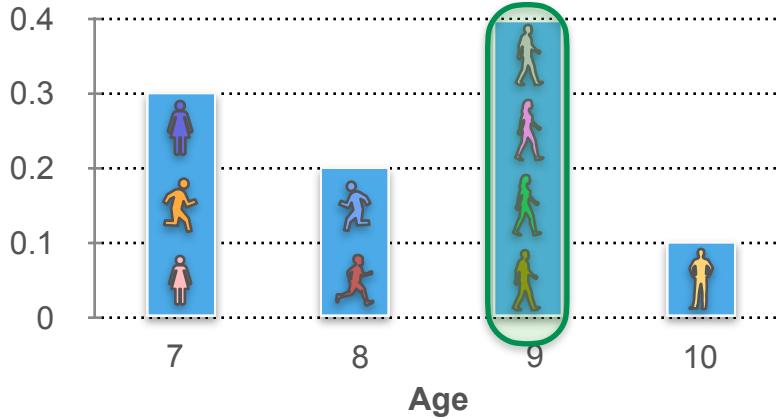
What is the probability that a child is **9 years** old and **49 inches** tall?

# Joint Distributions (Discrete): Example 1



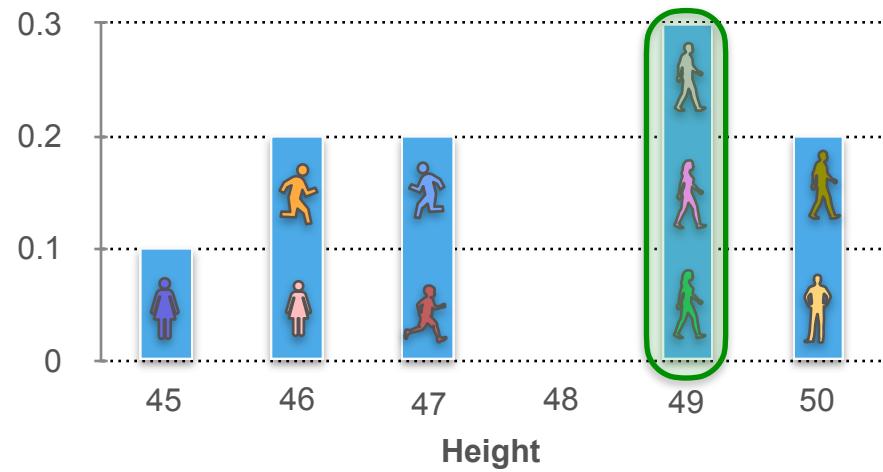
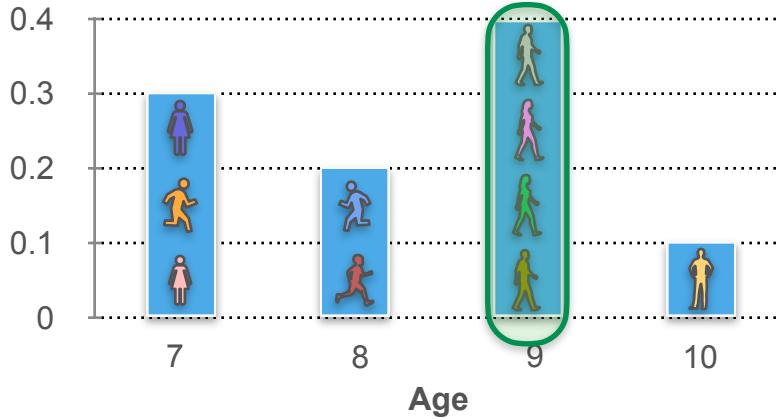
What is the probability that a child is **9 years** old and **49 inches** tall?

# Joint Distributions (Discrete): Example 1



What is the probability that a child is **9 years** old and **49 inches** tall?

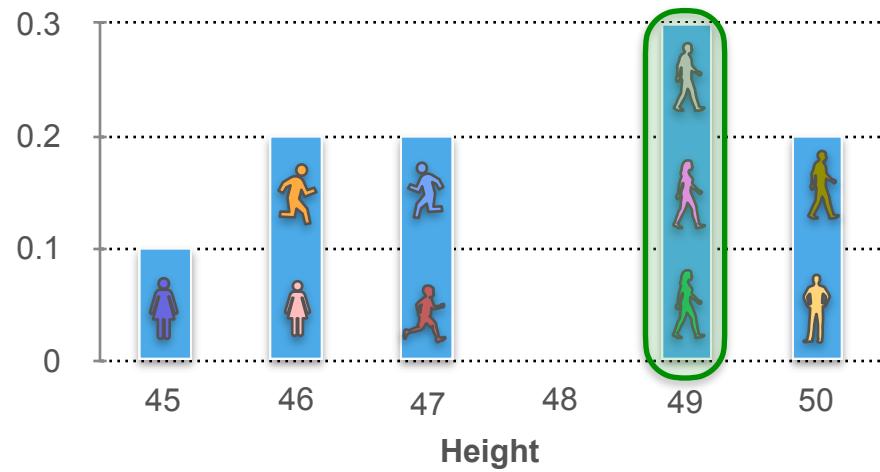
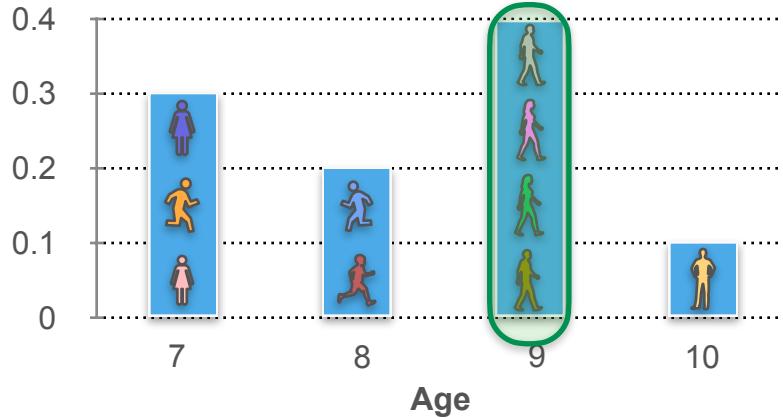
# Joint Distributions (Discrete): Example 1



What is the probability that a child is **9 years** old and **49 inches** tall?



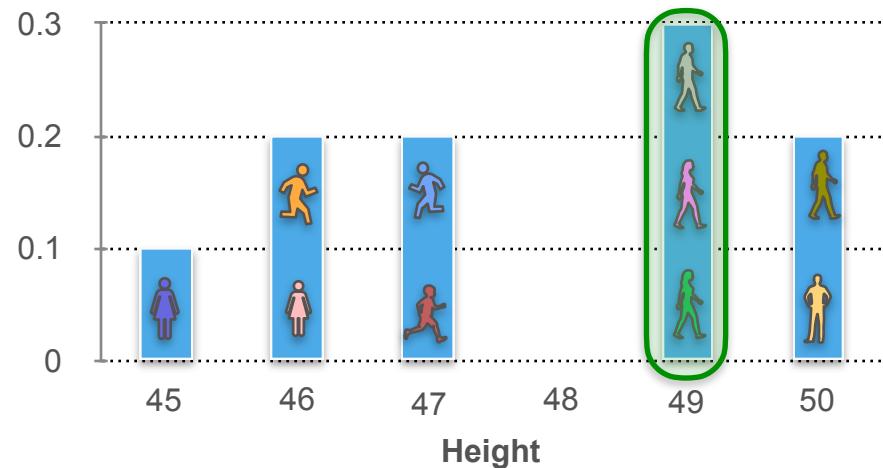
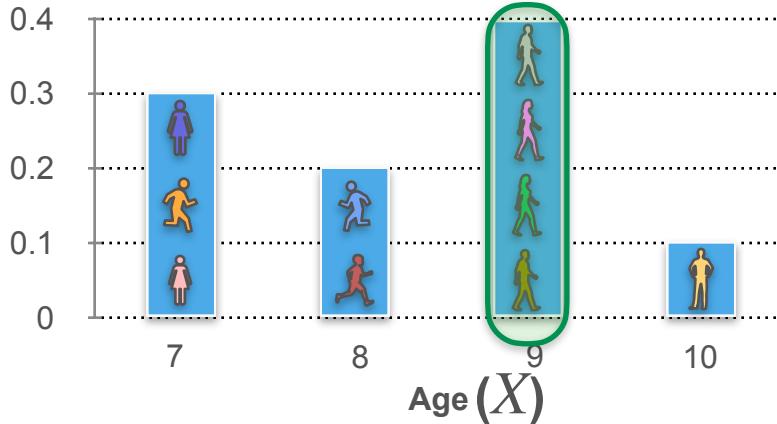
# Joint Distributions (Discrete): Example 1



What is the probability that a child is **9 years** old and **49 inches** tall?

$$\frac{\text{Grey circle} \times \text{Pink circle} \times \text{Green circle}}{10} = \frac{3}{10}$$

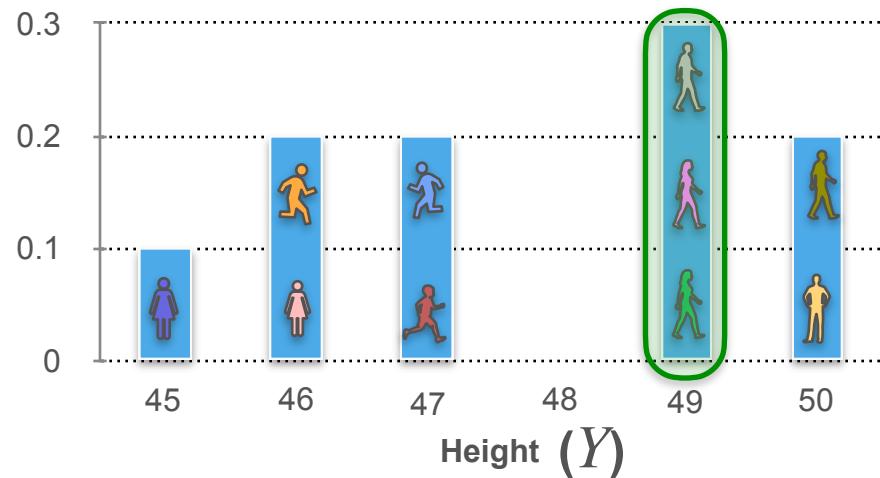
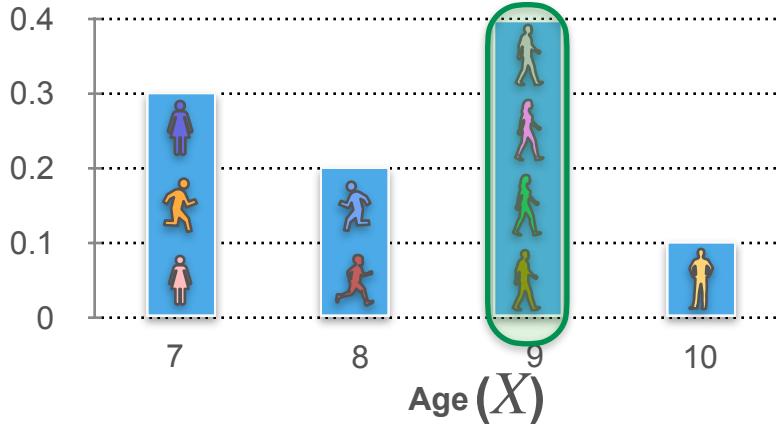
# Joint Distributions (Discrete): Example 1



What is the probability that a child is **9 years** old and **49 inches** tall?

$$\frac{\text{Grey circle} \times \text{Pink circle} \times \text{Green circle}}{10} = \frac{3}{10}$$

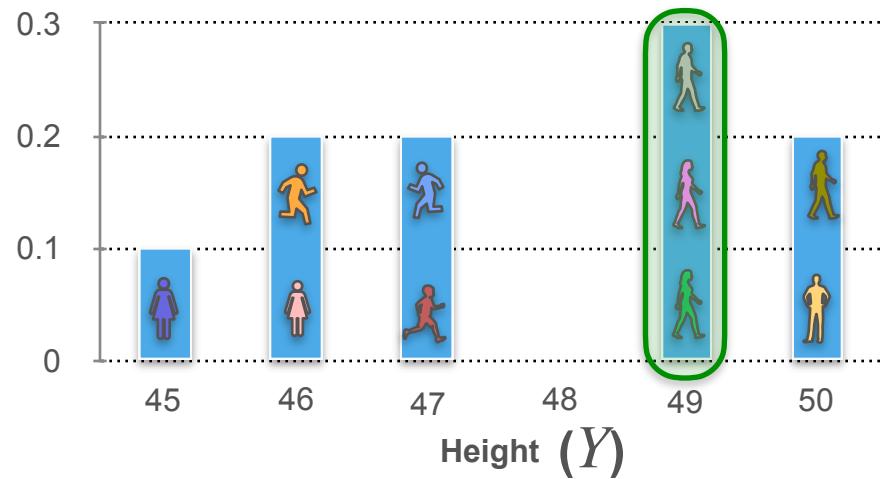
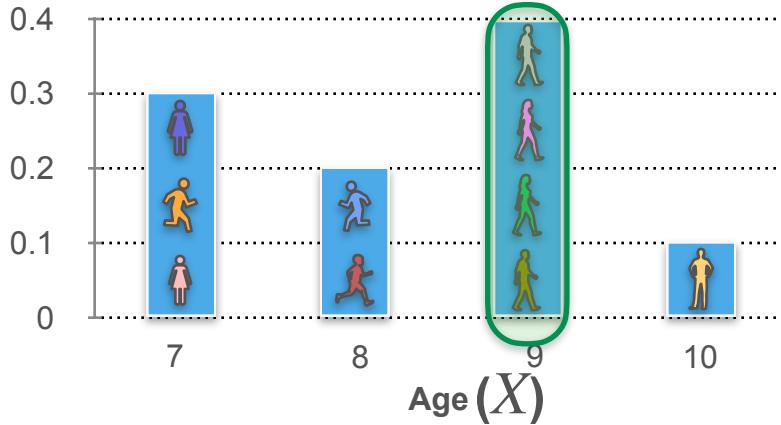
# Joint Distributions (Discrete): Example 1



What is the probability that a child is **9 years** old and **49 inches** tall?

$$\frac{\text{Number of favorable outcomes}}{\text{Total number of outcomes}} = \frac{3}{10}$$

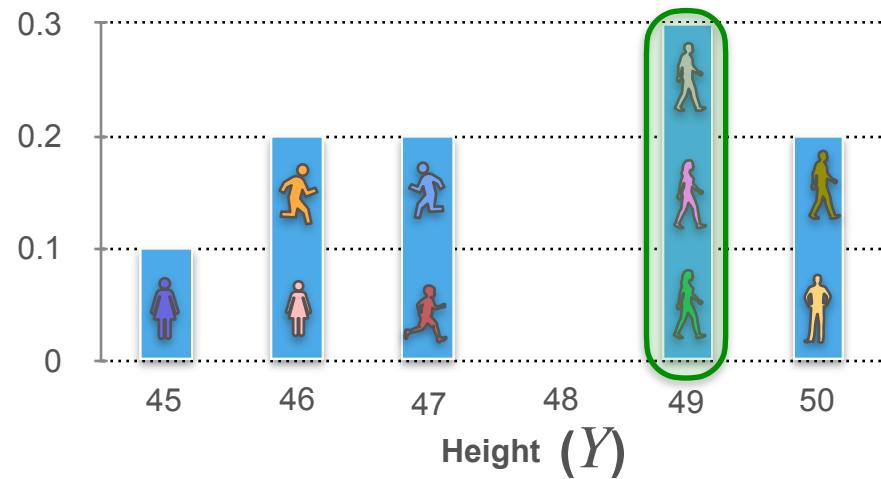
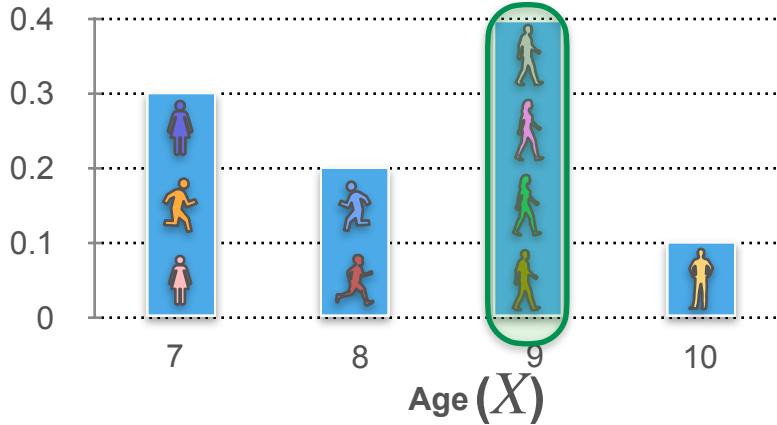
# Joint Distributions (Discrete): Example 1



What is the probability that a child is 9 years old and 49 inches tall?

$$\frac{3}{10} = \frac{3}{10}$$

# Joint Distributions (Discrete): Example 1

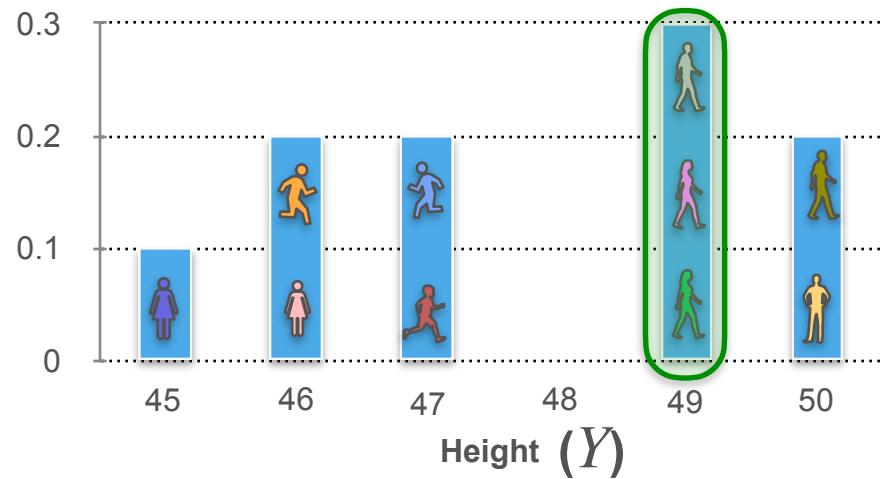
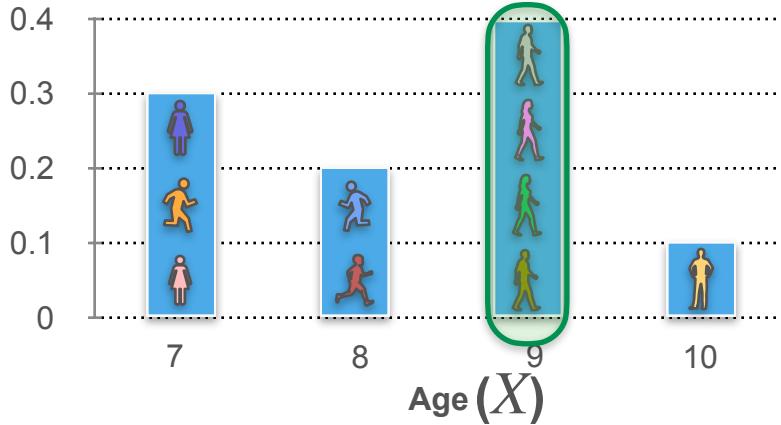


What is the probability that a child is 9 years old and 49 inches tall?

$$p_{XY}(9, 49)$$

$$\frac{3}{10} = \frac{3}{10}$$

# Joint Distributions (Discrete): Example 1



What is the probability that a child is 9 years old and 49 inches tall?

$$p_{XY}(9, 49) = P(X = 9, Y = 49) = \frac{3}{10}$$

# Joint Distributions (Discrete): Example 1

What is the probability that a child is **9 years** old and **49 inches** tall?

$$p_{XY}(9, 49) = \mathbf{P}(X = 9, Y = 49) = \frac{\text{_____}}{10} = \frac{3}{10}$$

# Joint Distributions (Discrete): Example 1

What is the probability that a child is **9 years** old and **49 inches** tall?

$$p_{XY}(9, 49) = \mathbf{P}(X = 9, Y = 49) = \frac{\text{_____}}{10} = \frac{3}{10}$$

$$p_{XY}(x, y)$$

# Joint Distributions (Discrete): Example 1

What is the probability that a child is **9 years** old and **49 inches** tall?

$$p_{XY}(9, 49) = \mathbf{P}(X = 9, Y = 49) = \frac{\text{_____}}{10} = \frac{3}{10}$$

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

# Joint Distributions: Example 1

										
Age (years):	7	7	7	8	8	9	9	9	9	10
Height (in):	45	46	46	47	47	49	49	49	50	50

# Joint Distributions: Example 1



Age (years): 7    7    7    8    8    9    9    9    9    10

Height (in): 45    46    46    47    47    49    49    49    50    50

		Height						
		45	46	47	48	49	50	
Age	7							
	8							
	9							
	10							

# Joint Distributions: Example 1

												
Age (years):	7	7	7	8	8	9	9	9	9	10		
Height (in):	45	46	46	47	47	49	49	49	50	50		

	Height						
	45	46	47	48	49	50	
Age	7	1					
	8						
	9						
	10						

# Joint Distributions: Example 1

										
Age (years):	7	7	7	8	8	9	9	9	9	10
Height (in):	45	46	46	47	47	49	49	49	50	50

		Height						
		45	46	47	48	49	50	
Age	7	1	2					
	8							
	9							
	10							

# Joint Distributions: Example 1



Age (years): 7    7    7    8    8    9    9    9    9    10

Height (in): 45    46    46    47    47    49    49    49    50    50

		Height						
		45	46	47	48	49	50	
Age	7	1	2	0	0	0	0	
	8							
	9							
	10							

# Joint Distributions: Example 1



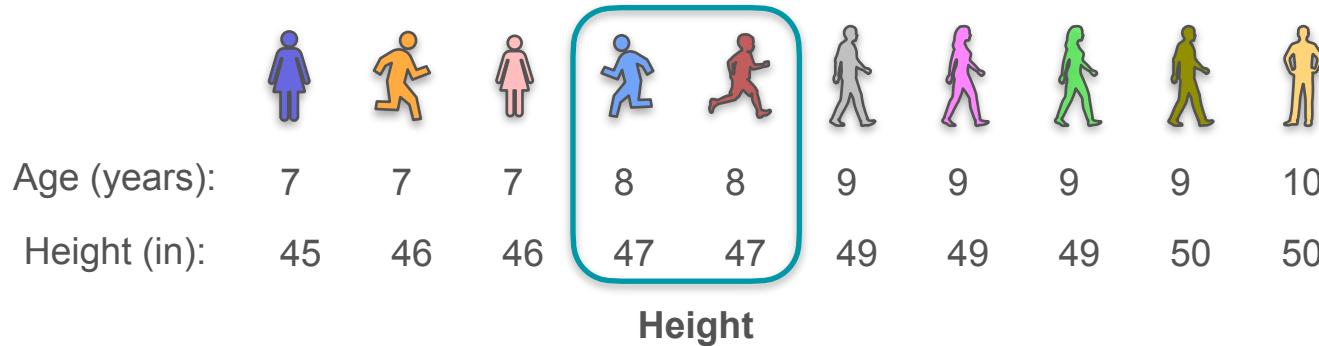
Age (years): 7    7    7    8    8    9    9    9    9    10

Height (in): 45    46    46    47    47    49    49    49    50    50

Height

	45	46	47	48	49	50
7	1	2	0	0	0	0
8	0	0				
9						
10						

# Joint Distributions: Example 1



	45	46	47	48	49	50
7	1	2	0	0	0	0
8	0	0	2			
9						
10						

# Joint Distributions: Example 1



Age (years): 7    7    7    8    8    9    9    9    9    10

Height (in): 45    46    46    47    47    49    49    49    50    50

Height

	45	46	47	48	49	50
7	1	2	0	0	0	0
8	0	0	2	0	0	0
9						
10						

# Joint Distributions: Example 1



Age (years): 7    7    7    8    8    9    9    9    9    10

Height (in): 45    46    46    47    47    49    49    49    50    50

Height

	45	46	47	48	49	50
7	1	2	0	0	0	0
8	0	0	2	0	0	0
9	0	0	0	0		
10						

# Joint Distributions: Example 1

Age (years):	7	7	7	8	8	9	9	9	9
Height (in):	45	46	46	47	47	49	49	49	50

		Height					
		45	46	47	48	49	50
Age	7	1	2	0	0	0	0
	8	0	0	2	0	0	0
	9	0	0	0	0	3	
	10						

# Joint Distributions: Example 1

Age (years):	7	7	7	8	8	9	9	9	10
Height (in):	45	46	46	47	47	49	49	49	50

		Height						
		45	46	47	48	49	50	
Age	7	1	2	0	0	0	0	
	8	0	0	2	0	0	0	
	9	0	0	0	0	3	1	
	10							

# Joint Distributions: Example 1



Age (years): 7    7    7    8    8    9    9    9    9    10

Height (in): 45    46    46    47    47    49    49    49    50    50

Height

	45	46	47	48	49	50
7	1	2	0	0	0	0
8	0	0	2	0	0	0
9	0	0	0	0	3	1
10	0	0	0	0	0	

# Joint Distributions: Example 1

										
Age (years):	7	7	7	8	8	9	9	9	9	10
Height (in):	45	46	46	47	47	49	49	49	50	50

		Height						
		45	46	47	48	49	50	
Age	7	1	2	0	0	0	0	
	8	0	0	2	0	0	0	
	9	0	0	0	0	3	1	
	10	0	0	0	0	0	1	

# Joint Distributions: Example 1



Age (years): 7    7    7    8    8    9    9    9    9    10

Height (in): 45    46    46    47    47    49    49    49    50    50

Height

	45	46	47	48	49	50
7	1	2	0	0	0	0
8	0	0	2	0	0	0
9	0	0	0	0	3	1
10	0	0	0	0	0	1

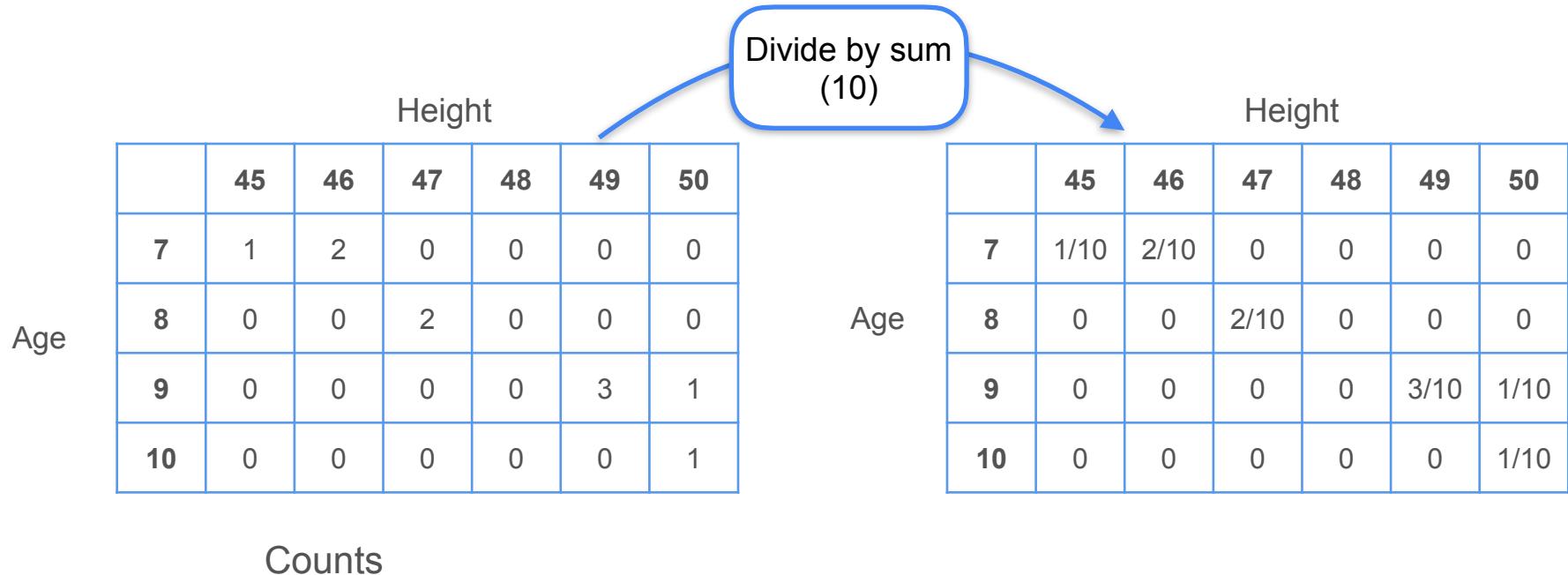
# Joint Distributions: Example 1

Height

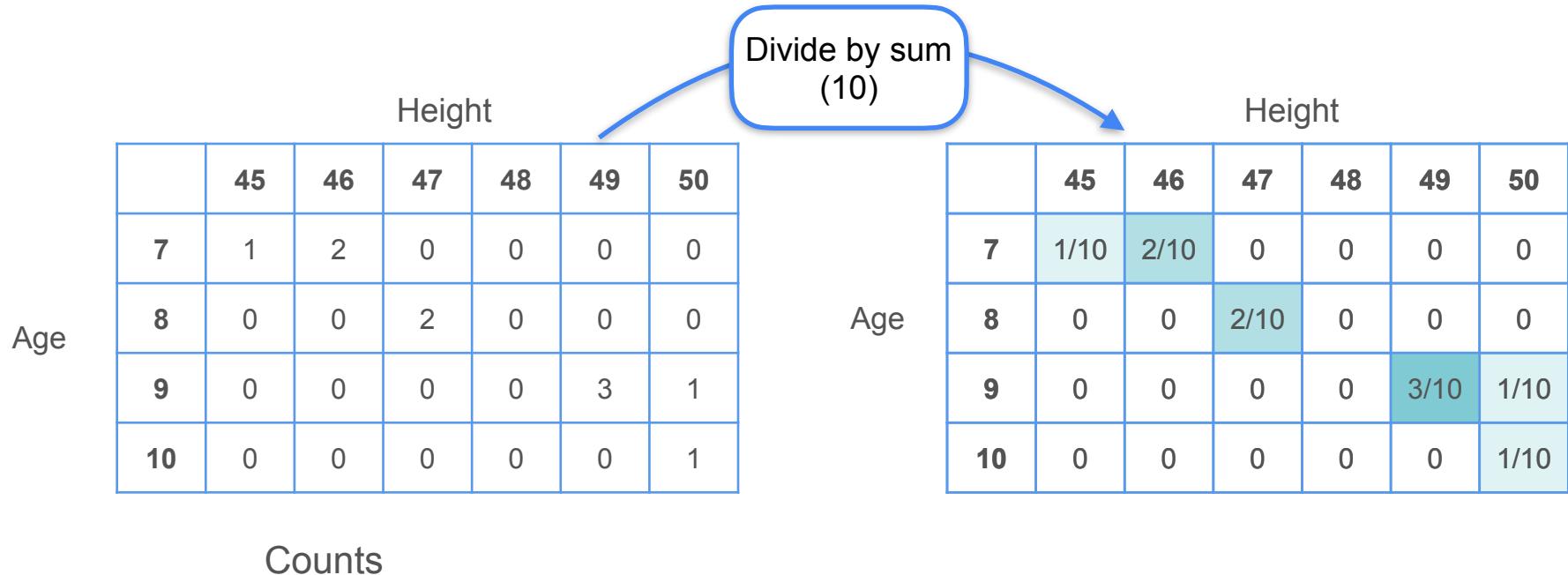
	45	46	47	48	49	50
7	1	2	0	0	0	0
8	0	0	2	0	0	0
9	0	0	0	0	3	1
10	0	0	0	0	0	1

Counts

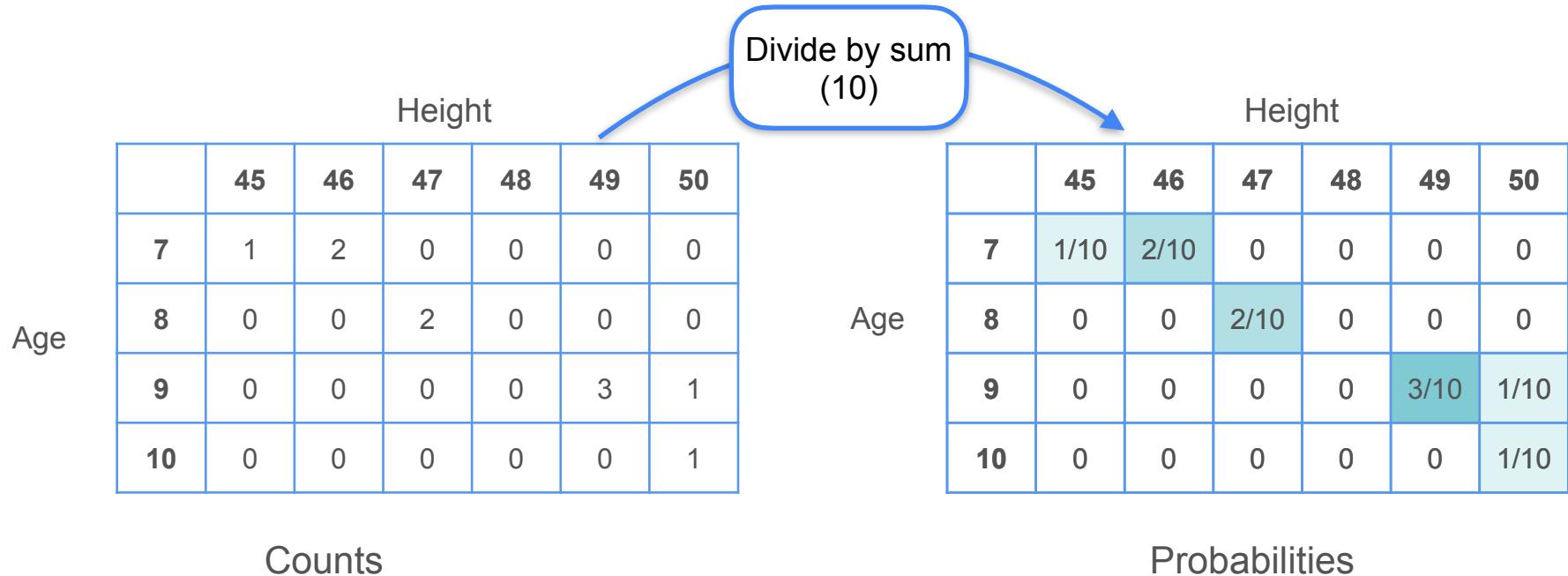
# Joint Distributions: Example 1



# Joint Distributions: Example 1



# Joint Distributions: Example 1



# Joint Distributions: Example 1

		Height						
		45	46	47	48	49	50	
Age	7	1/10	2/10	0	0	0	0	
	8	0	0	2/10	0	0	0	
	9	0	0	0	0	3/10	1/10	
	10	0	0	0	0	0	1/10	

Probabilities

# Joint Distributions: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10

Probabilities

# Joint Distributions: Example 1

All probabilities for all possible combinations of X and Y

Age  
(X)

Height (Y)

	45	46	47	48	49	50
7	1/10	2/10	0	0	0	0
8	0	0	2/10	0	0	0
9	0	0	0	0	3/10	1/10
10	0	0	0	0	0	1/10

Probabilities

# Joint Distributions: Example 1

## Joint Distribution

All probabilities for all possible combinations of X and Y

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		Probabilities					

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10

Probabilities

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10

Probabilities

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

$$p_{XY}(8, 48) = \mathbf{P}(X = 8, Y = 48)$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
	Probabilities						

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

$$p_{XY}(8, 48) = \mathbf{P}(X = 8, Y = 48)$$

	Height ( $Y$ )					
	45	46	47	48	49	50
7	1/10	2/10	0		0	0
8	0	0	2/10	0	0	0
9	0	0	0	0	3/10	1/10
10	0	0	0	0	0	1/10

Age ( $X$ )

Probabilities

Height ( $Y$ )

Age ( $X$ )

Probabilities

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

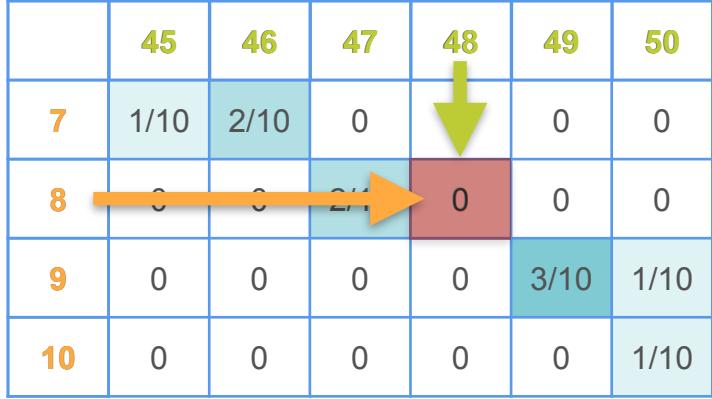
$$p_{XY}(8, 48) = \mathbf{P}(X = 8, Y = 48)$$

$$p_{XY}(8, 48) = 0$$

	Height ( $Y$ )					
	45	46	47	48	49	50
7	1/10	2/10	0		0	0
8	0	0	2/10	0	0	0
9	0	0	0	0	3/10	1/10
10	0	0	0	0	0	1/10

Age ( $X$ )

Probabilities



# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

$$p_{XY}(8, 48) = \mathbf{P}(X = 8, Y = 48)$$

$$p_{XY}(8, 48) = 0$$

$$p_{XY}(7, 46) =$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
	Probabilities						

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

$$p_{XY}(8, 48) = \mathbf{P}(X = 8, Y = 48)$$

$$p_{XY}(8, 48) = 0$$

$$p_{XY}(7, 46) =$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
	Probabilities						

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

$$p_{XY}(8, 48) = \mathbf{P}(X = 8, Y = 48)$$

$$p_{XY}(8, 48) = 0$$

$$p_{XY}(7, 46) =$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/1	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
	Probabilities						

# Joint Distributions: Example 1

What is the probability that a child is 8 and 48 inches tall?

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y)$$

$$p_{XY}(8, 48) = \mathbf{P}(X = 8, Y = 48)$$

$$p_{XY}(8, 48) = 0$$

$$p_{XY}(7, 46) = \frac{2}{10}$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/1	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
	Probabilities						

# Joint Distributions (Discrete): Example 2

# Joint Distributions (Discrete): Example 2

$X$

# Joint Distributions (Discrete): Example 2

$X$

the number rolled on the 1st dice

# Joint Distributions (Discrete): Example 2

$X$

the number rolled on the 1st dice

$Y$

# Joint Distributions (Discrete): Example 2

$X$

the number rolled on the 1st dice

$Y$

the number rolled on the 2nd dice

# Joint Distributions (Discrete): Example 2

$X$

the number rolled on the 1st dice



$Y$

the number rolled on the 2nd dice

# Joint Distributions (Discrete): Example 2

$X$

the number rolled on the 1st dice



$$\frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6}$$

$Y$

the number rolled on the 2nd dice

# Joint Distributions (Discrete): Example 2

$X$

the number rolled on the 1st dice



$$\frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6}$$

$Y$

the number rolled on the 2nd dice



# Joint Distributions (Discrete): Example 2

$X$

the number rolled on the 1st dice



$$\frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6}$$

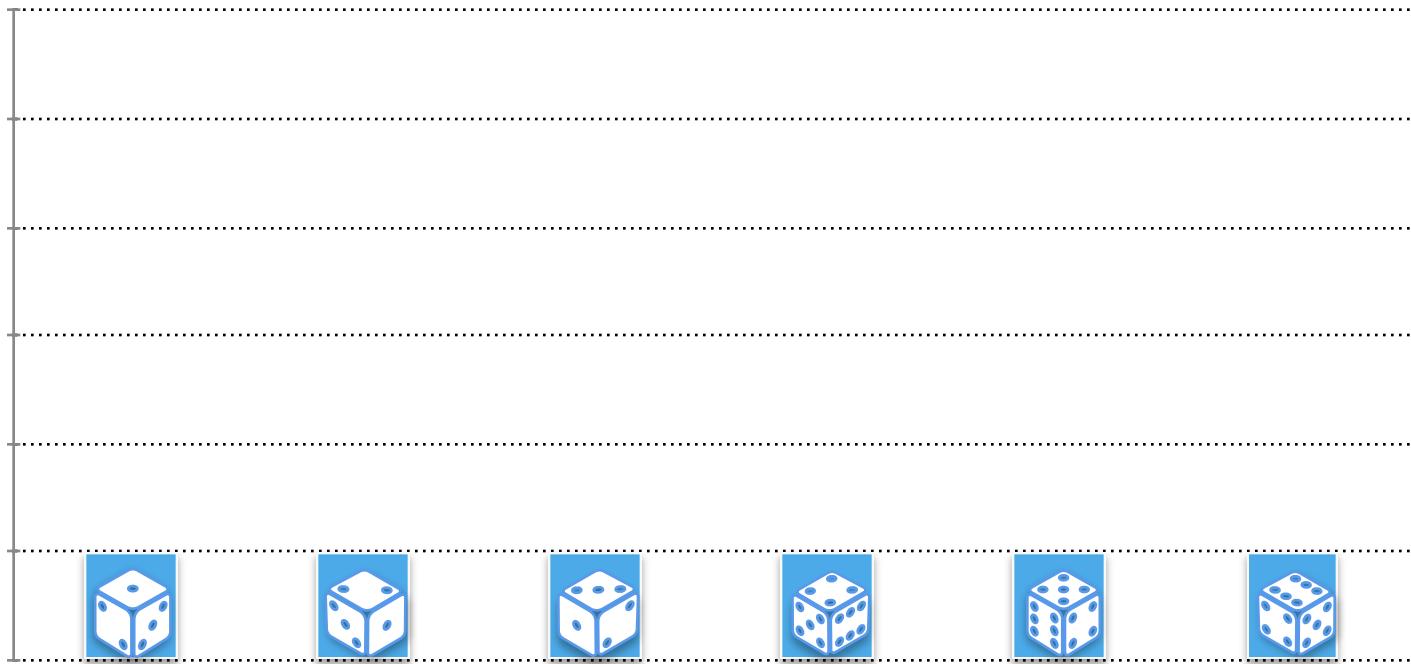
$Y$

the number rolled on the 2nd dice

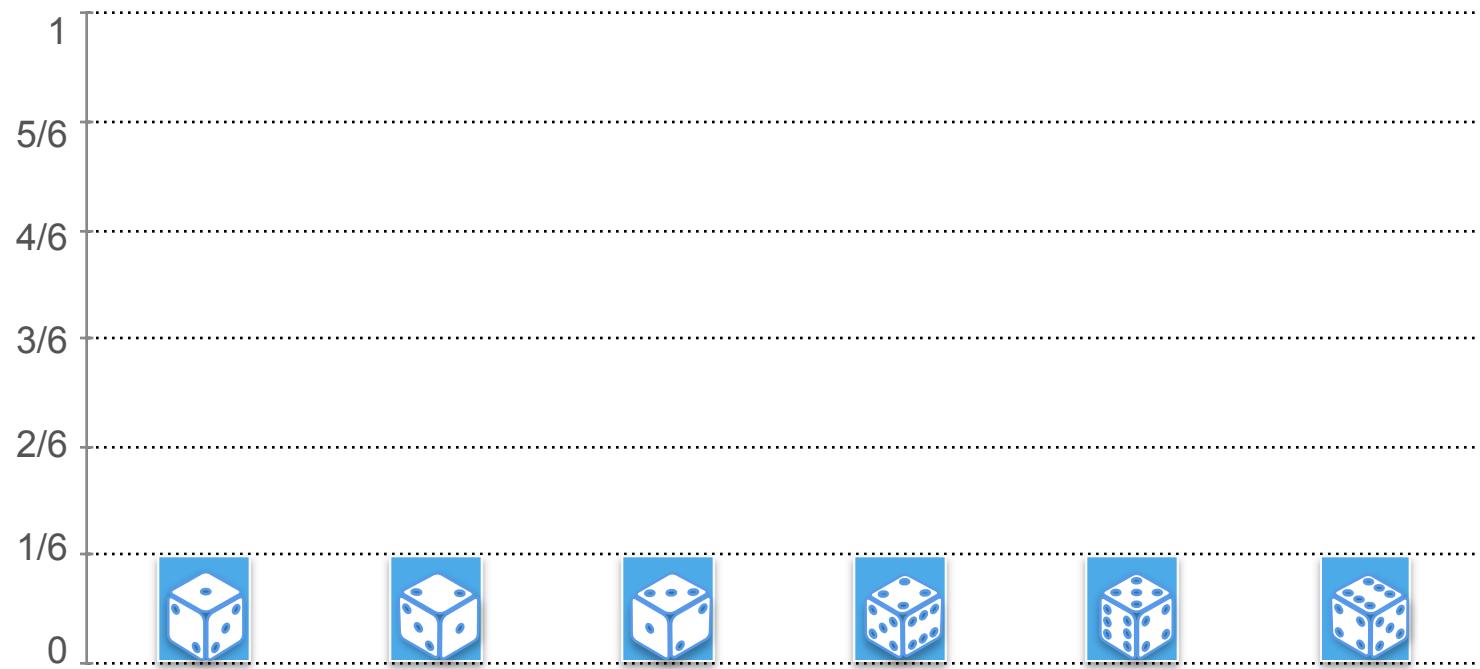


$$\frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6}$$

# Joint Distributions: Example 2



# Joint Distributions: Example 2



# Joint Distributions: Example 2

# Joint Distributions: Example 2

$X$

# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$

# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

						
$P(x)$	1/6	1/6	1/6	1/6	1/6	1/6
$P(y)$	1/6	1/6	1/6	1/6	1/6	1/6

# Joint Distributions: Example 2

$X$  : the number rolled on the 1st dice

$Y$  : the number rolled on the 2nd dice



$P(x)$     1/6    1/6    1/6    1/6    1/6    1/6

$P(y)$     1/6    1/6    1/6    1/6    1/6    1/6

	1	2	3	4	5	6
X	1					
	2					
	3					
	4					
	5					
	6					

# Joint Distributions: Example 2

$X$  : the number rolled on the 1st dice

$Y$  : the number rolled on the 2nd dice

**$X$  and  $Y$  are independent**



$P(x)$     1/6    1/6    1/6    1/6    1/6    1/6

$P(y)$     1/6    1/6    1/6    1/6    1/6    1/6

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

**$X$  and  $Y$  are independent**



$$\mathbf{P}(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$\mathbf{P}(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice 1}, \text{dice 2})$$

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

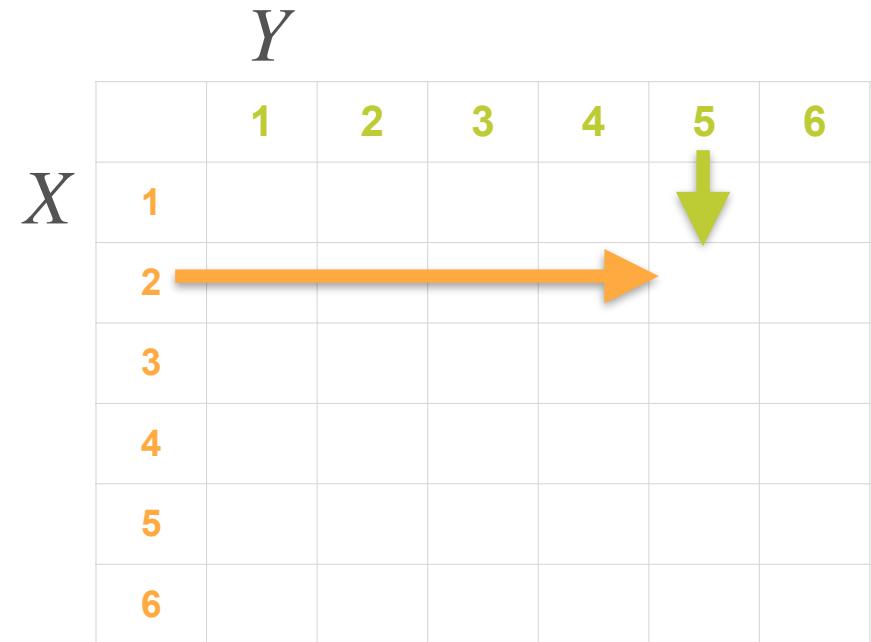
**$X$  and  $Y$  are independent**



$$\mathbf{P}(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$\mathbf{P}(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{orange die}, \text{yellow die})$$



# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

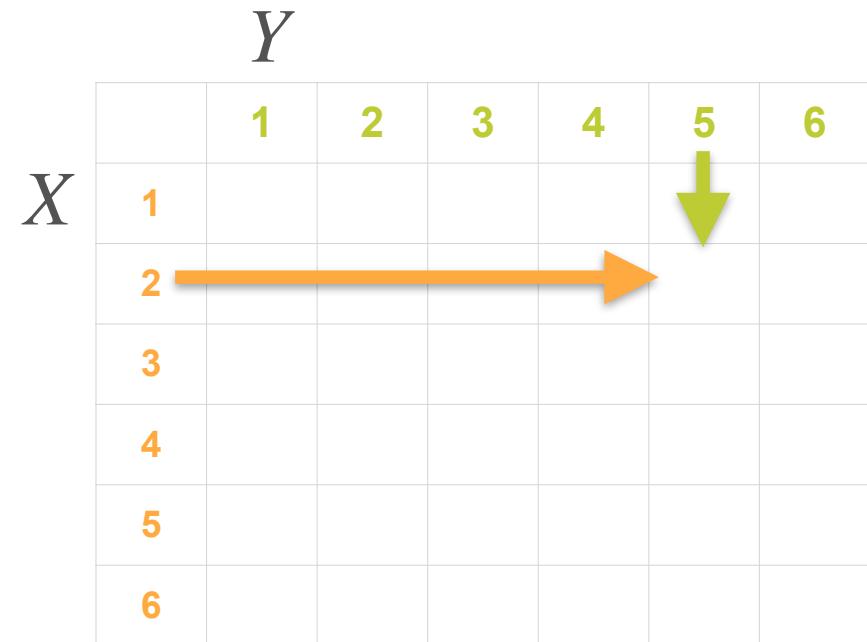
**$X$  and  $Y$  are independent**



$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } 1, \text{dice } 2) = P(\text{dice } 1) \cdot P(\text{dice } 2)$$



# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

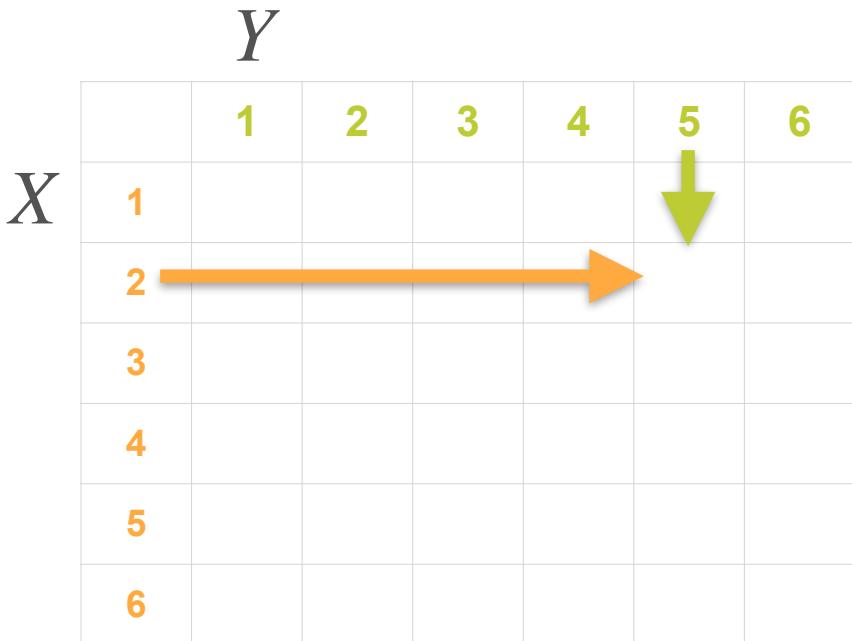
**$X$  and  $Y$  are independent**



$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } 1, \text{dice } 2) = P(\text{dice } 1) \cdot P(\text{dice } 2) = \frac{1}{6} \cdot \frac{1}{6}$$



# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

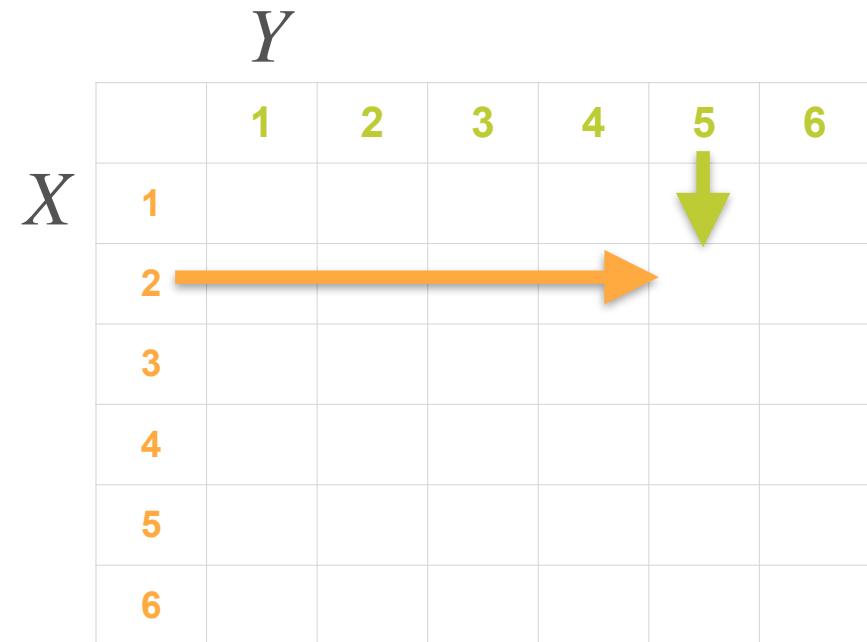
**$X$  and  $Y$  are independent**



$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } 1, \text{dice } 2) = P(\text{dice } 1) \cdot P(\text{dice } 2) = \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{36}$$



# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

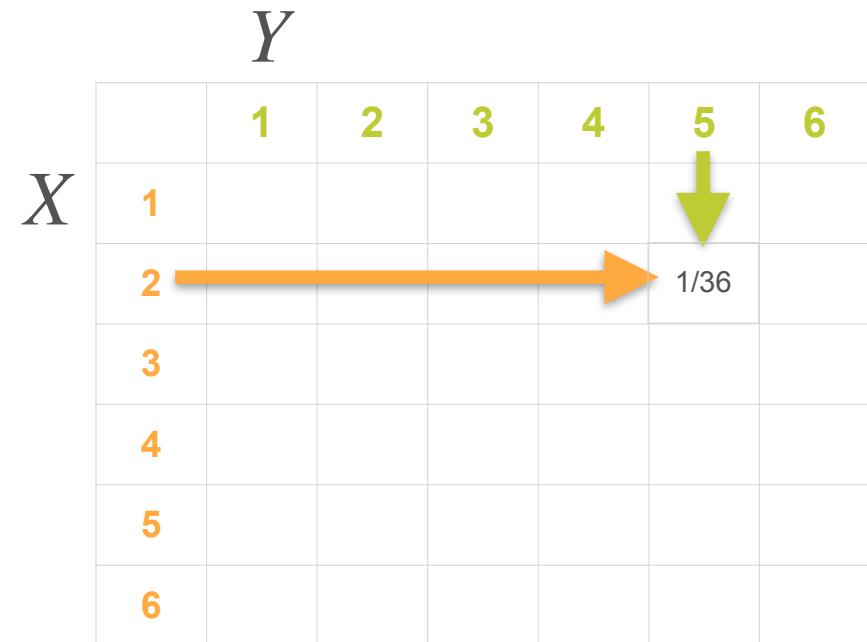
$X$  and  $Y$  are independent



$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } 1, \text{dice } 2) = P(\text{dice } 1) \cdot P(\text{dice } 2) = \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{36}$$



# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

**$X$  and  $Y$  are independent**

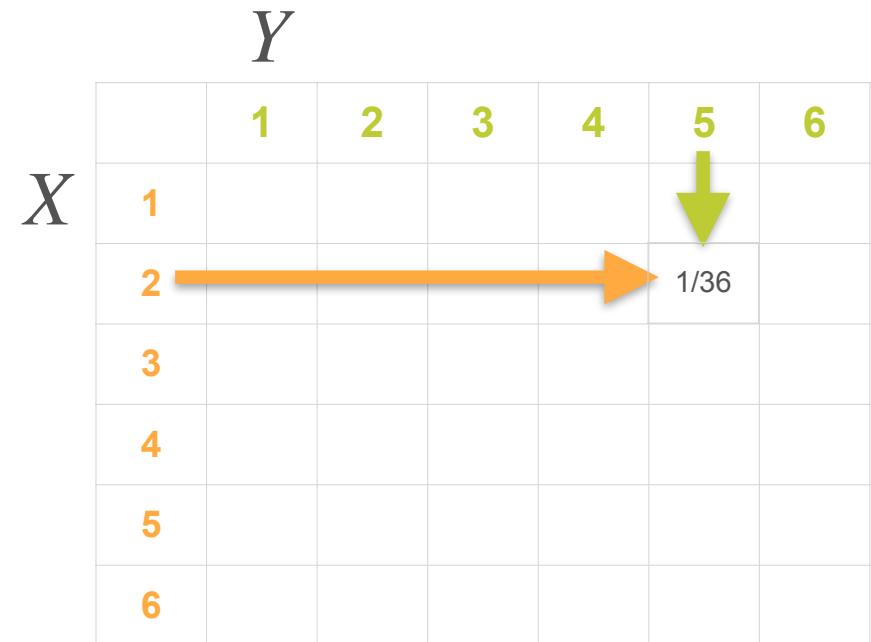


$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } 1, \text{dice } 2) = P(\text{dice } 1) \cdot P(\text{dice } 2) = \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{36}$$

$$p_{XY}(x, y) = P(X = x, Y = y)$$



# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

**$X$  and  $Y$  are independent**

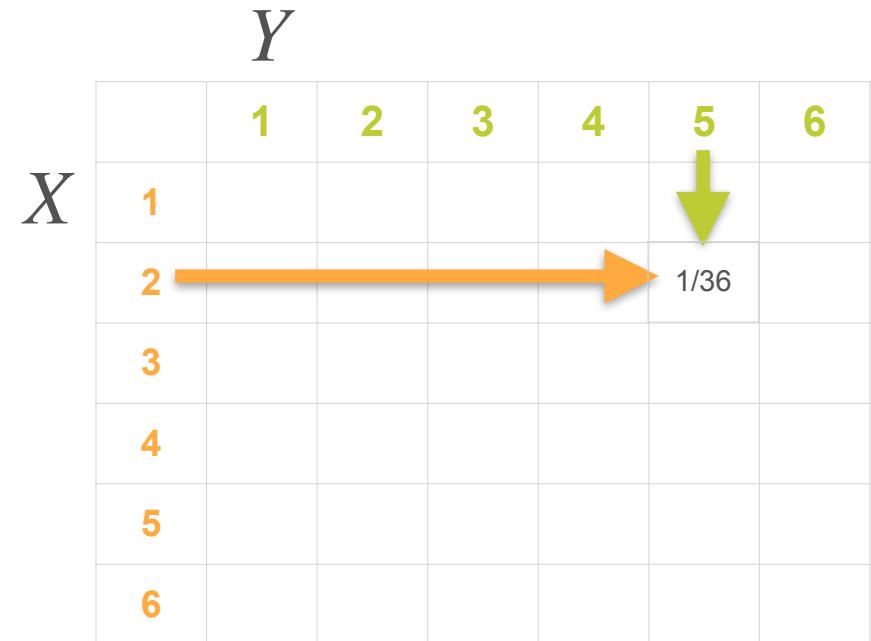


$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } 1, \text{dice } 2) = P(\text{dice } 1) \cdot P(\text{dice } 2) = \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{36}$$

$$p_{XY}(x, y) = P(X = x, Y = y) = \frac{1}{36}$$



# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

**$X$  and  $Y$  are independent**



$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } 1, \text{dice } 2) = P(\text{dice } 1) \cdot P(\text{dice } 2) = \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{36}$$

$$p_{XY}(x, y) = P(X = x, Y = y) = \frac{1}{36}$$

	1	2	3	4	5	6
1						
2						
3						
4						
5						
6						

# Joint Distributions: Example 2

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

**$X$  and  $Y$  are independent**



$$P(x) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$P(y) \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6 \quad 1/6$$

$$p_{XY}(\text{dice } x, \text{dice } y) = P(\text{dice } x) \cdot P(\text{dice } y) = \frac{1}{6} \cdot \frac{1}{6} = \frac{1}{36}$$

$$p_{XY}(x, y) = P(X = x, Y = y) = \frac{1}{36}$$

	$Y$	1	2	3	4	5	6
$X$	1	1/36	1/36	1/36	1/36	1/36	1/36
2	1/36	1/36	1/36	1/36	1/36	<b>1/36</b>	1/36
3	1/36	1/36	1/36	1/36	1/36	1/36	1/36
4	1/36	1/36	1/36	1/36	1/36	1/36	1/36
5	1/36	1/36	1/36	1/36	1/36	1/36	1/36
6	1/36	1/36	1/36	1/36	1/36	1/36	1/36

# Joint Distributions: Example 2

# Joint Distributions: Example 2

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y) = \mathbf{P}(x) \cdot \mathbf{P}(y)$$

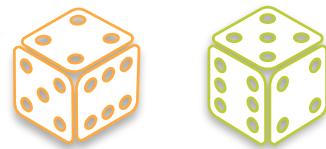
# Joint Distributions: Example 2

Thus for independent discrete random variables:

$$p_{XY}(x, y) = \mathbf{P}(X = x, Y = y) = \mathbf{P}(x) \cdot \mathbf{P}(y)$$

# Joint Distributions (Discrete): Example 2

# Joint Distributions (Discrete): Example 2



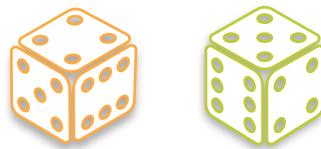
# Joint Distributions (Discrete): Example 2

$X$



# Joint Distributions (Discrete): Example 2

$X$



the number rolled on the 1st dice

# Joint Distributions (Discrete): Example 2

$X$

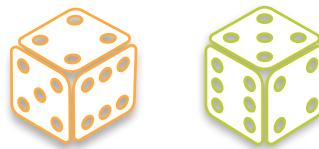


the number rolled on the 1st dice



# Joint Distributions (Discrete): Example 2

$X$



the number rolled on the 1st dice



$$X = 4$$

# Joint Distributions (Discrete): Example 2

$X$



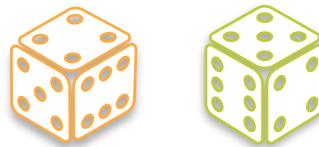
$Y$

the number rolled on the 1st dice



# Joint Distributions (Discrete): Example 2

$X$



$Y$

the number rolled on the 1st dice

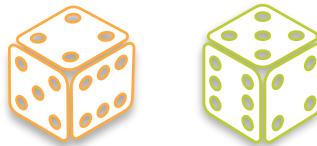
sum of the two dice



$$X = 4$$

# Joint Distributions (Discrete): Example 2

$X$



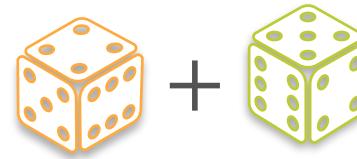
$Y$

the number rolled on the 1st dice

sum of the two dice



$$X = 4$$



$$Y = 4 + 5$$

# Joint Distributions: Example 2

# Joint Distributions: Example 2

$X$

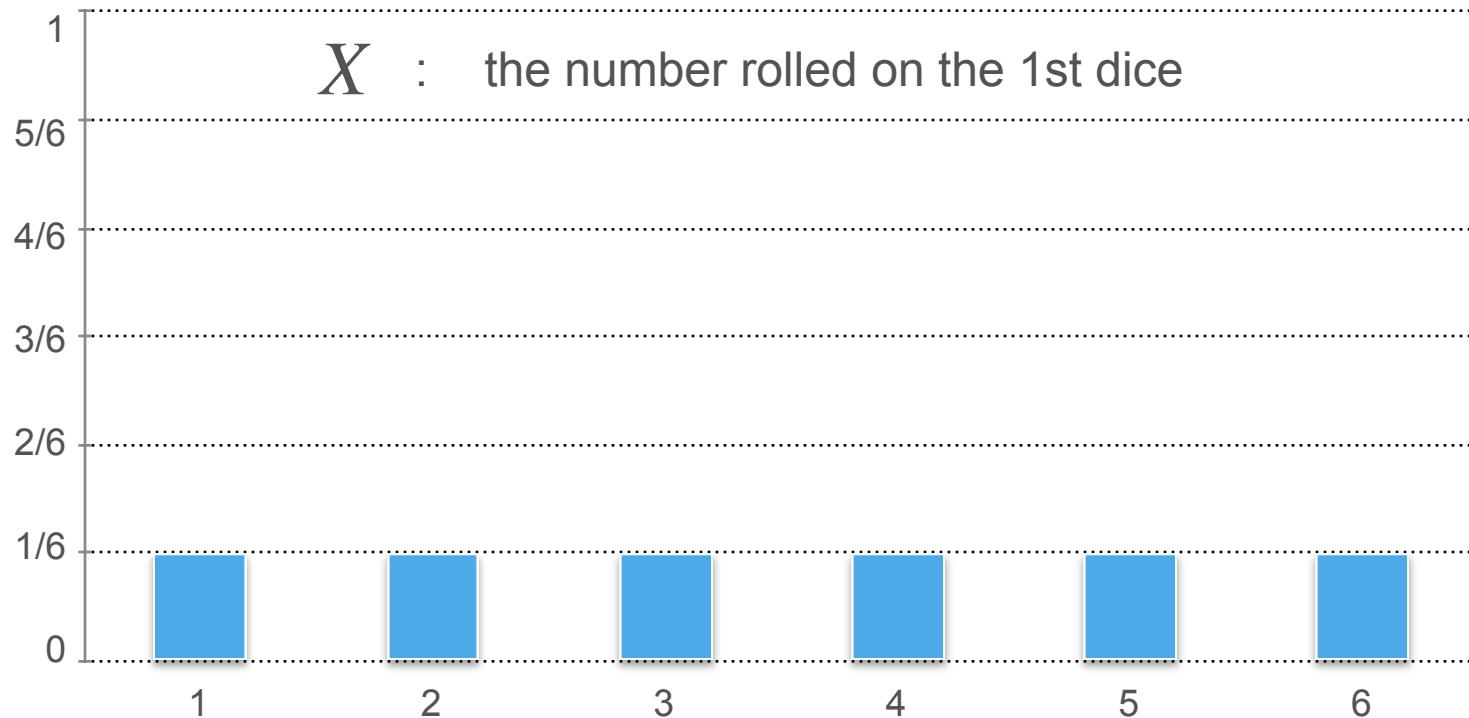
# Joint Distributions: Example 2

$X$  the number rolled on the 1st dice

# Joint Distributions: Example 2

$X$  : the number rolled on the 1st dice

# Joint Distributions: Example 2

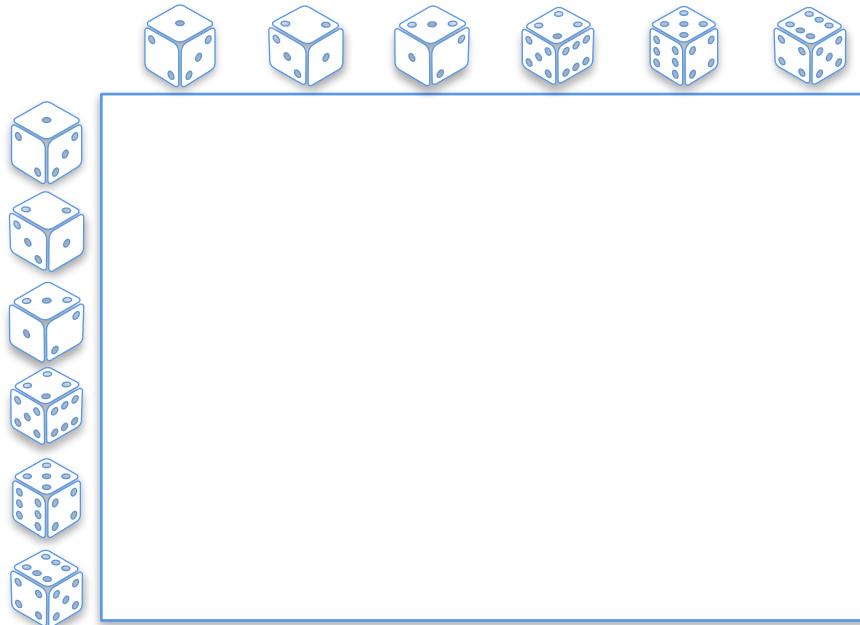


# Joint Distributions - Example 3

$Y$ : Sum of both dice

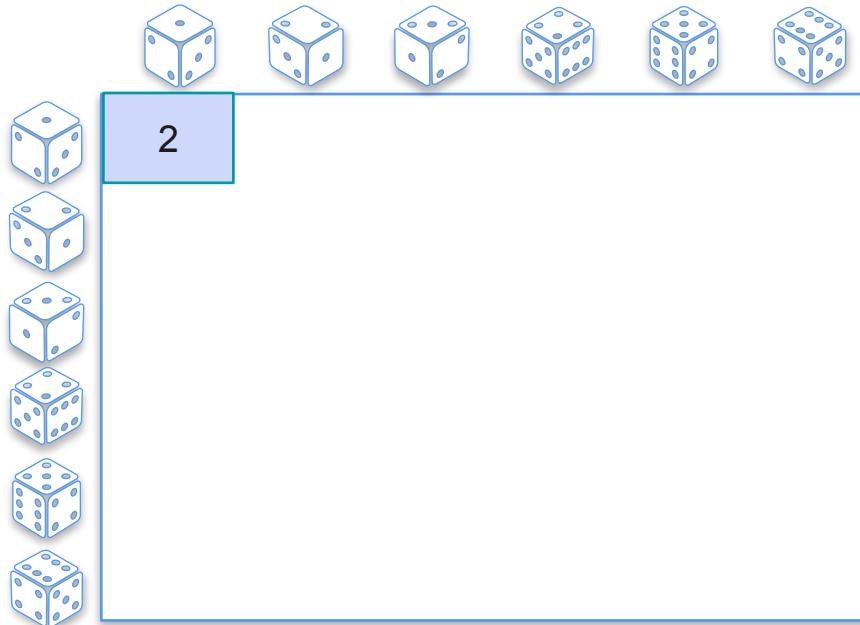
# Joint Distributions - Example 3

$Y$ : Sum of both dice



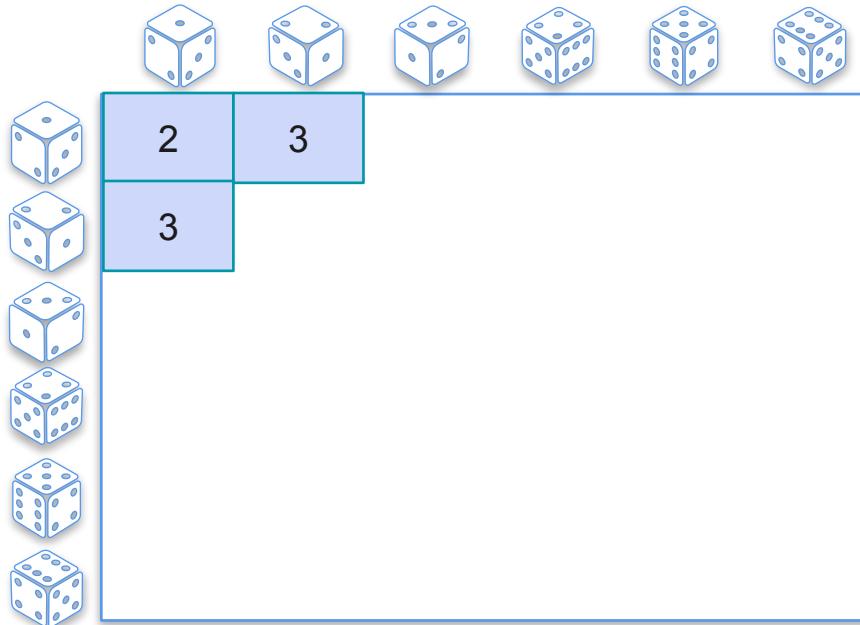
# Joint Distributions - Example 3

$Y$ : Sum of both dice



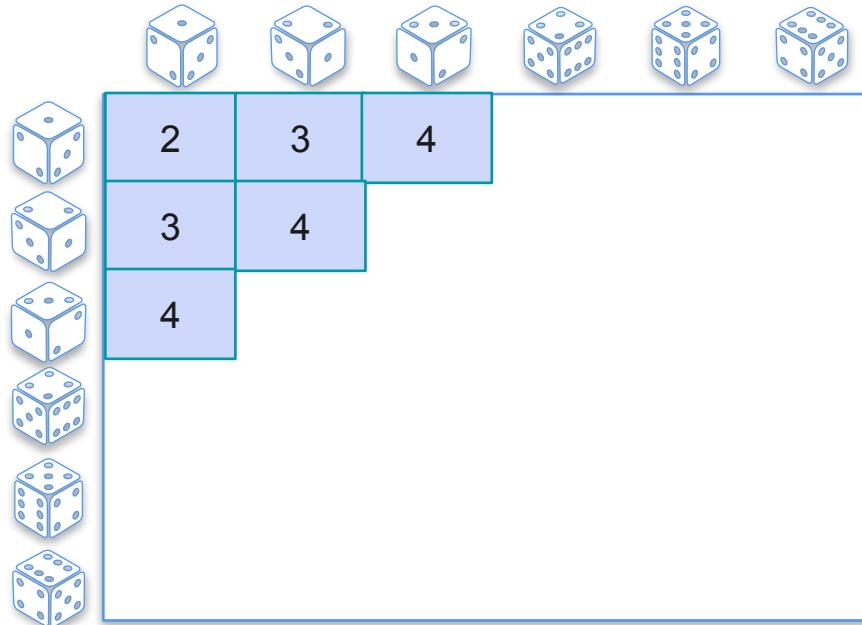
# Joint Distributions - Example 3

$Y$ : Sum of both dice



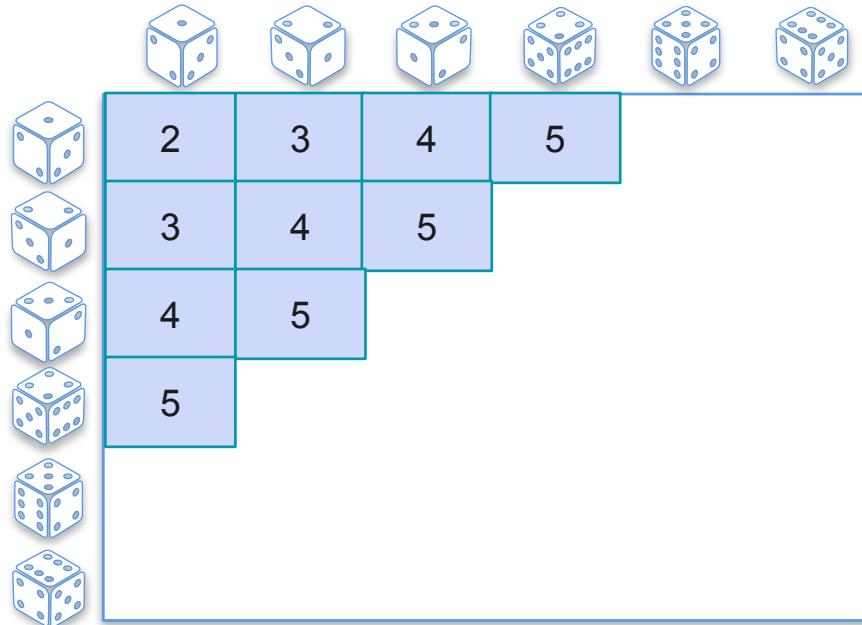
# Joint Distributions - Example 3

$Y$ : Sum of both dice



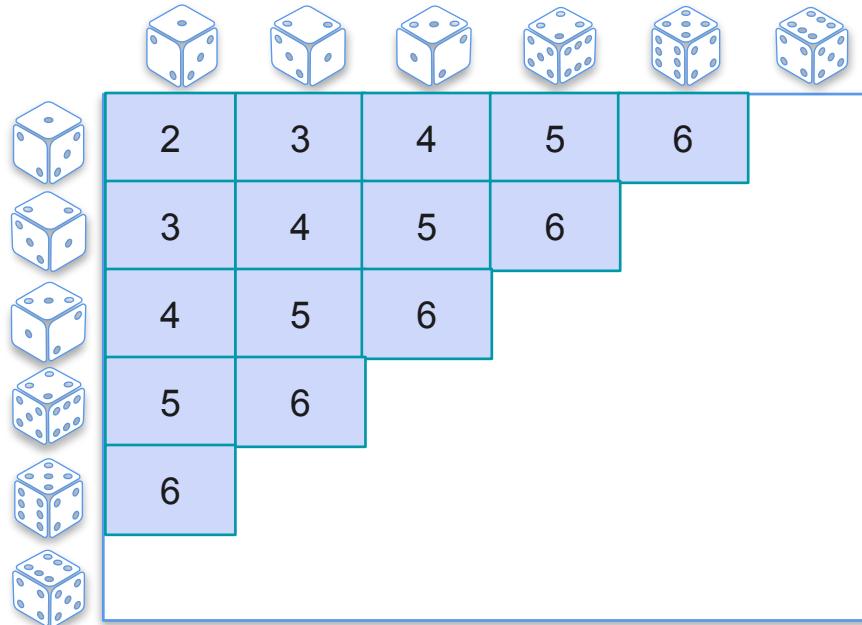
# Joint Distributions - Example 3

$Y$ : Sum of both dice



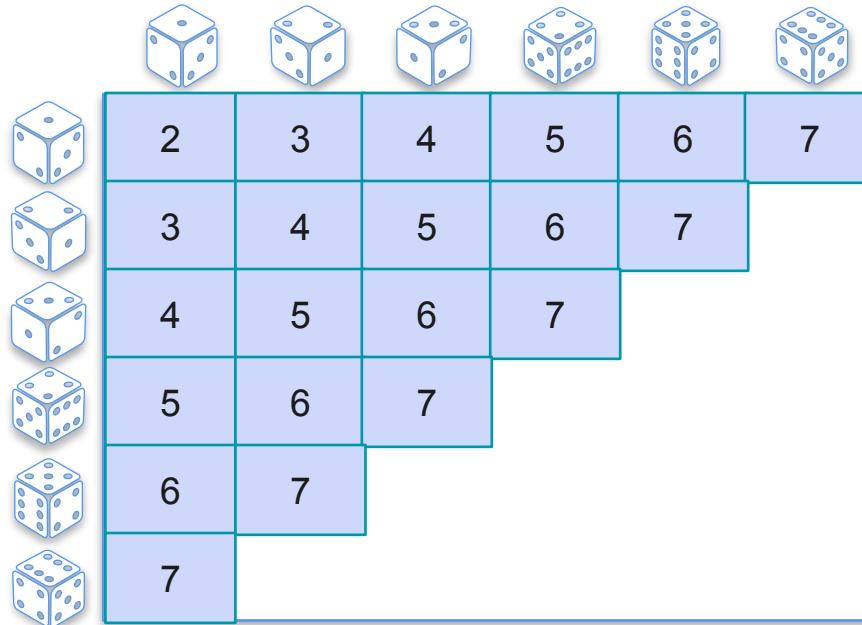
# Joint Distributions - Example 3

$Y$ : Sum of both dice



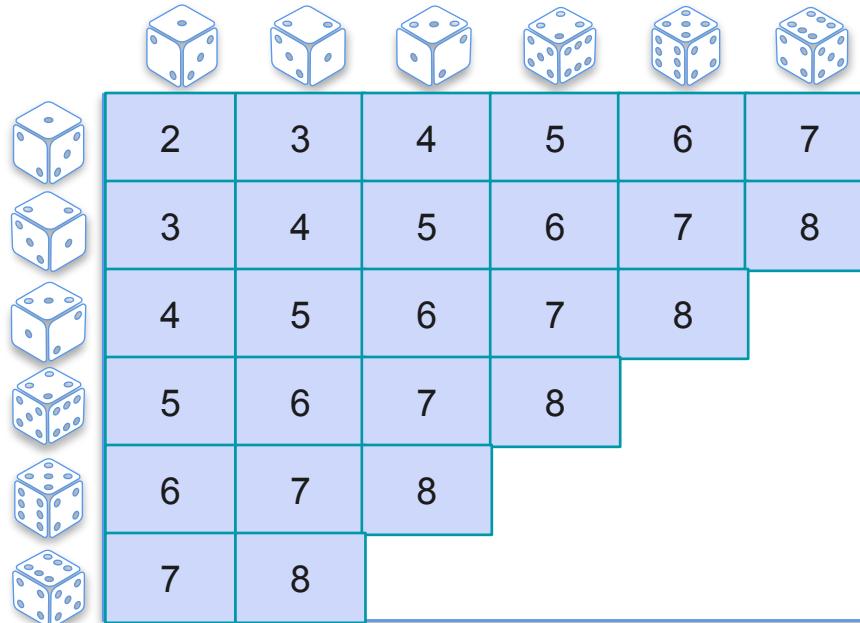
# Joint Distributions - Example 3

$Y$ : Sum of both dice



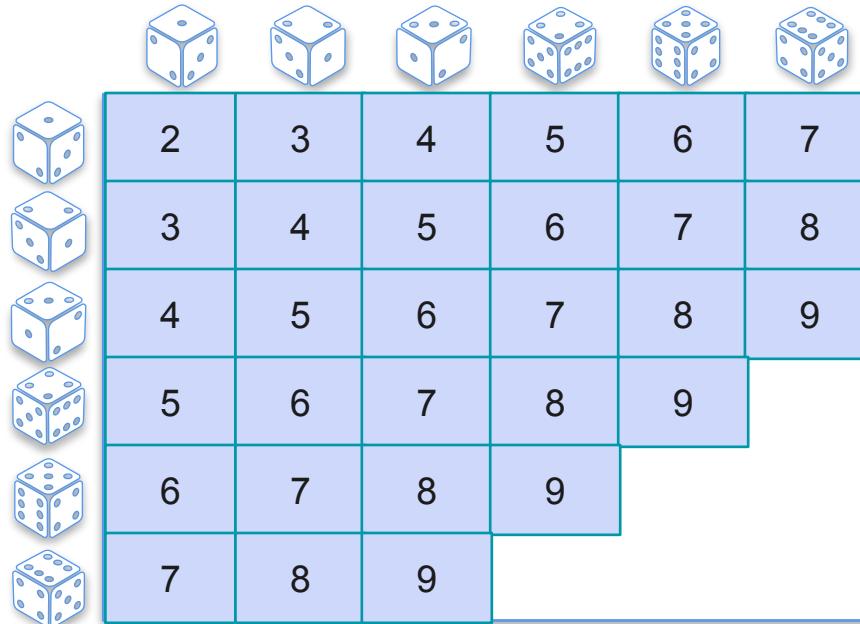
# Joint Distributions - Example 3

$Y$ : Sum of both dice



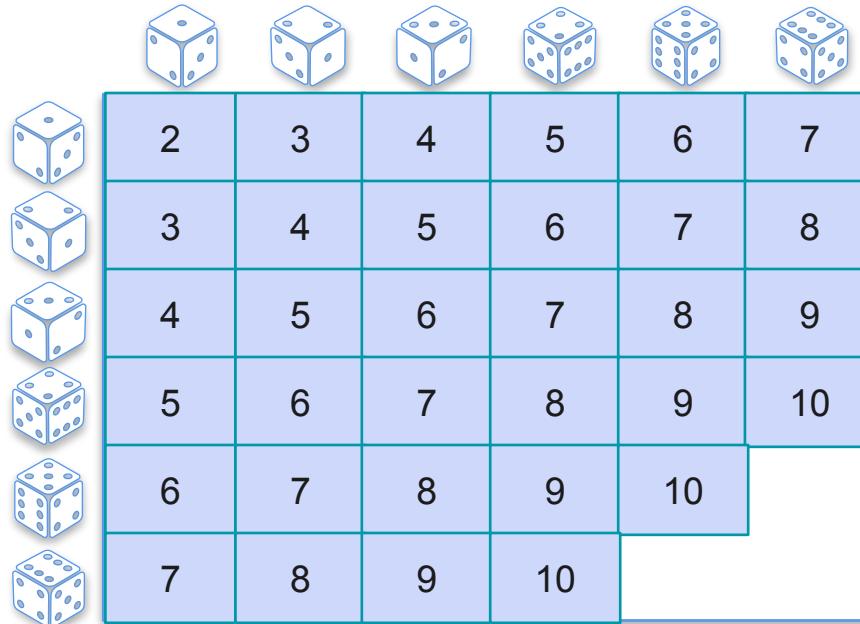
# Joint Distributions - Example 3

$Y$ : Sum of both dice



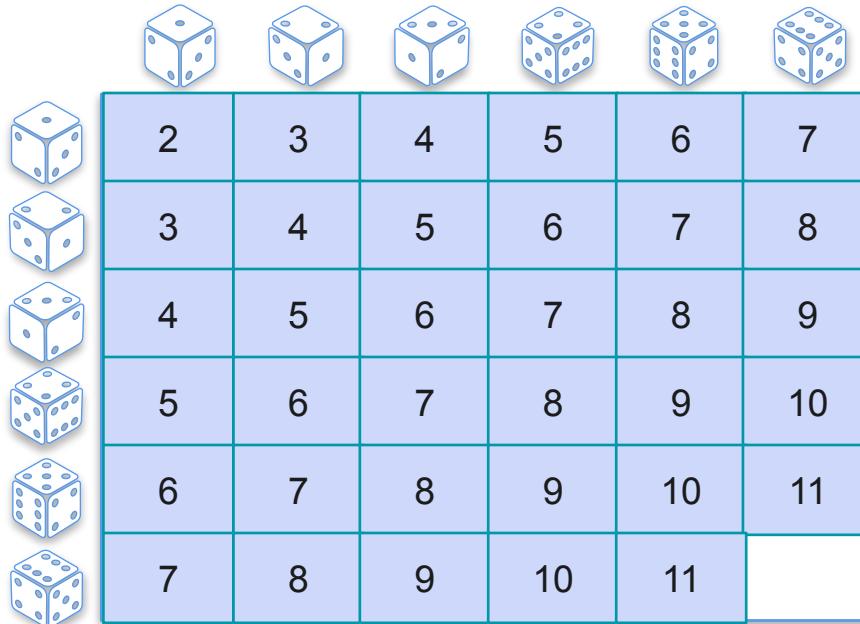
# Joint Distributions - Example 3

$Y$ : Sum of both dice



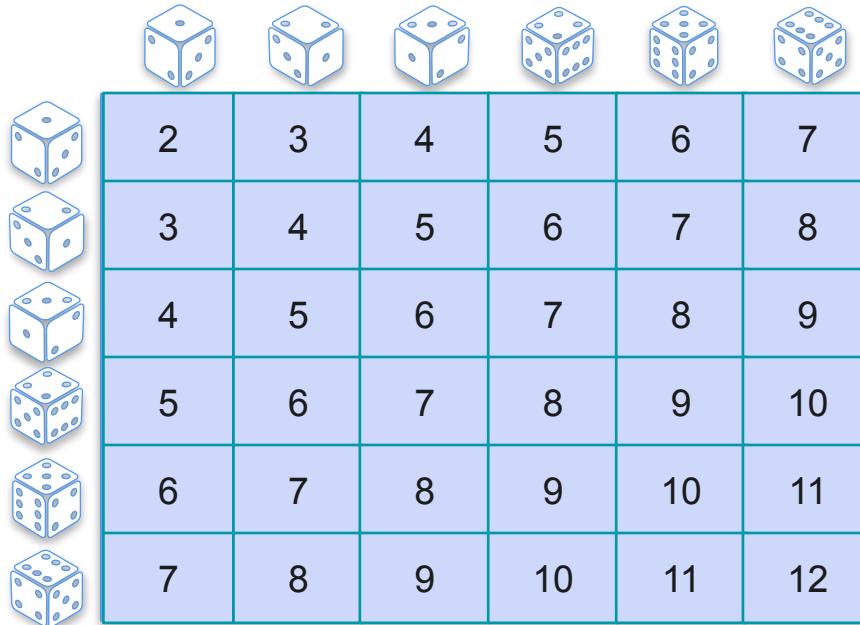
# Joint Distributions - Example 3

$Y$ : Sum of both dice



# Joint Distributions - Example 3

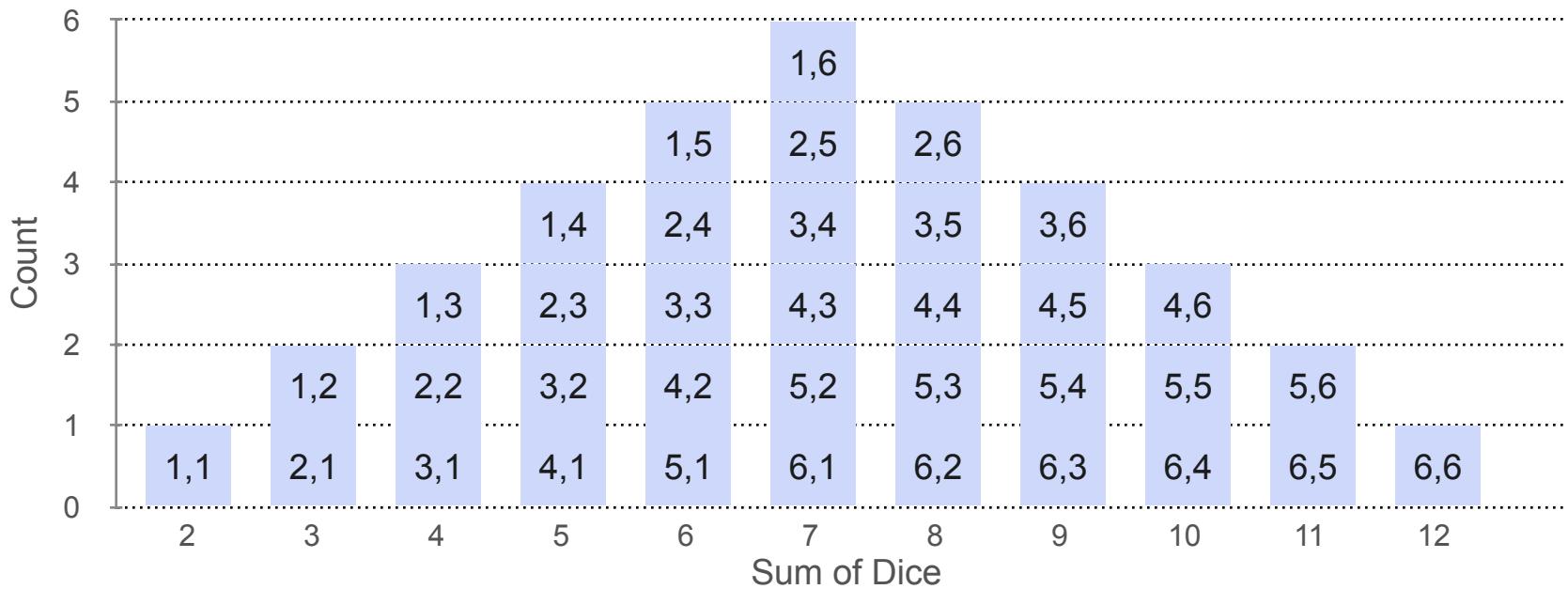
$Y$ : Sum of both dice



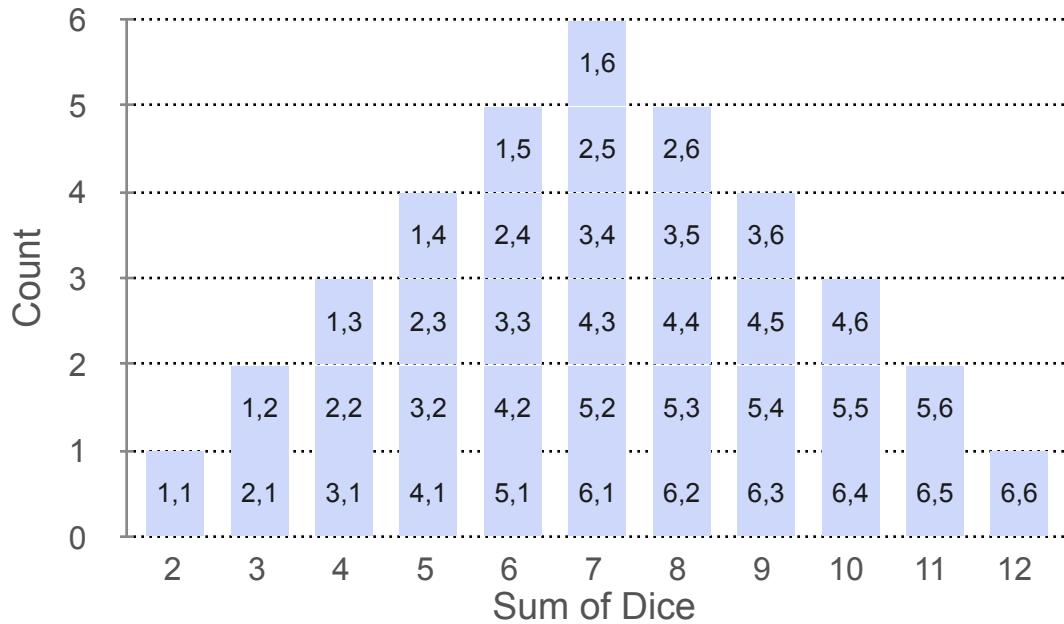
# Joint Distributions: Example 3



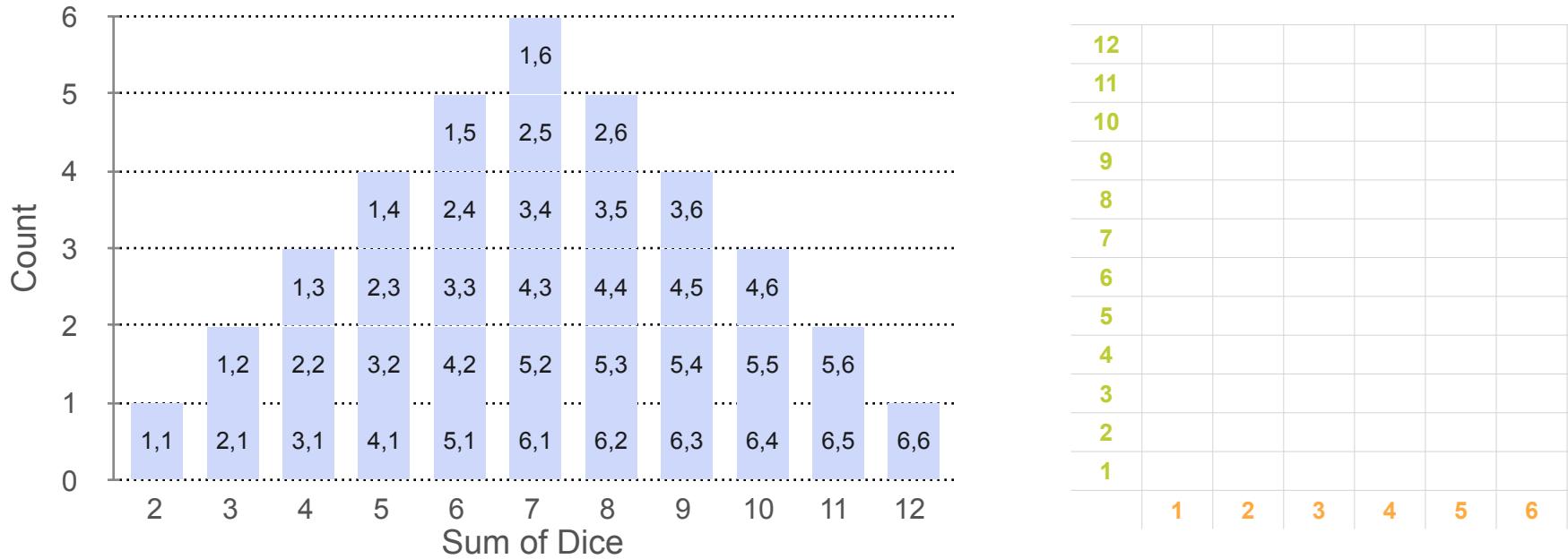
# Joint Distributions: Example 3



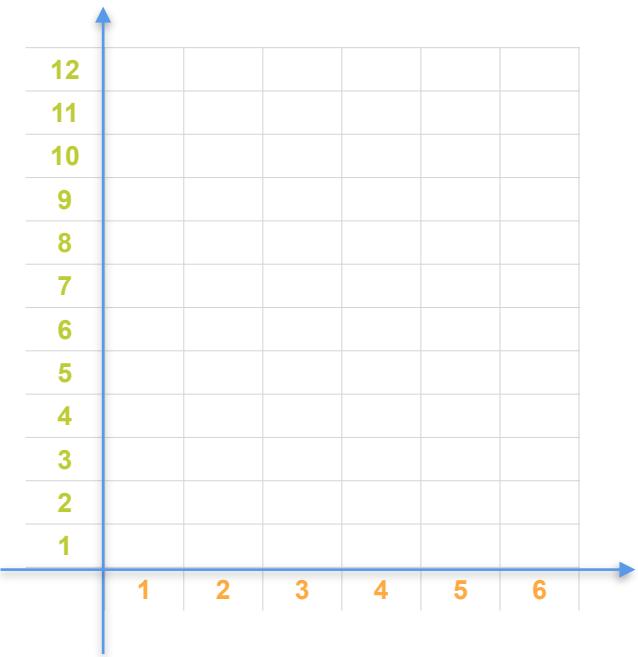
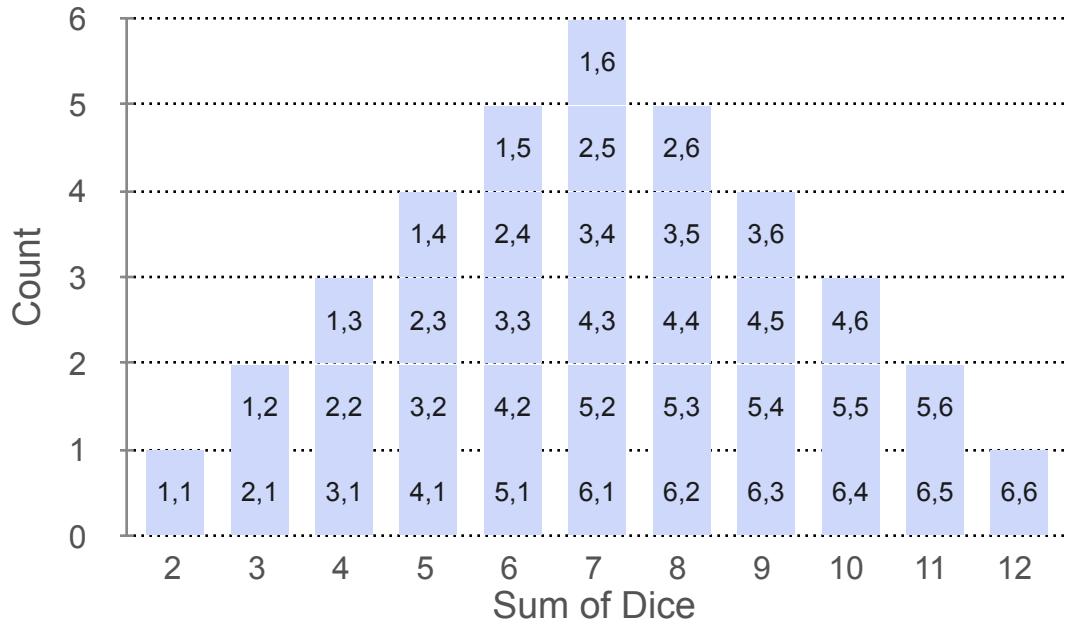
# Joint Distributions: Example 3



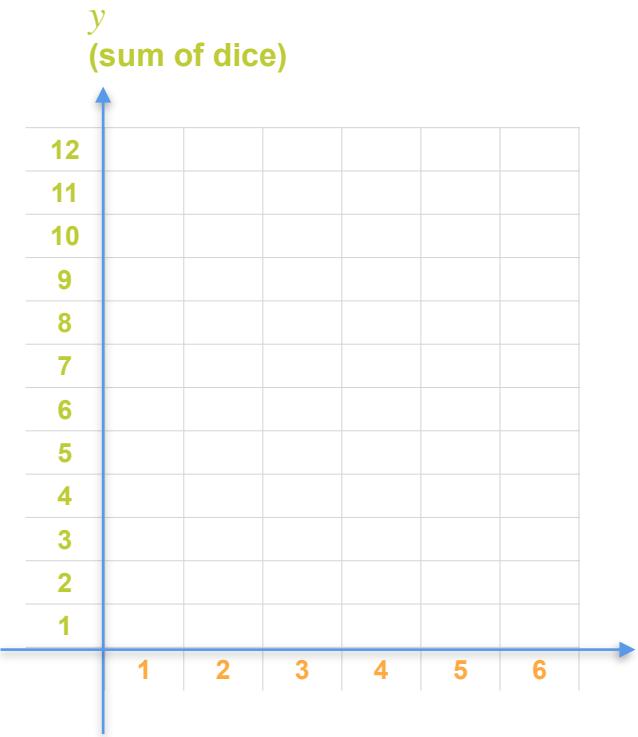
# Joint Distributions: Example 3



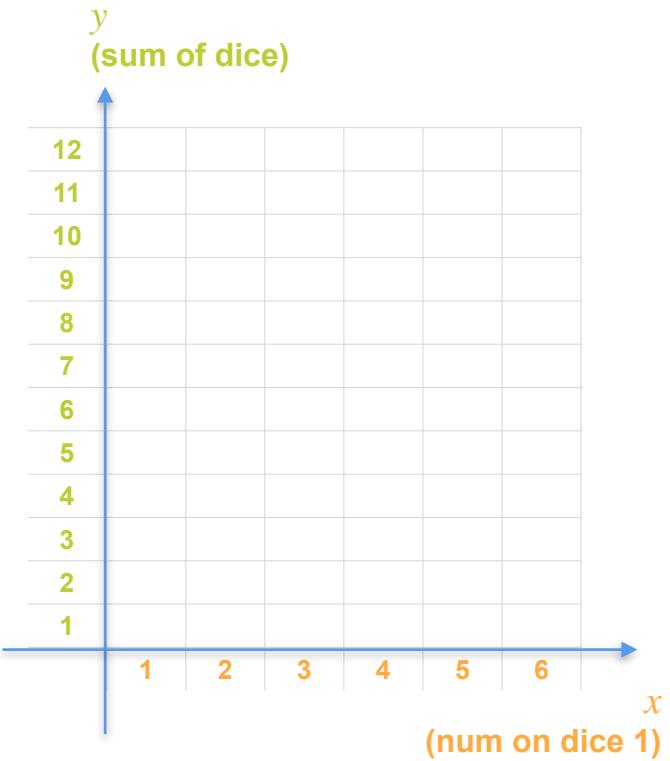
# Joint Distributions: Example 3



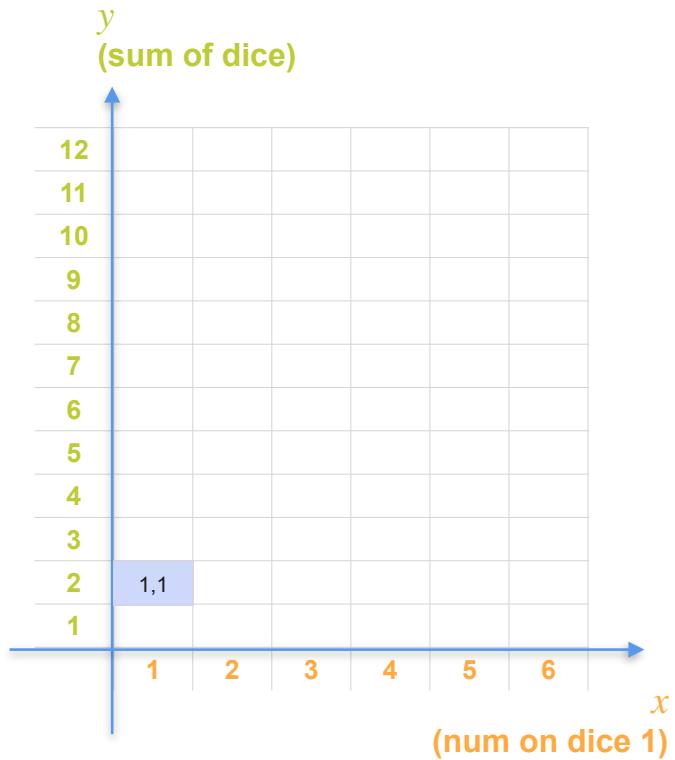
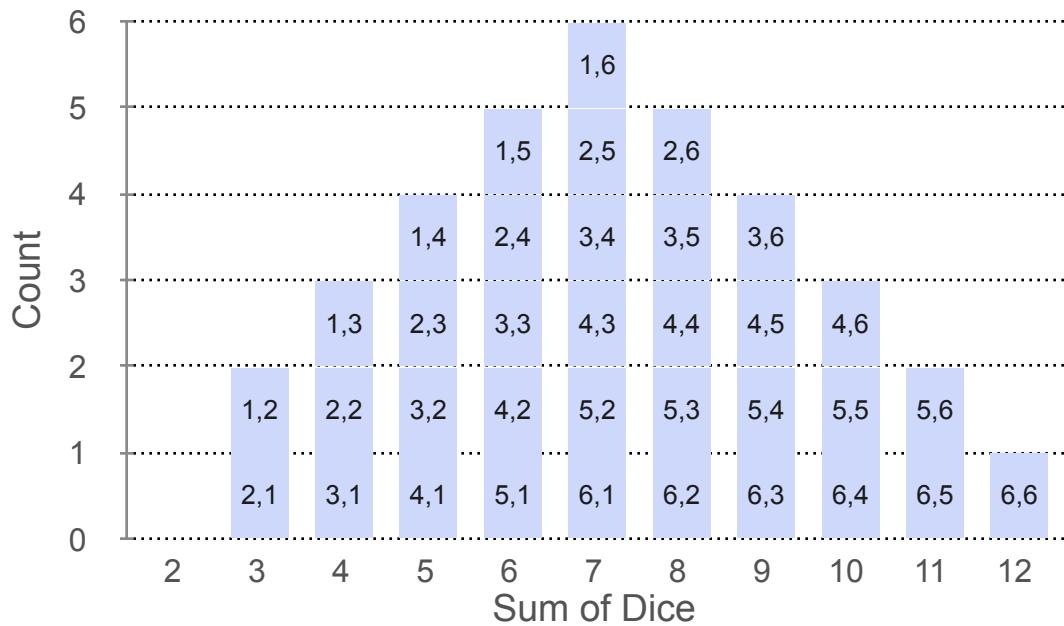
# Joint Distributions: Example 3



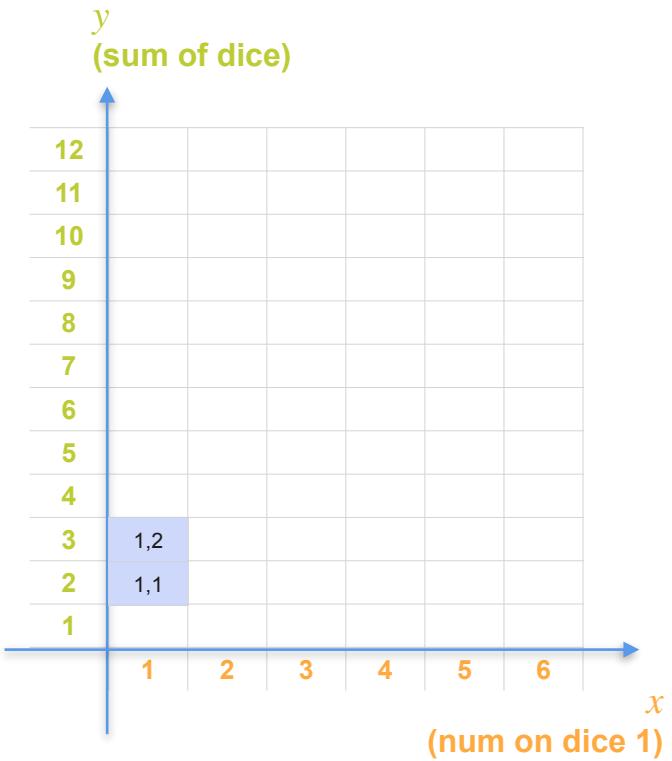
# Joint Distributions: Example 3



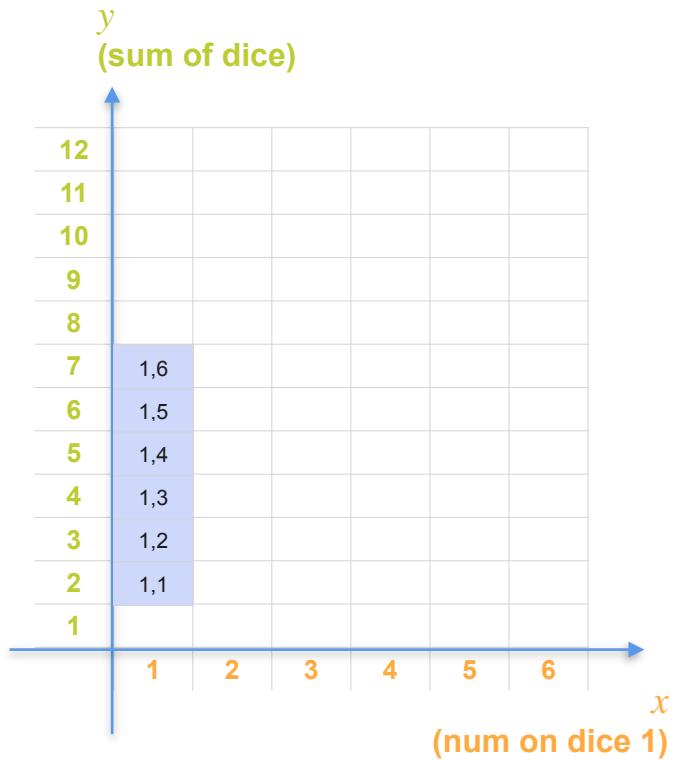
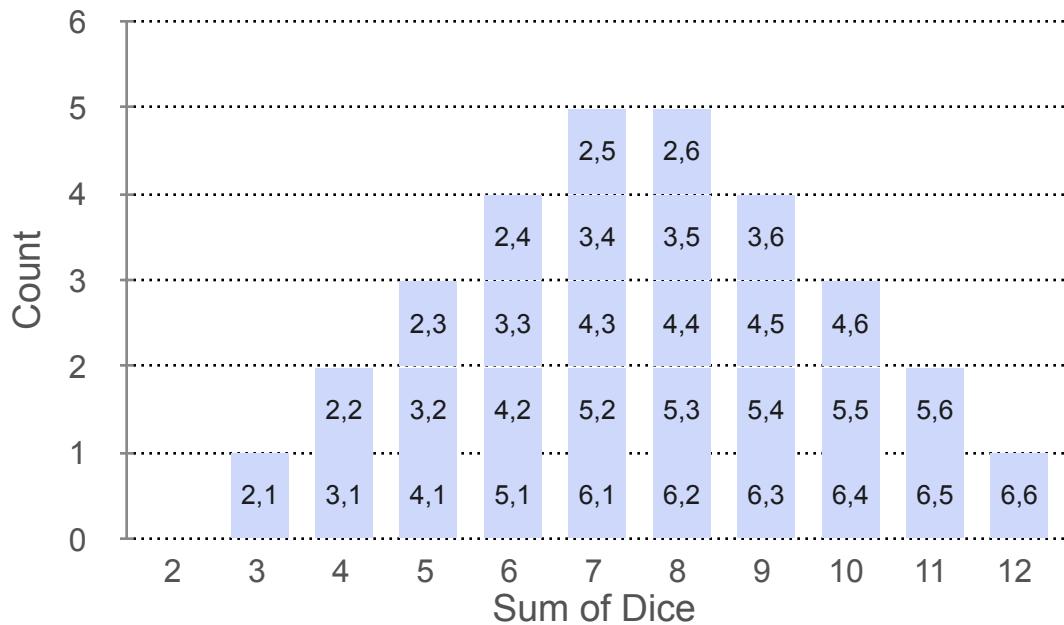
# Joint Distributions: Example 3



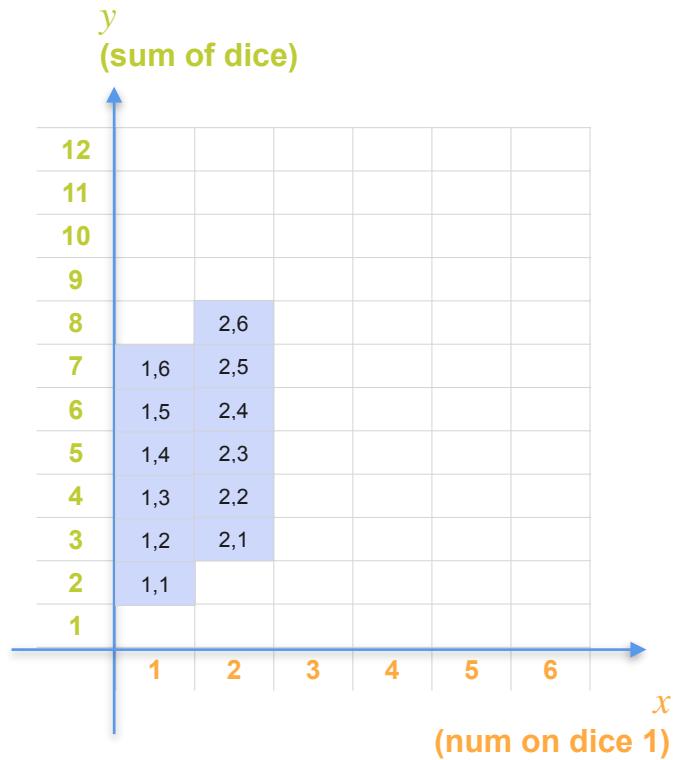
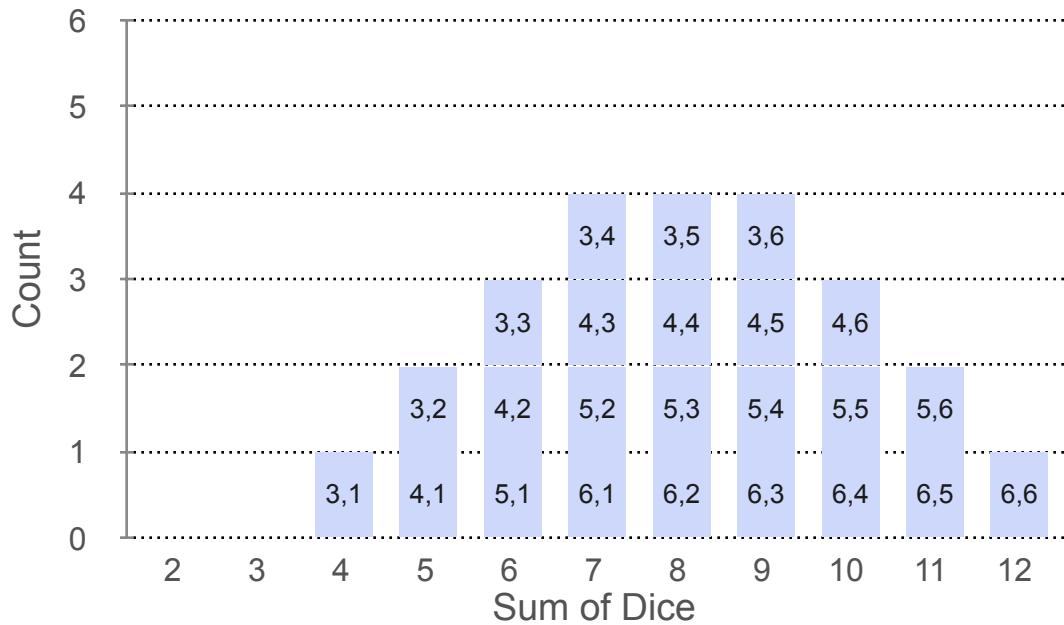
# Joint Distributions: Example 3



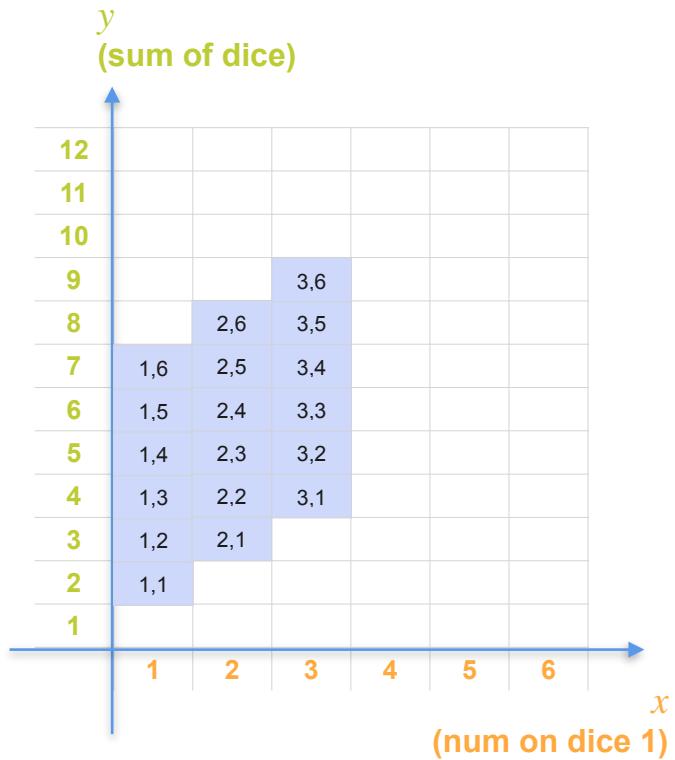
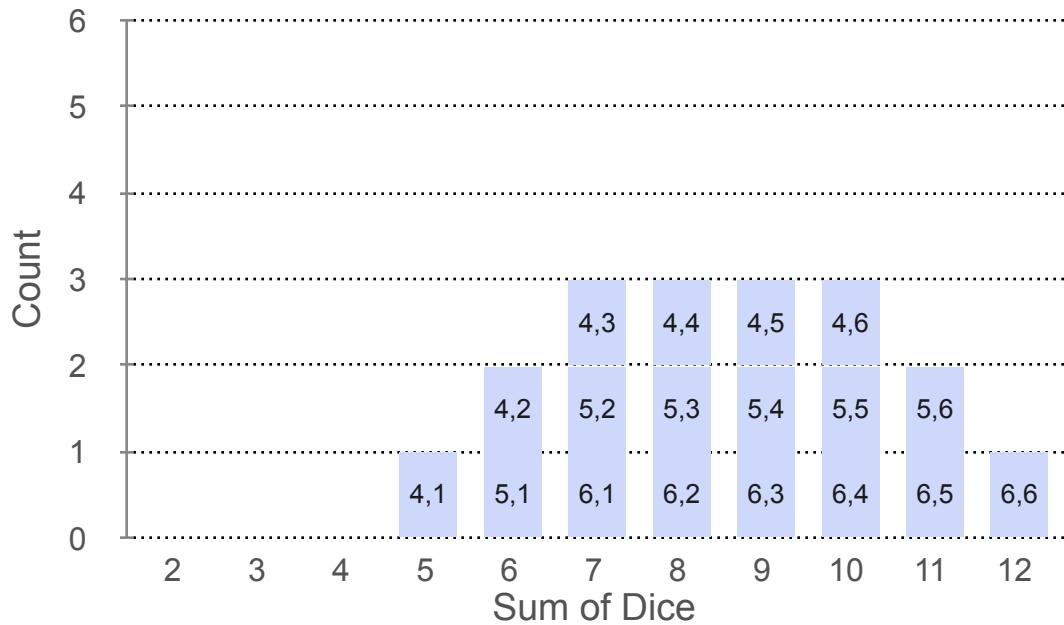
# Joint Distributions: Example 3



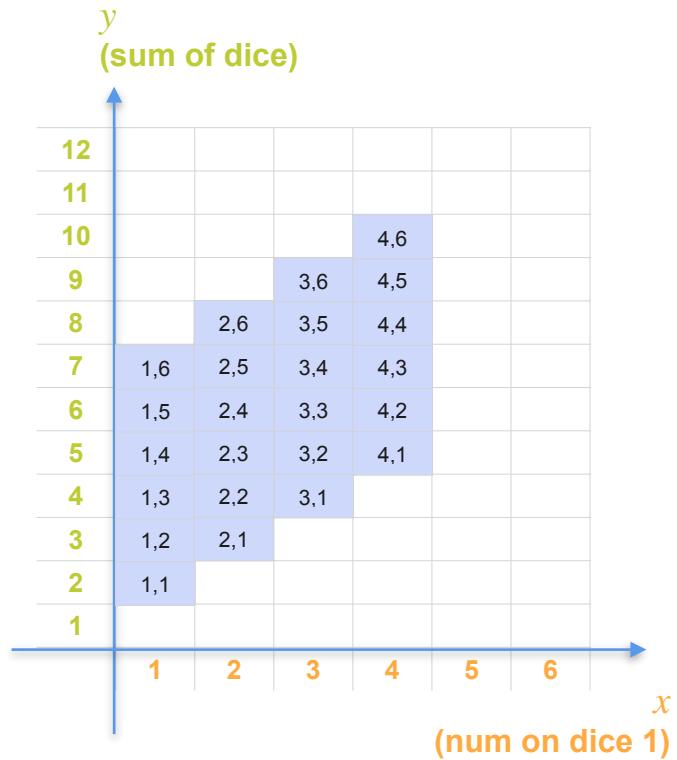
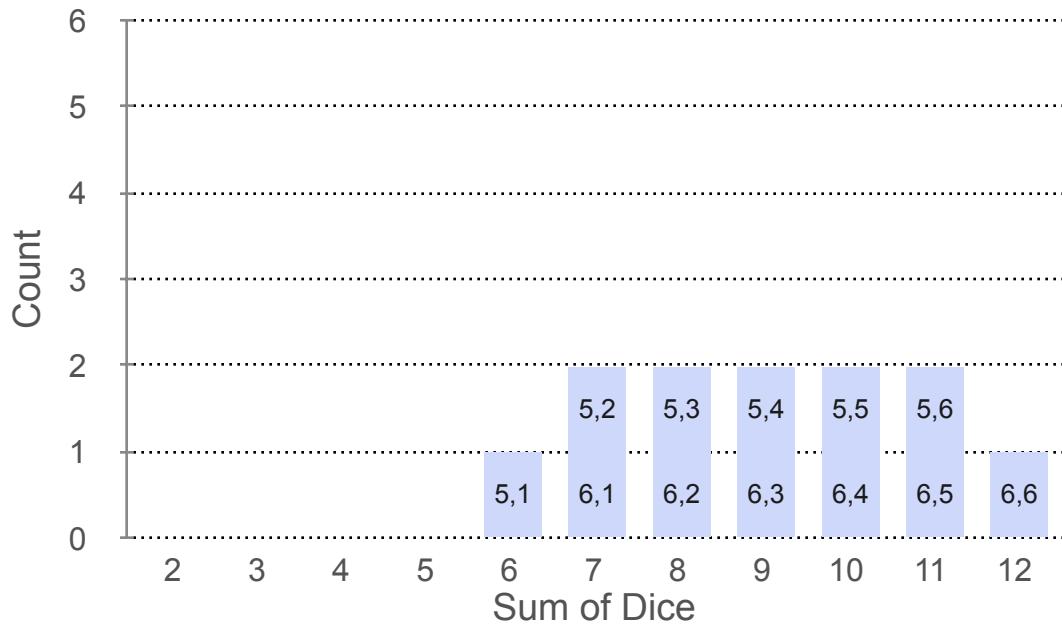
# Joint Distributions: Example 3



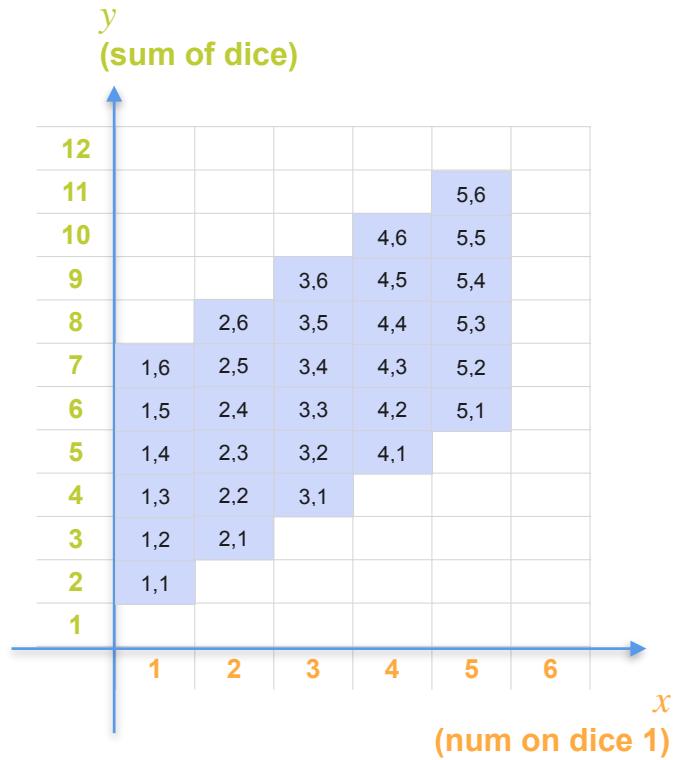
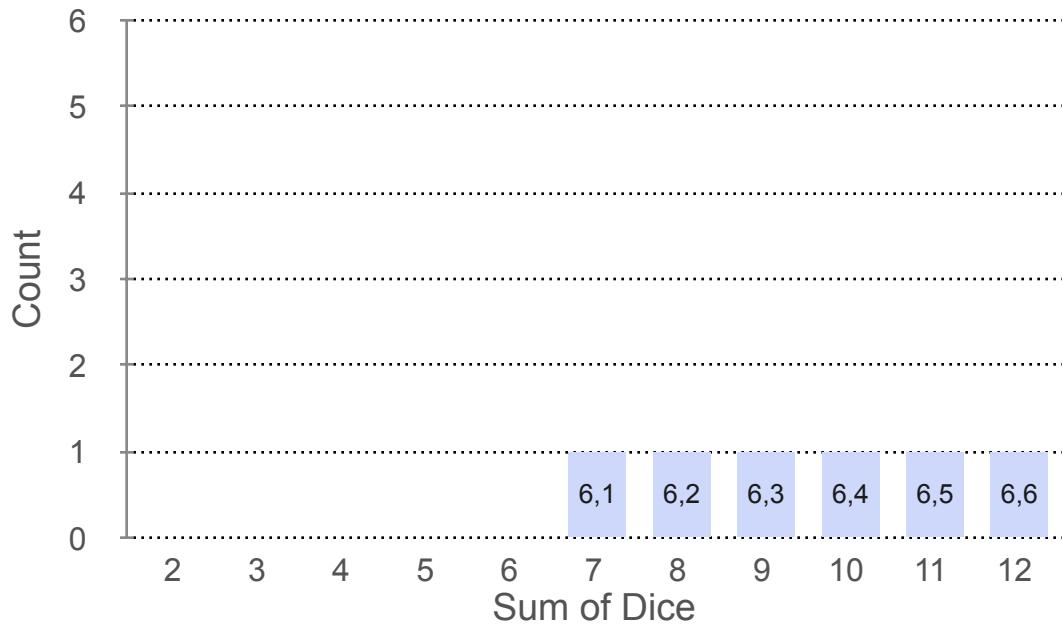
# Joint Distributions: Example 3



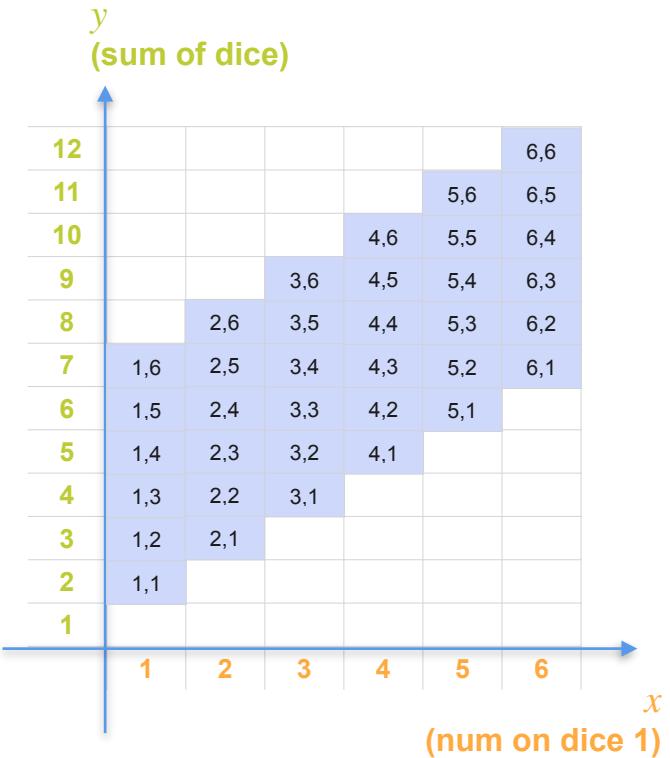
# Joint Distributions: Example 3



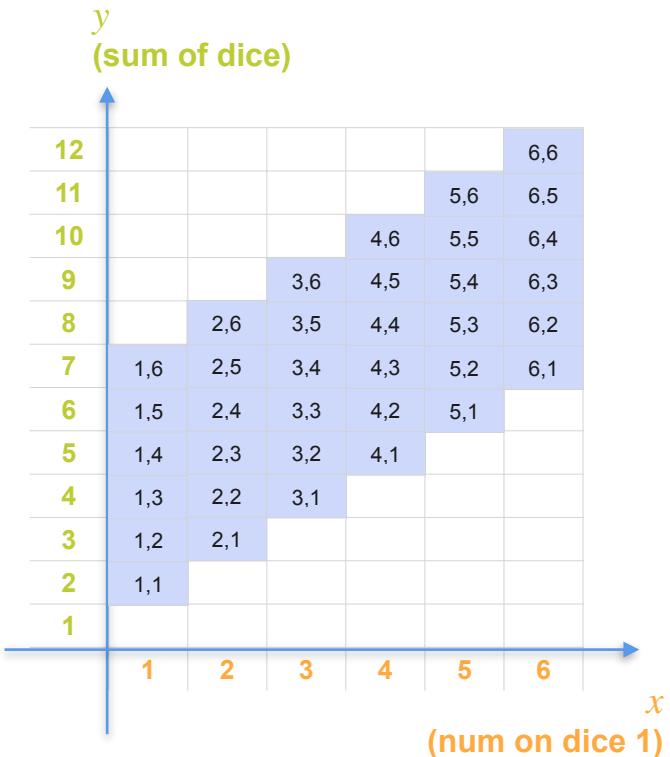
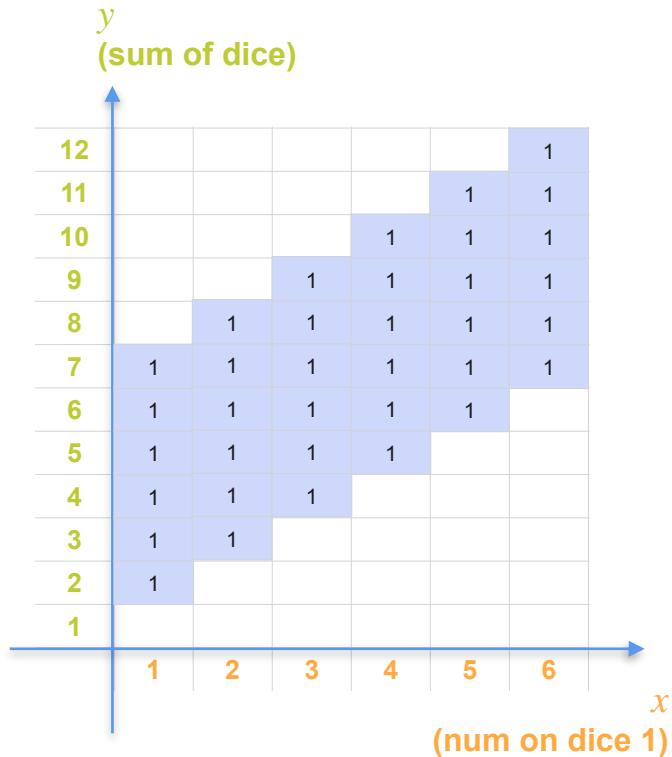
# Joint Distributions: Example 3



# Joint Distributions: Example 3



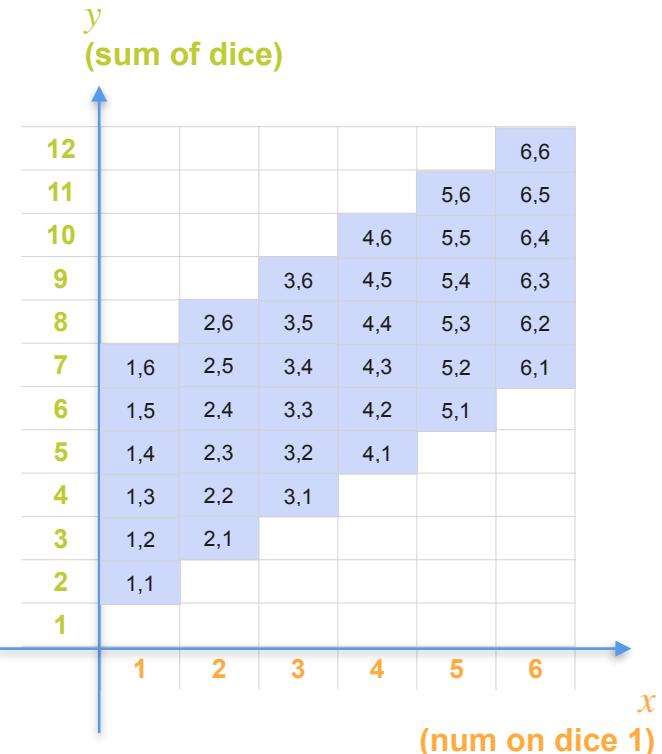
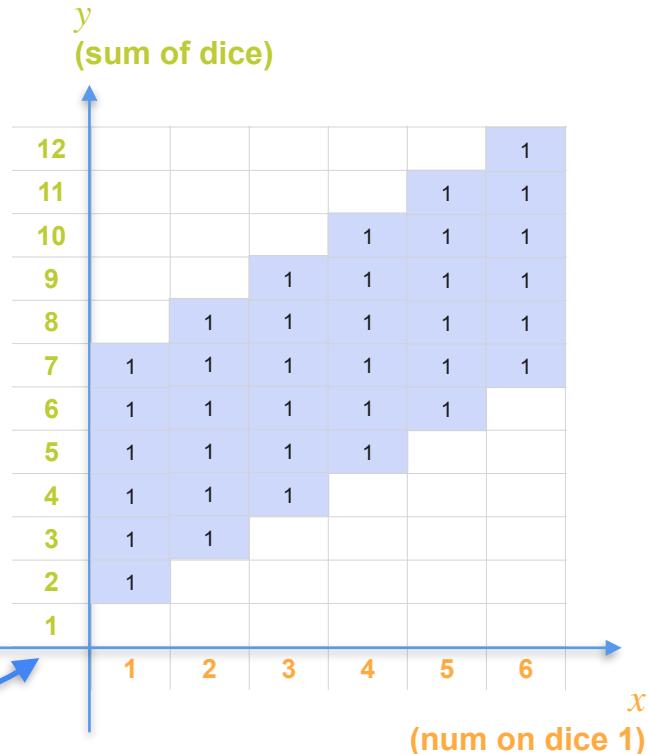
# Joint Distributions: Example 3



# Joint Distributions: Example 3

36  
possible  
outcomes

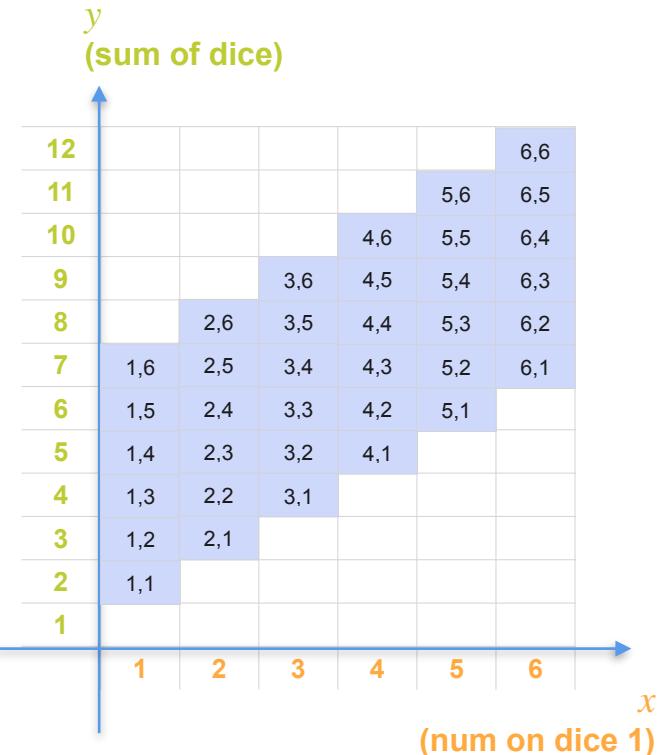
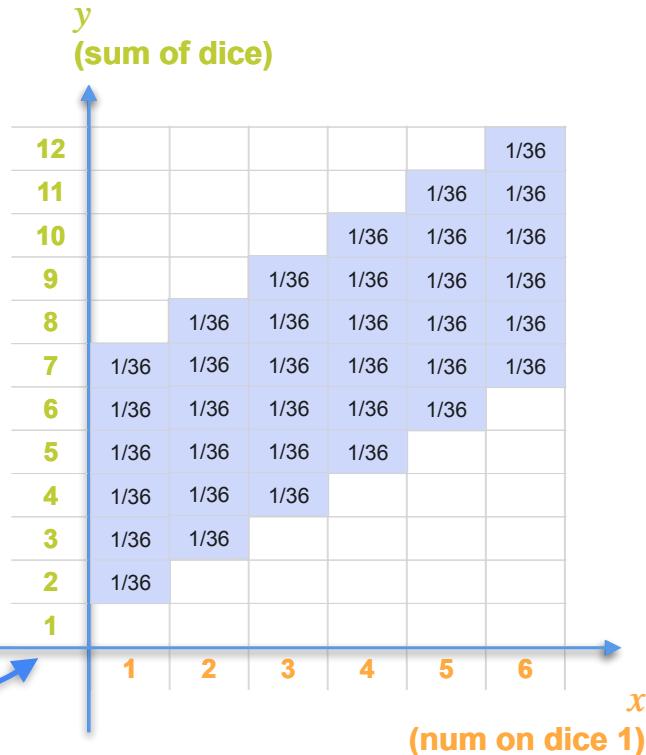
Divide by sum  
(36)



# Joint Distributions: Example 3

36  
possible  
outcomes

Divide by sum  
(36)

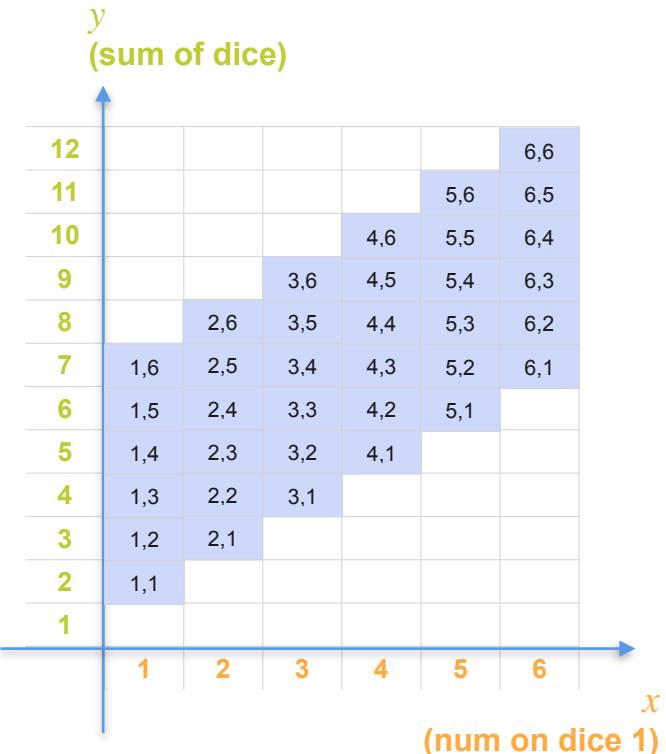
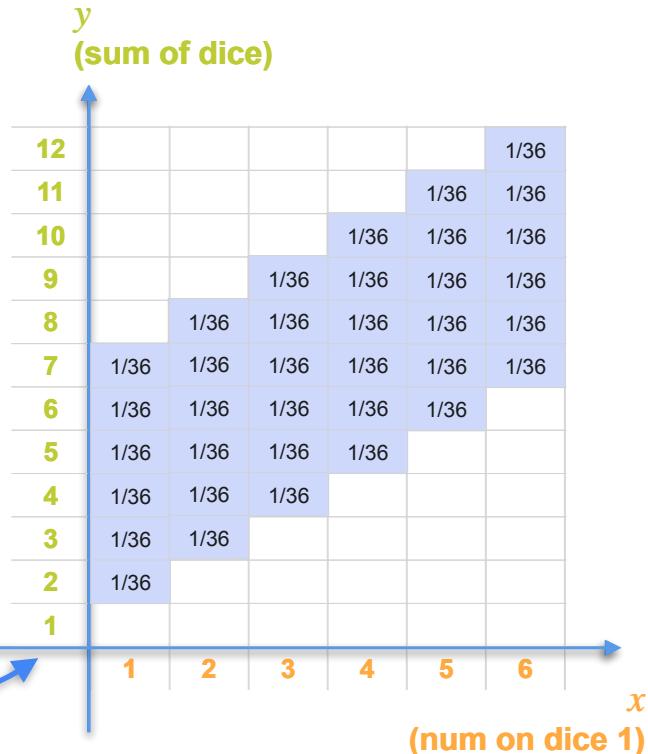


# Joint Distributions: Example 3

Joint Distribution for  
 $X$  and  $Y$

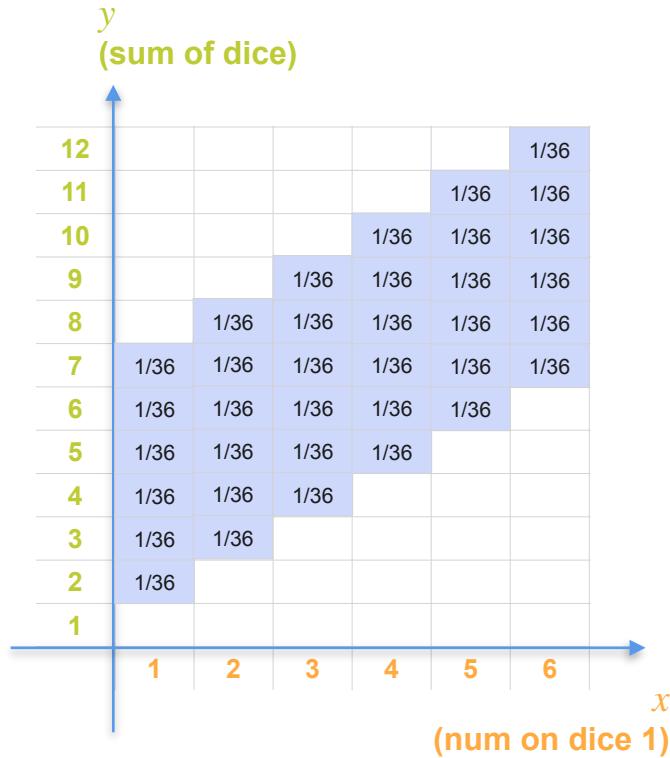
36  
possible  
outcomes

Divide by sum  
(36)



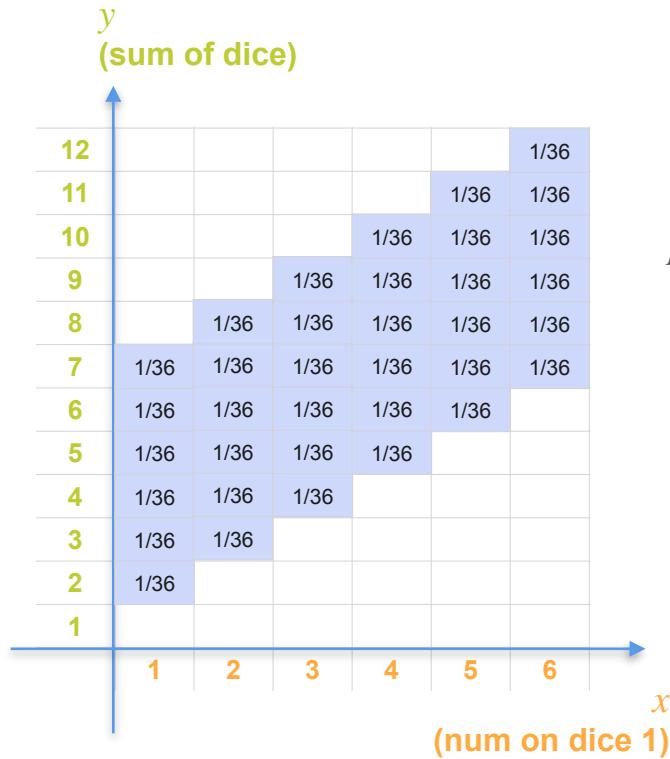
# Joint Distributions: Example 3

Joint Distribution for  
 $X$  and  $Y$



# Joint Distributions: Example 3

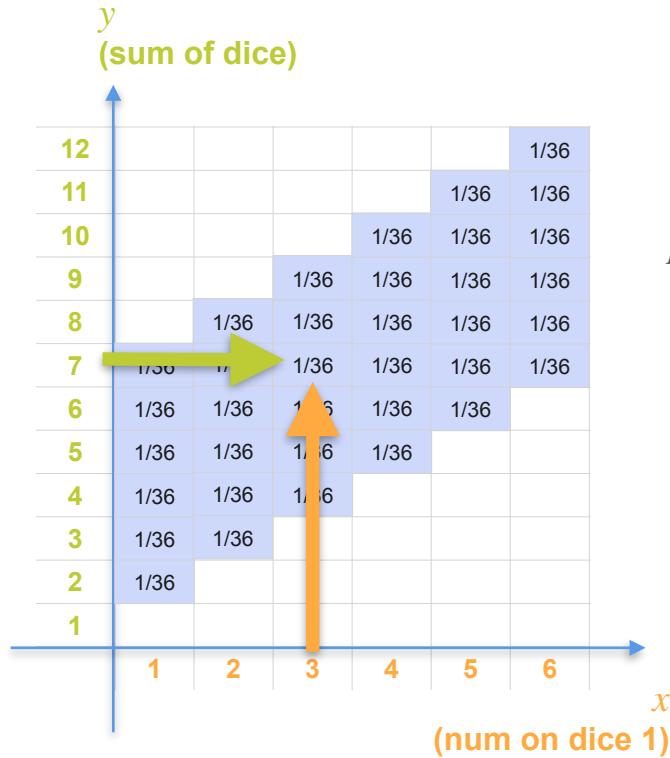
Joint Distribution for  
X and Y



$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7)$$

# Joint Distributions: Example 3

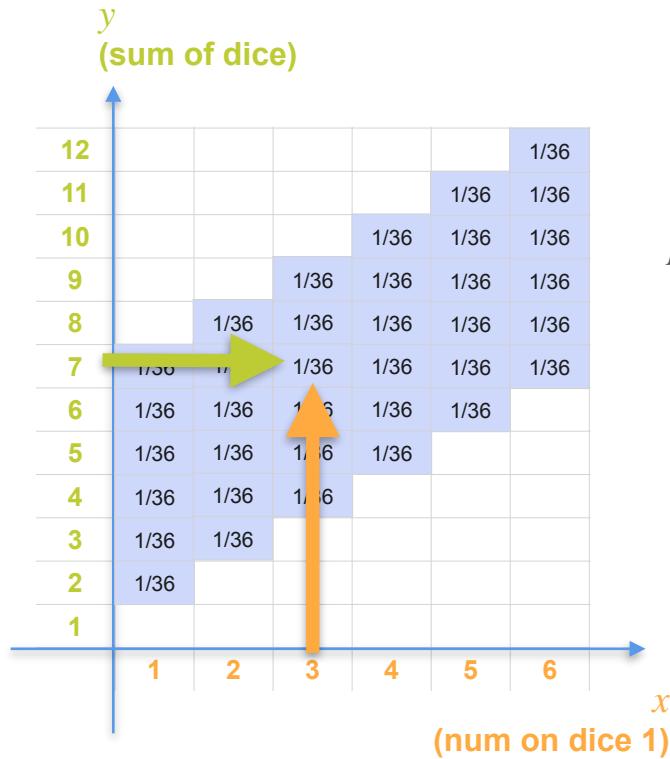
Joint Distribution for  
X and Y



$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7)$$

# Joint Distributions: Example 3

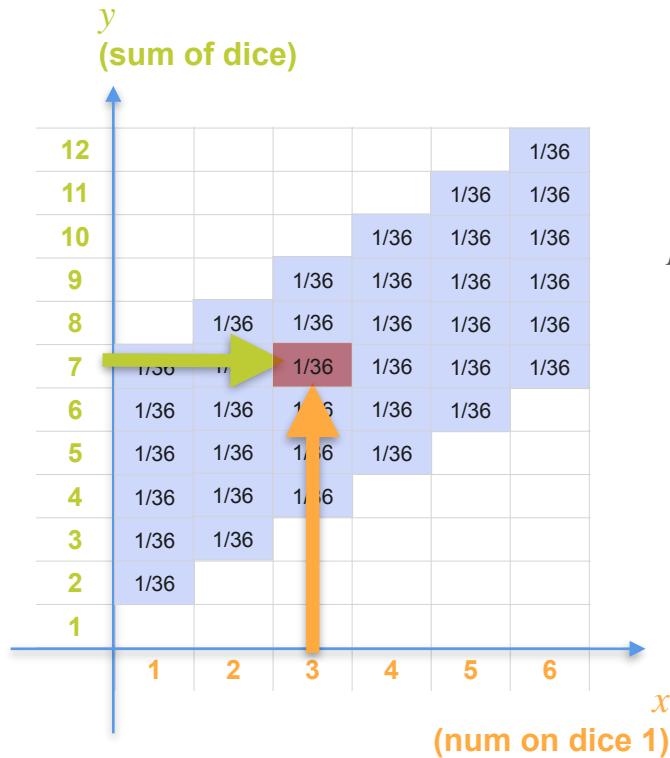
Joint Distribution for  
X and Y



$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7) = \frac{1}{36}$$

# Joint Distributions: Example 3

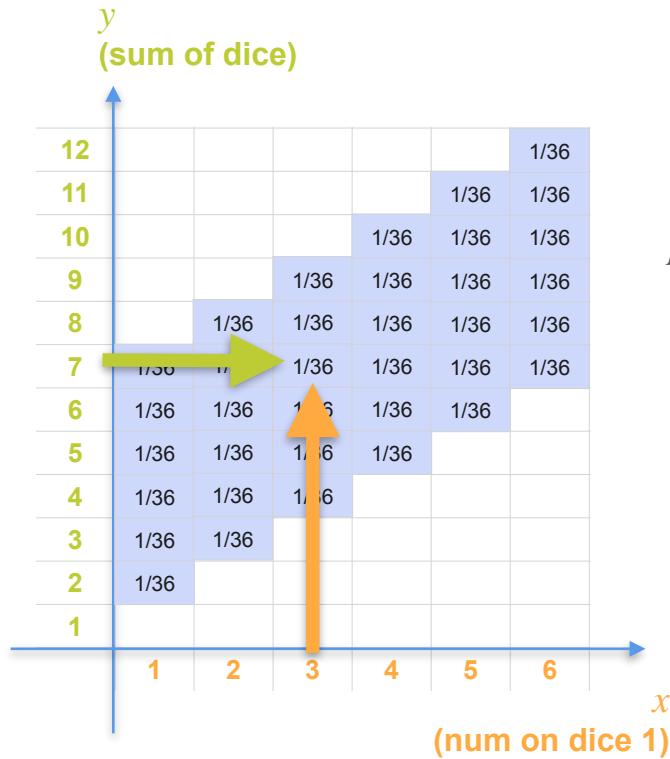
Joint Distribution for  
X and Y



$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7) = \frac{1}{36}$$

# Joint Distributions: Example 3

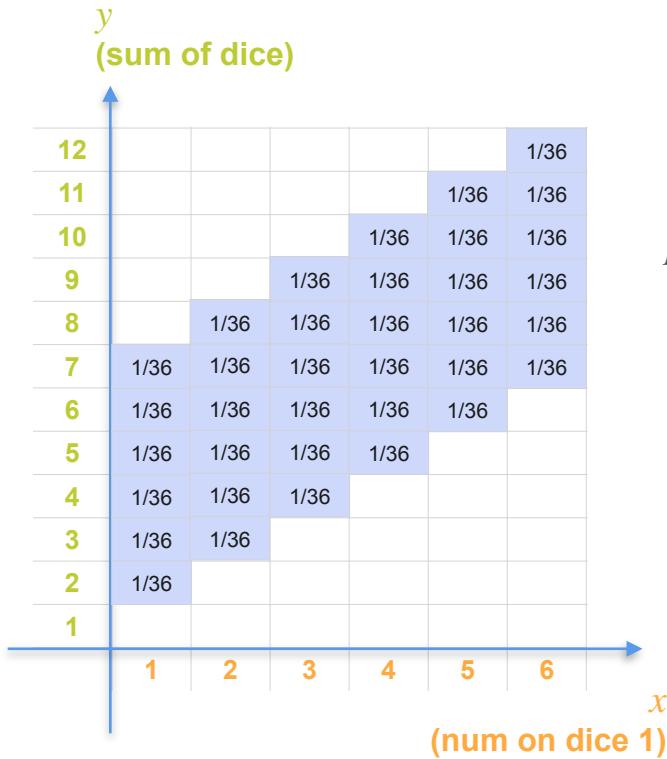
Joint Distribution for  
X and Y



$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7) = \frac{1}{36}$$

# Joint Distributions: Example 3

Joint Distribution for  
X and Y

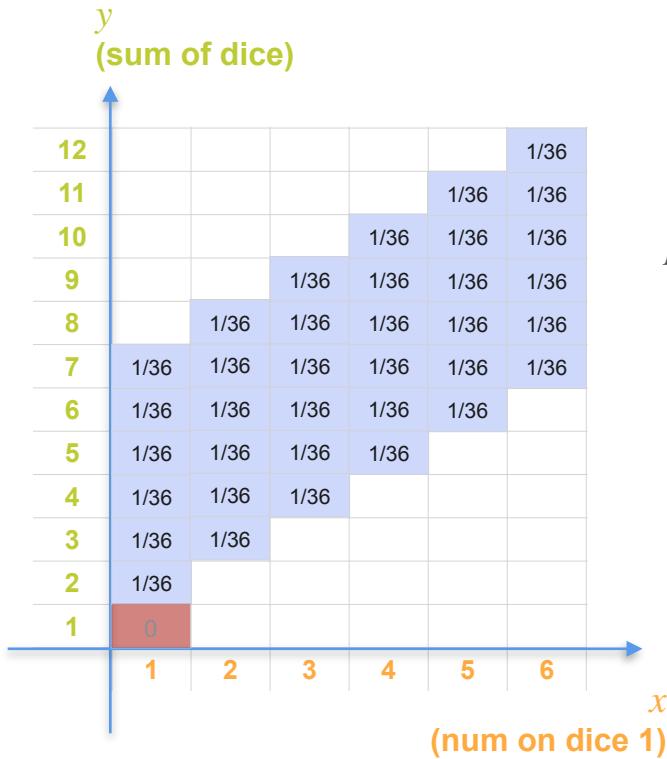


$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7) = \frac{1}{36}$$

$$p_{XY}(1, 1) = \mathbf{P}(X = 1, Y = 1)$$

# Joint Distributions: Example 3

Joint Distribution for  
X and Y

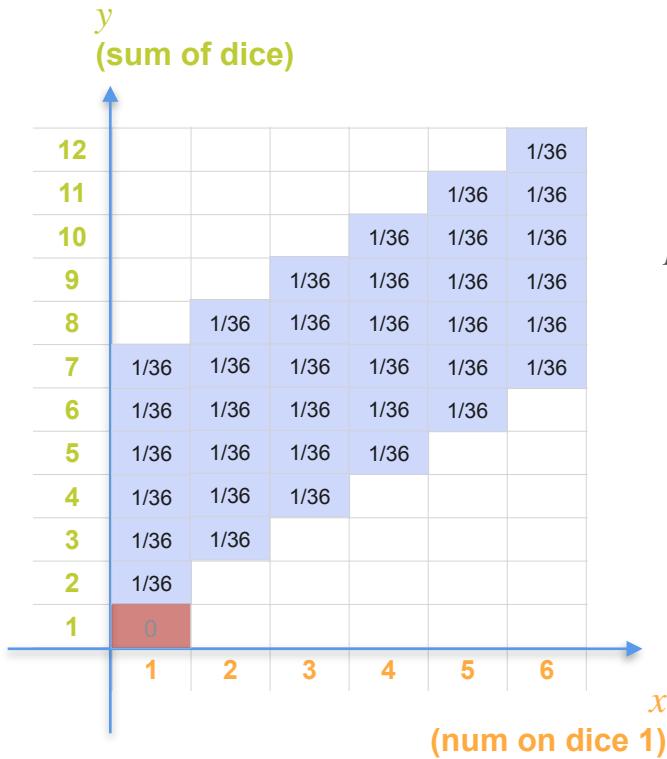


$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7) = \frac{1}{36}$$

$$p_{XY}(1, 1) = \mathbf{P}(X = 1, Y = 1)$$

# Joint Distributions: Example 3

Joint Distribution for  
X and Y



$$p_{XY}(3, 7) = \mathbf{P}(X = 3, Y = 7) = \frac{1}{36}$$

$$p_{XY}(1, 1) = \mathbf{P}(X = 1, Y = 1) = 0$$



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# Probability Distributions with Multiple Variables

---

**Joint Distribution  
(Continuous)**

# Joint Continuous Distributions

# Joint Continuous Distributions

$X$  : age of a child in year

$Y$  : discrete values of height of child in inches

$X$  : the number rolled on the 1st dice

$Y$  : the number rolled on the 2nd dice

$X$  : the number rolled on the 1st dice

$Y$  : sum of both dice

# Joint Continuous Distributions

$X$  : age of a child in year

$Y$  : discrete values of height of child in inches

$X$  : the number rolled on the 1st dice

$Y$  : the number rolled on the 2nd dice

$X$  : the number rolled on the 1st dice

$Y$  : sum of both dice

$X$  and  $Y$  are  
Discrete Random Variables

# Joint Continuous Distributions

$X$  : age of a child in year

$Y$  : discrete values of height of child in inches

$X$  : the number rolled on the 1st dice

$Y$  : the number rolled on the 2nd dice

$X$  : the number rolled on the 1st dice

$Y$  : sum of both dice

$X$  and  $Y$  are  
Discrete Random Variables

What about when  $X$  and  $Y$  are  
Continuous Random Variables?

# Joint Continuous Distributions

# Joint Continuous Distributions



# Joint Continuous Distributions

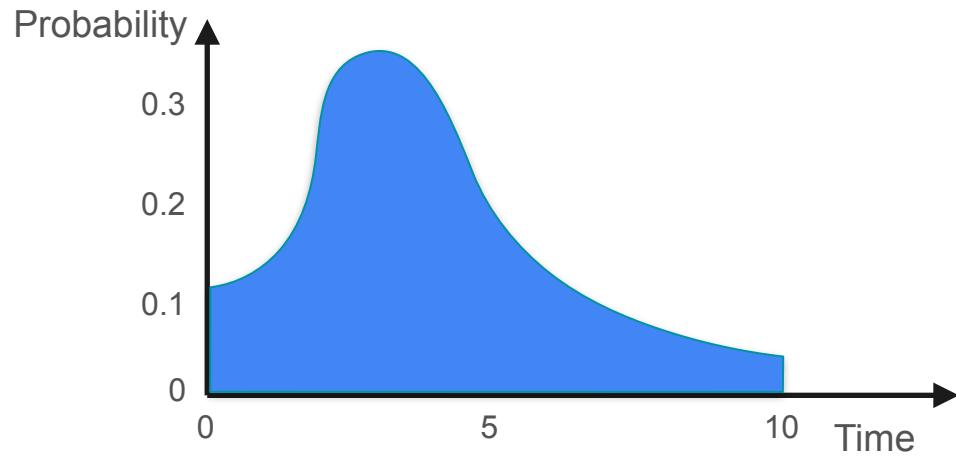


$X$  variable: Waiting time

# Joint Continuous Distributions



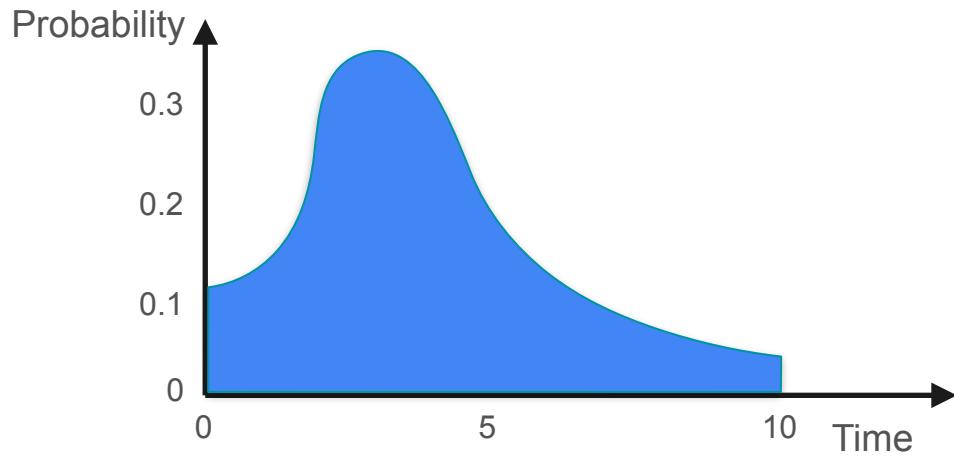
$X$  variable: Waiting time



# Joint Continuous Distributions



$X$  variable: Waiting time

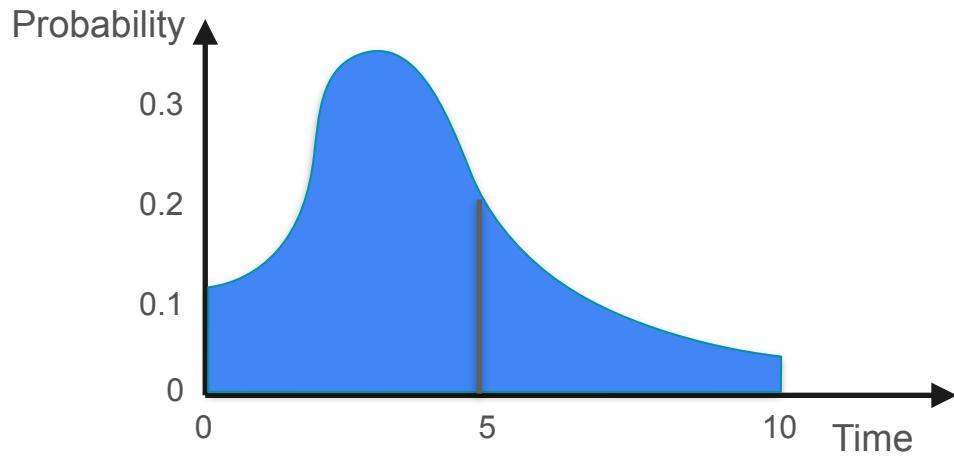


$P(X \text{ between } 0 \text{ and } 5 \text{ mins})$

# Joint Continuous Distributions



$X$  variable: Waiting time

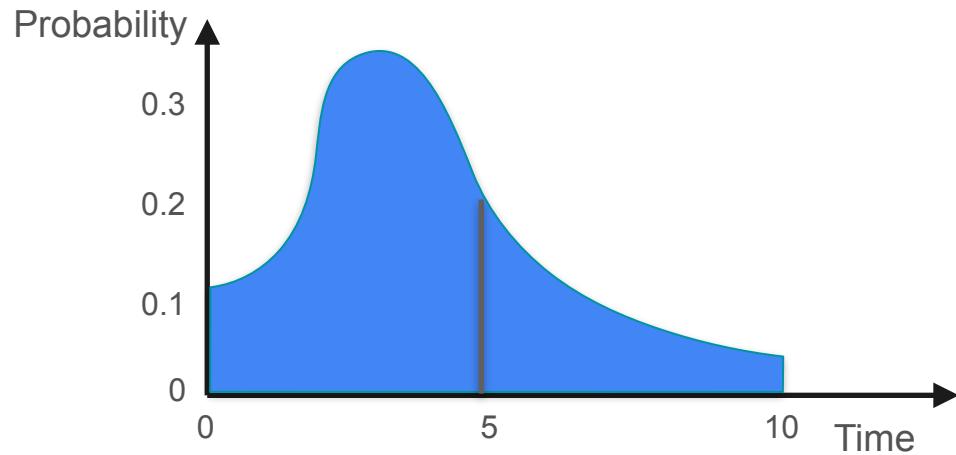


$P(X \text{ between } 0 \text{ and } 5 \text{ mins})$

# Joint Continuous Distributions



$X$  variable: Waiting time

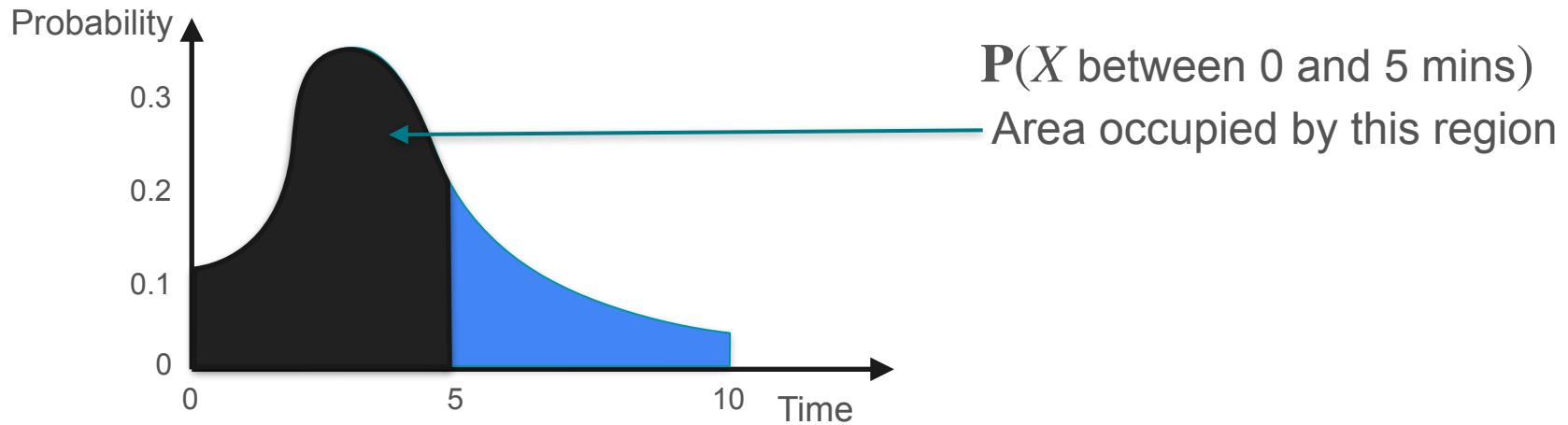


$P(X \text{ between } 0 \text{ and } 5 \text{ mins})$   
Area occupied by this region

# Joint Continuous Distributions



$X$  variable: Waiting time



# Joint Continuous Distributions

# Joint Continuous Distributions

$X$

$Y$

# Joint Continuous Distributions

$X$

Waiting time  
before a call is picked up  
[0 - 10 minutes]



$Y$

# Joint Continuous Distributions

$X$

Waiting time  
before a call is picked up  
[0 - 10 minutes]



$Y$

Customer  
satisfaction rating  
[0 - 10]



# Joint Continuous Distributions

$X$

Waiting time  
before a call is picked up  
[0 - 10 minutes]



$Y$

Customer  
satisfaction rating  
[0 - 10]



**Both variables are  
continuous**

# Joint Continuous Distributions

$X$

Waiting time  
before a call is picked up  
[0 - 10 minutes]



2.4 minutes

1.5 minutes

$Y$

Customer  
satisfaction rating  
[0 - 10]



Both variables are  
continuous

# Joint Continuous Distributions

$X$

Waiting time  
before a call is picked up  
[0 - 10 minutes]



2.4 minutes

1.5 minutes

$Y$

Customer  
satisfaction rating  
[0 - 10]



0.0

5.7

Both variables are  
continuous

# Joint Continuous Distributions: Dataset

# Joint Continuous Distributions: Dataset

$X$  variable: Waiting time (mins)

0 - 10 mins

# Joint Continuous Distributions: Dataset

$X$  variable: Waiting time (mins)

0 - 10 mins

1000 customers

# Joint Continuous Distributions: Dataset

X variable: Waiting time (mins)

0 - 10 mins

1000 customers



# Joint Continuous Distributions: Dataset

# Joint Continuous Distributions: Dataset

$Y$  variable: Satisfaction rating

0 - 10

# Joint Continuous Distributions: Dataset

$Y$  variable: Satisfaction rating

0 - 10

1000 customers

# Joint Continuous Distributions: Dataset

$Y$  variable: Satisfaction rating

0 - 10

1000 customers



# Joint Continuous Distributions: Dataset

# Joint Continuous Distributions: Dataset

$X$  variable: Waiting time (mins)  
0 - 10 mins

# Joint Continuous Distributions: Dataset

$X$  variable: Waiting time (mins)  
0 - 10 mins

$Y$  variable: Satisfaction rating  
0 - 10

# Joint Continuous Distributions: Dataset

$X$  variable: Waiting time (mins)  
0 - 10 mins

$Y$  variable: Satisfaction rating  
0 - 10

1000 customers

# Joint Continuous Distributions: Dataset

$X$  variable: Waiting time (mins)  
0 - 10 mins

$Y$  variable: Satisfaction rating  
0 - 10

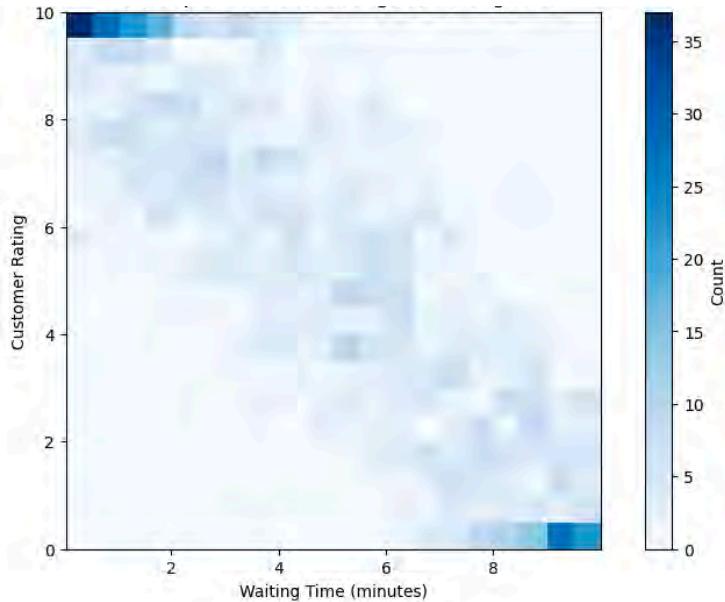
1000 customers



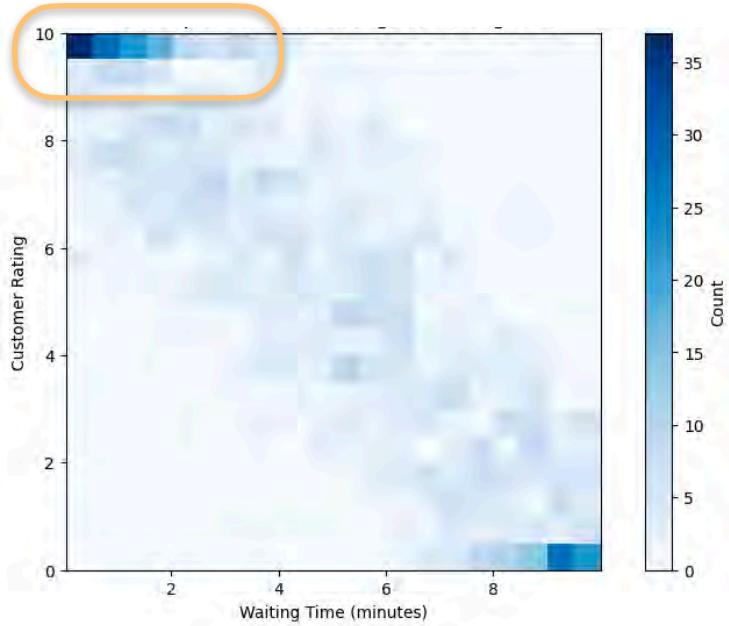
# Joint Continuous Distributions: Dataset



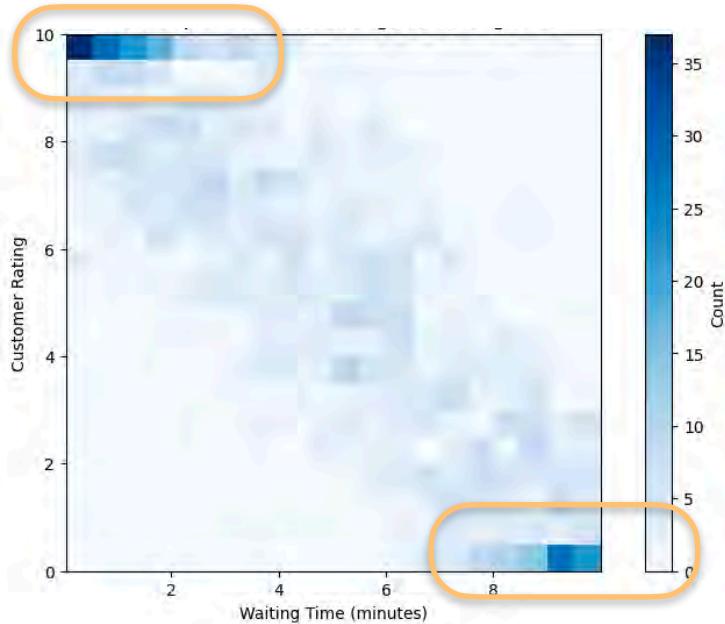
# Joint Continuous Distributions: Dataset



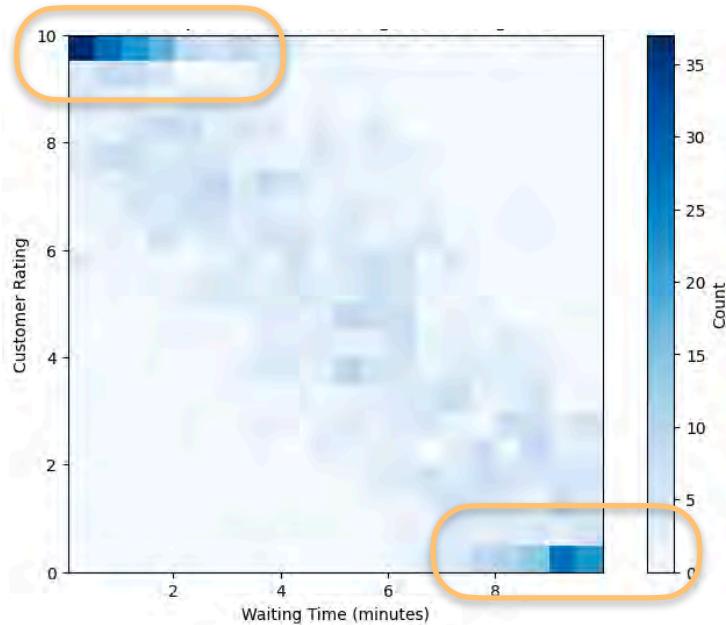
# Joint Continuous Distributions: Dataset



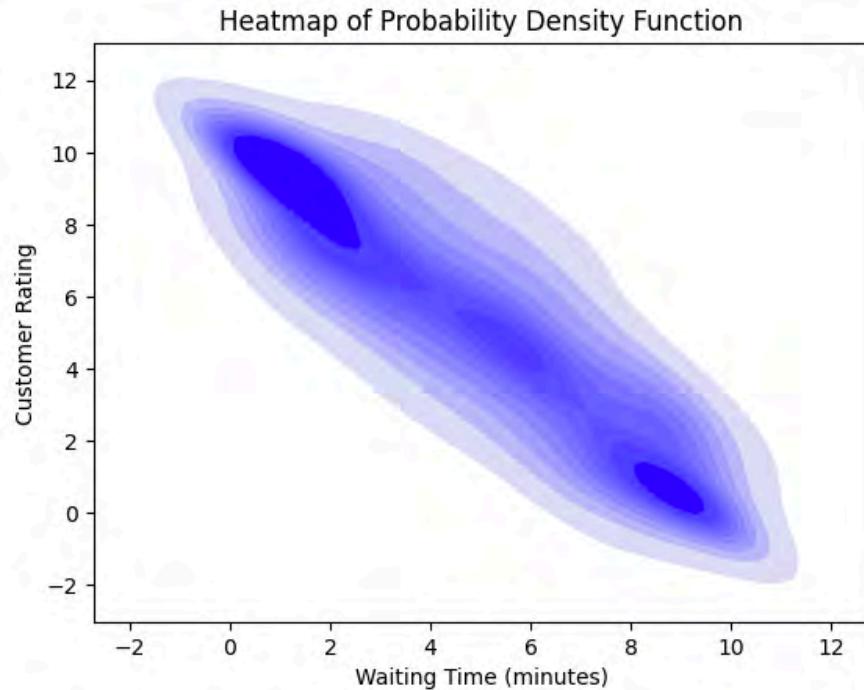
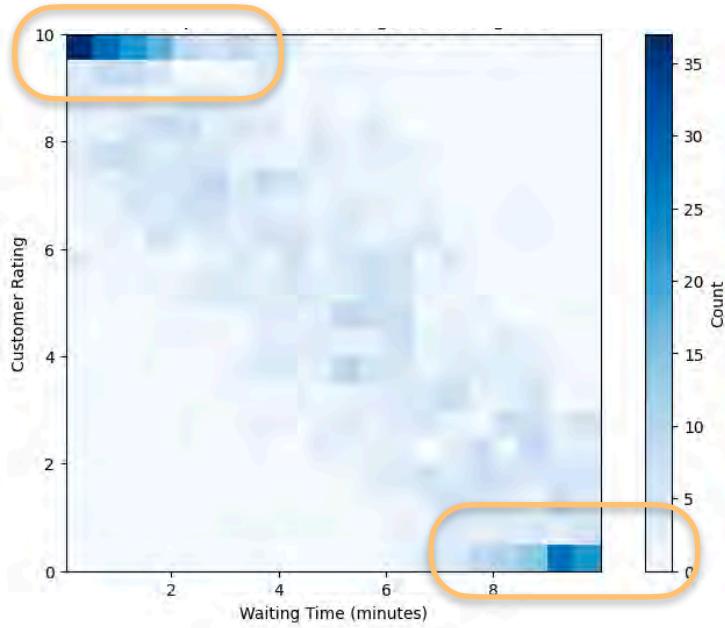
# Joint Continuous Distributions: Dataset



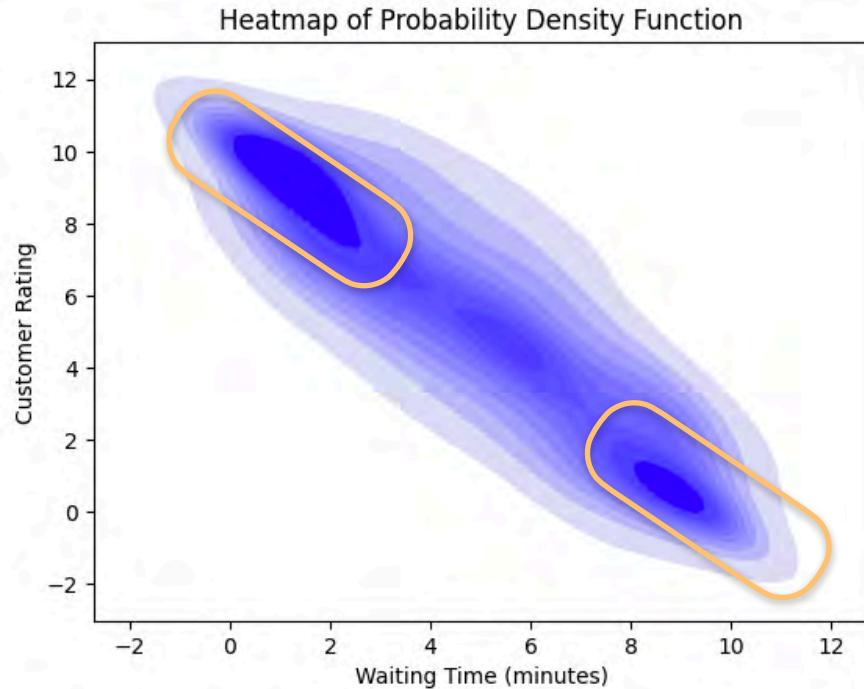
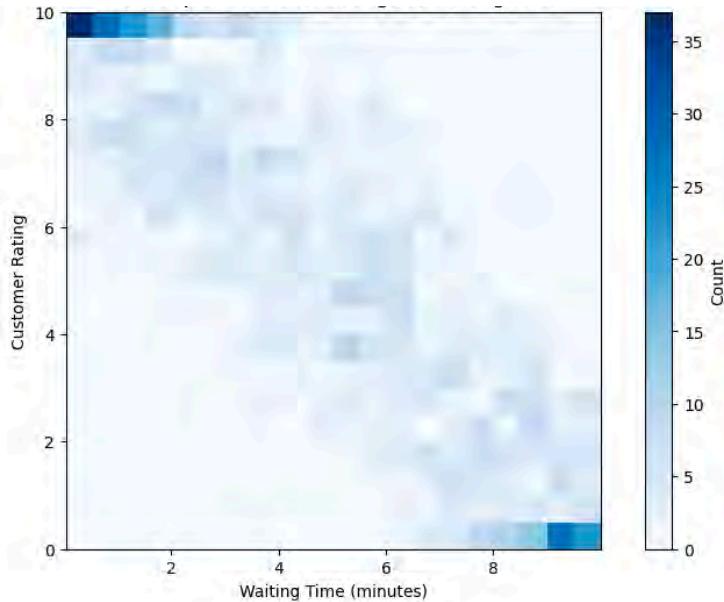
# Joint Continuous Distributions: Dataset



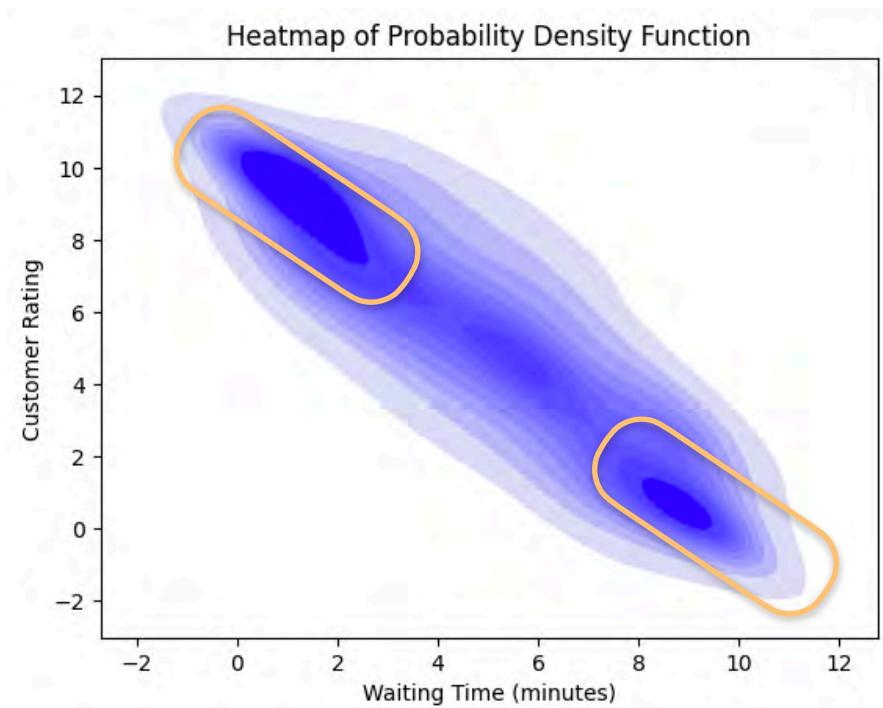
# Joint Continuous Distributions: Dataset



# Joint Continuous Distributions: Dataset

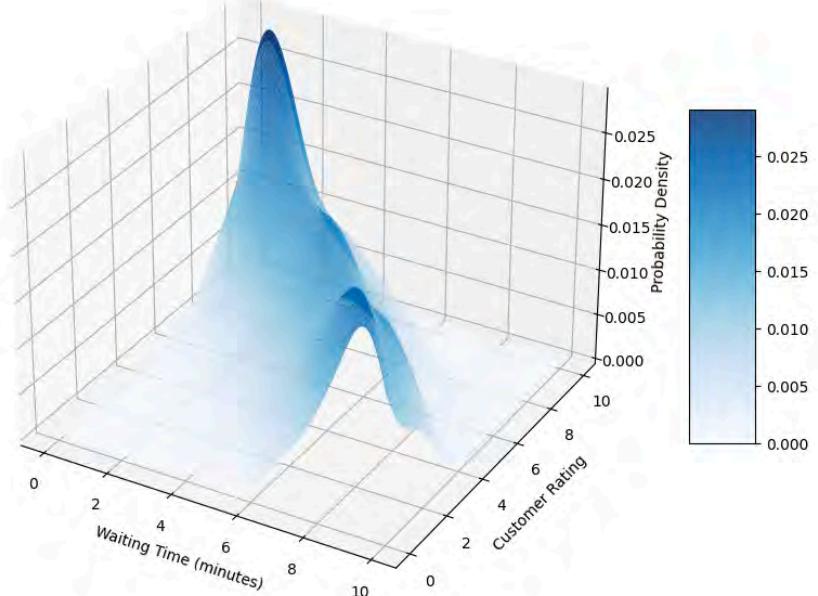


# Joint Continuous Distributions: Dataset

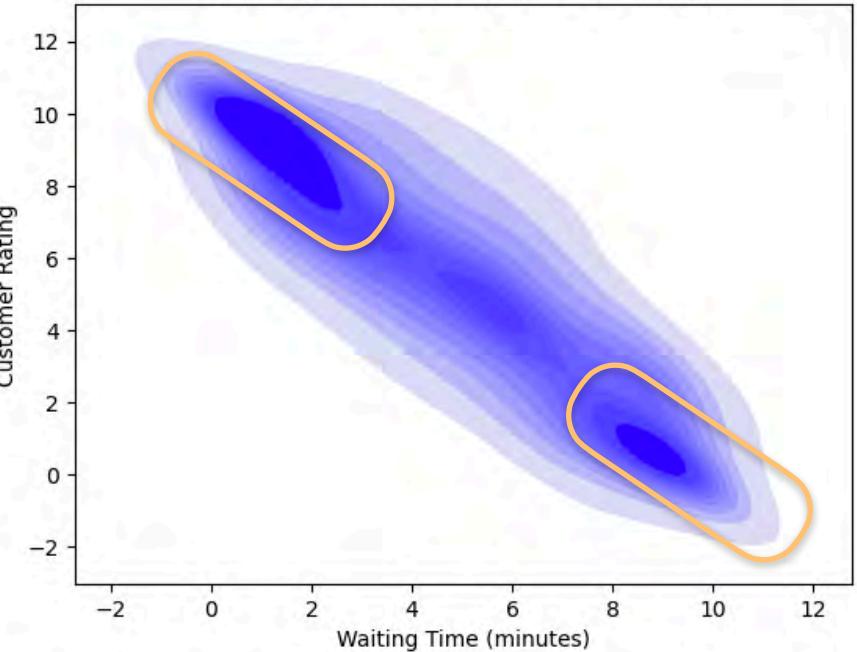


# Joint Continuous Distributions: Dataset

3D Probability Density Distribution for Customer Ratings vs Waiting Time

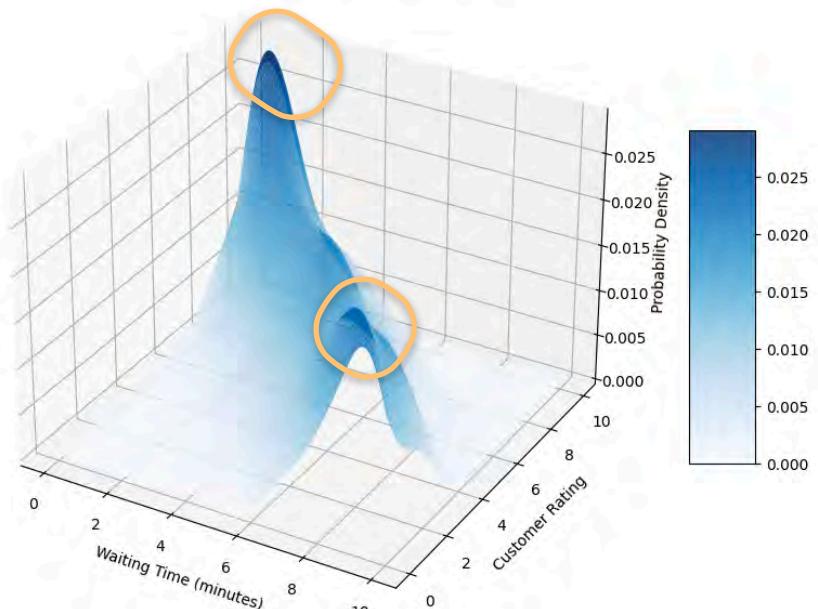


Heatmap of Probability Density Function

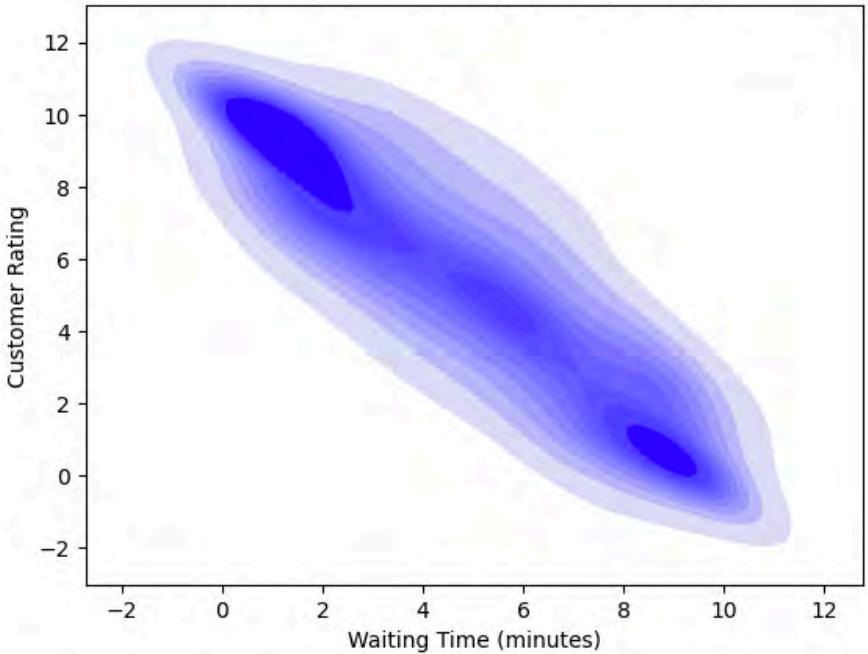


# Joint Continuous Distributions: Dataset

3D Probability Density Distribution for Customer Ratings vs Waiting Time



Heatmap of Probability Density Function



# Joint Continuous Distributions: Dataset

$X$  variable: Waiting time (mins)  
0 - 10 mins

$Y$  variable: Satisfaction rating  
0 - 10

1000 customers



# Expected Value

$X$  variable: Waiting time (mins)

0 - 10 mins

$Y$  variable: Satisfaction rating

0 - 10

1000 customers



# Expected Value

$X$  variable: Waiting time (mins)

0 - 10 mins

$Y$  variable: Satisfaction rating

0 - 10

1000 customers

$$\mathbb{E}[X] = 4.903 \text{ minutes}$$



# Expected Value

$X$  variable: Waiting time (mins)  
0 - 10 mins

$Y$  variable: Satisfaction rating  
0 - 10

1000 customers

$$\mathbb{E}[X] = 4.903 \text{ minutes}$$

$$\mathbb{E}[Y] = 5.280$$



# Expected Value

$X$  variable: Waiting time (mins)  
0 - 10 mins

$Y$  variable: Satisfaction rating  
0 - 10

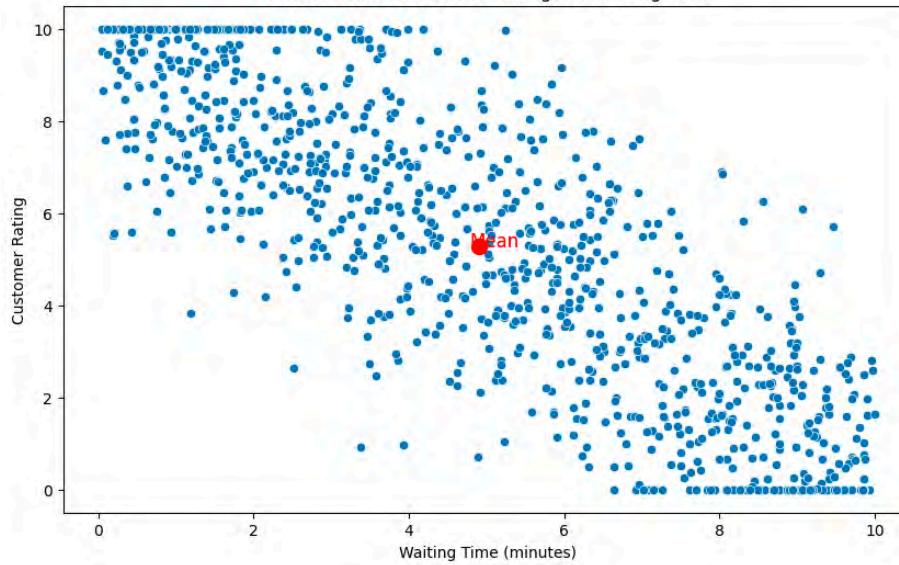
1000 customers

$$\mathbb{E}[X] = 4.903 \text{ minutes}$$

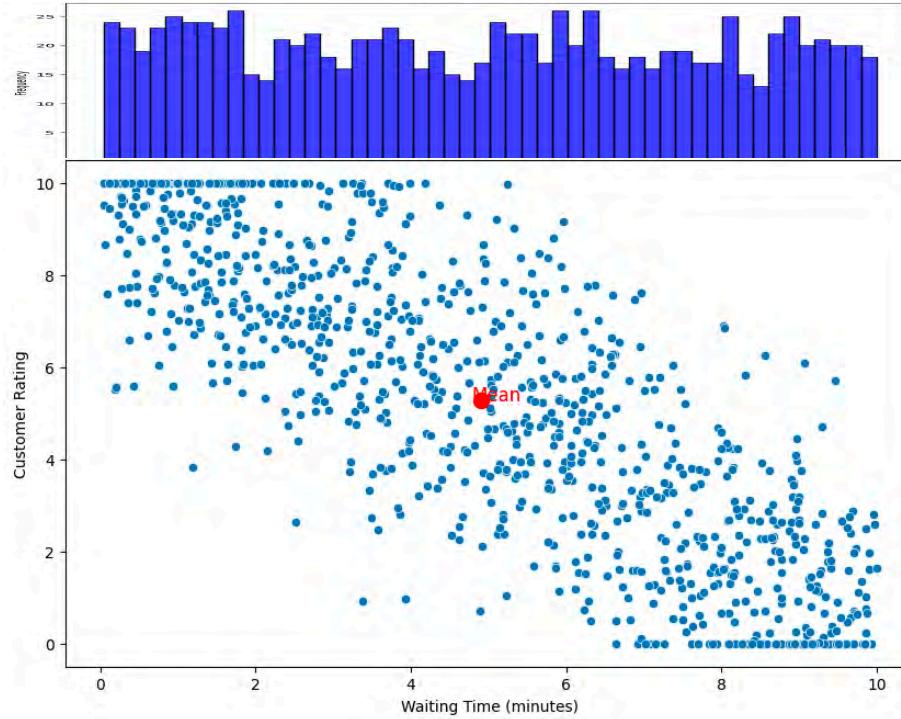
$$\mathbb{E}[Y] = 5.280$$



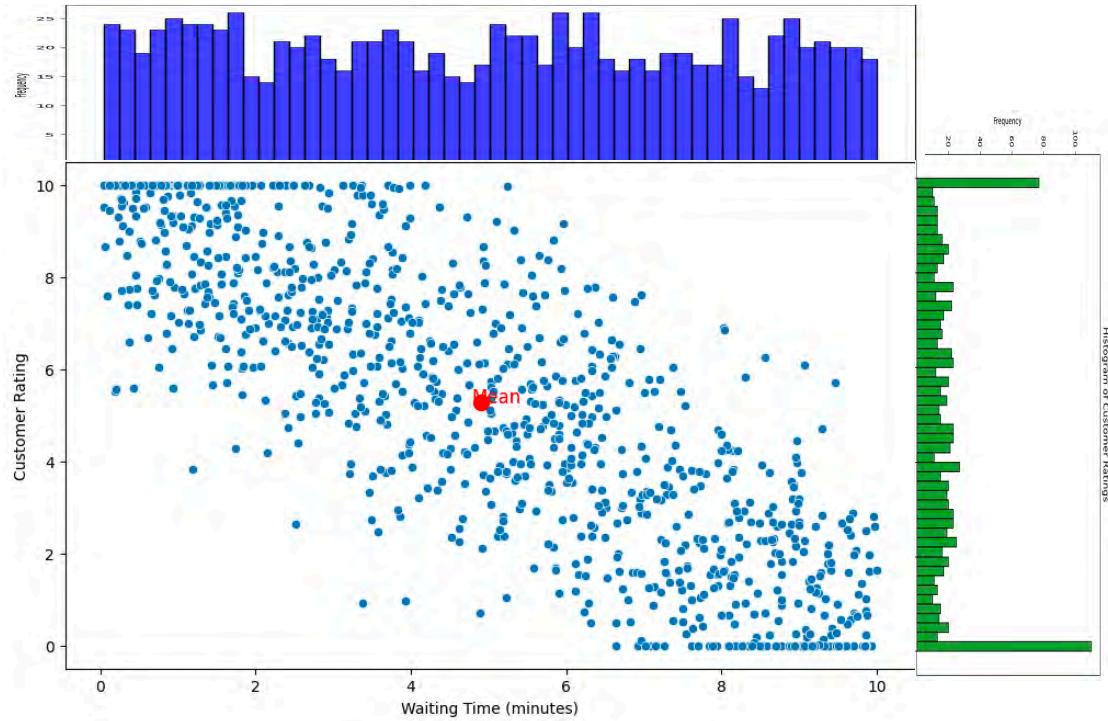
# Variances



# Variances

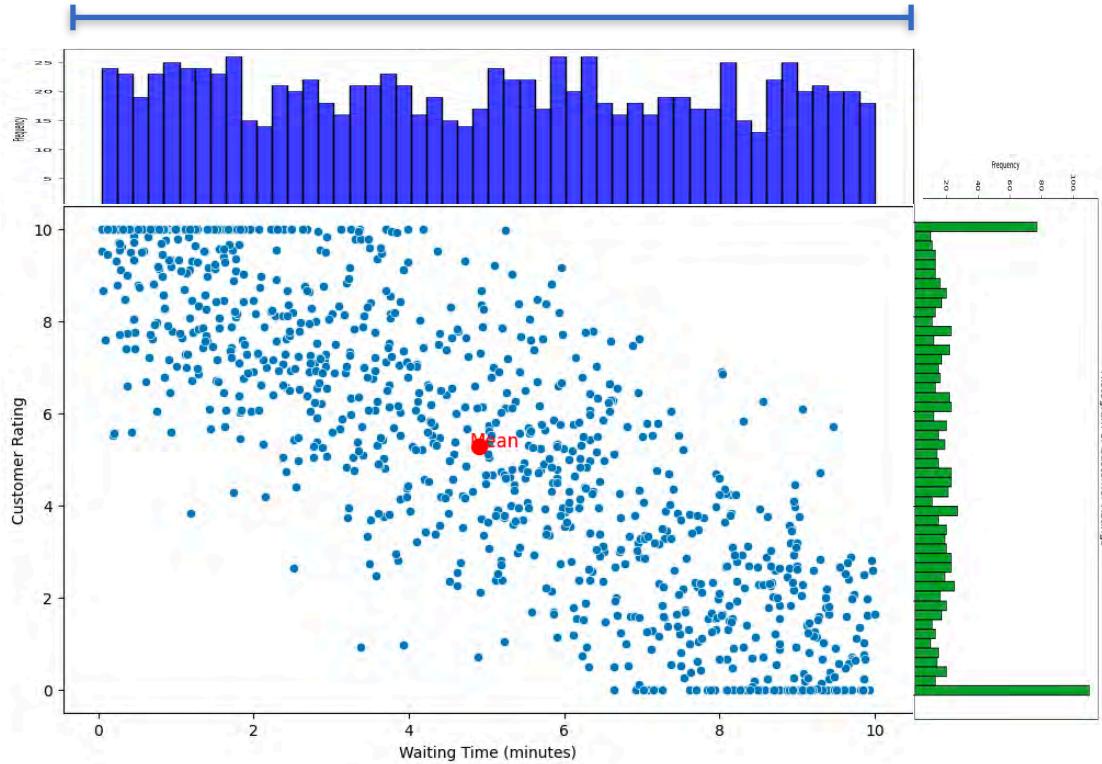


# Variances



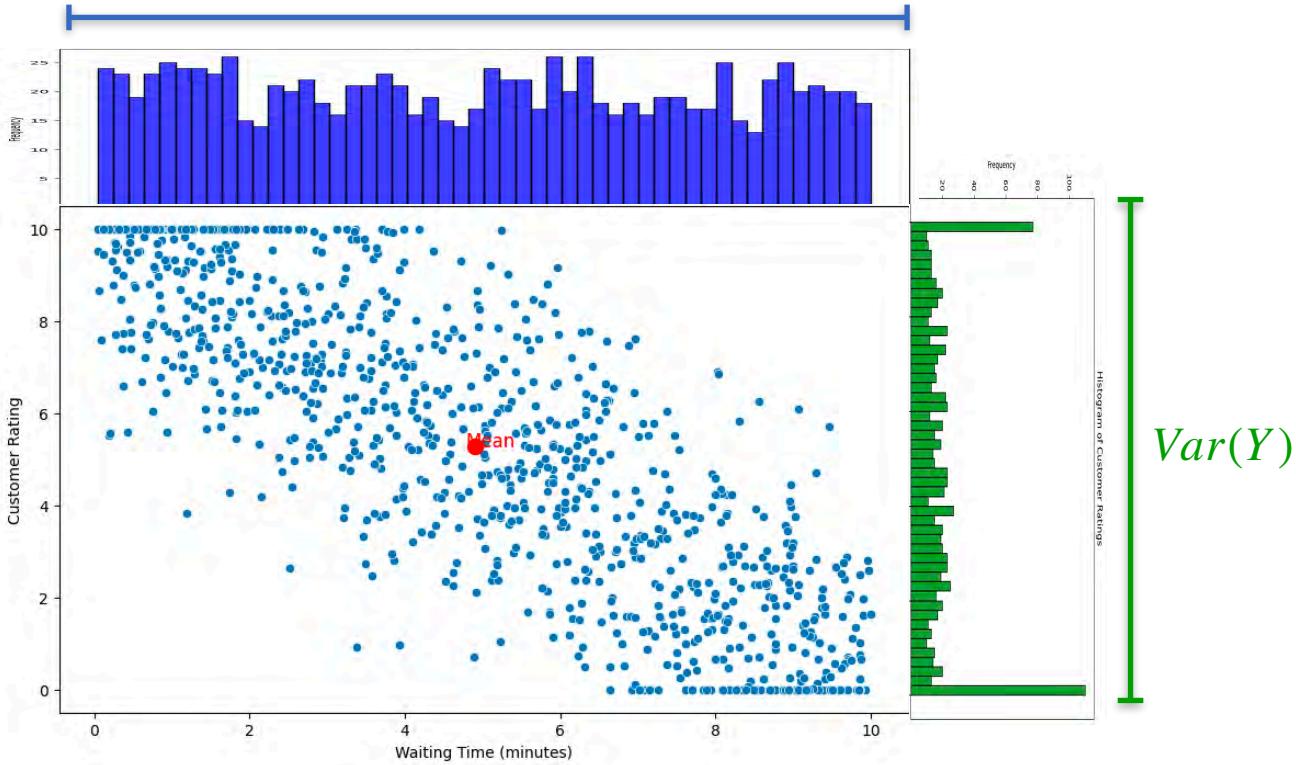
# Variances

$$Var(X)$$



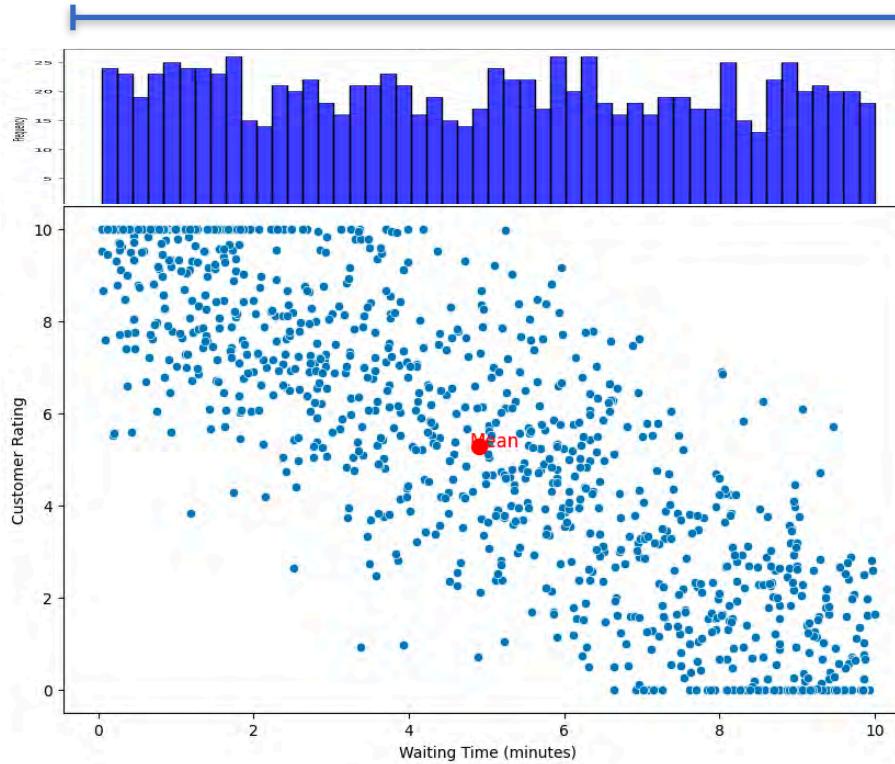
# Variances

$$Var(X)$$



# Variances

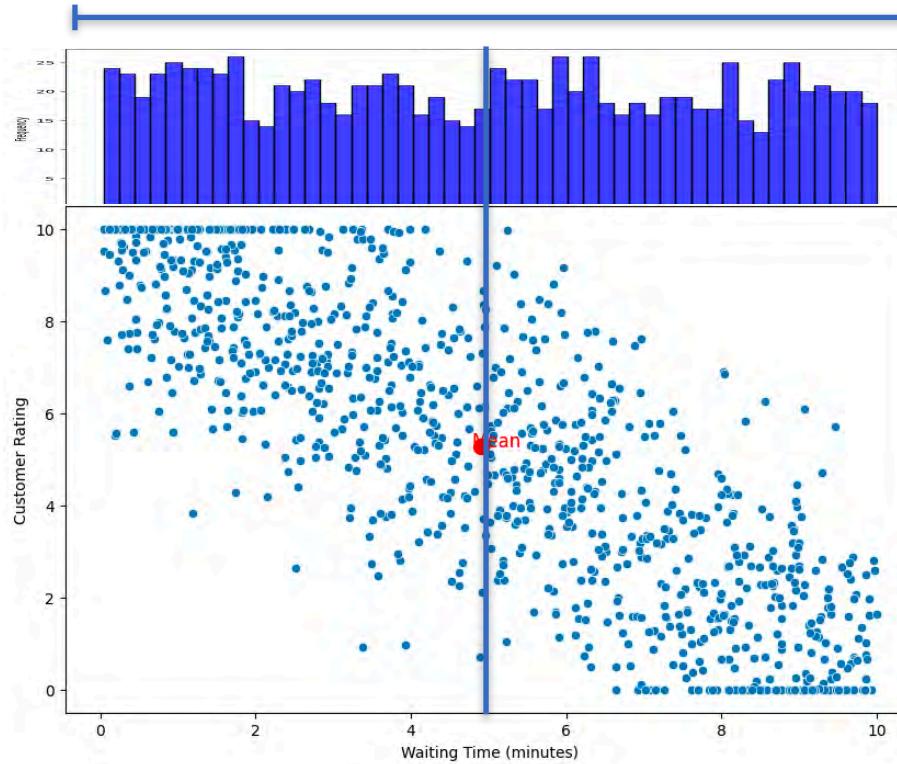
$$Var(X)$$



# Variances

$$\mathbb{E}[X] = 4.903 \text{ minutes}$$

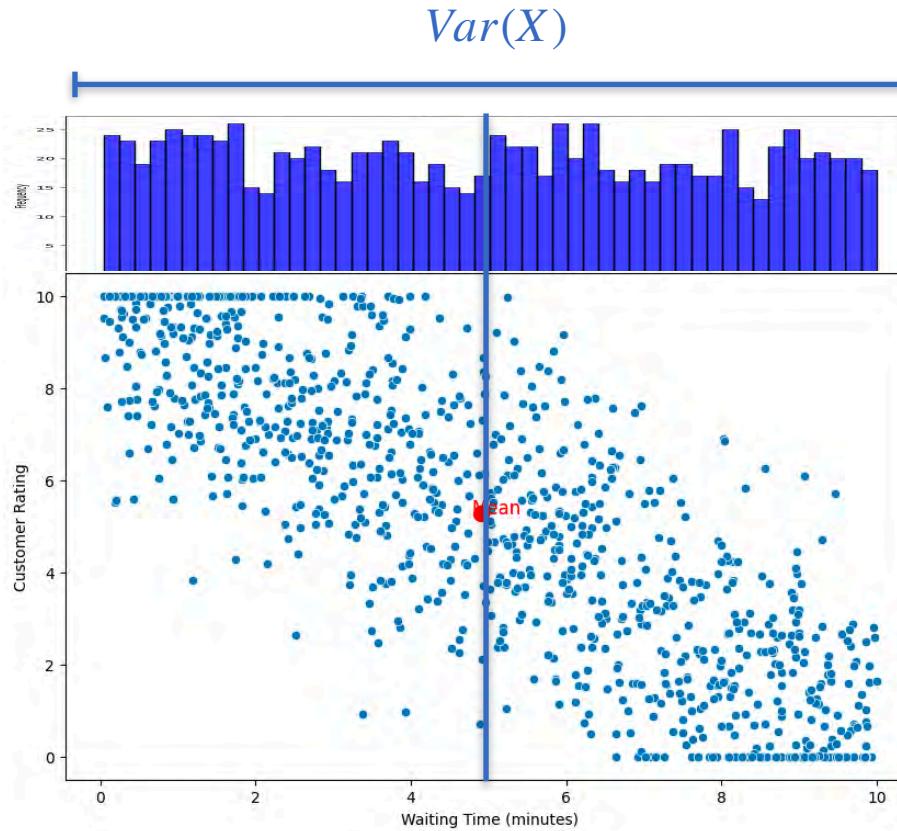
$$Var(X)$$



# Variances

$$\mathbb{E}[X] = 4.903 \text{ minutes}$$

$$\mathbb{E}[X^2] = 32.561$$

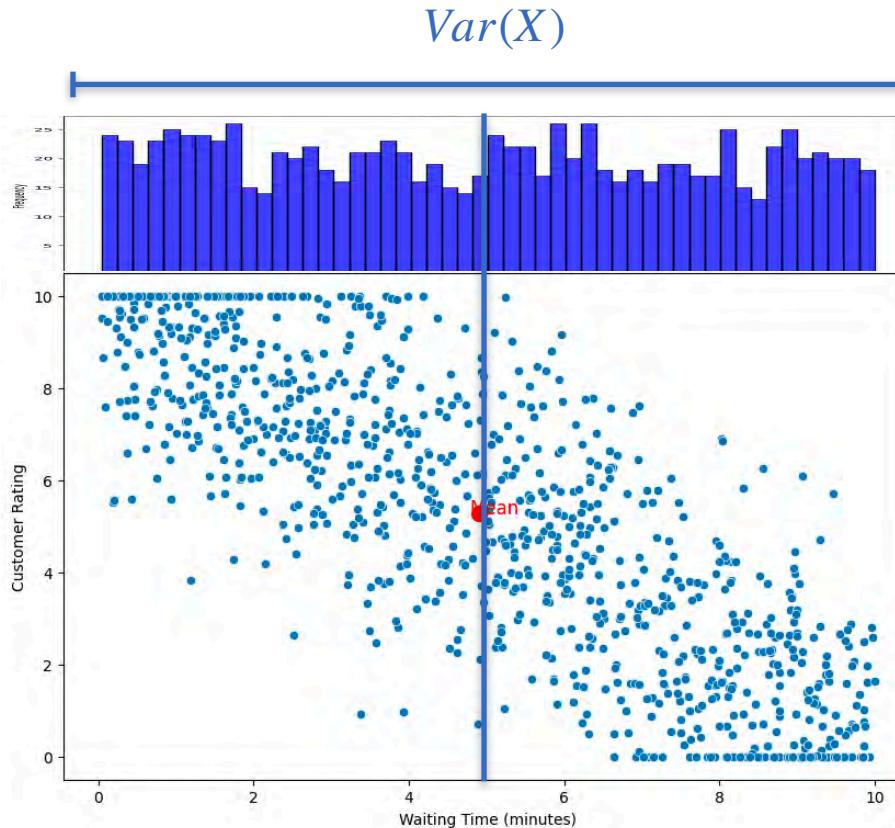


# Variances

$$\mathbb{E}[X] = 4.903 \text{ minutes}$$

$$\mathbb{E}[X^2] = 32.561$$

$$Var(X) = \mathbb{E}[X^2] - \mathbb{E}[X]^2$$

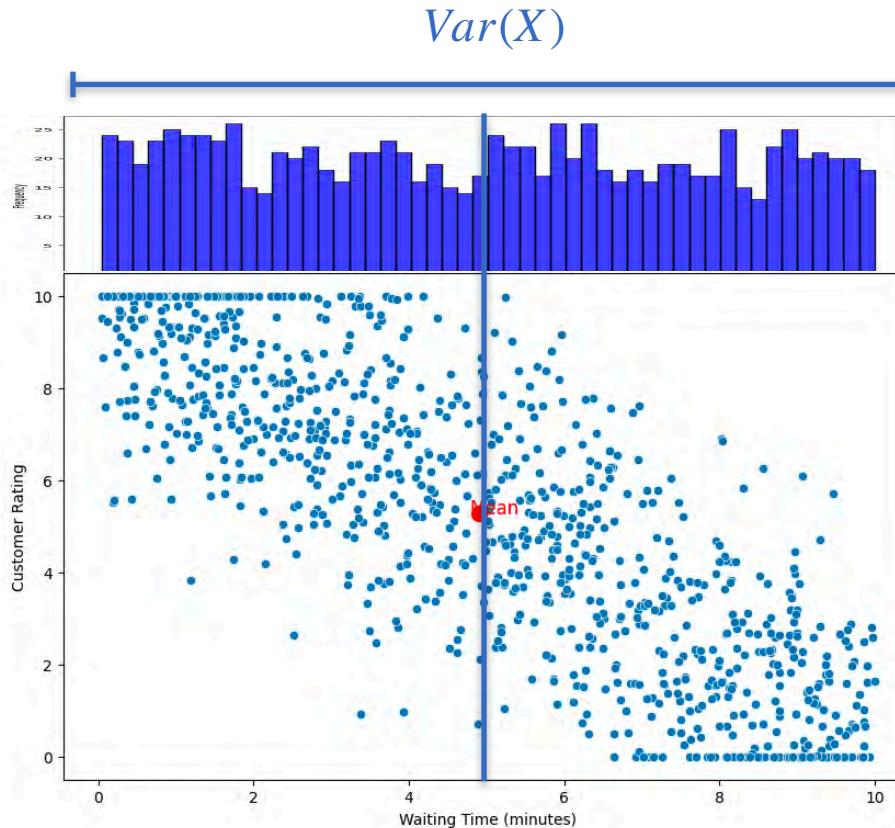


# Variances

$$\mathbb{E}[X] = 4.903 \text{ minutes}$$

$$\mathbb{E}[X^2] = 32.561$$

$$\begin{aligned} \text{Var}(X) &= \mathbb{E}[X^2] - \mathbb{E}[X]^2 \\ &= 32.561 - 4.903^2 \end{aligned}$$

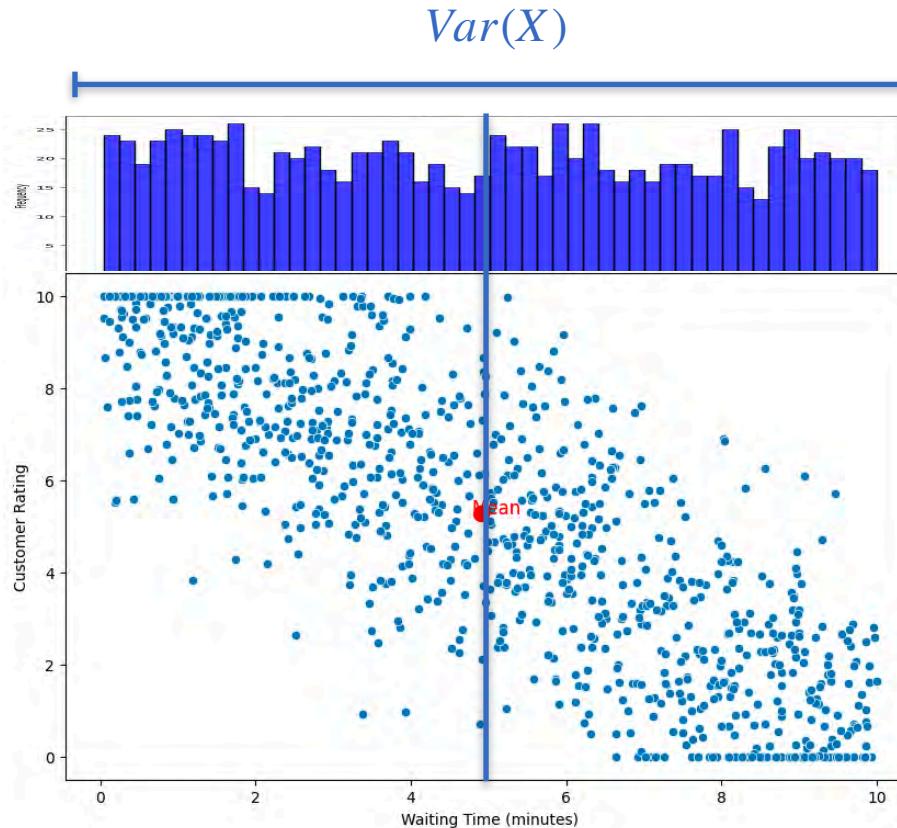


# Variances

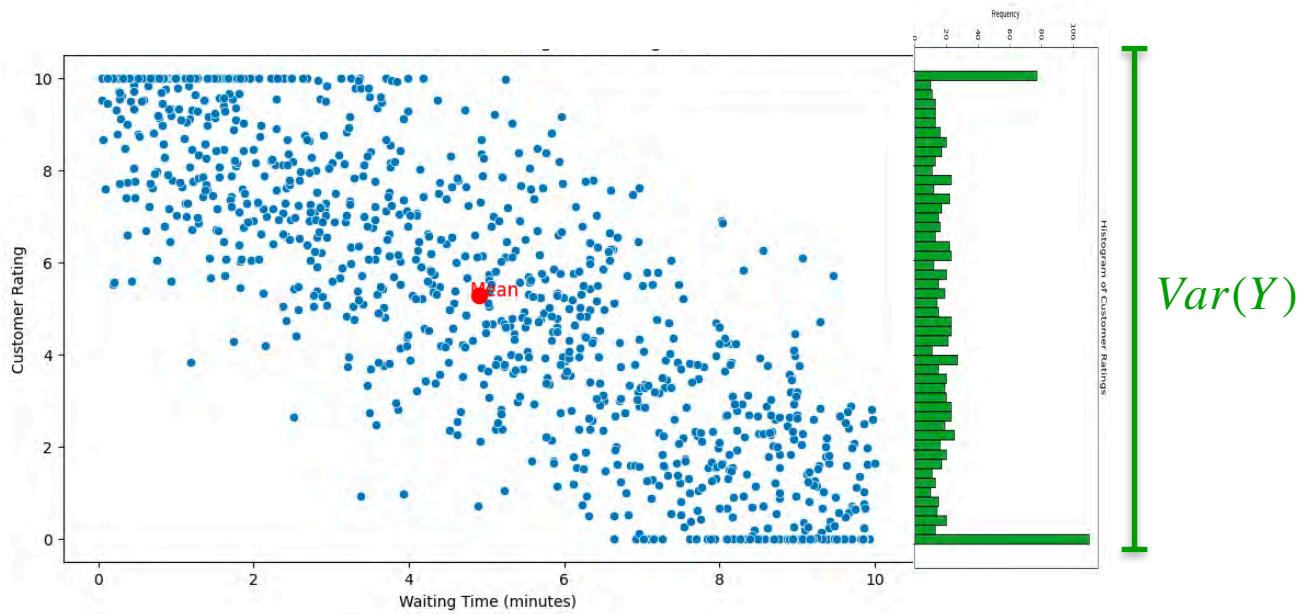
$$\mathbb{E}[X] = 4.903 \text{ minutes}$$

$$\mathbb{E}[X^2] = 32.561$$

$$\begin{aligned} \text{Var}(X) &= \mathbb{E}[X^2] - \mathbb{E}[X]^2 \\ &= 32.561 - 4.903^2 \\ &= 8.526 \end{aligned}$$

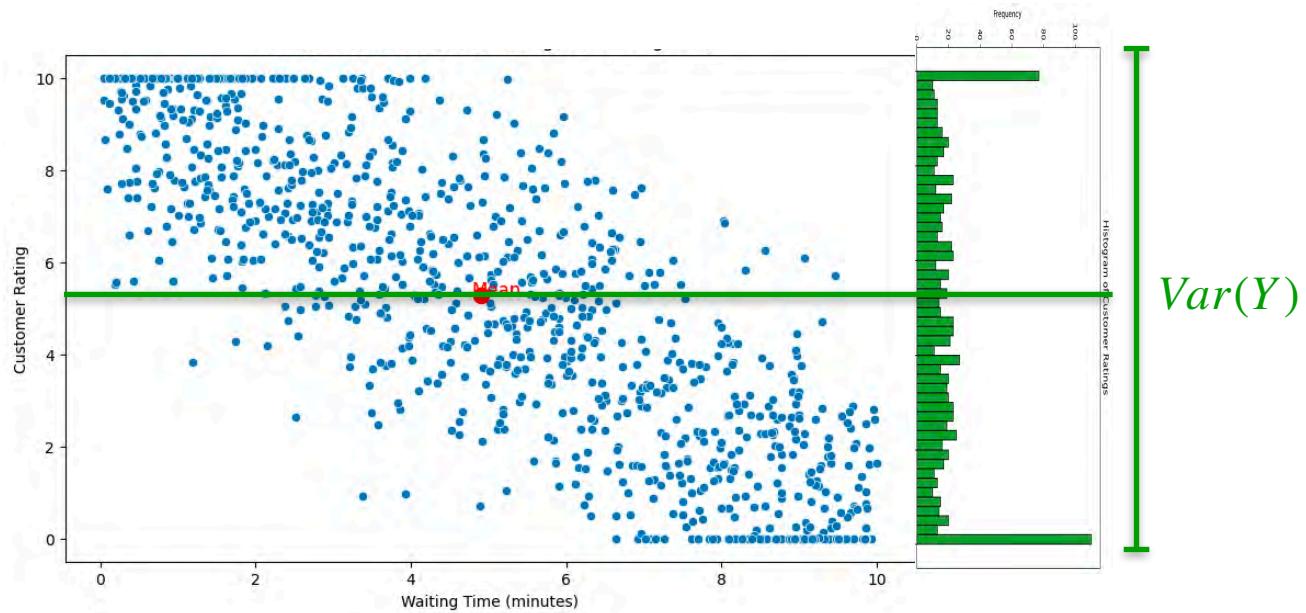


# Variances



# Variances

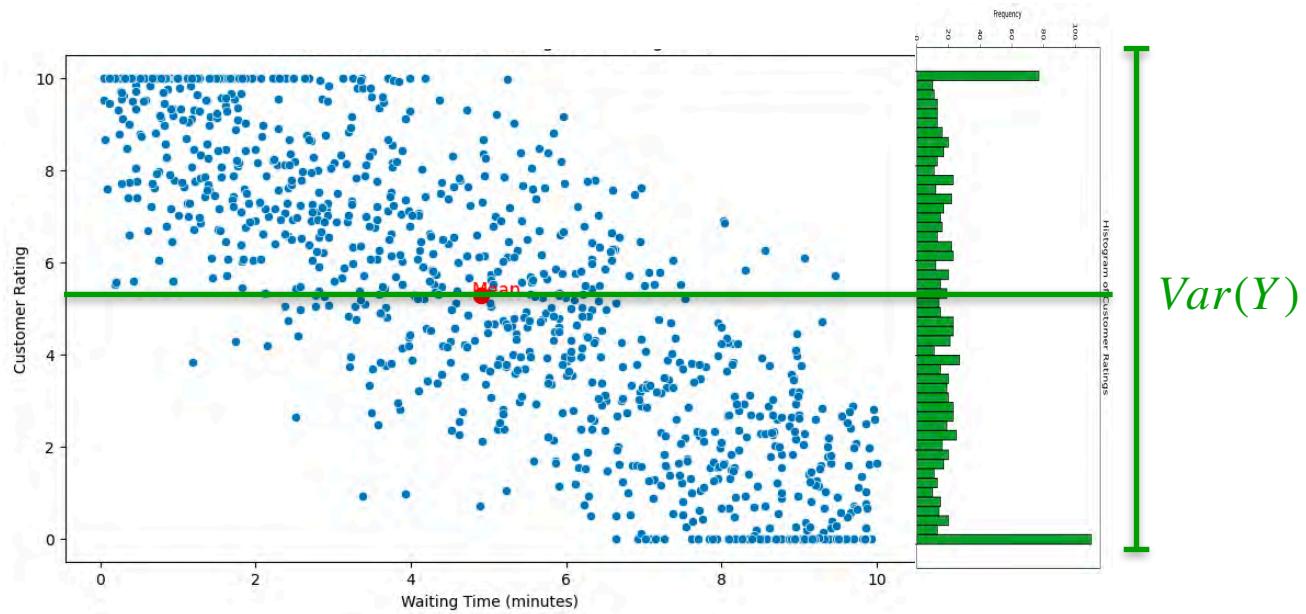
$$\mathbb{E}[Y] = 5.280$$



# Variances

$$\mathbb{E}[Y] = 5.280$$

$$\mathbb{E}[Y^2] = 38.037$$

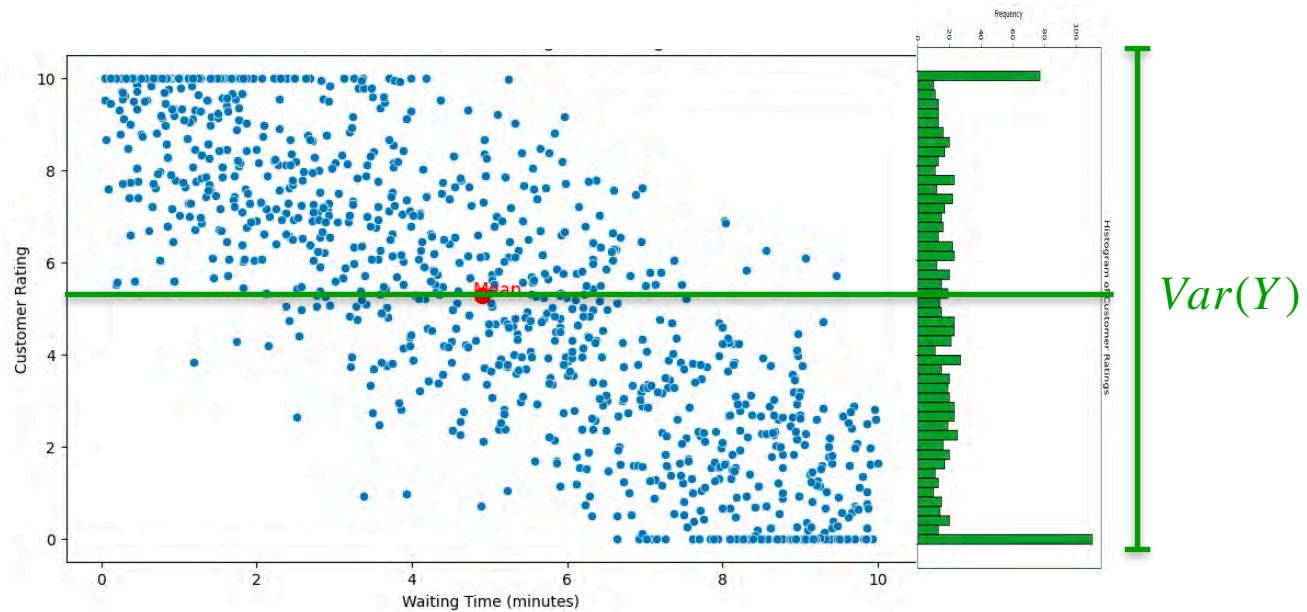


# Variances

$$\mathbb{E}[Y] = 5.280$$

$$\mathbb{E}[Y^2] = 38.037$$

$$Var(Y) = \mathbb{E}[Y^2] - \mathbb{E}[Y]^2$$

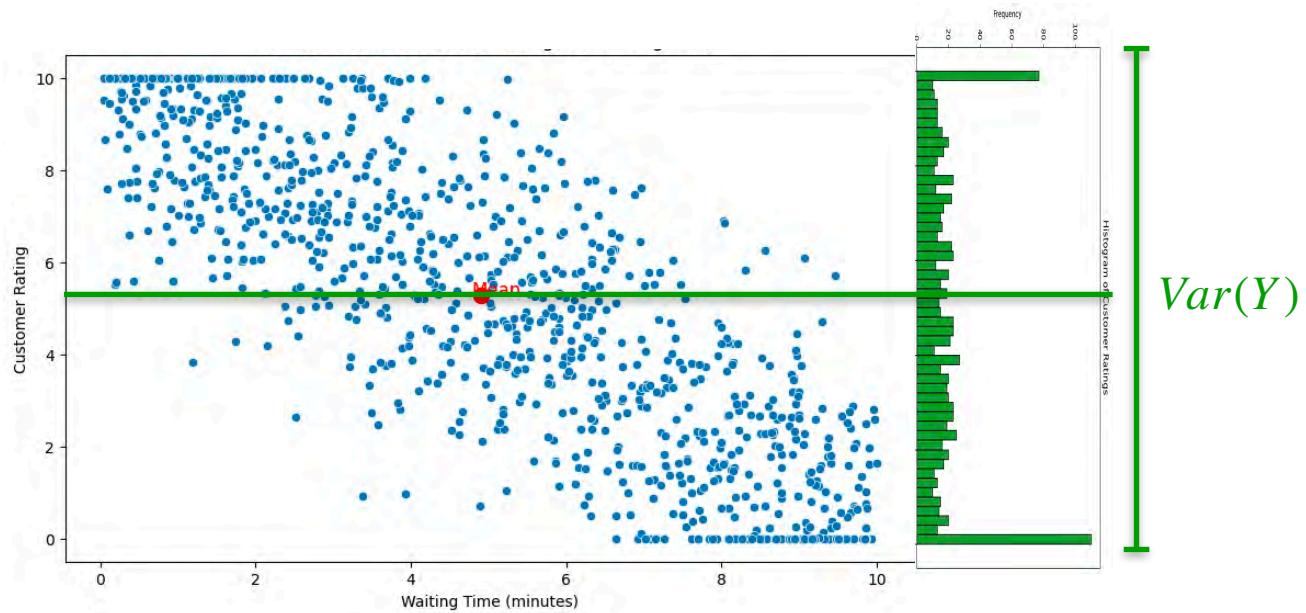


# Variances

$$\mathbb{E}[Y] = 5.280$$

$$\mathbb{E}[Y^2] = 38.037$$

$$\begin{aligned} \text{Var}(Y) &= \mathbb{E}[Y^2] - \mathbb{E}[Y]^2 \\ &= 38.037 - 5.280^2 \end{aligned}$$

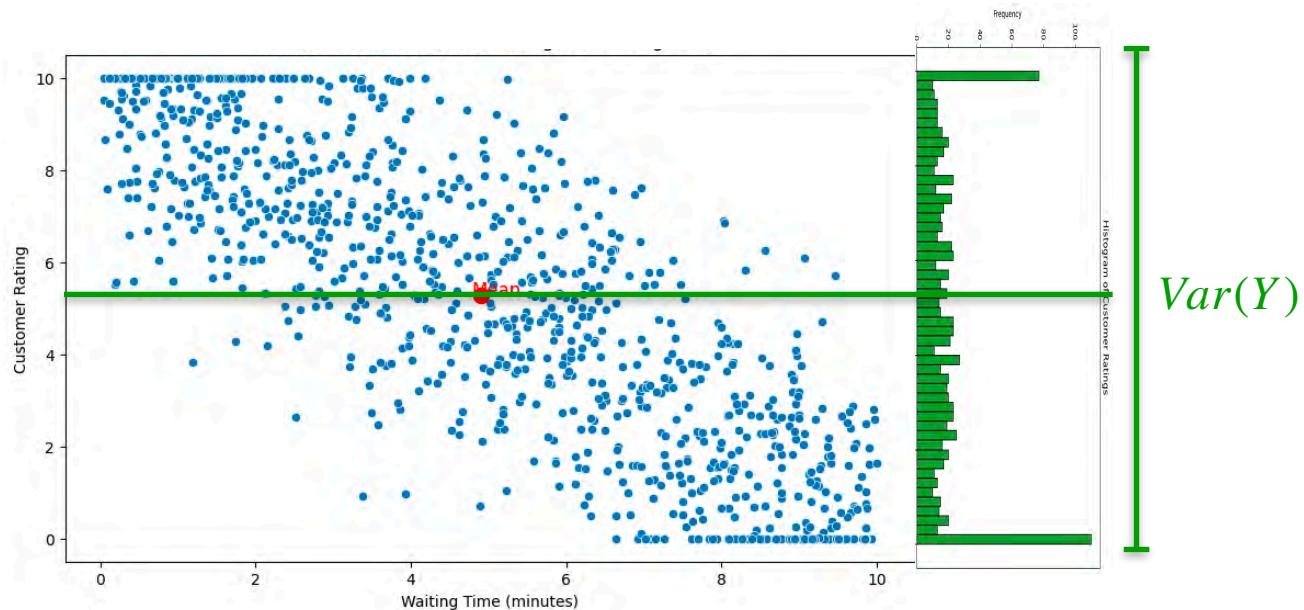


# Variances

$$\mathbb{E}[Y] = 5.280$$

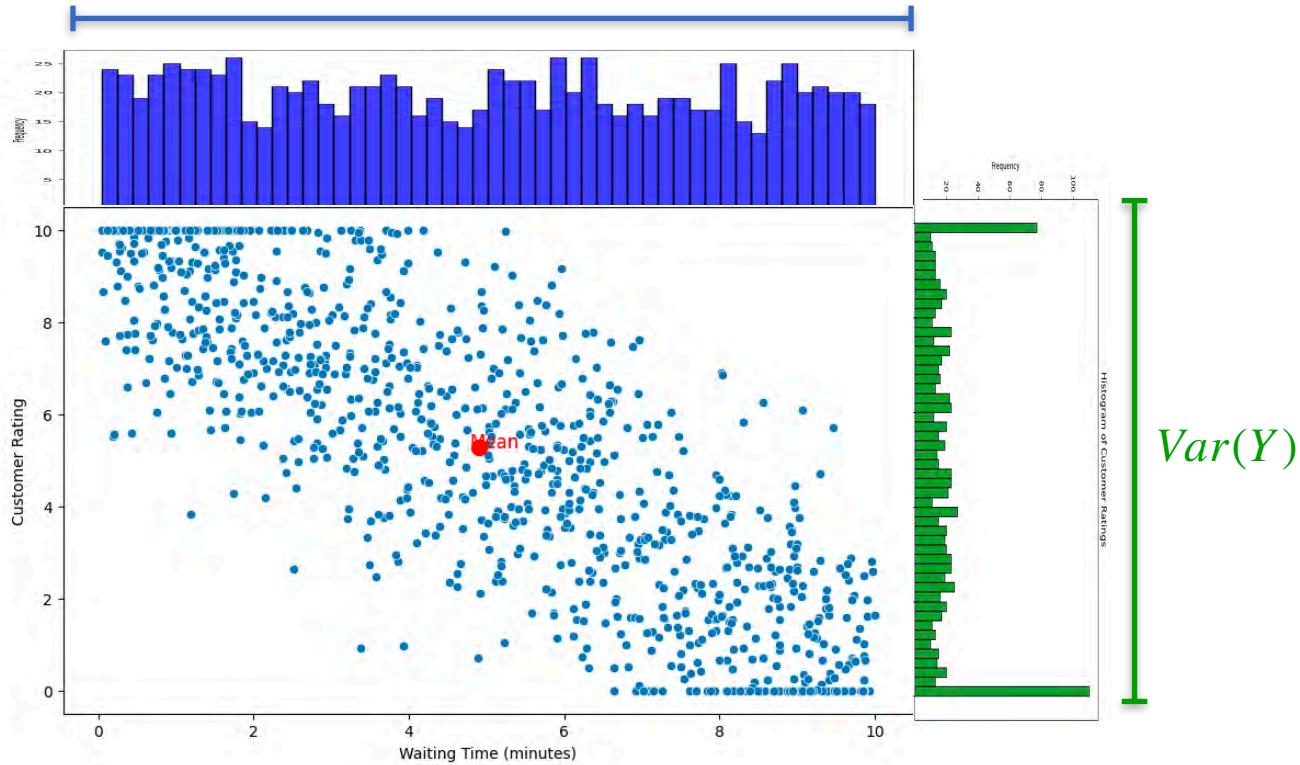
$$\mathbb{E}[Y^2] = 38.037$$

$$\begin{aligned} \text{Var}(Y) &= \mathbb{E}[Y^2] - \mathbb{E}[Y]^2 \\ &= 38.037 - 5.280^2 \\ &= 10.163 \end{aligned}$$



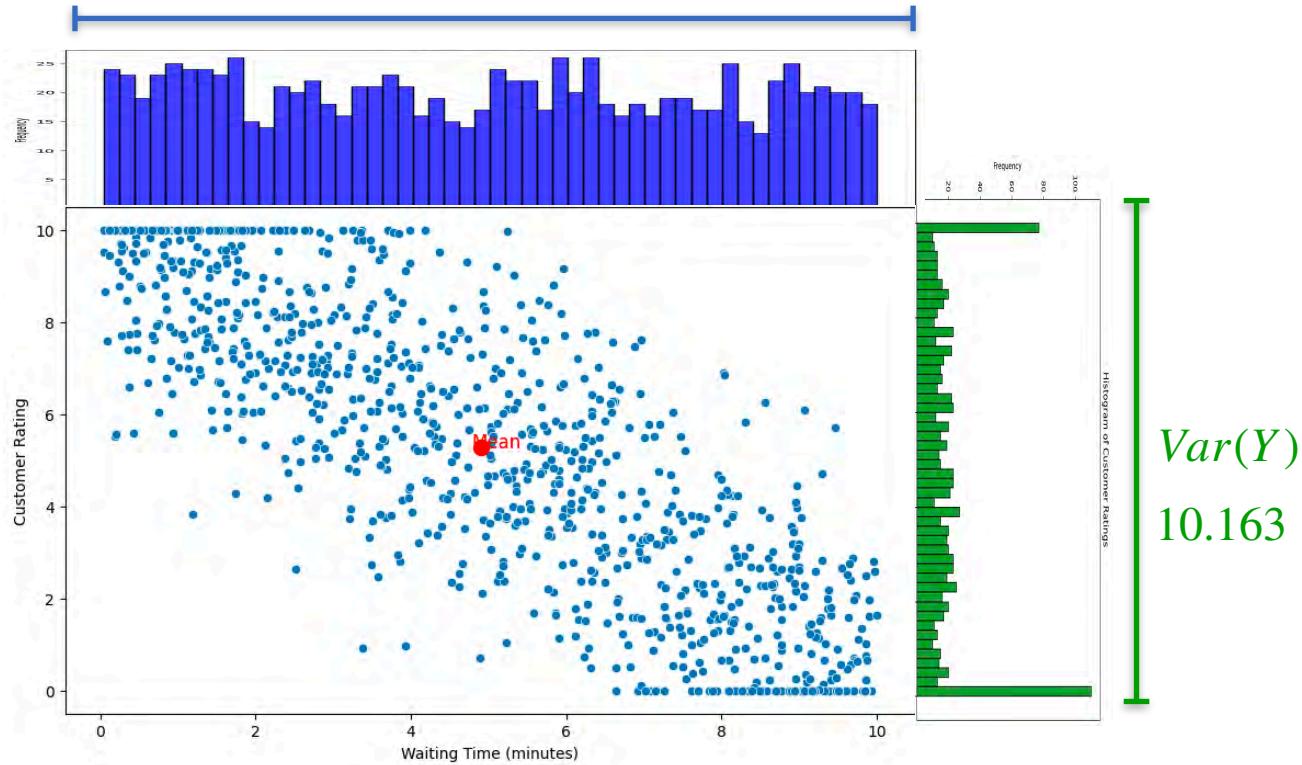
# Variances

$$Var(X)$$



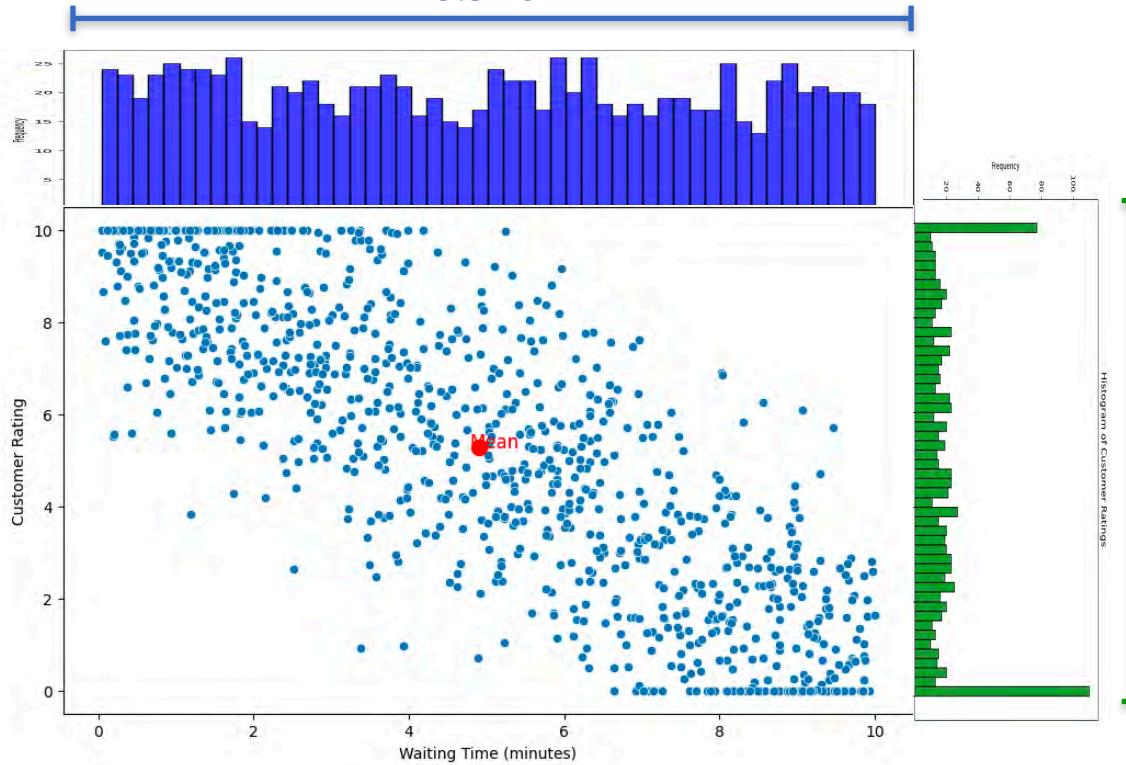
# Variances

$$Var(X)$$



# Variances

$$Var(X)$$
  
$$8.526$$





DeepLearning.AI

# Probability Distributions with Multiple Variables

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## Marginal and Conditional Distribution

# Marginal Distribution: Example 1

# Marginal Distribution: Example 1



# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



Marginal Distribution

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



## Marginal Distribution

Distribution of one variable while ignoring the other

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



To find the marginal distribution of height:

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



To find the marginal distribution of height:

sum the joint probability distribution over all values of age

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10



$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j)$$

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10



$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j)$$

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10



$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j)$$

$$p_Y(50) =$$

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10



$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j)$$

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10



$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j)$$

$$p_Y(50) = \sum_i p_{XY}(x_i, 50)$$

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10



$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j)$$

$$p_Y(50) = \sum_i p_{XY}(x_i, 50)$$

$$p_Y(50) = \frac{2}{10}$$

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10



# Marginal Distribution: Example 1

		Height ( $Y$ )						Age (years): 7 7 7 8 8 9 9 9 9 10									
		45	46	47	48	49	50	Height (in): 45 46 46 47 47 49 49 49 49 50 50									
Age ( $X$ )	7	1/10	2/10	0	0	0	0	3/10									
	8	0	0	2/10	0	0	0	2/10									
	9	0	0	0	0	3/10	1/10	4/10									
	10	0	0	0	0	0	1/10	1/10									
	1/10		2/10	2/10	0	3/10	2/10										

$$p_X(x_i) = \sum_j p_{XY}(x_i, y_j)$$

# Marginal Distribution: Example 1

		Height ( $Y$ )						Age (years): 7 7 7 8 8 9 9 9 9 10									
		45	46	47	48	49	50	Height (in): 45 46 46 47 47 49 49 49 49 50 50									
Age ( $X$ )	7	1/10	2/10	0	0	0	0	3/10									
	8	0	0	2/10	0	0	0	2/10									
	9	0	0	0	0	3/10	1/10	4/10									
	10	0	0	0	0	0	1/10	1/10									
	1/10		2/10	2/10	0	3/10	2/10										

$$p_X(x_i) = \sum_j p_{XY}(x_i, y_j)$$

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10

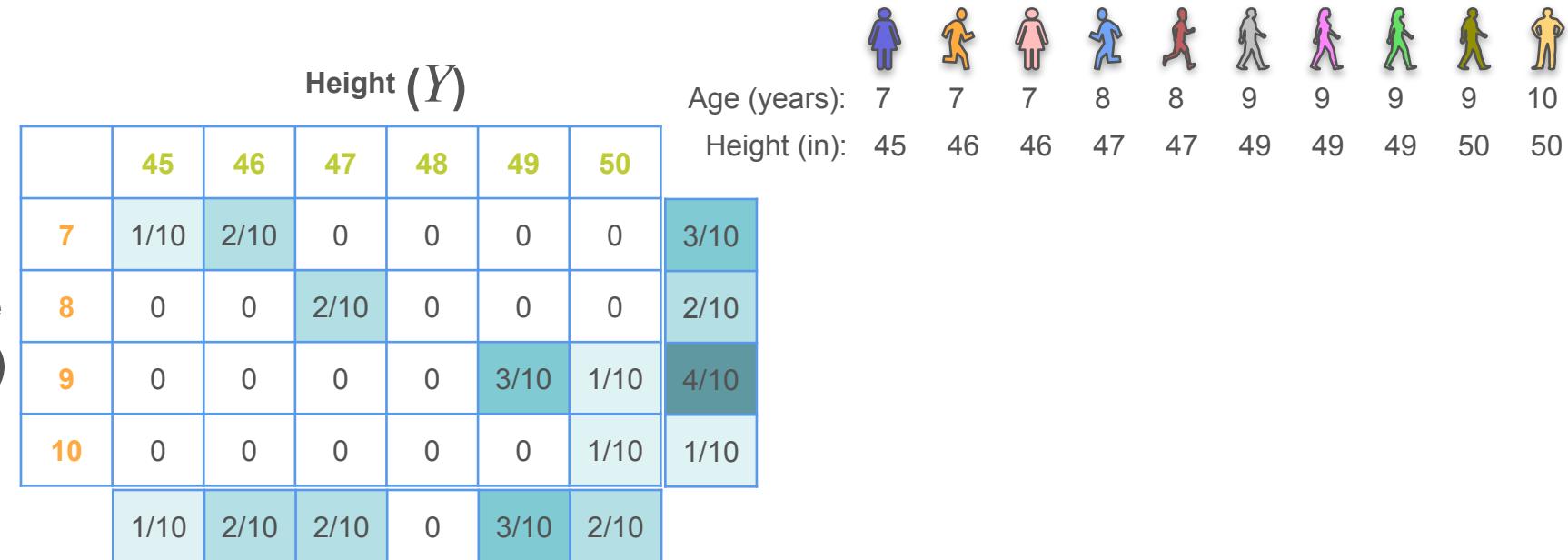


$$p_X(x_i) = \sum_j p_{XY}(x_i, y_j)$$

$$p_X(7) = \sum_j p_{XY}(7, y_j)$$

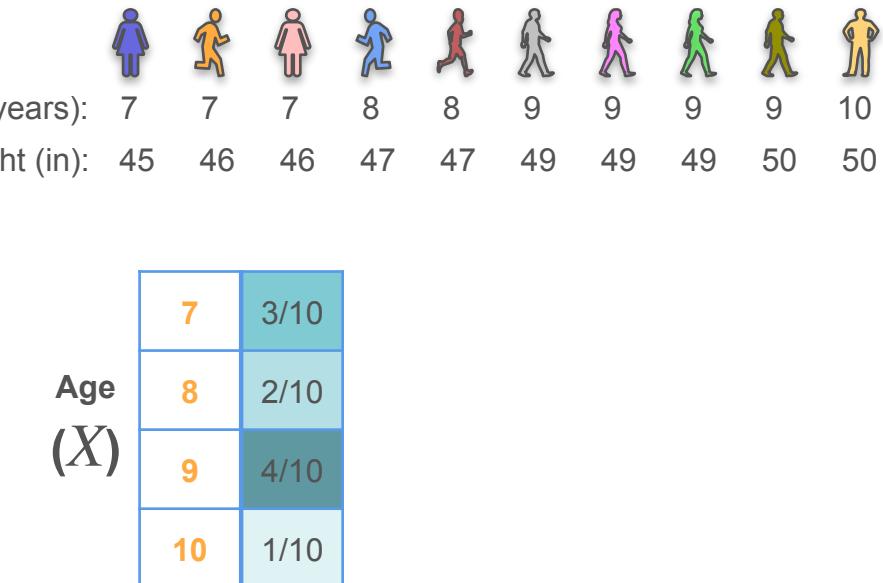
$$p_X(7) = \frac{3}{10}$$

# Marginal Distribution: Example 1



# Marginal Distribution: Example 1

		Height ( $Y$ )						Age (years): 7 7 7 8 8 9 9 9 9 10									
		45	46	47	48	49	50	Height (in): 45 46 46 47 47 47 49 49 49 49 50 50									
Age ( $X$ )	7	1/10	2/10	0	0	0	0	3/10									
	8	0	0	2/10	0	0	0	2/10									
	9	0	0	0	0	3/10	1/10	4/10									
	10	0	0	0	0	0	1/10	1/10									
			1/10	2/10	2/10	0	3/10	2/10									

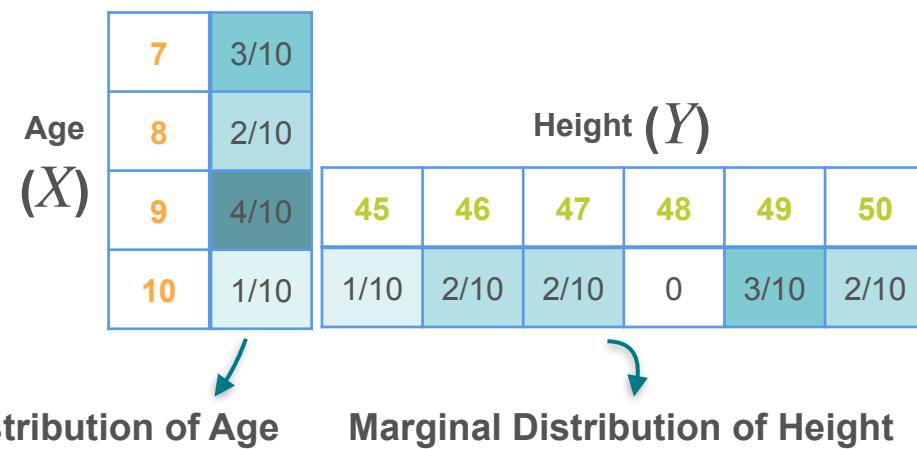


Marginal Distribution of Age

# Marginal Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10
		1/10	2/10	2/10	0	3/10	2/10

Age (years):	7	7	7	8	8	9	9	9	9	9	10
Height (in):	45	46	46	47	47	49	49	49	49	50	50



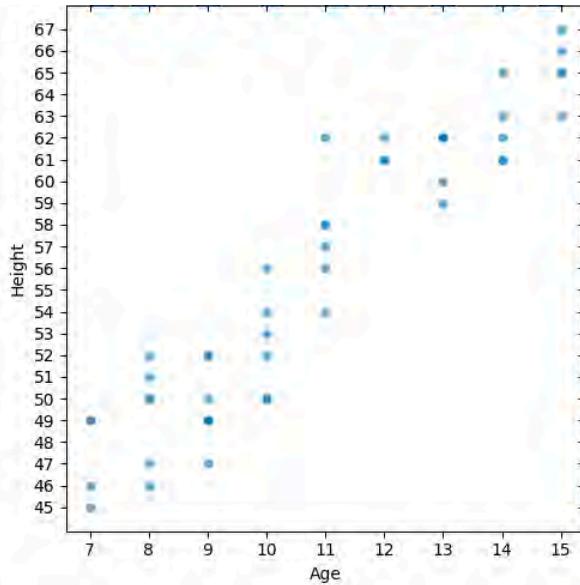
# Marginal Distribution: Example 1

# Marginal Distribution: Example 1

Age and Height Dataset  
for 50 children

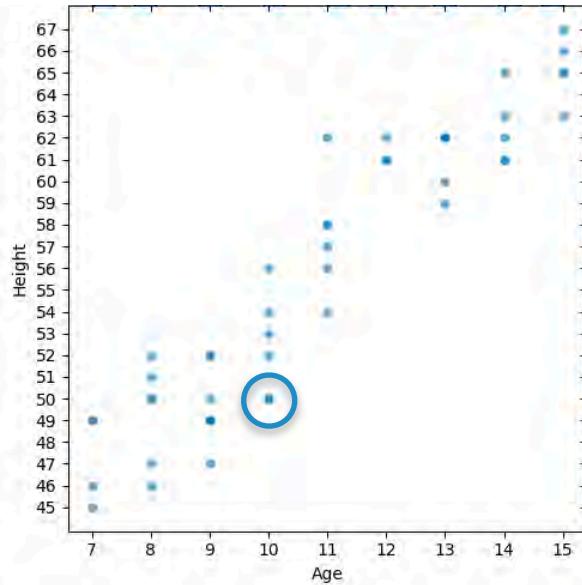
# Marginal Distribution: Example 1

Age and Height Dataset  
for 50 children



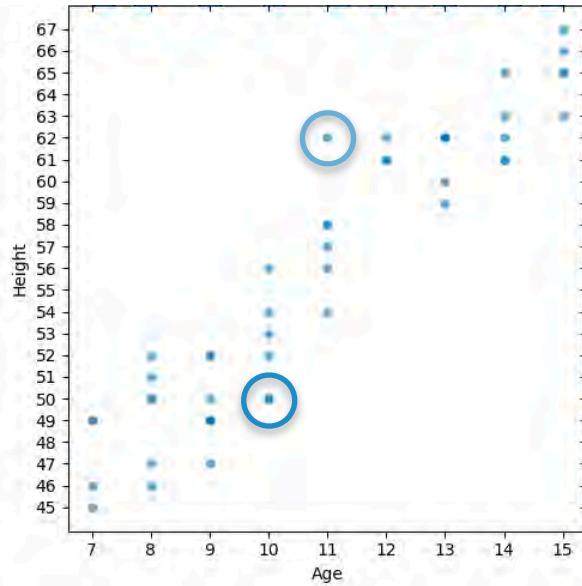
# Marginal Distribution: Example 1

Age and Height Dataset  
for 50 children



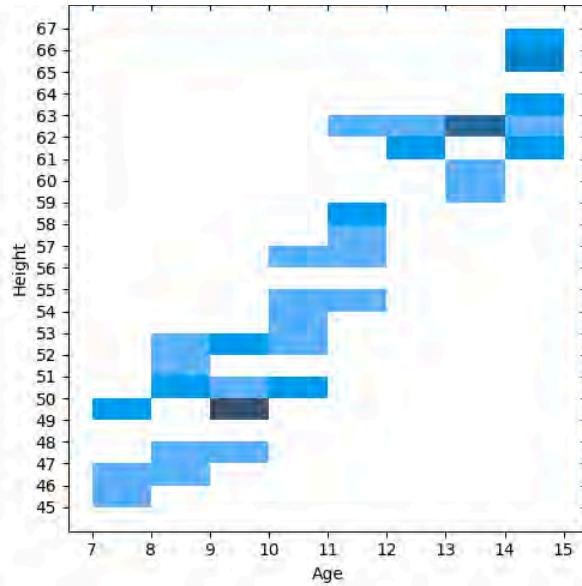
# Marginal Distribution: Example 1

Age and Height Dataset  
for 50 children



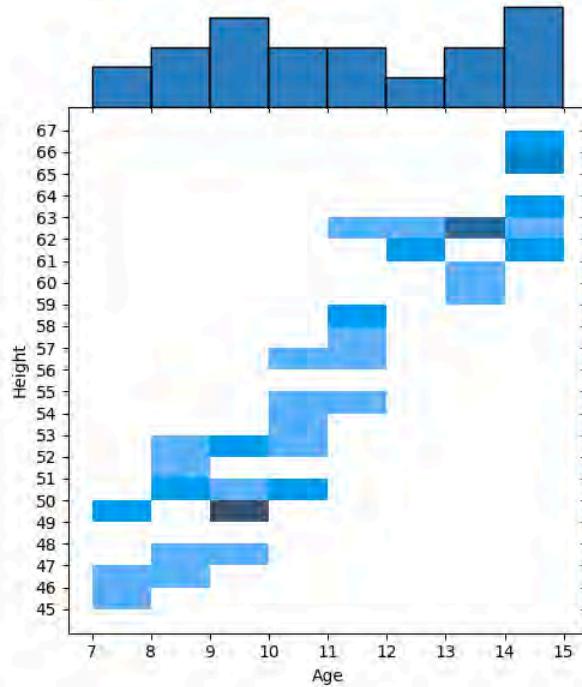
# Marginal Distribution: Example 1

Age and Height Dataset  
for 50 children



# Marginal Distribution: Example 1

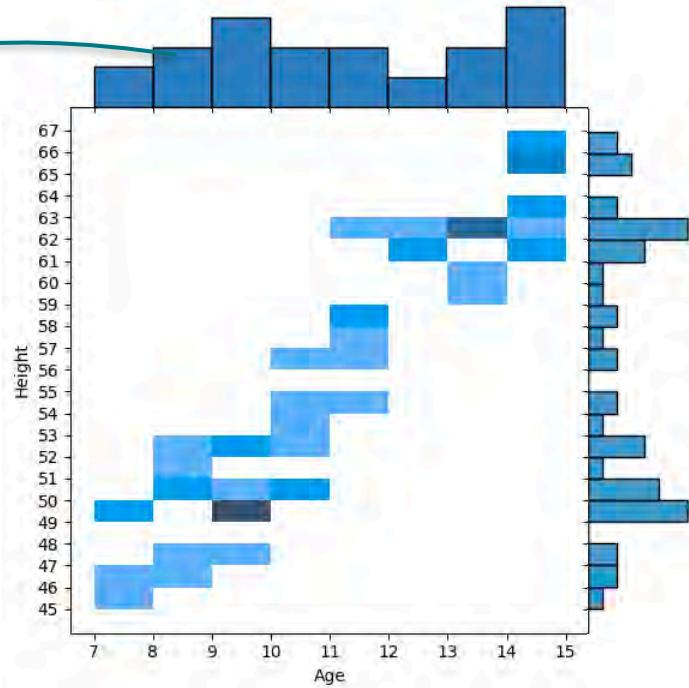
Age and Height Dataset  
for 50 children



# Marginal Distribution: Example 1

Marginal Distribution of Age

Age and Height Dataset  
for 50 children



Marginal Distribution of Height

# Marginal Distributions: Example 2

$X$  : the number rolled on the 1st dice



$$\frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6}$$

$Y$  : the number rolled on the 2nd dice



$$\frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6} \quad \frac{1}{6}$$

# Marginal Distributions: Example 2

		Y						
		1	2	3	4	5	6	
X		1	1/36	1/36	1/36	1/36	1/36	1/36
2		1/36	1/36	1/36	1/36	1/36	1/36	
3		1/36	1/36	1/36	1/36	1/36	1/36	
4		1/36	1/36	1/36	1/36	1/36	1/36	
5		1/36	1/36	1/36	1/36	1/36	1/36	
6		1/36	1/36	1/36	1/36	1/36	1/36	

$X$  : the number rolled on the 1st dice

$Y$  : the number rolled on the 2nd dice

# Marginal Distributions: Example 2

$Y$

$X$

	1	2	3	4	5	6	
1	1/36	1/36	1/36	1/36	1/36	1/36	1/6
2	1/36	1/36	1/36	1/36	1/36	1/36	1/6
3	1/36	1/36	1/36	1/36	1/36	1/36	1/6
4	1/36	1/36	1/36	1/36	1/36	1/36	1/6
5	1/36	1/36	1/36	1/36	1/36	1/36	1/6
6	1/36	1/36	1/36	1/36	1/36	1/36	1/6

$X$  : the number rolled on the 1st dice

$Y$  : the number rolled on the 2nd dice

# Marginal Distributions: Example 2

		Y												
		1	2	3	4	5	6							
X		1	1/36	1/36	1/36	1/36	1/36	1/36						
1		1/36	1/36	1/36	1/36	1/36	1/36	1/6						
2		1/36	1/36	1/36	1/36	1/36	1/36	1/6						
3		1/36	1/36	1/36	1/36	1/36	1/36	1/6						
4		1/36	1/36	1/36	1/36	1/36	1/36	1/6						
5		1/36	1/36	1/36	1/36	1/36	1/36	1/6						
6		1/36	1/36	1/36	1/36	1/36	1/36	1/6						
		1/6	1/6	1/6	1/6	1/6	1/6							

$X$  : the number rolled on the 1st dice  
 $Y$  : the number rolled on the 2nd dice

# Marginal Distributions: Example 2

		Y												
		1	2	3	4	5	6							
X		1	1/36	1/36	1/36	1/36	1/36	1/36						
1		1	1/36	1/36	1/36	1/36	1/36	1/36	1/6	1/6	1/6	1/6	1/6	1/6
2		2	1/36	1/36	1/36	1/36	1/36	1/36	1/6	1/6	1/6	1/6	1/6	1/6
3		3	1/36	1/36	1/36	1/36	1/36	1/36	1/6	1/6	1/6	1/6	1/6	1/6
4		4	1/36	1/36	1/36	1/36	1/36	1/36	1/6	1/6	1/6	1/6	1/6	1/6
5		5	1/36	1/36	1/36	1/36	1/36	1/36	1/6	1/6	1/6	1/6	1/6	1/6
6		6	1/36	1/36	1/36	1/36	1/36	1/36	1/6	1/6	1/6	1/6	1/6	1/6
		1/6	1/6	1/6	1/6	1/6	1/6	1/6	1/6	1/6	1/6	1/6	1/6	1/6

$X$ : the number rolled on the 1st dice

$Y$ : the number rolled on the 2nd dice

$$p_X(x_i) = \frac{1}{6}$$

# Marginal Distributions: Example 2

		Y							
		1	2	3	4	5	6		
X		1	1/36	1/36	1/36	1/36	1/36	1/36	1/6
1		1/36	1/36	1/36	1/36	1/36	1/36	1/36	1/6
2		1/36	1/36	1/36	1/36	1/36	1/36	1/36	1/6
3		1/36	1/36	1/36	1/36	1/36	1/36	1/36	1/6
4		1/36	1/36	1/36	1/36	1/36	1/36	1/36	1/6
5		1/36	1/36	1/36	1/36	1/36	1/36	1/36	1/6
6		1/36	1/36	1/36	1/36	1/36	1/36	1/36	1/6
		1/6	1/6	1/6	1/6	1/6	1/6		

$X$ : the number rolled on the 1st dice  
 $Y$ : the number rolled on the 2nd dice

$$p_X(x_i) = \frac{1}{6}$$
$$p_Y(y_j) = \frac{1}{6}$$

# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

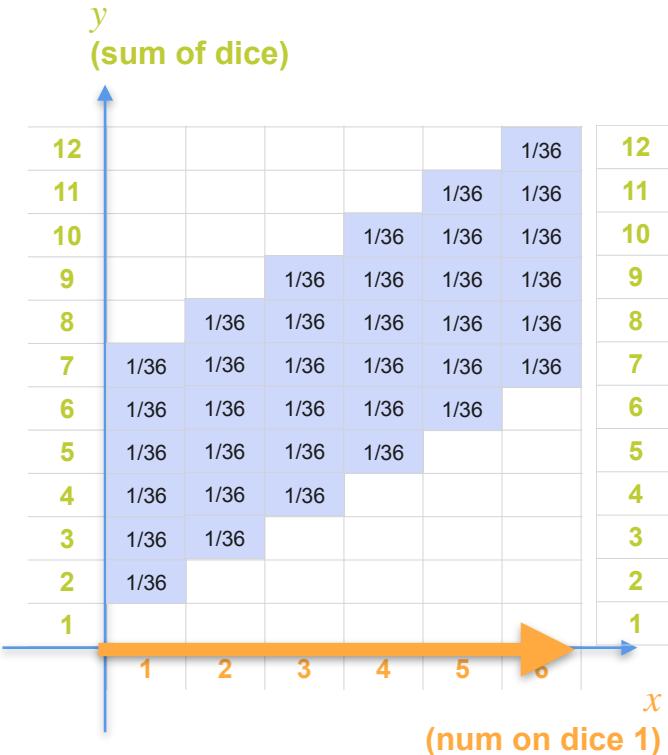
# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

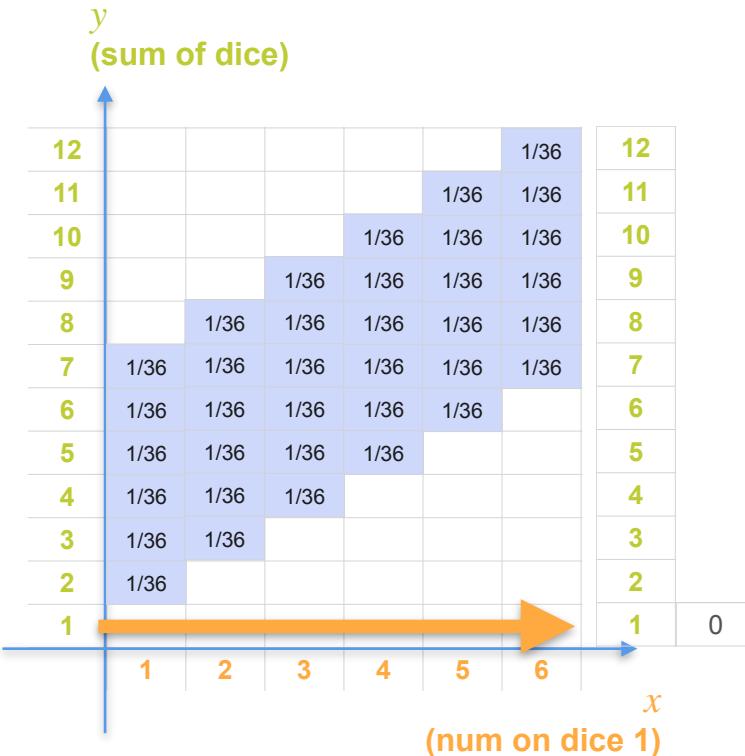
# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

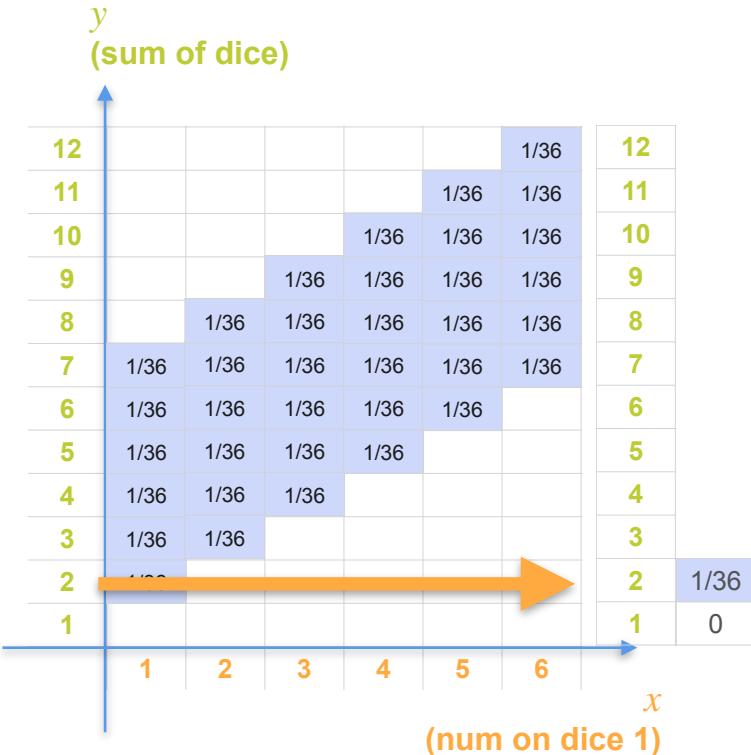
# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

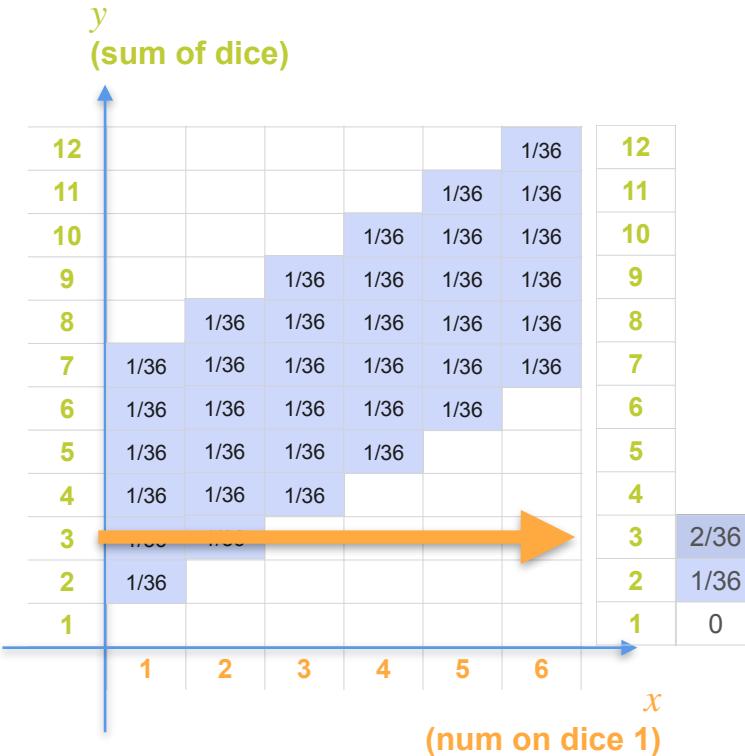
# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

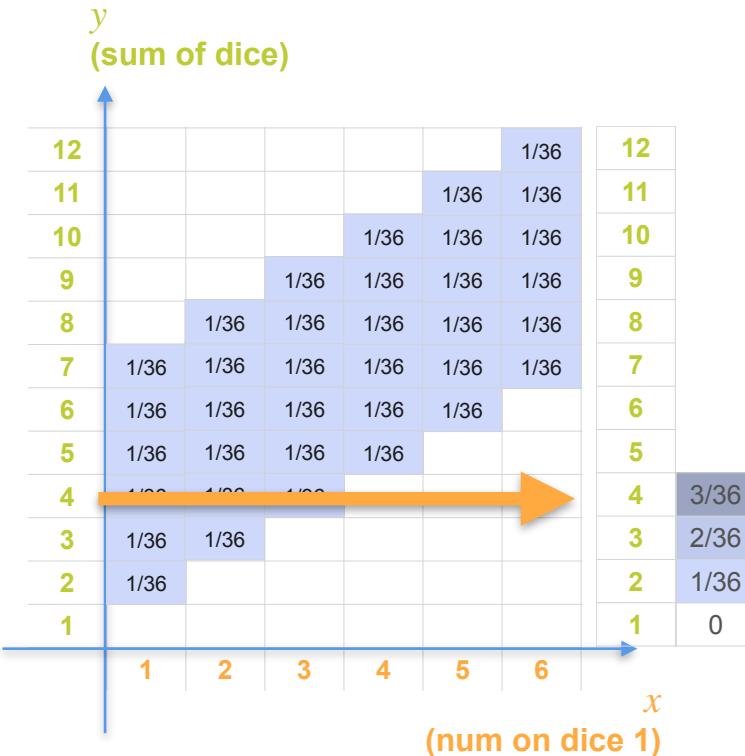
# Marginal Distributions: Example 3



$X$ : the number rolled on the 1st dice

$Y$ : sum of the two dice

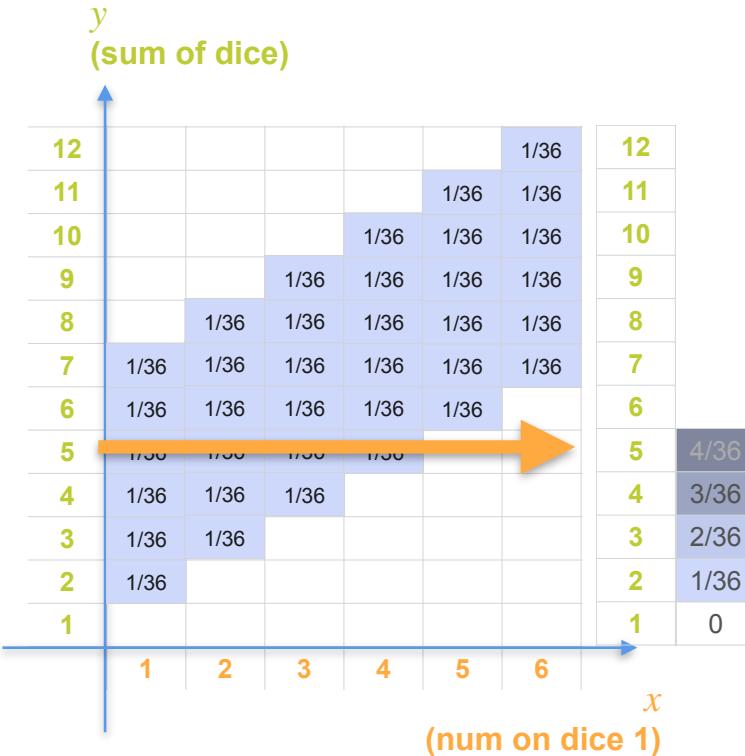
# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

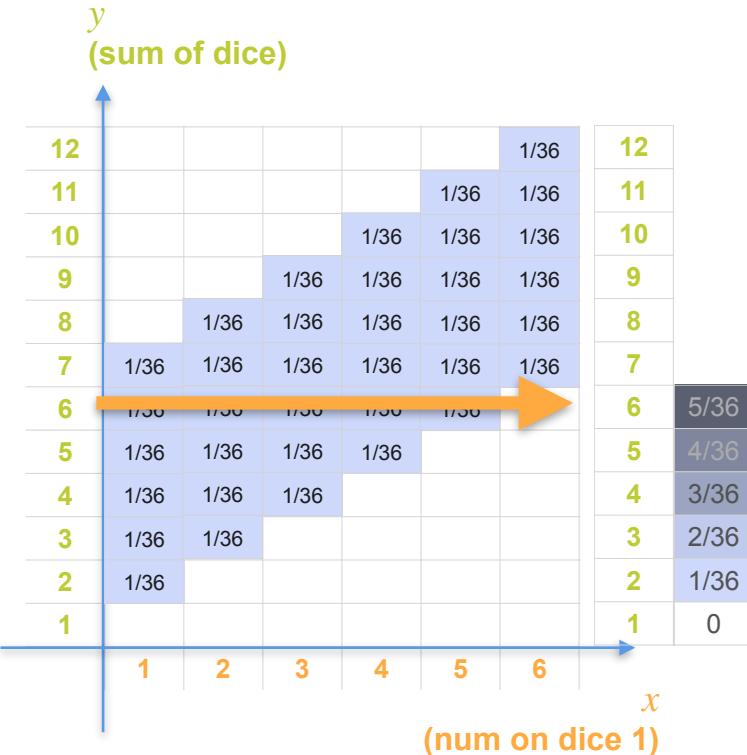
# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

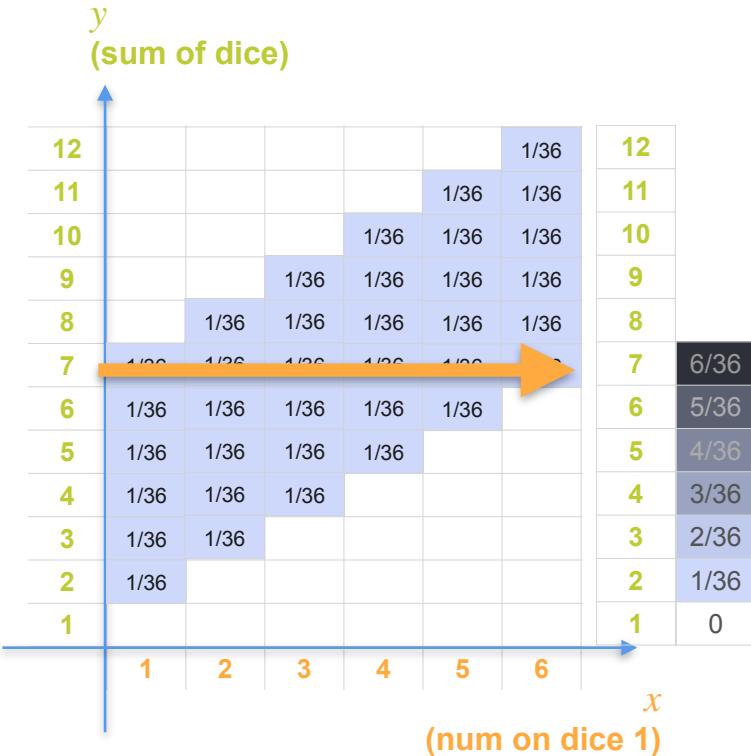
# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

# Marginal Distributions: Example 3



$X$ : the number rolled on the 1st dice

$Y$ : sum of the two dice

# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j) = ?$$

# Marginal Distributions: Example 3



$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j) = ?$$

$$p_Y(10) = ?$$

# Marginal Distributions: Example 3



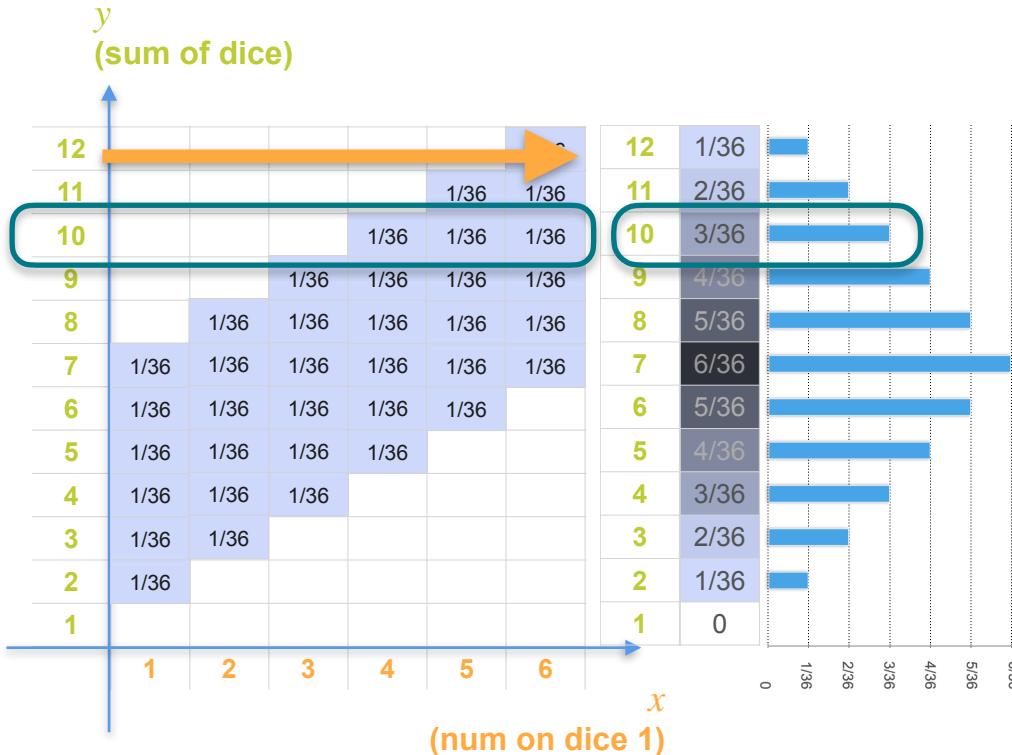
$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j) = ?$$

$$p_Y(10) = ?$$

# Marginal Distributions: Example 3



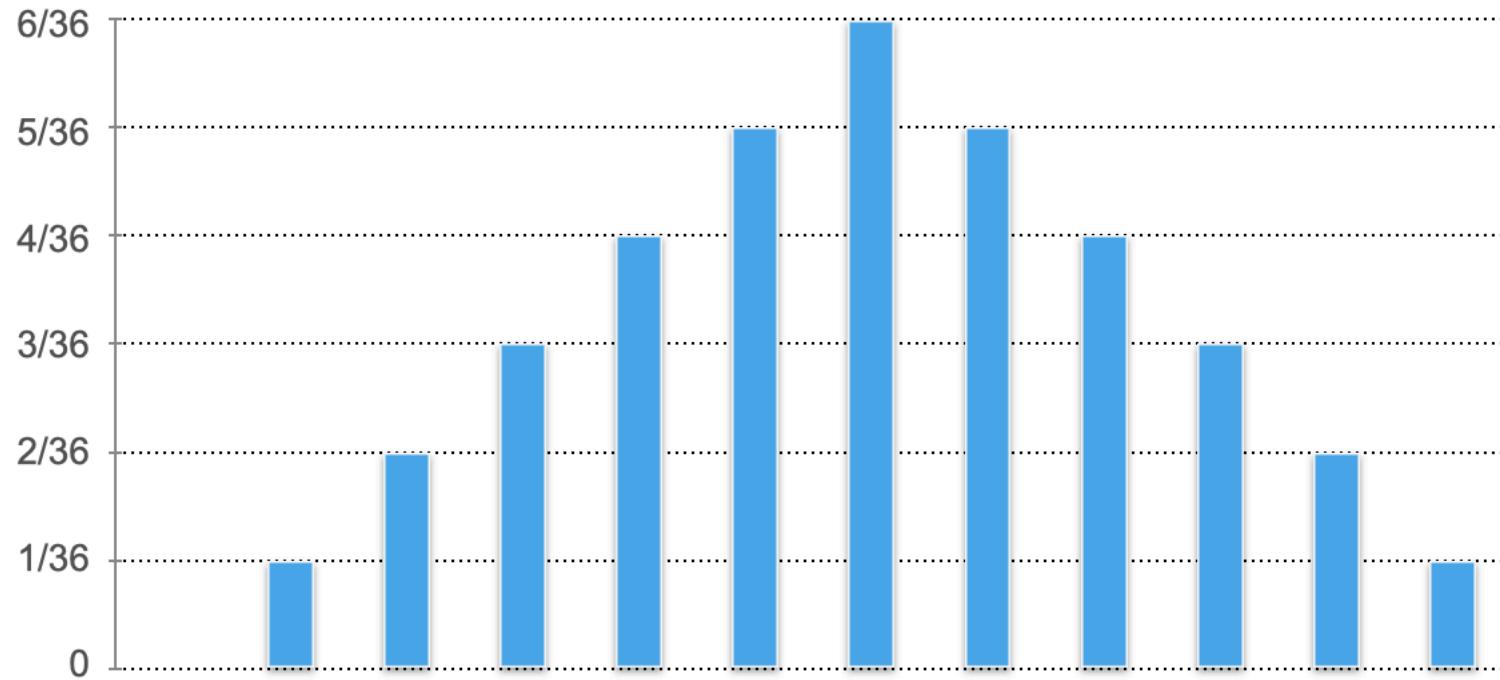
$X$  : the number rolled on the 1st dice

$Y$  : sum of the two dice

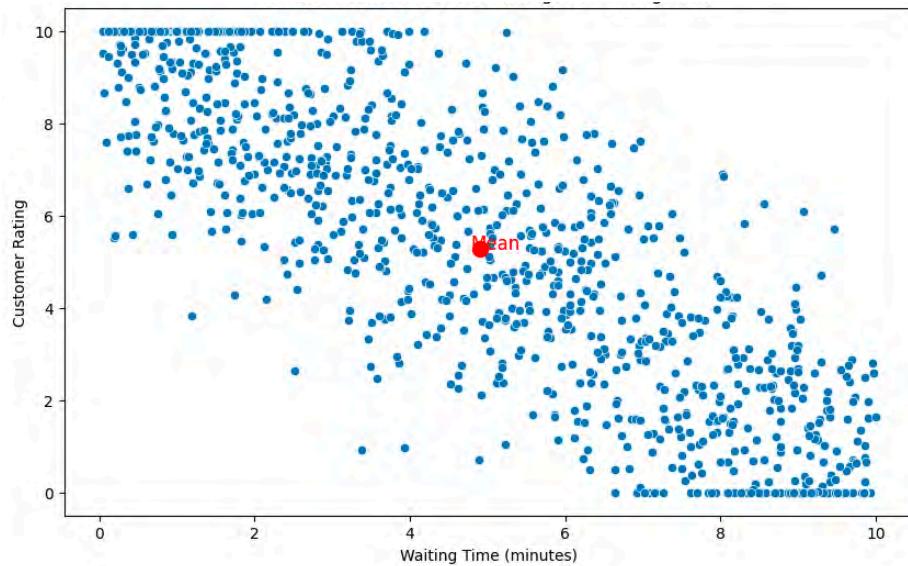
$$p_Y(y_j) = \sum_i p_{XY}(x_i, y_j) = ?$$

$$p_Y(10) = ? = \frac{3}{36}$$

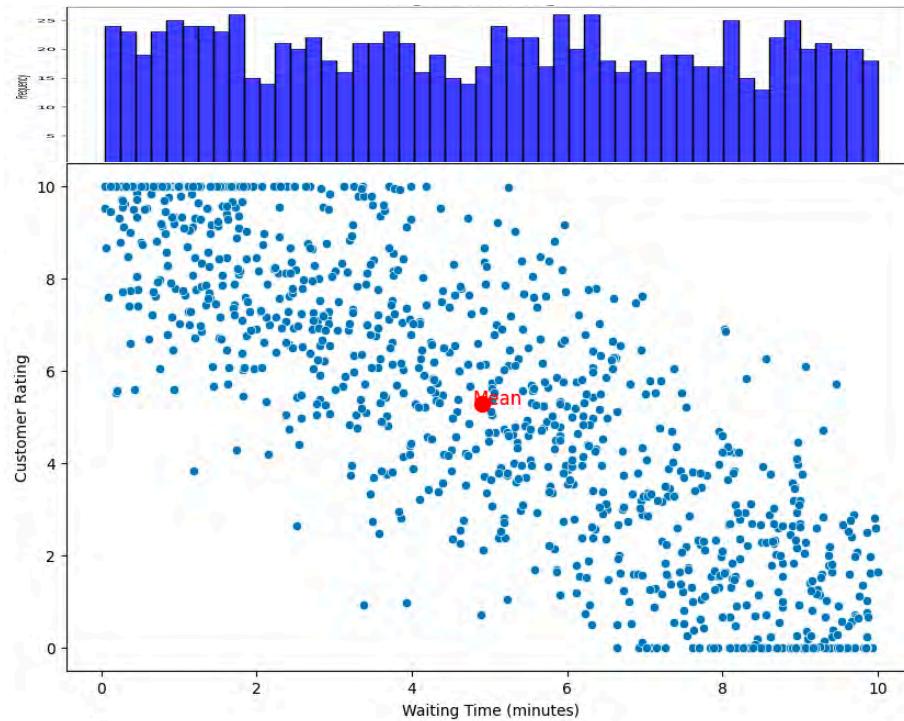
# Marginal Distributions: Example 2



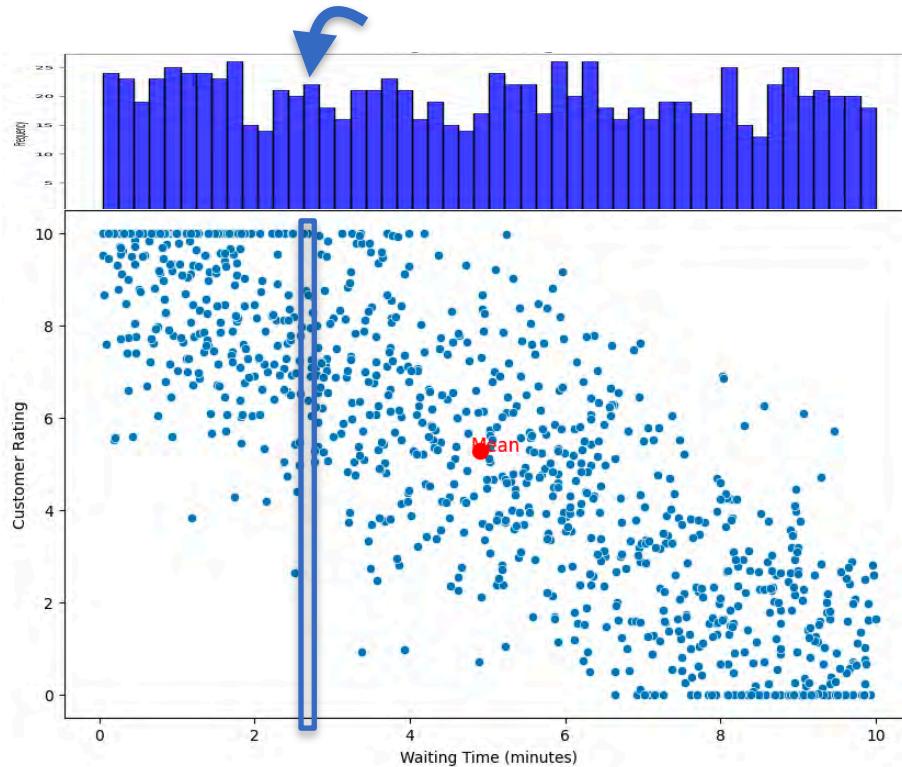
# Marginal Distributions



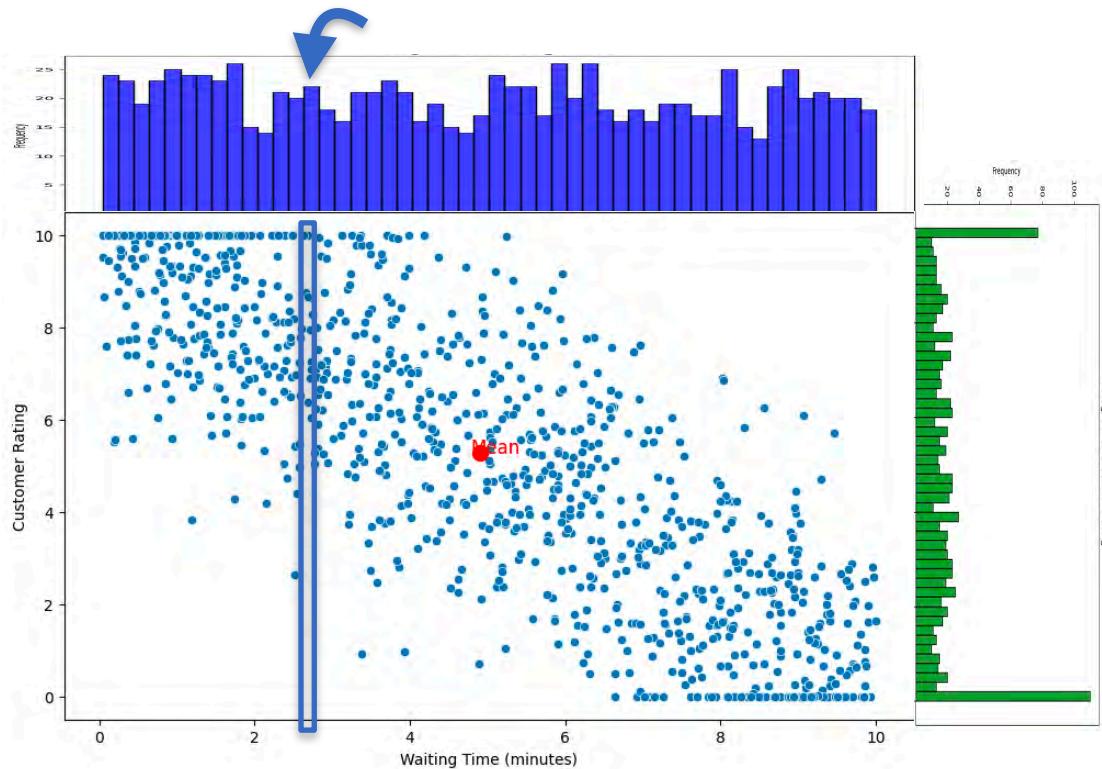
# Marginal Distributions



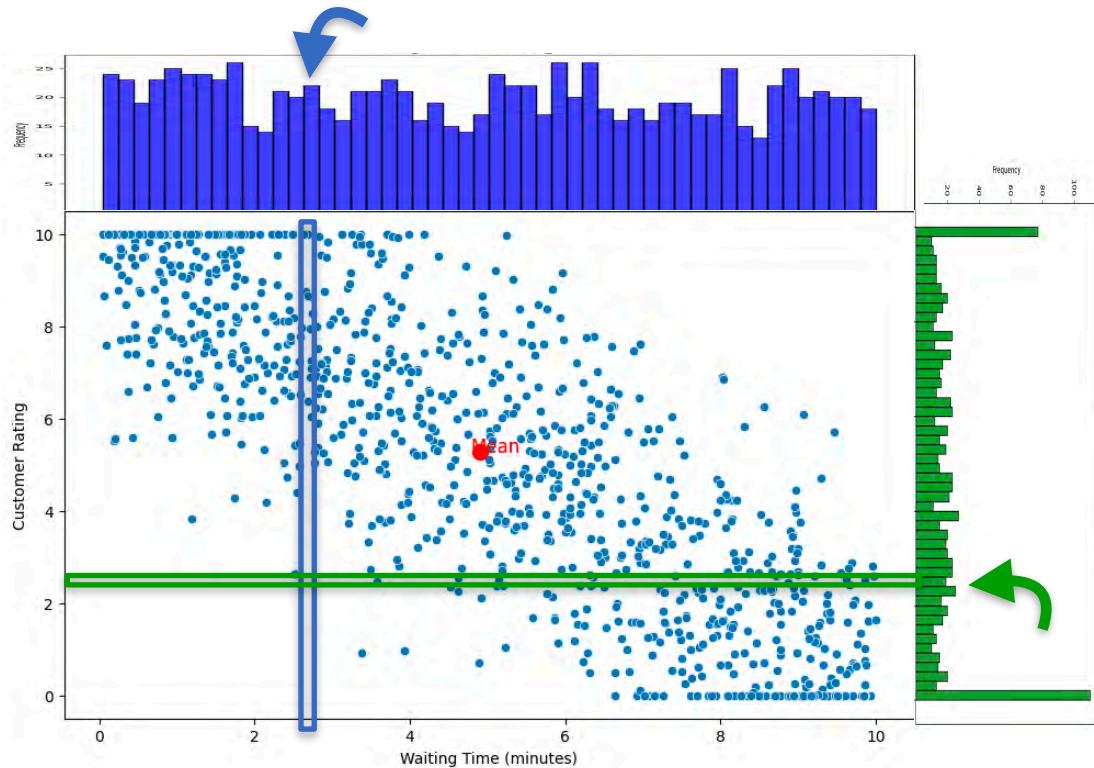
# Marginal Distributions



# Marginal Distributions



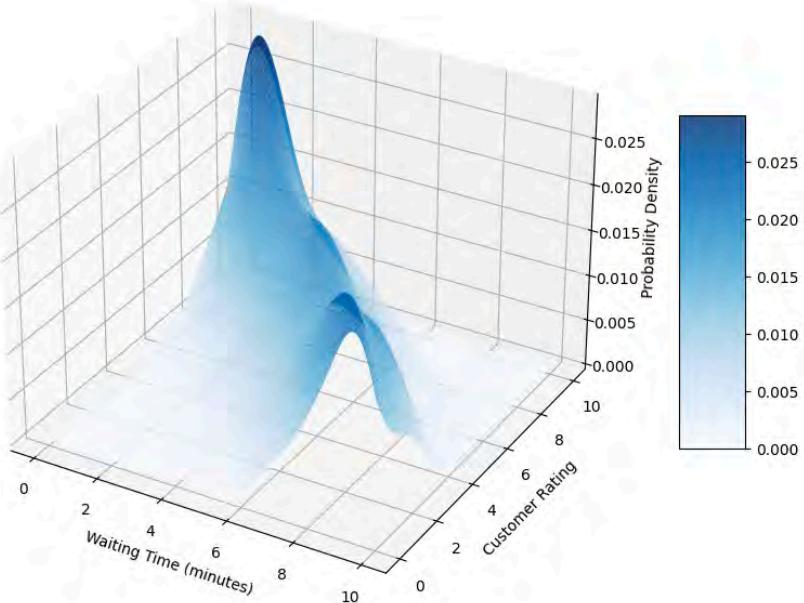
# Marginal Distributions



# Continuous Marginal Distribution

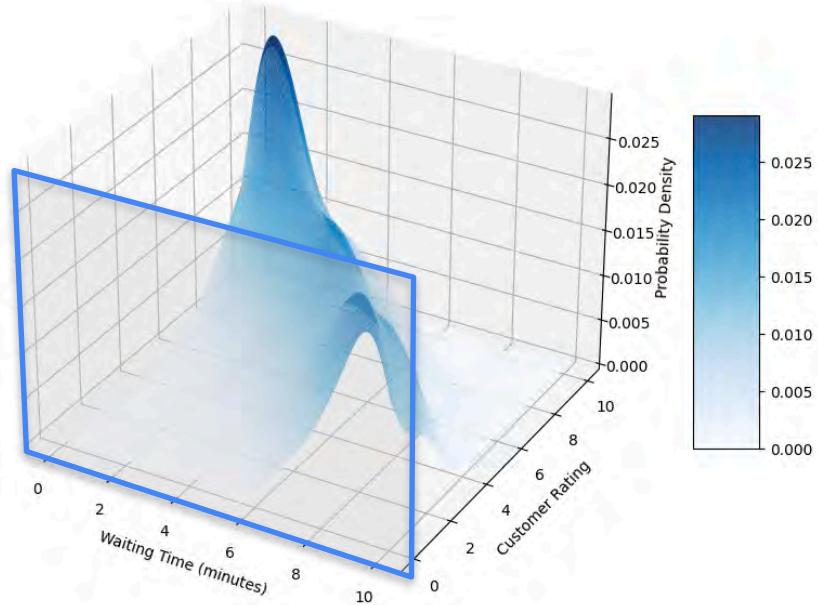
# Continuous Marginal Distribution

3D Probability Density Distribution for Customer Ratings vs Waiting Time



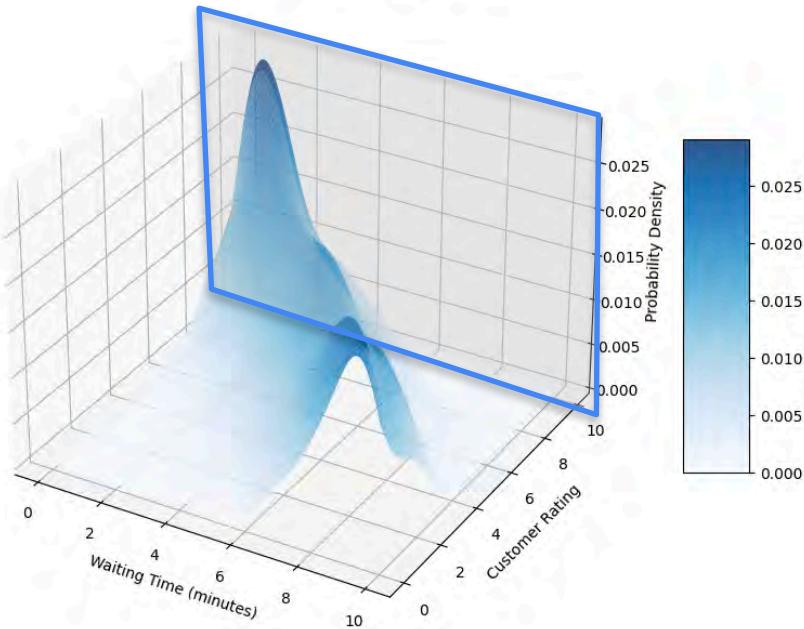
# Continuous Marginal Distribution

3D Probability Density Distribution for Customer Ratings vs Waiting Time



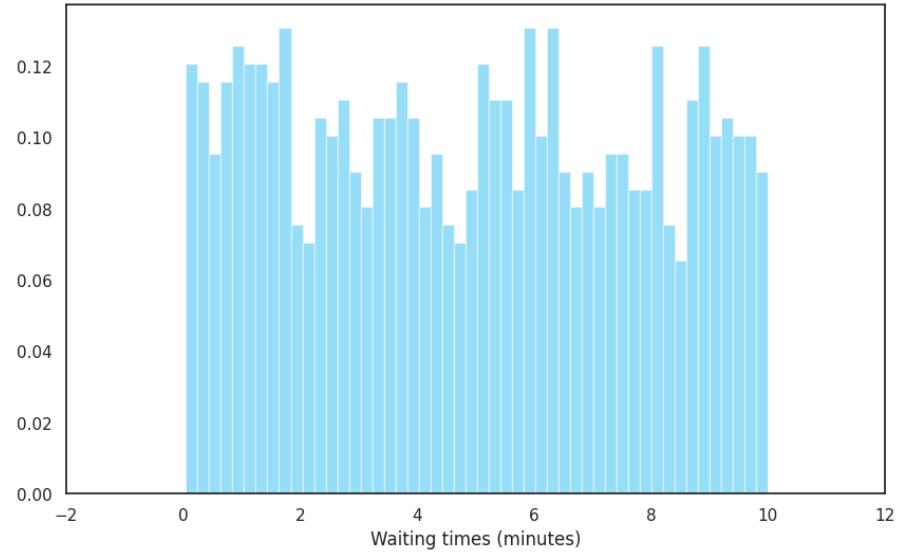
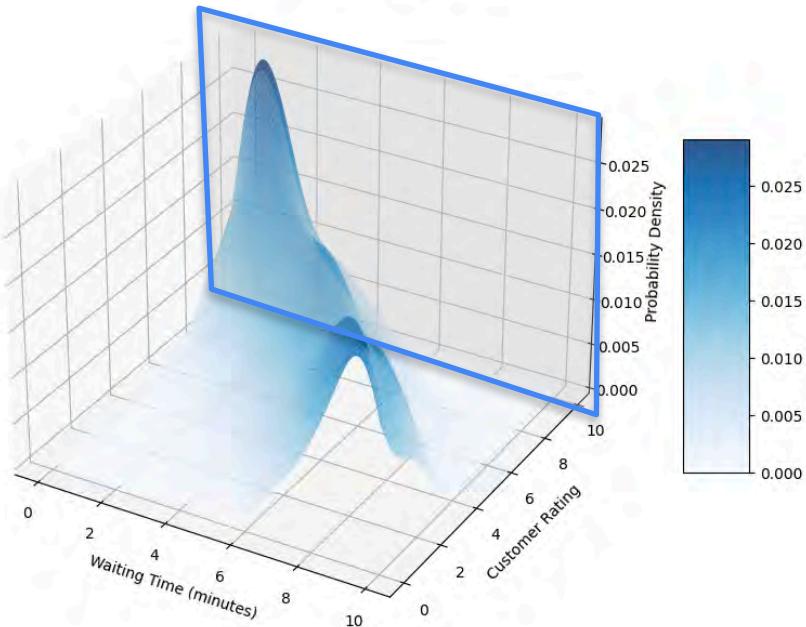
# Continuous Marginal Distribution

3D Probability Density Distribution for Customer Ratings vs Waiting Time



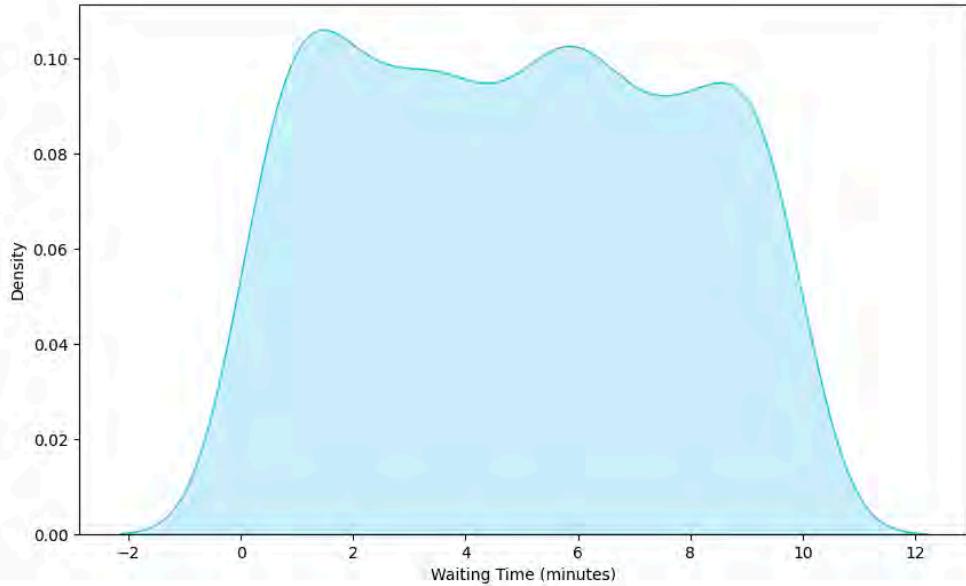
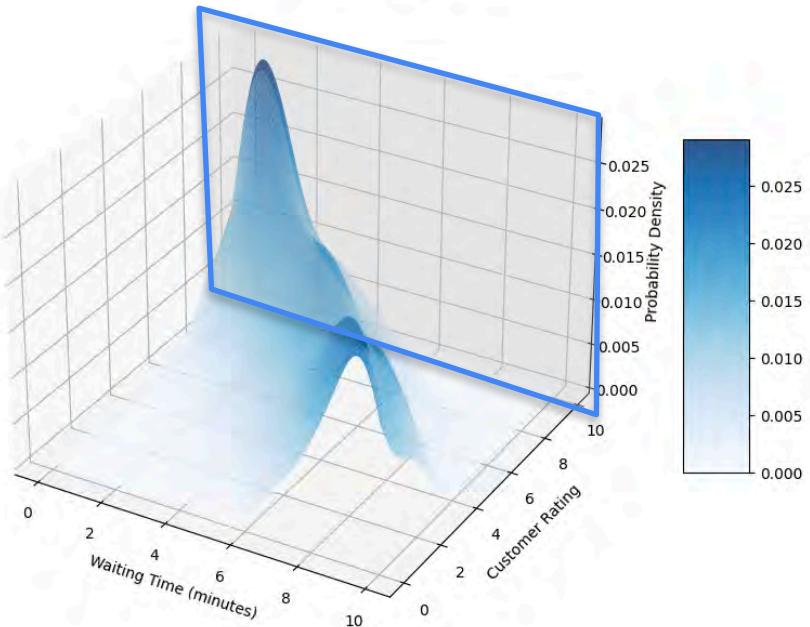
# Continuous Marginal Distribution

3D Probability Density Distribution for Customer Ratings vs Waiting Time

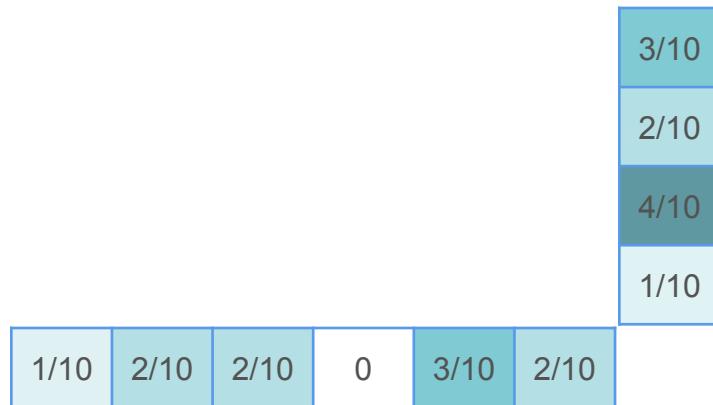


# Continuous Marginal Distribution

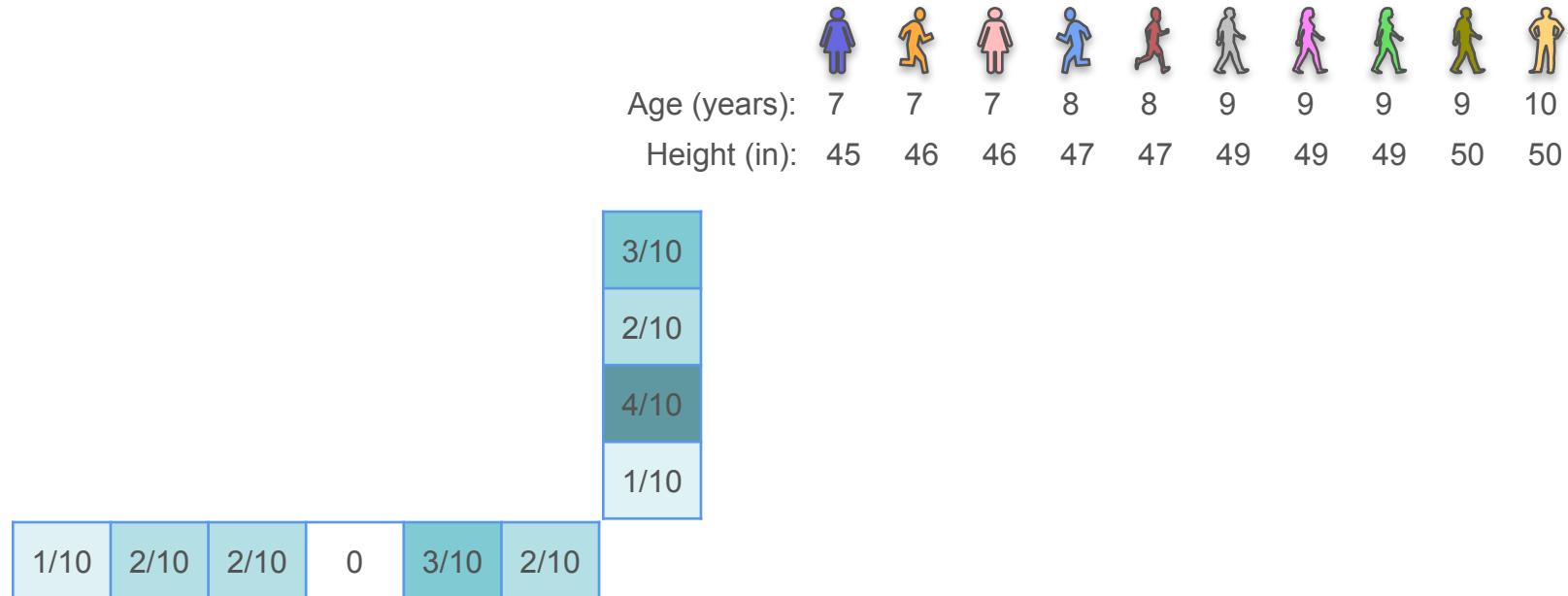
3D Probability Density Distribution for Customer Ratings vs Waiting Time



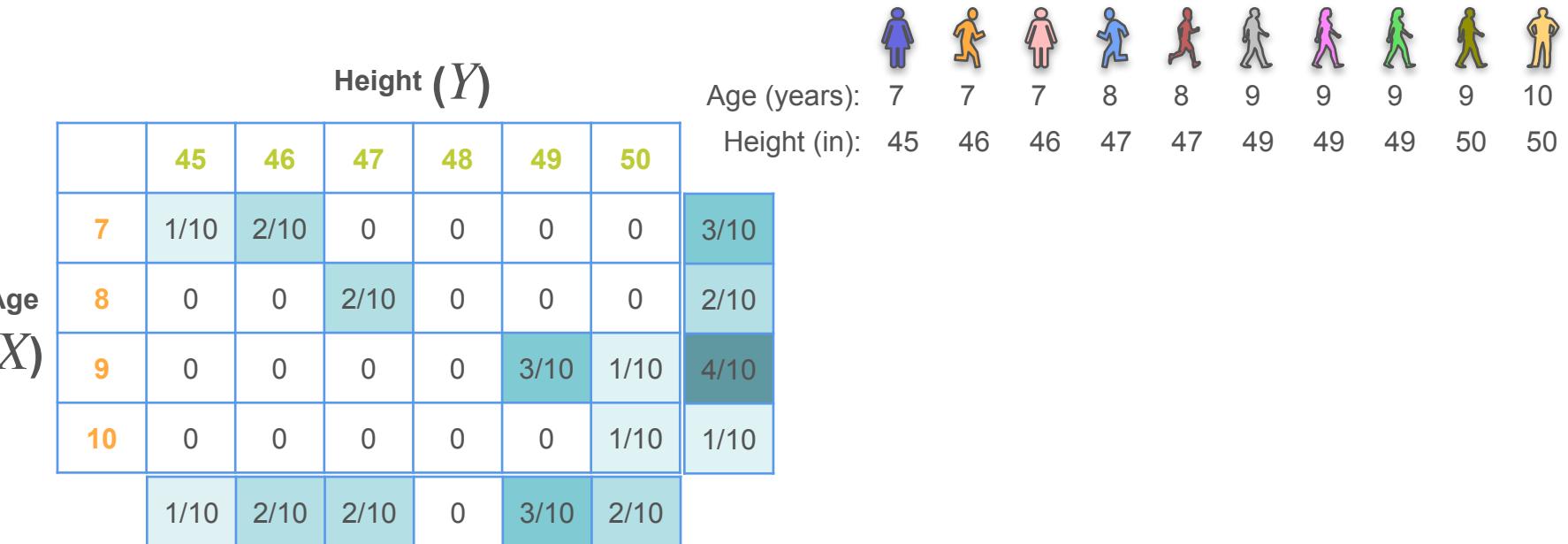
# Conditional Distribution: Example 1



# Conditional Distribution: Example 1



# Conditional Distribution: Example 1



# Conditional Distribution: Example 1

		Height ( $Y$ )							
		45	46	47	48	49	50		
Age ( $X$ )	7	1/10	2/10	0	0	0	0	3/10	
	8	0	0	2/10	0	0	0	2/10	
	9	0	0	0	0	3/10	1/10	4/10	
	10	0	0	0	0	0	1/10	1/10	
		1/10	2/10	2/10	0	3/10	2/10		

Age (years):	7	7	7	8	8	9	9	9	9	10
Height (in):	45	46	46	47	47	49	49	49	50	50

Age ( $X$ )	7	3/10
	8	2/10
	9	4/10
	10	1/10



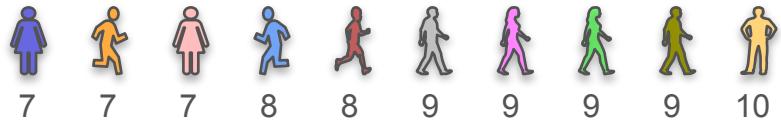
Marginal Distribution of Age

# Conditional Distribution: Example 1

		Height ( $Y$ )						Age (years):	Height (in):
		45	46	47	48	49	50		
Age ( $X$ )	7	1/10	2/10	0	0	0	0	3/10	
	8	0	0	2/10	0	0	0	2/10	
	9	0	0	0	0	3/10	1/10	4/10	
	10	0	0	0	0	0	1/10	1/10	
		1/10	2/10	2/10	0	3/10	2/10		

Age (years):

Height (in):



Age  
( $X$ )

7	3/10
8	2/10
9	4/10
10	1/10

Height ( $Y$ )

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	2/10	0	3/10	2/10
	8	0	0	0	0	0	0

Marginal Distribution of Age

Marginal Distribution of Height

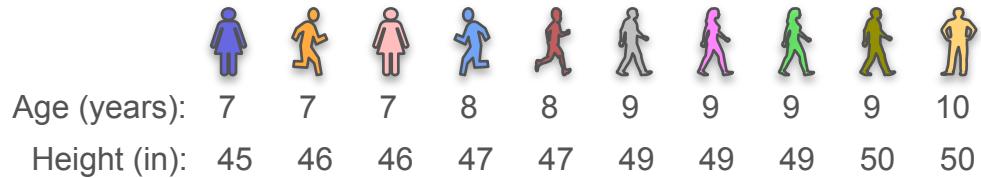
# Conditional Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



# Conditional Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



If age = 9, what is the distribution across the height variable?

# Conditional Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



If age = 9, what is the distribution across the height variable?

## Conditional Distribution

# Conditional Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



If age = 9, what is the distribution across the height variable?

# Conditional Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



If age = 9, what is the distribution across the height variable?

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

# Conditional Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	7	1/10	2/10	0	0	0	0
	8	0	0	2/10	0	0	0
	9	0	0	0	0	3/10	1/10
	10	0	0	0	0	0	1/10



If age = 9, what is the distribution across the height variable?

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

# Conditional Distribution: Example 1

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

		Height ( $Y$ )					
Age ( $X$ )		45	46	47	48	49	50
	9	0	0	0	0	3/10	1/10

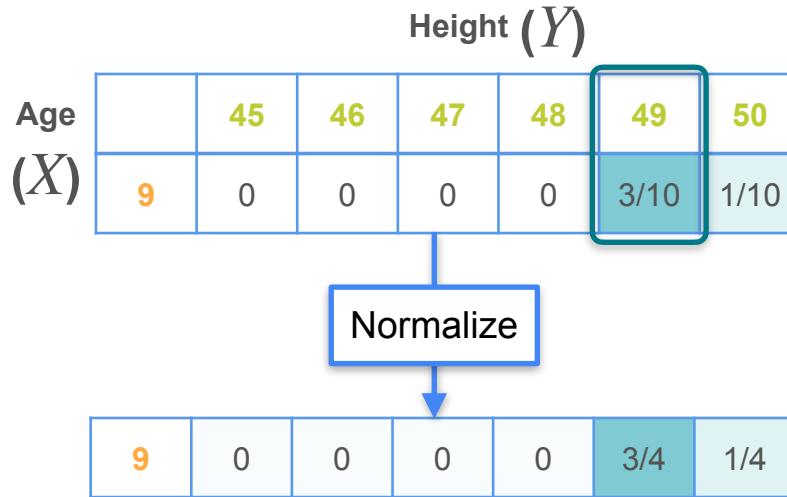
# Conditional Distribution: Example 1

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	9	0	0	0	0	3/10	1/10

# Conditional Distribution: Example 1

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$



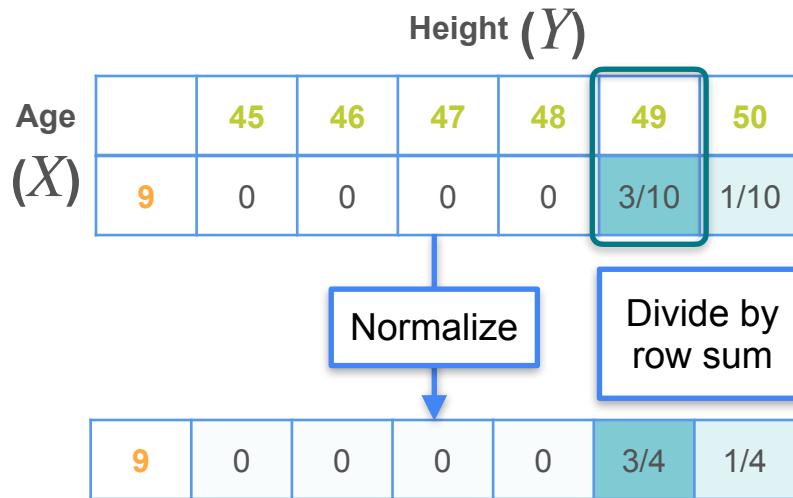
# Conditional Distribution: Example 1

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	9	0	0	0	0	3/10	1/10
	9	0	0	0	0	3/10	1/10
		Normalize		Divide by row sum			
		9	0	0	0	0	3/4

# Conditional Distribution: Example 1

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$



$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

# Conditional Distribution: Example 1

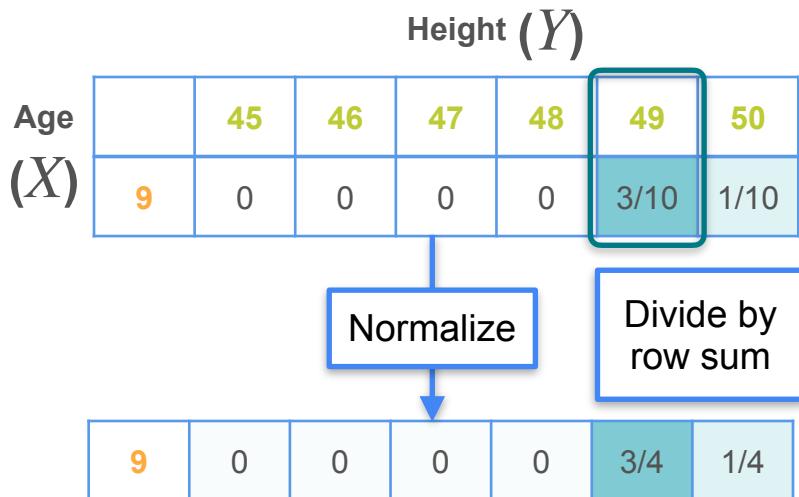
		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	9	0	0	0	0	3/10	1/10
	9	0	0	0	0	3/4	1/4

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

# Conditional Distribution: Example 1



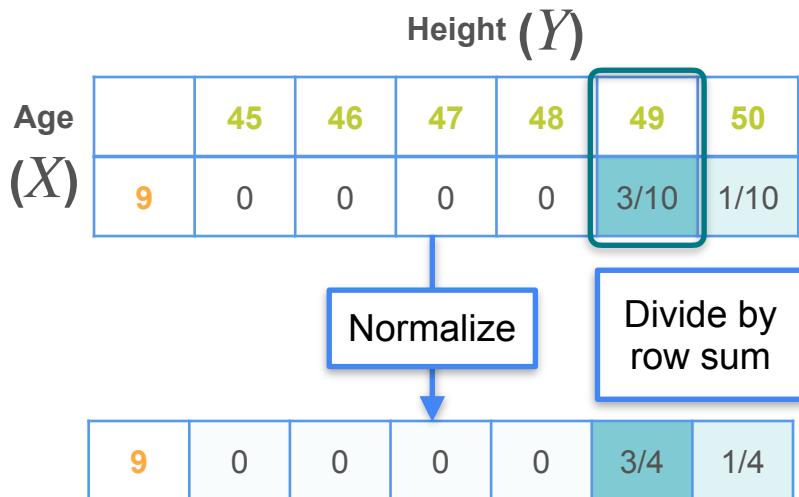
$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

$$\mathbf{P}(X = 9, Y = 49) = \mathbf{P}(X = 9) \cdot \mathbf{P}(Y = 49 | X = 9)$$

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

# Conditional Distribution: Example 1



$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

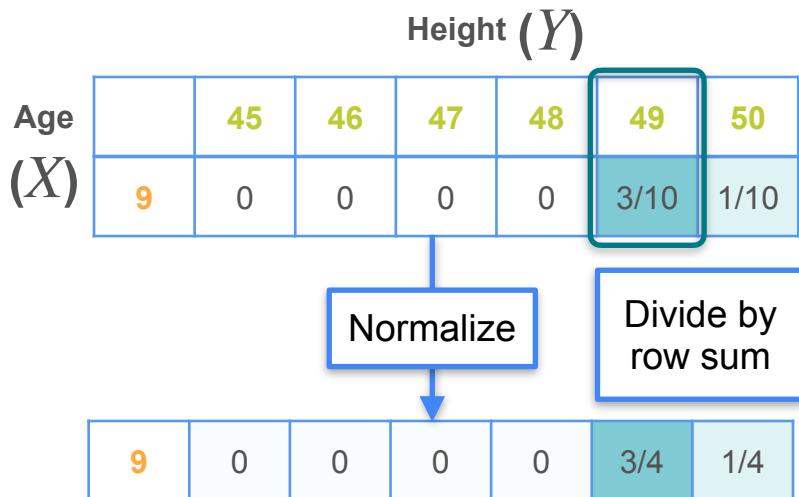
$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

$$\mathbf{P}(X = 9, Y = 49) = P(X = 9) \cdot P(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{\mathbf{P}(X = 9, Y = 49)}{P(X = 9)}$$

Row sum

# Conditional Distribution: Example 1



$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

$$\mathbf{P}(X = 9, Y = 49) = P(X = 9) \cdot P(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{\mathbf{P}(X = 9, Y = 49)}{P(X = 9)}$$

Row sum

$$\mathbf{P}(Y = 49 | X = 9)$$

# Conditional Distribution: Example 1

		Height ( $Y$ )					
		45	46	47	48	49	50
Age ( $X$ )	9	0	0	0	0	3/10	1/10
	9	0	0	0	0	3/4	1/4

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

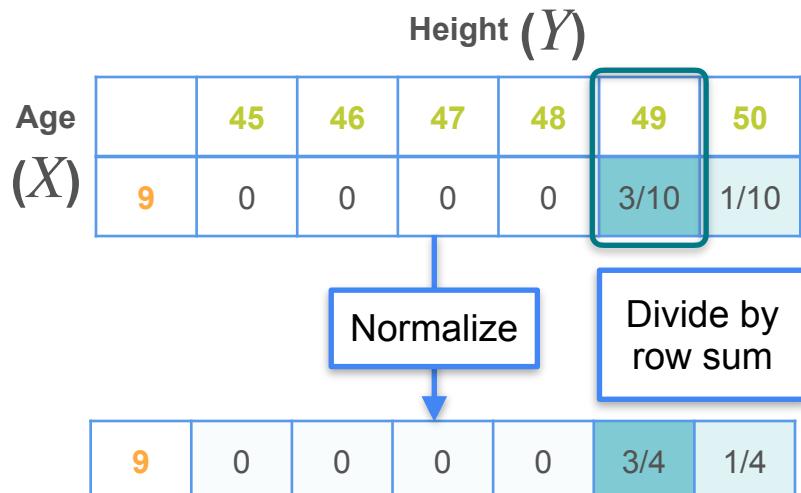
$$\mathbf{P}(X = 9, Y = 49) = P(X = 9) \cdot P(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{\mathbf{P}(X = 9, Y = 49)}{P(X = 9)}$$

Row sum

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3/10}{4/10}$$

# Conditional Distribution: Example 1



$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

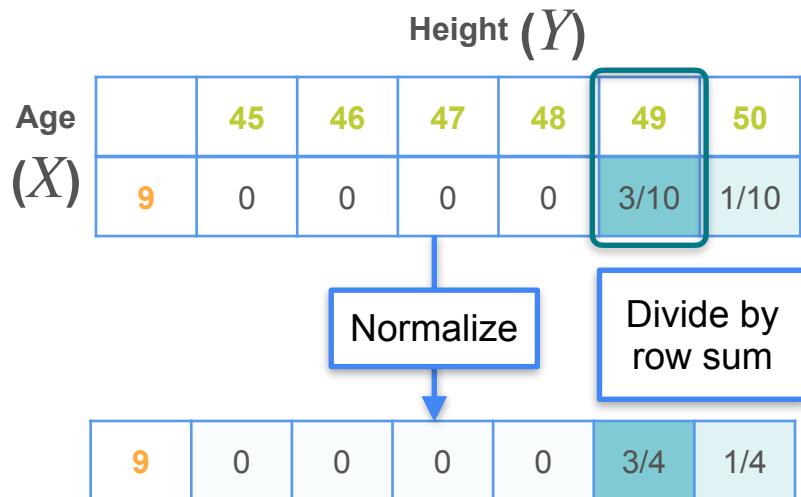
$$\mathbf{P}(X = 9, Y = 49) = \mathbf{P}(X = 9) \cdot \mathbf{P}(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{\mathbf{P}(X = 9, Y = 49)}{\mathbf{P}(X = 9)}$$

Row sum

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3/10}{4/10} = \frac{3}{4}$$

# Conditional Distribution: Example 1



$$P(Y = 49 | X = 9) = \frac{3}{4}$$

$$p_{Y|X=9}(y) = P(Y = y | X = 9)$$

$$P(A, B) = P(A) \cdot P(B | A)$$

$$P(X = 9, Y = 49) = P(X = 9) \cdot P(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{P(X = 9, Y = 49)}{P(X = 9)}$$

Row sum

# Conditional Distribution: Example 1

Age (X)	Height (Y)					P(X = 9)
	45	46	47	48	49	
9	0	0	0	0	3/10	1/10
	Normalize	Divide by row sum				
9	0	0	0	0	3/4	1/4

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3}{4}$$

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

$$\mathbf{P}(X = 9, Y = 49) = P(X = 9) \cdot P(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{\mathbf{P}(X = 9, Y = 49)}{P(X = 9)}$$

Row sum

# Conditional Distribution: Example 1

(X)	Height ( $Y$ )					Sum
	45	46	47	48	P( $X = 9$ )	
9	0	0	0	0	3/10	1/10

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

$$\mathbf{P}(X = 9, Y = 49) = P(X = 9) \cdot P(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{\mathbf{P}(X = 9, Y = 49)}{P(X = 9)}$$

Row sum

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3/10}{4/10} = \frac{3}{4}$$

# Conditional Distribution: Example 1

(X)	Height (Y)					P(X = 9)	Sum
	45	46	47	48	49		
9	0	0	0	0	3/10	1/10	

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

$$p_{Y|X=9}(y) = \mathbf{P}(Y = y | X = 9)$$

$$\mathbf{P}(A, B) = \mathbf{P}(A) \cdot \mathbf{P}(B | A)$$

$$\mathbf{P}(X = 9, Y = 49) = P(X = 9) \cdot P(Y = 49 | X = 9)$$

$$P(Y = 49 | X = 9) = \frac{\mathbf{P}(X = 9, Y = 49)}{P(X = 9)}$$

Row sum

$$\mathbf{P}(Y = 49 | X = 9) = \frac{3/10}{4/10} = \frac{3}{4}$$

# Discrete Conditional Distribution: Formula

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

# Discrete Conditional Distribution: Formula

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

Joint PDF of  $X$  and  $Y$



# Discrete Conditional Distribution: Formula

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

Conditional PDF of  $Y$

Joint PDF of  $X$  and  $Y$

A diagram illustrating the formula for conditional probability. On the left, the term "Conditional PDF of  $Y$ " is written. A curved teal arrow originates from this text and points to the numerator  $p_{XY}(x, y)$  in the formula. On the right, the term "Joint PDF of  $X$  and  $Y$ " is written. Another curved teal arrow originates from this text and points to the denominator  $p_X(x)$  in the formula.

# Discrete Conditional Distribution: Formula

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

Conditional PDF of  $Y$

Joint PDF of  $X$  and  $Y$

Marginal distribution of  $X$

The diagram illustrates the formula for the conditional probability of  $Y$  given  $X=x$ . It features a central equation  $p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$ . Three curved arrows originate from text labels to specific components of the equation: one arrow points from 'Conditional PDF of  $Y$ ' to the term  $p_{Y|X=x}(y)$ ; another arrow points from 'Joint PDF of  $X$  and  $Y$ ' to the term  $p_{XY}(x, y)$ ; and a third arrow points from 'Marginal distribution of  $X$ ' to the term  $p_X(x)$ .

# Conditional Distributions: Example 2



Die 1:    1/6    1/6    1/6    1/6    1/6    1/6  
Die 2:    1/6    1/6    1/6    1/6    1/6    1/6

	$Y$					
	1	2	3	4	5	6
1	1/36	1/36	1/36	1/36	1/36	1/36
2	1/36	1/36	1/36	1/36	1/36	1/36
3	1/36	1/36	1/36	1/36	1/36	1/36
4	1/36	1/36	1/36	1/36	1/36	1/36
5	1/36	1/36	1/36	1/36	1/36	1/36
6	1/36	1/36	1/36	1/36	1/36	1/36

$X$

# Conditional Distributions: Example 2



Die 1:    1/6    1/6    1/6    1/6    1/6    1/6  
Die 2:    1/6    1/6    1/6    1/6    1/6    1/6

$$p_{Y|X=4}(y = 1)$$

X

	1	2	3	4	5	6
1	1/36	1/36	1/36	1/36	1/36	1/36
2	1/36	1/36	1/36	1/36	1/36	1/36
3	1/36	1/36	1/36	1/36	1/36	1/36
4	1/36	1/36	1/36	1/36	1/36	1/36
5	1/36	1/36	1/36	1/36	1/36	1/36
6	1/36	1/36	1/36	1/36	1/36	1/36

# Conditional Distributions: Example 2



Die 1:    1/6    1/6    1/6    1/6    1/6    1/6  
Die 2:    1/6    1/6    1/6    1/6    1/6    1/6

$$p_{Y|X=4}(y=1) = \frac{p_{XY}(x=4, y=1)}{p_X(x=4)}$$

X

	1	2	3	4	5	6
1	1/36	1/36	1/36	1/36	1/36	1/36
2	1/36	1/36	1/36	1/36	1/36	1/36
3	1/36	1/36	1/36	1/36	1/36	1/36
4	1/36	1/36	1/36	1/36	1/36	1/36
5	1/36	1/36	1/36	1/36	1/36	1/36
6	1/36	1/36	1/36	1/36	1/36	1/36

# Conditional Distributions: Example 2



Die 1: 1/6 1/6 1/6 1/6 1/6 1/6

Die 2: 1/6 1/6 1/6 1/6 1/6 1/6

$$p_{Y|X=4}(y=1) = \frac{p_{XY}(x=4, y=1)}{p_X(x=4)}$$

	Y							
	1	2	3	4	5	6	Sum	
X	1	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	2	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	3	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	4	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	5	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	6	1/36	1/36	1/36	1/36	1/36	1/36	1/6

# Conditional Distributions: Example 2



Die 1:    1/6    1/6    1/6    1/6    1/6    1/6  
Die 2:    1/6    1/6    1/6    1/6    1/6    1/6

$$p_{Y|X=4}(y=1) = \frac{p_{XY}(x=4, y=1)}{p_X(x=4)}$$
$$= \frac{1/36}{1/6}$$

	<i>Y</i>							
	1	2	3	4	5	6	Sum	
1	1/36	1/36	1/36	1/36	1/36	1/36	1/6	
2	1/36	1/36	1/36	1/36	1/36	1/36	1/6	
3	1/36	1/36	1/36	1/36	1/36	1/36	1/6	
4	1/36	1/36	1/36	1/36	1/36	1/36	1/6	
5	1/36	1/36	1/36	1/36	1/36	1/36	1/6	
6	1/36	1/36	1/36	1/36	1/36	1/36	1/6	

# Conditional Distributions: Example 2

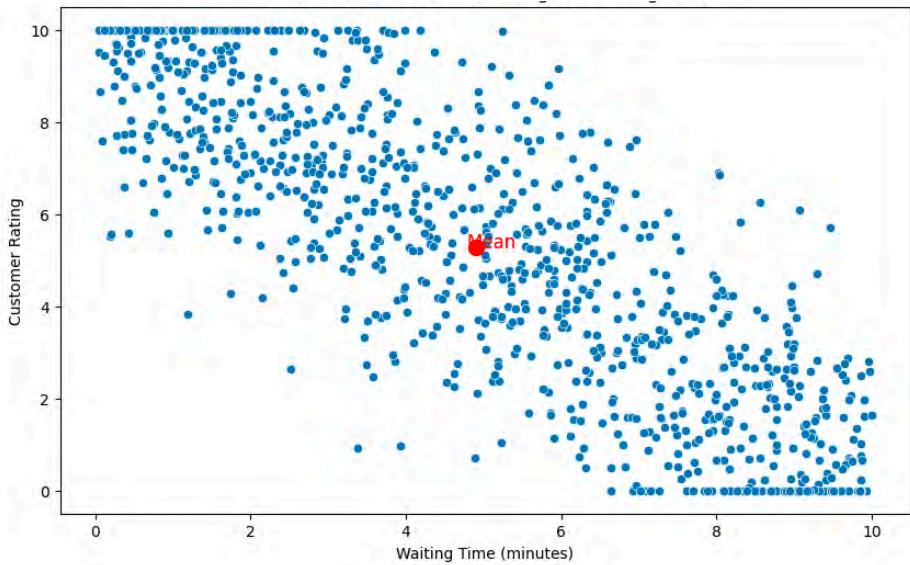


Die 1:    1/6    1/6    1/6    1/6    1/6    1/6  
Die 2:    1/6    1/6    1/6    1/6    1/6    1/6

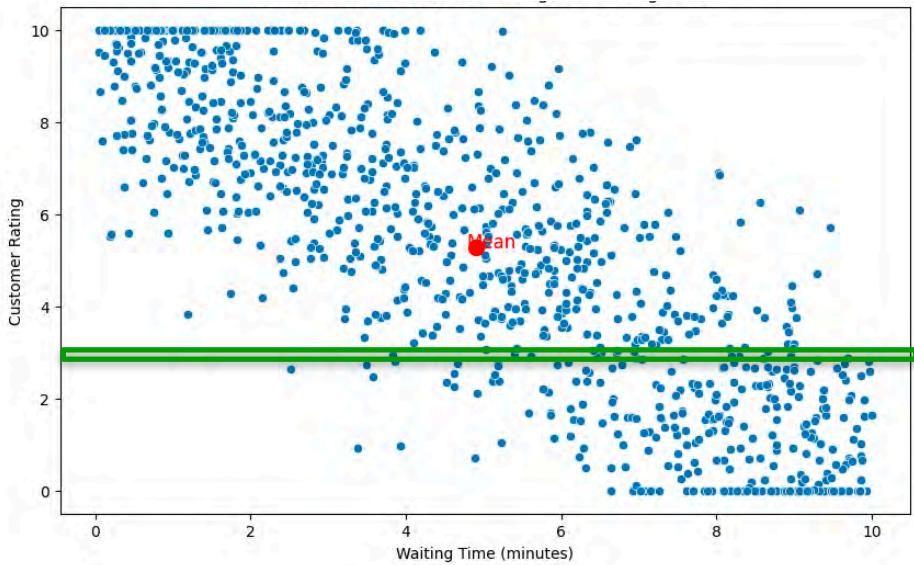
$$\begin{aligned} p_{Y|X=4}(y=1) &= \frac{p_{XY}(x=4, y=1)}{p_X(x=4)} \\ &= \frac{1/36}{1/6} \\ &= \frac{1}{6} \end{aligned}$$

	Y							
	1	2	3	4	5	6	Sum	
X	1	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	2	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	3	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	4	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	5	1/36	1/36	1/36	1/36	1/36	1/36	1/6
	6	1/36	1/36	1/36	1/36	1/36	1/36	1/6

# Conditional Distributions: Example 4



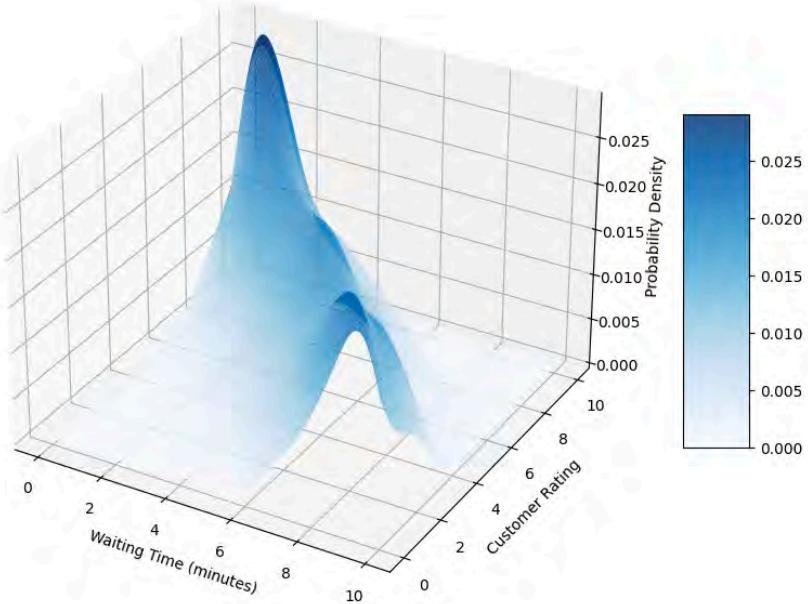
# Conditional Distributions: Example 4



# Continuous Conditional Distribution

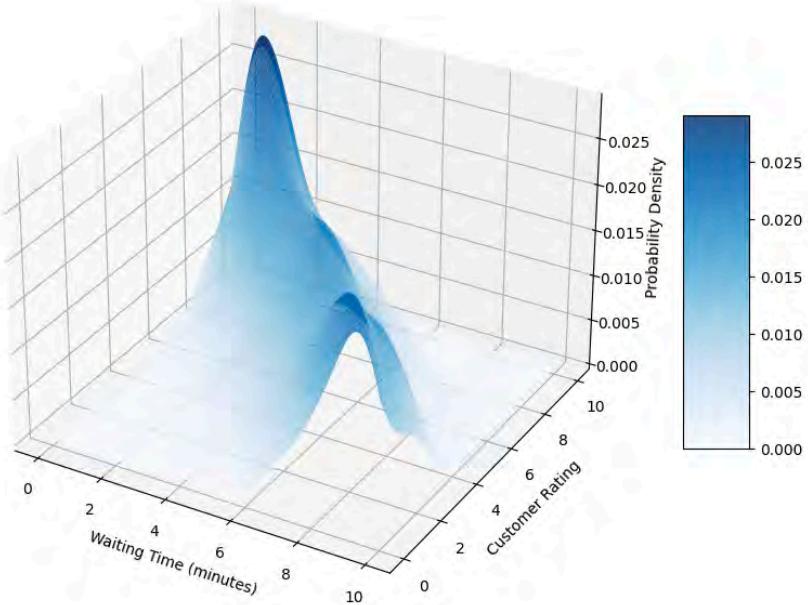
# Continuous Conditional Distribution

3D Probability Density Distribution for Customer Ratings vs Waiting Time



# Continuous Conditional Distribution

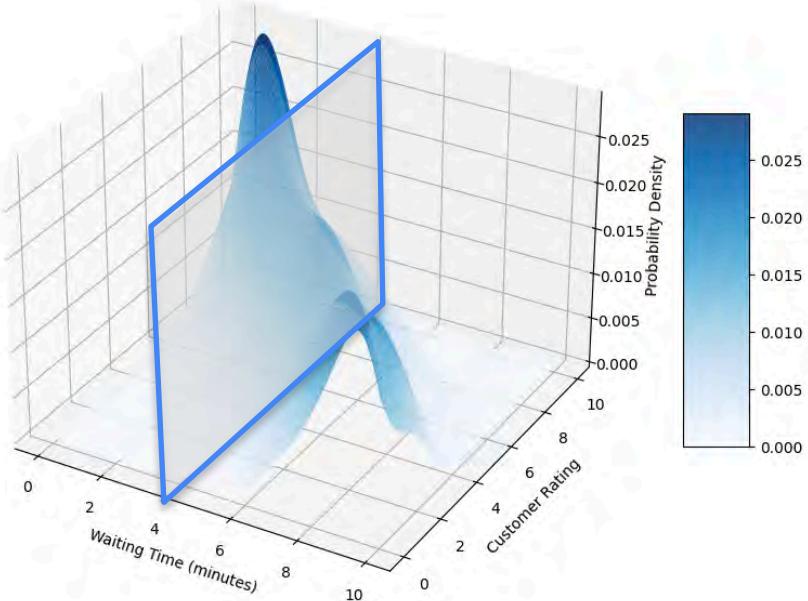
3D Probability Density Distribution for Customer Ratings vs Waiting Time



Probability distribution for rating given that waiting time was 4 minutes

# Continuous Conditional Distribution

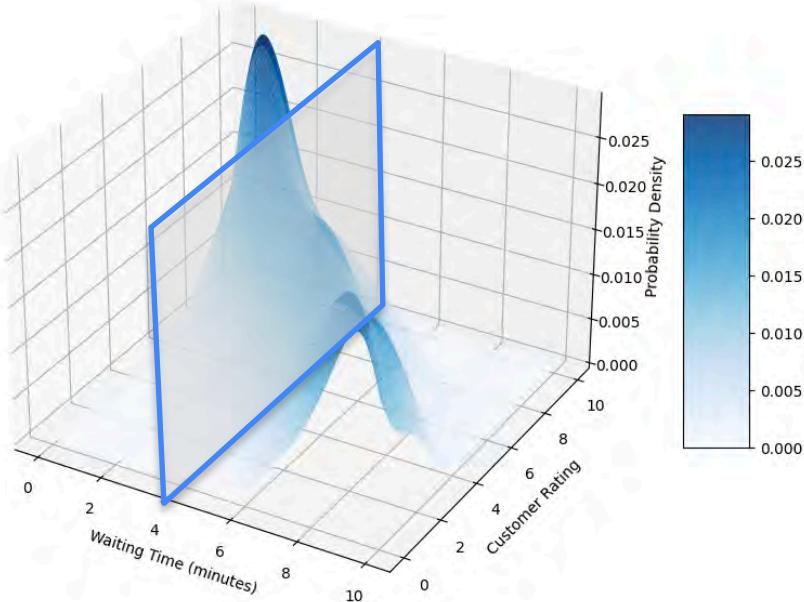
3D Probability Density Distribution for Customer Ratings vs Waiting Time



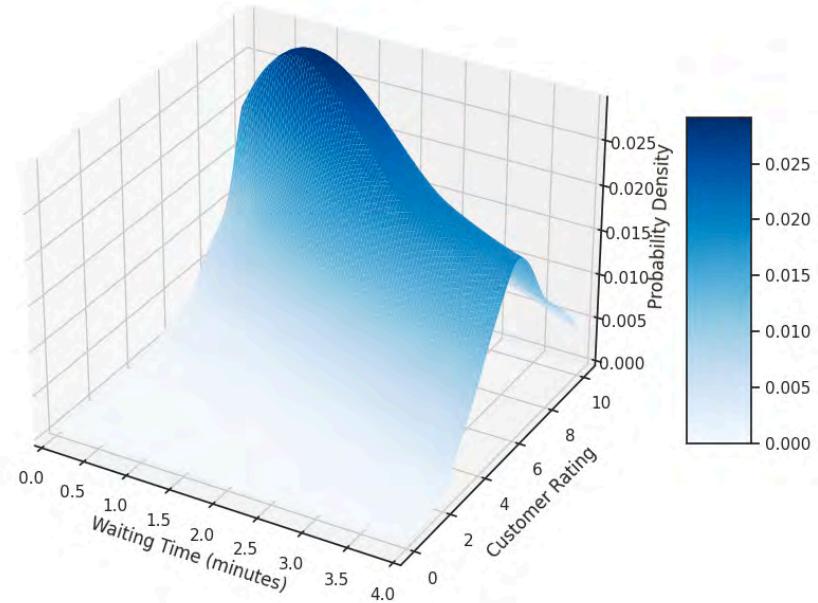
Probability distribution for rating given that waiting time was 4 minutes

# Continuous Conditional Distribution

3D Probability Density Distribution for Customer Ratings vs Waiting Time

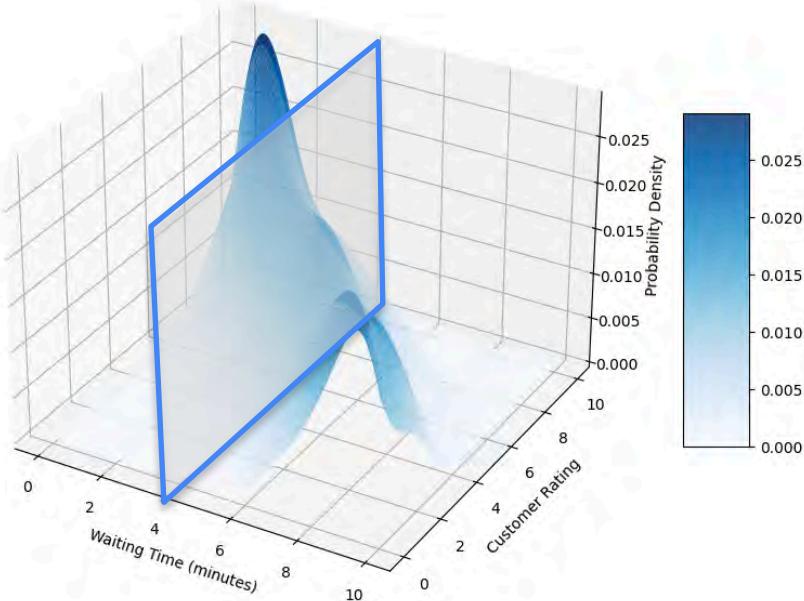


Probability distribution for rating given that waiting time was 4 minutes

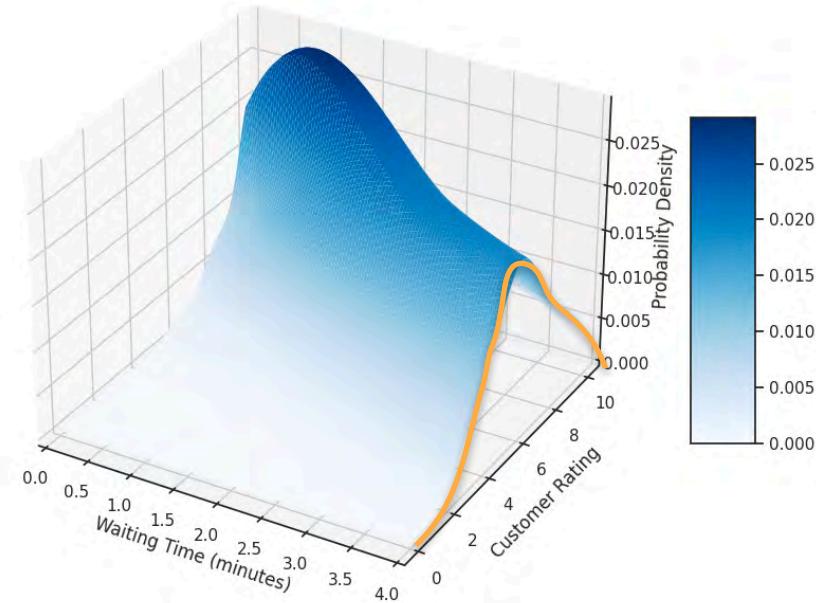


# Continuous Conditional Distribution

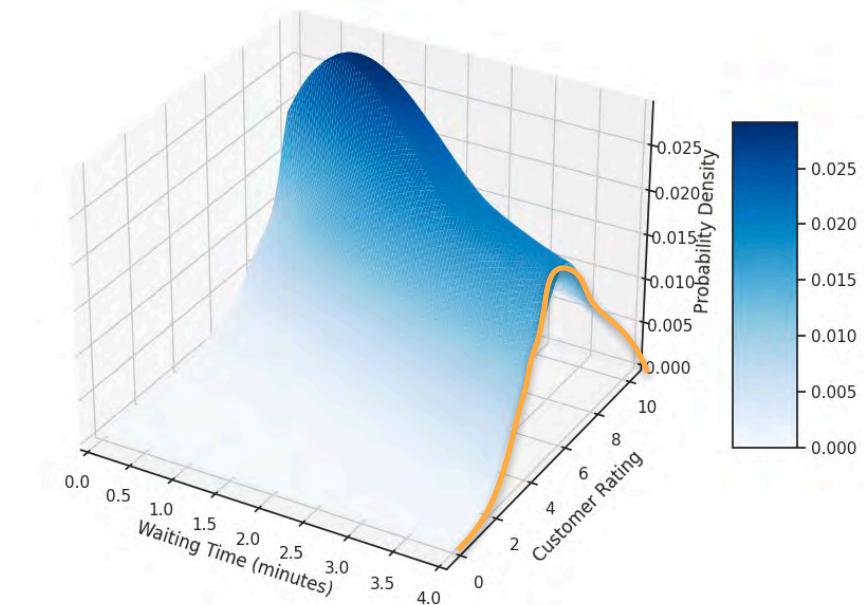
3D Probability Density Distribution for Customer Ratings vs Waiting Time



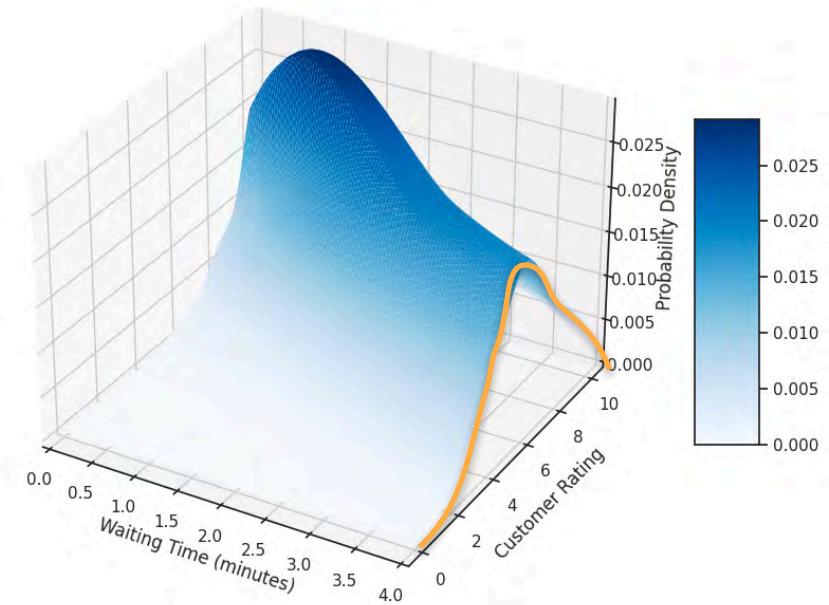
Probability distribution for rating given that waiting time was 4 minutes



# Continuous Conditional Distribution



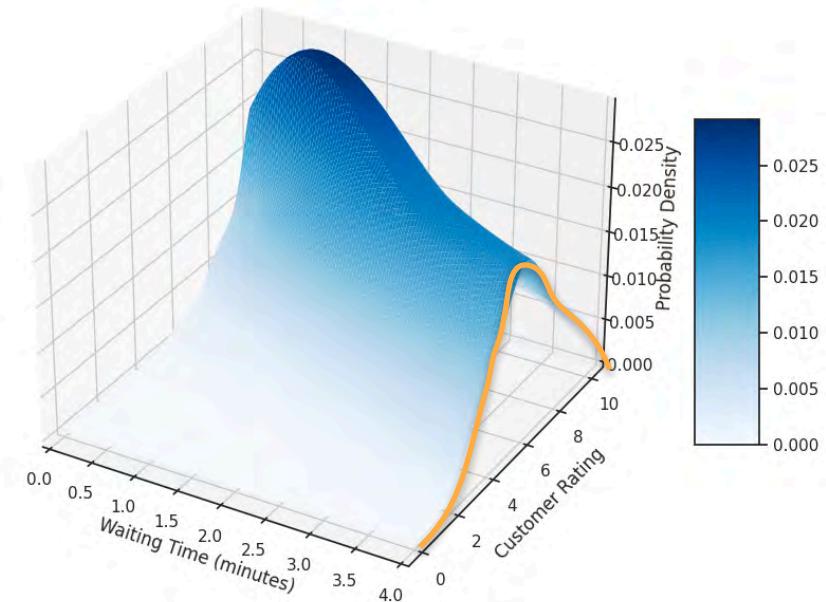
# Continuous Conditional Distribution



# Continuous Conditional Distribution



Conditional PDF of  $y$  given  $x = 4$



# Discrete Conditional Distribution

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

# Discrete Conditional Distribution

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

Joint PDF of  $X$  and  $Y$



# Discrete Conditional Distribution

The diagram illustrates the formula for a discrete conditional distribution. On the left, the text "Conditional PDF of  $Y$ " is written next to a teal curved arrow pointing towards the term  $p_{Y|X=x}(y)$ . On the right, the text "Joint PDF of  $X$  and  $Y$ " is written next to another teal curved arrow pointing towards the term  $p_{XY}(x,y)$ . The central equation is:

$$p_{Y|X=x}(y) = \frac{p_{XY}(x,y)}{p_X(x)}$$

# Discrete Conditional Distribution

$$p_{Y|X=x}(y) = \frac{p_{XY}(x, y)}{p_X(x)}$$

Conditional PDF of  $Y$

Joint PDF of  $X$  and  $Y$

Marginal distribution of  $X$

The diagram illustrates the derivation of the conditional probability formula. It shows three components: 'Conditional PDF of  $Y$ ' pointing to the numerator  $p_{XY}(x, y)$ ; 'Marginal distribution of  $X$ ' pointing to the denominator  $p_X(x)$ ; and 'Joint PDF of  $X$  and  $Y$ ' pointing to the overall fraction.

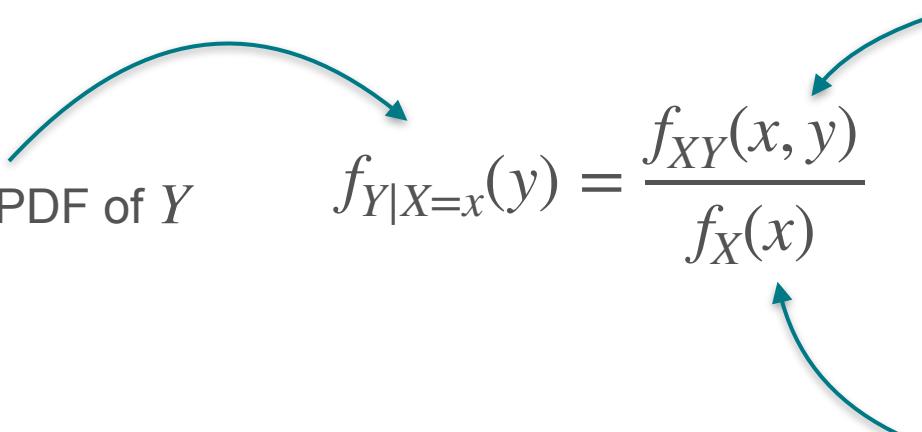
# Continuous Conditional Distribution: Formula

$$f_{Y|X=x}(y) = \frac{f_{XY}(x, y)}{f_X(x)}$$

Conditional PDF of  $Y$

Joint PDF of  $X$  and  $Y$

Marginal distribution of  $X$





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# Probability Distributions with Multiple Variables

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## Covariance

# Introduction to Covariance

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$X$  : age of a child

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Age ( $X$ )	Height ( $Y_1$ )
6	50
7	52
8	55
9	57
10	60
11	62
12	64
13	65
14	67
15	68

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$Y_2$  : grades in a test

Age ( $X$ )	Grades ( $Y_2$ )
6	5
7	7
8	8
9	3
10	1
11	1
12	6
13	10
14	2
15	7

$Y_3$ : number of naps per day

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$Y_3$ : number of naps per day

Age ( $X$ )	Naps per day ( $Y_3$ )
6	8
7	7
8	6
9	5
10	4
11	3
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13	1
14	1
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- How is variable  $X$  related to each of the  $Y$  variables?
- How do you compare these relations?

$Y_3$  : number of naps per day

Age (X)	Naps per day ( $Y_3$ )
6	8
7	7
8	6
9	5
10	4
11	3
12	2
13	1
14	1
15	0

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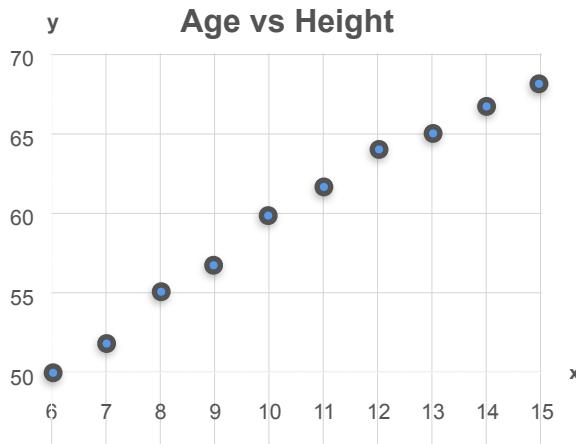
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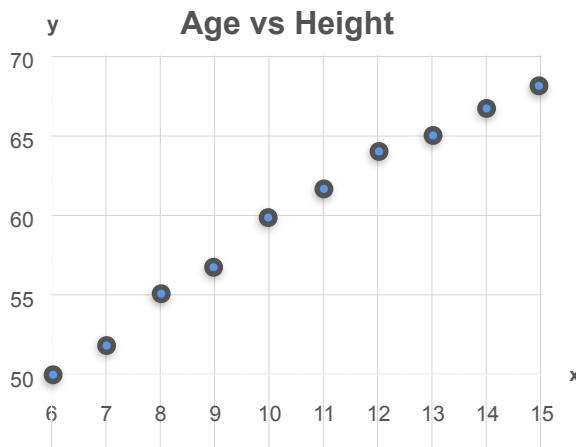
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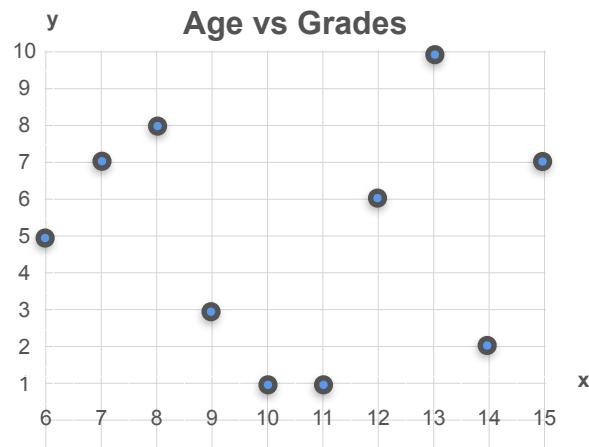
# Introduction to Covariance

$X$  : age of a child

$Y_1$  : height of the child (in)



$Y_2$  : grades in a test



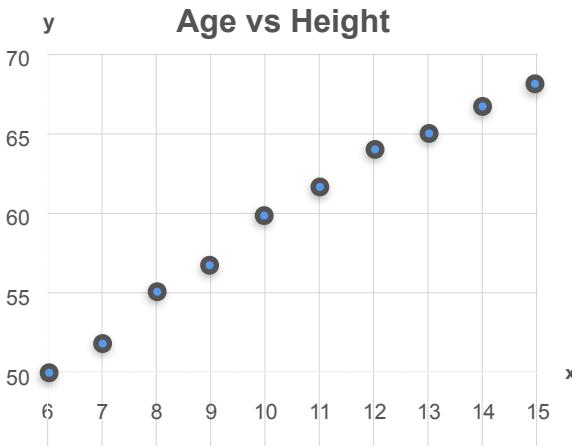
$Y_3$  : number of naps per day

Age (X)	Naps per day (Y <sub>3</sub> )
6	8
7	7
8	6
9	5
10	4
11	3
12	2
13	1
14	1
15	0

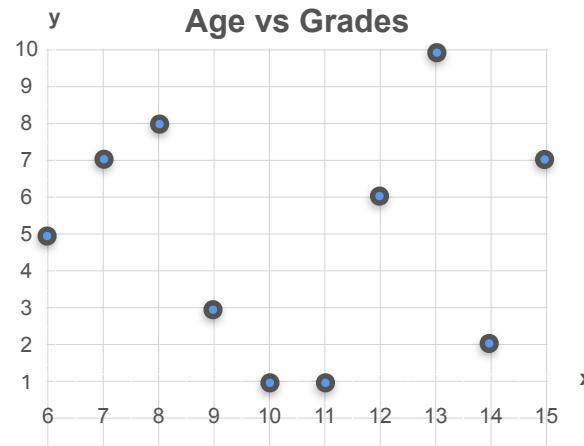
# Introduction to Covariance

$X$  : age of a child

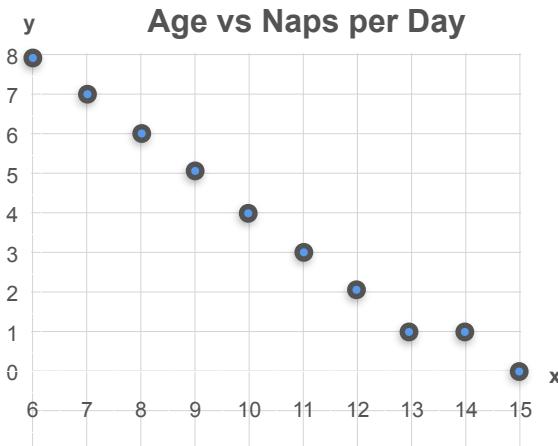
$Y_1$  : height of the child (in)



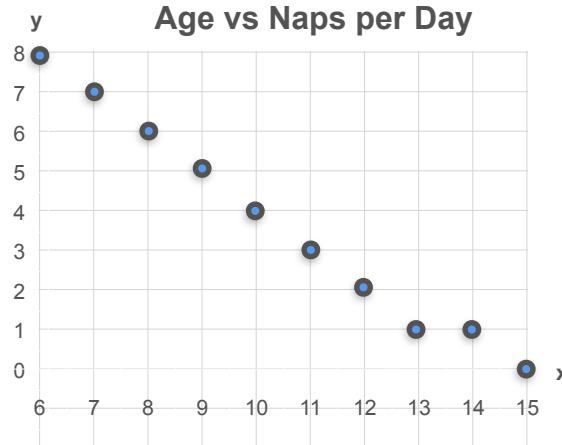
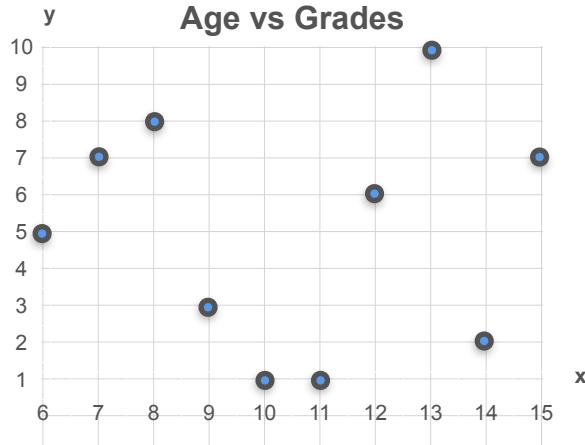
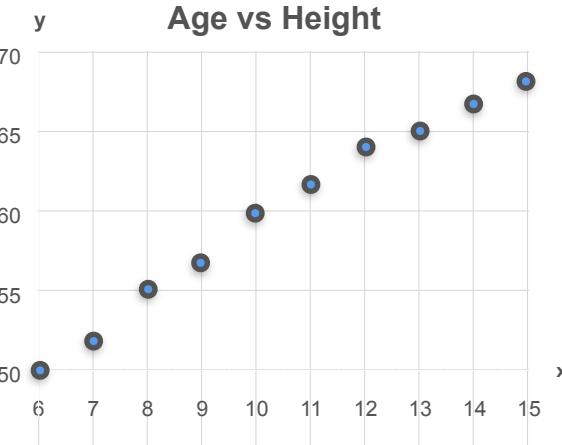
$Y_2$  : grades in a test



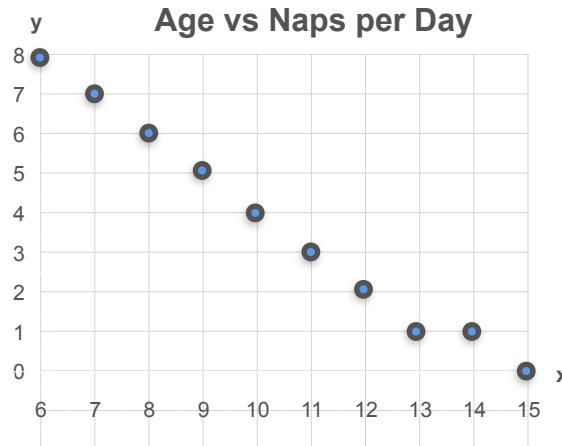
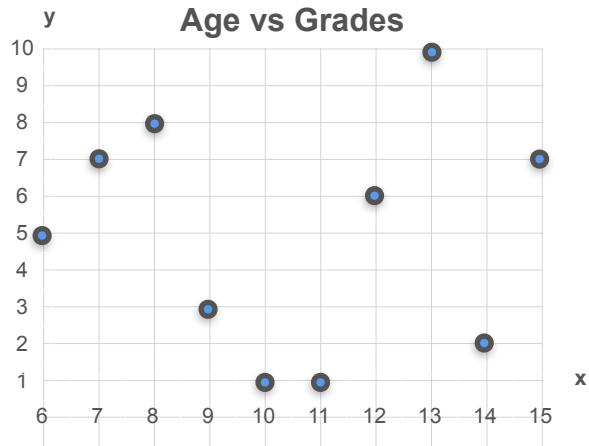
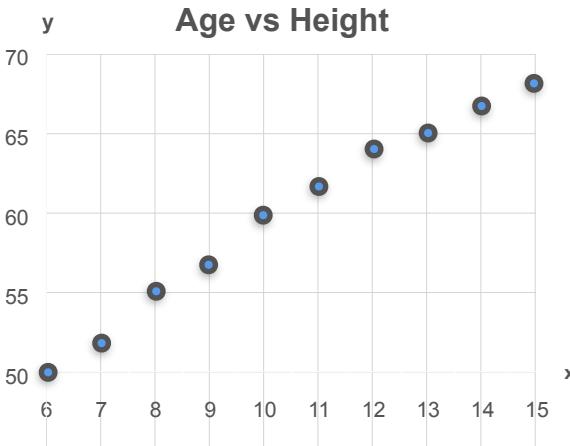
$Y_3$  : number of naps per day



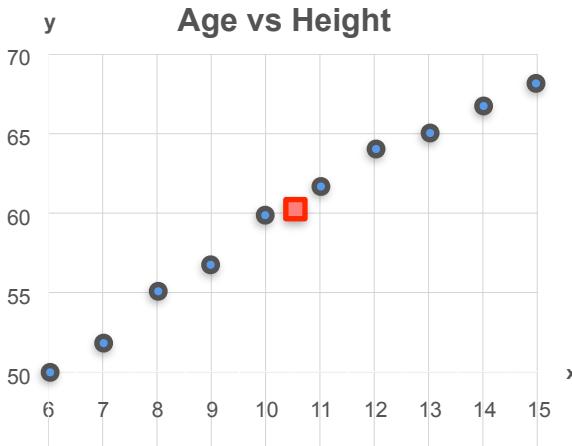
# How To Compare These?



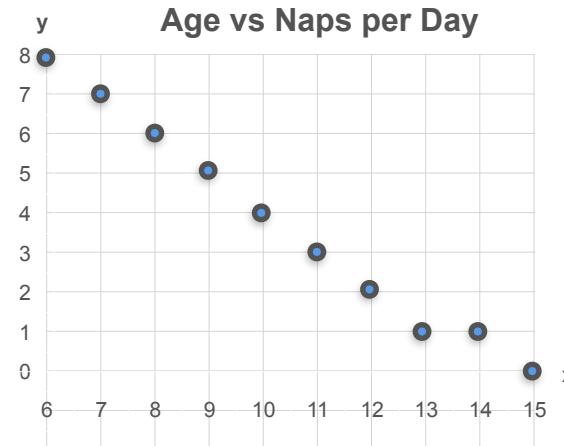
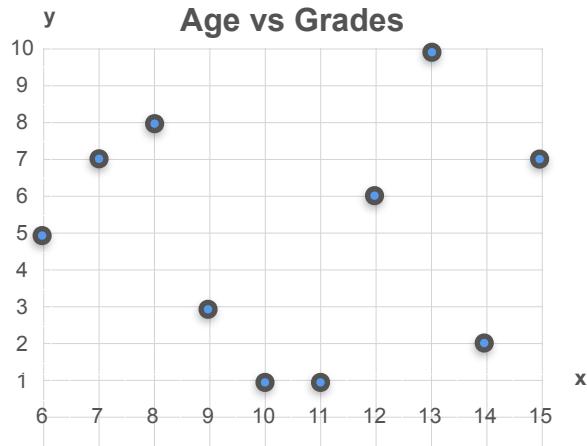
# Mean?



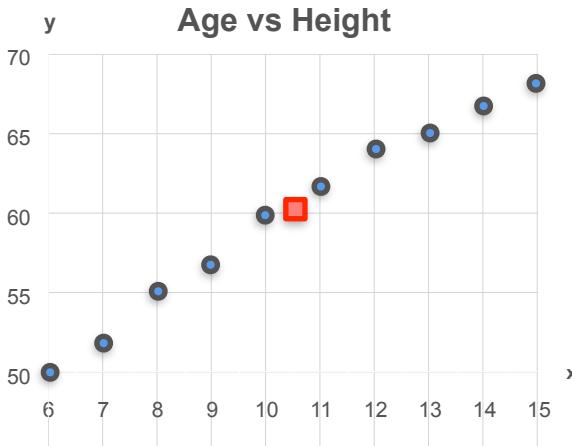
# Mean?



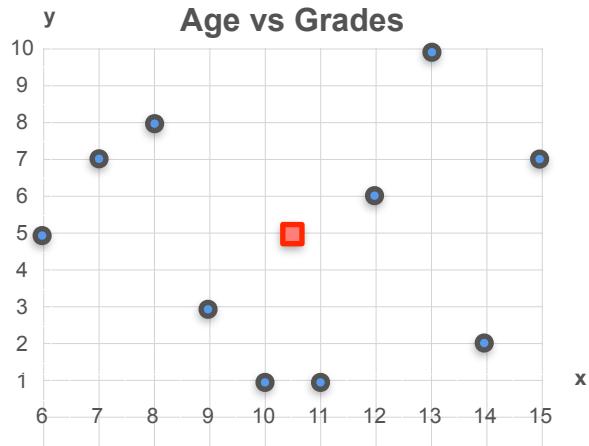
$$\mu_x = 10.5 \quad \mu_y = 60$$



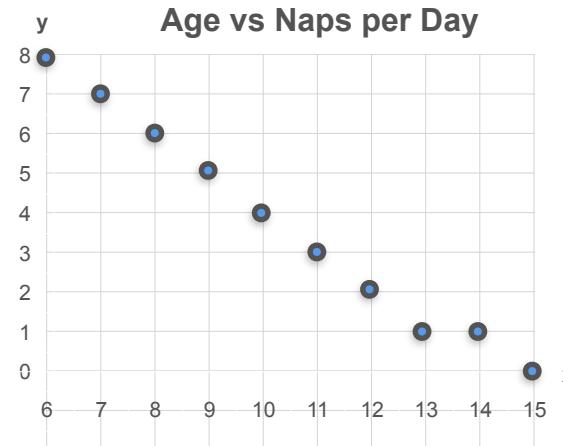
# Mean?



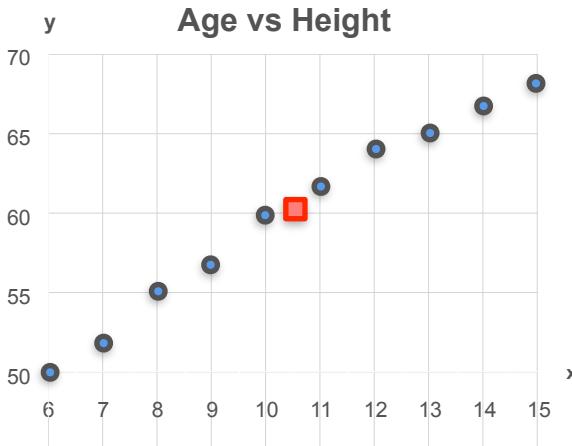
$$\mu_x = 10.5 \quad \mu_y = 60$$



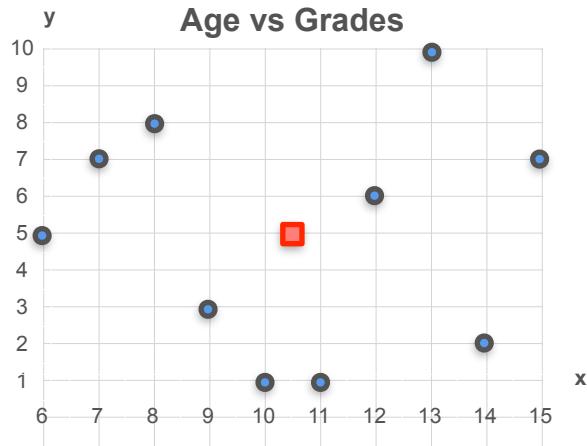
$$\mu_x = 10.5 \quad \mu_y = 5$$



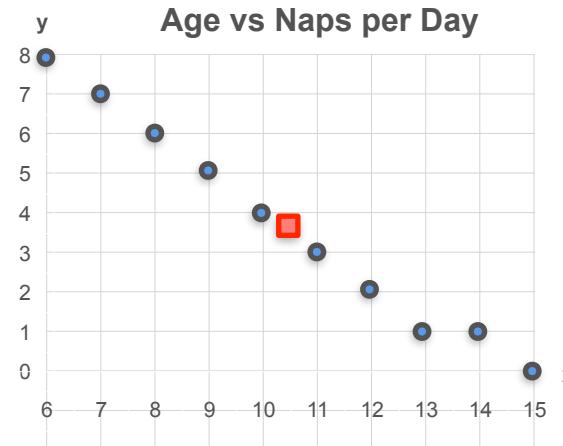
# Mean?



$$\mu_x = 10.5 \quad \mu_y = 60$$

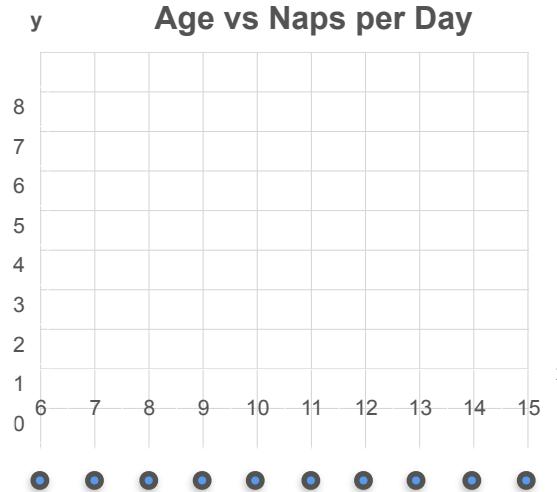
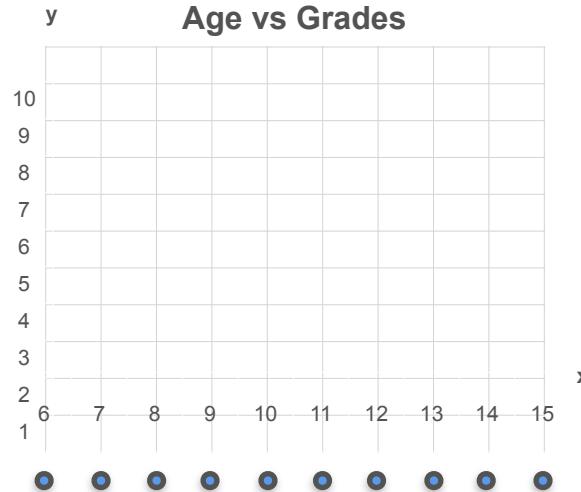
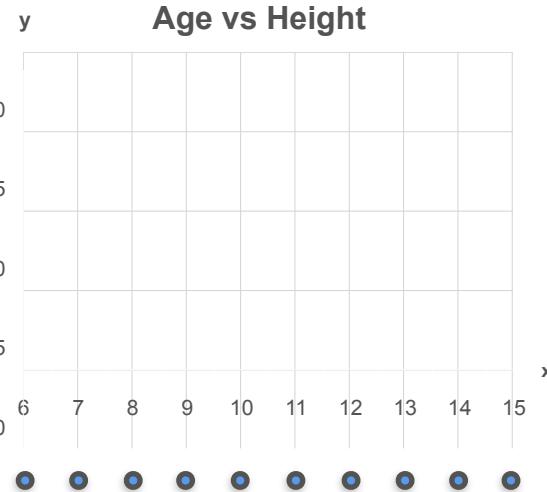


$$\mu_x = 10.5 \quad \mu_y = 5$$

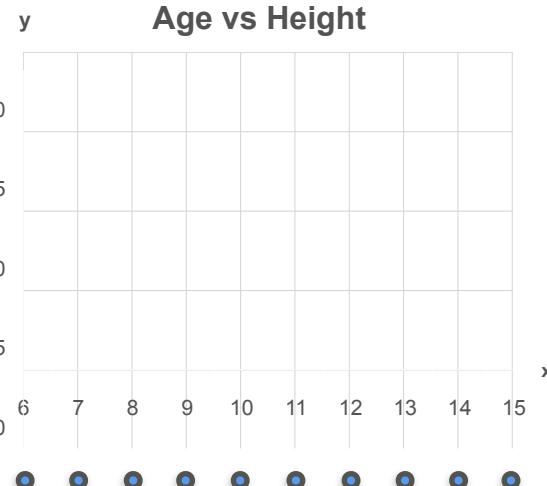


$$\mu_x = 10.5 \quad \mu_y = 3.7$$

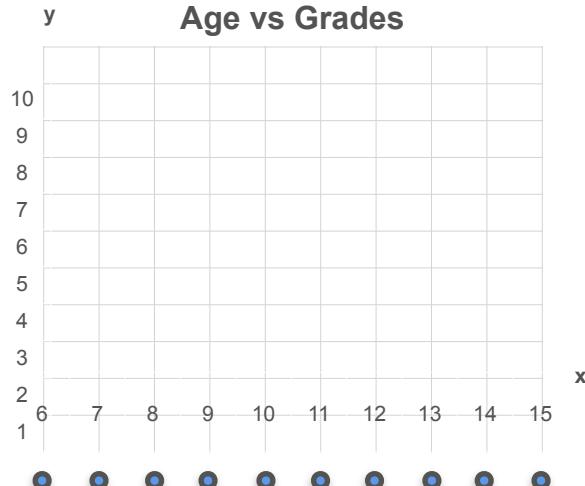
# Horizontal (X) Variance



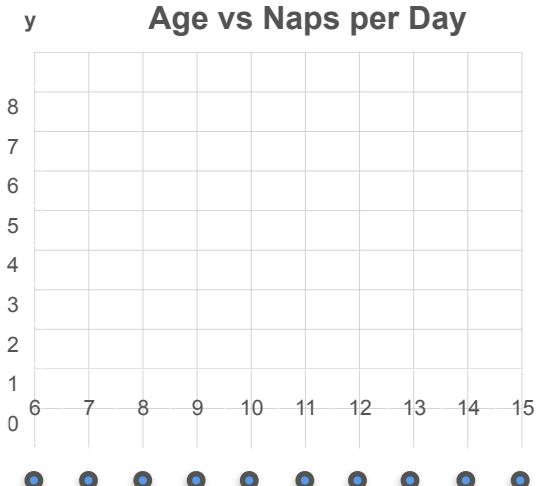
# Horizontal (X) Variance



$$Var(X) = 9.17$$

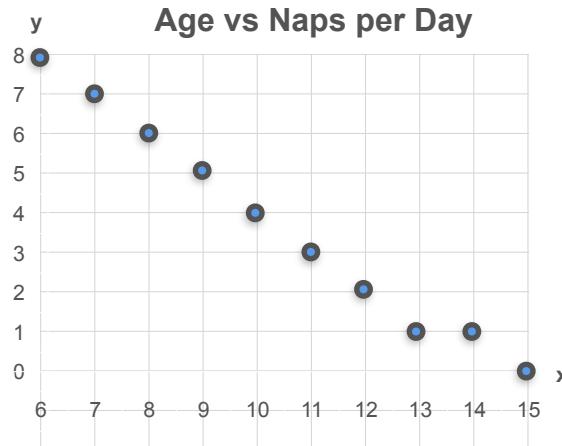
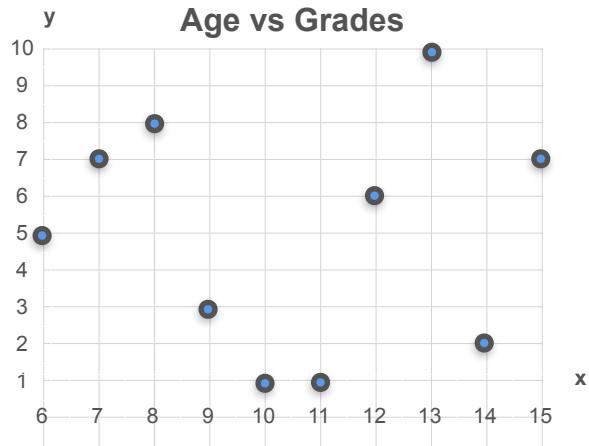
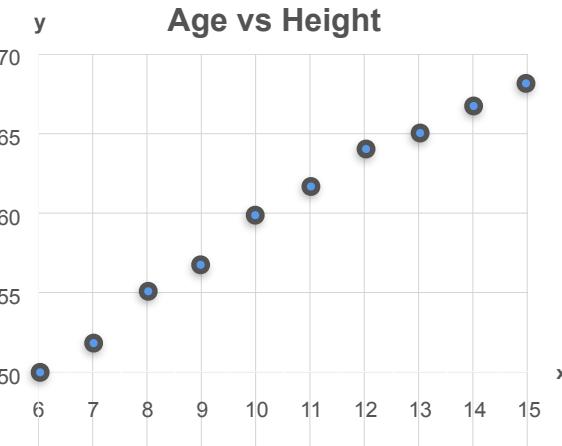


$$Var(X) = 9.17$$

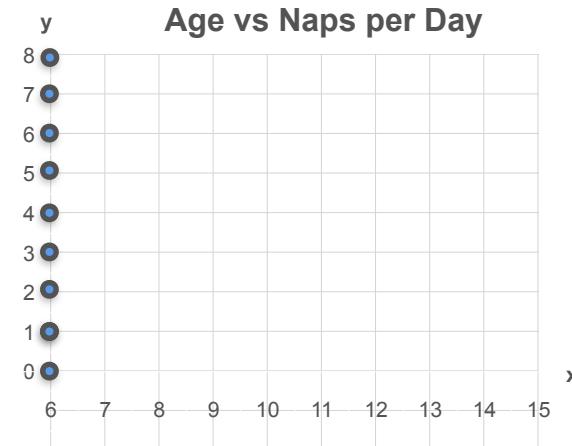
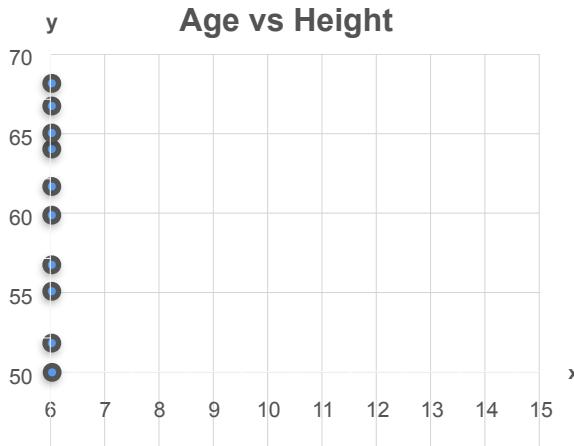


$$Var(X) = 9.17$$

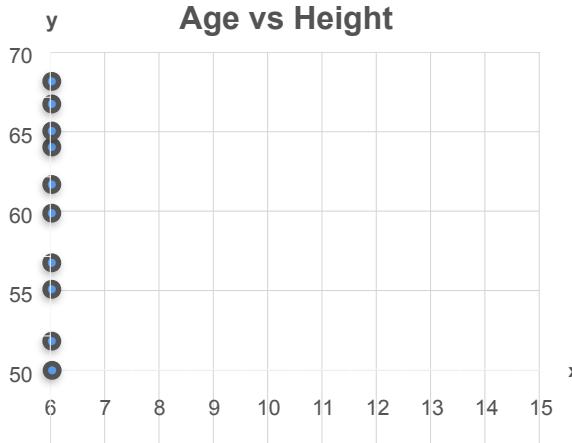
# Anything Else?



# Vertical (Y) Variance



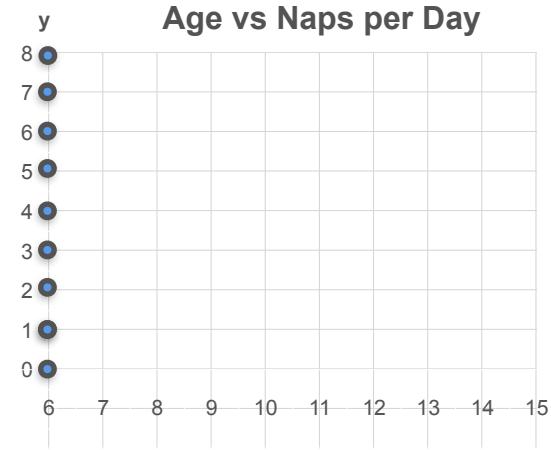
# Vertical (Y) Variance



$$Var(Y) = 39.56$$

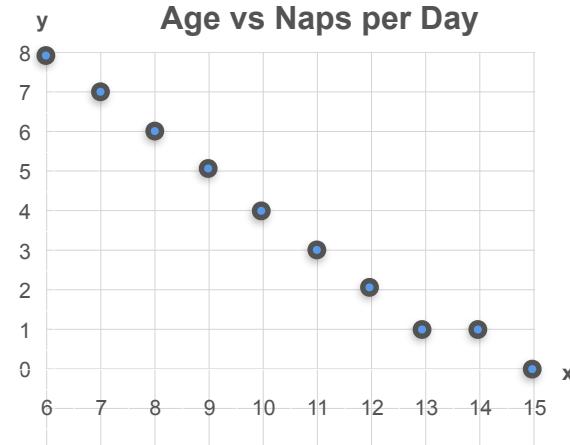
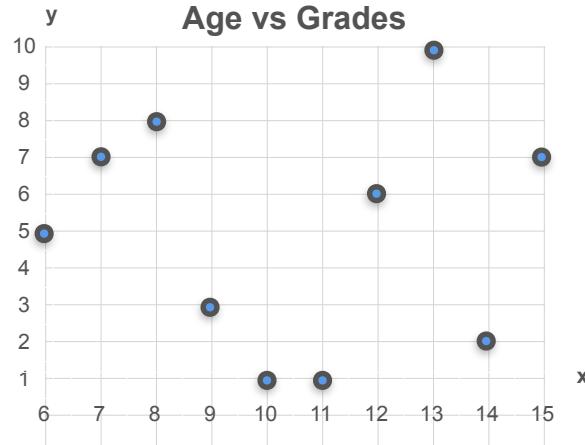
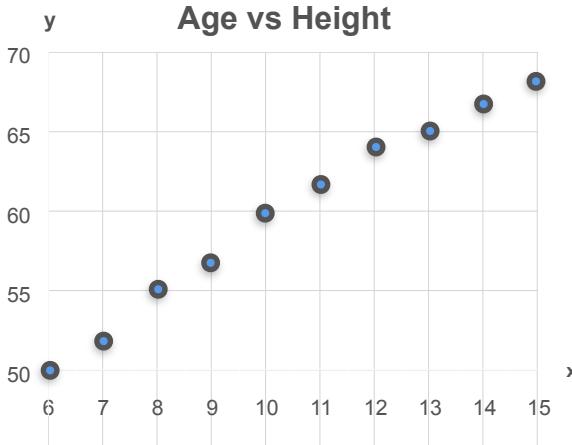


$$Var(Y) = 9.78$$

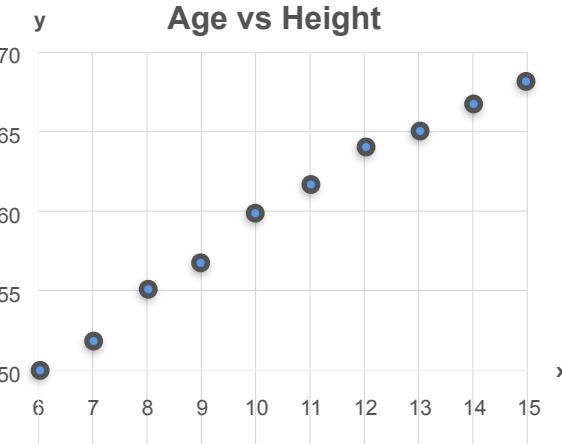


$$Var(Y) = 7.57$$

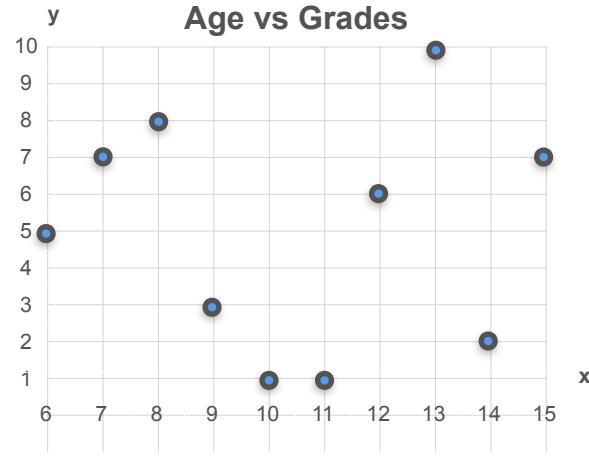
# Still no Way To Compare Them



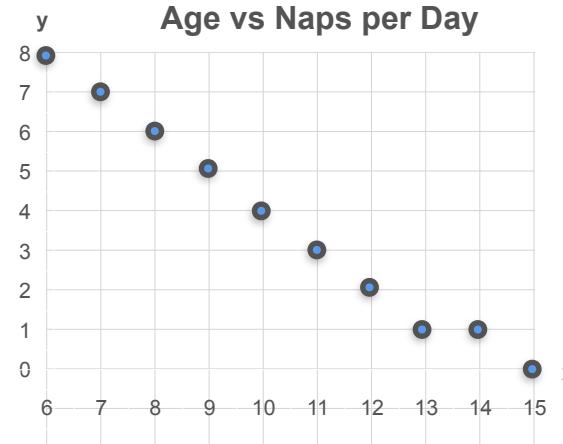
# Still no Way To Compare Them



Covariance > 0



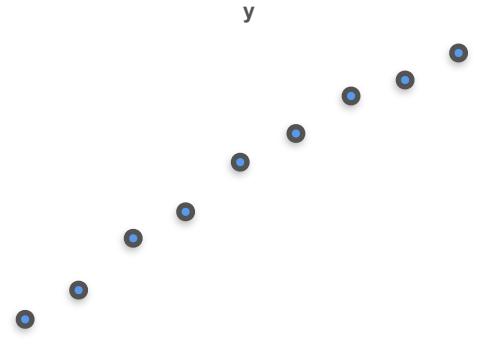
Covariance  $\approx 0$



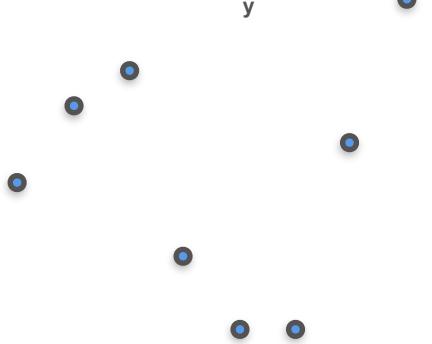
Covariance < 0

# First Step: Center Them

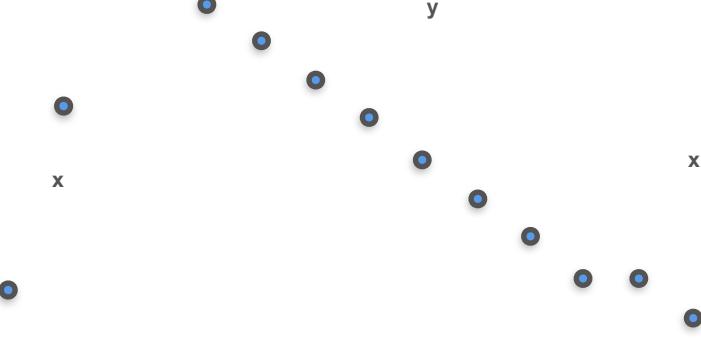
Age vs Height



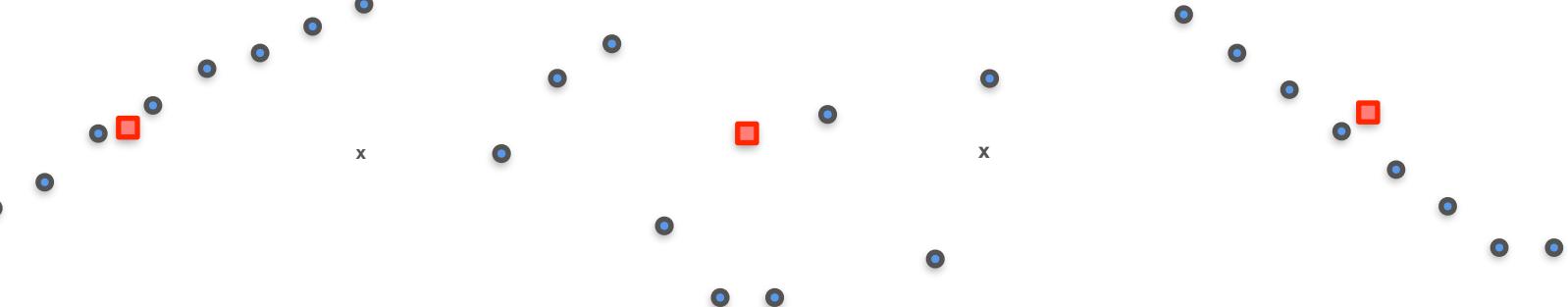
Age vs Grades



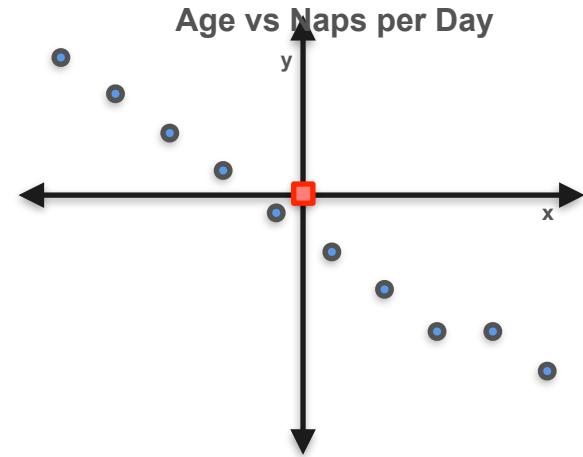
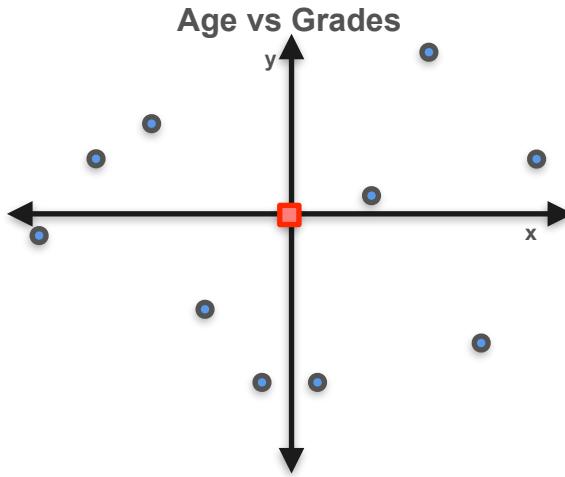
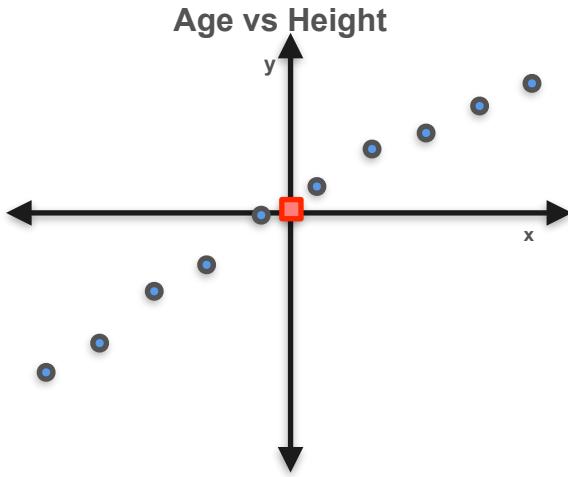
Age vs Naps per Day



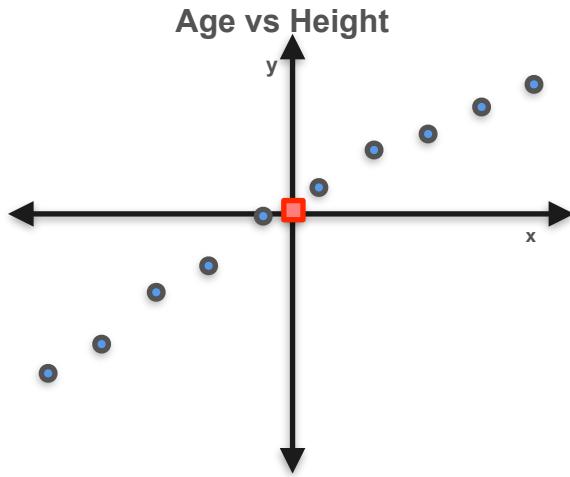
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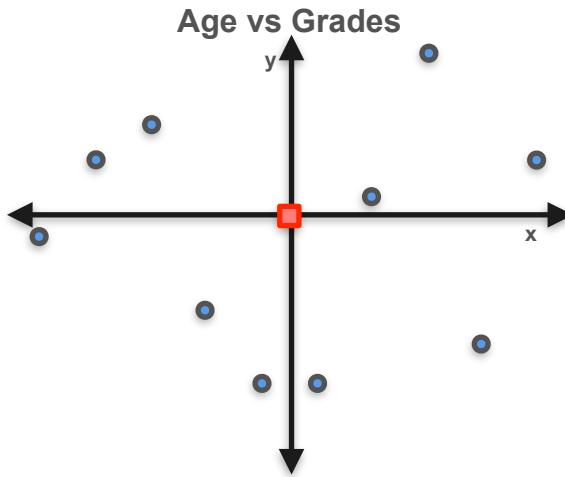


$$\mu_x = 0$$

$$\mu_y = 0$$

$$Var(X) = 1$$

$$Var(Y) = 1$$

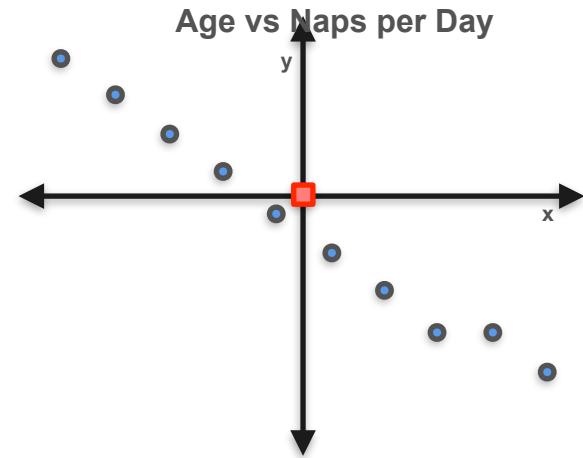


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$$Var(X) = 1$$

$$Var(Y) = 1$$



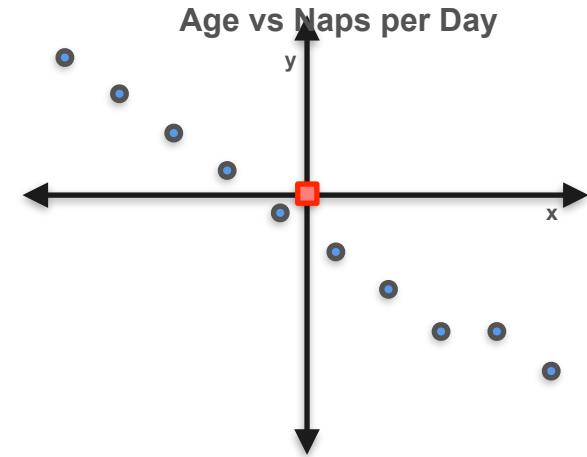
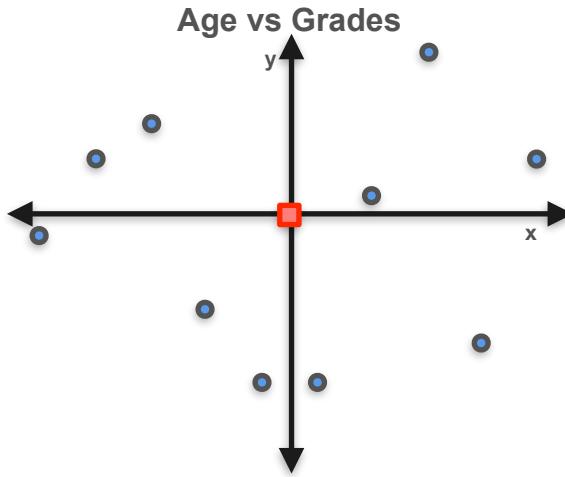
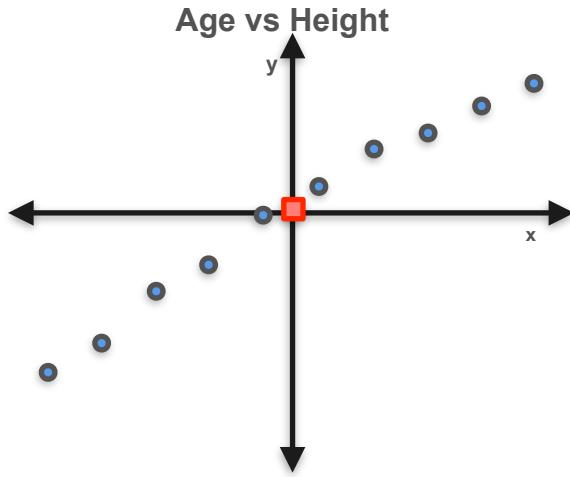
$$\mu_x = 0$$

$$\mu_y = 0$$

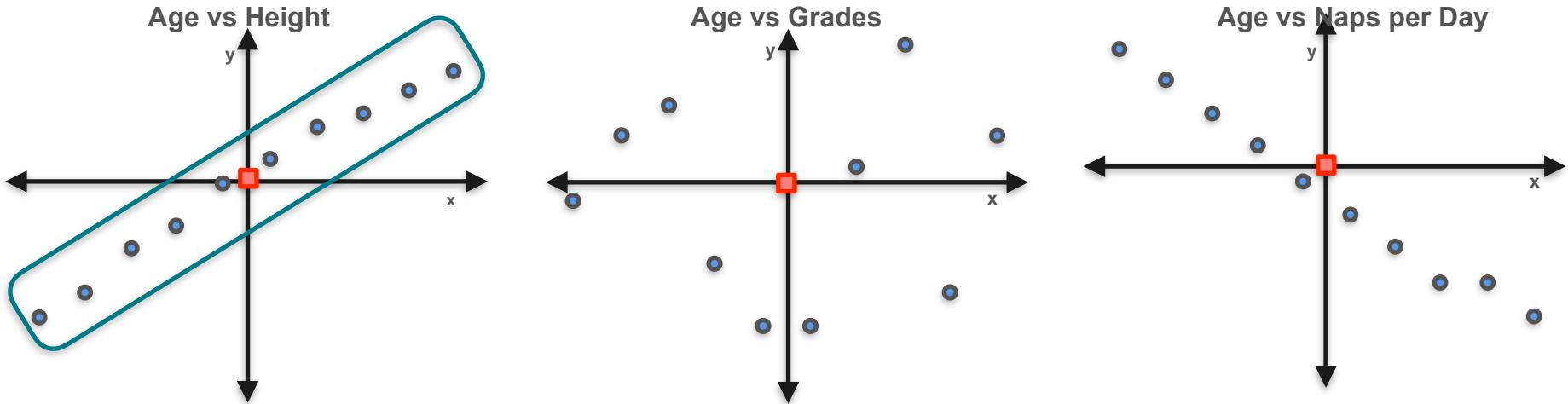
$$Var(X) = 1$$

$$Var(Y) = 1$$

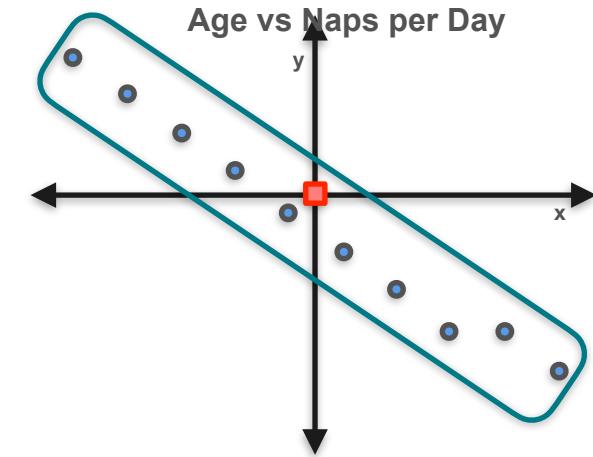
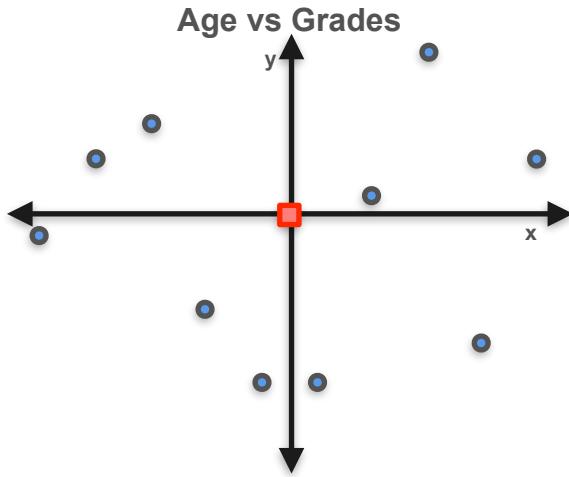
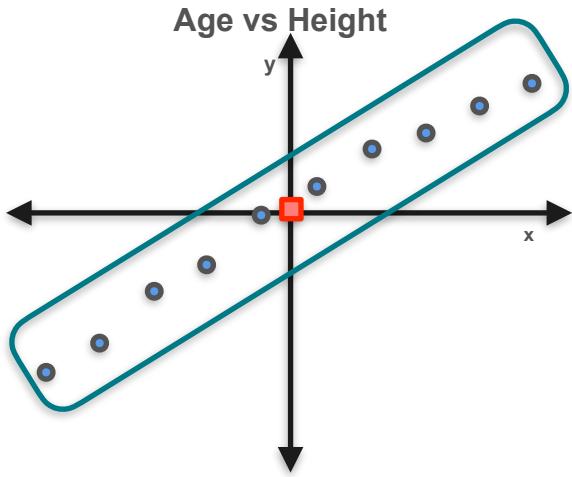
# Second Step: Notice Trend



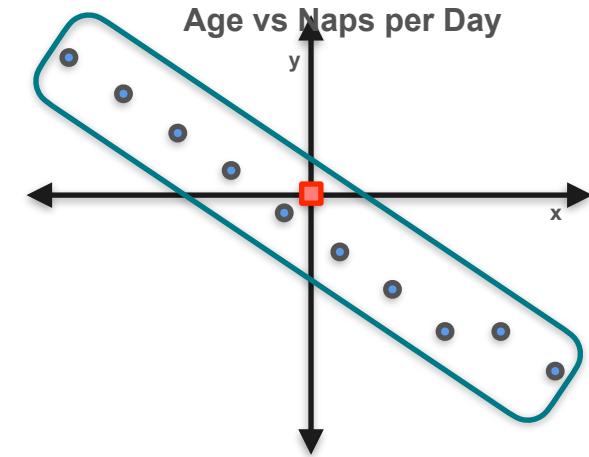
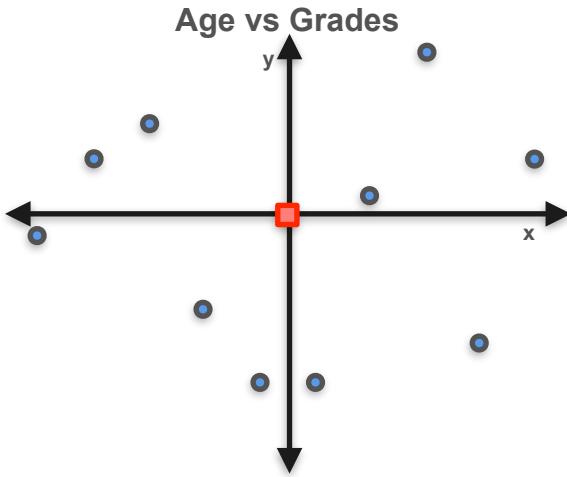
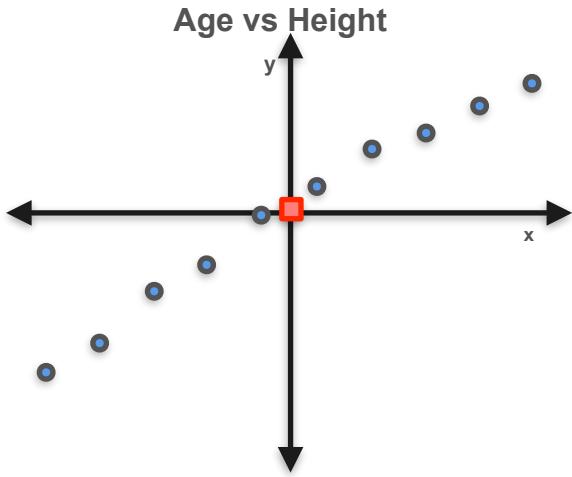
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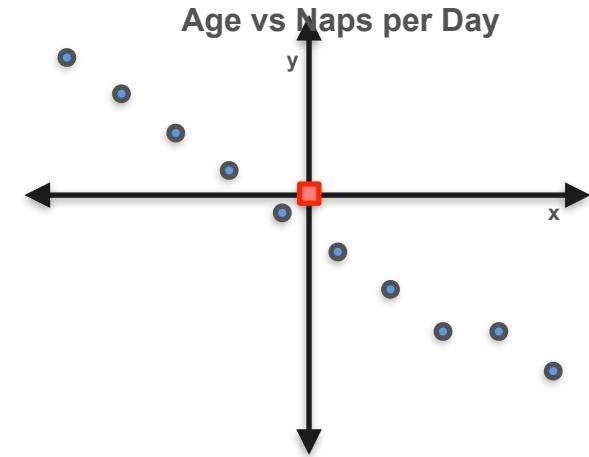
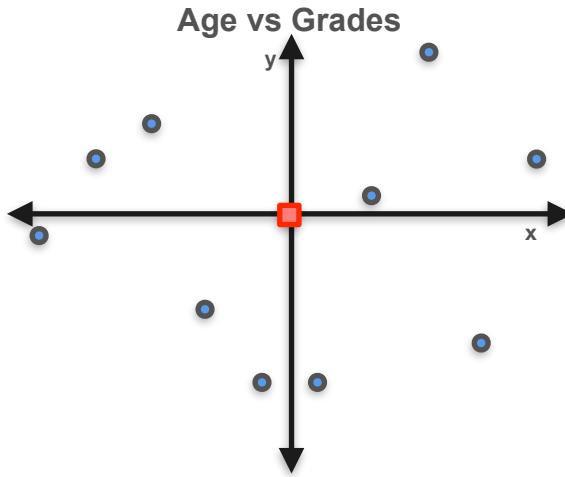
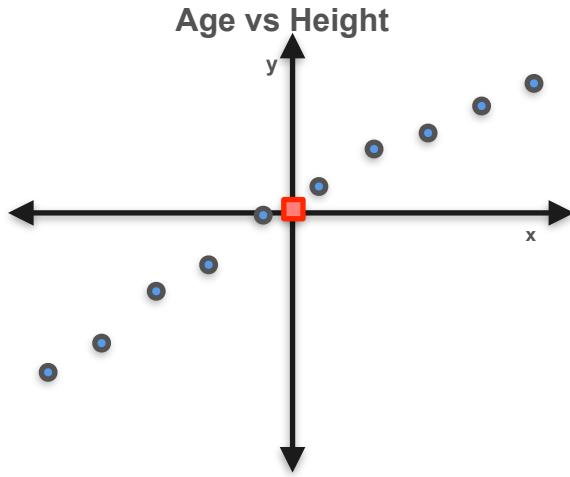
# Second Step: Notice Trend



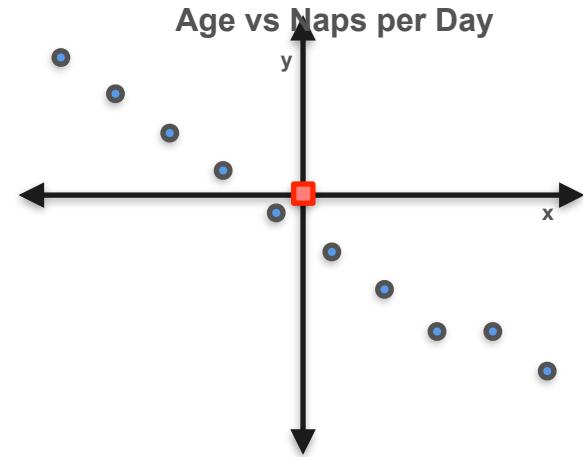
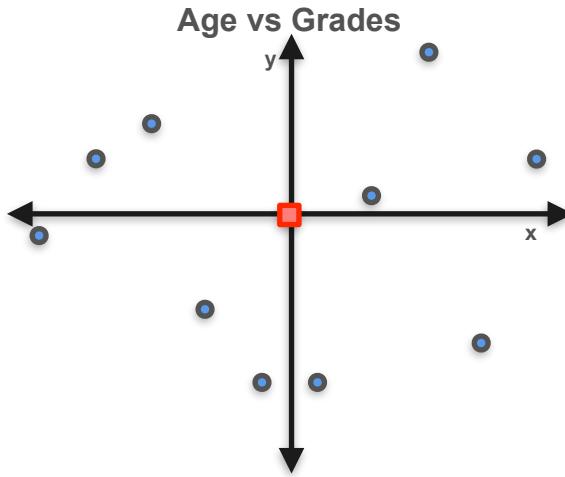
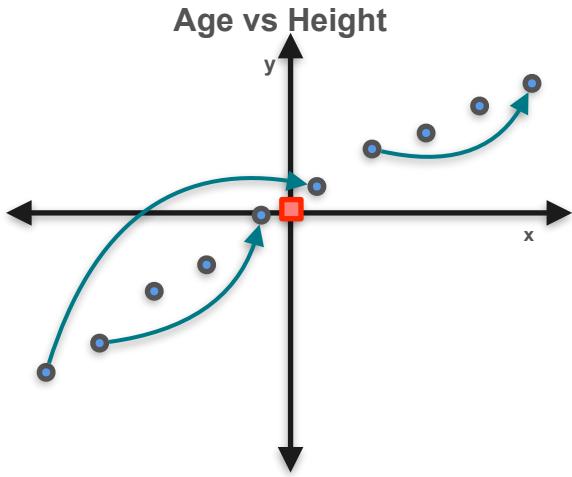
# Second Step: Notice Trend



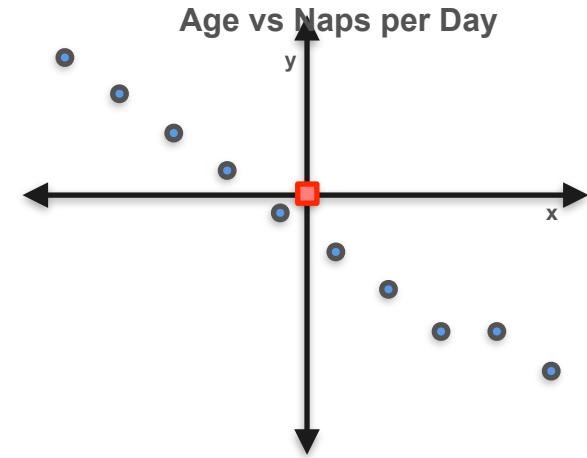
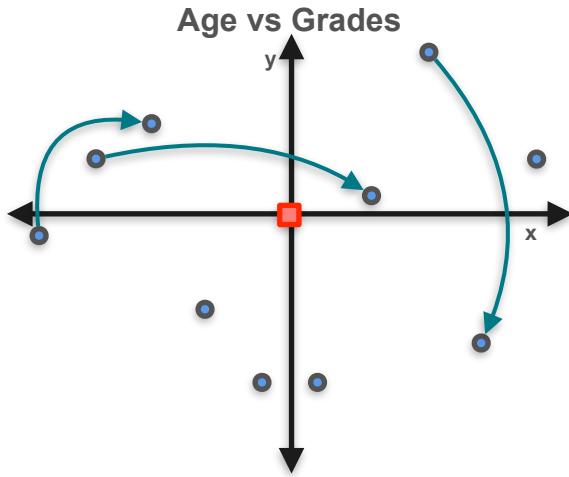
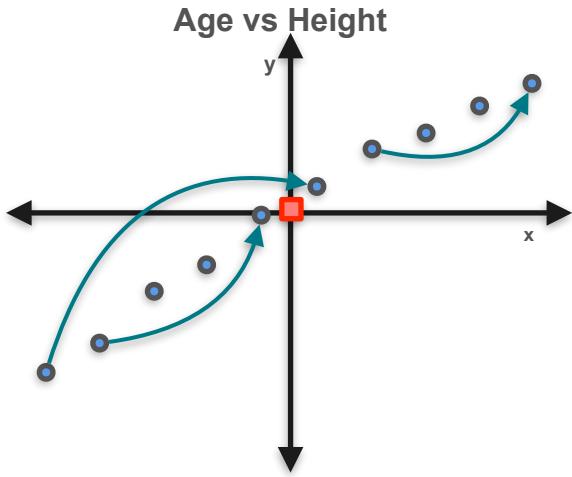
# Second Step: Notice Trend



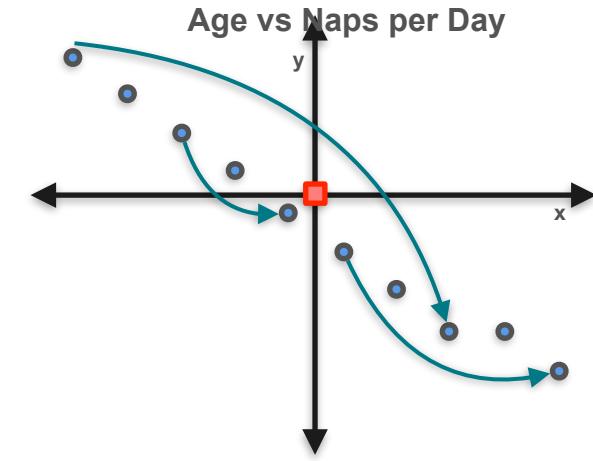
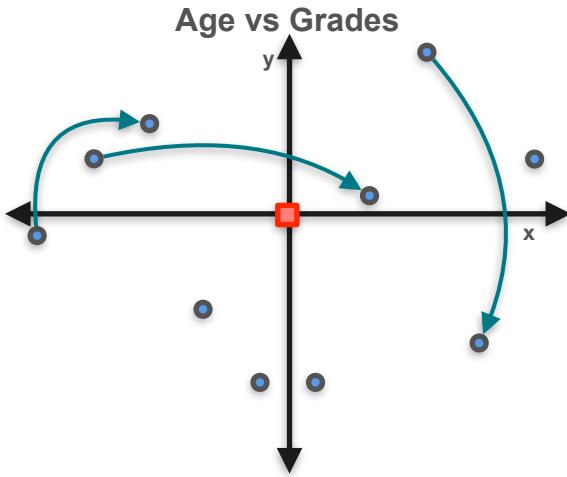
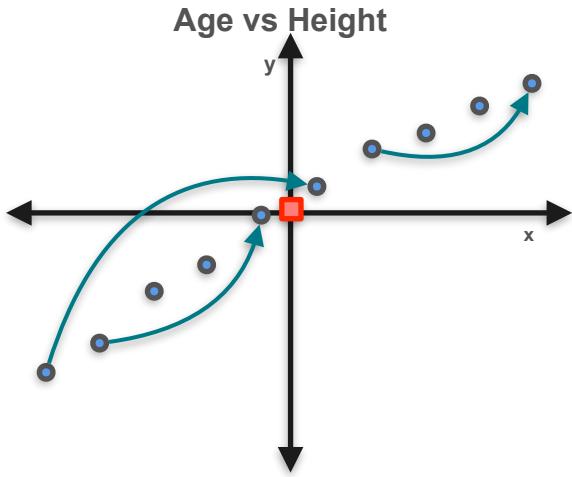
# Second Step: Notice Trend



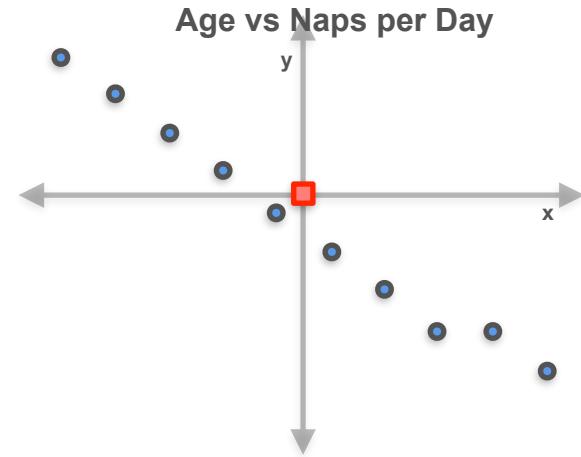
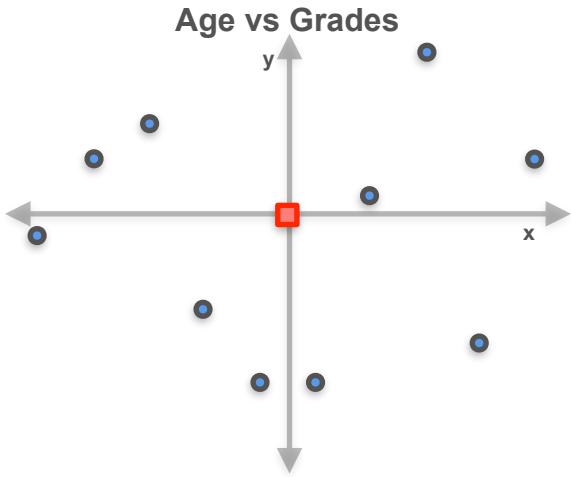
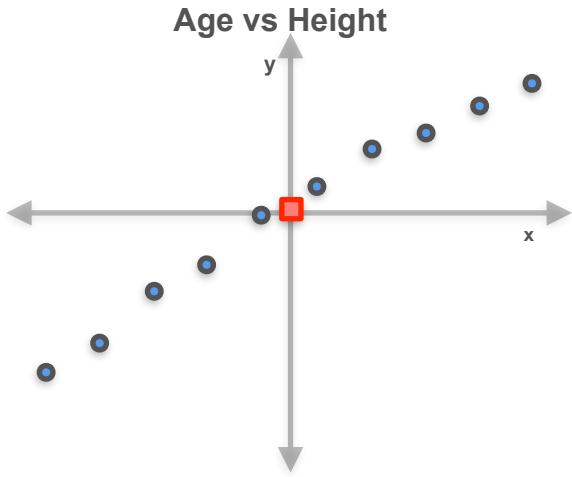
# Second Step: Notice Trend



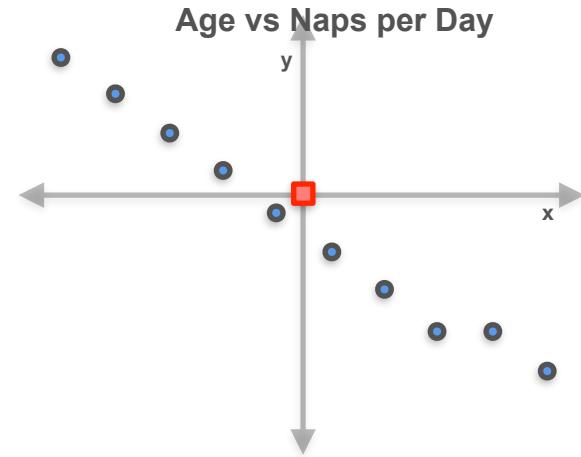
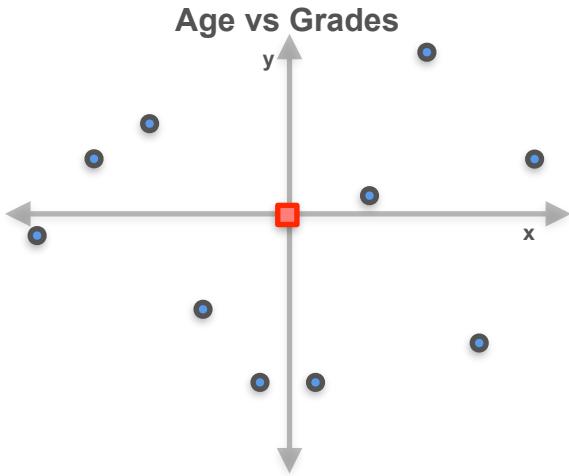
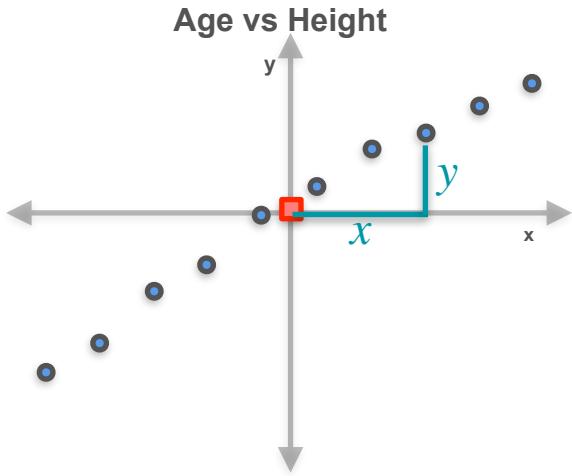
# Second Step: Notice Trend



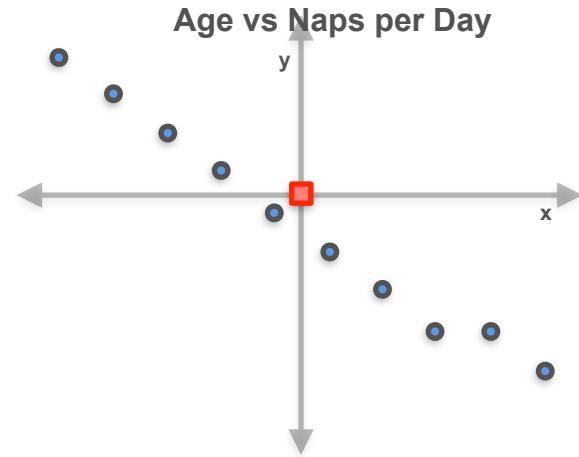
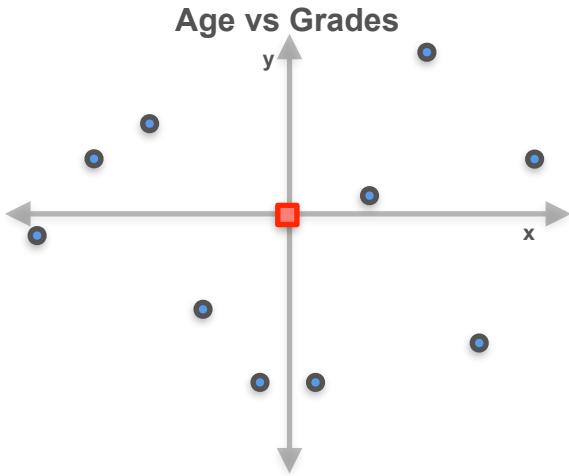
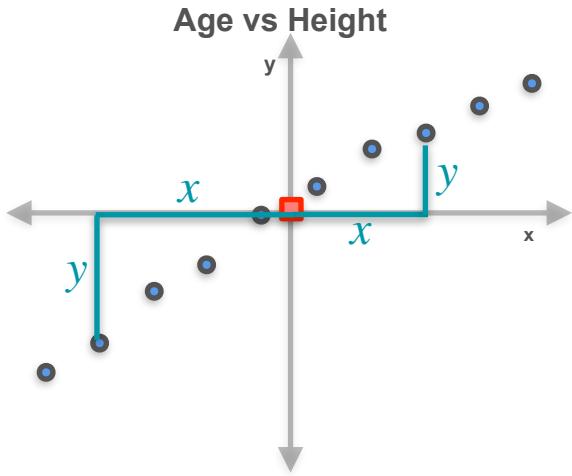
# Positives and Negatives



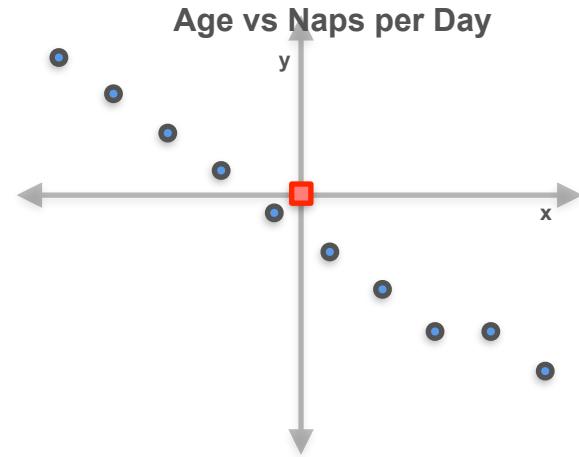
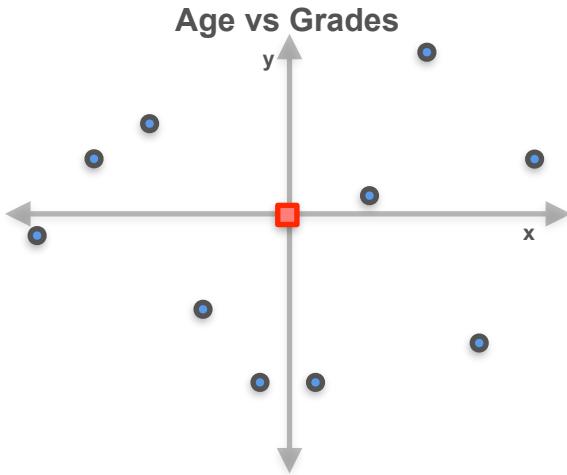
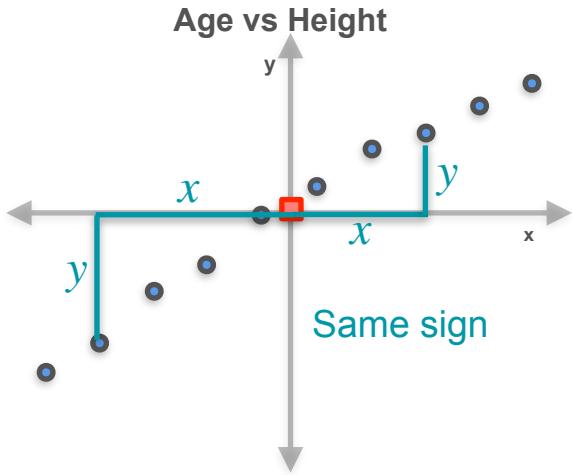
# Positives and Negatives



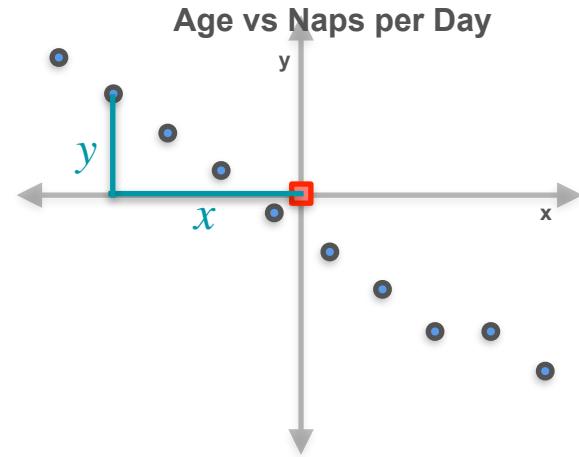
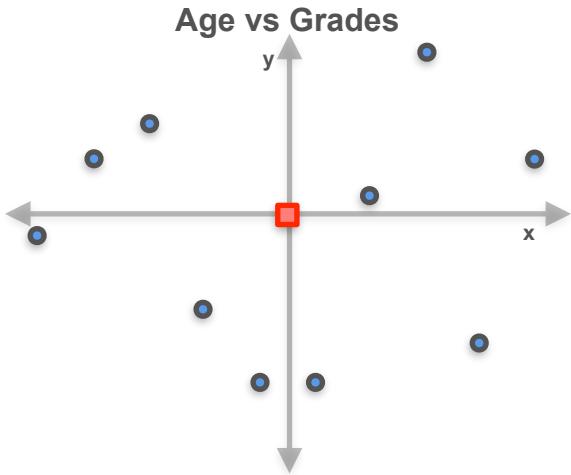
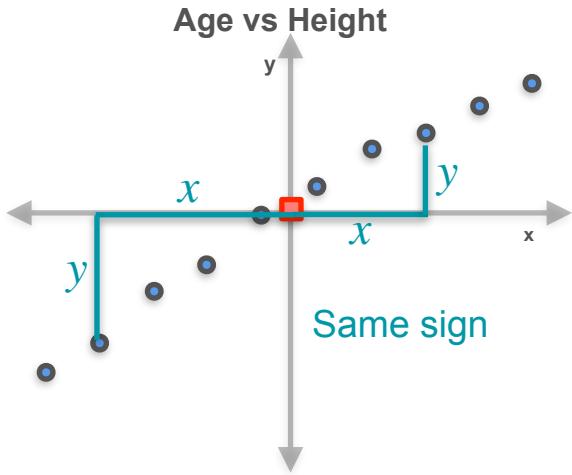
# Positives and Negatives



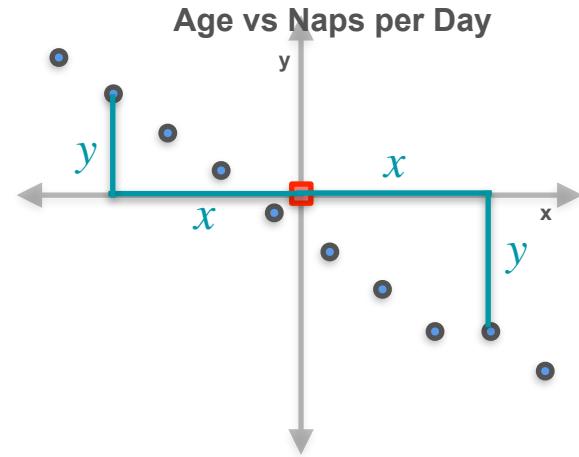
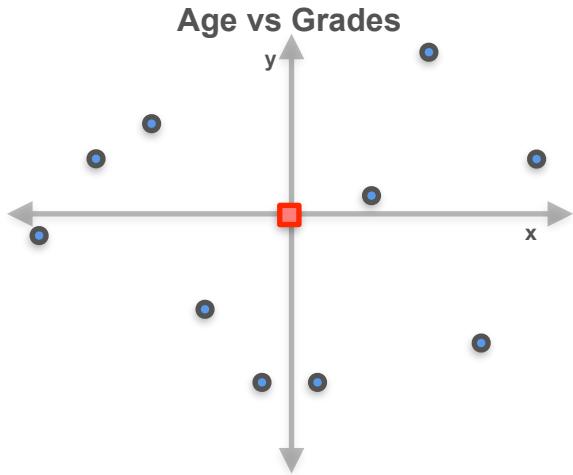
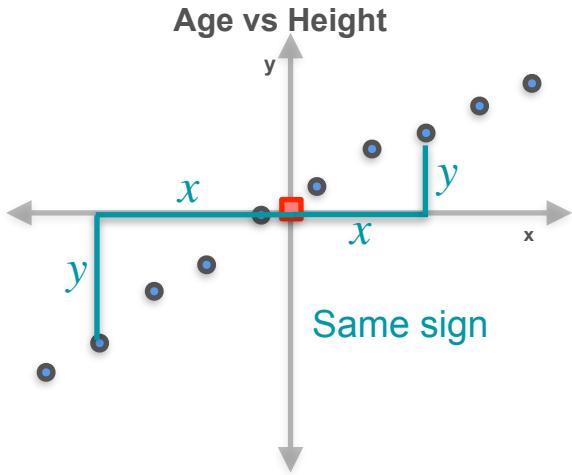
# Positives and Negatives



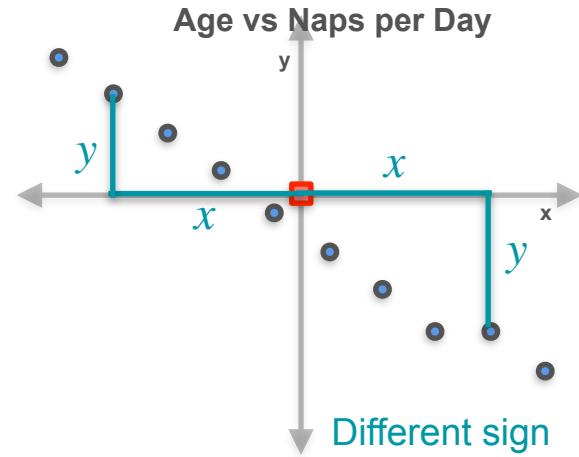
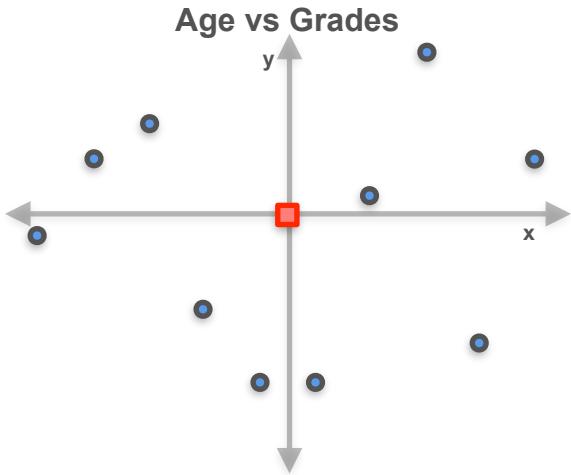
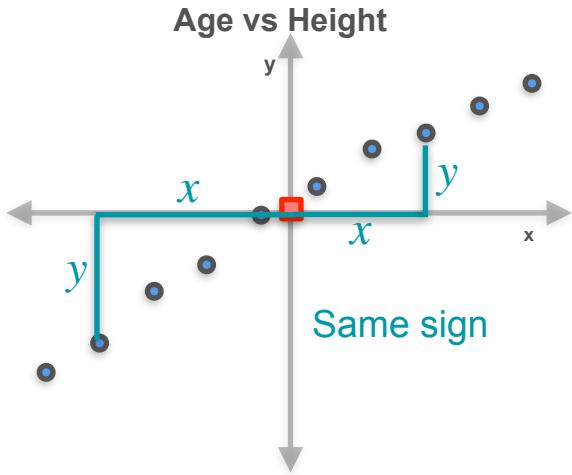
# Positives and Negatives



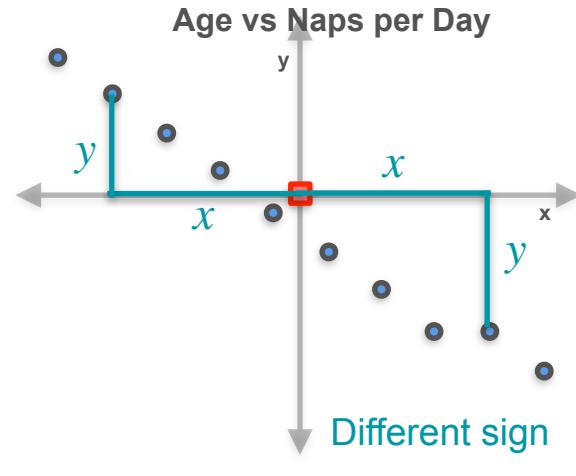
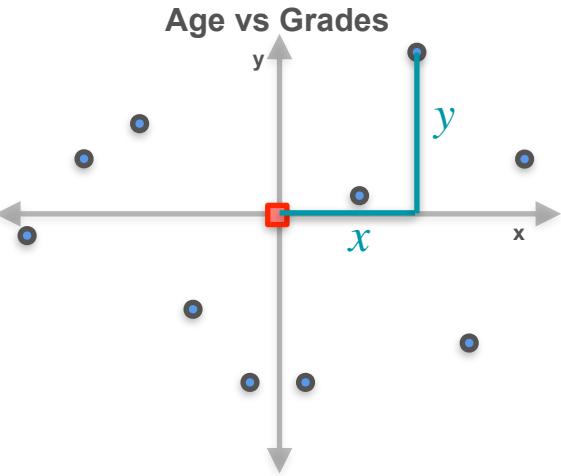
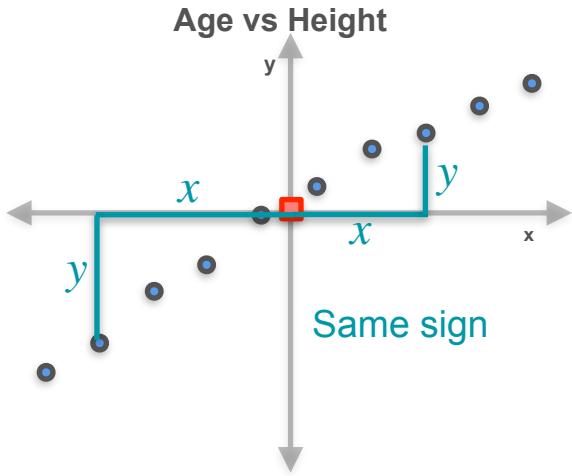
# Positives and Negatives



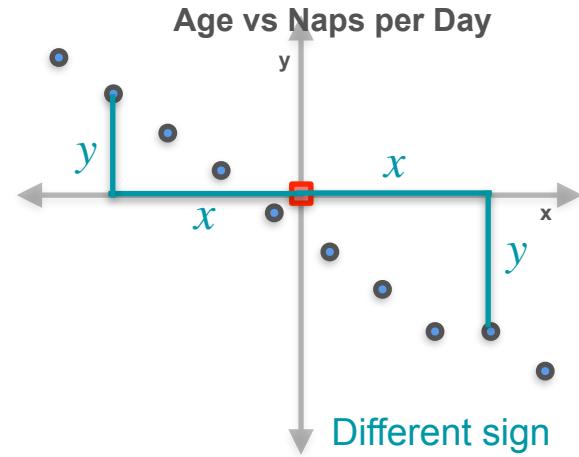
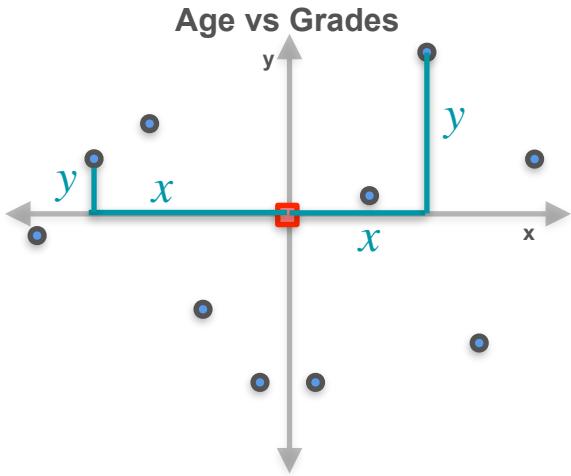
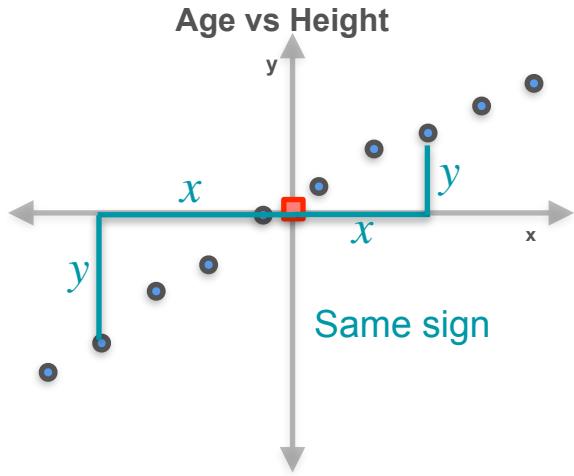
# Positives and Negatives



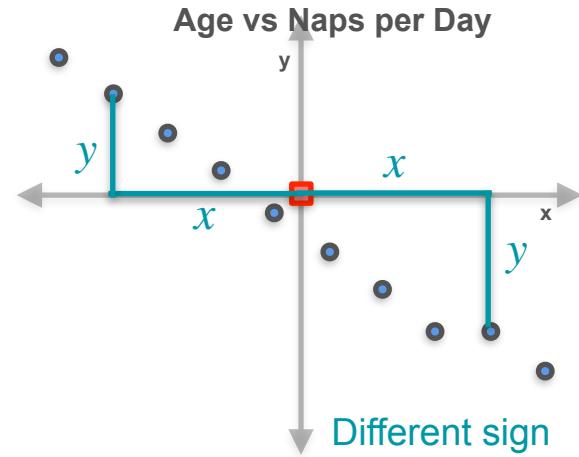
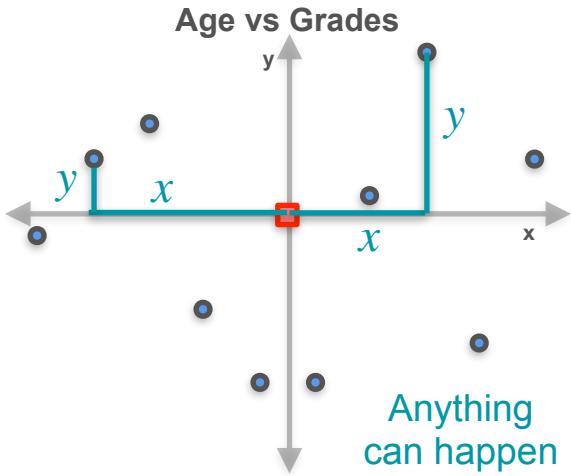
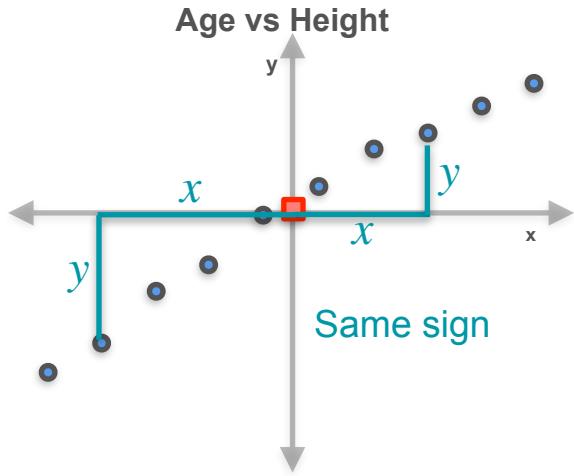
# Positives and Negatives



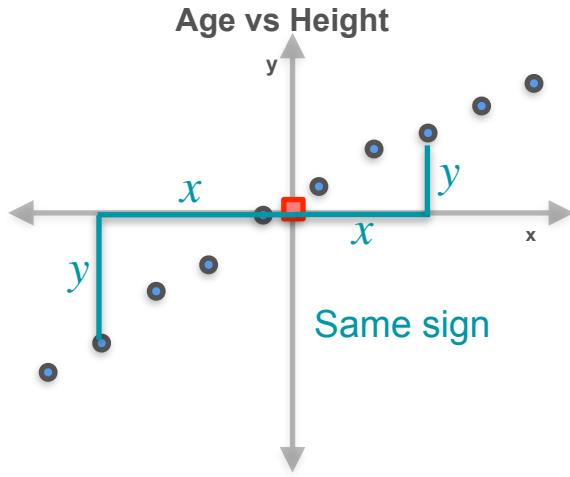
# Positives and Negatives



# Positives and Negatives

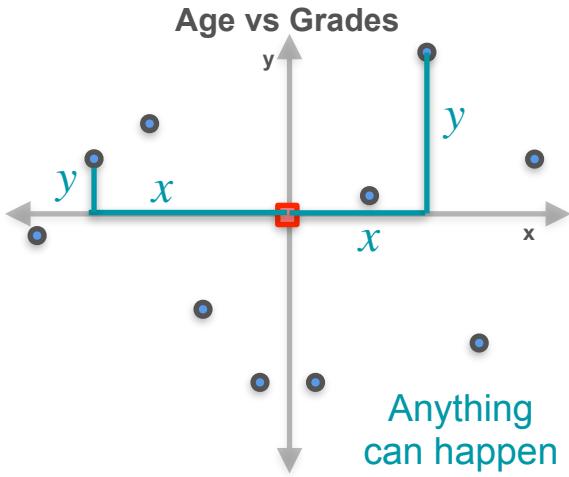


# Positives and Negatives

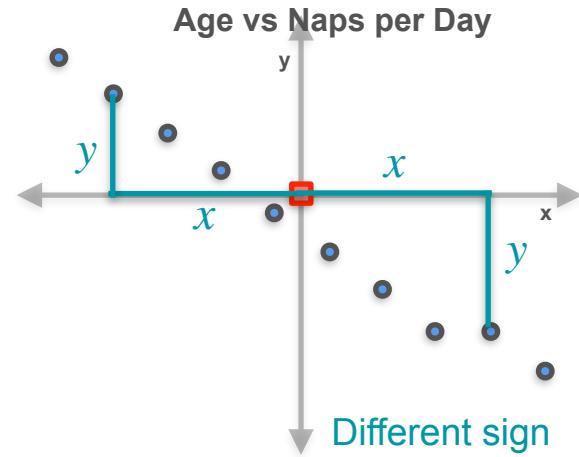


$xy$

Positive

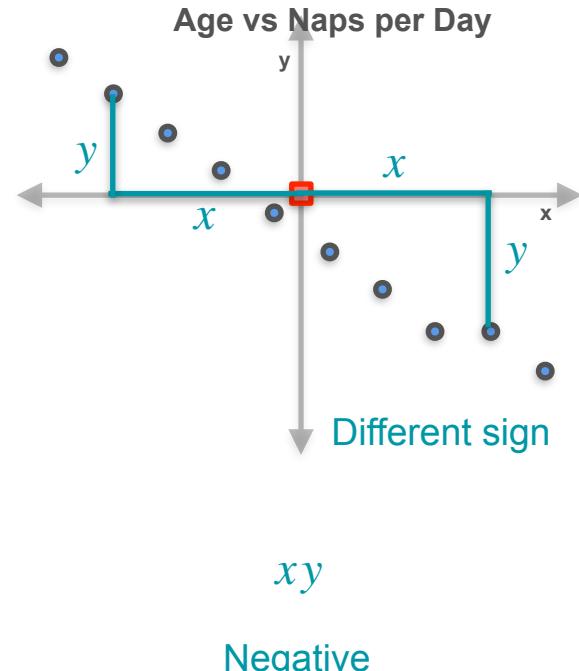
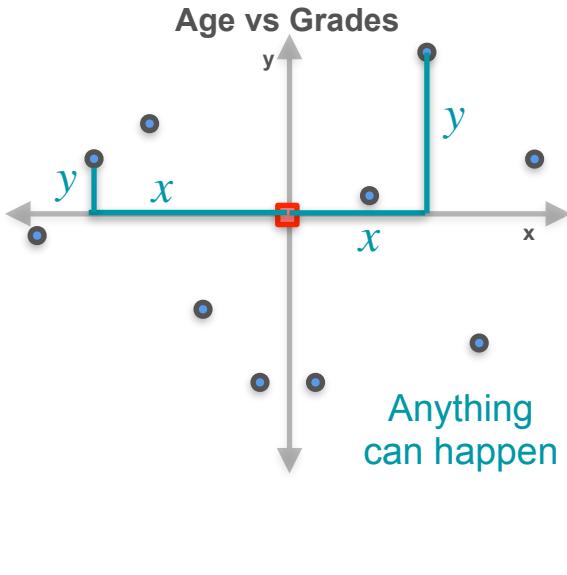
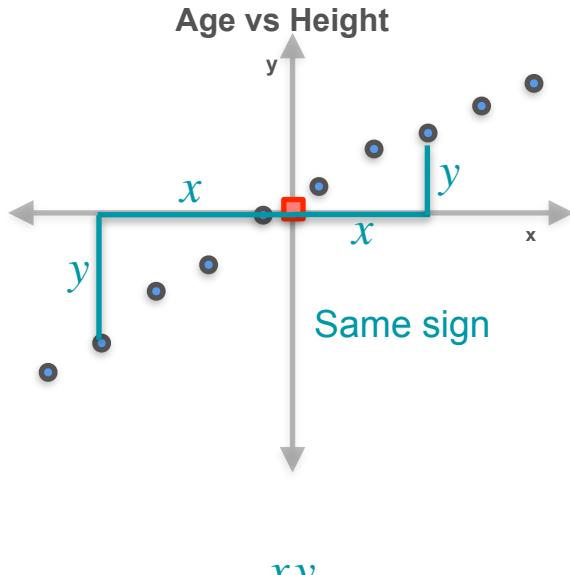


Anything  
can happen

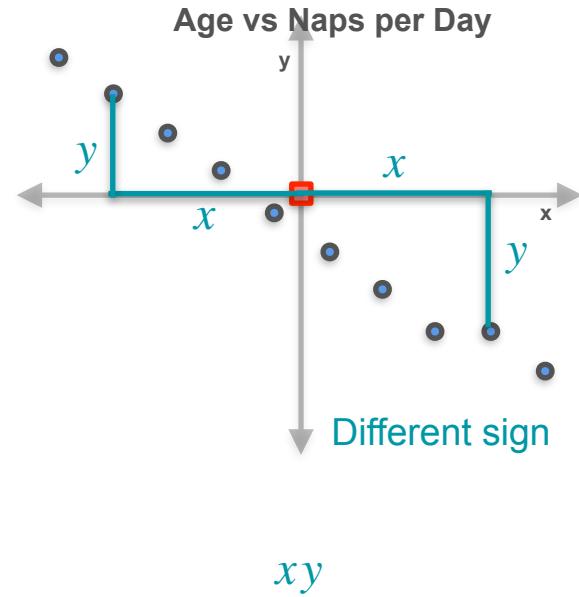
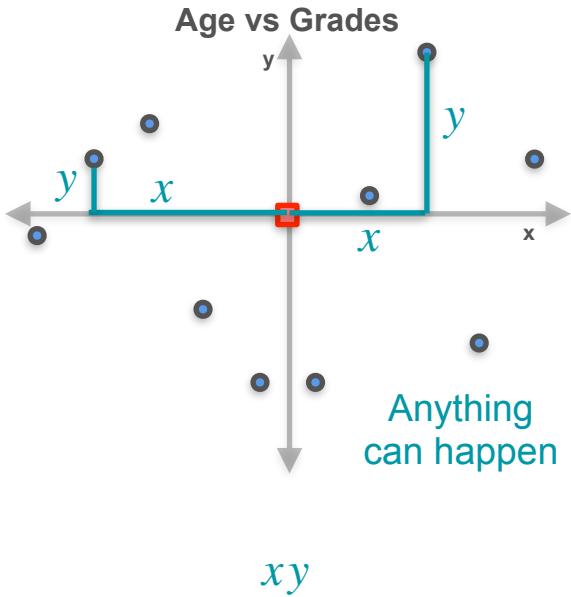
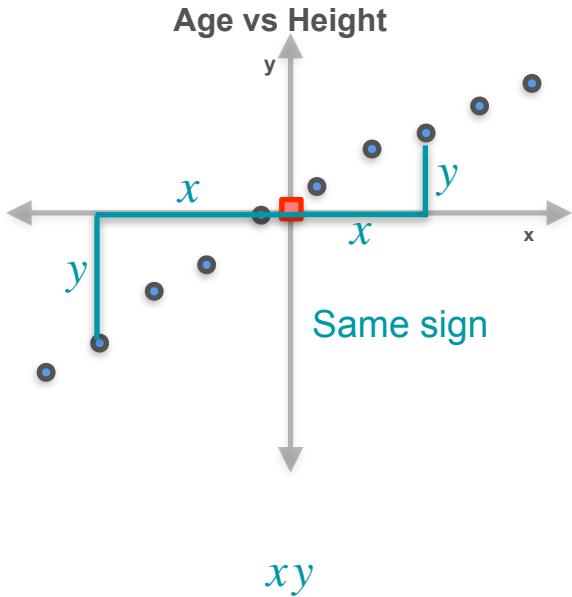


Different sign

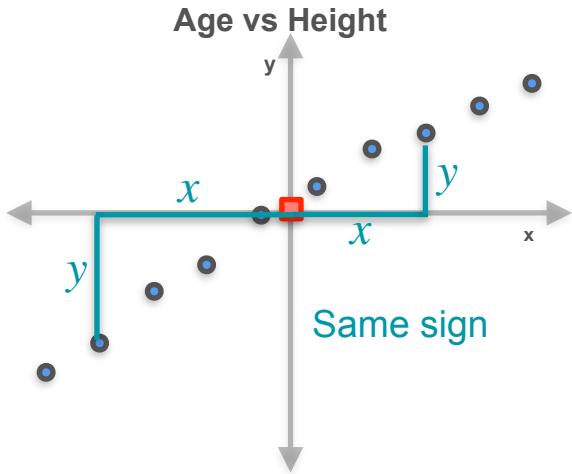
# Positives and Negatives



# Positives and Negatives

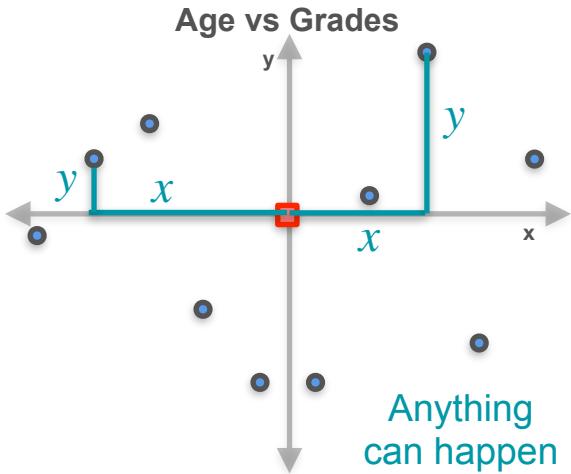


# Positives and Negatives



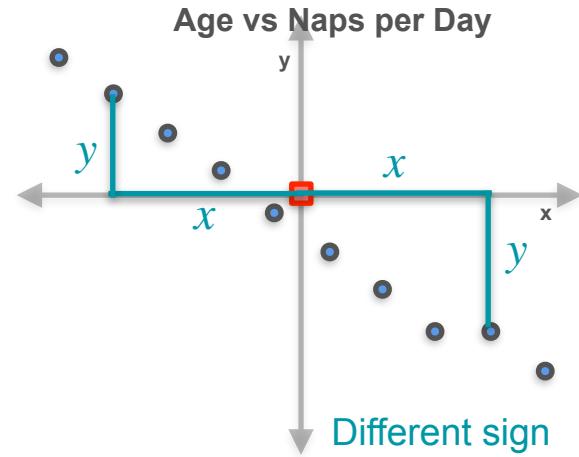
$$\sum xy$$

Positive



$$\sum xy$$

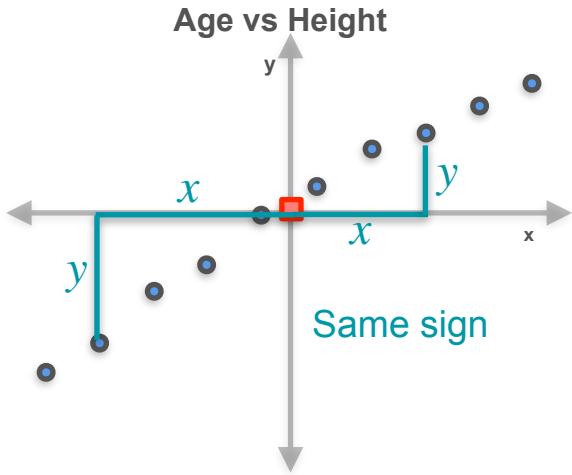
Both positive  
and negative



$$\sum xy$$

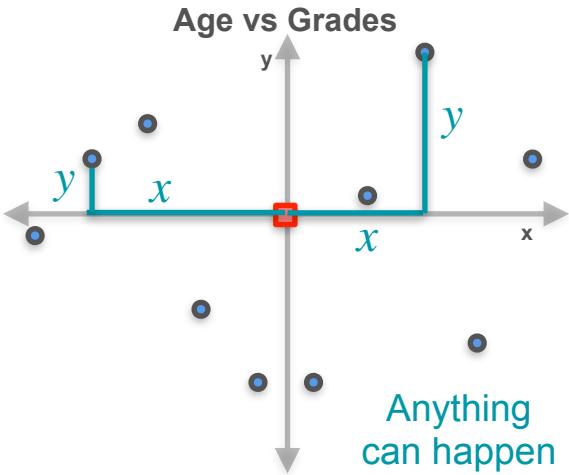
Negative

# Positives and Negatives



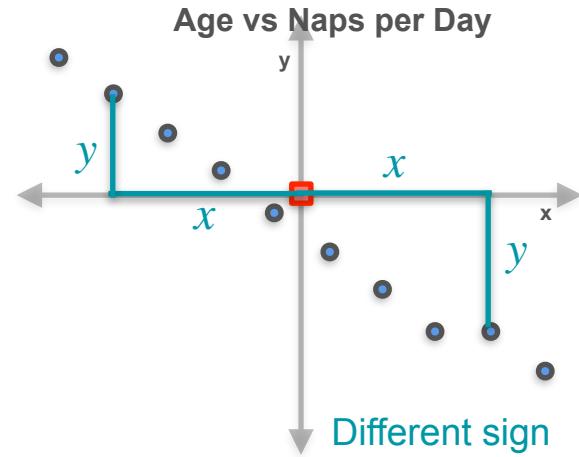
$$\sum xy > 0$$

Positive



$$\sum xy$$

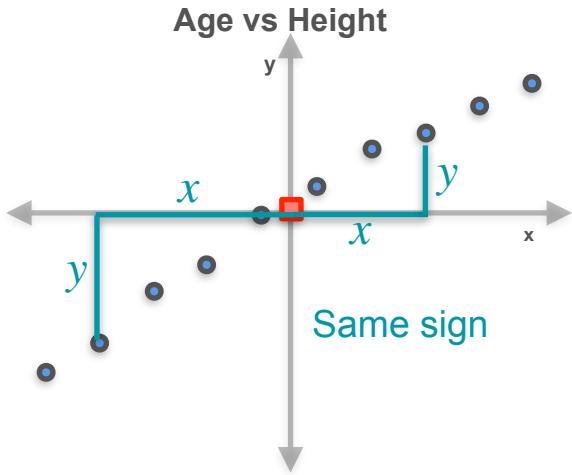
Both positive  
and negative



$$\sum xy$$

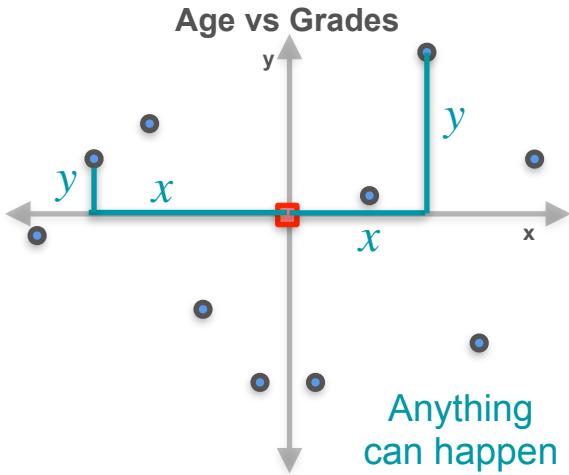
Negative

# Positives and Negatives



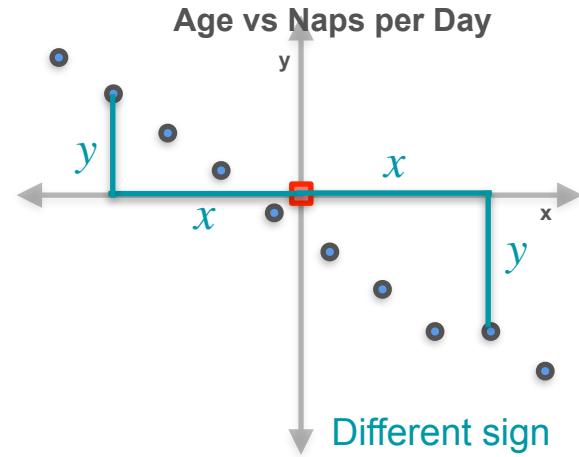
$$\sum xy > 0$$

Positive



$$\sum xy$$

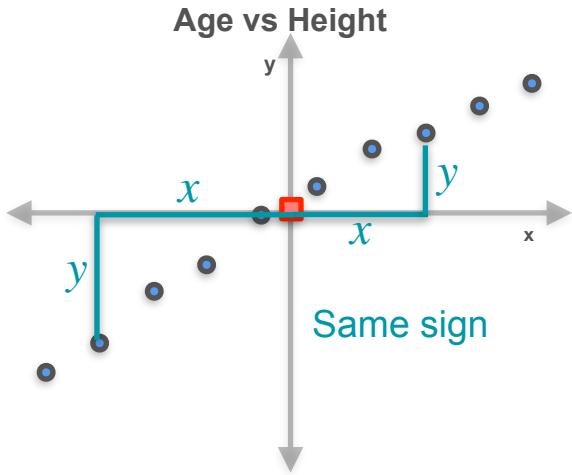
Both positive  
and negative



$$\sum xy < 0$$

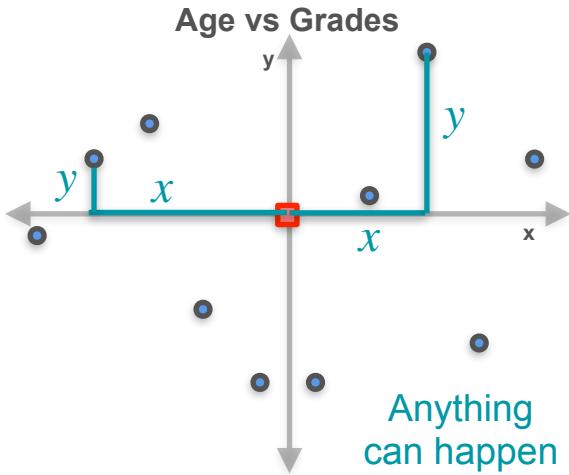
Negative

# Positives and Negatives



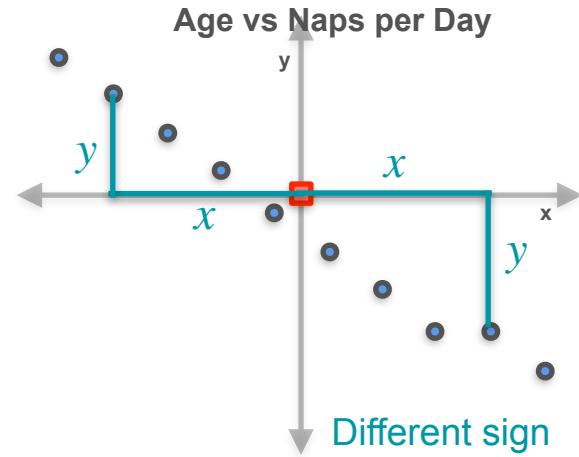
$$\sum xy > 0$$

Positive



$$\sum xy \approx 0$$

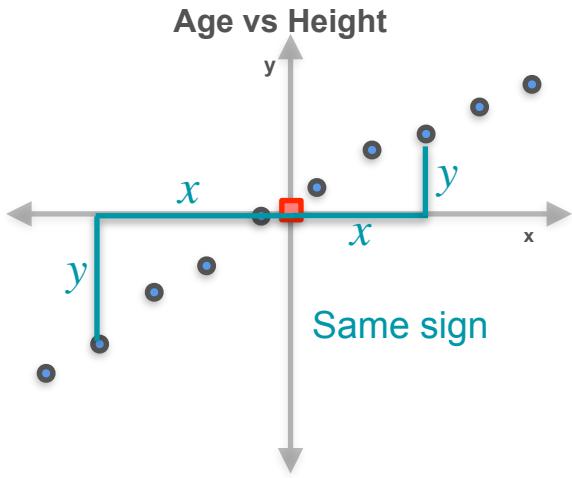
Both positive  
and negative



$$\sum xy < 0$$

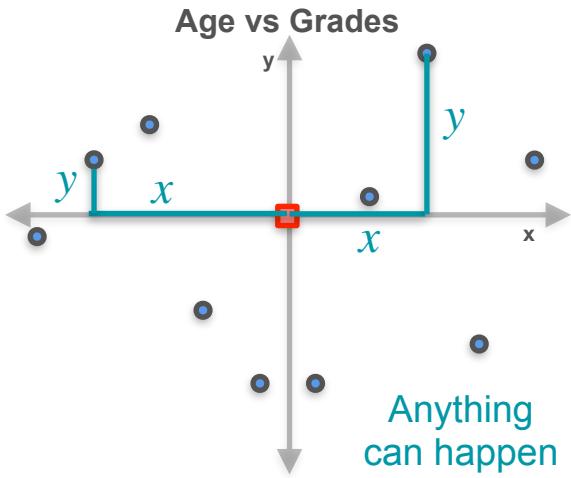
Negative

# Covariance



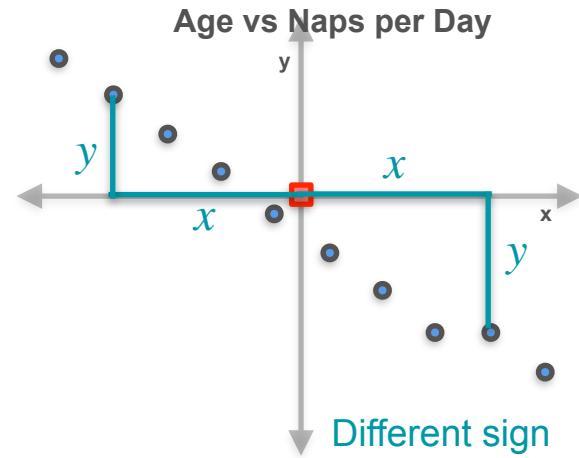
$$\sum xy > 0$$

Positive



$$\sum xy \approx 0$$

Both positive  
and negative



$$\sum xy < 0$$

Negative

# Covariance

# Covariance

$$Cov(X, Y) = \sum xy$$

# Covariance

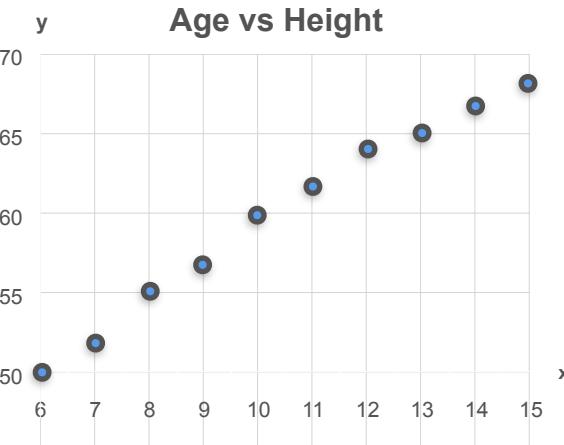
$$Cov(X, Y) = \sum xy \quad \text{Almost...}$$

# Covariance

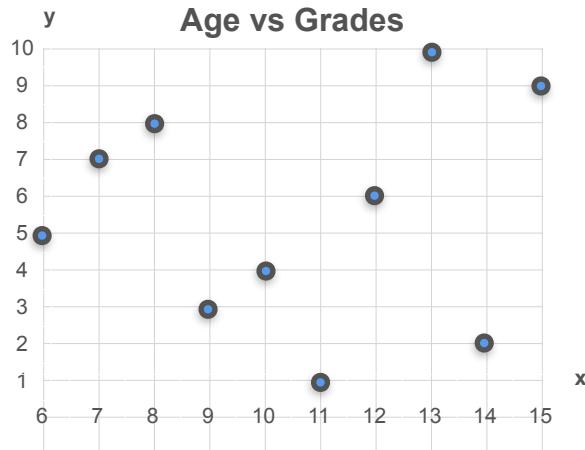
$$Cov(X, Y) = \sum xy \quad \text{Almost...}$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

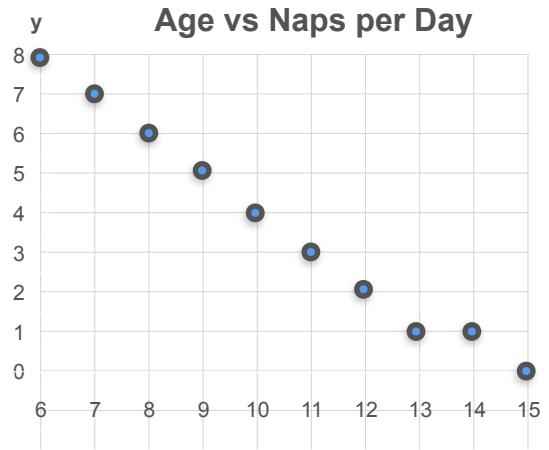
# Covariance



$$\text{Cov}(X, Y) > 0$$



$$\text{Cov}(X, Y) \approx 0$$



$$\text{Cov}(X, Y) < 0$$

# Covariance Formula

# Covariance Formula

Age vs Height

# Covariance Formula

**Age vs Height**

Covariance > 0

# Covariance Formula

**Age vs Height**

Covariance > 0

$$\mu_x = 10.5$$

# Covariance Formula

**Age vs Height**

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

Age (x)	Height (y)
6	50
7	52
8	55
9	57
10	60
11	62
12	64
13	65
14	67
15	68

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

Age (x)	Height (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	50	-4.5	-10	
7	52	-3.5	-8	
8	55	-2.5	-5	
9	57	-1.5	-3	
10	60	-0.5	0	
11	62	0.5	2	
12	64	1.5	4	
13	65	2.5	5	
14	67	3.5	7	
15	68	4.5	8	

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

Age (x)	Height (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	50	-4.5	-10	45
7	52	-3.5	-8	28
8	55	-2.5	-5	12.5
9	57	-1.5	-3	4.5
10	60	-0.5	0	0
11	62	0.5	2	1
12	64	1.5	4	6
13	65	2.5	5	12.5
14	67	3.5	7	24.5
15	68	4.5	8	36

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

Age (x)	Height (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	50	-4.5	-10	45
7	52	-3.5	-8	28
8	55	-2.5	-5	12.5
9	57	-1.5	-3	4.5
10	60	-0.5	0	0
11	62	0.5	2	1
12	64	1.5	4	6
13	65	2.5	5	12.5
14	67	3.5	7	24.5
15	68	4.5	8	36

$$\sum = 170$$

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

Age (x)	Height (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	50	-4.5	-10	45
7	52	-3.5	-8	28
8	55	-2.5	-5	12.5
9	57	-1.5	-3	4.5
10	60	-0.5	0	0
11	62	0.5	2	1
12	64	1.5	4	6
13	65	2.5	5	12.5
14	67	3.5	7	24.5
15	68	4.5	8	36

$$\sum = 170$$

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{170}{10}$$

Age (x)	Height (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	50	-4.5	-10	45
7	52	-3.5	-8	28
8	55	-2.5	-5	12.5
9	57	-1.5	-3	4.5
10	60	-0.5	0	0
11	62	0.5	2	1
12	64	1.5	4	6
13	65	2.5	5	12.5
14	67	3.5	7	24.5
15	68	4.5	8	36

$$\sum = 170$$

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{170}{10} = 17$$

Age (x)	Height (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	50	-4.5	-10	45
7	52	-3.5	-8	28
8	55	-2.5	-5	12.5
9	57	-1.5	-3	4.5
10	60	-0.5	0	0
11	62	0.5	2	1
12	64	1.5	4	6
13	65	2.5	5	12.5
14	67	3.5	7	24.5
15	68	4.5	8	36

$$\sum = 170$$

# Covariance Formula

Age vs Height

Covariance > 0

$$\mu_x = 10.5 \quad \mu_y = 60$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{170}{10} = 17 > 0$$

Age (x)	Height (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	50	-4.5	-10	45
7	52	-3.5	-8	28
8	55	-2.5	-5	12.5
9	57	-1.5	-3	4.5
10	60	-0.5	0	0
11	62	0.5	2	1
12	64	1.5	4	6
13	65	2.5	5	12.5
14	67	3.5	7	24.5
15	68	4.5	8	36

$$\sum = 170$$

# Covariance Formula

# Covariance Formula

Age vs Naps per Day

# Covariance Formula

Age vs Naps per Day

Covariance < 0

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5$$

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

Age (x)
6
7
8
9
10
11
12
13
14
15

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

Age (x)	Naps (y)
6	8
7	7
8	6
9	5
10	4
11	3
12	2
13	1
14	1
15	0

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

Age (x)	Naps (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	8	-4.5	4.3	-19.35
7	7	-3.5	3.3	-11.55
8	6	-2.5	2.3	-5.75
9	5	-1.5	1.3	-1.95
10	4	-0.5	0.3	-0.15
11	3	0.5	-0.7	-0.35
12	2	1.5	-1.7	-2.55
13	1	2.5	-2.7	-6.75
14	1	3.5	-2.7	-9.45
15	0	4.5	-3.7	-16.65

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

Age (x)	Naps (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	8	-4.5	4.3	-19.35
7	7	-3.5	3.3	-11.55
8	6	-2.5	2.3	-5.75
9	5	-1.5	1.3	-1.95
10	4	-0.5	0.3	-0.15
11	3	0.5	-0.7	-0.35
12	2	1.5	-1.7	-2.55
13	1	2.5	-2.7	-6.75
14	1	3.5	-2.7	-9.45
15	0	4.5	-3.7	-16.65

$$\sum = -74.5$$

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{-74.5}{10}$$

Age (x)	Naps (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	8	-4.5	4.3	-19.35
7	7	-3.5	3.3	-11.55
8	6	-2.5	2.3	-5.75
9	5	-1.5	1.3	-1.95
10	4	-0.5	0.3	-0.15
11	3	0.5	-0.7	-0.35
12	2	1.5	-1.7	-2.55
13	1	2.5	-2.7	-6.75
14	1	3.5	-2.7	-9.45
15	0	4.5	-3.7	-16.65

$$\sum = -74.5$$

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{-74.5}{10} = -7.45$$

Age (x)	Naps (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	8	-4.5	4.3	-19.35
7	7	-3.5	3.3	-11.55
8	6	-2.5	2.3	-5.75
9	5	-1.5	1.3	-1.95
10	4	-0.5	0.3	-0.15
11	3	0.5	-0.7	-0.35
12	2	1.5	-1.7	-2.55
13	1	2.5	-2.7	-6.75
14	1	3.5	-2.7	-9.45
15	0	4.5	-3.7	-16.65

$$\sum = -74.5$$

# Covariance Formula

Age vs Naps per Day

Covariance < 0

$$\mu_x = 10.5 \quad \mu_y = 3.7$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{-74.5}{10} = -7.45 < 0$$

Age (x)	Naps (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	8	-4.5	4.3	-19.35
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10	4	-0.5	0.3	-0.15
11	3	0.5	-0.7	-0.35
12	2	1.5	-1.7	-2.55
13	1	2.5	-2.7	-6.75
14	1	3.5	-2.7	-9.45
15	0	4.5	-3.7	-16.65

$$\sum = -74.5$$

# Covariance Formula

$$(x_i - \mu_x)$$

# Covariance Formula

Age vs Grades

Covariance  $\approx 0$

$$\mu_x = 10.5 \quad \mu_y = 5$$

Age (x)	Grades (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	5	-4.5	0	0
7	7	-3.5	2	-7
8	8	-2.5	3	-7.5
9	3	-1.5	-2	3
10	1	-0.5	-4	2
11	1	0.5	-4	-2
12	6	1.5	1	1.5
13	10	2.5	5	12.5
14	2	3.5	-3	-10.5
15	7	4.5	2	9

# Covariance Formula

Age vs Grades

Covariance  $\approx 0$

$$\mu_x = 10.5 \quad \mu_y = 5$$

Age (x)	Grades (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	5	-4.5	0	0
7	7	-3.5	2	-7
8	8	-2.5	3	-7.5
9	3	-1.5	-2	3
10	1	-0.5	-4	2
11	1	0.5	-4	-2
12	6	1.5	1	1.5
13	10	2.5	5	12.5
14	2	3.5	-3	-10.5
15	7	4.5	2	9

$$\sum = 1$$

# Covariance Formula

Age vs Grades

Covariance  $\approx 0$

$$\mu_x = 10.5 \quad \mu_y = 5$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

Age (x)	Grades (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	5	-4.5	0	0
7	7	-3.5	2	-7
8	8	-2.5	3	-7.5
9	3	-1.5	-2	3
10	1	-0.5	-4	2
11	1	0.5	-4	-2
12	6	1.5	1	1.5
13	10	2.5	5	12.5
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$$\sum = 1$$

# Covariance Formula

Age vs Grades

Covariance  $\approx 0$

$$\mu_x = 10.5 \quad \mu_y = 5$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{1}{10}$$

Age (x)	Grades (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	5	-4.5	0	0
7	7	-3.5	2	-7
8	8	-2.5	3	-7.5
9	3	-1.5	-2	3
10	1	-0.5	-4	2
11	1	0.5	-4	-2
12	6	1.5	1	1.5
13	10	2.5	5	12.5
14	2	3.5	-3	-10.5
15	7	4.5	2	9

$$\sum = 1$$

# Covariance Formula

Age vs Grades

Covariance  $\approx 0$

$$\mu_x = 10.5 \quad \mu_y = 5$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$Cov(X, Y) = \frac{1}{10} = 0.1$$

Age (x)	Grades (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	5	-4.5	0	0
7	7	-3.5	2	-7
8	8	-2.5	3	-7.5
9	3	-1.5	-2	3
10	1	-0.5	-4	2
11	1	0.5	-4	-2
12	6	1.5	1	1.5
13	10	2.5	5	12.5
14	2	3.5	-3	-10.5
15	7	4.5	2	9

$$\sum = 1$$

# Covariance Formula

Age vs Grades

Covariance  $\approx 0$

$$\mu_x = 10.5 \quad \mu_y = 5$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

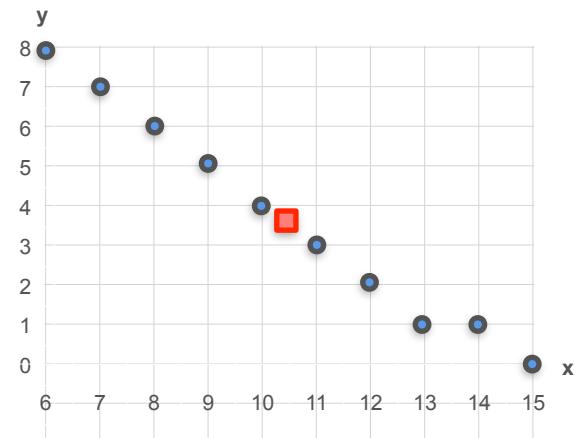
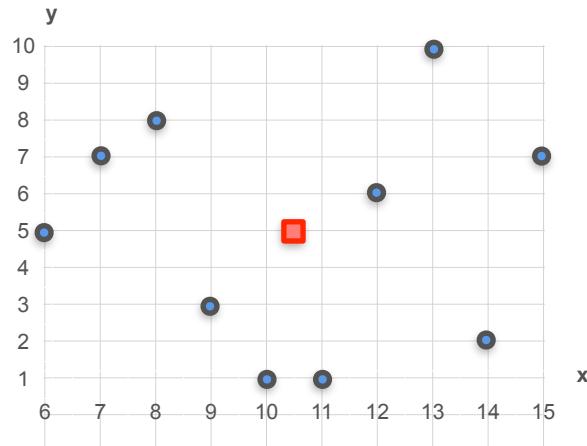
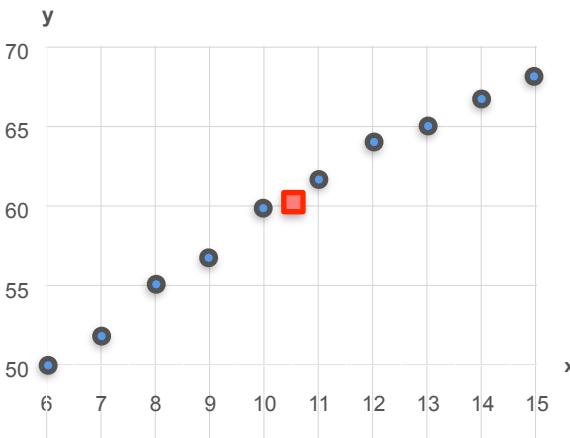
$$Cov(X, Y) = \frac{1}{10} = 0.1 \quad \approx 0$$

Age (x)	Grades (y)	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
6	5	-4.5	0	0
7	7	-3.5	2	-7
8	8	-2.5	3	-7.5
9	3	-1.5	-2	3
10	1	-0.5	-4	2
11	1	0.5	-4	-2
12	6	1.5	1	1.5
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15	7	4.5	2	9

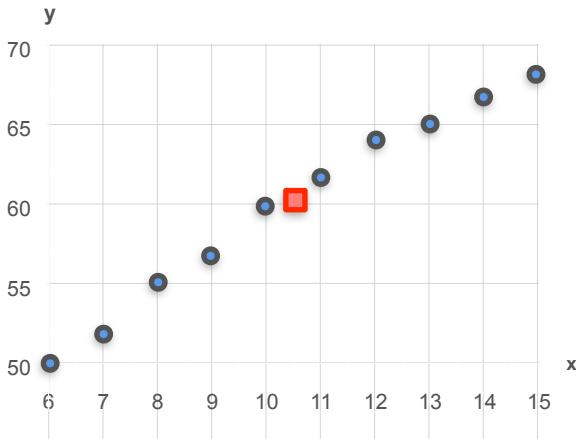
$$\sum = 1$$

# Comparing Correlations

# Comparing Correlations



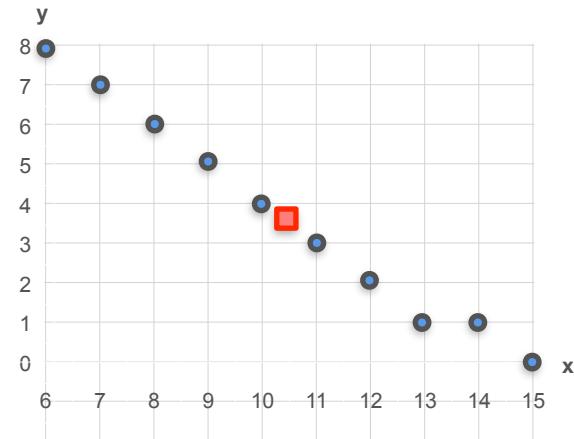
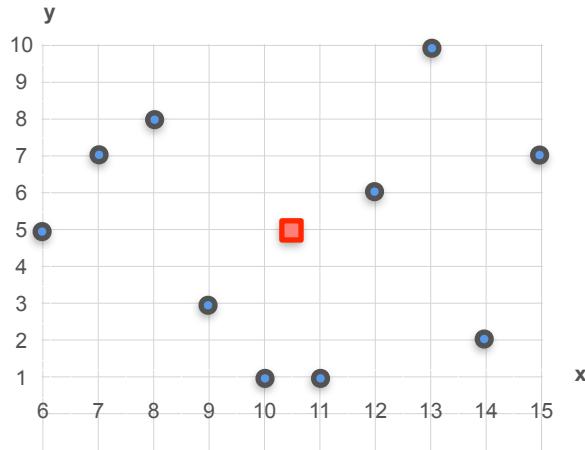
# Comparing Correlations



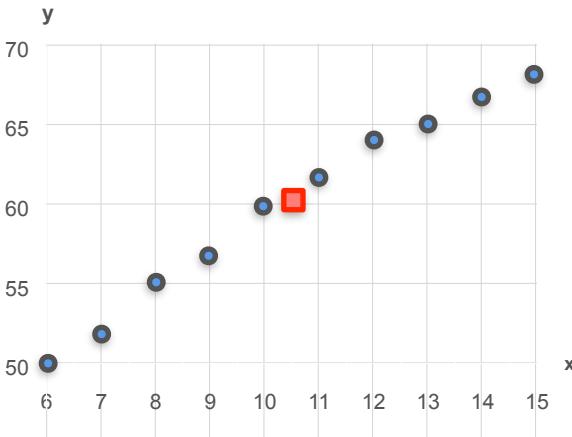
Age vs Height

Covariance > 0

$$Cov(x, y) = 17$$



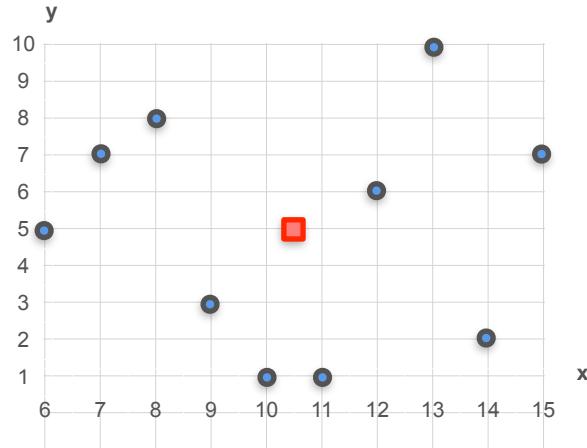
# Comparing Correlations



Age vs Height

Covariance > 0

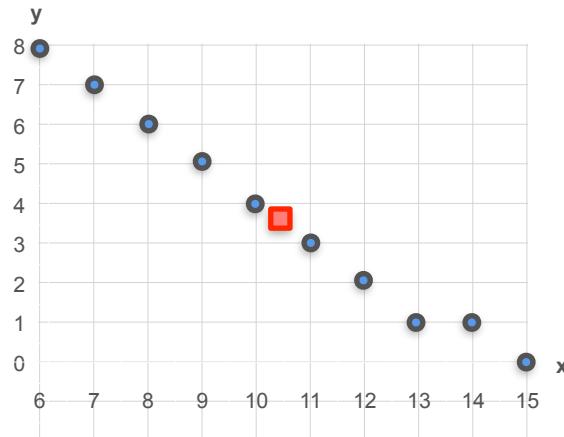
$$Cov(x, y) = 17$$



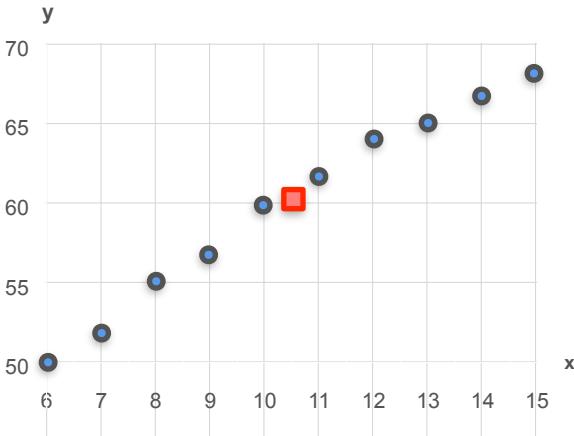
Age vs Grades

Covariance ≈ 0

$$Cov(x, y) = 0.1$$



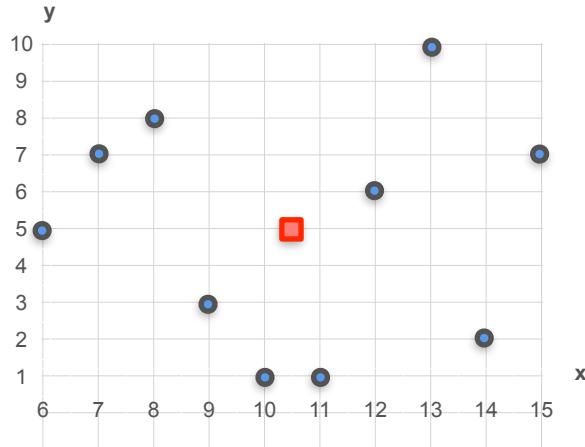
# Comparing Correlations



Age vs Height

Covariance > 0

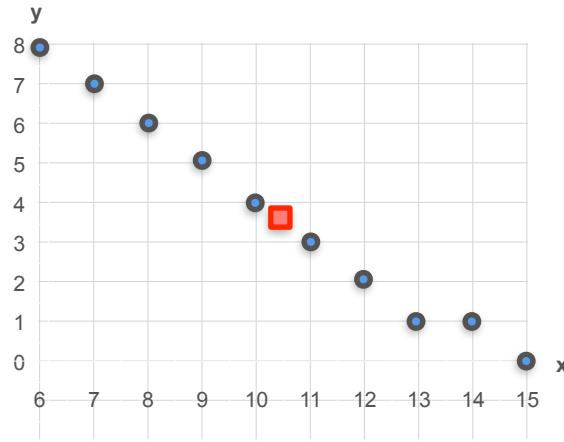
$$Cov(x, y) = 17$$



Age vs Grades

Covariance  $\approx 0$

$$Cov(x, y) = 0.1$$



Age vs Naps per Day

Covariance < 0

$$Cov(x, y) = -7.45$$

# Covariance of a Probability Distribution: Motivation

# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

**GAME 1**

**GAME 2**

**GAME 3**

# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

**GAME 1**

**GAME 2**

**GAME 3**

*a:* Both players win \$1 each

# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

## GAME 1

*a*: Both players win \$1 each

*b*: Both players lose \$1 each

## GAME 2

## GAME 3

# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

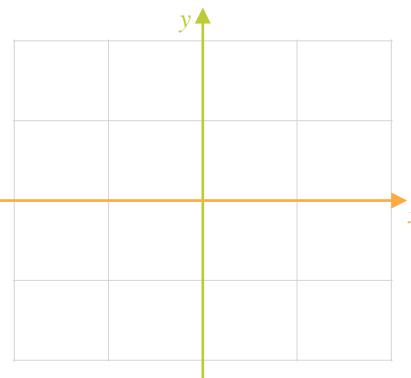
## GAME 1

*a*: Both players win \$1 each

*b*: Both players lose \$1 each

## GAME 2

## GAME 3



# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

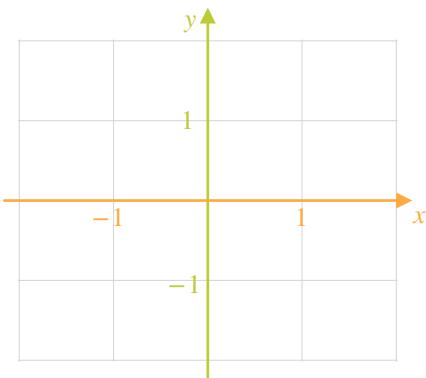
## GAME 1

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

## GAME 2

## GAME 3



# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

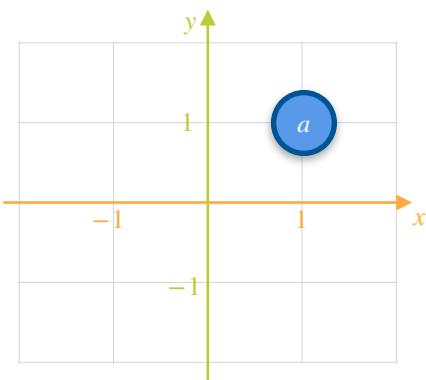
## GAME 1

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

## GAME 2

## GAME 3



# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

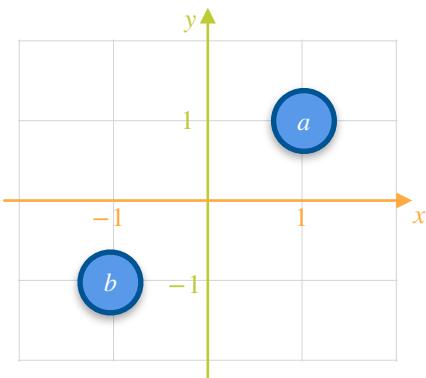
## GAME 1

$a$ : Both players win \$1 each

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## GAME 2

## GAME 3



# Covariance of a Probability Distribution: Motivation

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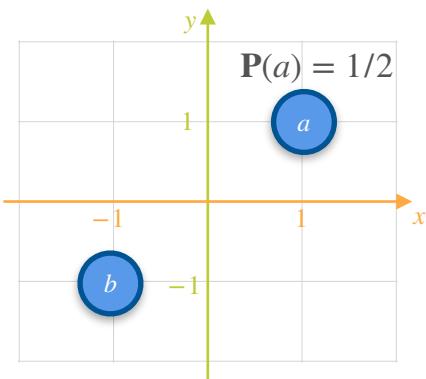
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## GAME 3



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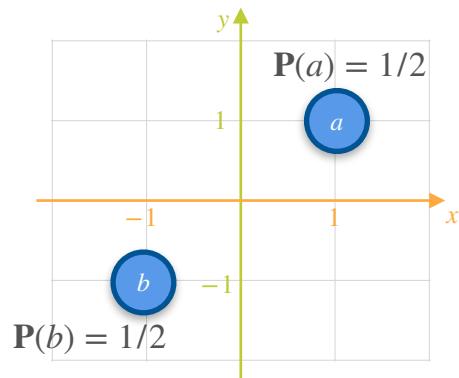
## GAME 1

$a$ : Both players win \$1 each

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## GAME 2

## GAME 3



# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

## GAME 1

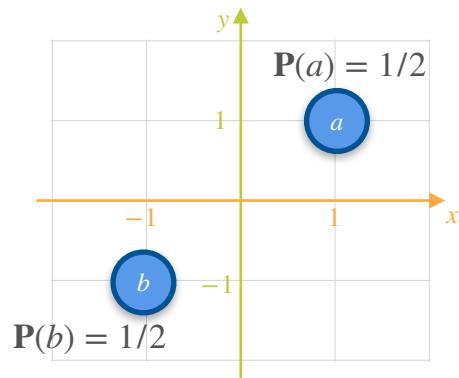
a: Both players win \$1 each

b: Both players lose \$1 each

## GAME 2

c: X wins \$1 and Y loses \$1

## GAME 3



# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

## GAME 1

a: Both players win \$1 each

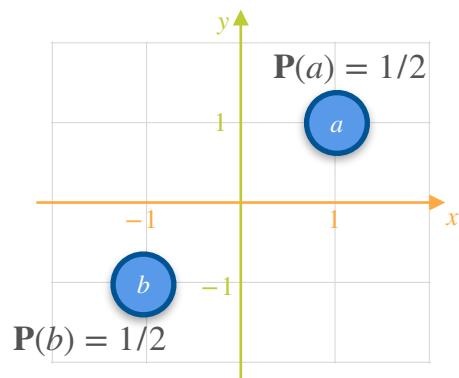
b: Both players lose \$1 each

## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1

## GAME 3



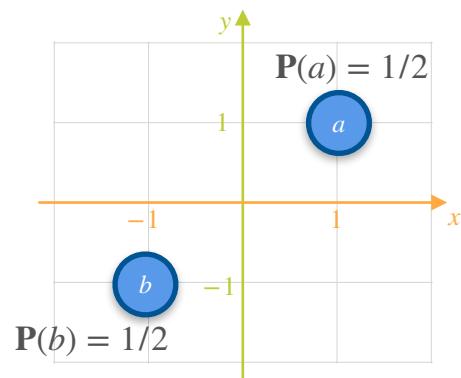
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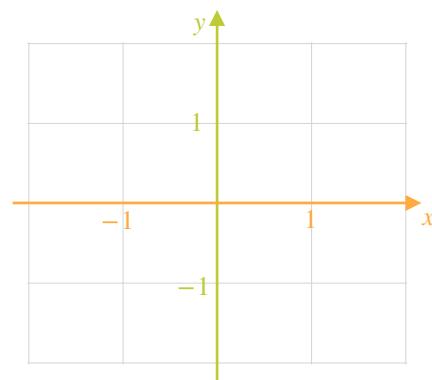
b: Both players lose \$1 each



## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

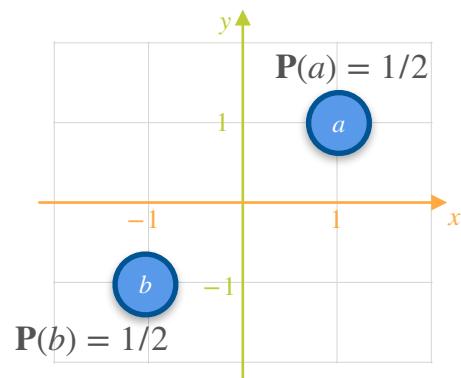
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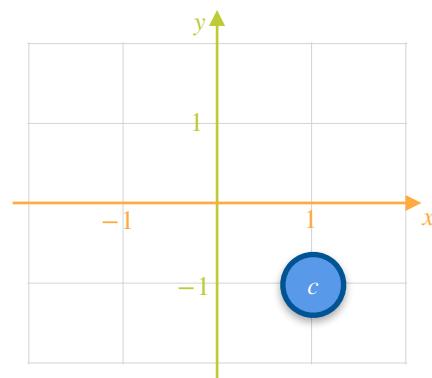
b: Both players lose \$1 each



## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

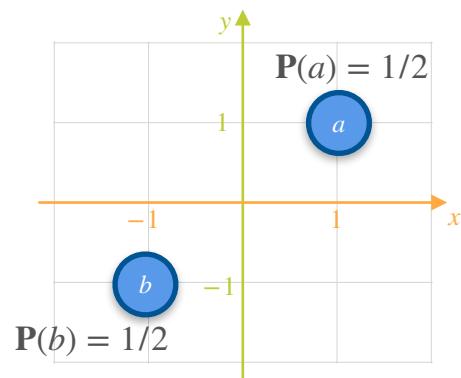
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X and Y are playing 3 games to either win or lose a dollar

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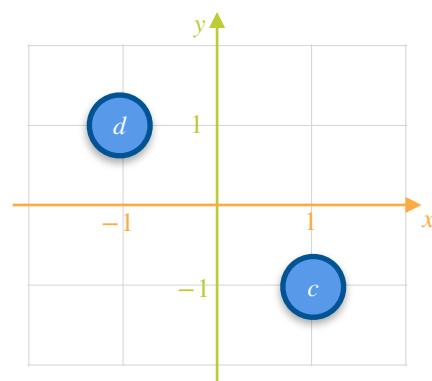
b: Both players lose \$1 each



## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

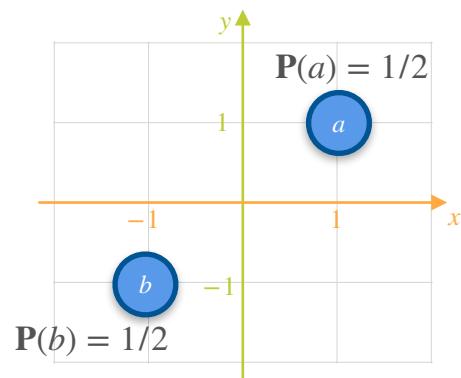
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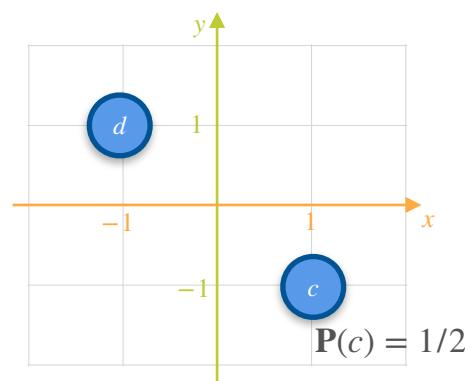
b: Both players lose \$1 each



## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

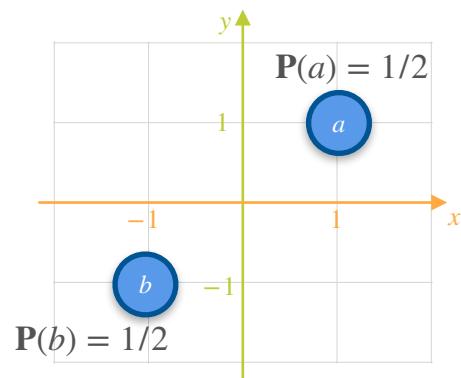
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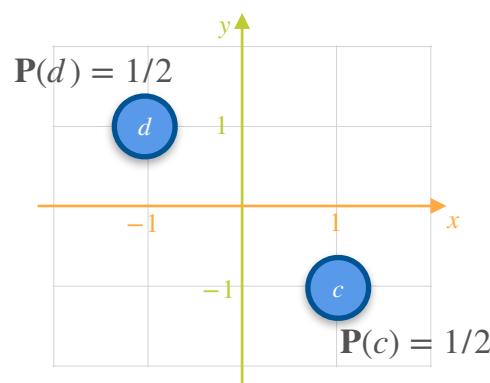
b: Both players lose \$1 each



## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

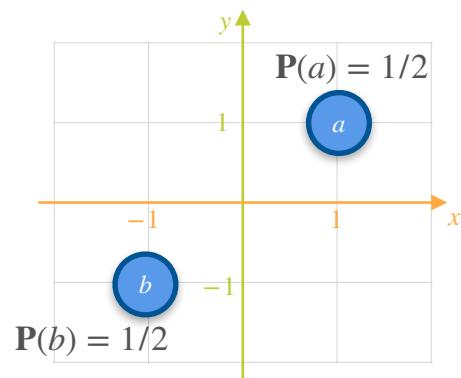
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## GAME 1

a: Both players win \$1 each

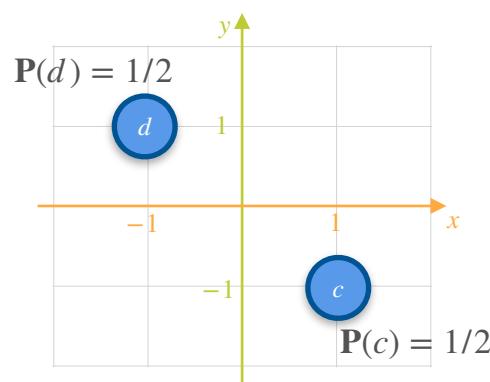
b: Both players lose \$1 each



## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

a, b, c or d

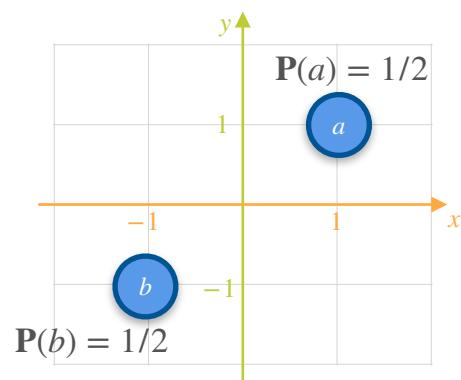
# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

## GAME 1

a: Both players win \$1 each

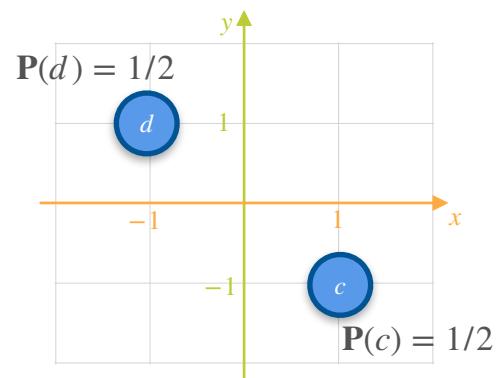
b: Both players lose \$1 each



## GAME 2

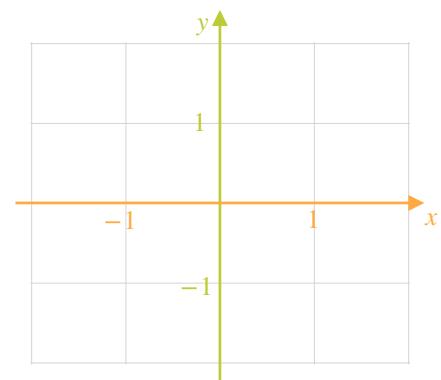
c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

$a, b, c$  or  $d$



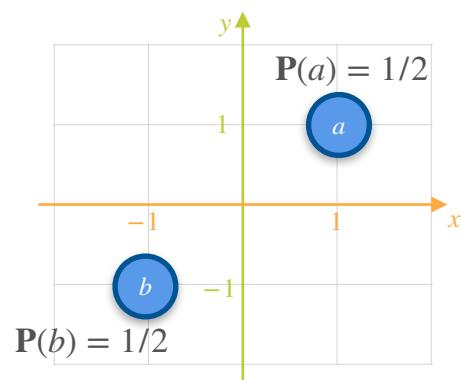
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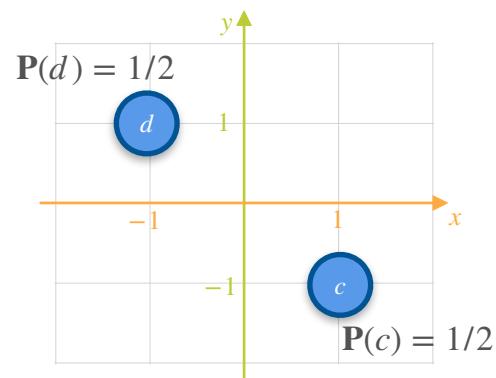
b: Both players lose \$1 each



## GAME 2

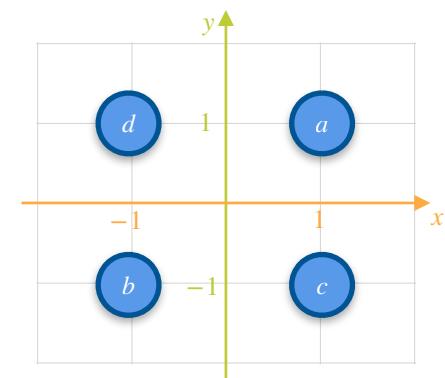
c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

a, b, c or d



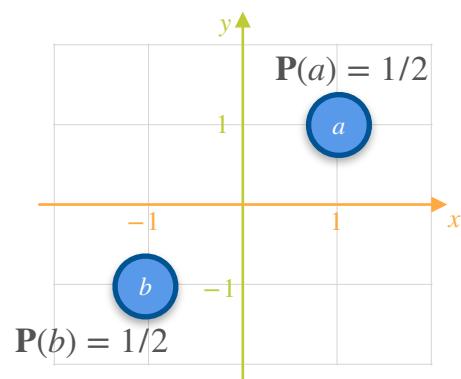
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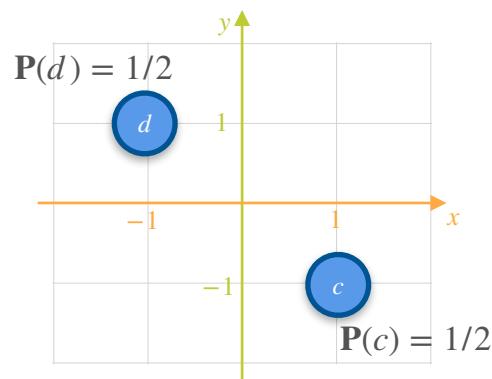
b: Both players lose \$1 each



## GAME 2

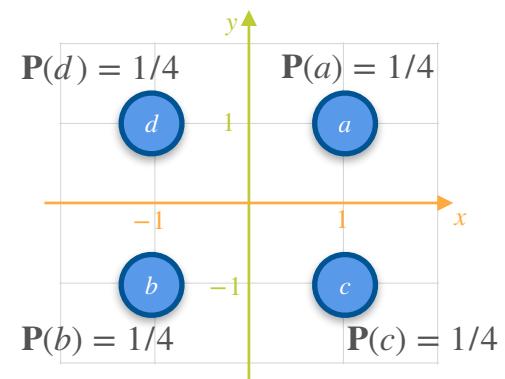
c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1



## GAME 3

a, b, c or d



# Covariance of a Probability Distribution: Motivation

X and Y are playing 3 games to either win or lose a dollar

## GAME 1

a: Both players win \$1 each

b: Both players lose \$1 each

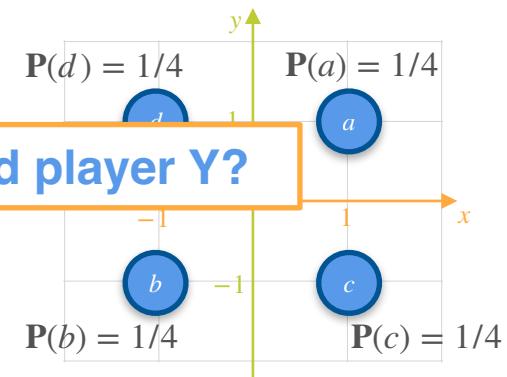
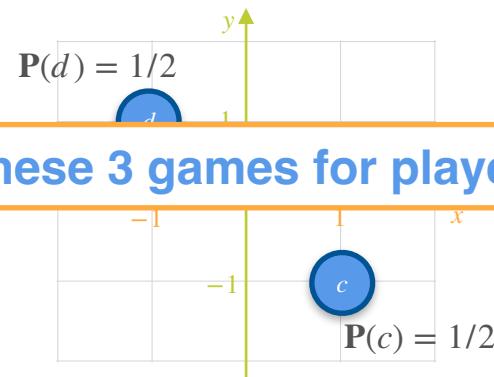
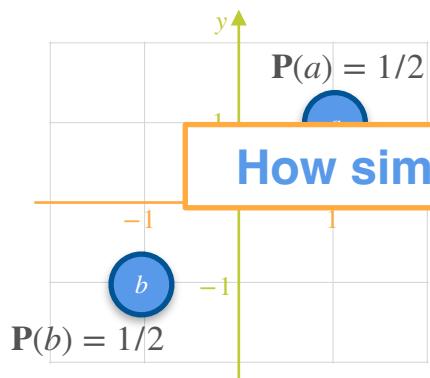
## GAME 2

c: X wins \$1 and Y loses \$1

d: X loses \$1 and Y win \$1

## GAME 3

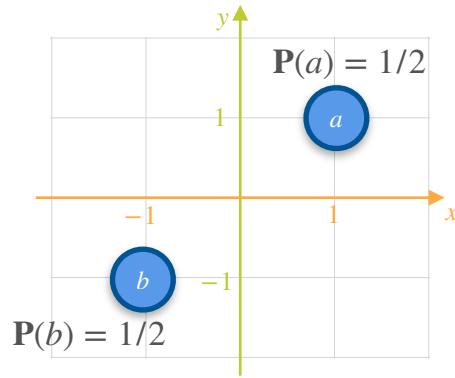
a, b, c or d



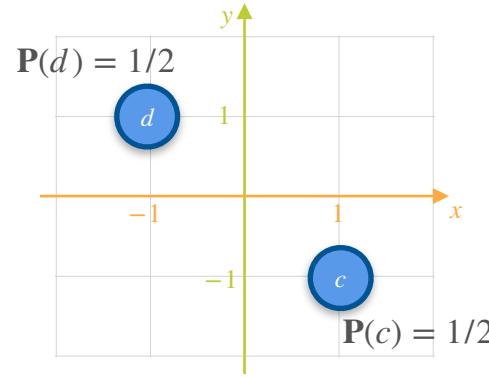
How similar are these 3 games for player X and player Y?

# Covariance of a Probability Distribution: Motivation

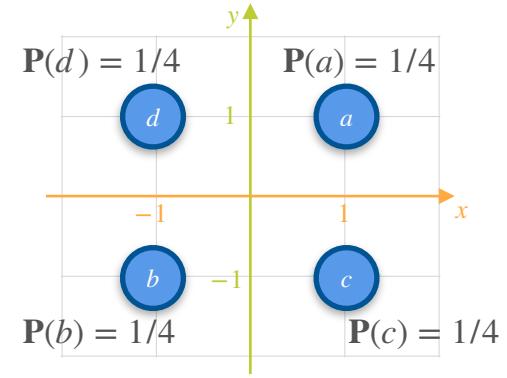
GAME 1



GAME 2



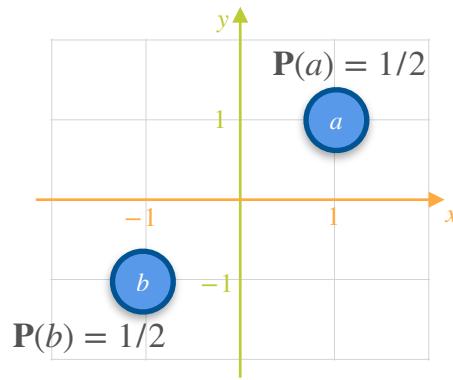
GAME 3



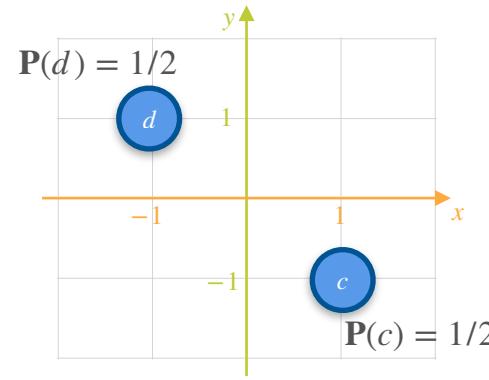
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# Covariance of a Probability Distribution: Motivation

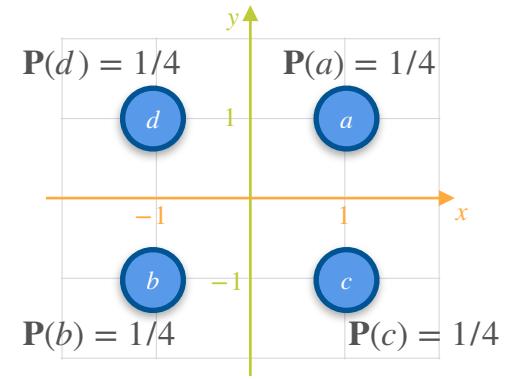
GAME 1



GAME 2



GAME 3

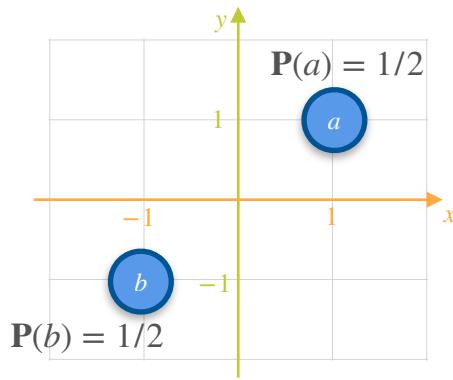


How similar are these 3 games for player X and player Y?

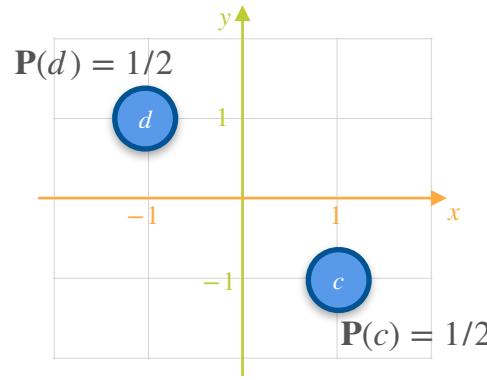
$X$  : how much money in dollars player X wins

# Covariance of a Probability Distribution: Motivation

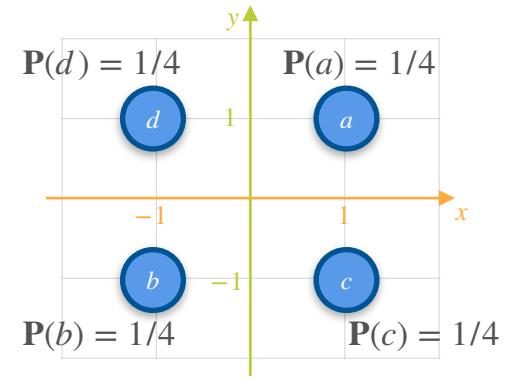
GAME 1



GAME 2



GAME 3



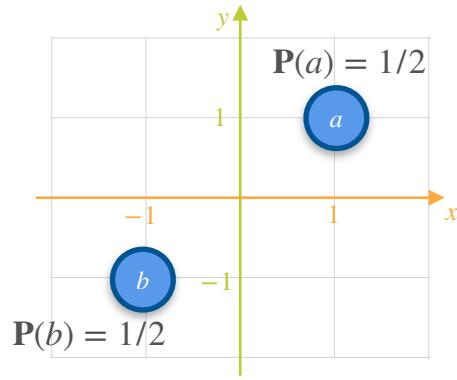
How similar are these 3 games for player X and player Y?

$X$  : how much money in dollars player X wins

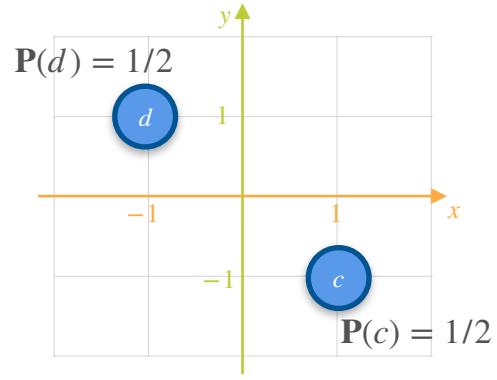
$Y$  : how much money in dollars player Y wins

# Covariance of a Probability Distribution: Motivation

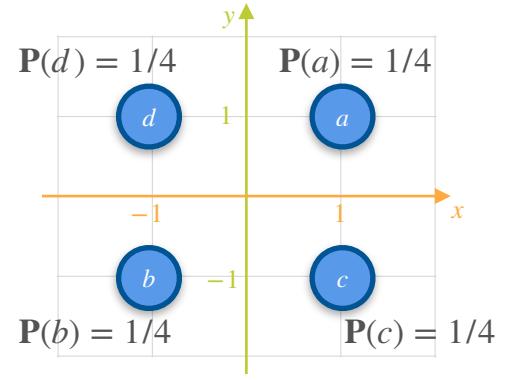
**GAME 1**



**GAME 2**

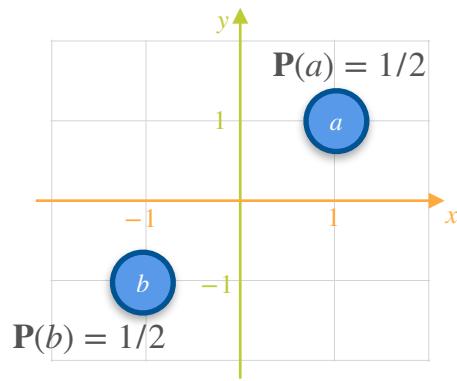


**GAME 3**

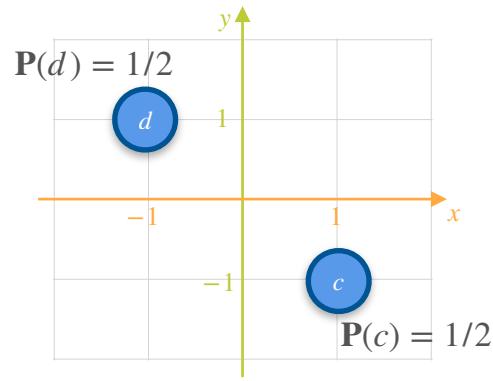


# Covariance of a Probability Distribution: Motivation

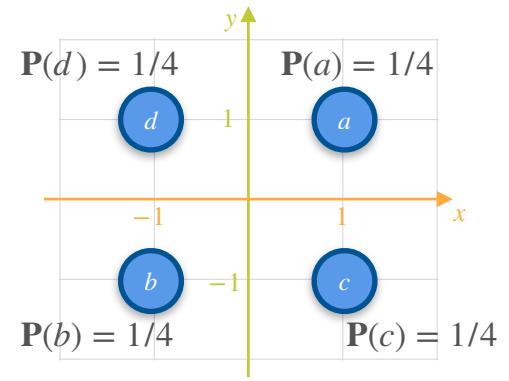
GAME 1



GAME 2



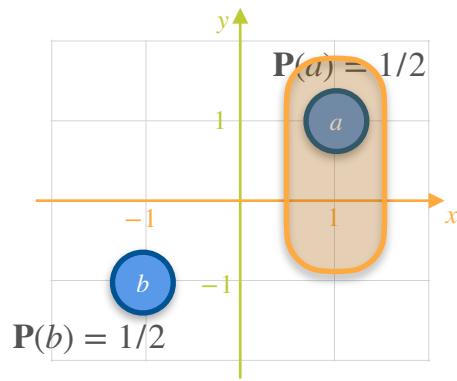
GAME 3



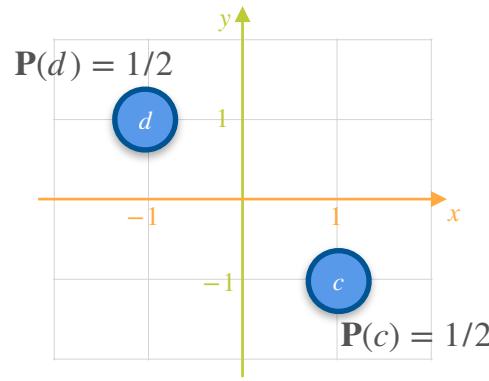
$$\mathbb{E}[X_1] =$$

# Covariance of a Probability Distribution: Motivation

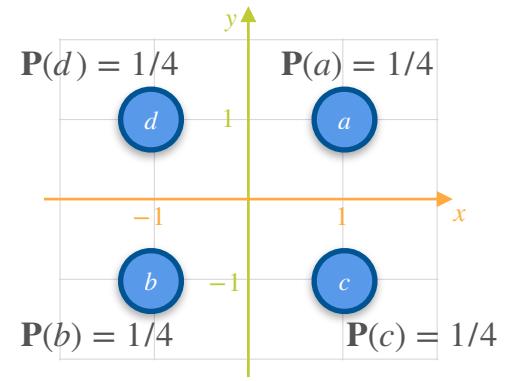
GAME 1



GAME 2



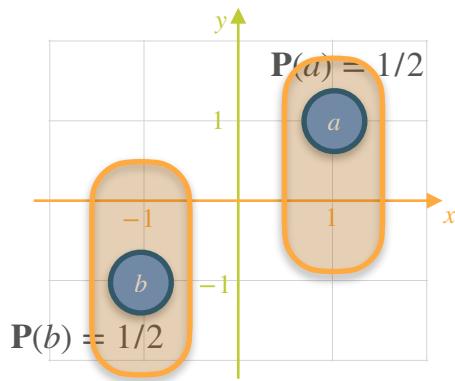
GAME 3



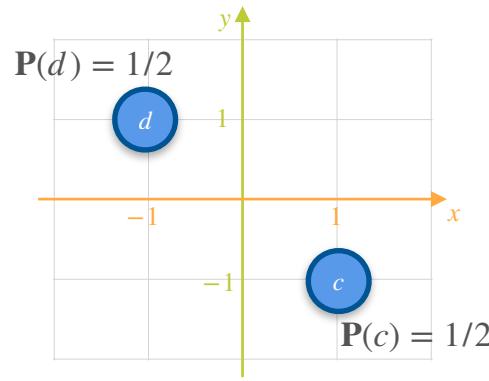
$$\mathbb{E}[X_1] = \frac{1}{2}(1)$$

# Covariance of a Probability Distribution: Motivation

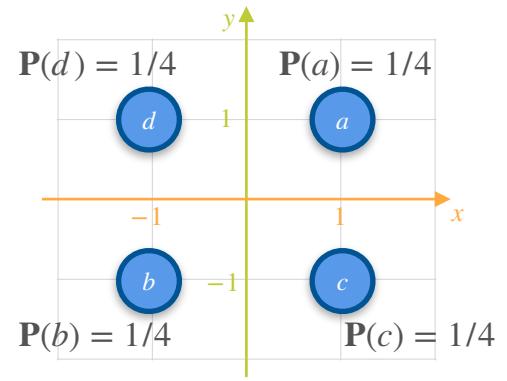
GAME 1



GAME 2



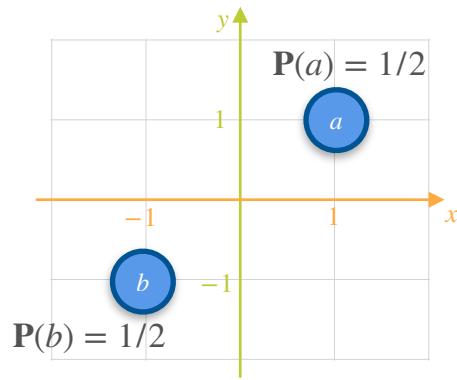
GAME 3



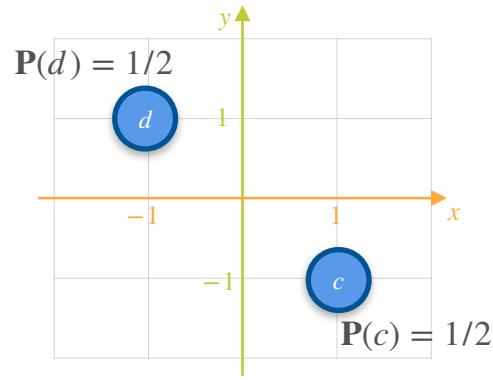
$$\mathbb{E}[X_1] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

# Covariance of a Probability Distribution: Motivation

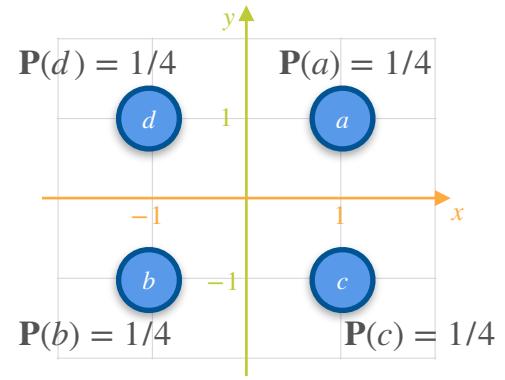
**GAME 1**



**GAME 2**



**GAME 3**

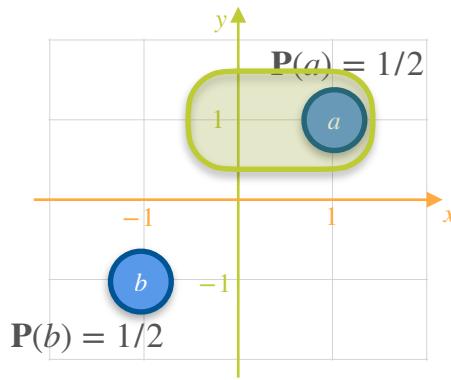


$$\mathbb{E}[X_1] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

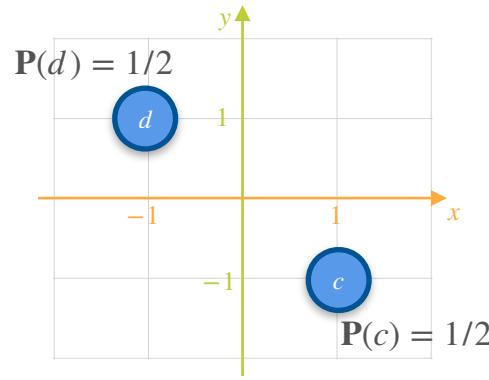
$$\mathbb{E}[Y_1] =$$

# Covariance of a Probability Distribution: Motivation

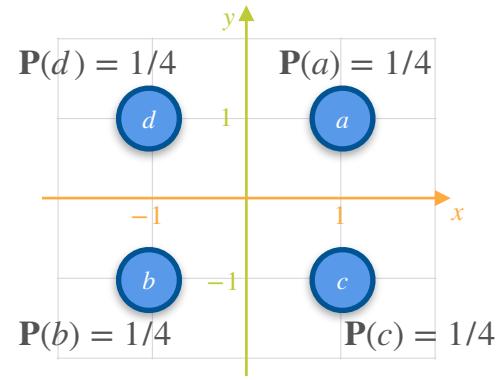
GAME 1



GAME 2



GAME 3

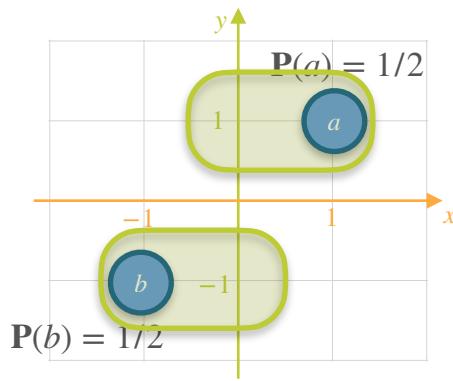


$$\mathbb{E}[X_1] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

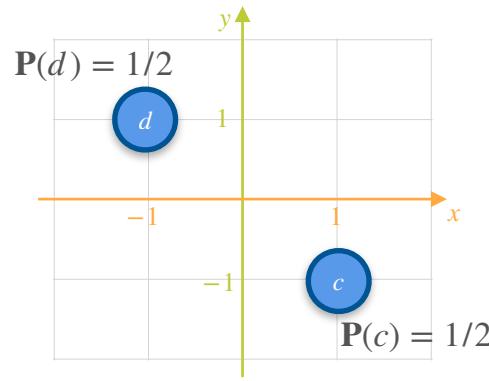
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# Covariance of a Probability Distribution: Motivation

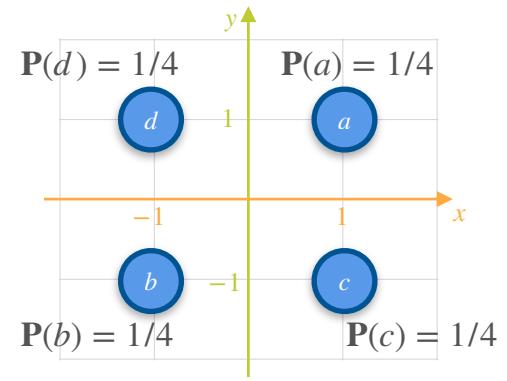
GAME 1



GAME 2



GAME 3

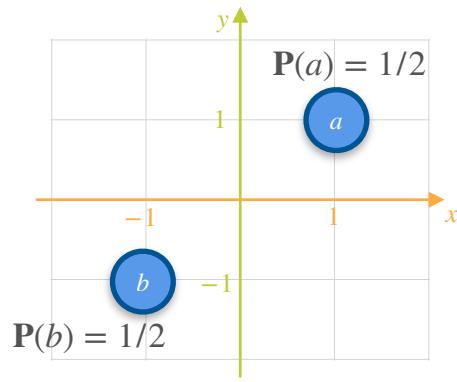


$$\mathbb{E}[X_1] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

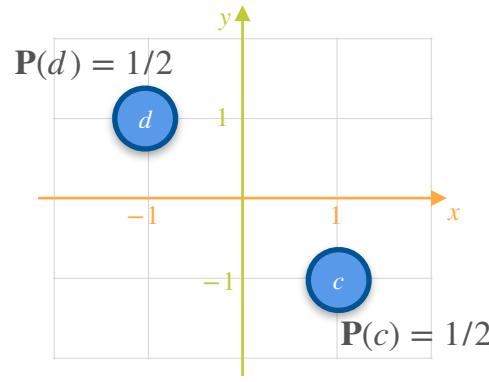
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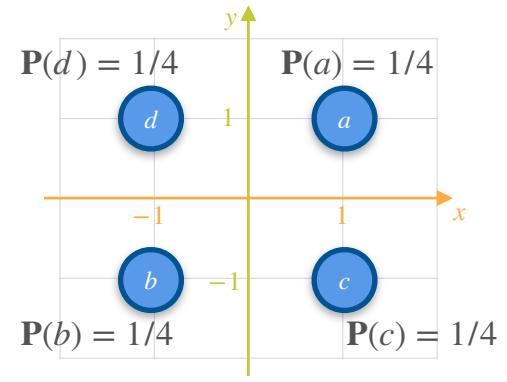
**GAME 1**



**GAME 2**



**GAME 3**

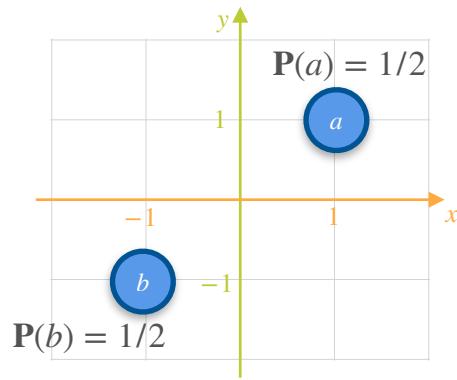


$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

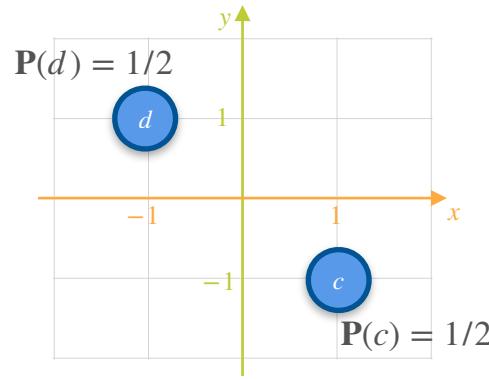
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

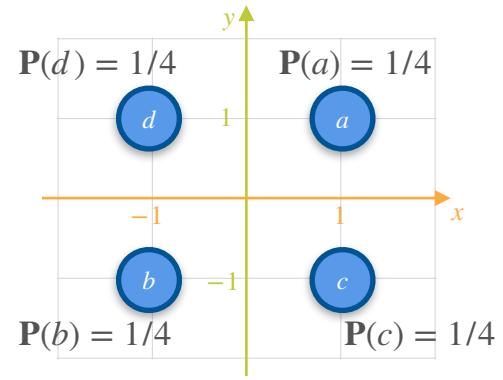
$$\mathbb{E}[Y_1] = 0$$

**GAME 2**



$$\mathbb{E}[X_2] =$$

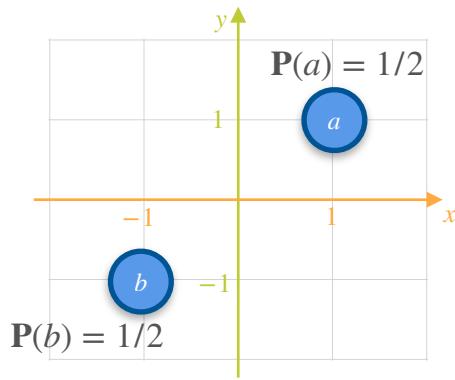
**GAME 3**



$$\mathbb{E}[X_3] =$$

# Covariance of a Probability Distribution: Motivation

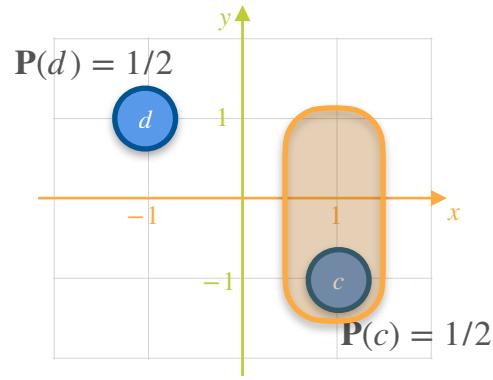
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

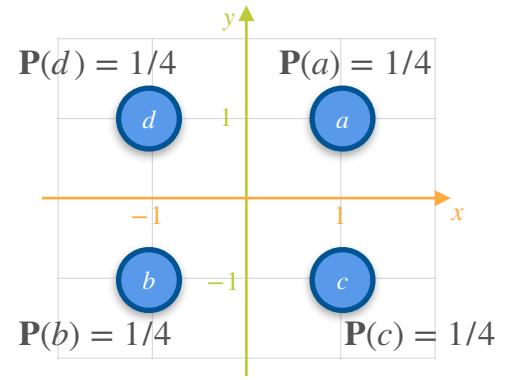
$$\mathbb{E}[Y_1] = 0$$

**GAME 2**



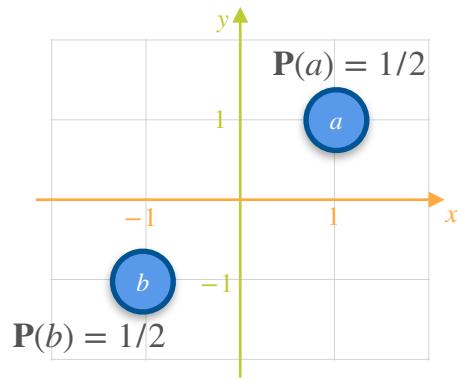
$$\mathbb{E}[X_2] = \frac{1}{2}(1)$$

**GAME 3**



# Covariance of a Probability Distribution: Motivation

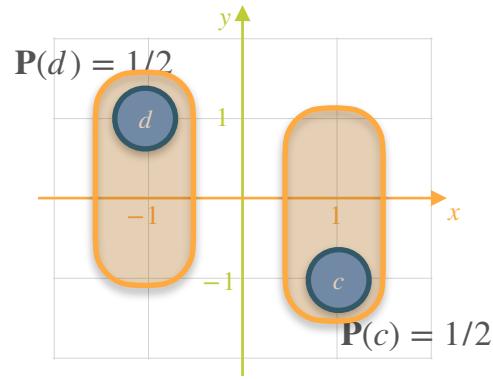
GAME 1



$$\mathbb{E}[X_1] = 0$$

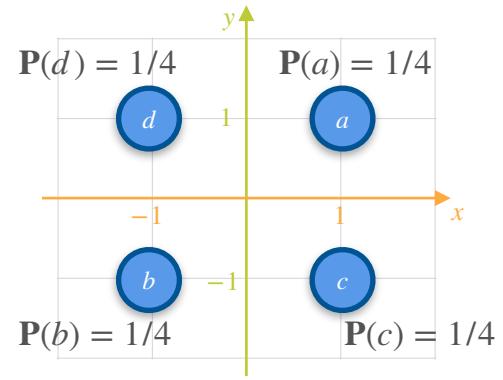
$$\mathbb{E}[Y_1] = 0$$

GAME 2



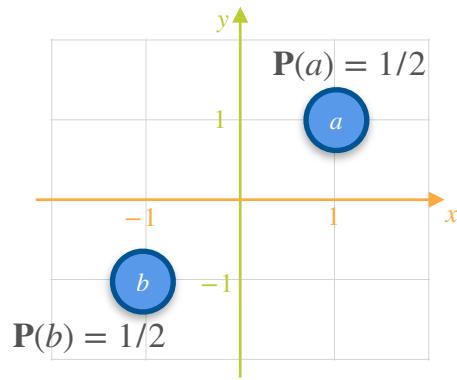
$$\mathbb{E}[X_2] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

GAME 3



# Covariance of a Probability Distribution: Motivation

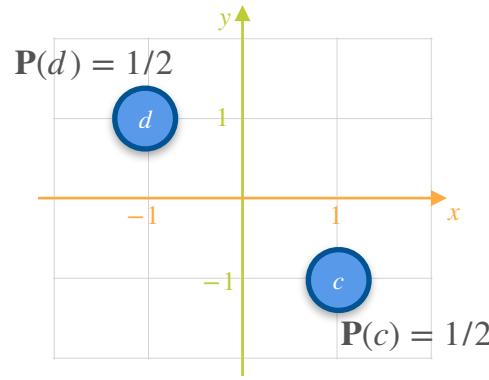
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

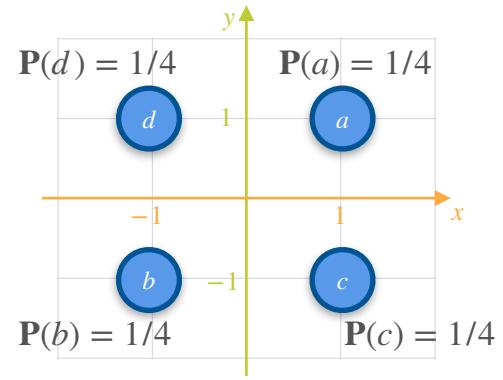
**GAME 2**



$$\mathbb{E}[X_2] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

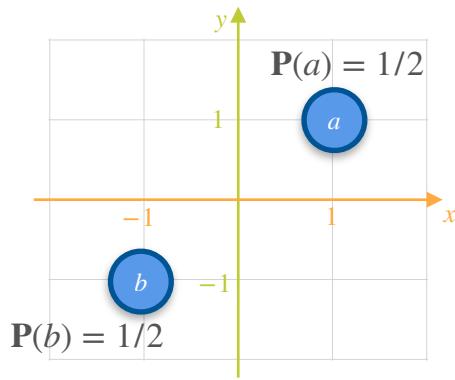
$$\mathbb{E}[Y_2] =$$

**GAME 3**



# Covariance of a Probability Distribution: Motivation

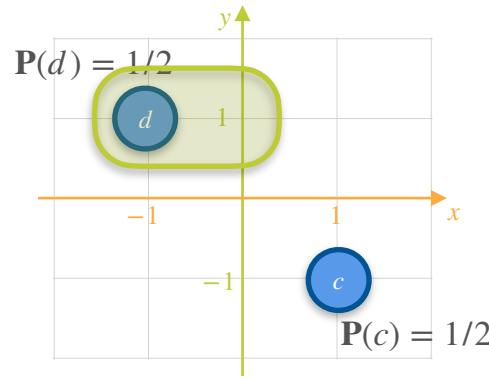
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

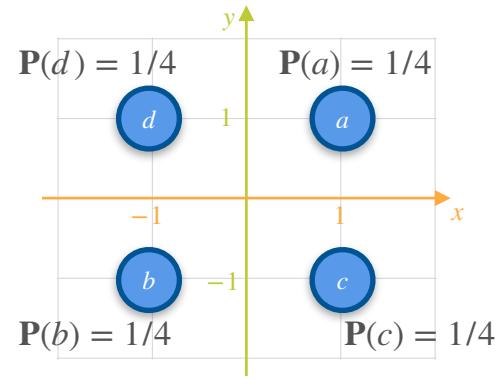
**GAME 2**



$$\mathbb{E}[X_2] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

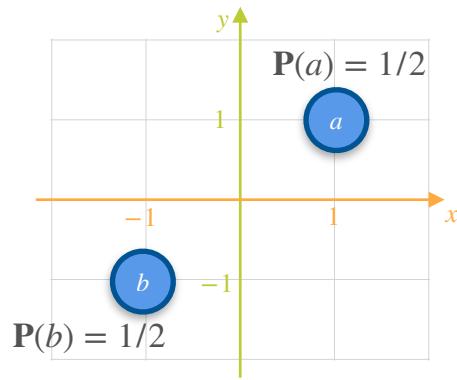
$$\mathbb{E}[Y_2] = \frac{1}{2}(1)$$

**GAME 3**



# Covariance of a Probability Distribution: Motivation

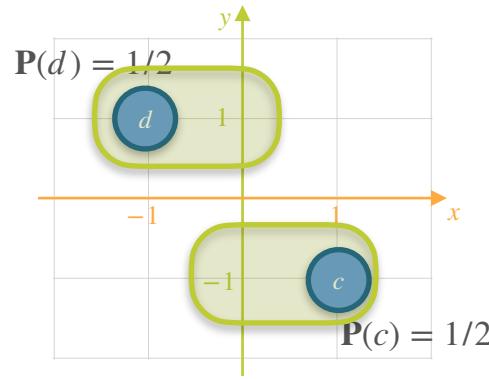
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

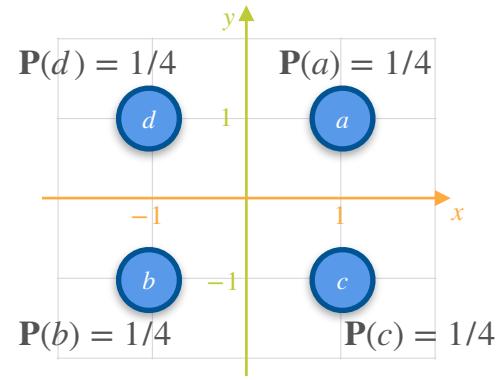
**GAME 2**



$$\mathbb{E}[X_2] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

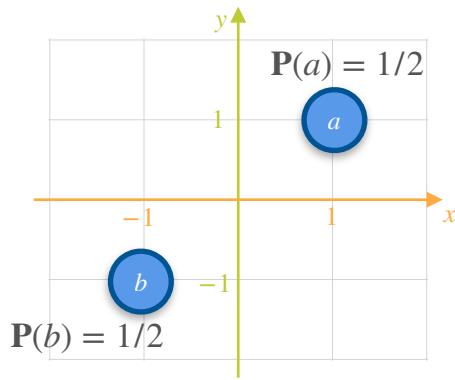
$$\mathbb{E}[Y_2] = \frac{1}{2}(1) + \frac{1}{2}(-1) = 0$$

**GAME 3**

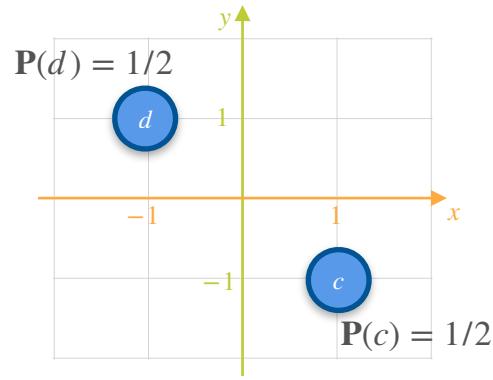


# Covariance of a Probability Distribution: Motivation

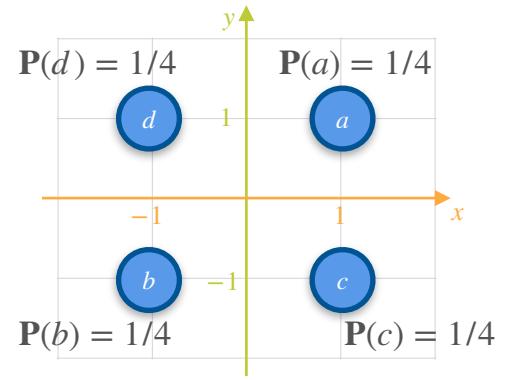
**GAME 1**



**GAME 2**



**GAME 3**



$$\mathbb{E}[X_1] = 0$$

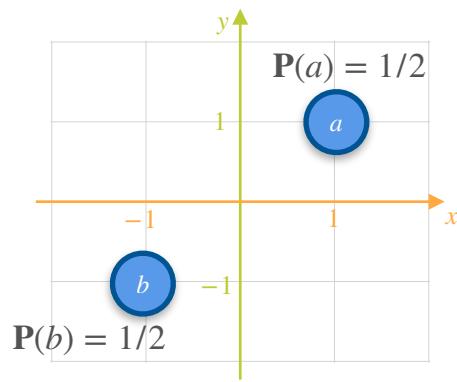
$$\mathbb{E}[Y_1] = 0$$

$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation

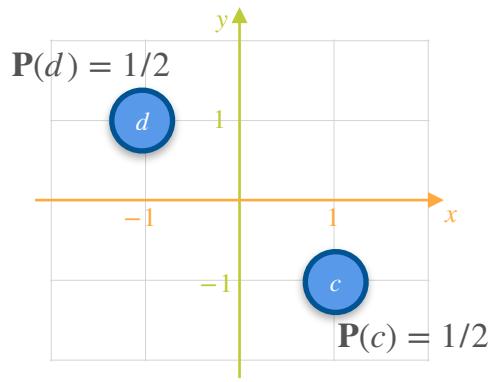
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

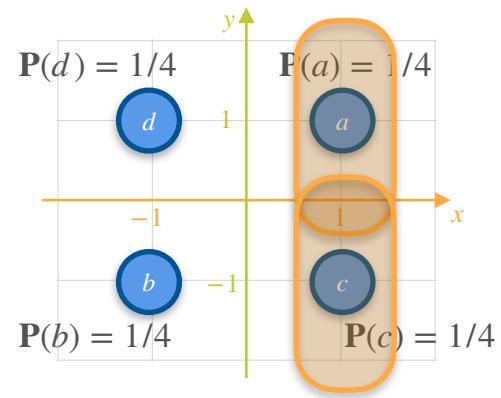
**GAME 2**



$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[Y_2] = 0$$

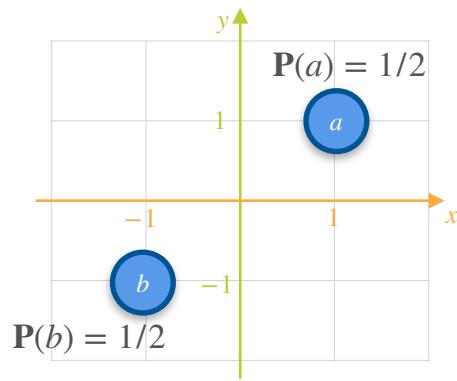
**GAME 3**



$$\mathbb{E}[X_3] = 2\left(\frac{1}{4}(1)\right)$$

# Covariance of a Probability Distribution: Motivation

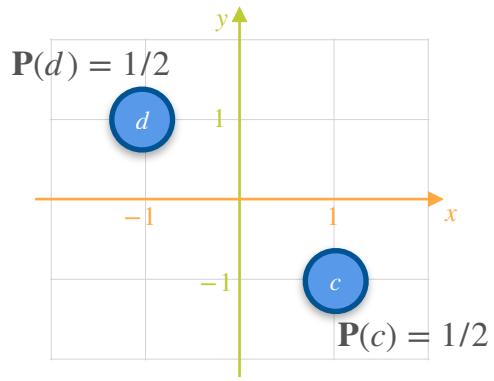
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

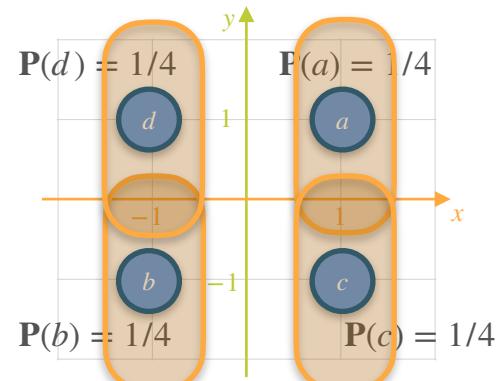
**GAME 2**



$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[Y_2] = 0$$

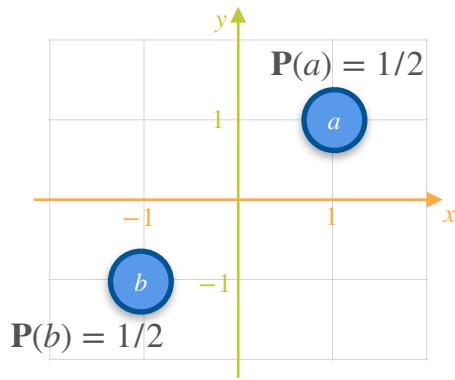
**GAME 3**



$$\mathbb{E}[X_3] = 2\left(\frac{1}{4}(1)\right) + 2\left(\frac{1}{4}(-1)\right) = 0$$

# Covariance of a Probability Distribution: Motivation

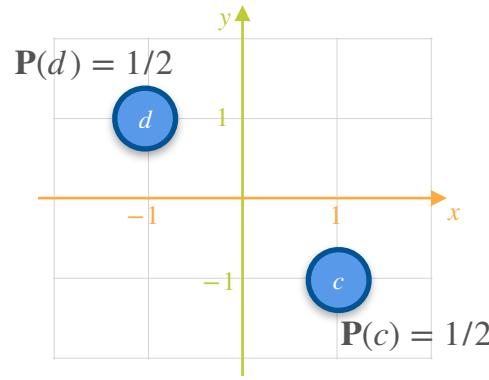
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

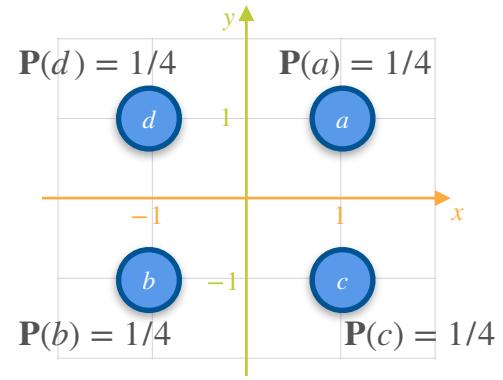
**GAME 2**



$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[Y_2] = 0$$

**GAME 3**

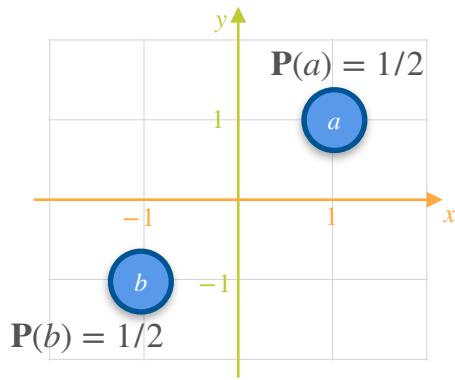


$$\mathbb{E}[X_3] = 2\left(\frac{1}{4}(1)\right) + 2\left(\frac{1}{4}(-1)\right) = 0$$

$$\mathbb{E}[Y_3] =$$

# Covariance of a Probability Distribution: Motivation

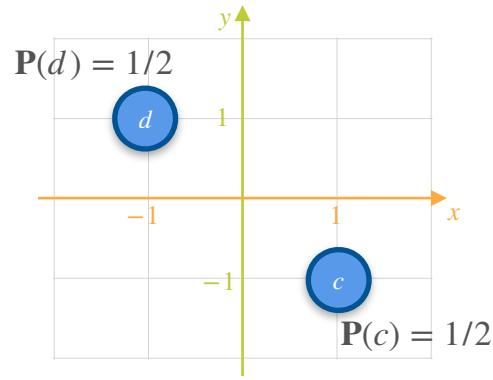
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

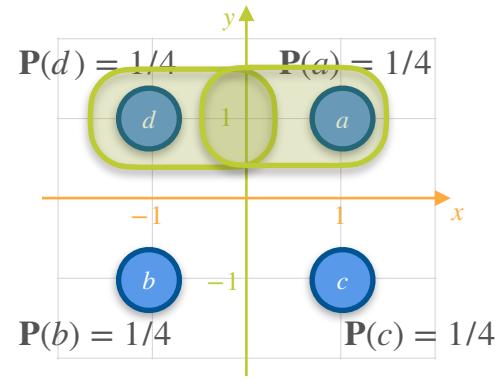
**GAME 2**



$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[Y_2] = 0$$

**GAME 3**

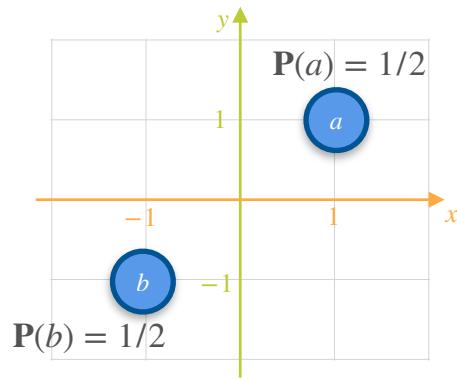


$$\mathbb{E}[X_3] = 2\left(\frac{1}{4}(1)\right) + 2\left(\frac{1}{4}(-1)\right) = 0$$

$$\mathbb{E}[Y_3] = 2\left(\frac{1}{4}(1)\right)$$

# Covariance of a Probability Distribution: Motivation

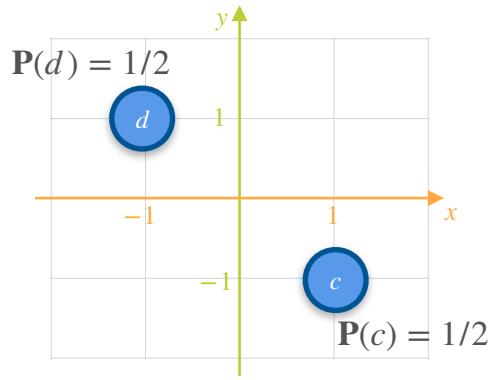
**GAME 1**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

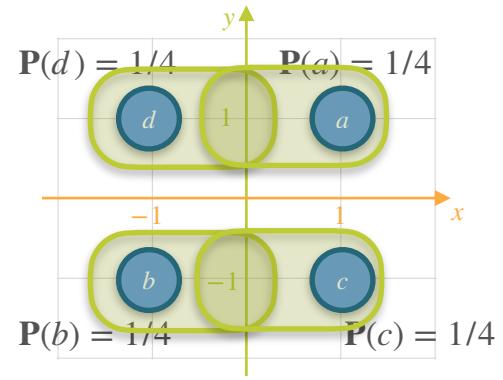
**GAME 2**



$$\mathbb{E}[X_2] = 0$$

$$\mathbb{E}[Y_2] = 0$$

**GAME 3**

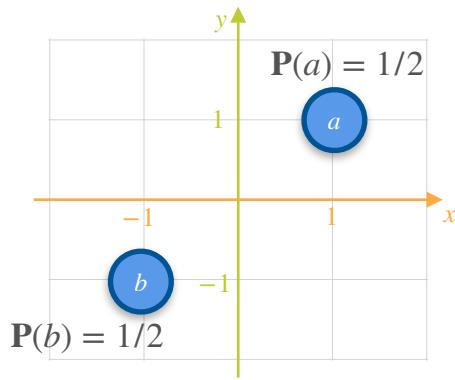


$$\mathbb{E}[X_3] = 2\left(\frac{1}{4}(1)\right) + 2\left(\frac{1}{4}(-1)\right) = 0$$

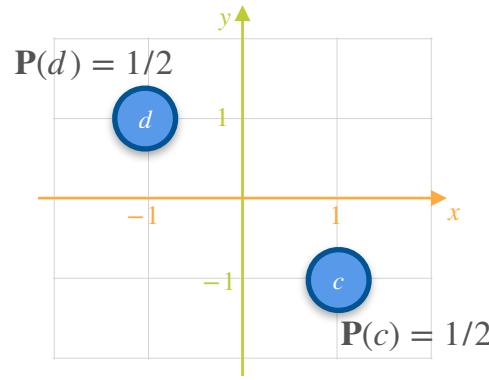
$$\mathbb{E}[Y_3] = 2\left(\frac{1}{4}(1)\right) + 2\left(\frac{1}{4}(-1)\right) = 0$$

# Covariance of a Probability Distribution: Motivation

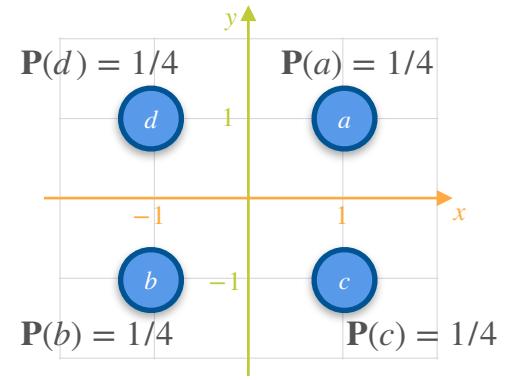
**GAME 1**



**GAME 2**



**GAME 3**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

$$\mathbb{E}[X_2] = 0$$

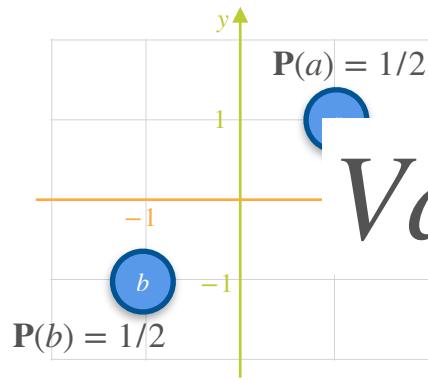
$$\mathbb{E}[Y_2] = 0$$

$$\mathbb{E}[X_3] = 0$$

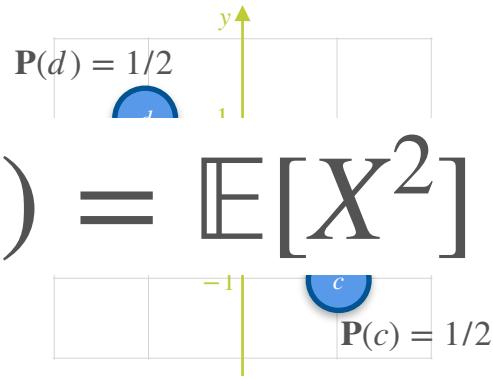
$$\mathbb{E}[Y_3] = 0$$

# Covariance of a Probability Distribution: Motivation

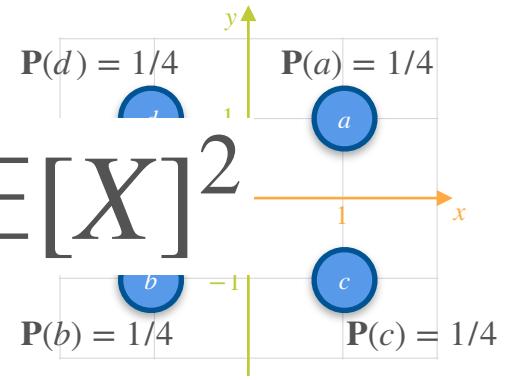
**GAME 1**



**GAME 2**



**GAME 3**



$$\mathbb{E}[X_1] = 0$$

$$\mathbb{E}[Y_1] = 0$$

$$\mathbb{E}[X_2] = 0$$

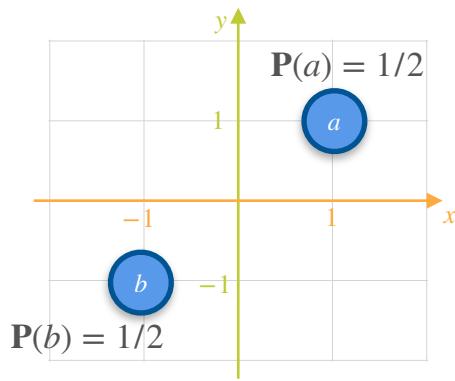
$$\mathbb{E}[Y_2] = 0$$

$$\mathbb{E}[X_3] = 0$$

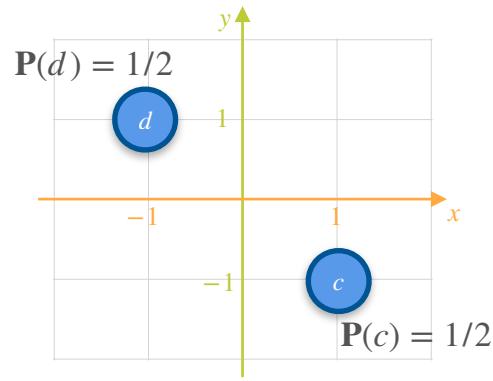
$$\mathbb{E}[Y_3] = 0$$

# Covariance of a Probability Distribution: Motivation

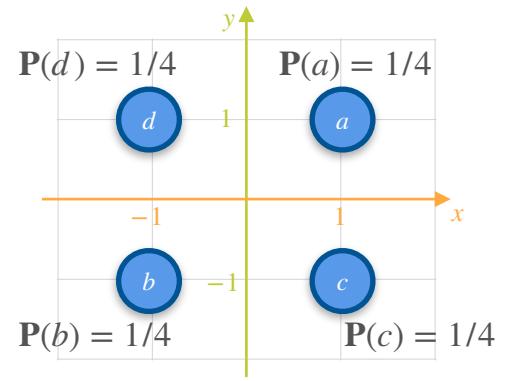
**GAME 1**



**GAME 2**



**GAME 3**



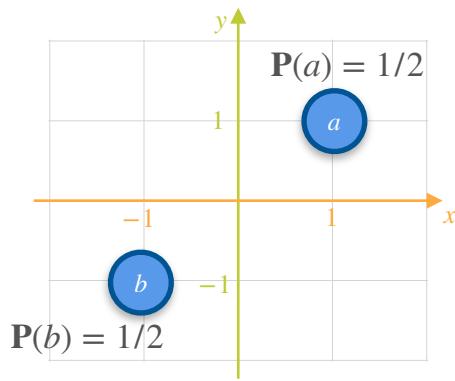
$$\mathbb{E}[X_1] = 0 \quad \mathbb{E}[Y_1] = 0$$

$$\mathbb{E}[X_2] = 0 \quad \mathbb{E}[Y_2] = 0$$

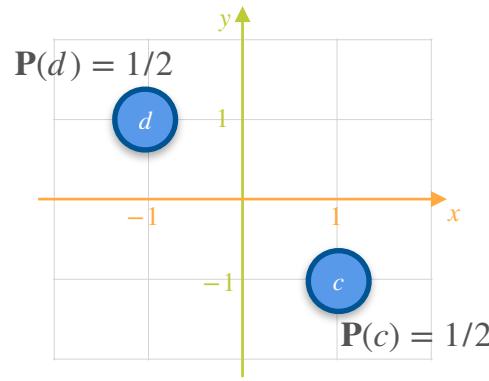
$$\mathbb{E}[X_3] = 0 \quad \mathbb{E}[Y_3] = 0$$

# Covariance of a Probability Distribution: Motivation

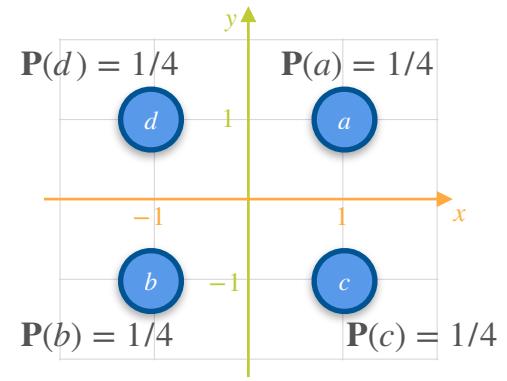
**GAME 1**



**GAME 2**



**GAME 3**



$$\mathbb{E}[X_1] = 0 \quad \mathbb{E}[Y_1] = 0$$

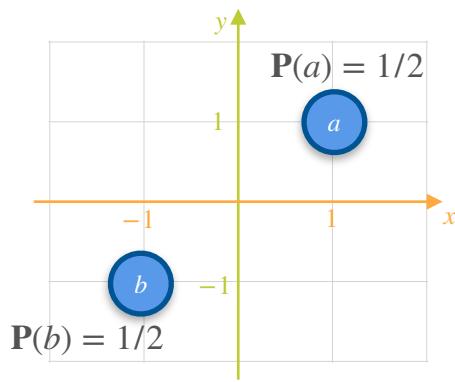
$$\mathbb{E}[X_2] = 0 \quad \mathbb{E}[Y_2] = 0$$

$$\mathbb{E}[X_3] = 0 \quad \mathbb{E}[Y_3] = 0$$

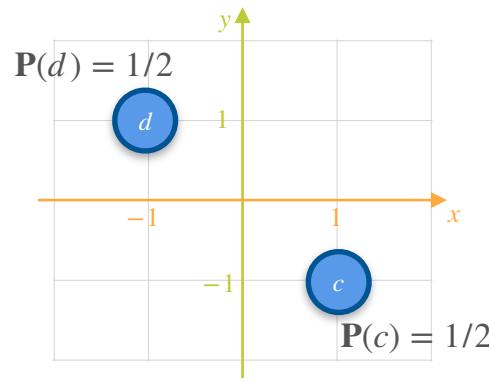
$$Var(X_1) =$$

# Covariance of a Probability Distribution: Motivation

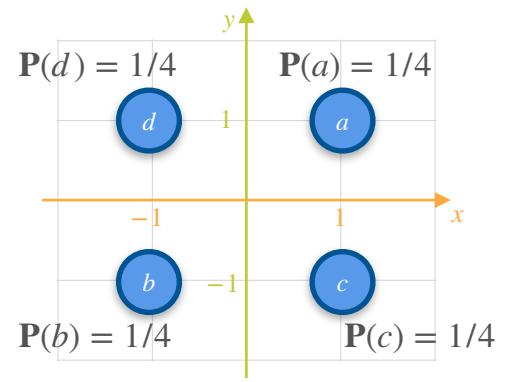
**GAME 1**



**GAME 2**



**GAME 3**



$$\mathbb{E}[X_1] = 0 \quad \mathbb{E}[Y_1] = 0$$

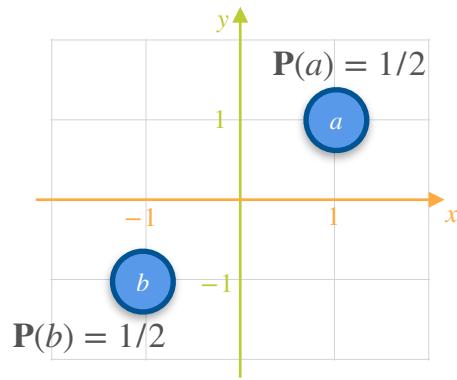
$$\mathbb{E}[X_2] = 0 \quad \mathbb{E}[Y_2] = 0$$

$$\mathbb{E}[X_3] = 0 \quad \mathbb{E}[Y_3] = 0$$

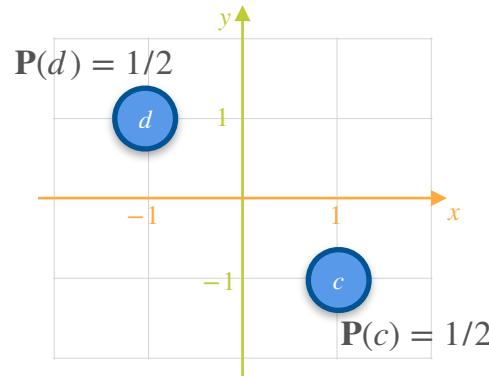
$$Var(X_1) = \mathbb{E}[X_1^2] - E[X_1]^2$$

# Covariance of a Probability Distribution: Motivation

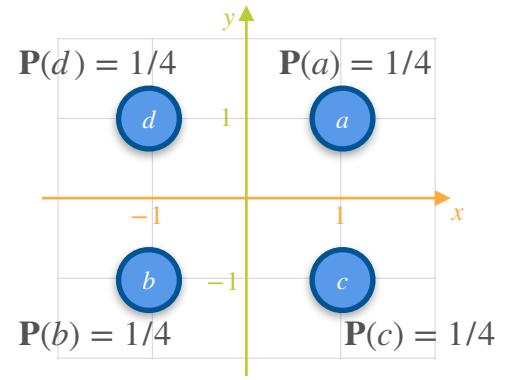
**GAME 1**



**GAME 2**



**GAME 3**



$$\mathbb{E}[X_1] = 0 \quad \mathbb{E}[Y_1] = 0$$

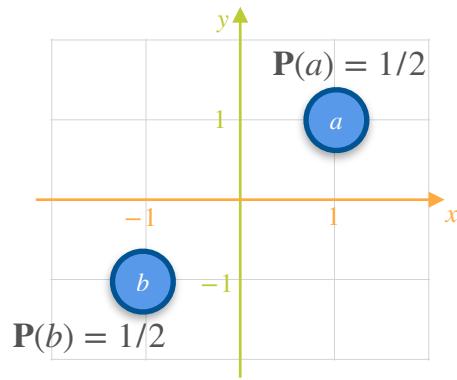
$$\mathbb{E}[X_2] = 0 \quad \mathbb{E}[Y_2] = 0$$

$$\mathbb{E}[X_3] = 0 \quad \mathbb{E}[Y_3] = 0$$

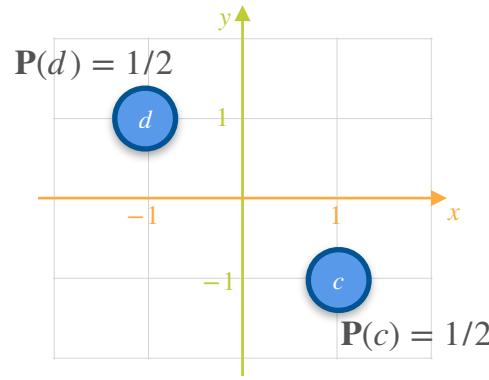
$$Var(X_1) = \mathbb{E}[X_1^2] - E[X_1]^2 = \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 - 0^2 =$$

# Covariance of a Probability Distribution: Motivation

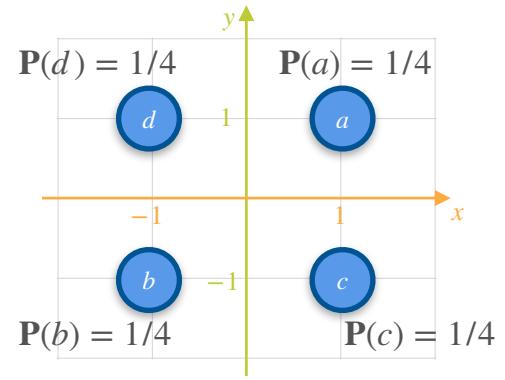
**GAME 1**



**GAME 2**



**GAME 3**



$$\mathbb{E}[X_1] = 0 \quad \mathbb{E}[Y_1] = 0$$

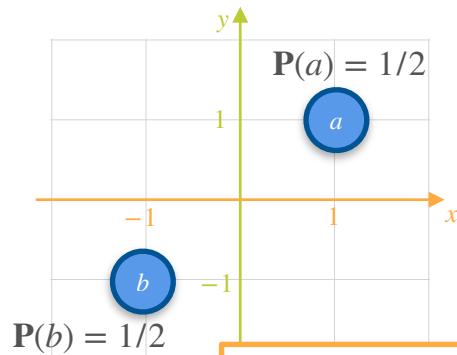
$$\mathbb{E}[X_2] = 0 \quad \mathbb{E}[Y_2] = 0$$

$$\mathbb{E}[X_3] = 0 \quad \mathbb{E}[Y_3] = 0$$

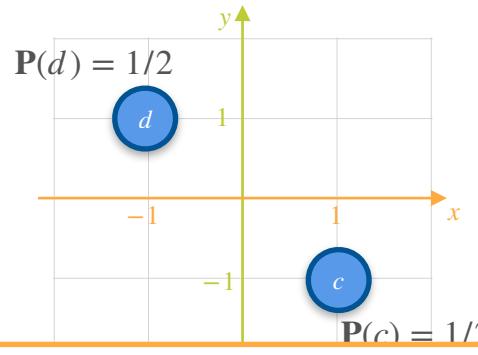
$$Var(X_1) = \mathbb{E}[X_1^2] - E[X_1]^2 = \frac{1}{2}(-1)^2 + \frac{1}{2}(1)^2 - 0^2 = 1$$

# Covariance of a Probability Distribution: Motivation

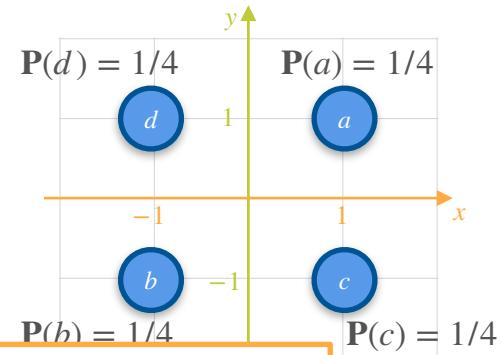
GAME 1



GAME 2



GAME 3



How similar are these 3 games for player X and player Y?

$$\mathbb{E}[X_1] = 0 \quad \mathbb{E}[Y_1] = 0$$

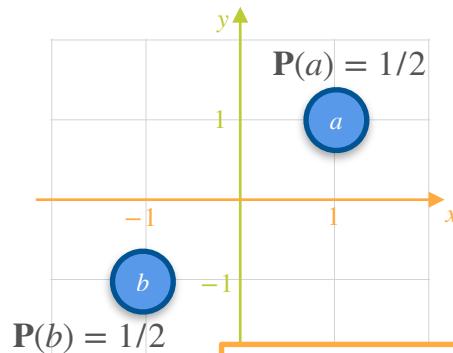
$$\mathbb{E}[X_2] = 0 \quad \mathbb{E}[Y_2] = 0$$

$$\mathbb{E}[X_3] = 0 \quad \mathbb{E}[Y_3] = 0$$

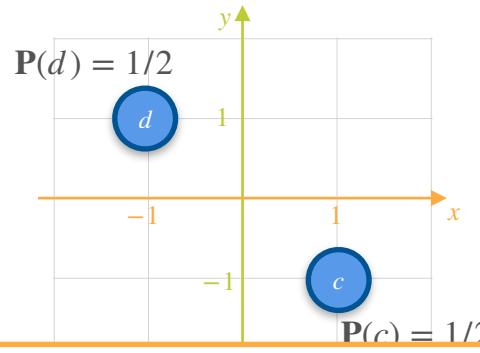
$$Var(X_1) = 1$$

# Covariance of a Probability Distribution: Motivation

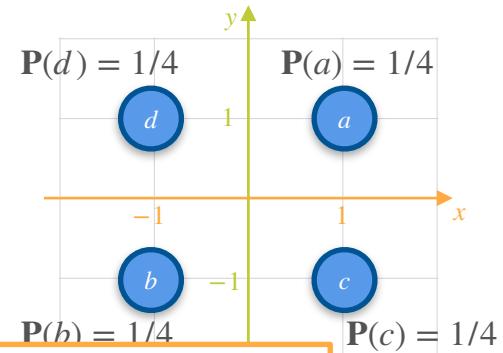
GAME 1



GAME 2



GAME 3



How similar are these 3 games for player X and player Y?

$$\mathbb{E}[X_1] = 0 \quad \mathbb{E}[Y_1] = 0$$

$$Var(X_1) = 1$$

$$Var(Y_1) = 1$$

$$\mathbb{E}[X_2] = 0 \quad \mathbb{E}[Y_2] = 0$$

$$Var(X_2) = 1$$

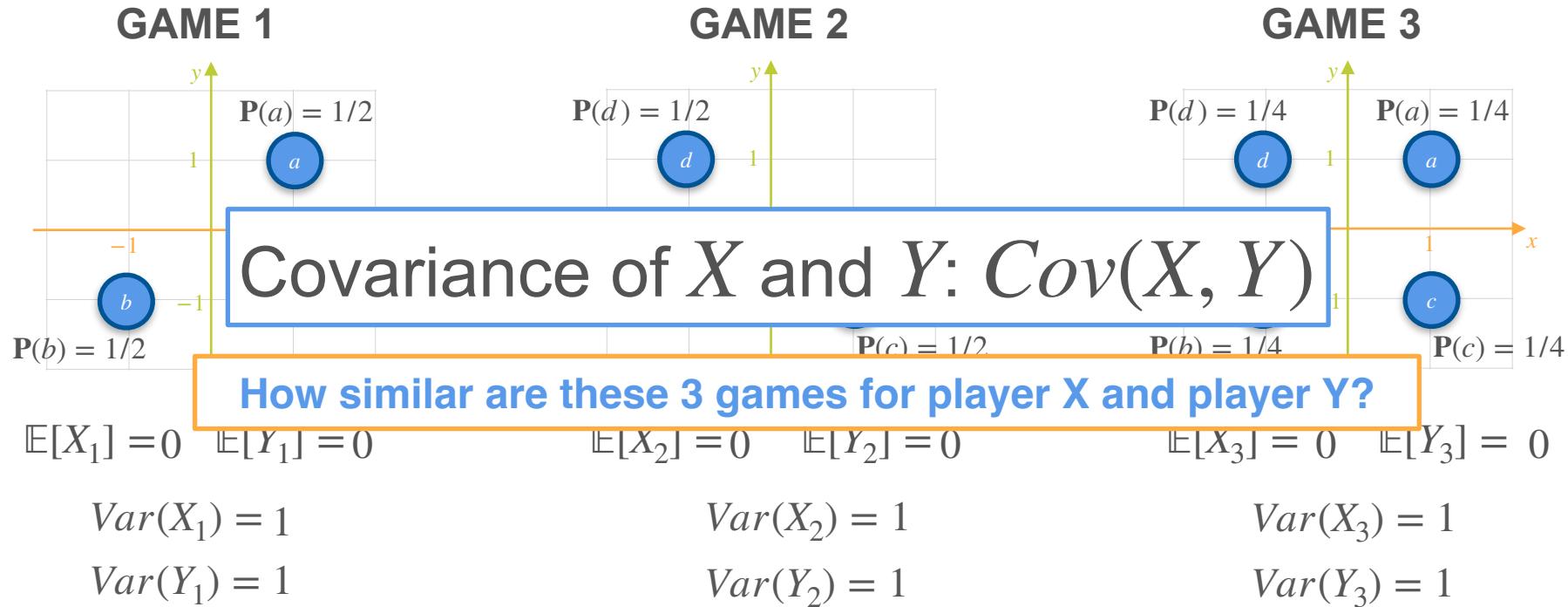
$$Var(Y_2) = 1$$

$$\mathbb{E}[X_3] = 0 \quad \mathbb{E}[Y_3] = 0$$

$$Var(X_3) = 1$$

$$Var(Y_3) = 1$$

# Covariance of a Probability Distribution: Motivation



# Covariance of a Probability Distribution: Motivation

# Covariance of a Probability Distribution: Motivation

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

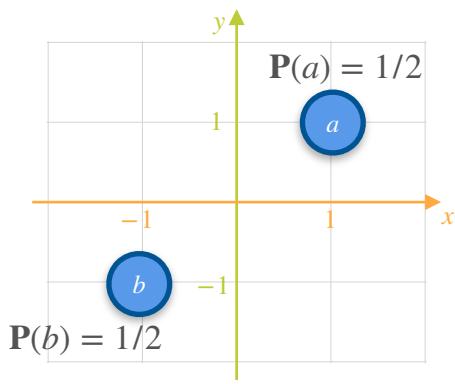
# Covariance of a Probability Distribution: Motivation

Covariance of  $X$  and  $Y$ :  $Cov(X, Y)$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

# Covariance of a Probability Distribution: Motivation

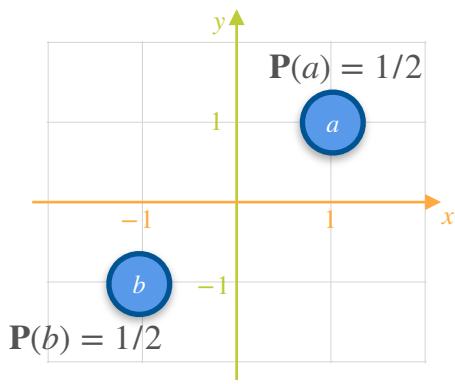
**GAME 1**



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

# Covariance of a Probability Distribution: Motivation

## GAME 1

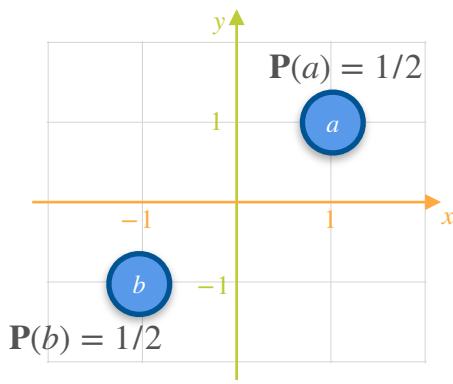


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
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# Covariance of a Probability Distribution: Motivation

## GAME 1

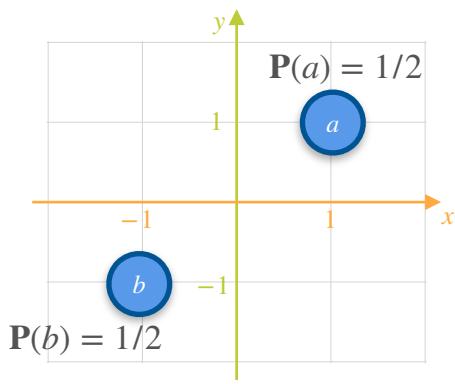


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1				
-1				

# Covariance of a Probability Distribution: Motivation

## GAME 1

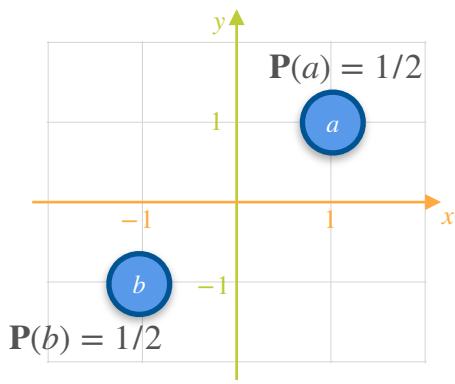


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1			
-1	-1			

# Covariance of a Probability Distribution: Motivation

**GAME 1**

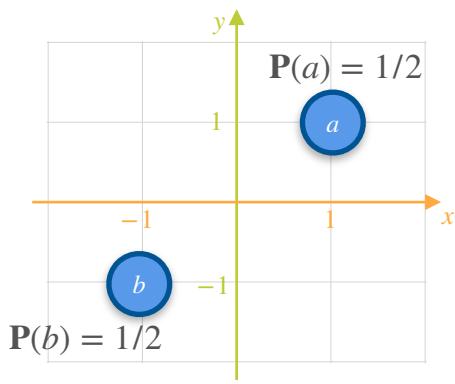


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	-1

# Covariance of a Probability Distribution: Motivation

**GAME 1**

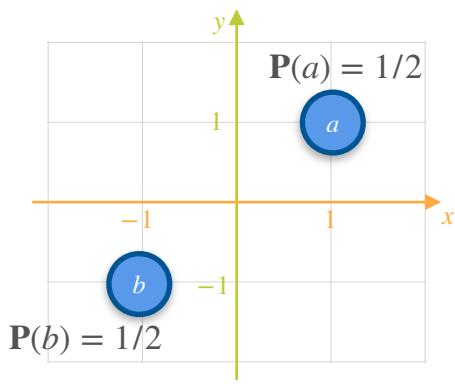


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	-1

# Covariance of a Probability Distribution: Motivation

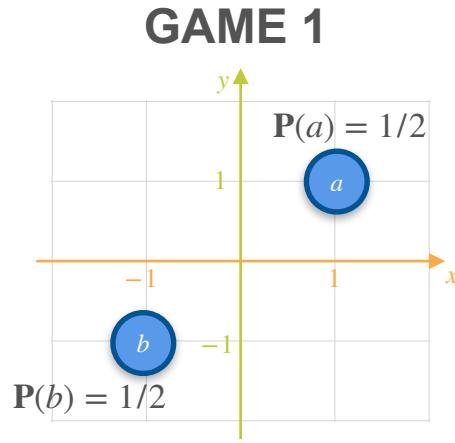
GAME 1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

# Covariance of a Probability Distribution: Motivation

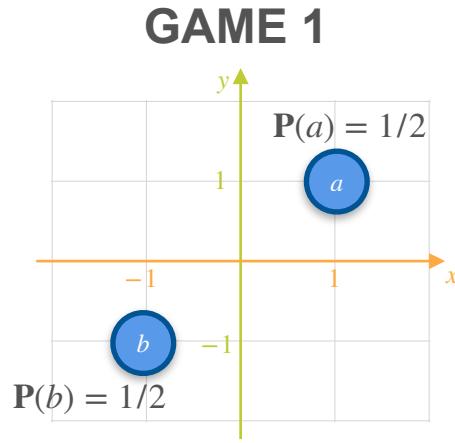


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

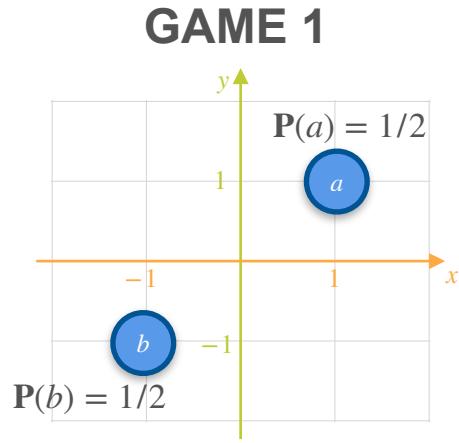


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

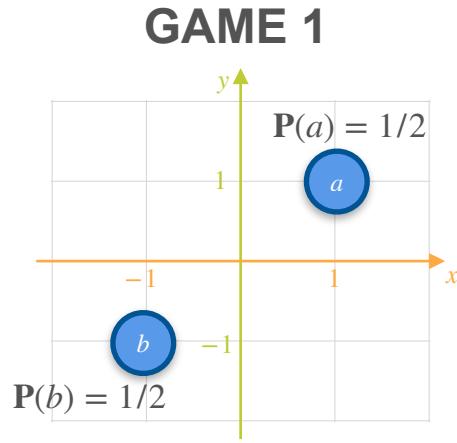


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) = 2$$

# Covariance of a Probability Distribution: Motivation

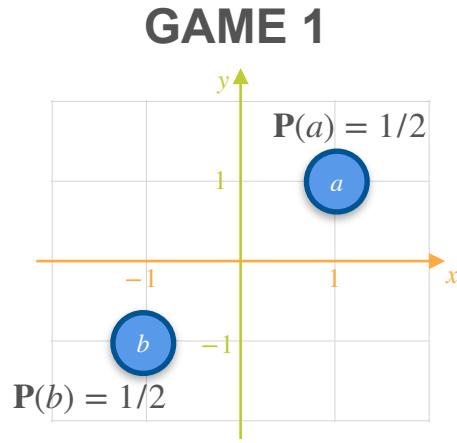


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \sum (x_i - \mu_x)(y_i - \mu_y) = 2$$

# Covariance of a Probability Distribution: Motivation

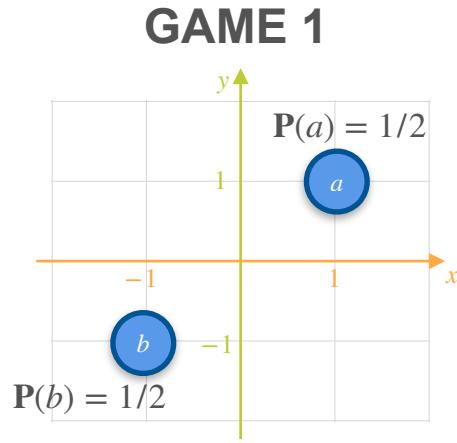


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = 2$$

# Covariance of a Probability Distribution: Motivation

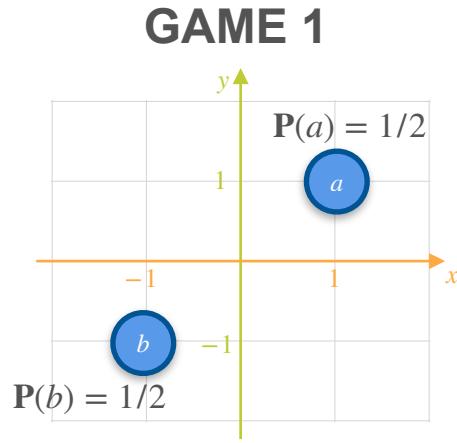


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{2}{2}$$

# Covariance of a Probability Distribution: Motivation



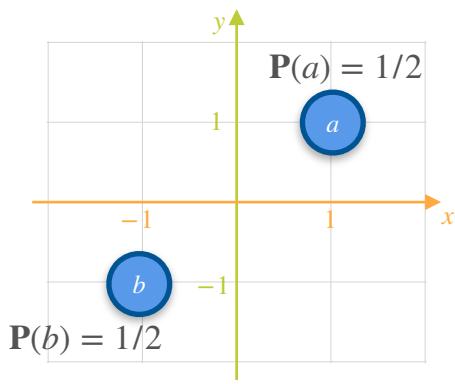
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{2}{2} = 1$$

# Covariance of a Probability Distribution: Motivation

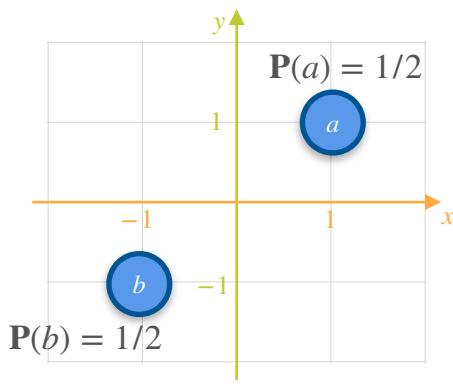
**GAME 1**



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

# Covariance of a Probability Distribution: Motivation

**GAME 1**

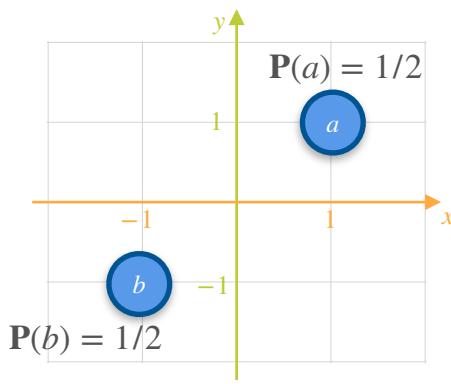


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$\mu_x = \mathbb{E}[X_1] = 0$$

# Covariance of a Probability Distribution: Motivation

**GAME 1**



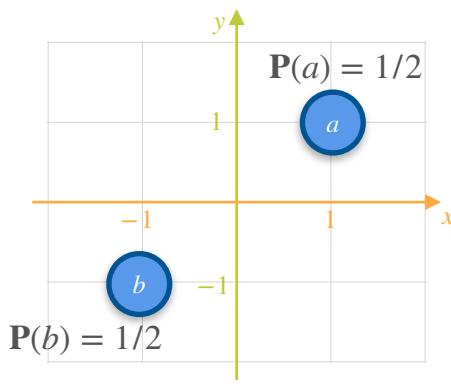
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

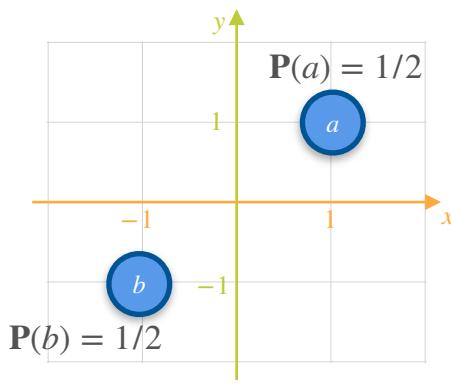
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
-----	-----	-----------------	-----------------	------------------------------

$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

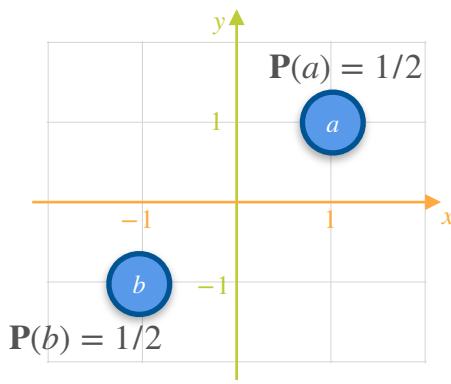
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1				
-1				

$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

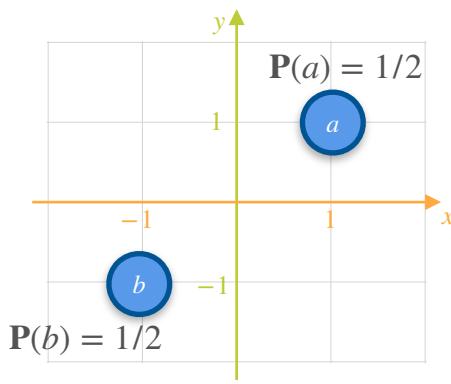
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	0	0	0
-1	-1	-2	-2	4

$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

GAME 1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

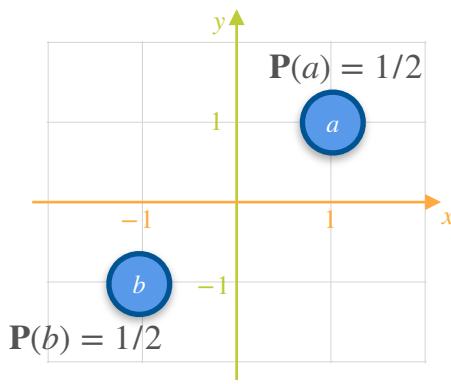
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	-1

$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

GAME 1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

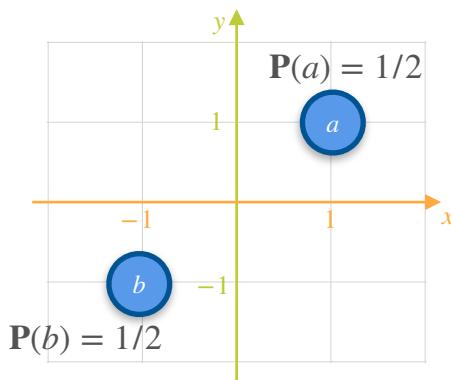
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	-1

$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

GAME 1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

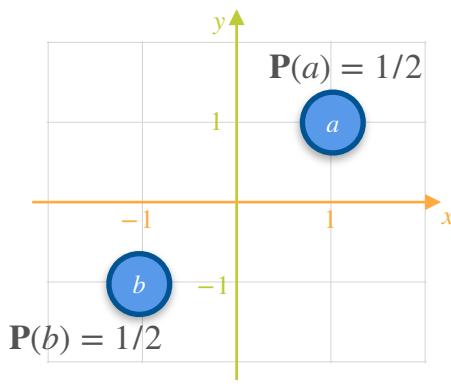
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 1



$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

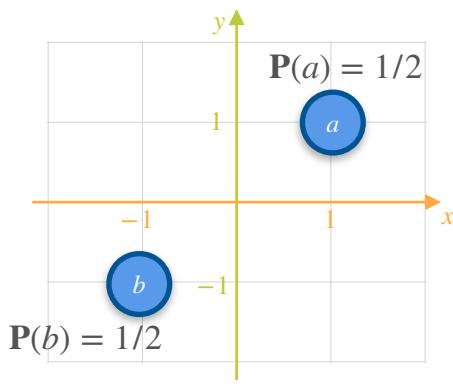
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

## GAME 1



$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

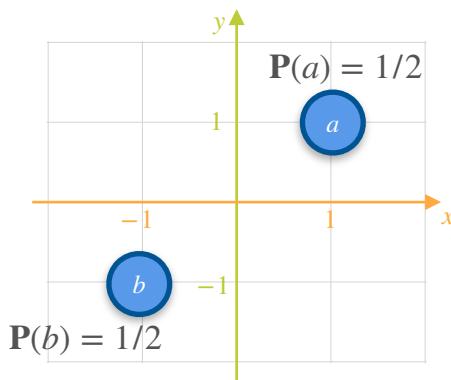
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

## GAME 1



$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

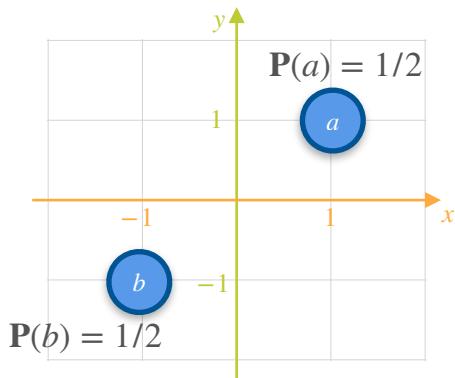
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) = 2$$

# Covariance of a Probability Distribution: Motivation

## GAME 1



$$\mu_x = \mathbb{E}[X_1] = 0$$

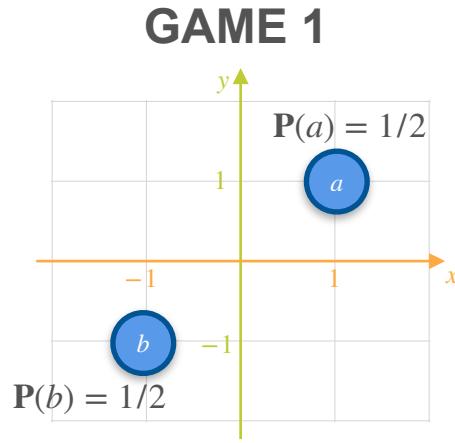
$$\mu_y = \mathbb{E}[Y_1] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \sum (x_i - \mu_x)(y_i - \mu_y) = 2$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_1] = 0$$

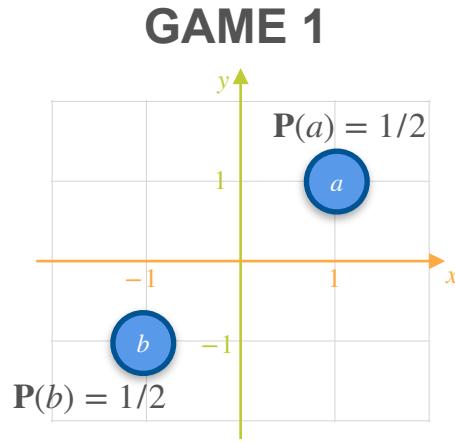
$$\mu_y = \mathbb{E}[Y_1] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = 2$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

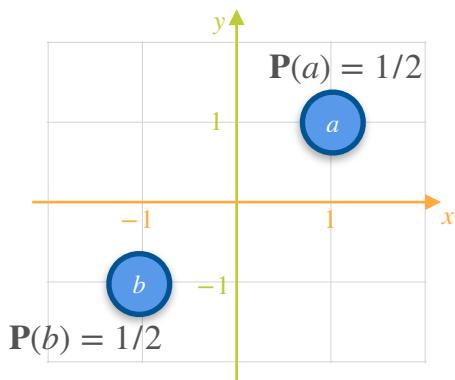
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{2}{2}$$

# Covariance of a Probability Distribution: Motivation

GAME 1



$$\mu_x = \mathbb{E}[X_1] = 0$$

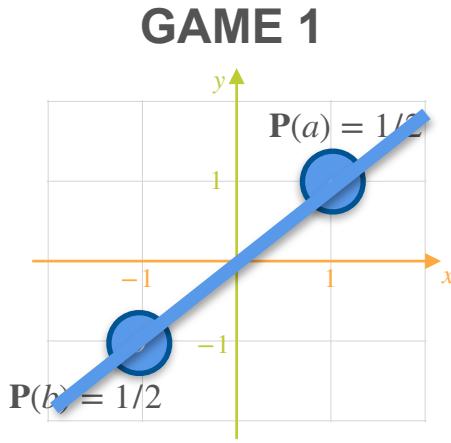
$$\mu_y = \mathbb{E}[Y_1] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{2}{2} = 1$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_1] = 0$$

$$\mu_y = \mathbb{E}[Y_1] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{2}{2} = 1$$

# Covariance of a Probability Distribution: Motivation

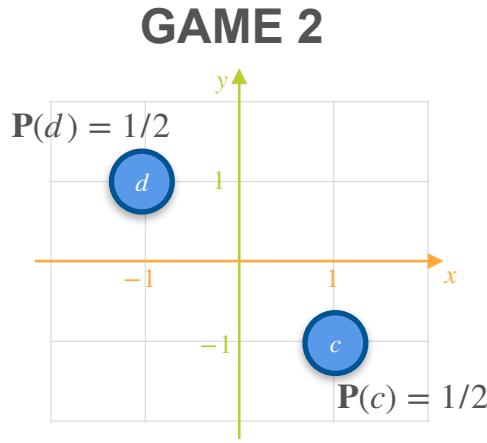
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

# Covariance of a Probability Distribution: Motivation

## GAME 2

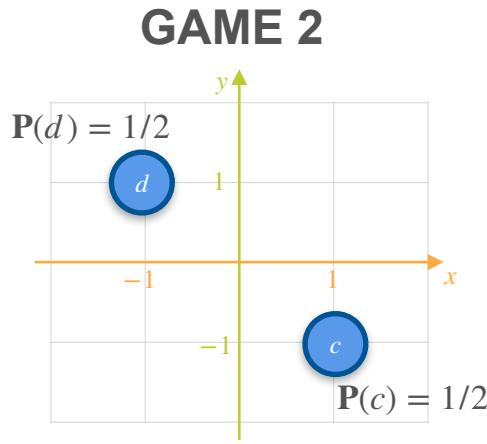
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

# Covariance of a Probability Distribution: Motivation



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

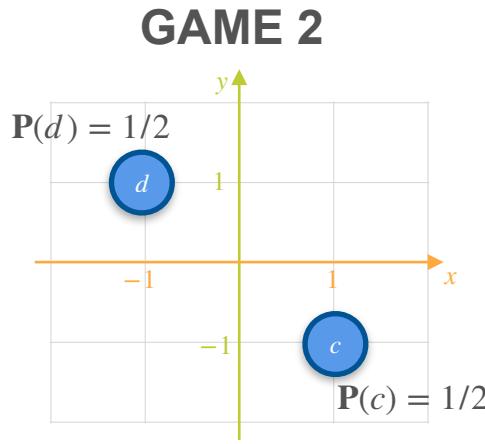
# Covariance of a Probability Distribution: Motivation



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$\mu_x = \mathbb{E}[X_2] = 0$$

# Covariance of a Probability Distribution: Motivation

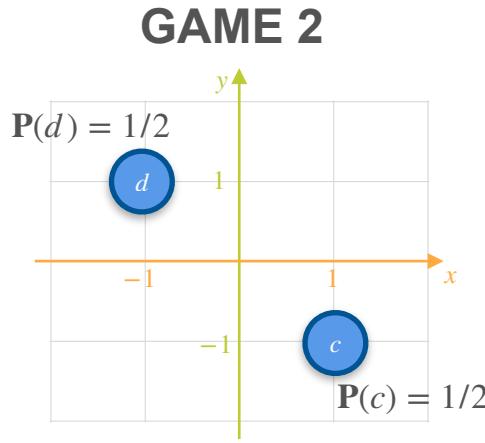


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation



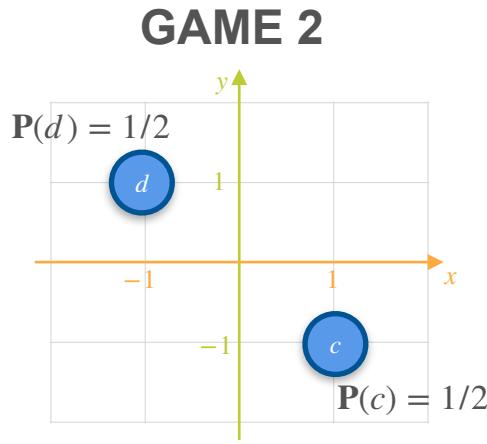
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
-----	-----	-----------------	-----------------	------------------------------

$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

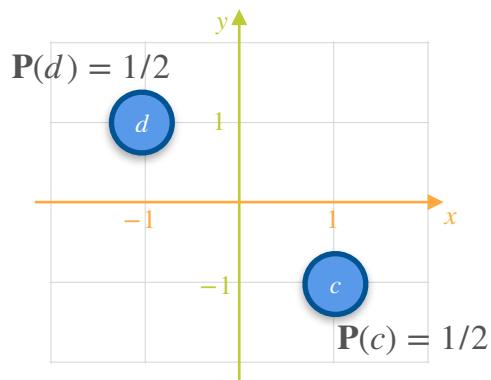
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1				
-1				

$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 2



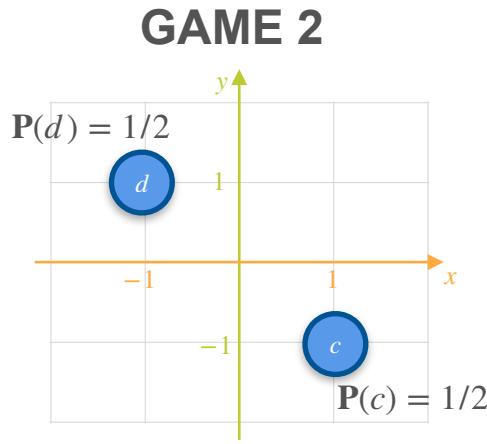
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	0	-2	0
-1	1	-2	0	-2

$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation



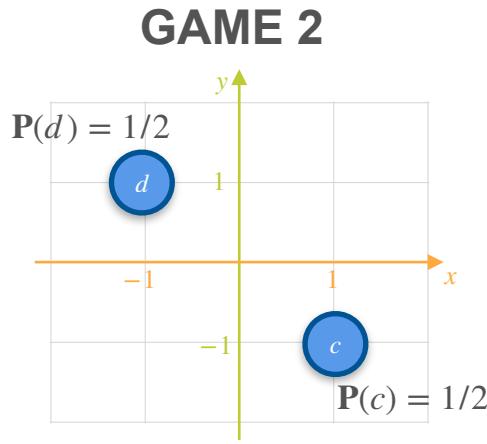
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$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	1

$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation



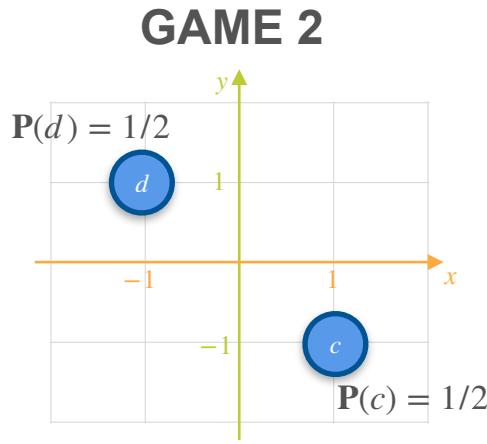
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$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	1

$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation



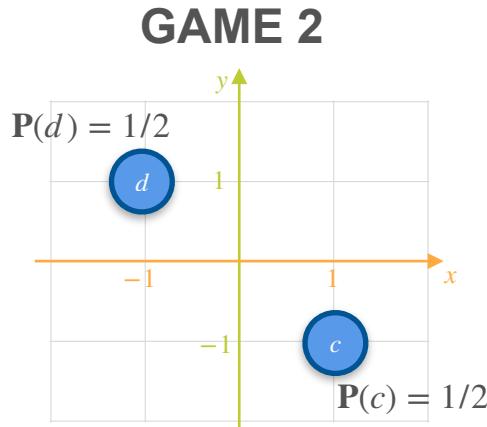
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

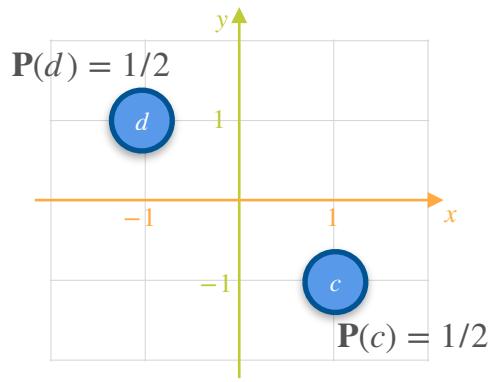
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

## GAME 2



$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

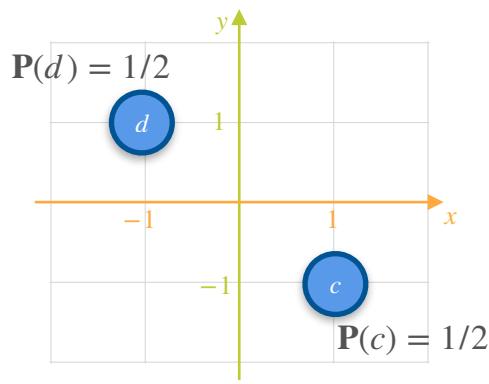
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

GAME 2



$$\mu_x = \mathbb{E}[X_2] = 0$$

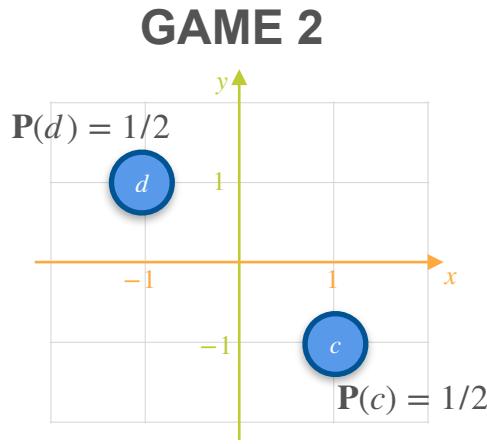
$$\mu_y = \mathbb{E}[Y_2] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$\sum (x_i - \mu_x)(y_i - \mu_y) = -2$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_2] = 0$$

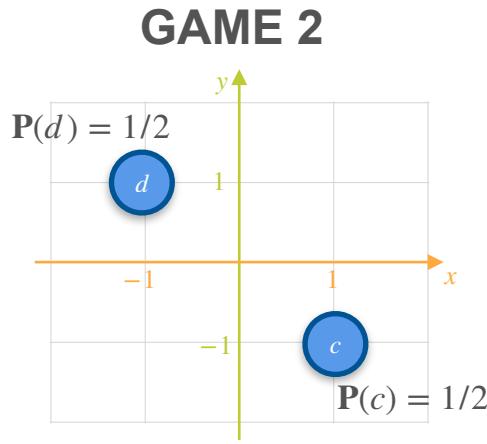
$$\mu_y = \mathbb{E}[Y_2] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$Cov(X, Y) = \sum (x_i - \mu_x)(y_i - \mu_y) = -2$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_2] = 0$$

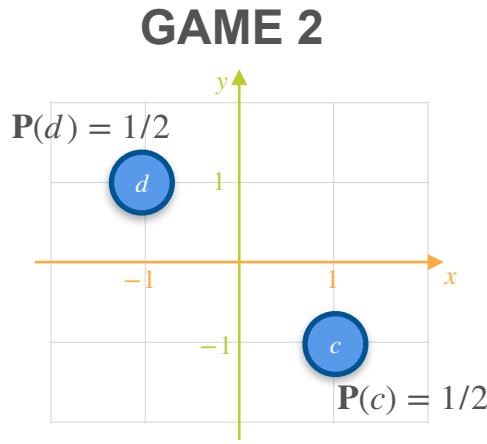
$$\mu_y = \mathbb{E}[Y_2] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = -2$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_2] = 0$$

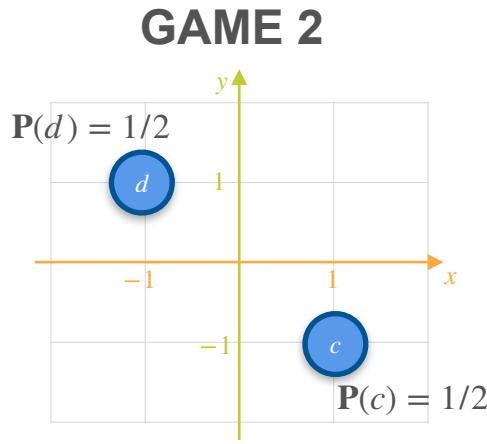
$$\mu_y = \mathbb{E}[Y_2] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{-2}{2}$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_2] = 0$$

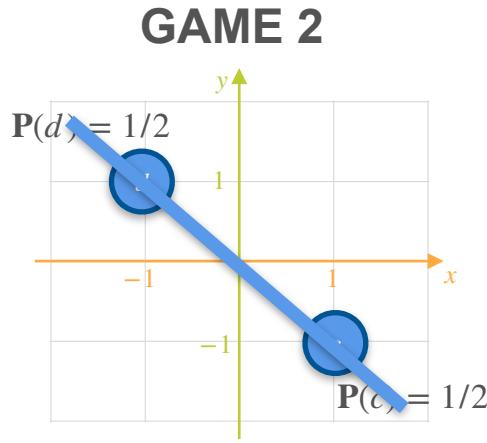
$$\mu_y = \mathbb{E}[Y_2] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{-2}{2} = -1$$

# Covariance of a Probability Distribution: Motivation



$$\mu_x = \mathbb{E}[X_2] = 0$$

$$\mu_y = \mathbb{E}[Y_2] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	-1	1	-1	-1
-1	1	-1	1	-1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{-2}{2} = -1$$

# Covariance of a Probability Distribution: Motivation

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

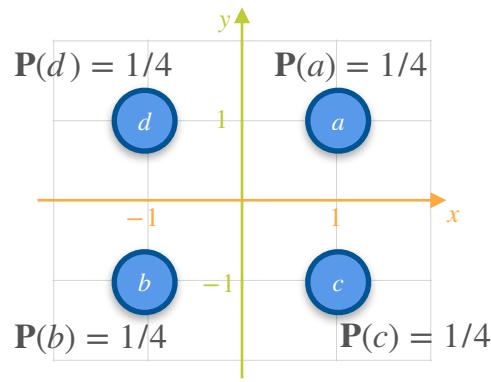
# Covariance of a Probability Distribution: Motivation

## GAME 3

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

# Covariance of a Probability Distribution: Motivation

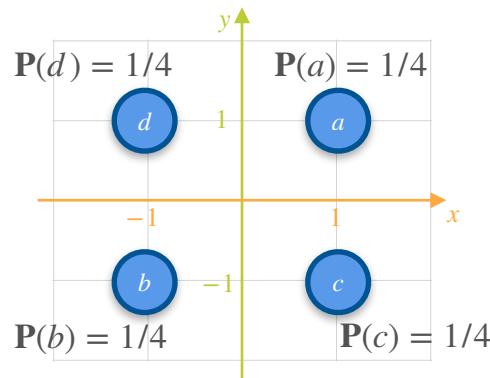
GAME 3



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

# Covariance of a Probability Distribution: Motivation

GAME 3

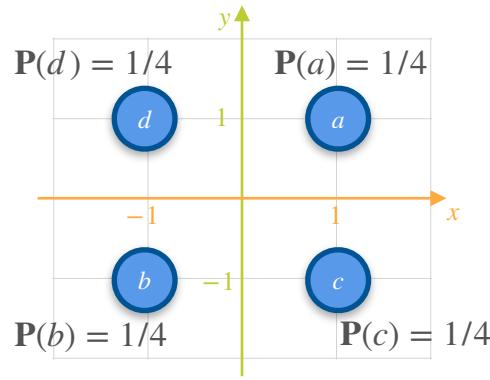


$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$\mu_x = \mathbb{E}[X_3] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



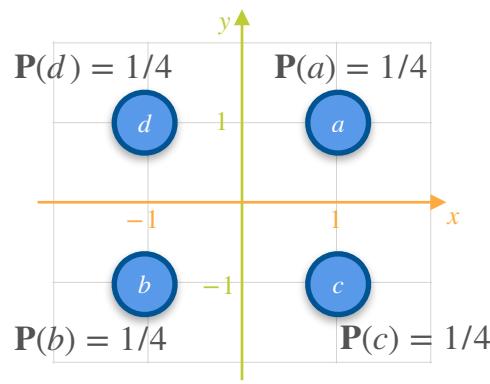
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



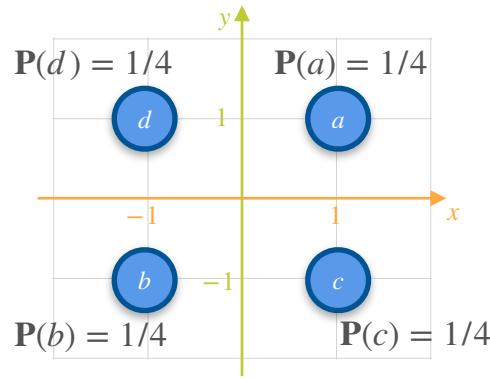
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

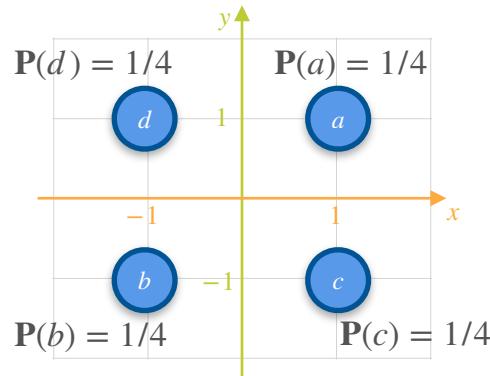
$$\mu_y = \mathbb{E}[Y_3] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1				
1				
-1				
-1				

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

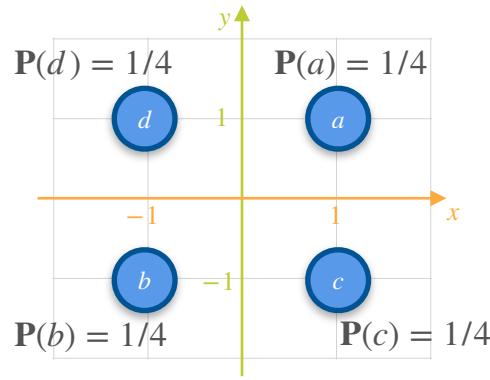
$$\mu_y = \mathbb{E}[Y_3] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	0	0	0
1	-1	0	-2	0
-1	1	-2	0	-2
-1	-1	-2	-2	4

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

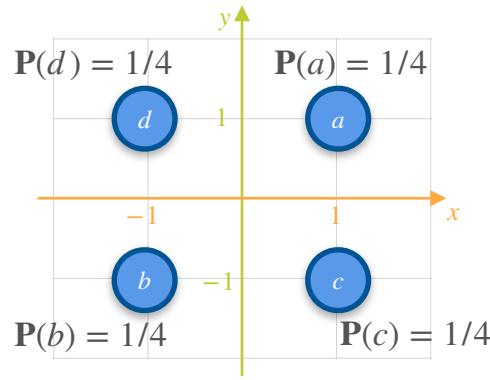
$$\mu_y = \mathbb{E}[Y_3] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	1	-1	-1
-1	1	-1	1	-1
-1	-1	-1	-1	1

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

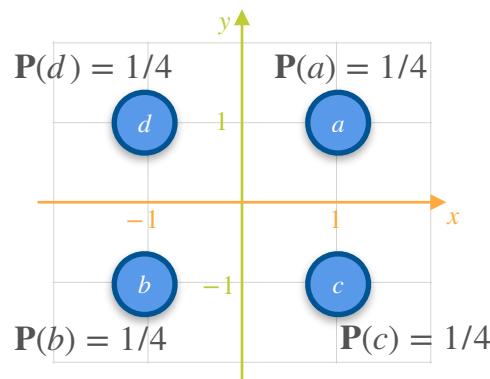
$$\mu_y = \mathbb{E}[Y_3] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	-1	1
-1	1	1	-1	-1
-1	-1	-1	-1	-1

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

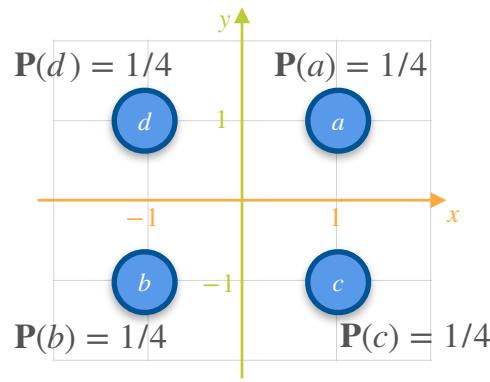
$$\mu_y = \mathbb{E}[Y_3] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

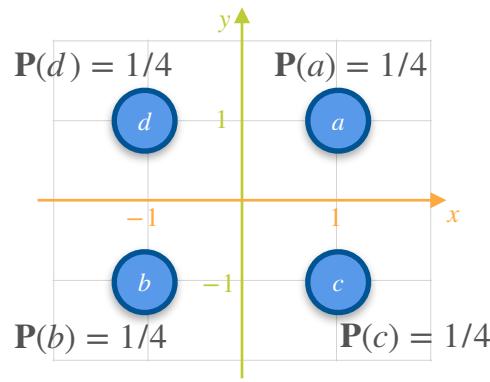
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

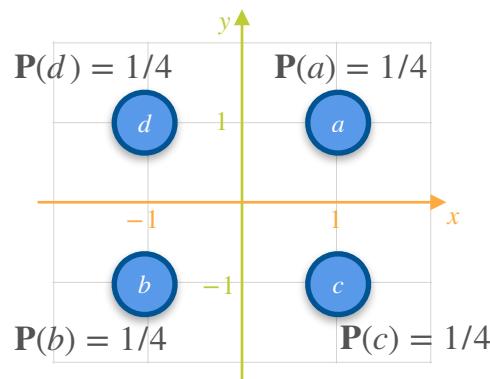
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) =$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

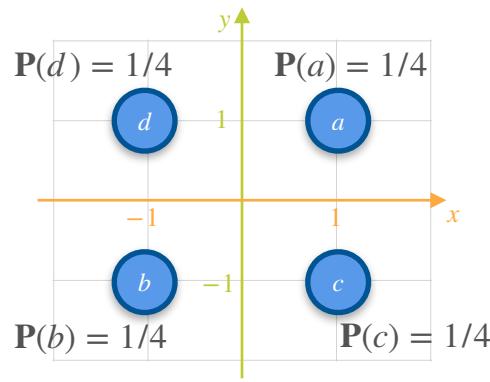
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

$$\sum (x_i - \mu_x)(y_i - \mu_y) = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

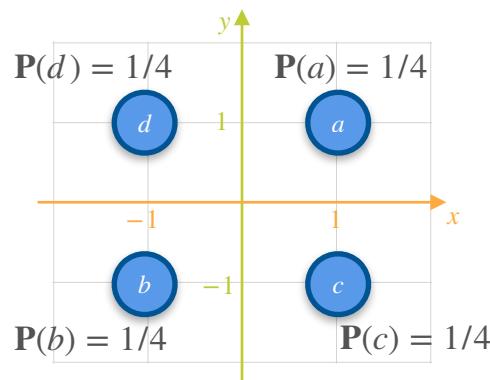
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

$$Cov(X, Y) = \sum (x_i - \mu_x)(y_i - \mu_y) = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

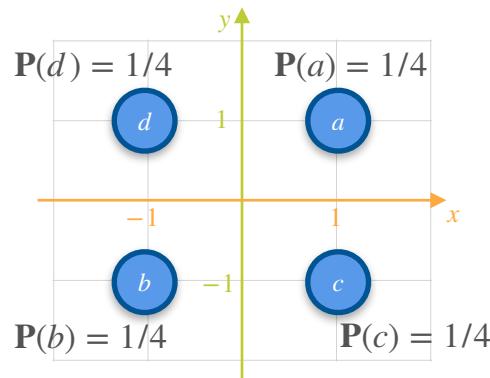
x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1



$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

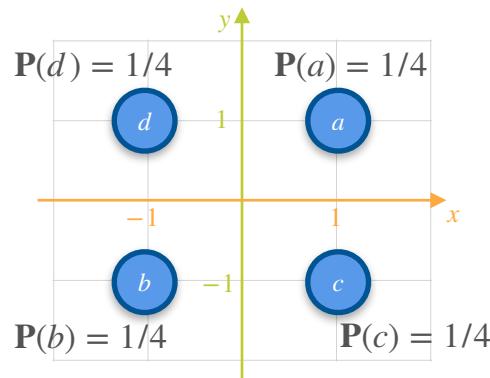
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{0}{4}$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

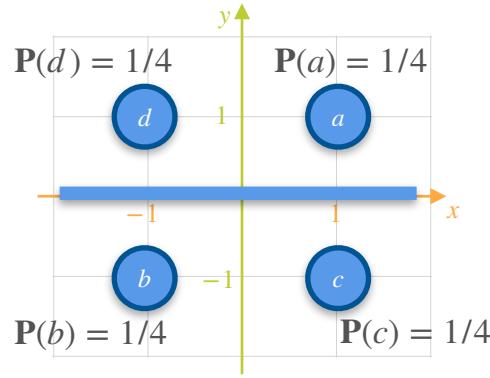
$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

x	y	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{0}{4} = 0$$

# Covariance of a Probability Distribution: Motivation

## GAME 3



$$\mu_x = \mathbb{E}[X_3] = 0$$

$$\mu_y = \mathbb{E}[Y_3] = 0$$

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

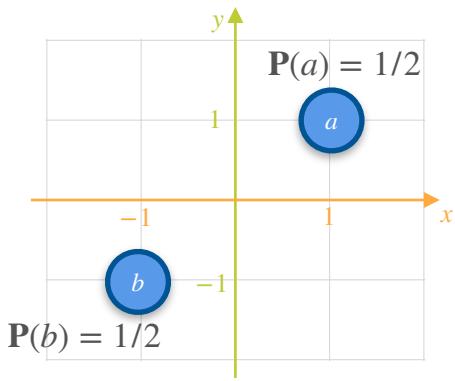
$x$	$y$	$(x_i - \mu_x)$	$(y_i - \mu_y)$	$(x_i - \mu_x)(y_i - \mu_y)$
1	1	1	1	1
1	-1	-1	1	-1
-1	1	1	-1	-1
-1	-1	-1	-1	1

$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n} = \frac{0}{4} = 0$$

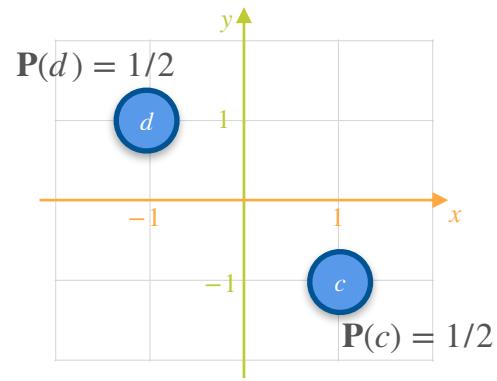
# Covariance of a Probability Distribution: Motivation

# Covariance of a Probability Distribution: Motivation

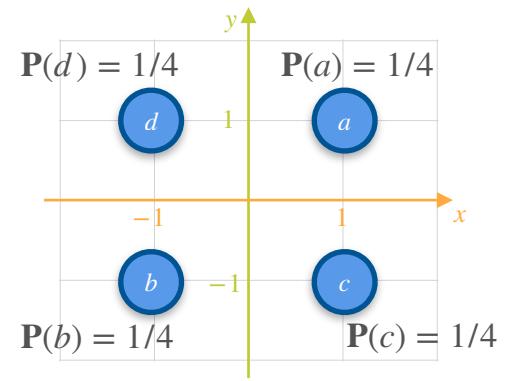
**GAME 1**



**GAME 2**

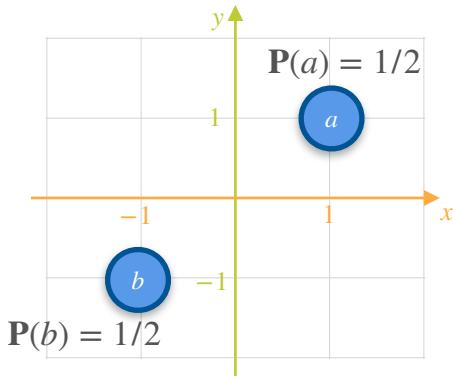


**GAME 3**



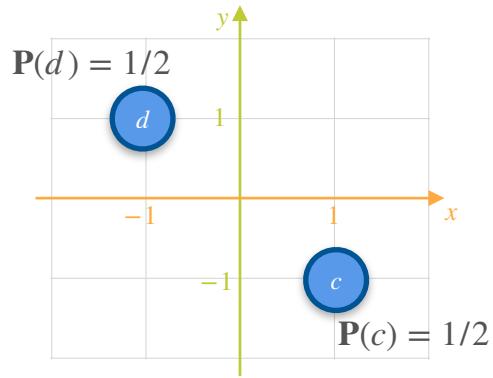
# Covariance of a Probability Distribution: Motivation

**GAME 1**



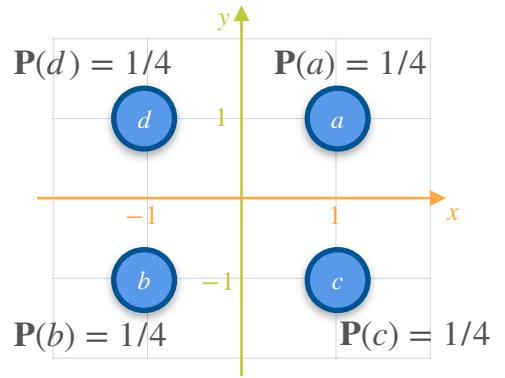
$$Cov(X, Y) = 1$$

**GAME 2**



$$Cov(X, Y) = -1$$

**GAME 3**



$$Cov(X, Y) = 0$$

# Covariance of a Probability Distribution: Motivation

# Covariance of a Probability Distribution: Motivation

**GAME 4**

# Covariance of a Probability Distribution: Motivation

## GAME 4

*a:* Both players win \$1 each

# Covariance of a Probability Distribution: Motivation

## GAME 4

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

# Covariance of a Probability Distribution: Motivation

## GAME 4

*a*: Both players win \$1 each

*b*: Both players lose \$1 each

*c*: Neither players wins nor lose anything

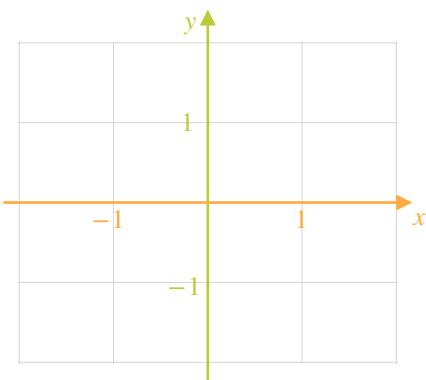
# Covariance of a Probability Distribution: Motivation

## GAME 4

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

$c$ : Neither players wins nor lose anything



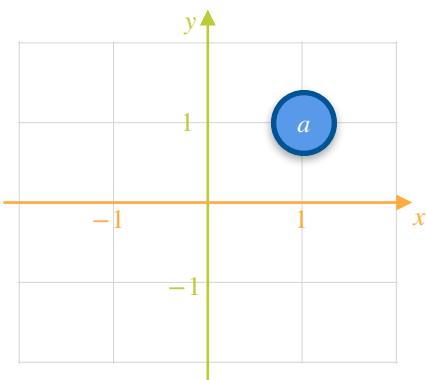
# Covariance of a Probability Distribution: Motivation

## GAME 4

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

$c$ : Neither players wins nor lose anything



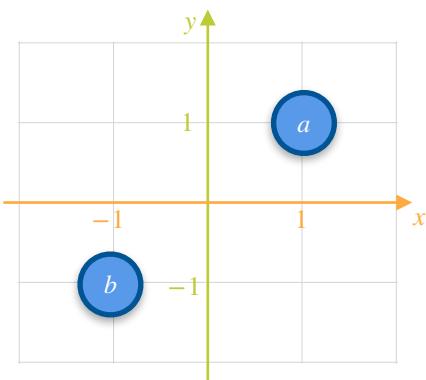
# Covariance of a Probability Distribution: Motivation

## GAME 4

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

$c$ : Neither players wins nor lose anything



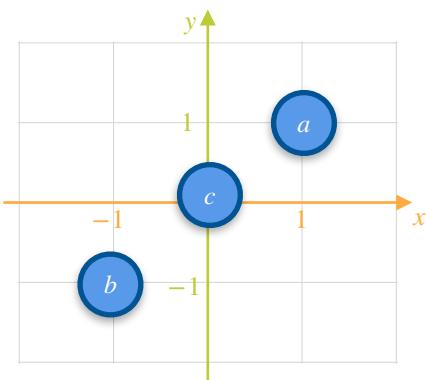
# Covariance of a Probability Distribution: Motivation

## GAME 4

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

$c$ : Neither players wins nor lose anything



# Covariance of a Probability Distribution: Motivation

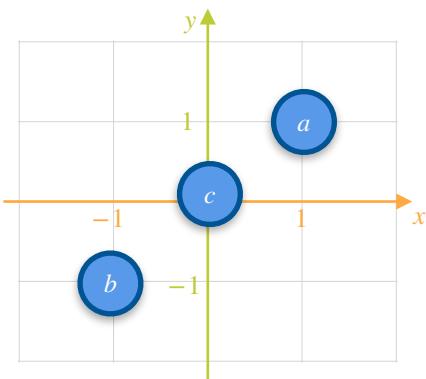
## GAME 4

$a$ : Both players win \$1 each

$b$ : Both players lose \$1 each

$c$ : Neither players wins nor lose anything

Unequal Probabilities



# Covariance of a Probability Distribution: Motivation

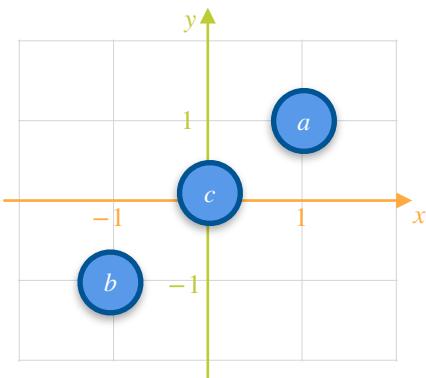
## GAME 4

$a$ : Both players win \$1 each     $P(a) = 1/2$

$b$ : Both players lose \$1 each

$c$ : Neither players wins nor lose anything

Unequal Probabilities



# Covariance of a Probability Distribution: Motivation

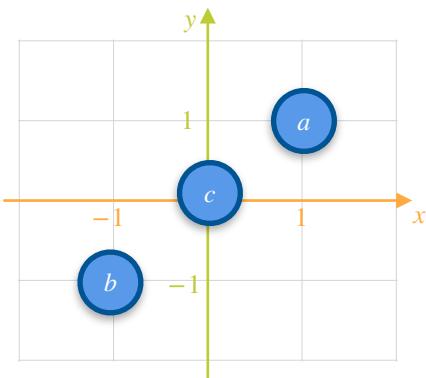
## GAME 4

$a$ : Both players win \$1 each    $P(a) = 1/2$

$b$ : Both players lose \$1 each    $P(b) = 1/3$

$c$ : Neither players wins nor lose anything

Unequal Probabilities



# Covariance of a Probability Distribution: Motivation

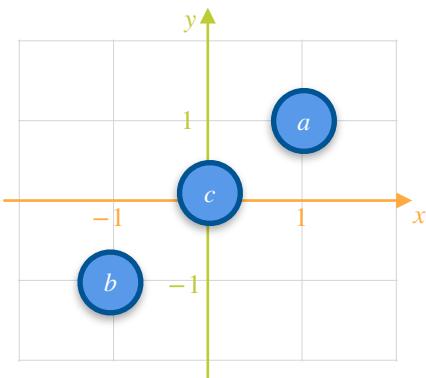
## GAME 4

$a$ : Both players win \$1 each  $P(a) = 1/2$

$b$ : Both players lose \$1 each  $P(b) = 1/3$

$c$ : Neither players wins nor lose anything  $P(c) = 1/6$

Unequal Probabilities



# Covariance of a Probability Distribution: Motivation

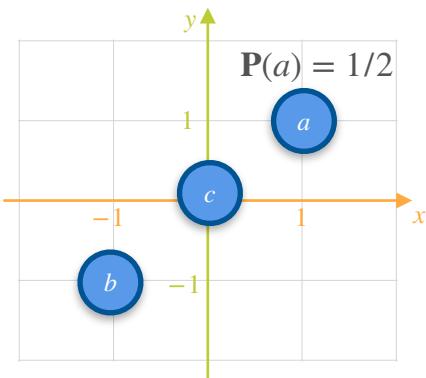
## GAME 4

$a$ : Both players win \$1 each  $P(a) = 1/2$

$b$ : Both players lose \$1 each  $P(b) = 1/3$

$c$ : Neither players wins nor lose anything  $P(c) = 1/6$

Unequal Probabilities



# Covariance of a Probability Distribution: Motivation

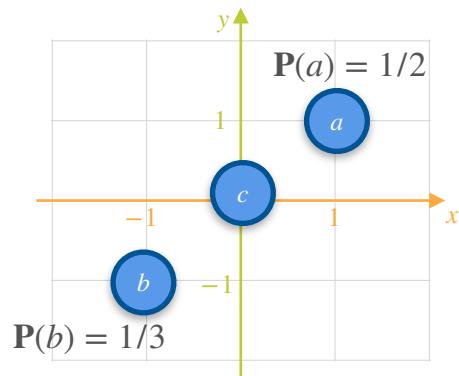
## GAME 4

$a$ : Both players win \$1 each  $P(a) = 1/2$

$b$ : Both players lose \$1 each  $P(b) = 1/3$

$c$ : Neither players wins nor lose anything  $P(c) = 1/6$

Unequal Probabilities



# Covariance of a Probability Distribution: Motivation

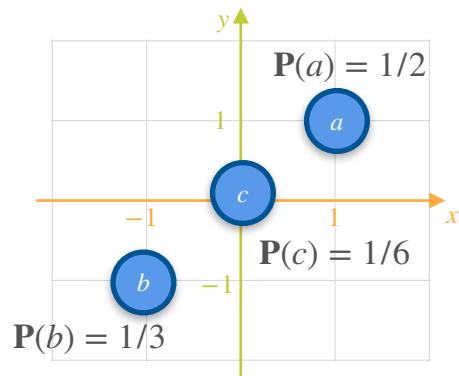
## GAME 4

$a$ : Both players win \$1 each  $P(a) = 1/2$

$b$ : Both players lose \$1 each  $P(b) = 1/3$

$c$ : Neither players wins nor lose anything  $P(c) = 1/6$

Unequal Probabilities



# Covariance of a Probability Distribution: Motivation

## GAME 4

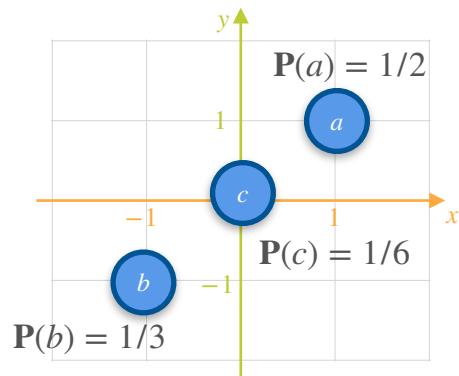
a: Both players win \$1 each  $P(a) = 1/2$

b: Both players lose \$1 each  $P(b) = 1/3$

c: Neither players wins nor lose anything  $P(c) = 1/6$

Unequal Probabilities

$$\mathbb{E}[X_4] =$$



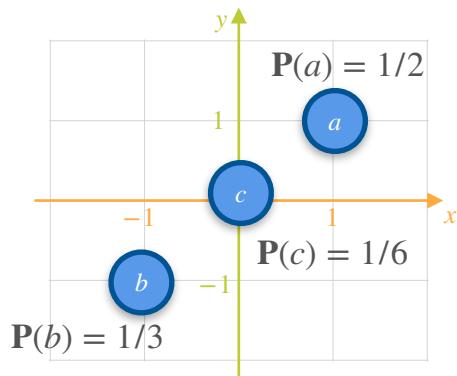
# Covariance of a Probability Distribution: Motivation

## GAME 4

a: Both players win \$1 each  $P(a) = 1/2$

b: Both players lose \$1 each  $P(b) = 1/3$

c: Neither players wins nor lose anything  $P(c) = 1/6$



### Unequal Probabilities

$$\mathbb{E}[X_4] = \frac{1}{2}(1) + \frac{1}{6}(0) + \frac{1}{3}(-1) =$$

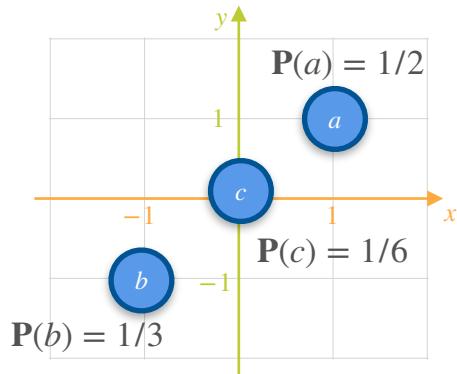
# Covariance of a Probability Distribution: Motivation

## GAME 4

a: Both players win \$1 each  $P(a) = 1/2$

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### Unequal Probabilities

$$\mathbb{E}[X_4] = \frac{1}{2}(1) + \frac{1}{6}(0) + \frac{1}{3}(-1) = \frac{1}{6}$$

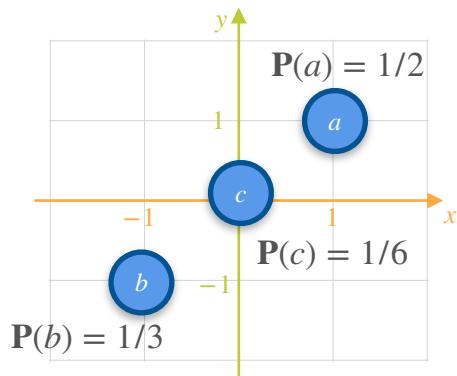
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$$\mathbb{E}[X_4] = \frac{1}{2}(1) + \frac{1}{6}(0) + \frac{1}{3}(-1) = \frac{1}{6}$$

$$\mathbb{E}[Y_4] =$$

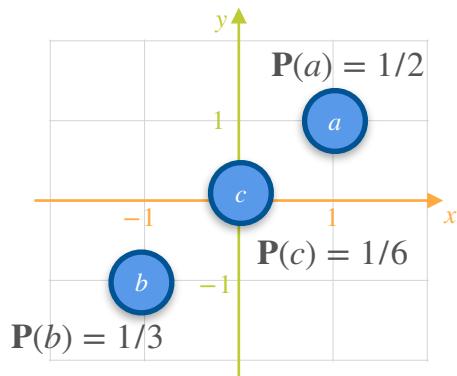
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### Unequal Probabilities

$$\mathbb{E}[X_4] = \frac{1}{2}(1) + \frac{1}{6}(0) + \frac{1}{3}(-1) = \frac{1}{6}$$

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# Covariance of a Probability Distribution: Motivation

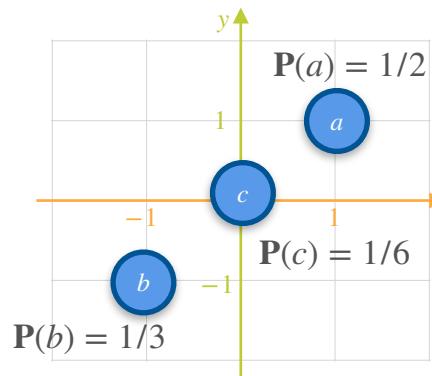
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Unequal Probabilities



$$\mathbb{E}[X_4] = \frac{1}{6}$$

$$\mathbb{E}[Y_4] = \frac{1}{6}$$

# Covariance of a Probability Distribution: Motivation

## GAME 4

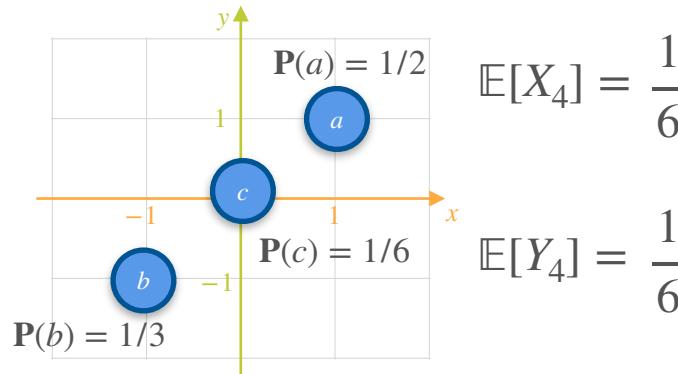
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$$Var(X_4) =$$



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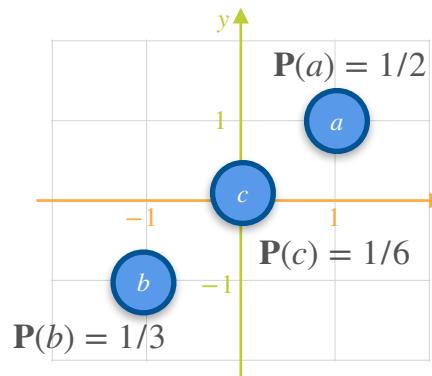
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$$\mathbb{E}[X_4] = \frac{1}{6}$$

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### Unequal Probabilities

$$Var(X_4) = \sum_{n=1}^N (\mathbb{E}[X_4] - \mu_x)^2 \cdot \mathbf{P}(x_i)$$

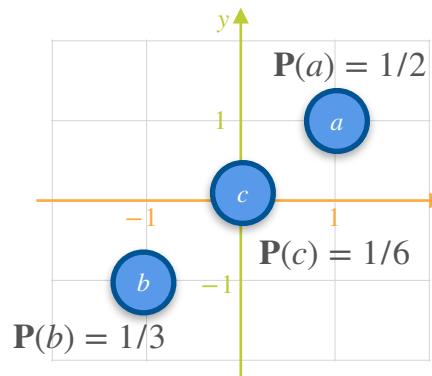
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### Unequal Probabilities

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$$\mathbb{E}[X_4] = \frac{1}{6} \quad \text{Var}(X_4) =$$

$$\mathbb{E}[Y_4] = \frac{1}{6}$$

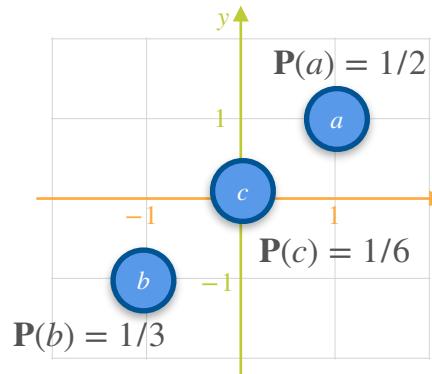
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$$\mathbb{E}[X_4] = \frac{1}{6}$$

$$\text{Var}(X_4) = \frac{1}{2}\left(1 - \frac{1}{6}\right)^2 + \frac{1}{6}\left(0 - \frac{1}{6}\right)^2 + \frac{1}{3}\left(-1 - \frac{1}{6}\right)^2$$

$$\mathbb{E}[Y_4] = \frac{1}{6}$$

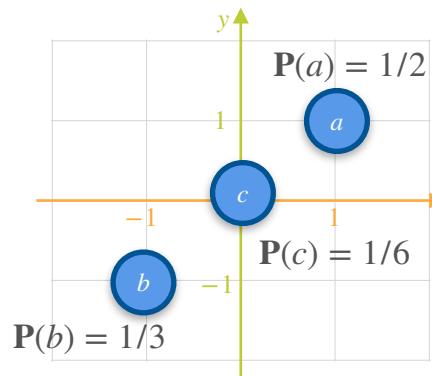
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$$\mathbb{E}[Y_4] = \frac{1}{6}$$

$$= 0.806$$

# Covariance of a Probability Distribution: Motivation

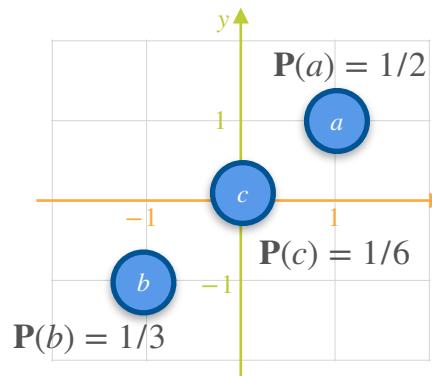
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### Unequal Probabilities



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# Covariance of a Probability Distribution: Motivation

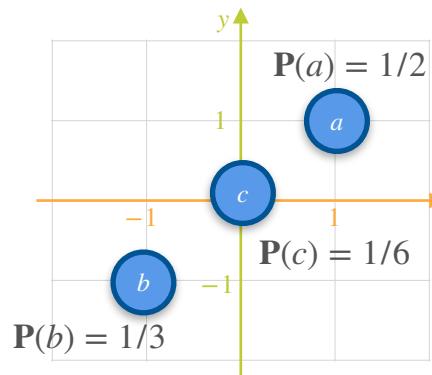
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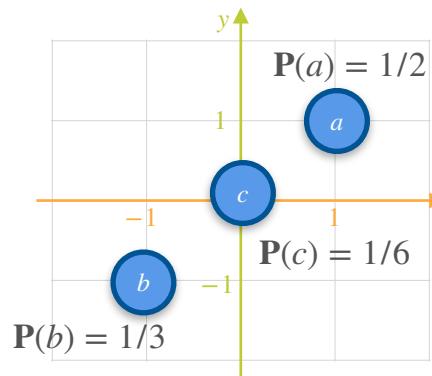
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Unequal Probabilities

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$$\mathbb{E}[Y_4] = \frac{1}{6} \quad \text{Var}(Y_4) = 0.806$$

$\text{Cov}(X, Y) = ?$

# Covariance of Probability Distributions

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$$Cov(X, Y) = \frac{\sum (x_i - \mu_x)(y_i - \mu_y)}{n}$$

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**equal probabilities**

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$$Cov(X, Y) = \sum p_{XY}(x_i, y_i)(x_i - \mu_x)(y_i - \mu_y)$$

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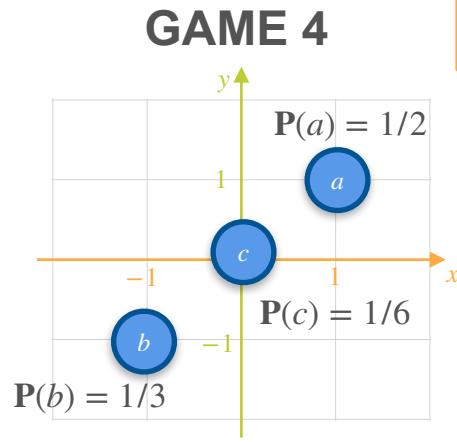
equal probabilities

$$Cov(X, Y) = \sum p_{XY}(x_i, y_i)(x_i - \mu_x)(y_i - \mu_y)$$

unequal probabilities

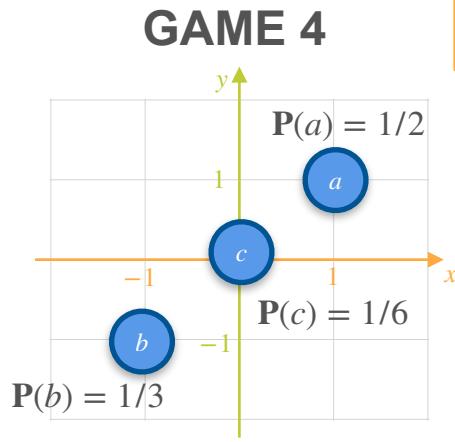
$$Cov(X, Y) = \mathbb{E}[XY] - \mathbb{E}[X]\mathbb{E}[Y]$$

# Covariance of a Probability Distribution: Motivation



Unequal Probabilities

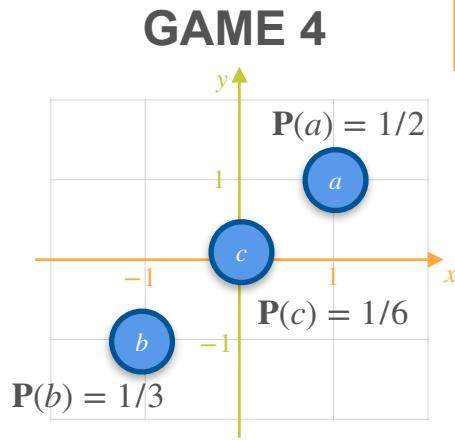
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**Unequal Probabilities**

$$Cov(X, Y) = \sum p_{XY}(x_i, y_i)(x_i - \mu_x)(y_i - \mu_y) = \mathbb{E}[XY] - \mathbb{E}[X]\mathbb{E}[Y]$$

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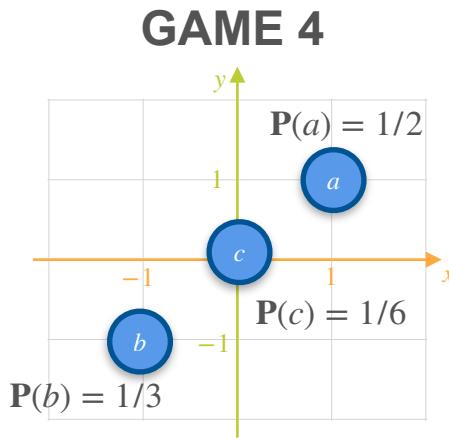


**Unequal Probabilities**

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$$\mu_x = \mu_y = \mathbb{E}[X_4] = \mathbb{E}[Y_4] = 1/6$$

# Covariance of a Probability Distribution: Motivation



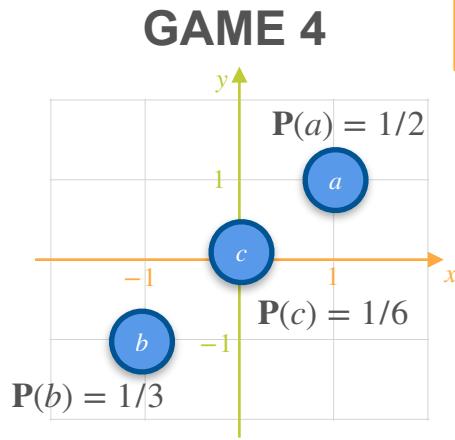
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# Covariance of a Probability Distribution: Motivation



## Unequal Probabilities

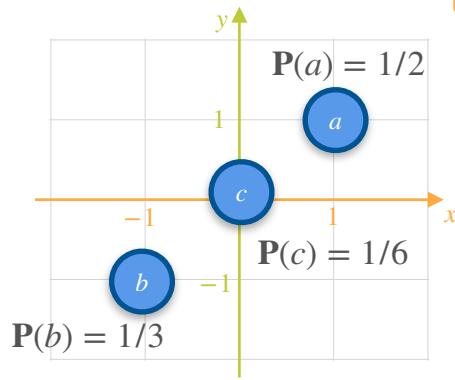
$$\begin{aligned} \text{Cov}(X, Y) &= \sum p_{XY}(x_i, y_i)(x_i - \mu_x)(y_i - \mu_y) = \mathbb{E}[XY] - \mathbb{E}[X]\mathbb{E}[Y] \\ &= \frac{1}{2}\left(1 - \frac{1}{6}\right)^2 + \frac{1}{6}\left(0 - \frac{1}{6}\right)^2 + \frac{1}{3}\left(-1 - \frac{1}{6}\right)^2 \end{aligned}$$

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# Covariance of a Probability Distribution: Motivation

GAME 4



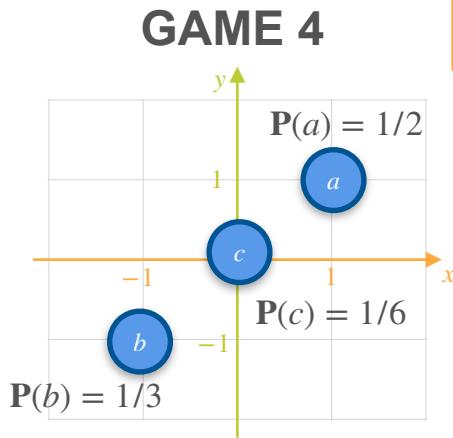
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# Covariance of a Probability Distribution: Motivation



**Unequal Probabilities**

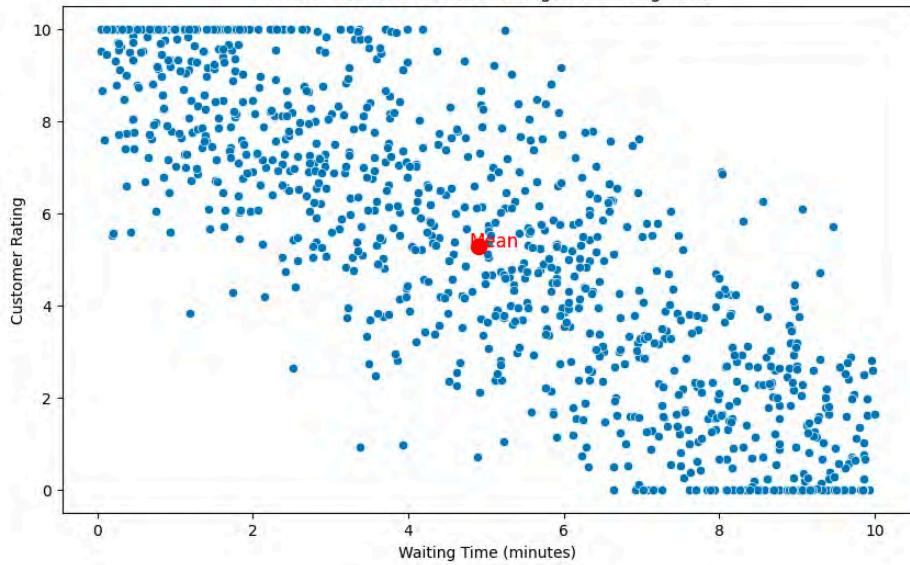
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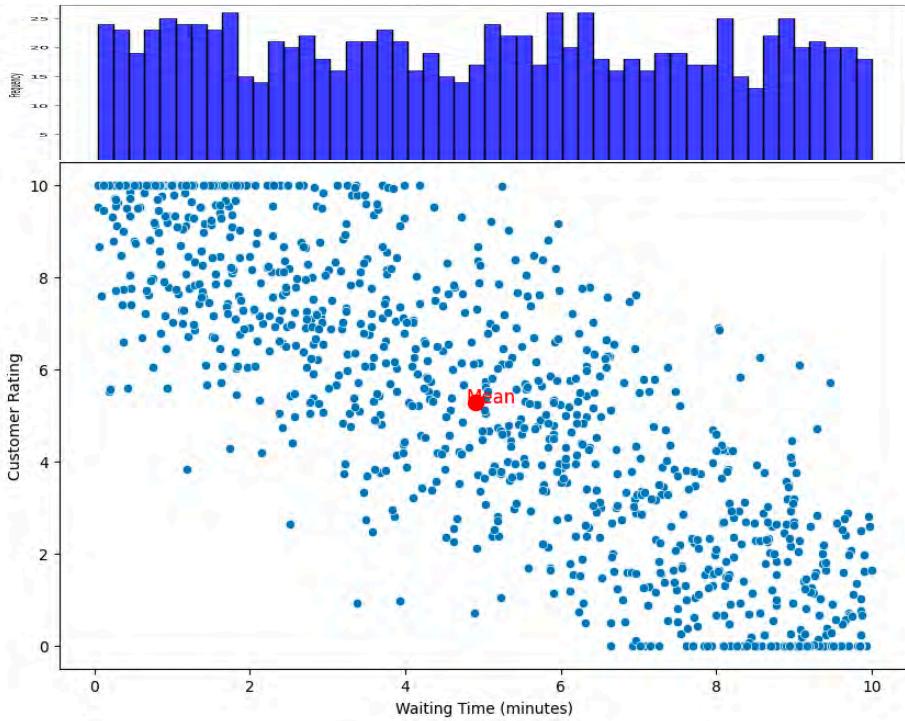
$$\text{Var}(X_4) = \text{Var}(Y_4) = 0.806$$

$$\text{Cov}(X, Y) = 0.806$$

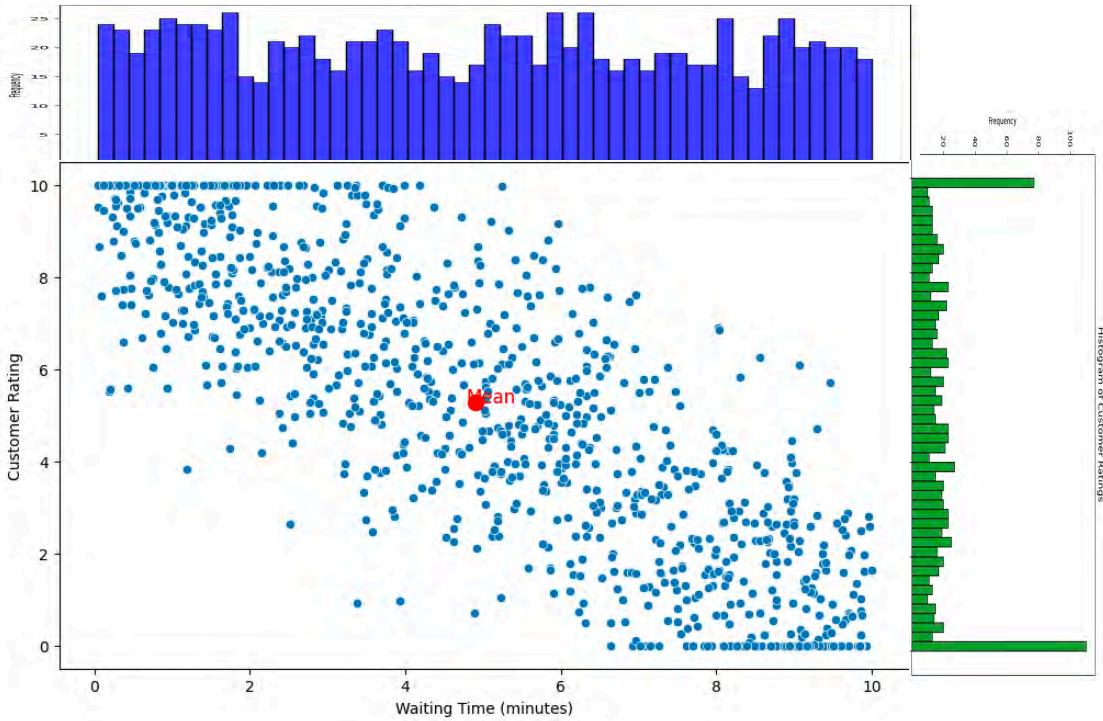
# Covariance?



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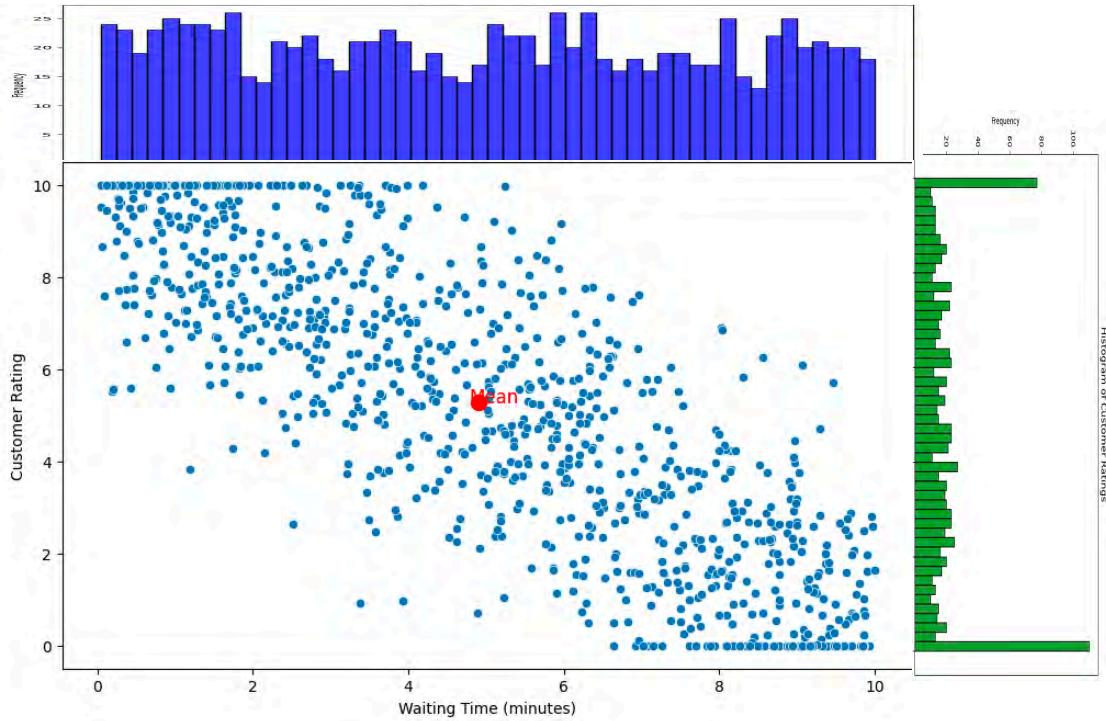


# Covariance?



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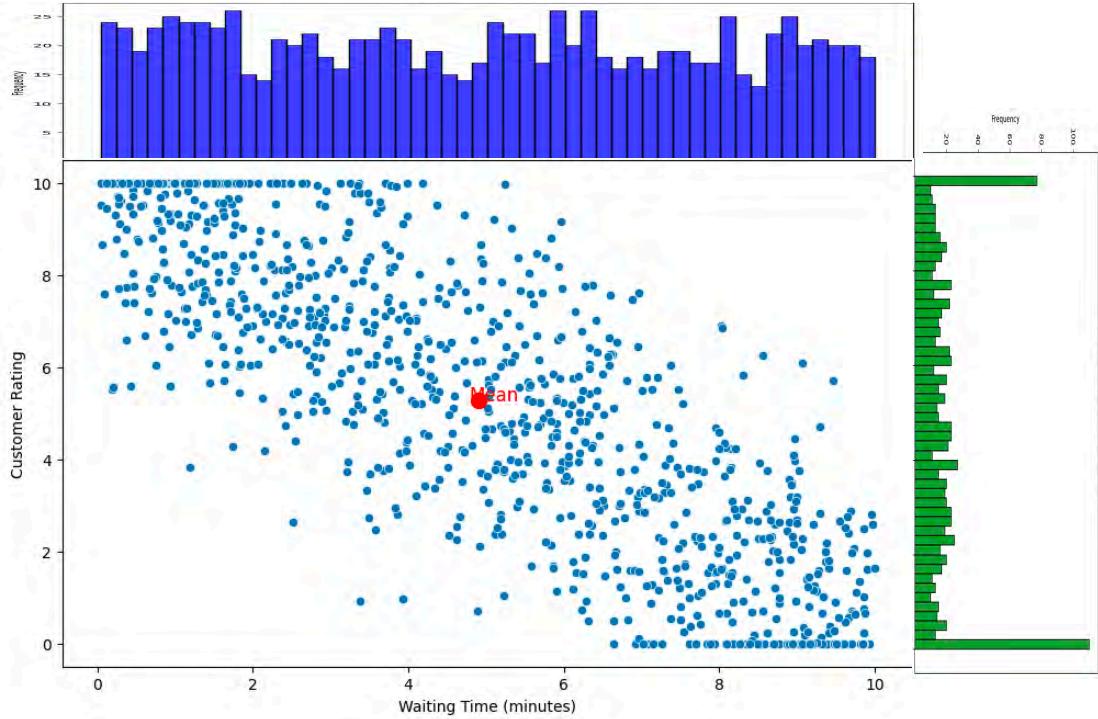
$$\text{Cov}(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$



# Covariance?

$$\text{Cov}(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

$$\text{Cov}(X, Y) = 18.014 - (4.903)(5.280)$$

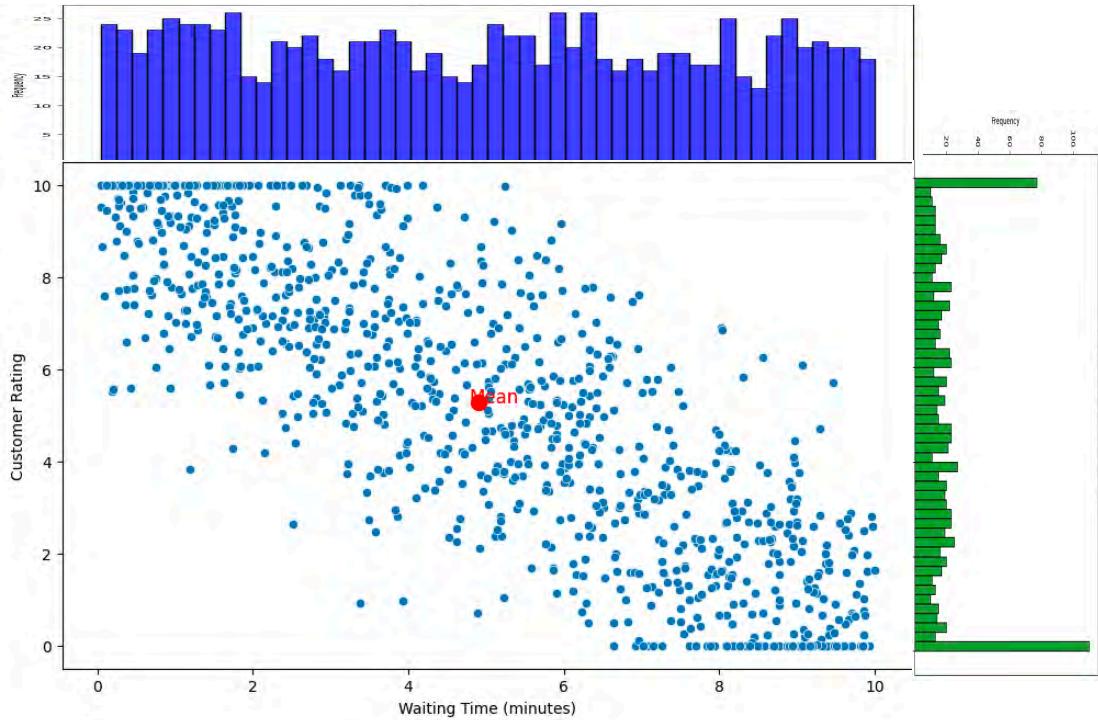


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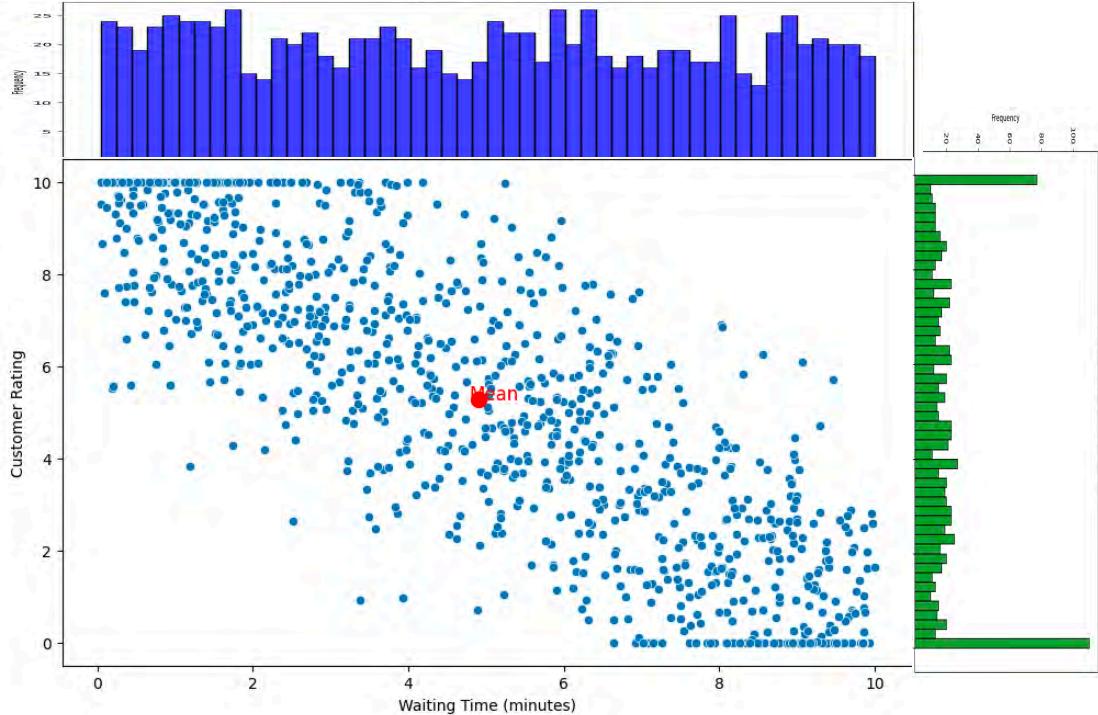
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$$\text{Cov}(X, Y) = -7.878$$



# Covariance?

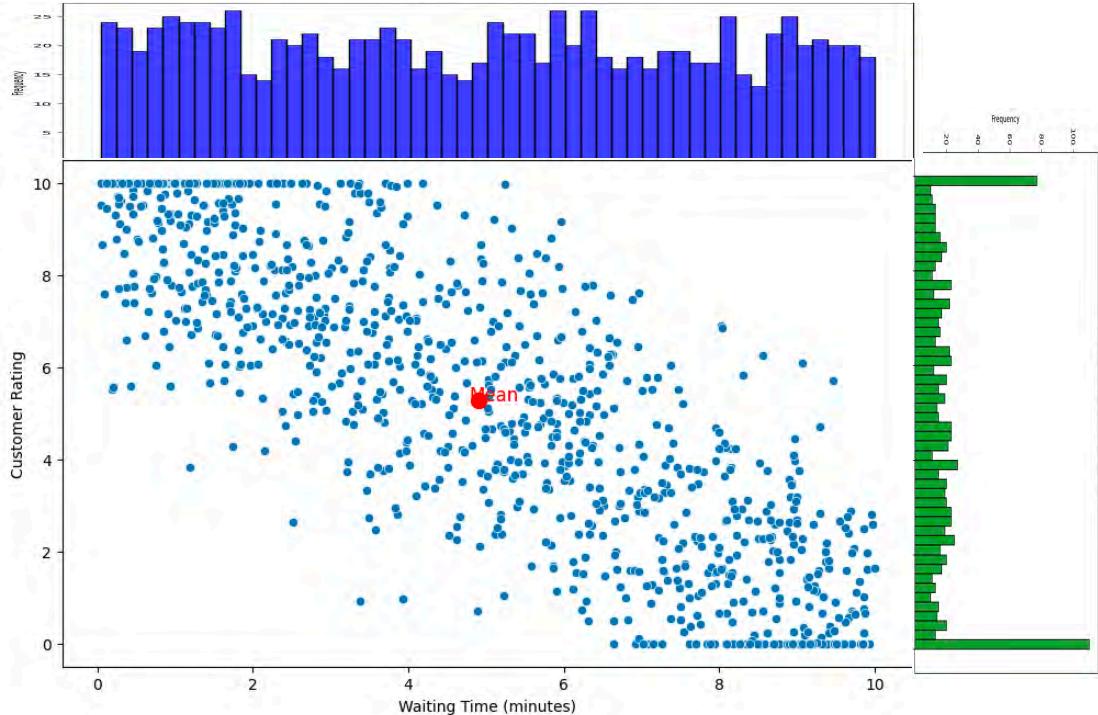
$$\mathbb{E}(X) = 4.903$$

$$Cov(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

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# Covariance?

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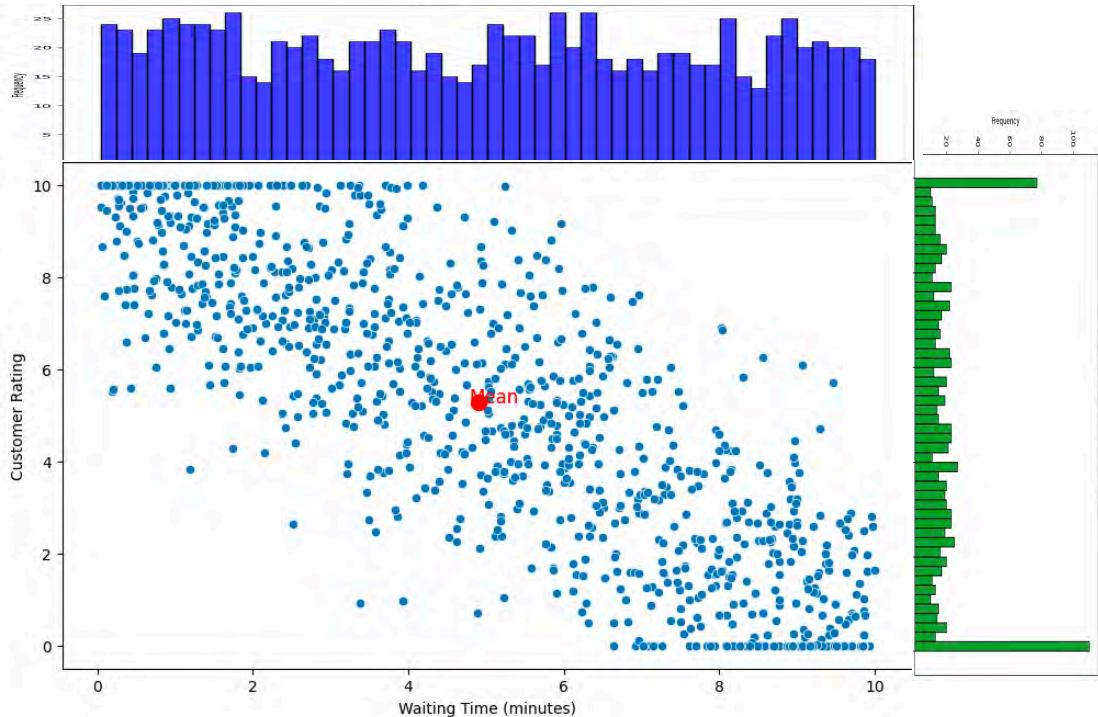
$$\mathbb{E}(Y) = 5.280$$

$$Cov(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

$$Cov(X, Y) = 18.014 - (4.903)(5.280)$$

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# Covariance?

$$\mathbb{E}(X) = 4.903$$

$$\mathbb{E}(Y) = 5.280$$

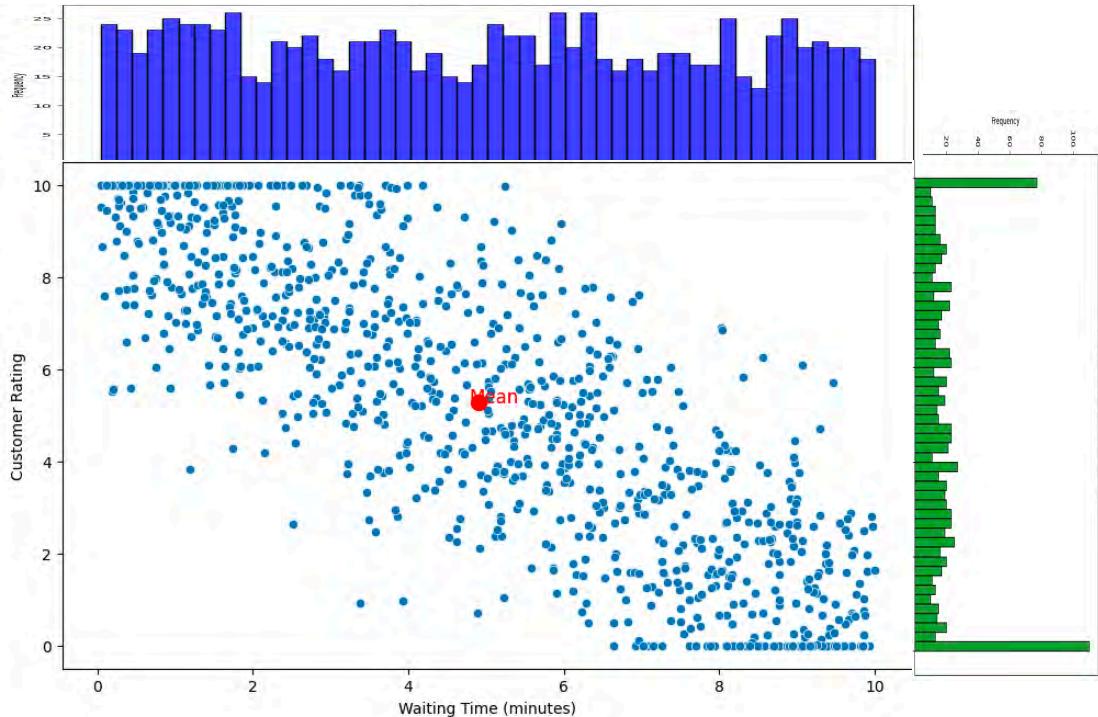
$$\mathbb{E}(XY) = 18.014$$

$$Cov(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

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# Covariance of a Joint Continuous Distribution

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$$Cov(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

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$$Cov(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

$$\mathbb{E}(X) = 4.903$$

$$\mathbb{E}(Y) = 5.280$$

$$\mathbb{E}(XY) = 18.014$$

# Covariance of a Joint Continuous Distribution

$$Cov(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

$$\mathbb{E}(X) = 4.903$$

$$Cov(X, Y) = 18.014 - (4.903)(5.280)$$

$$\mathbb{E}(Y) = 5.280$$

$$\mathbb{E}(XY) = 18.014$$

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$$Cov(X, Y) = \mathbb{E}(XY) - \mathbb{E}(X)\mathbb{E}(Y)$$

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$$Cov(X, Y) = 18.014 - (4.903)(5.280)$$

$$\mathbb{E}(Y) = 5.280$$

$$Cov(X, Y) = 18.014 - (4.903)(5.280)$$

$$\mathbb{E}(XY) = 18.014$$

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$$Cov(X, Y) = 18.014 - (4.903)(5.280)$$

$$\mathbb{E}(Y) = 5.280$$

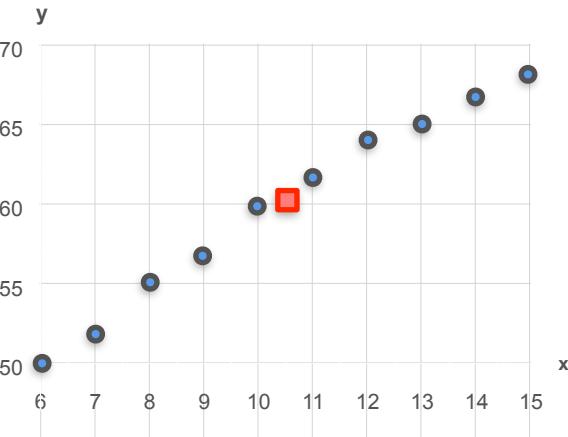
$$Cov(X, Y) = 18.014 - (4.903)(5.280)$$

$$\mathbb{E}(XY) = 18.014$$

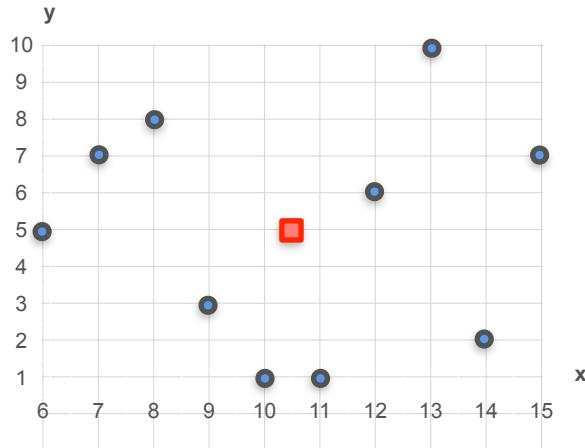
$$Cov(X, Y) = -7.878$$

# Covariance Matrix

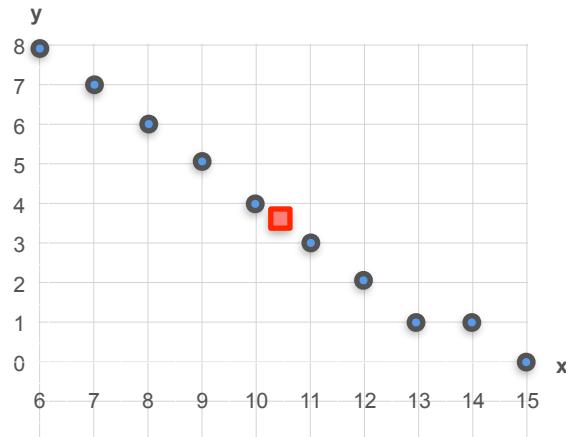
# Covariance Matrix



Age vs Height

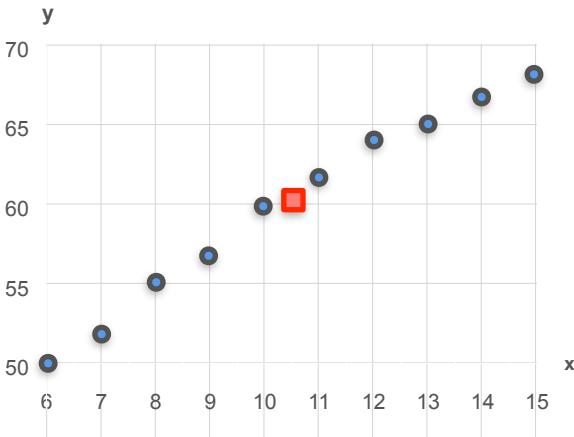


Age vs Grades



Age vs Naps per Day

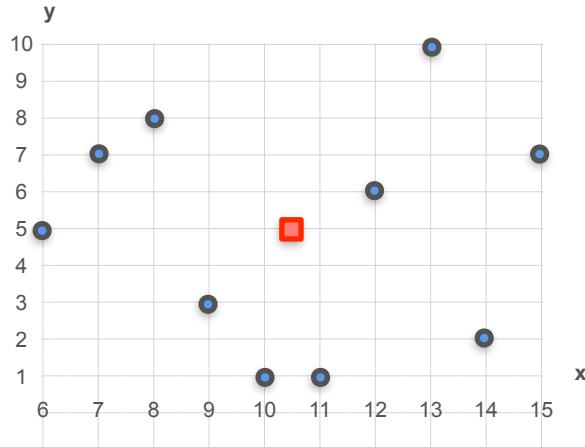
# Covariance Matrix



**Age vs Height**

$$\text{Var}(X) = 9.17$$

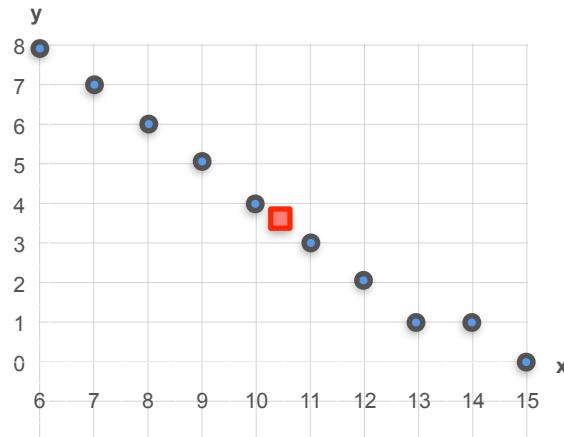
$$\text{Var}(Y) = 39.56$$



**Age vs Grades**

$$\text{Var}(X) = 9.17$$

$$\text{Var}(Y) = 9.78$$

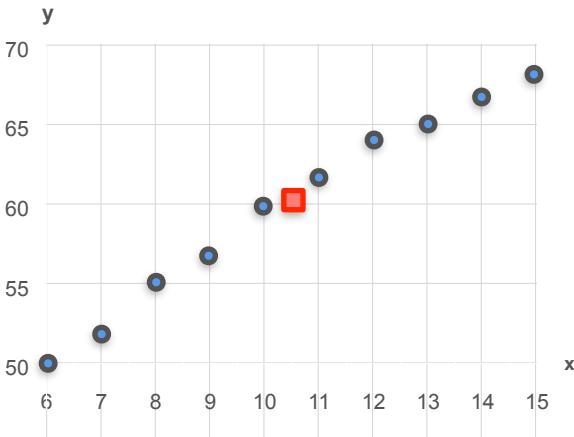


**Age vs Naps per Day**

$$\text{Var}(X) = 9.17$$

$$\text{Var}(Y) = 7.57$$

# Covariance Matrix

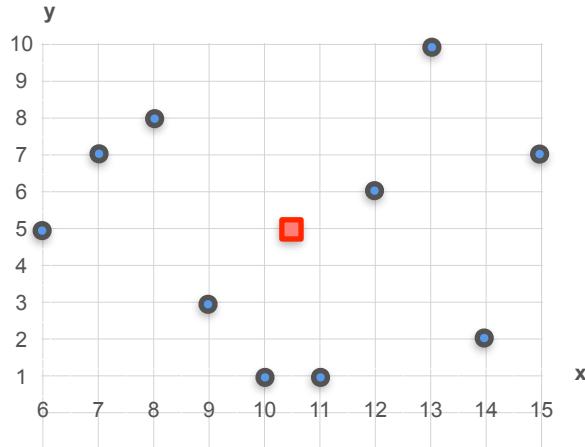


**Age vs Height**

$$\text{Var}(X) = 9.17$$

$$\text{Var}(Y) = 39.56$$

$$\text{Cov}(X, Y) = 17$$

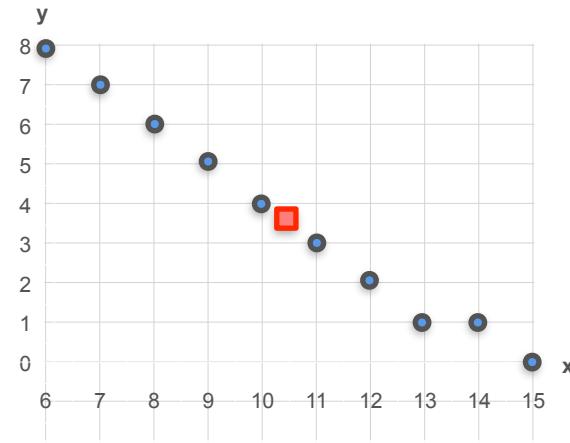


**Age vs Grades**

$$\text{Var}(X) = 9.17$$

$$\text{Var}(Y) = 9.78$$

$$\text{Cov}(X, Y) = 0.1$$



**Age vs Naps per Day**

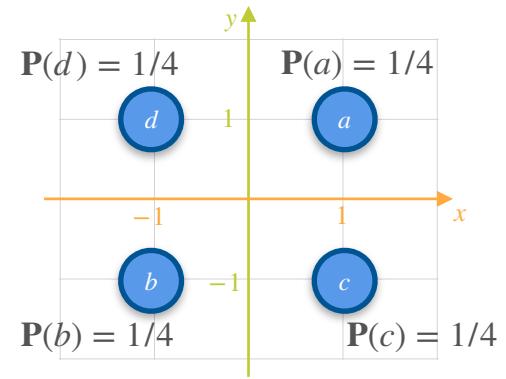
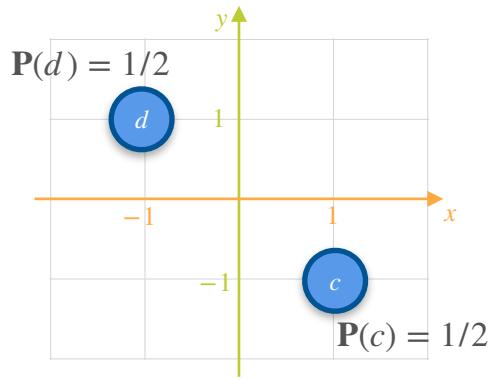
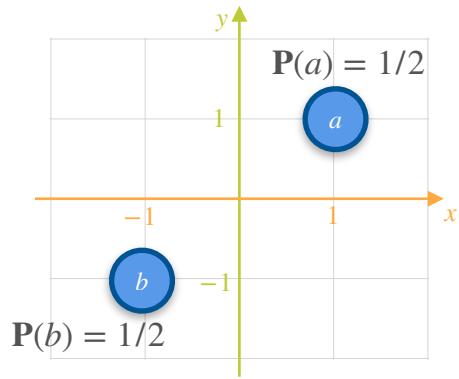
$$\text{Var}(X) = 9.17$$

$$\text{Var}(Y) = 7.57$$

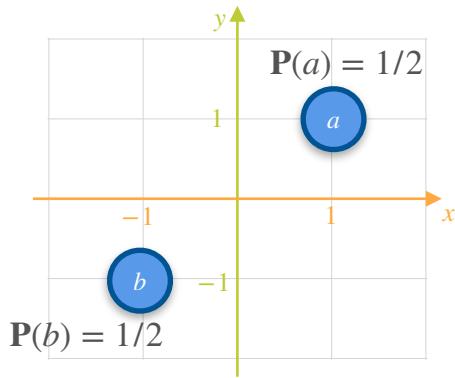
$$\text{Cov}(X, Y) = -7.45$$

# Covariance Matrix

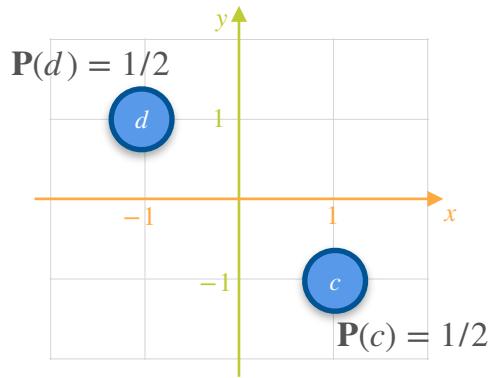
# Covariance Matrix



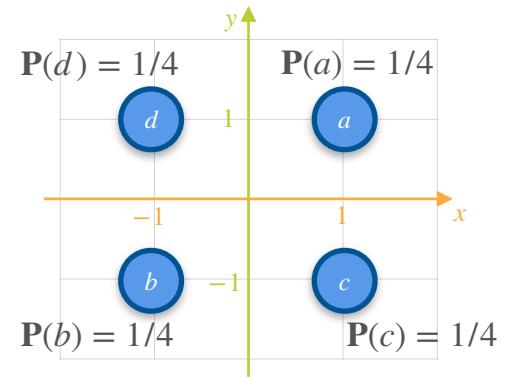
# Covariance Matrix



$$\text{Var}(X) = \text{Var}(Y) = 1$$

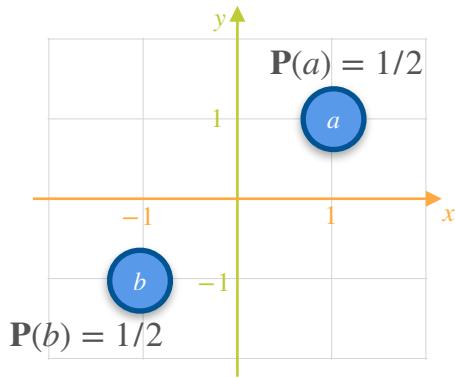


$$\text{Var}(X) = \text{Var}(Y) = 1$$



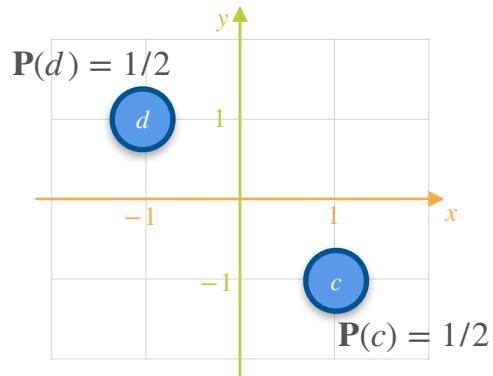
$$\text{Var}(X) = \text{Var}(Y) = 1$$

# Covariance Matrix



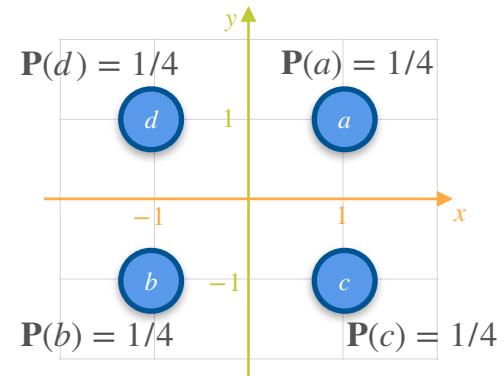
$$Var(X) = Var(Y) = 1$$

$$Cov(X, Y) = 1$$



$$Var(X) = Var(Y) = 1$$

$$Cov(X, Y) = -1$$

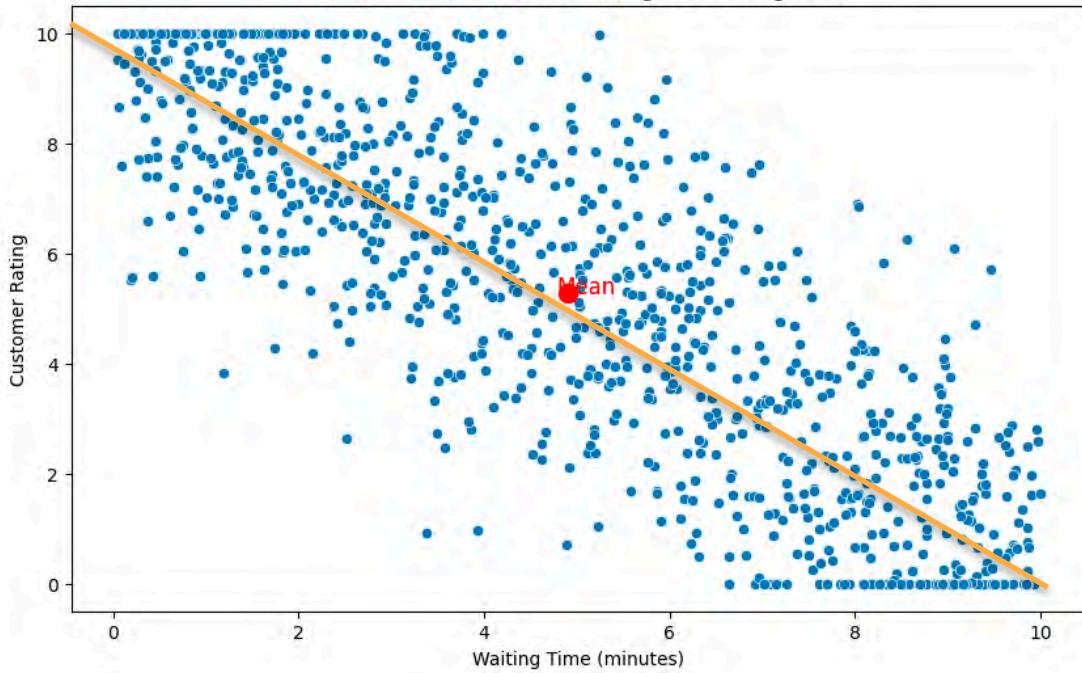


$$Var(X) = Var(Y) = 1$$

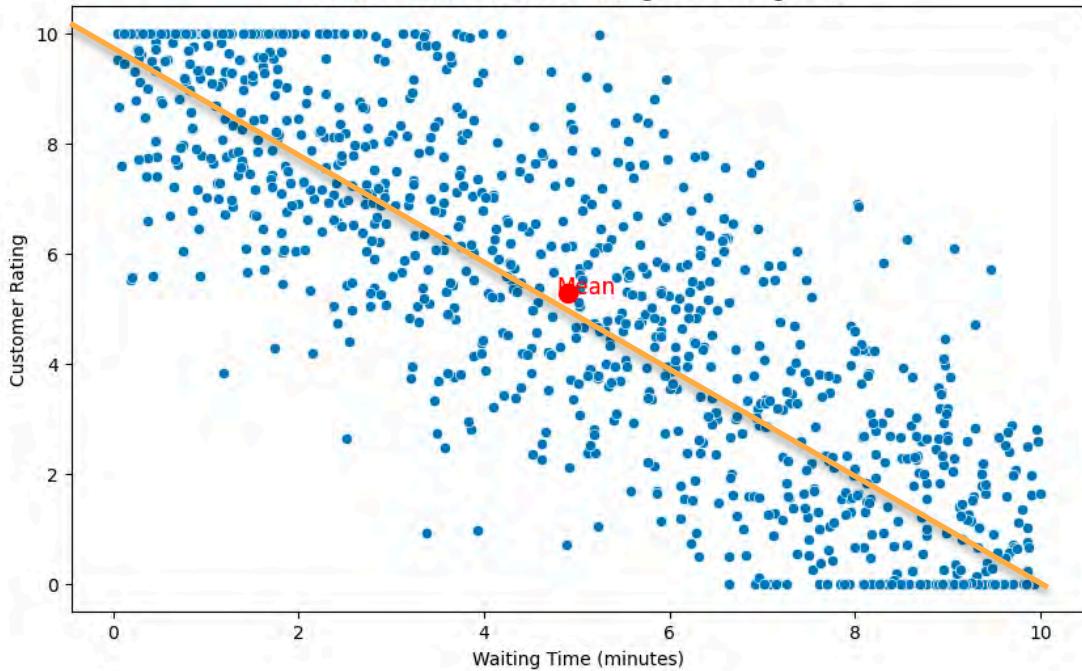
$$Cov(X, Y) = 0$$

# Covariance Matrix

# Covariance Matrix



# Covariance Matrix

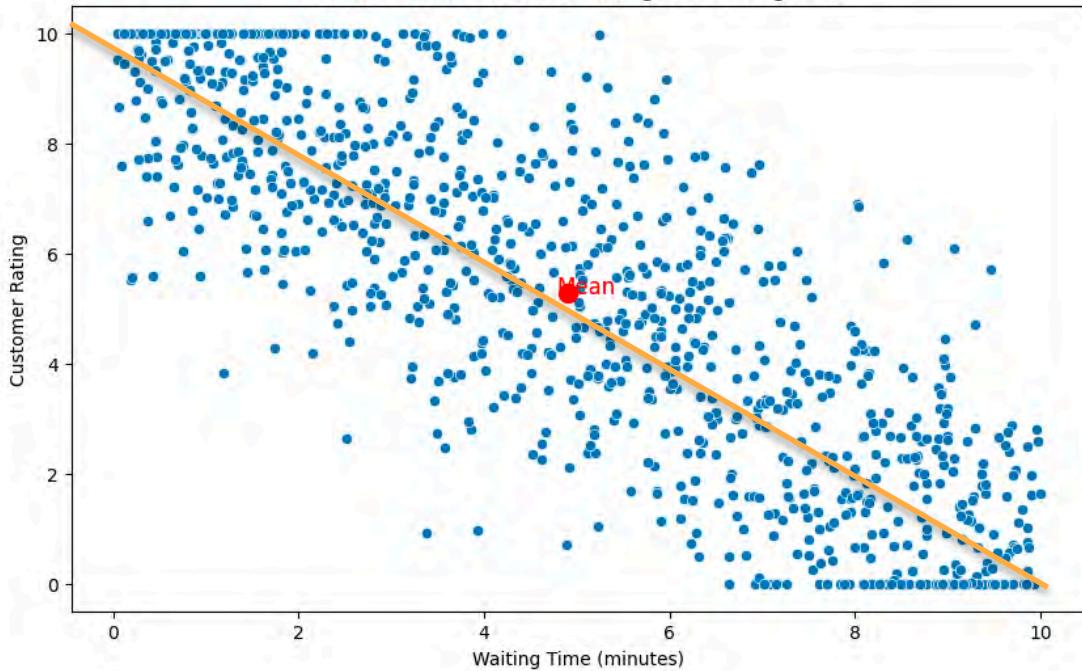


$$\text{Var}(X) = 8.526$$

$$\text{Var}(Y) = 10.163$$

$$\text{Cov}(X, Y) = -7.878$$

# Covariance Matrix

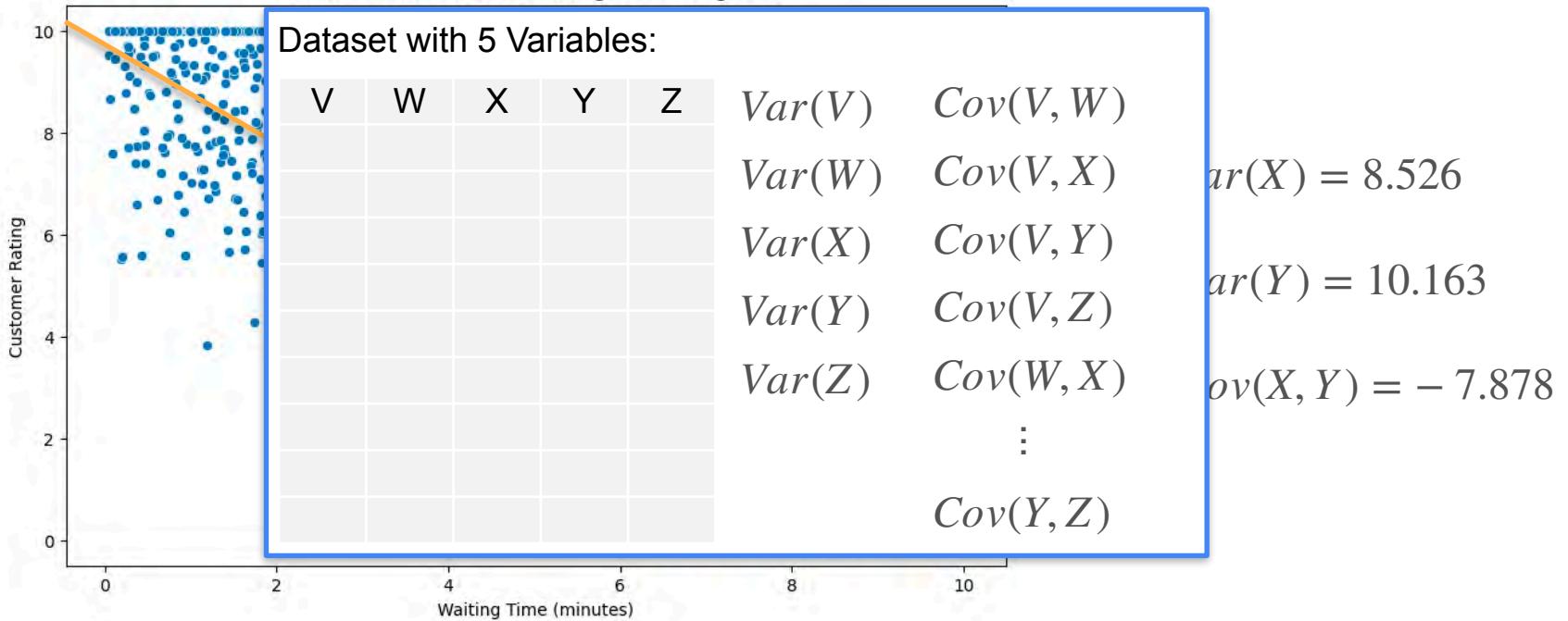


$$\text{Var}(X) = 8.526$$

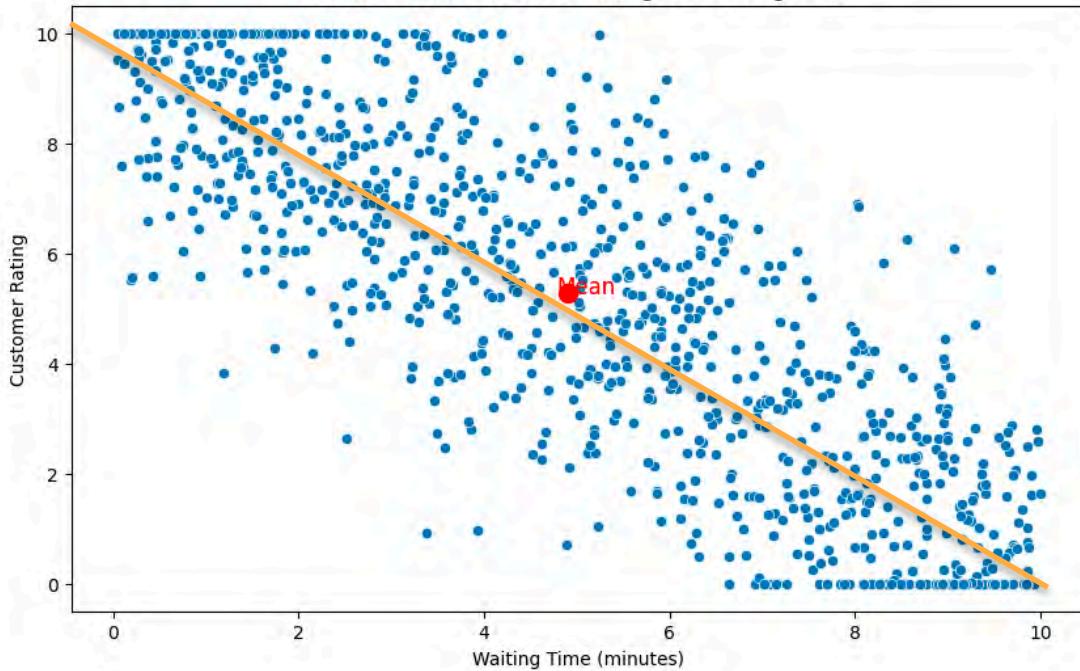
$$\text{Var}(Y) = 10.163$$

$$\text{Cov}(X, Y) = -7.878$$

# Covariance Matrix



# Covariance Matrix

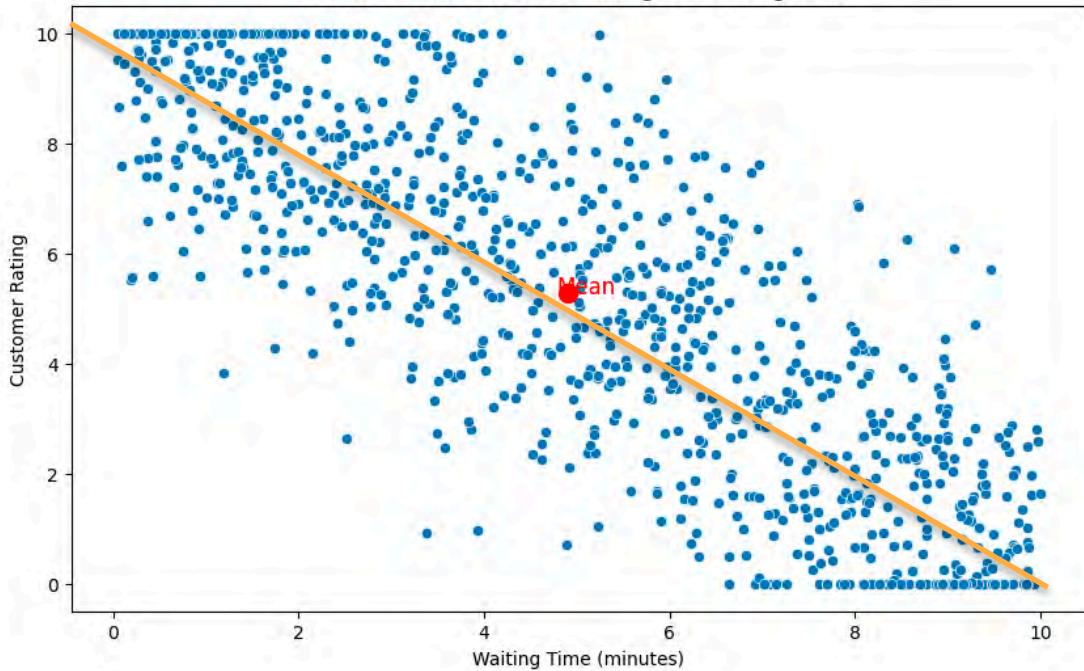


$$\text{Var}(X) = 8.526$$

$$\text{Var}(Y) = 10.163$$

$$\text{Cov}(X, Y) = -7.878$$

# Covariance Matrix



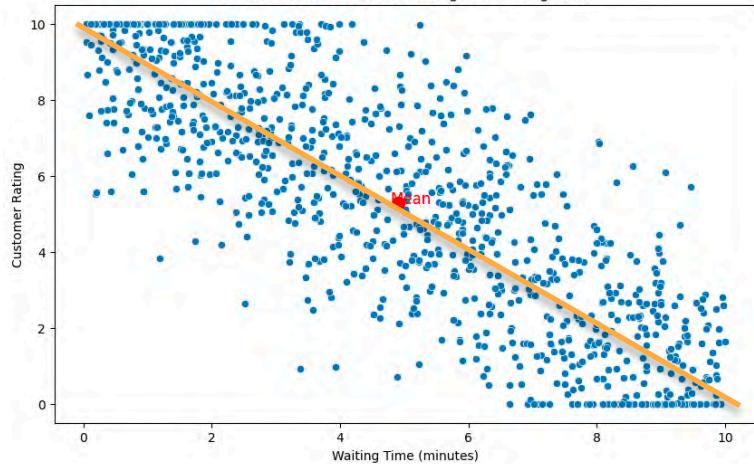
$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

# Covariance Matrix

# Covariance Matrix

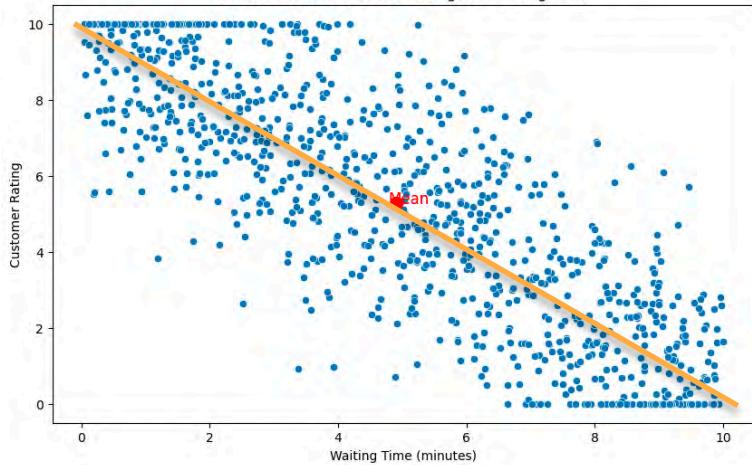


$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

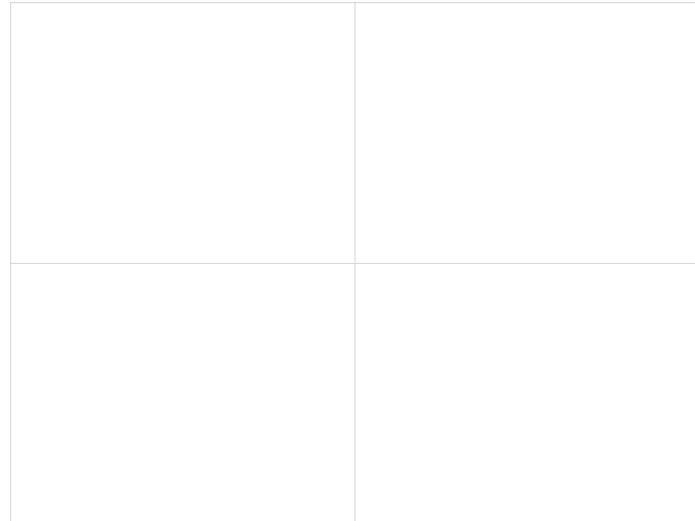
# Covariance Matrix



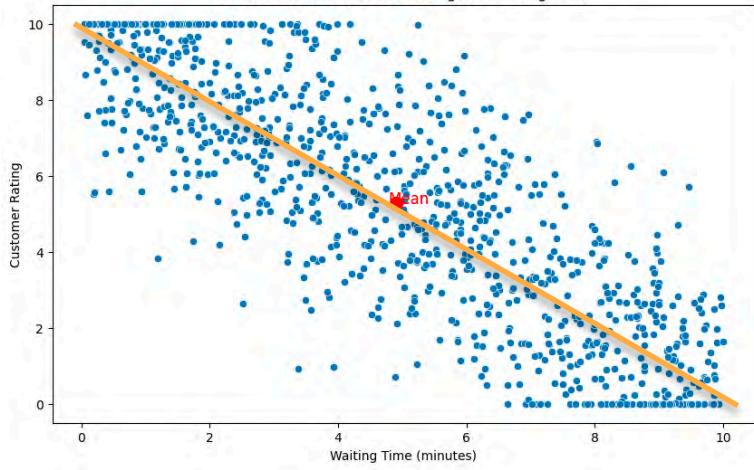
$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$



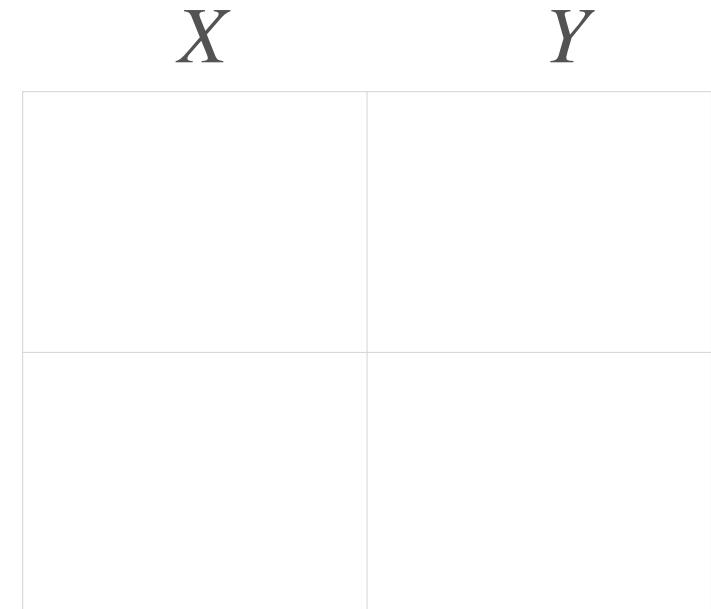
# Covariance Matrix



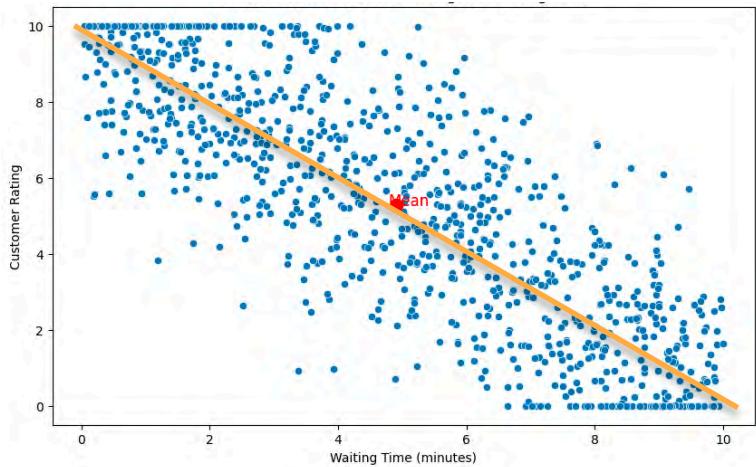
$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$



# Covariance Matrix



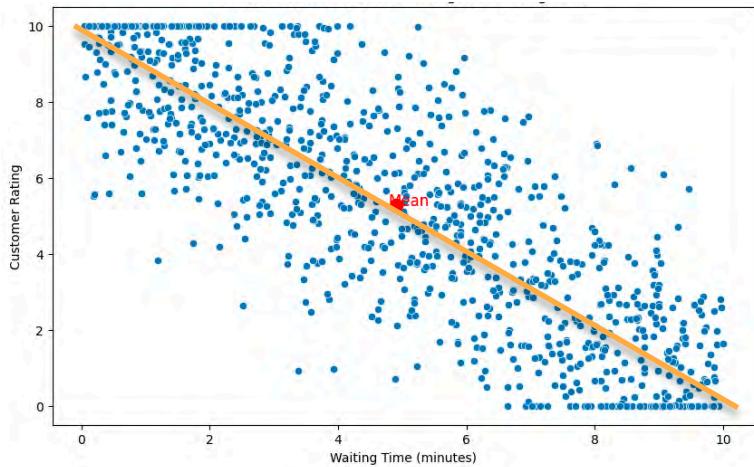
$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

$X$		$Y$
	$Var(X)$	
$Y$		$Var(Y)$

# Covariance Matrix



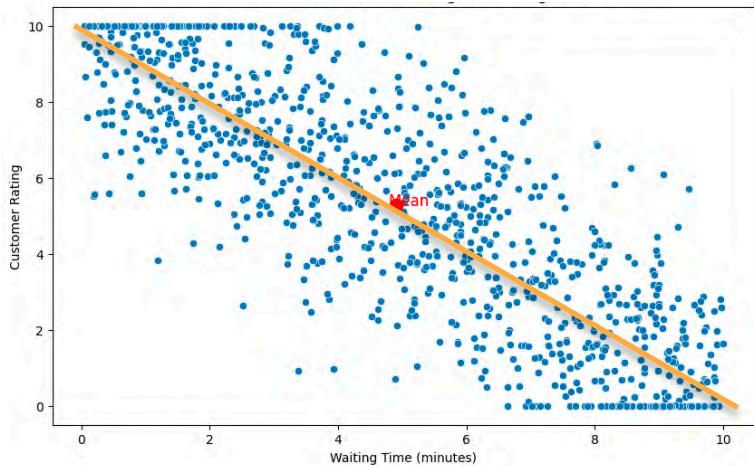
$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

$X$	$X$	$Y$
$Var(X)$	$Cov(X, Y)$	$Var(Y)$
$Y$	$Cov(X, Y)$	$Var(Y)$

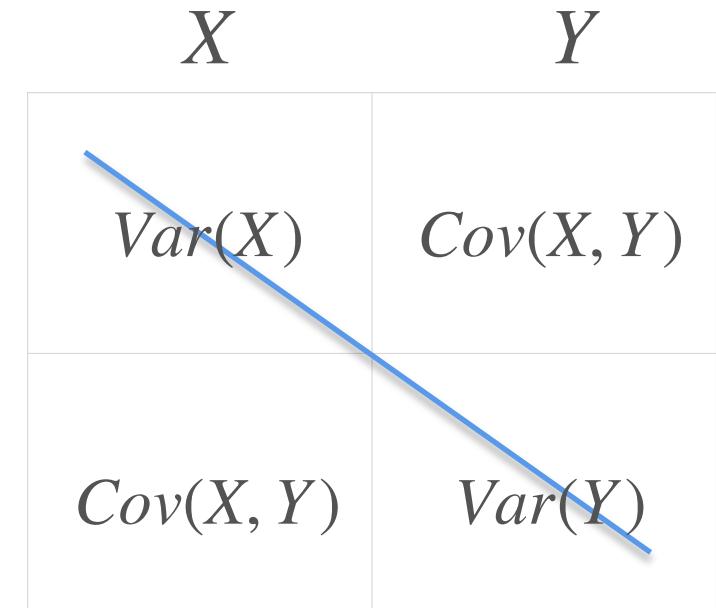
# Covariance Matrix



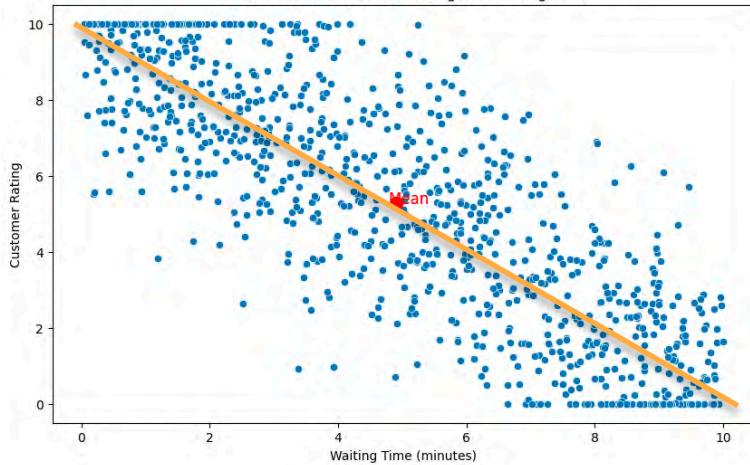
$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$



# Covariance Matrix



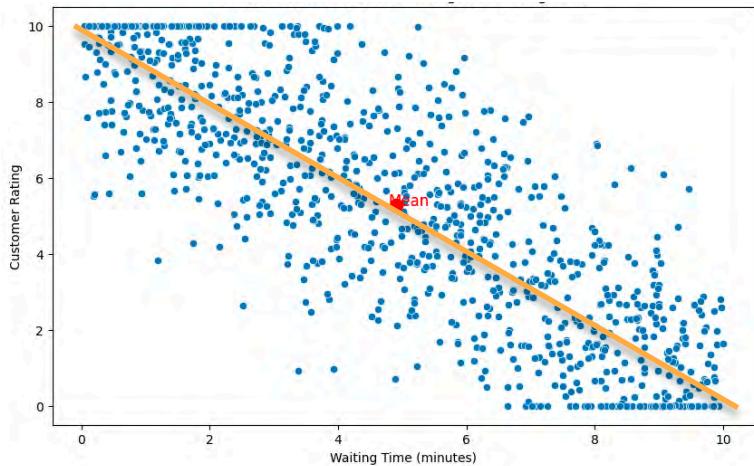
$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

	$X$	$Y$
$X$	$Var(X)$	$Cov(X, Y)$
$Y$	$Cov(X, Y)$	$Var(Y)$

# Covariance Matrix



$$Var(X) = 8.526$$

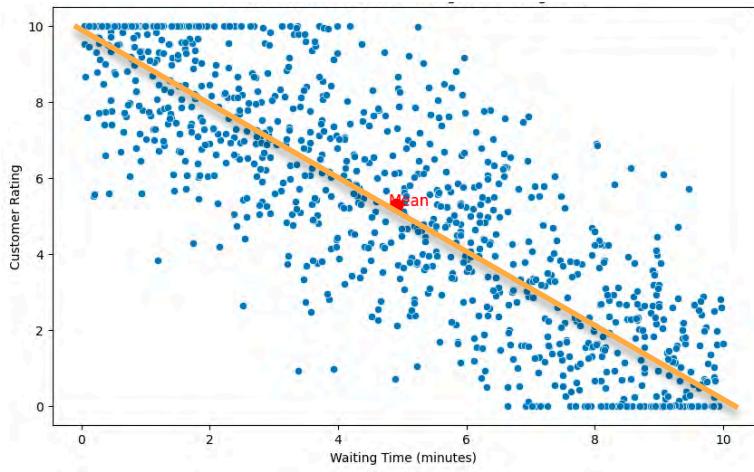
$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

	$X$	$Y$
$X$	$Var(X)$	$Cov(X, Y)$
$Y$	$Cov(X, Y)$	$Var(Y)$

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

# Covariance Matrix



$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

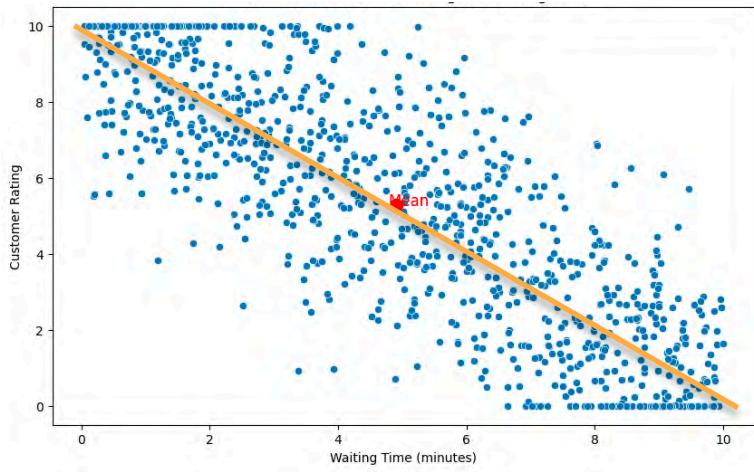
$$Cov(X, Y) = -7.878$$

	$X$	$Y$
$X$	$Var(X)$	$Cov(X, Y)$
$Y$	$Cov(X, Y)$	$Var(Y)$

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

8.526	-7.878
-7.878	10.163

# Covariance Matrix



$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

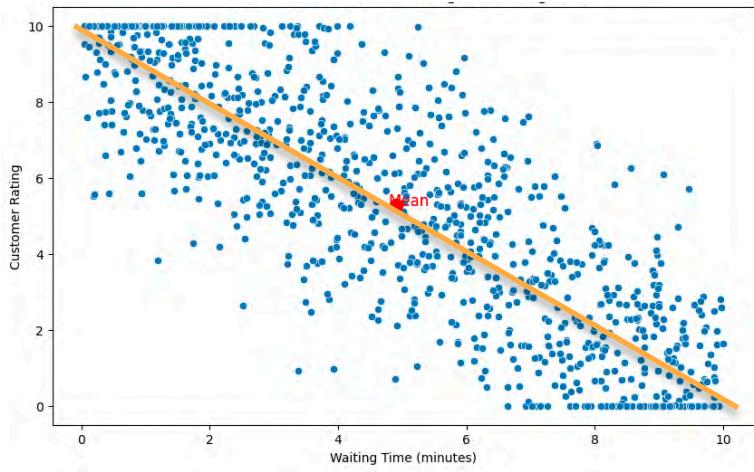
	$X$	$Y$
$X$	$Var(X)$	$Cov(X, Y)$
$Y$	$Cov(X, Y)$	$Var(Y)$

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

8.526	-7.878
-7.878	10.163

$$\begin{bmatrix} 8.534 & -7.878 \\ -7.878 & 10.173 \end{bmatrix}$$

# Covariance Matrix



$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

	$X$	$Y$
$X$	$Var(X)$	$Cov(X, Y)$
$Y$	$Cov(X, Y)$	$Var(Y)$

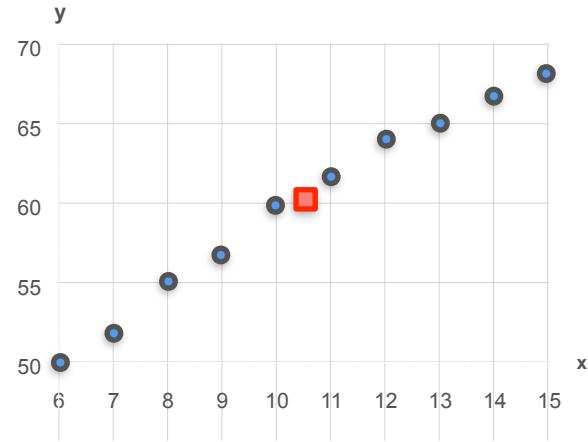
$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

8.526	-7.878
-7.878	10.163

$$\begin{bmatrix} 8.534 & -7.878 \\ -7.878 & 10.173 \end{bmatrix}$$

**Covariance Matrix**

# Covariance Matrix



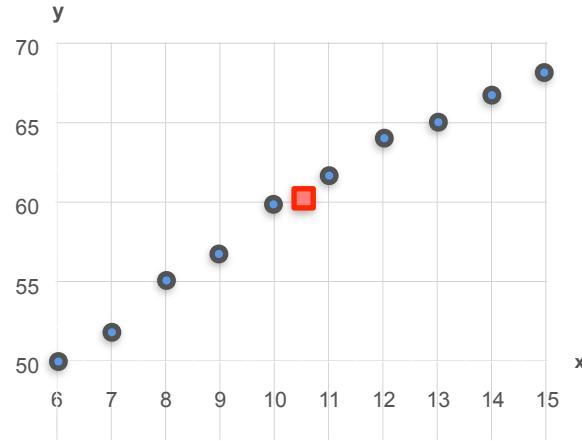
**Age vs Height**

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Covariance Matrix



**Age vs Height**

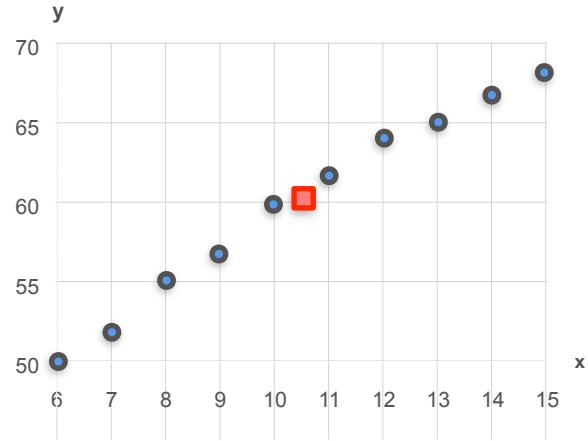
$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

# Covariance Matrix



Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

$$\begin{bmatrix} 9.17 & 17 \\ 17 & 39.56 \end{bmatrix}$$

# Covariance Matrix

$$Var(X) = 1$$

$$Var(Y) = 1$$

$$Cov(X, Y) = 1$$

$$Var(X) = 1$$

$$Var(Y) = 1$$

$$Cov(X, Y) = -1$$

# Covariance Matrix

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

$$Var(X) = 1$$

$$Var(X) = 1$$

$$Var(Y) = 1$$

$$Var(Y) = 1$$

$$Cov(X, Y) = 1$$

$$Cov(X, Y) = -1$$

# Covariance Matrix

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

$$Var(X) = 1$$

$$Var(Y) = 1$$

$$Cov(X, Y) = 1$$

$$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

$$Var(X) = 1$$

$$Var(Y) = 1$$

$$Cov(X, Y) = -1$$

# Covariance Matrix

$$\begin{bmatrix} Var(X) & Cov(X, Y) \\ Cov(X, Y) & Var(Y) \end{bmatrix}$$

$$Var(X) = 1$$

$$Var(Y) = 1$$

$$Cov(X, Y) = 1$$

$$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

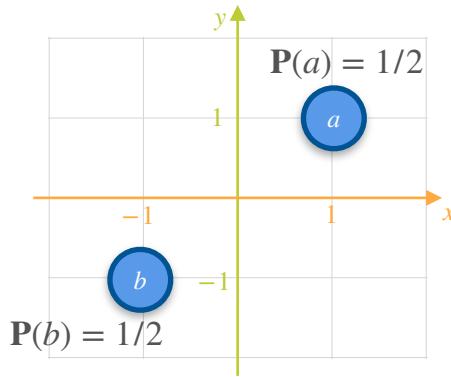
$$\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$Var(X) = 1$$

$$Var(Y) = 1$$

$$Cov(X, Y) = -1$$

# Covariance Matrix



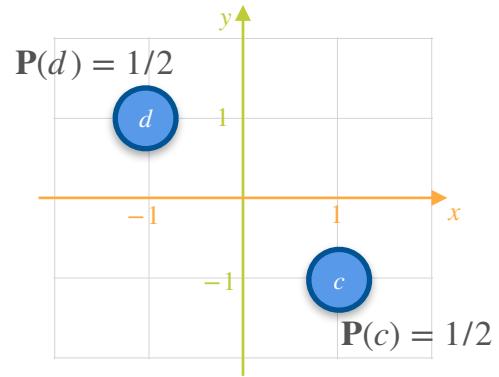
$$\begin{bmatrix} \mathbf{Var}(X) & \mathbf{Cov}(X, Y) \\ \mathbf{Cov}(X, Y) & \mathbf{Var}(Y) \end{bmatrix}$$

$$\mathbf{Var}(X) = 1$$

$$\mathbf{Var}(Y) = 1$$

$$\mathbf{Cov}(X, Y) = 1$$

$$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$



$$\mathbf{Var}(X) = 1$$

$$\mathbf{Var}(Y) = 1$$

$$\mathbf{Cov}(X, Y) = -1$$

$$\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

# Covariance of a Joint Continuous Distribution

# Covariance of a Joint Continuous Distribution

Dataset with 3 Variables:

X	Y	Z	$Var(X)$	$Cov(X, Y)$
			$Var(Y)$	$Cov(X, Z)$
			$Var(Z)$	$Cov(Y, Z)$

# Covariance of a Joint Continuous Distribution

## Dataset with 3 Variables:

$X$	$Y$	$Z$	$Var(X)$	$Cov(X, Y)$
			$Var(Y)$	$Cov(X, Z)$
			$Var(Z)$	$Cov(Y, Z)$

X

Y

Z

X

Y

Z

# Covariance of a Joint Continuous Distribution

Dataset with 3 Variables:

X	Y	Z	$Var(X)$	$Cov(X, Y)$
			$Var(Y)$	$Cov(X, Z)$
			$Var(Z)$	$Cov(Y, Z)$

X                  Y                  Z

X

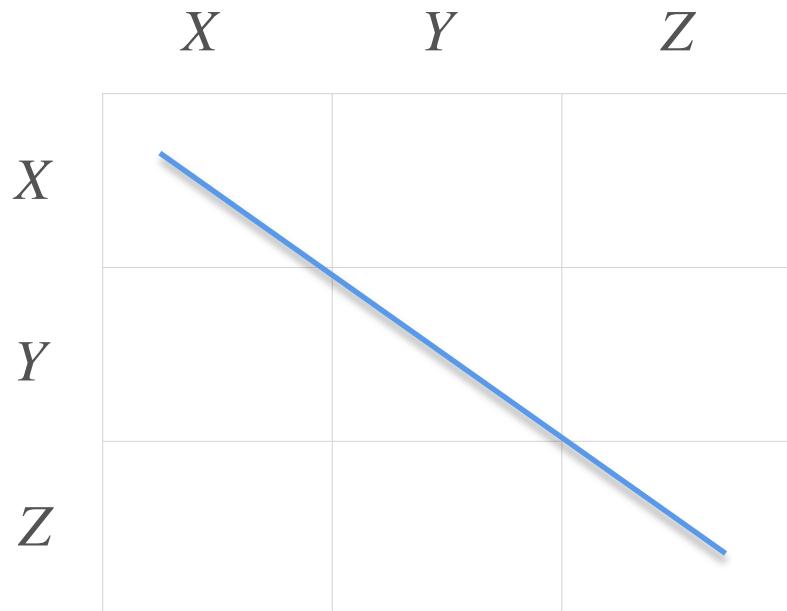
Y

Z


# Covariance of a Joint Continuous Distribution

Dataset with 3 Variables:

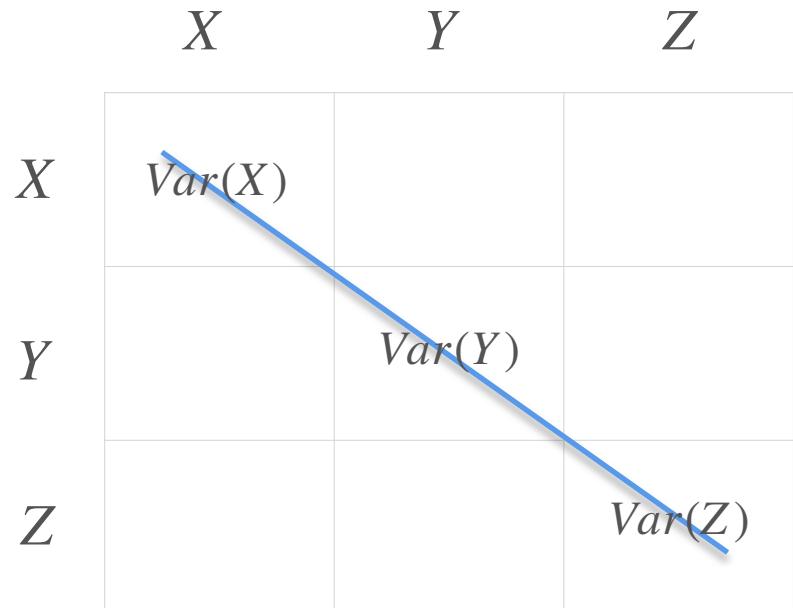
X	Y	Z	$Var(X)$	$Cov(X, Y)$
			$Var(Y)$	$Cov(X, Z)$
			$Var(Z)$	$Cov(Y, Z)$



# Covariance of a Joint Continuous Distribution

Dataset with 3 Variables:

X	Y	Z	$Var(X)$	$Cov(X, Y)$
			$Var(Y)$	$Cov(X, Z)$
			$Var(Z)$	$Cov(Y, Z)$



# Covariance of a Joint Continuous Distribution

Dataset with 3 Variables:

X	Y	Z	$Var(X)$	$Cov(X, Y)$
			$Var(Y)$	$Cov(X, Z)$
			$Var(Z)$	$Cov(Y, Z)$

X	$Var(X)$	$Cov(X, Y)$	$Cov(X, Z)$
Y	$Cov(X, Y)$	$Var(Y)$	$Cov(Y, Z)$
Z	$Cov(X, Z)$	$Cov(Y, Z)$	$Var(Z)$

# Covariance of a Joint Continuous Distribution

# Covariance of a Joint Continuous Distribution

Dataset with 5 Variables:

V	W	X	Y	Z	$Var(V)$	$Cov(V, W)$
					$Var(W)$	$Cov(V, X)$
					$Var(X)$	$Cov(V, Y)$
					$Var(Y)$	$Cov(V, Z)$
					$Var(Z)$	$Cov(W, X)$
						$\vdots$
						$Cov(Y, Z)$

# Covariance of a Joint Continuous Distribution

## Dataset with 5 Variables:

$$Var(V) \quad Cov(V, W)$$

$$Var(W) \quad Cov(V, X)$$

$$Var(X) \quad Cov(V, Y)$$

$$Var(Y) \quad Cov(V, Z)$$

$$Var(Z) \quad Cov(W, X)$$

三

$$Cov(Y, Z)$$

$V$        $W$        $X$        $Y$        $Z$

V

W

X

V

Z

# Covariance of a Joint Continuous Distribution

## Dataset with 5 Variables:

$$Var(V) \quad Cov(V, W)$$

$$Var(W) \quad Cov(V, X)$$

$$Var(X) \quad Cov(V, Y)$$

$$Var(Y) \quad Cov(V, Z)$$

$$Var(Z) \quad Cov(W, X)$$

三

$$Cov(Y, Z)$$

# Covariance of a Joint Continuous Distribution

## Dataset with 5 Variables:

$Var(V)$	$Cov(V, W)$
$Var(W)$	$Cov(V, X)$
$Var(X)$	$Cov(V, Y)$
$Var(Y)$	$Cov(V, Z)$
$Var(Z)$	$Cov(W, X)$
	⋮
	$Cov(Y, Z)$

	$V$	$W$	$X$	$Y$	$Z$
$V$	$Var(V)$				
$W$		$Var(W)$			
$X$			$Var(X)$		
$Y$				$Var(Y)$	
$Z$					$Var(Z)$

# Covariance of a Joint Continuous Distribution

Dataset with 5 Variables:

V	W	X	Y	Z
			$Var(V)$	$Cov(V, W)$
			$Var(W)$	$Cov(V, X)$
			$Var(X)$	$Cov(V, Y)$
			$Var(Y)$	$Cov(V, Z)$
			$Var(Z)$	$Cov(W, X)$
				$\vdots$
				$Cov(Y, Z)$

$Var(V) \quad Cov(V, W)$   
 $Var(W) \quad Cov(V, X)$   
 $Var(X) \quad Cov(V, Y)$   
 $Var(Y) \quad Cov(V, Z)$   
 $Var(Z) \quad Cov(W, X)$   
 $\vdots$   
 $Cov(Y, Z)$

	V	W	X	Y	Z
V	$Var(V)$	$Cov(V, W)$	$Cov(V, X)$	$Cov(V, Y)$	$Cov(V, Z)$
W	$Cov(V, W)$	$Var(W)$	$Cov(W, X)$	$Cov(W, Y)$	$Cov(W, Z)$
X	$Cov(V, X)$	$Cov(W, X)$	$Var(X)$	$Cov(X, Y)$	$Cov(X, Z)$
Y	$Cov(V, Y)$	$Cov(W, Y)$	$Cov(X, Y)$	$Var(Y)$	$Cov(Y, Z)$
Z	$Cov(V, Z)$	$Cov(W, Z)$	$Cov(X, Z)$	$Cov(Y, Z)$	$Var(Z)$

# Covariance of a Joint Continuous Distribution

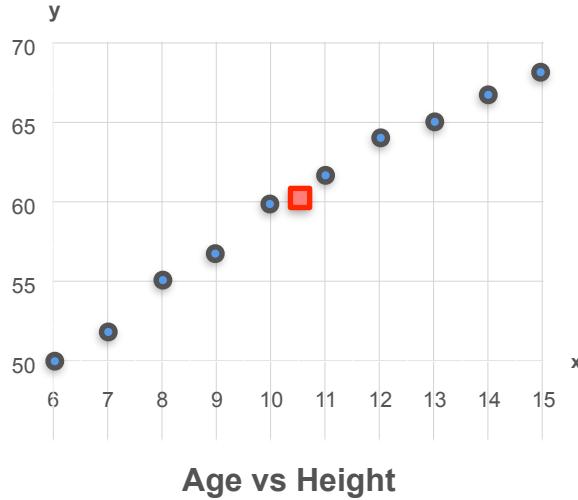
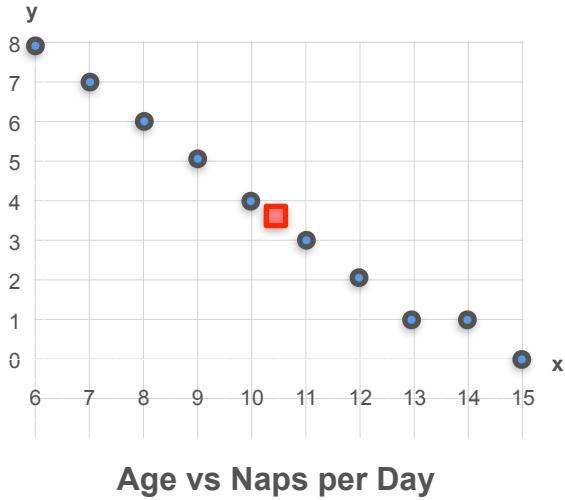
$\sum =$

**Covariance Matrix**

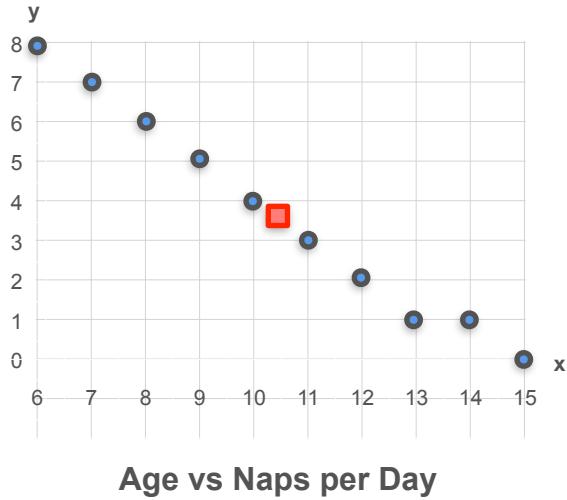
	$V$	$W$	$X$	$Y$	$Z$
$V$	$Var(V)$	$Cov(V, W)$	$Cov(V, X)$	$Cov(V, Y)$	$Cov(V, Z)$
$W$	$Cov(V, W)$	$Var(W)$	$Cov(W, X)$	$Cov(W, Y)$	$Cov(W, Z)$
$X$	$Cov(V, X)$	$Cov(W, X)$	$Var(X)$	$Cov(X, Y)$	$Cov(X, Z)$
$Y$	$Cov(V, Y)$	$Cov(W, Y)$	$Cov(X, Y)$	$Var(Y)$	$Cov(Y, Z)$
$Z$	$Cov(V, Z)$	$Cov(W, Z)$	$Cov(X, Z)$	$Cov(Y, Z)$	$Var(Z)$

# Correlation Coefficient

# Correlation Coefficient



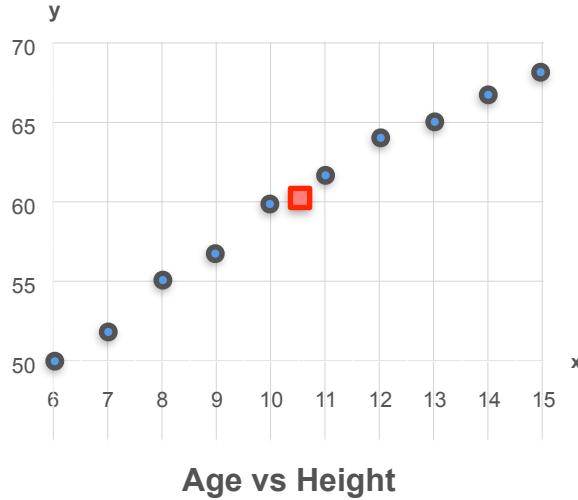
# Correlation Coefficient



Age vs Naps per Day

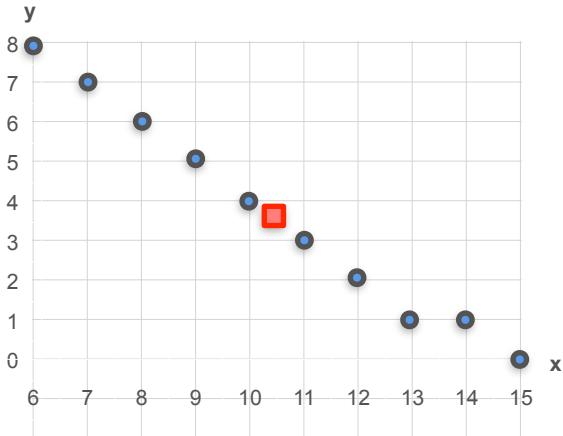
$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$



Age vs Height

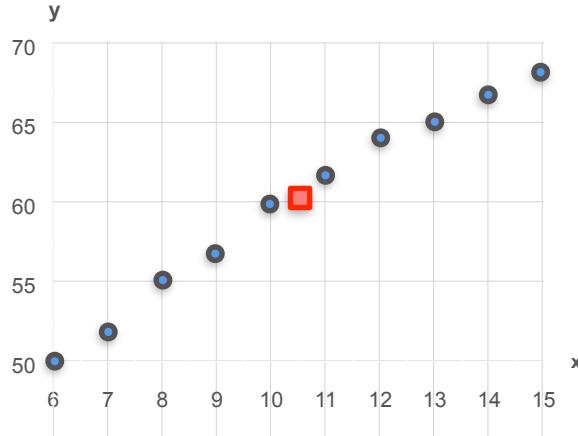
# Correlation Coefficient



Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

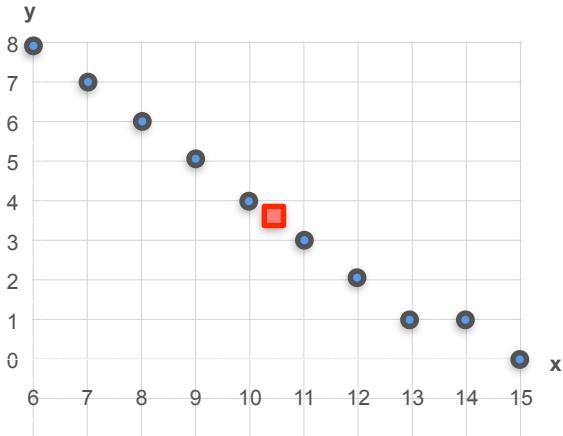


Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

# Correlation Coefficient

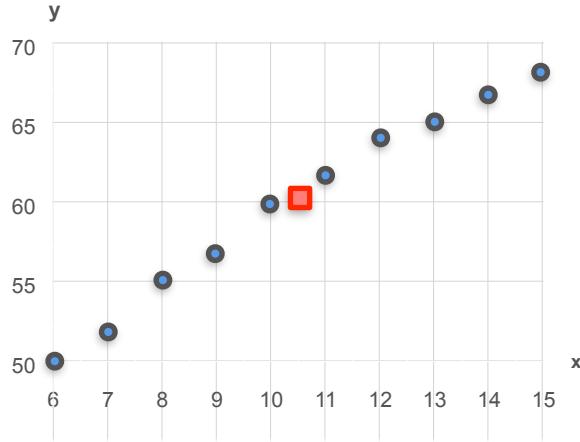


Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



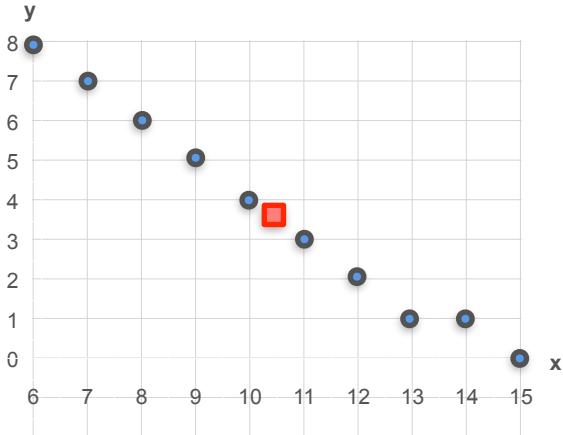
Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Correlation Coefficient

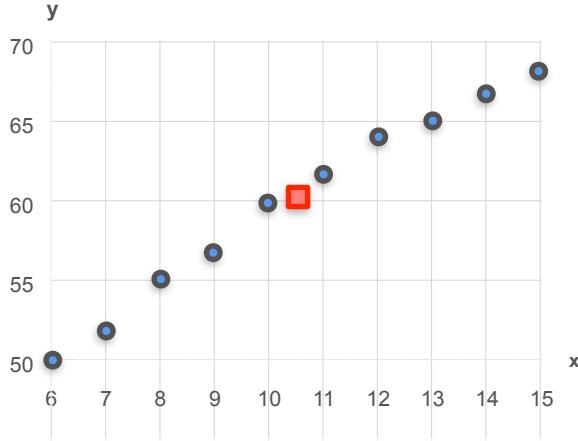


Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



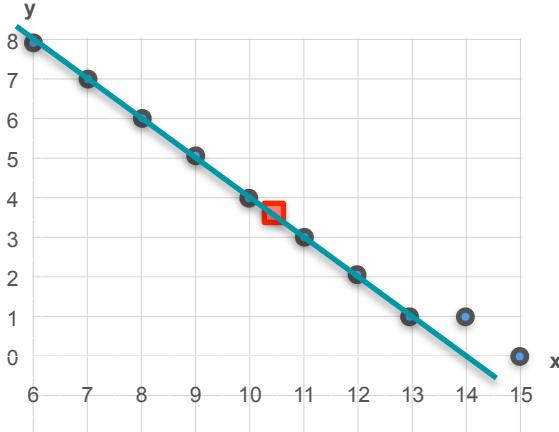
Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Correlation Coefficient

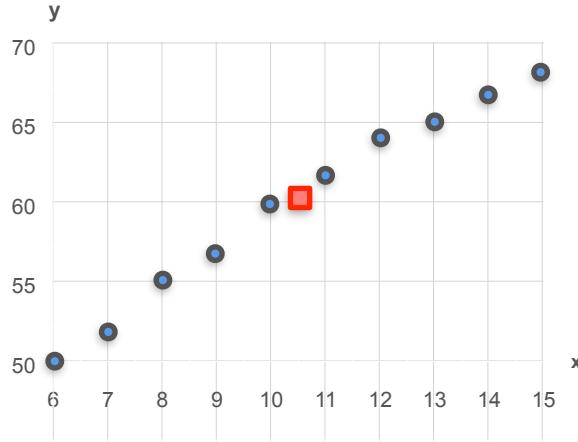


Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



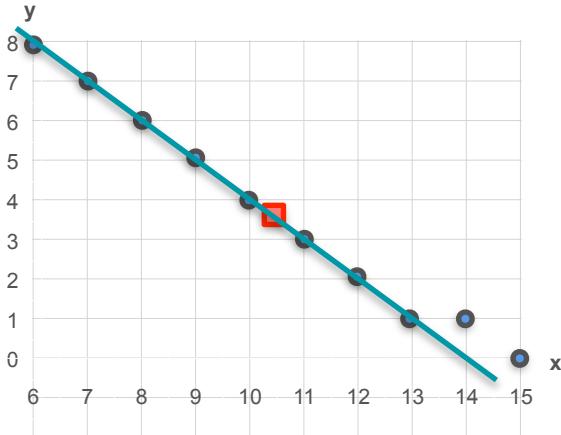
Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Correlation Coefficient

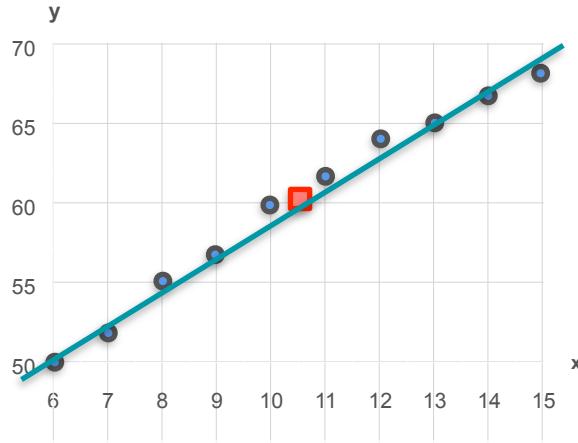


Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



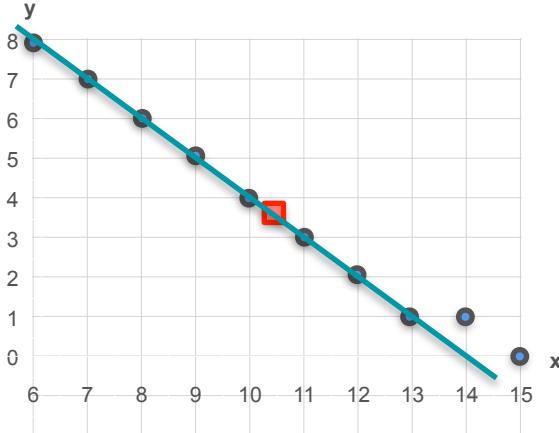
Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Correlation Coefficient

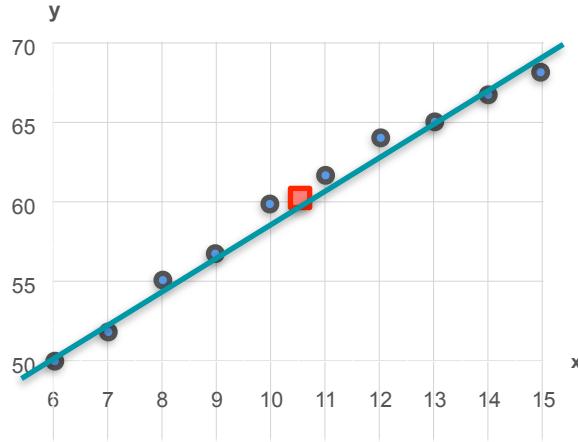


Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



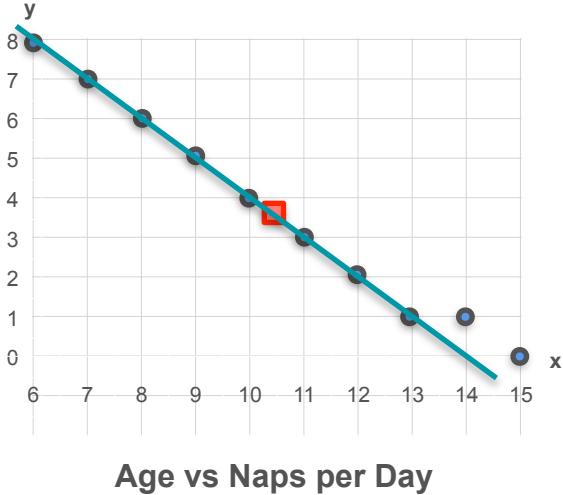
Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Correlation Coefficient



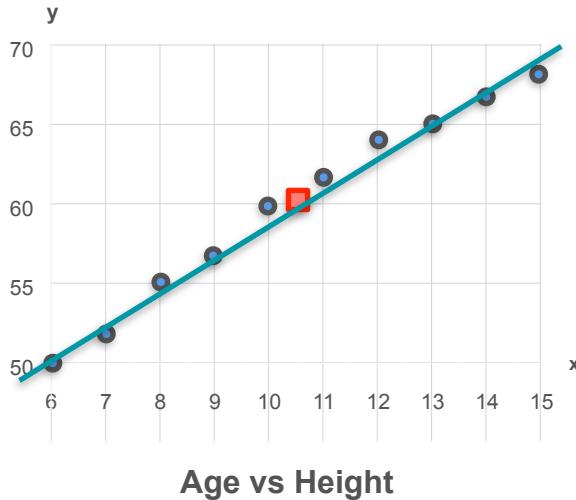
Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

Is the correlation  
here stronger?



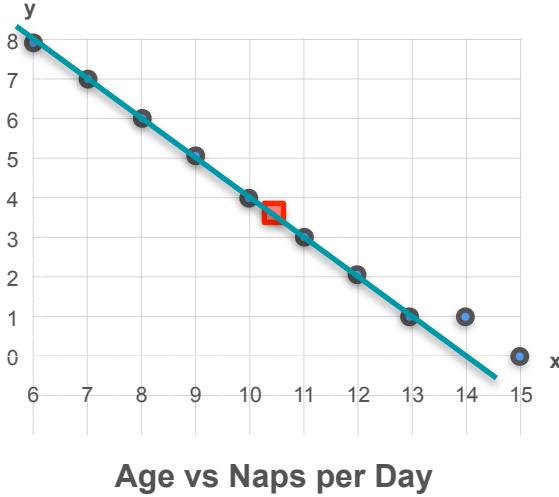
Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

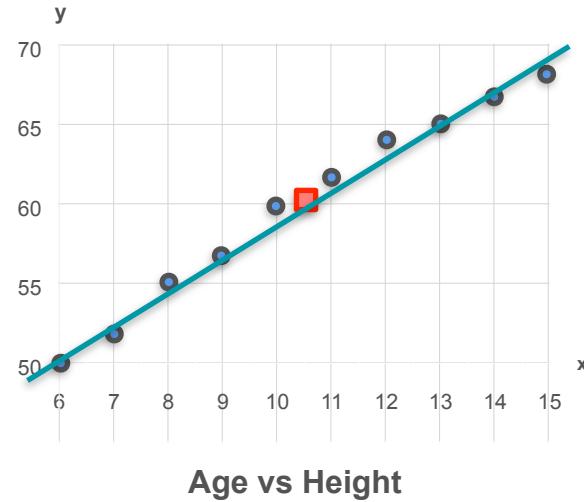
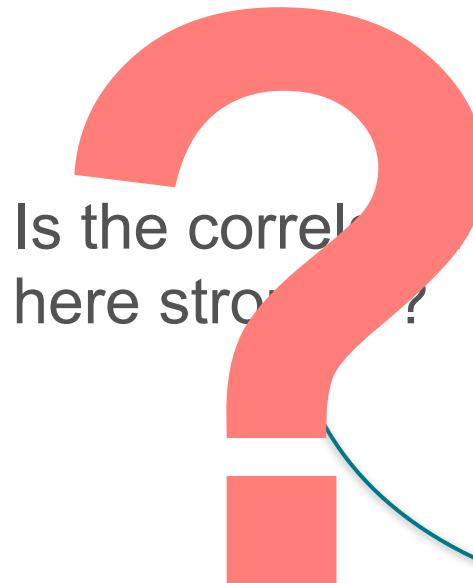
# Correlation Coefficient



$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

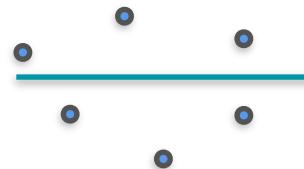
$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

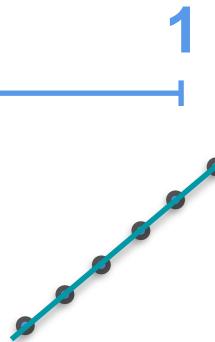


Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



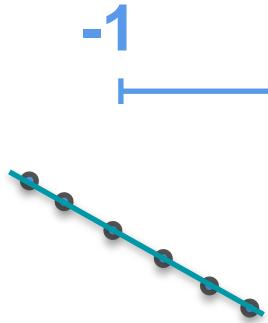
# Correlation Coefficient

# Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



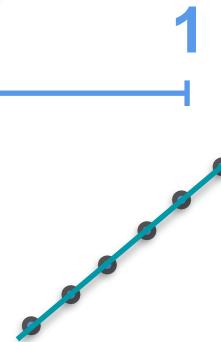
0

# Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

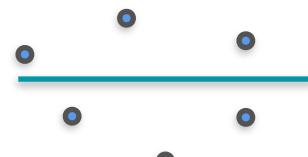
$$Cov(X, Y) = -7.45$$

-1



## Correlation Coefficient

0



Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

1



# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

Correlation  
Coefficient

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

Correlation  
Coefficient =

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

Correlation  
Coefficient =  $Cov(X, Y)$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

Correlation Coefficient =  $\frac{Cov(X, Y)}{\sqrt{Var(X) \cdot Var(Y)}}$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sigma_x}$$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sigma_x \cdot \sigma_y}$$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

**Correlation  
Coefficient** =  $\frac{Cov(X, Y)}{\sigma_x \cdot \sigma_y}$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

**Correlation Coefficient** =  $\frac{Cov(X, Y)}{\sigma_x \cdot \sigma_y}$  =

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

-1

0

1

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sigma_x \cdot \sigma_y} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

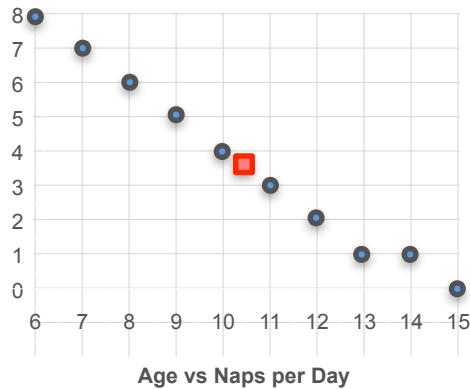
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

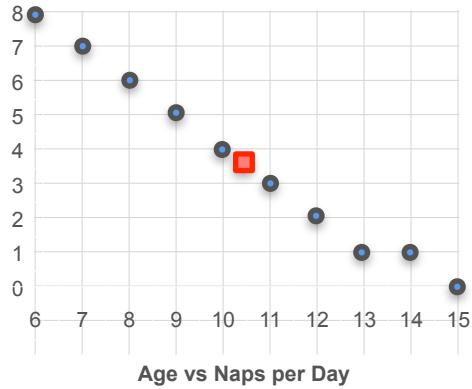
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

=

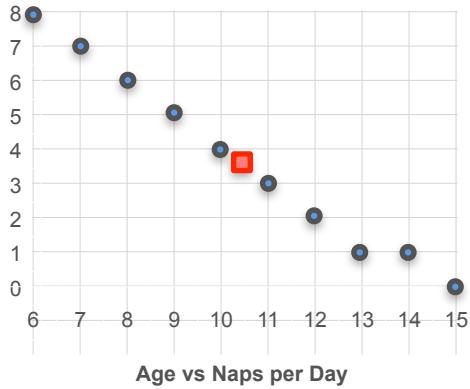
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



$$\begin{aligned}\text{Correlation Coefficient} &= \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \\ &= \frac{-7.45}{\sqrt{9.17} \cdot \sqrt{7.57}}\end{aligned}$$

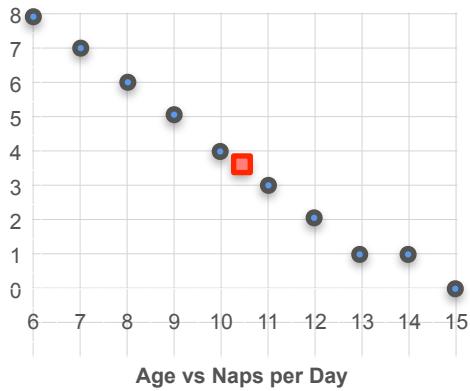
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

$$= \frac{-7.45}{\sqrt{9.17} \cdot \sqrt{7.57}}$$

$$\approx -0.894$$

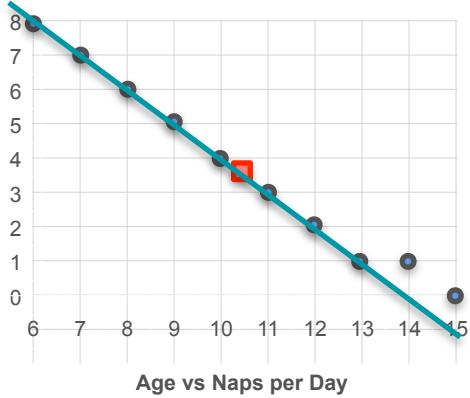
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

$$= \frac{-7.45}{\sqrt{9.17} \cdot \sqrt{7.57}}$$

$$\approx -0.894$$

# Correlation Coefficient

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

**Correlation Coefficient** =  $\frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$

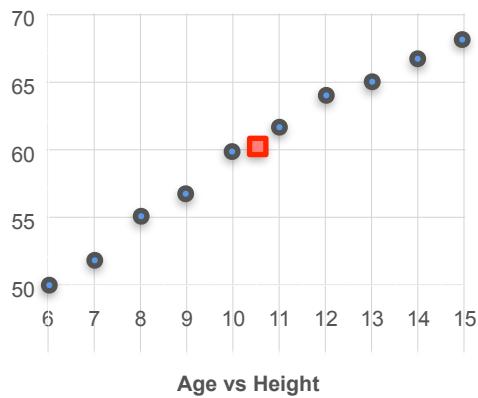
# Correlation Coefficient

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



**Correlation Coefficient** = 
$$\frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

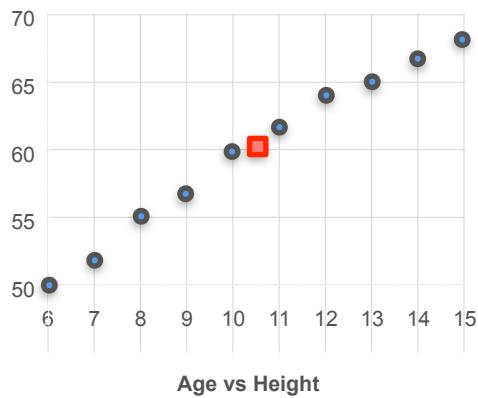
# Correlation Coefficient

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

=

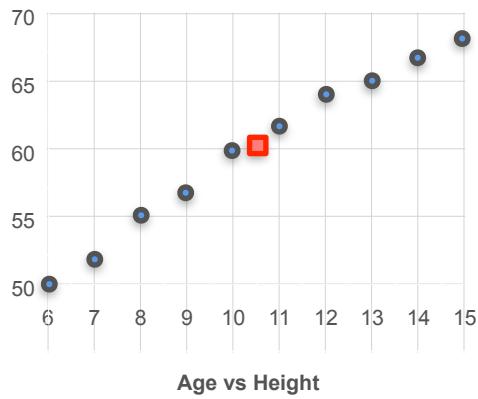
# Correlation Coefficient

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



$$\begin{aligned}\text{Correlation Coefficient} &= \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \\ &= \frac{17}{\sqrt{9.17} \cdot \sqrt{39.56}}\end{aligned}$$

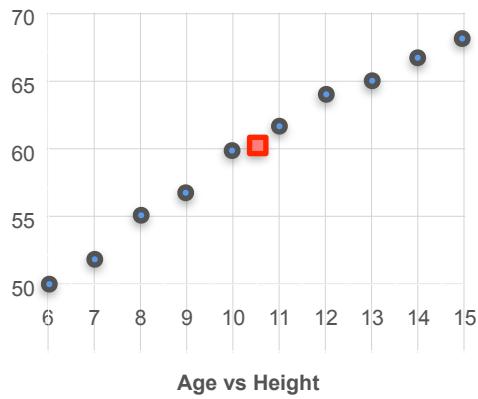
# Correlation Coefficient

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



$$\begin{aligned}\text{Correlation Coefficient} &= \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \\ &= \frac{17}{\sqrt{9.17} \cdot \sqrt{39.56}} \\ &\approx 0.893\end{aligned}$$

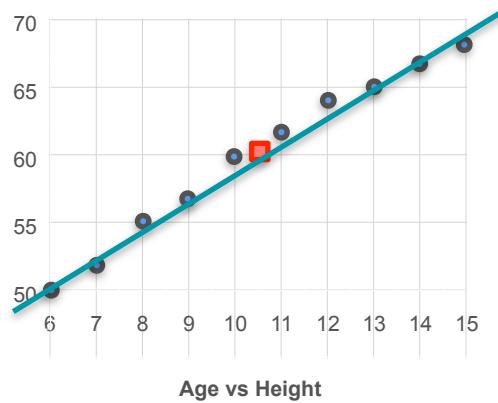
# Correlation Coefficient

Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

$$= \frac{17}{\sqrt{9.17} \cdot \sqrt{39.56}}$$

$$\approx 0.893$$

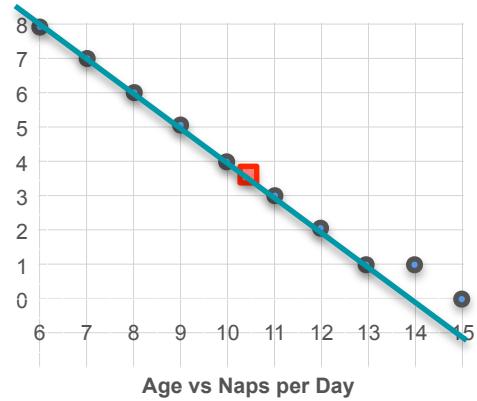
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$



Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$

$$\approx 0.893$$

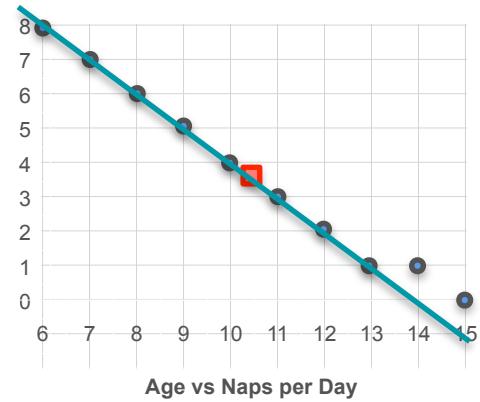
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

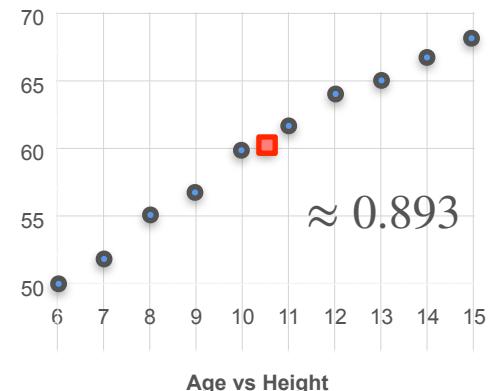


Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



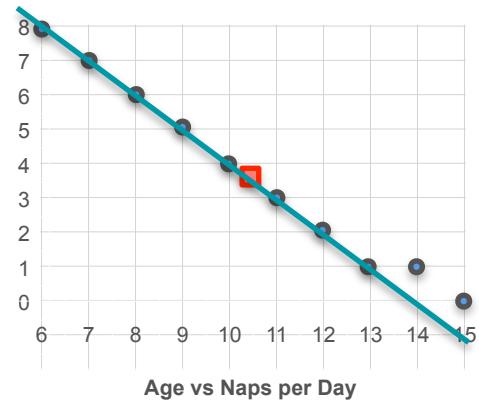
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

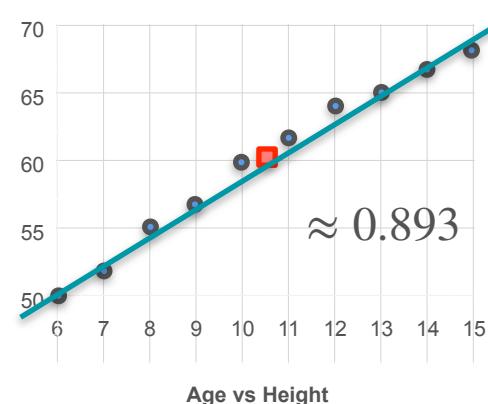


Age vs Height

$$Var(X) = 9.17$$

$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



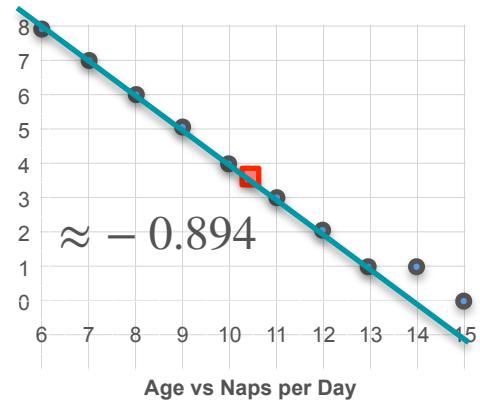
# Correlation Coefficient

Age vs Naps per Day

$$Var(X) = 9.17$$

$$Var(Y) = 7.57$$

$$Cov(X, Y) = -7.45$$

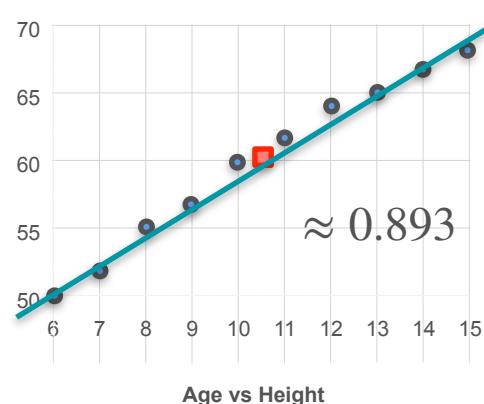


Age vs Height

$$Var(X) = 9.17$$

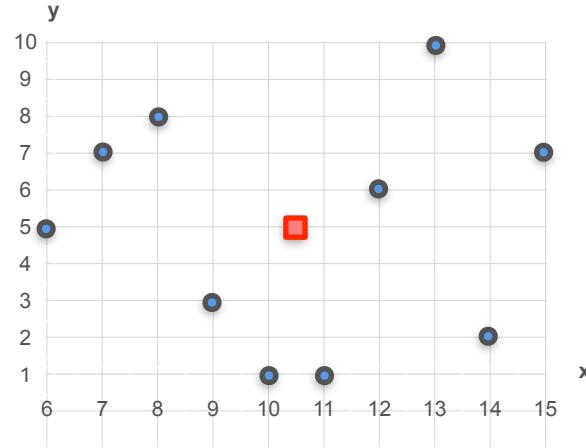
$$Var(Y) = 39.56$$

$$Cov(X, Y) = 17$$



# Correlation Coefficient

# Correlation Coefficient



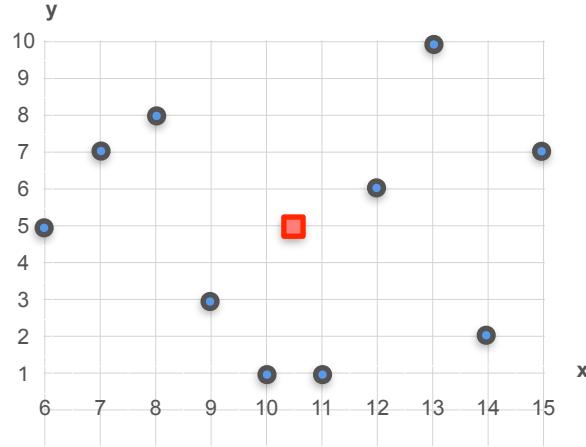
**Age vs Grades**

$$Var(X) = 9.17$$

$$Var(Y) = 9.78$$

$$Cov(X, Y) = 0.1$$

# Correlation Coefficient



**Age vs Grades**

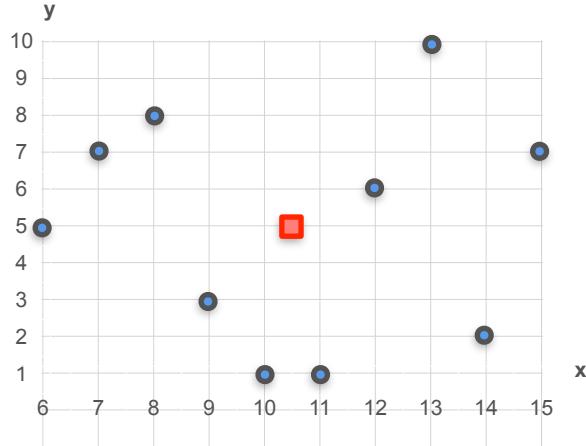
$$Var(X) = 9.17$$

$$Var(Y) = 9.78$$

$$Cov(X, Y) = 0.1$$

$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

# Correlation Coefficient



**Age vs Grades**

$$Var(X) = 9.17$$

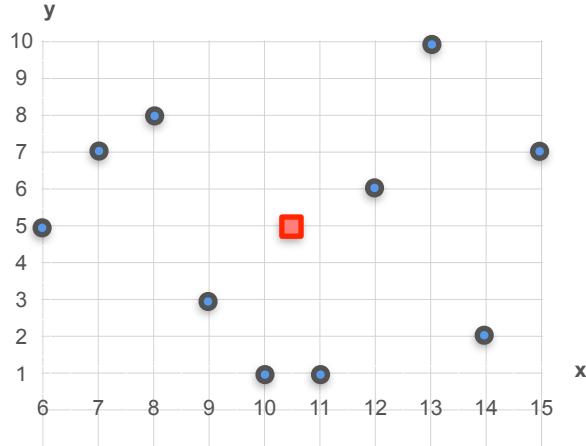
$$Var(Y) = 9.78$$

$$Cov(X, Y) = 0.1$$

$$\text{Correlation Coefficient} = \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$$

=

# Correlation Coefficient



**Age vs Grades**

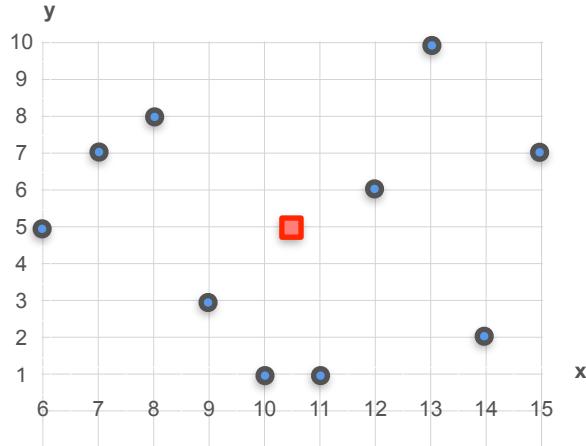
$$Var(X) = 9.17$$

$$Var(Y) = 9.78$$

$$Cov(X, Y) = 0.1$$

$$\begin{aligned}\text{Correlation Coefficient} &= \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \\ &= \frac{0.1}{\sqrt{9.17} \cdot \sqrt{9.78}}\end{aligned}$$

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$$\approx 0.01$$

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=

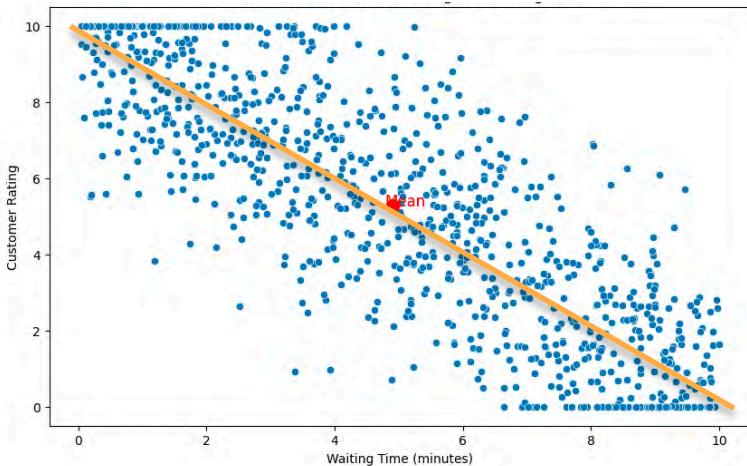
# Correlation Coefficient

$$\begin{aligned}\text{Correlation Coefficient} &= \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \\ &= \frac{-7.878}{\sqrt{8.562} \cdot \sqrt{10.163}}\end{aligned}$$

# Correlation Coefficient

$$\begin{aligned}\text{Correlation Coefficient} &= \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \\ &= \frac{-7.878}{\sqrt{8.562} \cdot \sqrt{10.163}} \\ &\approx -0.845\end{aligned}$$

# Correlation Coefficient



$$Var(X) = 8.526$$

$$Var(Y) = 10.163$$

$$Cov(X, Y) = -7.878$$

$$\begin{aligned}\text{Correlation Coefficient} &= \frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}} \\ &= \frac{-7.878}{\sqrt{8.562} \cdot \sqrt{10.163}}\end{aligned}$$

$\approx -0.845$

# Correlation Coefficient

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Correlation  
Coefficient =

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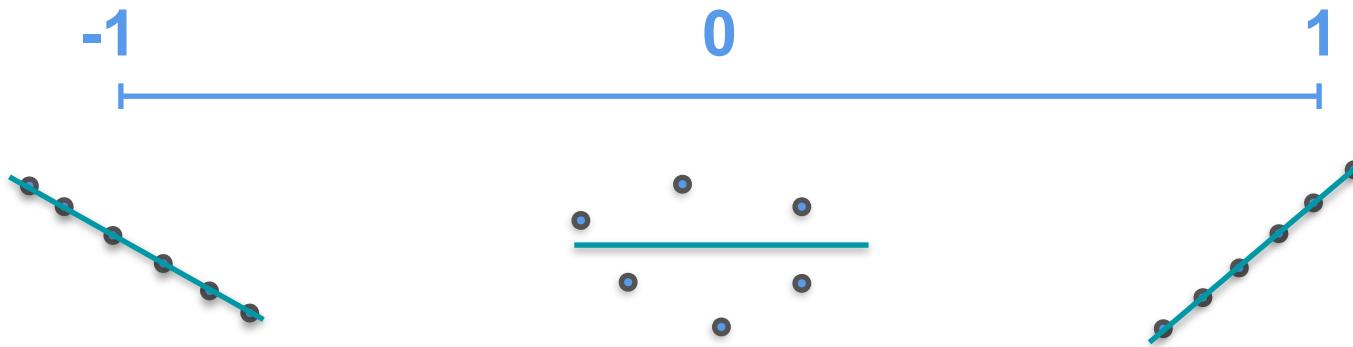
$$\text{Correlation Coefficient} = \frac{\text{Cov}(X, Y)}{\sigma_x \cdot \sigma_y}$$

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# Correlation Coefficient

**Correlation Coefficient** =  $\frac{Cov(X, Y)}{\sigma_x \cdot \sigma_y}$  =  $\frac{Cov(X, Y)}{\sqrt{Var(X)} \cdot \sqrt{Var(Y)}}$





DeepLearning.AI

# Probability Distributions with Multiple Variables

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## Multivariate Gaussian Distribution

# Multivariate Gaussian Distribution

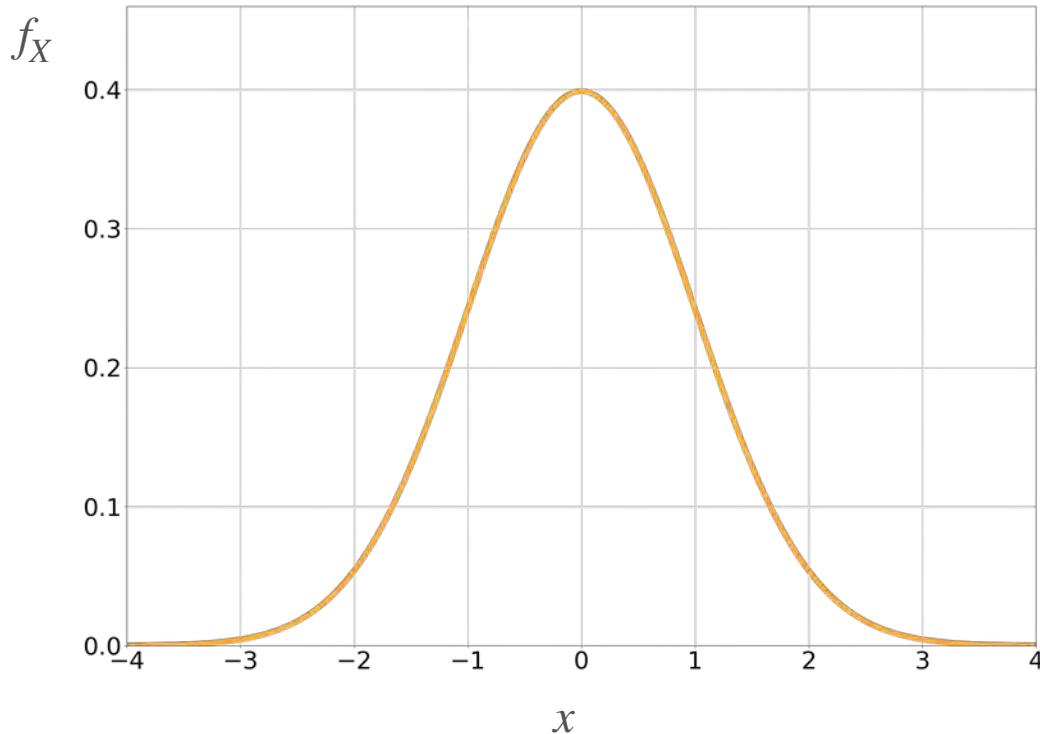
# Multivariate Gaussian Distribution

For a single variable,  $X$

$$f_X(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{1}{2}\frac{(x-\mu)^2}{\sigma^2}}$$

Parameters:

- $\mu$ : center of the bell
- $\sigma$ : spread of the bell



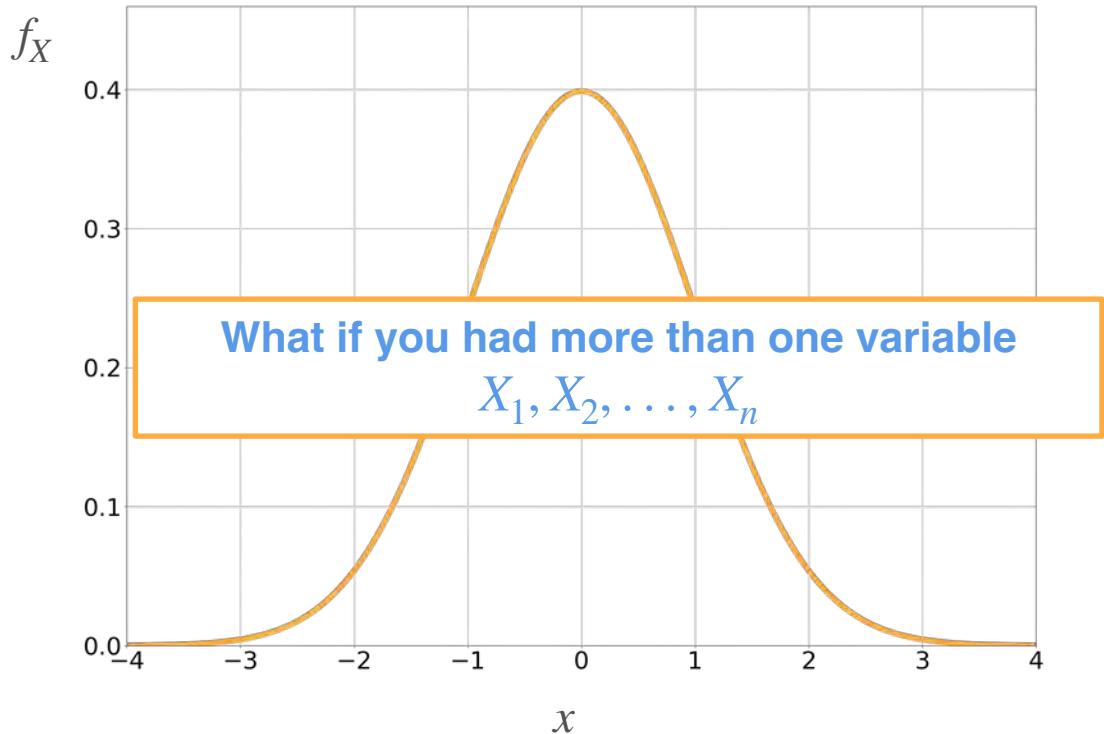
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# Multivariate Gaussian Distribution: An Example

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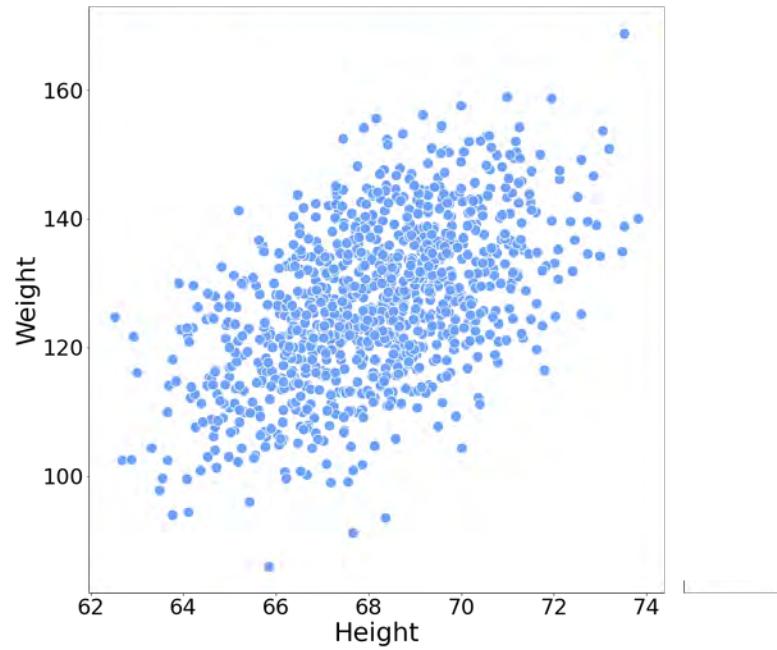
Two variables

# Multivariate Gaussian Distribution: An Example

Two variables

$H$  : Height of an adult in inches

$W$  : Weight of an adult in pounds

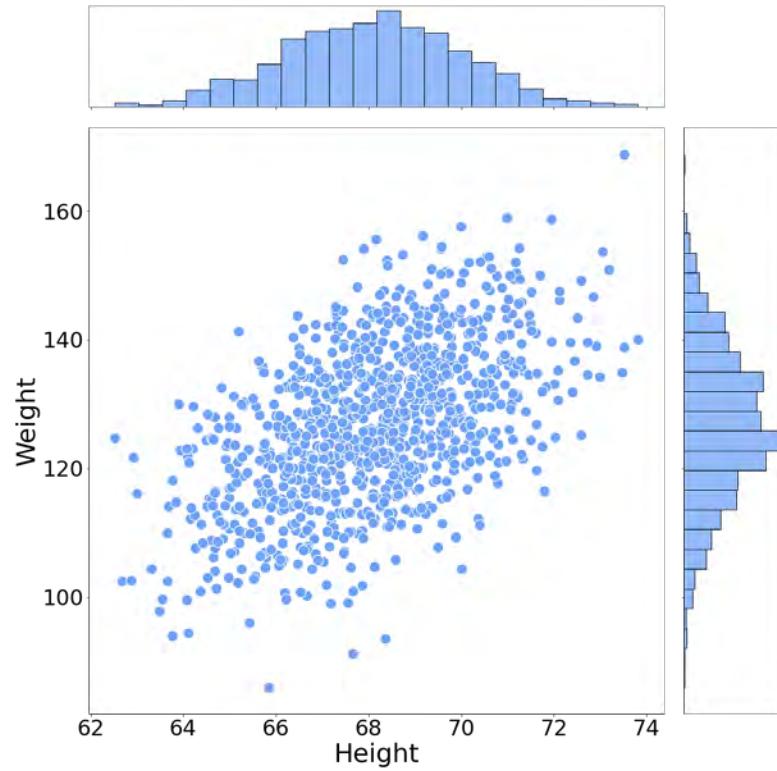


# Multivariate Gaussian Distribution: An Example

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# Multivariate Gaussian Distribution: An Example

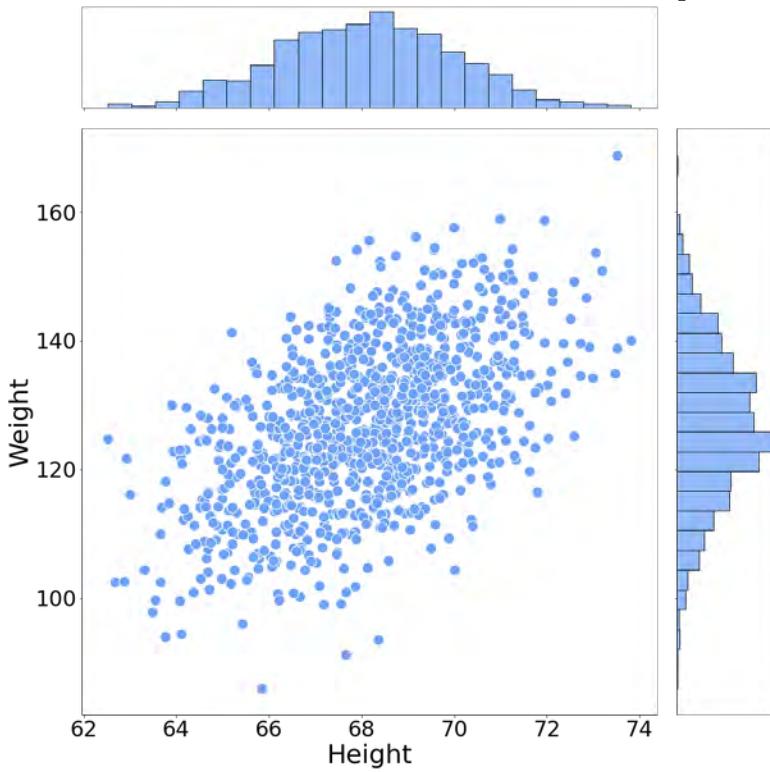
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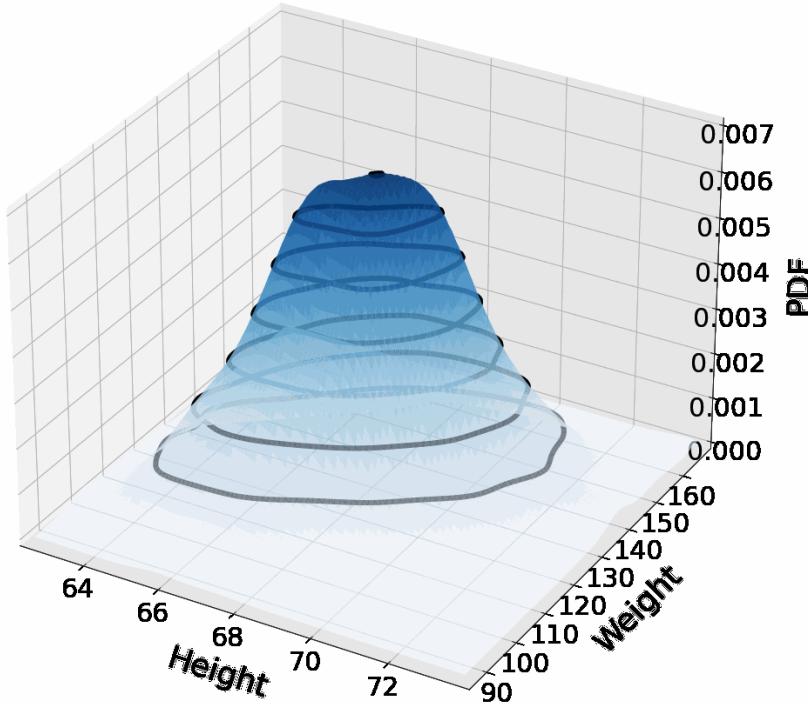
$$H \sim \mathcal{N}(\mu_H, \sigma_H)$$

$W$  : Weight of an adult in pounds

$$W \sim \mathcal{N}(\mu_W, \sigma_W)$$



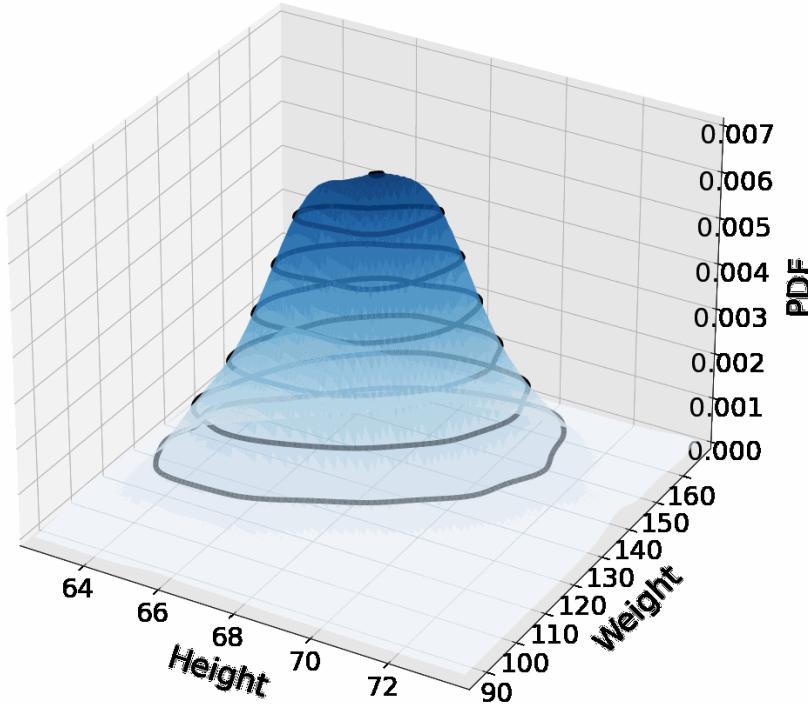
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If  $W, H$  were independent

$$f_{HW}(h, w) = f_H(h)f_W(w)$$

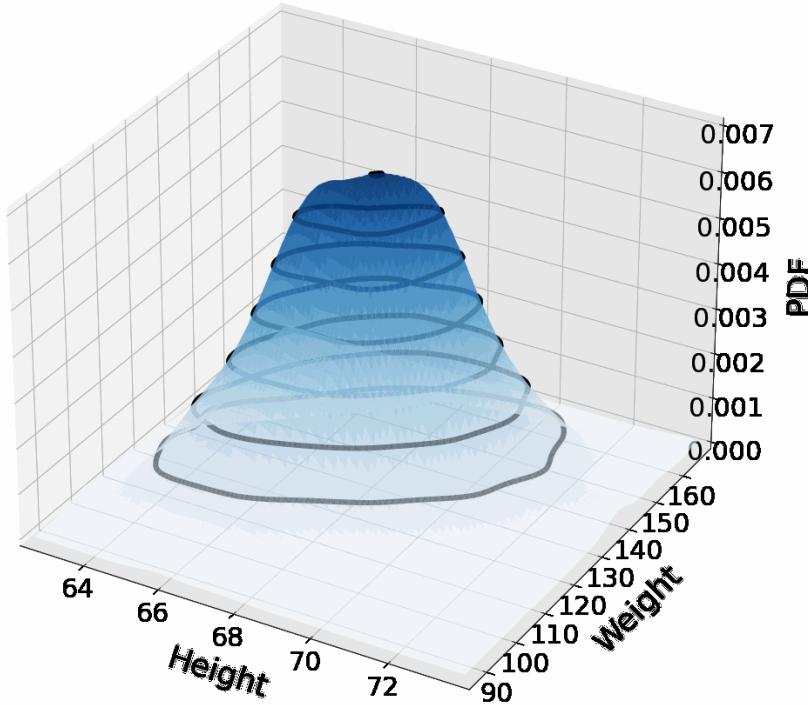
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# Multivariate Gaussian Distribution: An Example

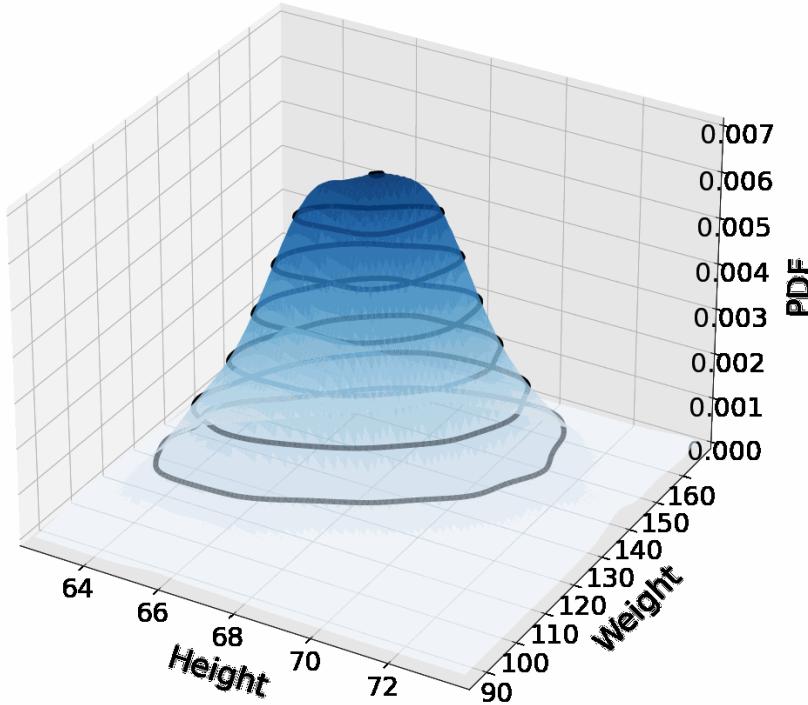


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$$f_{HW}(h, w) = f_H(h)f_W(w)$$

$$= \frac{1}{\sqrt{2\pi}\sigma_H} e^{-\frac{1}{2}\frac{(h - \mu_H)^2}{\sigma_H^2}} \cdot \frac{1}{\sqrt{2\pi}\sigma_W} e^{-\frac{1}{2}\frac{(w - \mu_W)^2}{\sigma_W^2}}$$

# Multivariate Gaussian Distribution: An Example



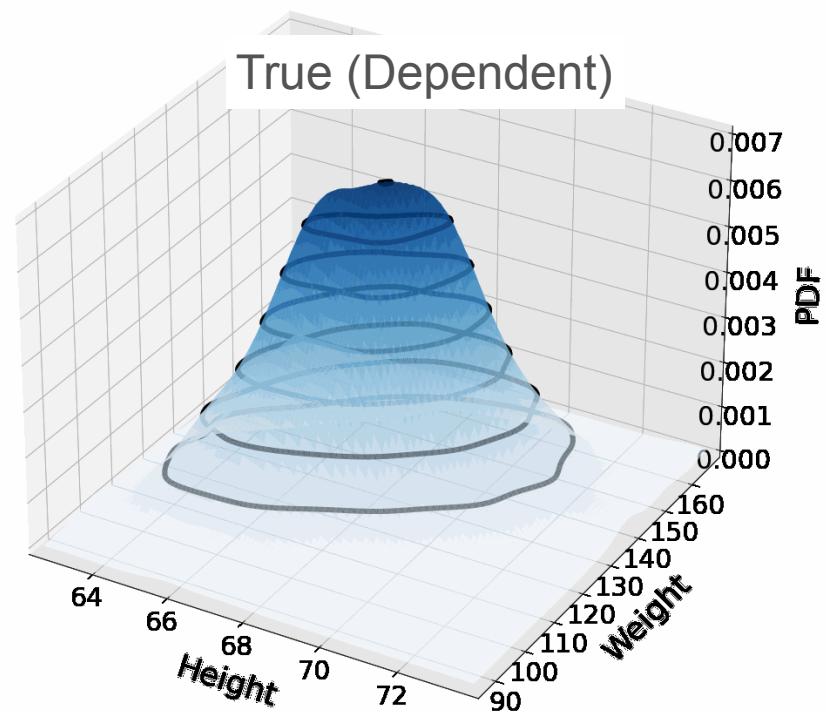
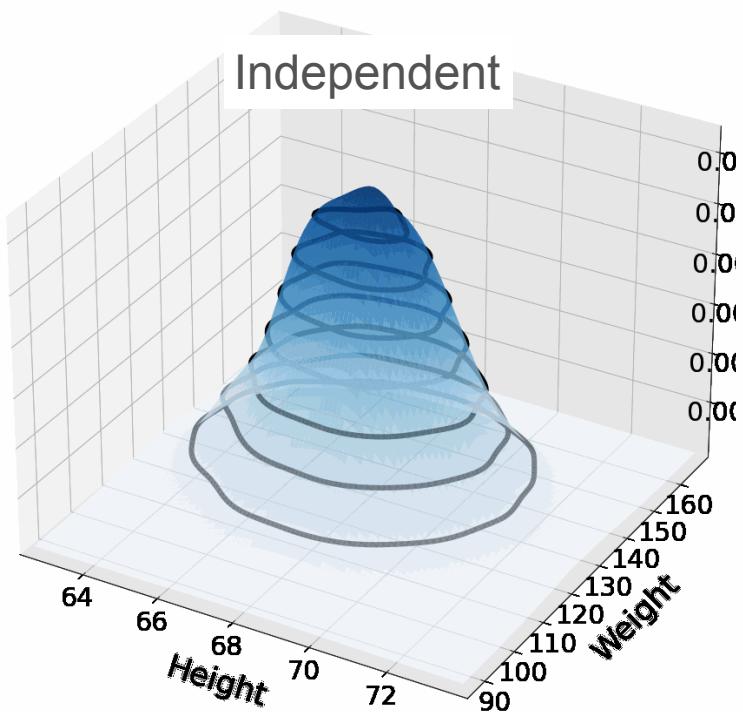
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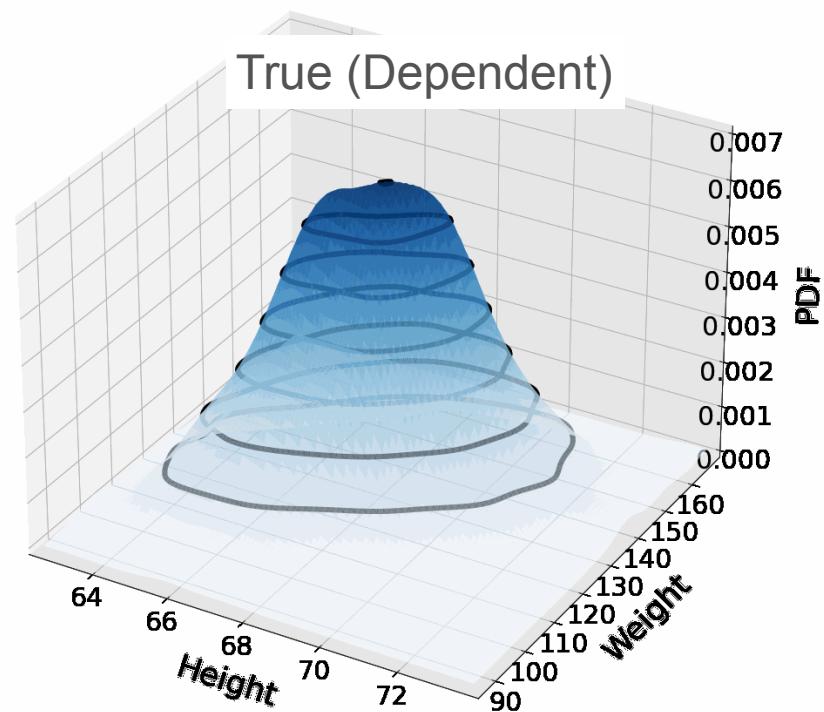
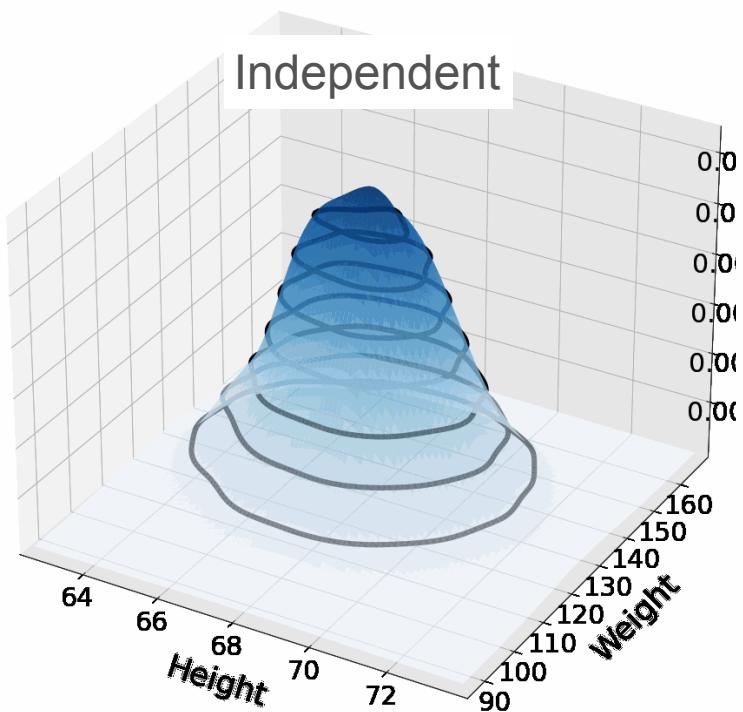
$$= \frac{1}{\sqrt{2\pi}\sigma_H} e^{-\frac{1}{2}\frac{(h-\mu_H)^2}{\sigma_H^2}} \cdot \frac{1}{\sqrt{2\pi}\sigma_W} e^{-\frac{1}{2}\frac{(w-\mu_W)^2}{\sigma_W^2}}$$

$$= \frac{1}{2\pi\sigma_H\sigma_W} e^{-\frac{1}{2}\left(\frac{(h-\mu_H)^2}{\sigma_H^2} + \frac{(w-\mu_W)^2}{\sigma_W^2}\right)}$$

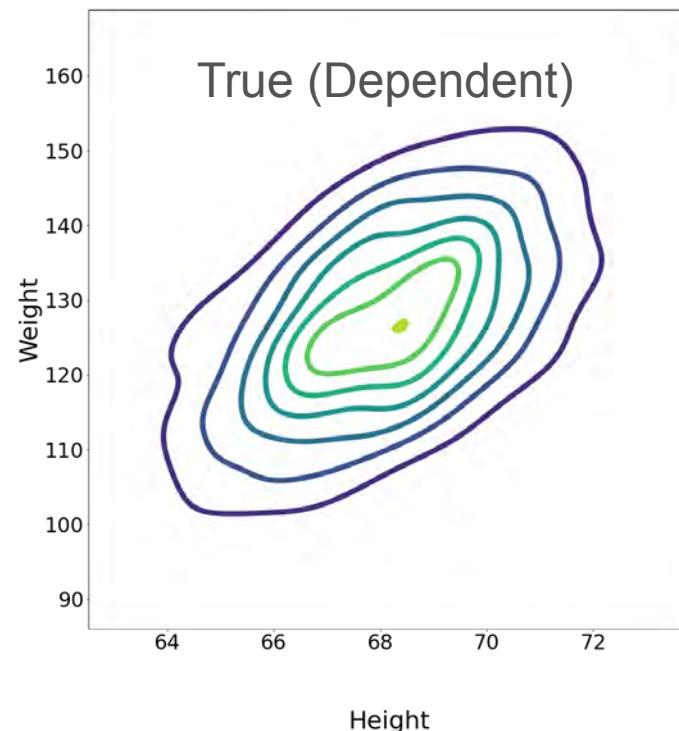
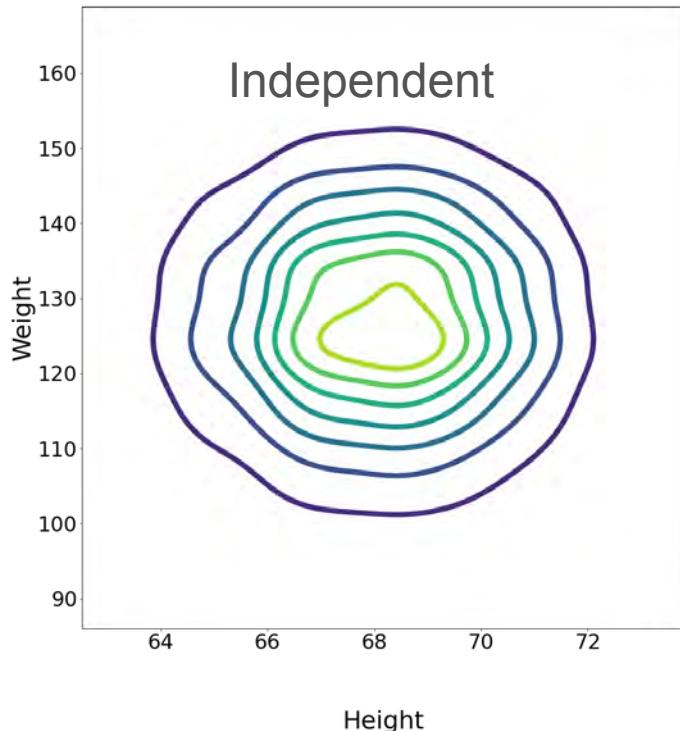
# Multivariate Gaussian Distribution: An Example



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$$\left\| \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix} \right\|_2^2$$

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$$\left\| \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix} \right\|_2^2 = \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} & \frac{w-\mu_W}{\sigma_W} \end{bmatrix} \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix}$$

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$$\left\| \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix} \right\|^2 = \begin{bmatrix} h-\mu_H & w-\mu_W \\ \sigma_H & \sigma_W \end{bmatrix} \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix}$$
$$\left[ \begin{array}{c} h - \mu_h \\ w - \mu_w \end{array} \right] = \left[ \begin{array}{c} h \\ w \end{array} \right] - \left[ \begin{array}{c} \mu_h \\ \mu_w \end{array} \right]$$

# Multivariate Gaussian Distribution: An Example

If  $W, H$  were independent

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$$\left[ \begin{bmatrix} h - \mu_h \\ w - \mu_w \end{bmatrix} \right] = \left[ \begin{bmatrix} h \\ w \end{bmatrix} \right] - \left[ \begin{bmatrix} \mu_h \\ \mu_w \end{bmatrix} \right]$$

Multiply by diagonal matrix

# Multivariate Gaussian Distribution: An Example

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$$\begin{aligned} & \left\| \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix} \right\|_2^2 \\ &= ([h \ w] - [\mu_H \ \mu_W]) \begin{bmatrix} \frac{1}{\sigma_H^2} & 0 \\ 0 & \frac{1}{\sigma_W^2} \end{bmatrix} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right) \end{aligned}$$

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$$\begin{aligned} & \left\| \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix} \right\|_2^2 \\ &= \left[ \frac{h-\mu_H}{\sigma_H} \quad \frac{w-\mu_W}{\sigma_W} \right] \begin{bmatrix} \frac{1}{\sigma_H^2} & 0 \\ 0 & \frac{1}{\sigma_W^2} \end{bmatrix} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right) \\ &= \left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right)^T \begin{bmatrix} \sigma_H^2 & 0 \\ 0 & \sigma_W^2 \end{bmatrix}^{-1} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right) \end{aligned}$$

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Covariance matrix!  
( $\Sigma$ )

$$= \left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right)^T \begin{bmatrix} \sigma_H^2 & 0 \\ 0 & \sigma_W^2 \end{bmatrix}^{-1} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right)$$

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# Multivariate Gaussian Distribution: An Example

If  $W, H$  were independent

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det ( $\Sigma$ )<sup>1/2</sup>

$$\left\| \begin{bmatrix} \frac{h-\mu_H}{\sigma_H} \\ \frac{w-\mu_W}{\sigma_W} \end{bmatrix} \right\|_2^2 = \begin{bmatrix} h-\mu_H & w-\mu_W \\ \sigma_H & \sigma_W \end{bmatrix} \begin{bmatrix} \frac{1}{\sigma_H^2} & 0 \\ 0 & \frac{1}{\sigma_W^2} \end{bmatrix} \begin{bmatrix} h-\mu_H \\ w-\mu_W \\ \sigma_W \end{bmatrix}$$
$$= ([h \ w] - [\mu_H \ \mu_W]) \begin{bmatrix} \frac{1}{\sigma_H^2} & 0 \\ 0 & \frac{1}{\sigma_W^2} \end{bmatrix} \left( [h \ w] - [\mu_H \ \mu_W] \right)$$

Covariance matrix!  
( $\Sigma$ )

$$= \left( [h \ w] - [\mu_H \ \mu_W] \right)^T \begin{bmatrix} \sigma_H^2 & 0 \\ 0 & \sigma_W^2 \end{bmatrix}^{-1} \left( [h \ w] - [\mu_H \ \mu_W] \right)$$

$\mu$

# Multivariate Gaussian Distribution: An Example

If  $W, H$  were independent

$$f_{HW}(h, w) = f_H(h)f_W(w)$$

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$$\left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right)^T \begin{bmatrix} \sigma_H^2 & 0 \\ 0 & \sigma_W^2 \end{bmatrix}^{-1} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \begin{bmatrix} \mu_H \\ \mu_W \end{bmatrix} \right)$$

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$$= \frac{1}{2\pi \det \Sigma^{1/2}} \exp \left( -\frac{1}{2} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \boldsymbol{\mu} \right)^T \boldsymbol{\Sigma^{-1}} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \boldsymbol{\mu} \right) \right)$$

# Multivariate Gaussian Distribution: An Example

**Dependent case:**

$$f_{HW}(h, w) = f_H(h)f_W(w)$$

$$= \frac{1}{2\pi\sigma_H\sigma_W} e^{-\frac{1}{2}\left(\frac{(h-\mu_H)^2}{\sigma_H^2} + \frac{(w-\mu_W)^2}{\sigma_W^2}\right)}$$

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# Multivariate Gaussian Distribution: An Example

Dependent case:

$$\begin{aligned} f_{HW}(h, w) &= \cancel{f_H(h)f_W(w)} \\ &= \frac{1}{2\pi\sigma_H\sigma_W} e^{-\frac{1}{2}\left(\frac{(h-\mu_H)^2}{\sigma_H^2} + \frac{(w-\mu_W)^2}{\sigma_W^2}\right)} \\ &= \frac{1}{2\pi\det\Sigma^{1/2}} \exp\left(-\frac{1}{2} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \boldsymbol{\mu} \right)^T \Sigma^{-1} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \boldsymbol{\mu} \right) \right) \end{aligned}$$

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$$\Sigma = \begin{bmatrix} \sigma_H^2 & Cov(H, W) \\ Cov(H, W) & \sigma_W^2 \end{bmatrix}$$

$$= \frac{1}{2\pi \det \Sigma^{1/2}} \exp \left( -\frac{1}{2} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \boldsymbol{\mu} \right)^T \Sigma^{-1} \left( \begin{bmatrix} h \\ w \end{bmatrix} - \boldsymbol{\mu} \right) \right)$$

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# Multivariate Gaussian Distribution: General Definition

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$$f_X(x_1, x_2, \dots, x_n) = \frac{1}{\sqrt{2\pi}\sigma}$$

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covariance matrix  
spread of the bell



$|\Sigma|$  determinant of the covariance matrix

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$$\boldsymbol{x} = [x_1 \ x_2 \ \dots \ x_n]^T$$
$$\boldsymbol{\mu} = [\mu_1, \mu_2, \dots, \mu_n]^T$$
$$f_X(x_1, x_2, \dots, x_n) = \frac{1}{(2\pi)^{n/2} |\Sigma|^{\frac{1}{2}}} e^{-\frac{1}{2} (\boldsymbol{x}-\boldsymbol{\mu})^T}$$

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$$x = [x_1 \ x_2 \ \dots \ x_n]^T$$

Mean vector  
 $\mu = [\mu_1, \mu_2, \dots, \mu_n]^T$

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Rescaling / standardization

$|\Sigma|$  determinant of the covariance matrix

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Mean vector  
 $\boldsymbol{\mu} = [\mu_1, \mu_2, \dots, \mu_n]^T$

$f_X(x_1, x_2)$   
random  
 $X = [X_1 \ X_2 \ \dots \ X_n]$

- For univariate, we work with scalar values and variances
- For multivariate, we work with vectors and the covariance matrix

covariance matrix  
spread of the bell

$|\Sigma|$  determinant of the covariance matrix

# Multivariate Gaussian Distribution: Conditionals



DeepLearning.AI

# Probability Distributions with Multiple Variables

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## Conclusion