

Unit 2: Probability and distributions

3. Normal and binomial distributions

GOVT 3990 - Spring 2020

Cornell University

1. Housekeeping

2. Main ideas

1. Two types of probability distributions: discrete and continuous
2. Normal distribution is unimodal, symmetric, and follows the 68-95-99.7 rule
3. Z scores serve as a ruler for any distribution
4. Binomial distribution is used for calculating the probability of exact number of successes for a given number of trials
5. Expected value and standard deviation of the binomial can be calculated using its parameters n and p
6. Shape of the binomial distribution approaches normal when the S-F rule is met

3. Summary

- ▶ Labs:
 - what you did right

- ▶ Labs:
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 - Lab 1 graded, lab 2 this weekend

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 - Lab 3 Due next week

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1. Two types of probability distributions: discrete and continuous

- ▶ A *discrete probability distribution* lists all possible events and the probabilities with which they occur
 - The events listed must be disjoint
 - Each probability must be between 0 and 1
 - The probabilities must total 1

Example: Binomial distribution

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Example: Binomial distribution

- ▶ A *continuous probability distribution* differs from a discrete probability distribution in several ways:
 - The probability that a continuous random variable will equal to any specific value is zero.
 - As such, they cannot be expressed in tabular form.
 - Instead, we use an equation or a formula to describe its distribution via a probability density function (pdf).
 - We can calculate the probability for ranges of values the random variable takes (area under the curve).

Example: Normal distribution

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Your turn

Speeds of cars on a highway are normally distributed with mean 65 miles / hour. The minimum speed recorded is 48 miles / hour and the maximum speed recorded is 83 miles / hour. Which of the following is most likely to be the standard deviation of the distribution?

- (a) -5
- (b) 5
- (c) 10
- (d) 15
- (e) 30

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- (a) $-5 \rightarrow SD \text{ cannot be negative}$
- (b) **5** $\rightarrow 65 \pm (3 \times 5) = (50, 80)$
- (c) $10 \rightarrow 65 \pm (3 \times 10) = (35, 95)$
- (d) $15 \rightarrow 65 \pm (3 \times 15) = (20, 110)$
- (e) $30 \rightarrow 65 \pm (3 \times 30) = (-25, 155)$

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A Z score creates a common scale so you can assess data without worrying about the specific units in which it was measured.

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How can we determine if it would be unusual for an adult woman in Ithaca to be 96" (8 ft) tall?

How can we determine if it would be unusual for an adult alien woman(?) to be 103 metreloots tall, assuming the distribution of heights of adult alien women is approximately normal?

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- ▶ Observations with $|Z| > 2$ are usually considered *unusual*

Your turn

Scores on a standardized test are normally distributed with a mean of 100 and a standard deviation of 20. If these scores are converted to standard normal Z scores, which of the following statements will be correct?

- (a) The mean will equal 0, but the median cannot be determined.
- (b) The mean of the standardized Z-scores will equal 100.
- (c) The mean of the standardized Z-scores will equal 5.
- (d) Both the mean and median score will equal 0.
- (e) A score of 70 is considered unusually low on this test.

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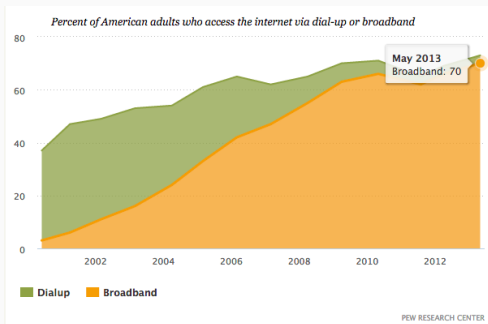
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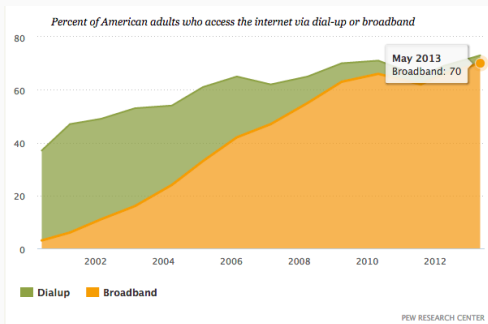
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High-speed broadband connection at home in the US

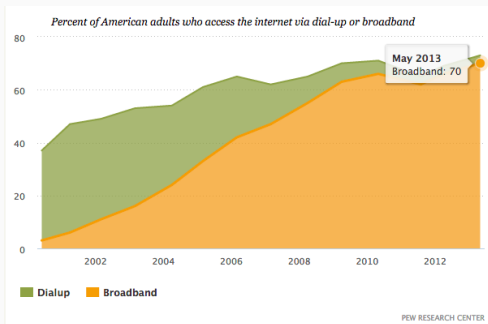


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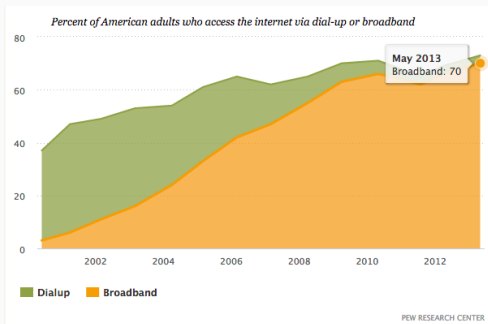
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- ▶ Each person in the poll thought of as a *trial*
- ▶ A person is labeled a *success* if s/he has high-speed broadband connection at home, *failure* if not
- ▶ Since 70% have high-speed broadband connection at home, *probability of success* is $p = 0.70$

Considering many scenarios

Suppose we randomly select three individuals from the US, what is the probability that exactly 1 has high-speed broadband connection at home?

Let's call these people Anthony (A), Barry (B), Cam (C). Each one of the three scenarios below will satisfy the condition of "exactly 1 of them says Yes":

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$$\text{Scenario 1: } \frac{0.70}{(A) \text{ yes}} \times \frac{0.30}{(B) \text{ no}} \times \frac{0.30}{(C) \text{ no}} \approx 0.063$$

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$$\text{Scenario 3: } \frac{0.30}{(A) \text{ no}} \times \frac{0.30}{(B) \text{ no}} \times \frac{0.70}{(C) \text{ yes}} \approx 0.063$$

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The probability of exactly one 1 of 3 people saying Yes is the sum of all of these probabilities.

$$0.063 + 0.063 + 0.063 = 3 \times 0.063 = 0.189$$

The question from the prior slide asked for the probability of given number of successes, k , in a given number of trials, n , ($k = 1$ success in $n = 3$ trials), and we calculated this probability as

$$\# \text{ of scenarios} \times P(\text{single scenario})$$

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► $P(\text{single scenario}) = p^k (1 - p)^{(n-k)}$

probability of success to the power of number of successes, probability of failure to the power of number of failures

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The *Binomial distribution* describes the probability of having exactly k successes in n independent trials with probability of success p .

$$P(k \text{ successes in } n \text{ trials}) = \binom{n}{k} p^k (1 - p)^{(n-k)}$$

Binomial distribution (cont.)

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Note: You can also use `R` for the calculation of number of scenarios:

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> choose(3,1)
```

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[1] 3
```

Note: And to compute probabilities

```
> dbinom(1, size = 3, prob = 0.7)
```

```
[1] 0.189
```


Your turn

Which of the following is not a condition that needs to be met for the binomial distribution to be applicable?

- (a) the trials must be independent
- (b) the number of trials, n , must be fixed
- (c) each trial outcome must be classified as a *success* or a *failure*
- (d) the number of desired successes, k , must be greater than the number of trials
- (e) the probability of success, p , must be the same for each trial

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Your turn

According to the results of the Pew poll suggesting that 70% of Americans have high-speed broadband connection at home, is the probability of exactly 2 out of 15 randomly sampled Americans having such connection at home pretty high or pretty low?

- (a) pretty high
- (b) pretty low

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According to the results of the Pew poll suggesting that 70% of Americans have high-speed broadband connection at home, is the probability of exactly 2 out of 15 randomly sampled Americans having such connection at home pretty high or pretty low?

- (a) pretty high
- (b) **pretty low**

Your turn

According to the results of the Pew poll 70% of Americans have high-speed broadband connection at home, what is the probability that exactly 2 out of 15 randomly sampled Americans have such connection at home?

- (a) $0.70^2 \times 0.30^{13}$
- (b) $\binom{2}{15} \times 0.70^2 \times 0.30^{13}$
- (c) $\binom{15}{2} \times 0.70^2 \times 0.30^{13}$
- (d) $\binom{15}{2} \times 0.70^{13} \times 0.30^2$

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(b) $\binom{2}{15} \times 0.70^2 \times 0.30^{13}$

(c) $\binom{15}{2} \times 0.70^2 \times 0.30^{13}$

$$= \frac{15!}{13! \times 2!} \times 0.70^2 \times 0.30^{13} = 105 \times 0.70^2 \times 0.30^{13} = 8.2e - 06$$

(d) $\binom{15}{2} \times 0.70^{13} \times 0.30^2$

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Expected value and standard deviation of binomial

According to the results of the Pew poll suggestion that 70% of Americans have high-speed broadband connection at home, among a random sample of 100 Americans, how many would you expect to have such connection at home?

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– Or more formally, $\mu = np = 100 \times 0.7 = 70$

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- ▶ $100 \times 0.70 = 70$
 - Or more formally, $\mu = np = 100 \times 0.7 = 70$
- ▶ But this doesn't mean in every random sample of 100 Americans exactly 70 will have high-speed broadband connection at home. In some samples there will be fewer of those, and in others more. How much would we expect this value to vary?

According to the results of the Pew poll suggestion that 70% of Americans have high-speed broadband connection at home, among a random sample of 100 Americans, how many would you expect to have such connection at home?

- ▶ $100 \times 0.70 = 70$
 - Or more formally, $\mu = np = 100 \times 0.7 = 7$
- ▶ But this doesn't mean in every random sample of 100 Americans exactly 70 will have high-speed broadband connection at home. In some samples there will be fewer of those, and in others more. How much would we expect this value to vary?
 - $\sigma = \sqrt{np(1-p)} = \sqrt{100 \times 0.70 \times 0.30} \approx 4.58$

Note: Mean and standard deviation of a binomial might not always be whole numbers, and that is alright, these values represent what we would expect to see on average.

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https://gallery.shinyapps.io/dist_calc/

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You can use the normal distribution to approximate binomial probabilities when the sample size is large enough.

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You can use the normal distribution to approximate binomial probabilities when the sample size is large enough.

S-F rule: The sample size is considered large enough if the expected number of successes and failures are both at least 10

$$np \geq 10 \quad \text{and} \quad n(1 - p) \geq 10$$

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$$\text{Binom}(n = 1000, p = 0.7)$$

$$P(K \geq 750) = P(K = 750) + P(K = 751) + P(K = 752) + \cdots + P(K = 1000)$$

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1. Using R:

```
> sum(dbinom(750:1000, size = 1000, prob = 0.7))
```

```
[1] 0.00026
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2. Using the normal approximation to the binomial: Since we have at least expected successes ($1000 \times 0.7 = 700$) and 10 expected failures ($1000 \times 0.3 = 300$),

$$\begin{aligned} \text{Binom}(n = 1000, p = 0.7) &\sim \\ N(\mu = 1000 \times 0.7, \sigma = \sqrt{1000 \times 0.7 \times 0.3}) \end{aligned}$$

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