# Fundamentals of Hypothesis Testing: One-Sample Tests

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# Learning Objectives

## In this lecture, you learn:

- The basic principles of hypothesis testing
- How to use hypothesis testing to test a mean or proportion
- The assumptions of each hypothesis-testing procedure, how to evaluate them, and the consequences if they are seriously violated
- How to avoid the pitfalls involved in hypothesis testing
- The ethical issues involved in hypothesis testing


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# What is a Hypothesis?

- A hypothesis is a claim (assumption) about a population parameter:
  - population mean

Example: The mean of systolic blood pressure among adults of this city is $\mu = 120$ mmHg

  - population proportion

Example: The proportion of adults in this city with hypertension is $\pi = 0.118$


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# The Null Hypothesis, $H_0$

- States the claim or assertion to be tested

> **Example:** The average number of children in NTT woman is equal to three $(H_0: \mu = 3)$

- Is always about a population parameter, not about a sample statistic

$$H_0: \mu = 3$$

$$H_0: \bar{X} = 3$$



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# The Null Hypothesis, $H_0$

*(continued)*

- Begin with the assumption that the null hypothesis is true
  - Similar to the notion of innocent until proven guilty
- Refers to the status quo
- Always contains "=" , "≤" or "≥" sign
- May or may not be rejected



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# The Alternative Hypothesis, $H_1$

- Is the opposite of the null hypothesis
  - e.g., The average number of children in NTT woman is not equal to 3 ( $H_1: \mu \neq 3$ )
- Challenges the status quo
- Contains the "=" , "≤" or "≥" sign
- May or may not be proven
- Is generally the hypothesis that the researcher is trying to prove


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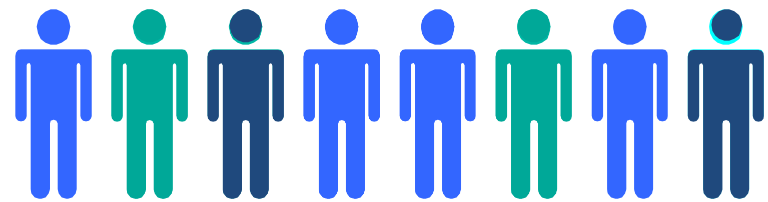
# Hypothesis Testing Process

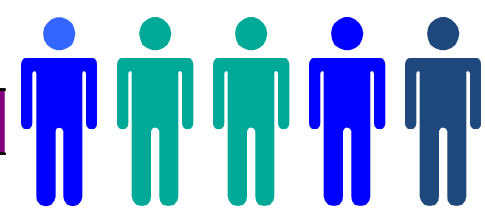
**Claim: the population mean age is 50. (Null Hypothesis:**

**$H_0$: μ = 50 )**



**Population**

Now select a random sample



**Sample**

**Is $\bar{X}$=20** likely if μ = 50?

**Suppose the sample mean age is 20: $\bar{X}$ = 20**

**If not likely,**

**REJECT**

**Null Hypothesis**



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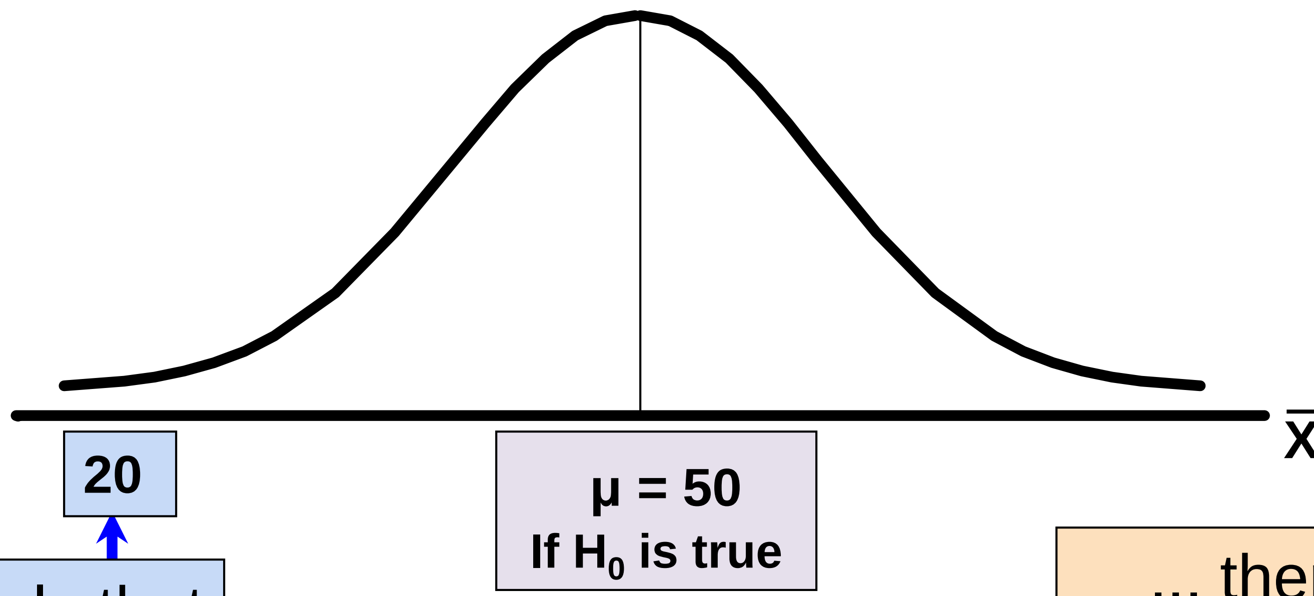
# Reason for Rejecting $H_0$

Sampling Distribution of $\bar{X}$




If it is unlikely that we would get a sample mean of this value ...

... if in fact this were the population mean…

... then we reject the null hypothesis that $\mu = 50$.

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# Level of Significance, $\alpha$

- Defines the unlikely values of the sample statistic if the null hypothesis is true
  - Defines rejection region of the sampling distribution
- Is designated by $\alpha$ , (level of significance)
  - Typical values are 0.01, 0.05, or 0.10
- Is selected by the researcher at the beginning
- Provides the critical value(s) of the test


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# Level of Significance and the Rejection Region

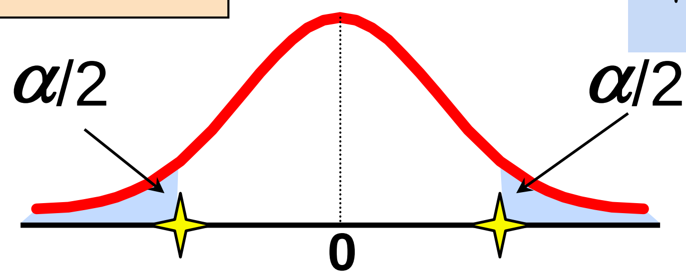
Level of significance = $\alpha$

Represents critical value

Rejection region is shaded

$H_0: \mu = 3$

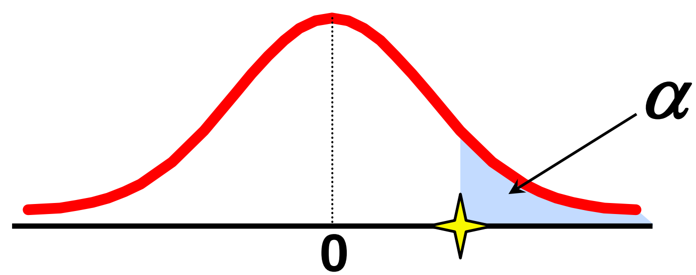
$H_1: \mu \neq 3$




Two-tail test

$H_0: \mu \leq 3$

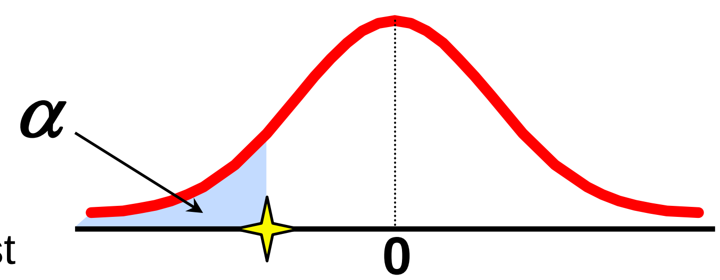
$H_1: \mu > 3$




Upper-tail test

$H_0: \mu \geq 3$

$H_1: \mu < 3$




Lower-tail test



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# Errors in Making Decisions

- **Type I Error**
  - Reject a true null hypothesis
  - Considered a serious type of error

| |
|---|
| The probability of Type I Error is $\alpha$ |

- Called **level of significance** of the test
- Set by the researcher in advance



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# Errors in Making Decisions

*(continued)*

- **Type II Error**
  - **Fail to reject a false null hypothesis**

The probability of Type II Error is $\beta$



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# Outcomes and Probabilities

**Possible Hypothesis Test Outcomes**

| | **Actual situation** | |
|---|---|---|
| **Decision** | $H_0$ True | $H_0$ False |
| Do Not Reject **$H_0$** | **No error** **(1 - α )** | **Type II Error** **( β )** |
| Reject **$H_0$** | **Type I Error** **( α )** | **No Error** **( 1 - β )** |

**Key:**
**Outcome**
**(Probability)**



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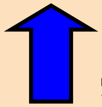
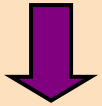
# Type I & II Error Relationship

- Type I and Type II errors cannot happen at the same time
  - Type I error can only occur if $H_0$ is true
  - Type II error can only occur if $H_0$ is false

If Type I error probability ( $\alpha$ ) , then

Type II error probability ( $\beta$ ) 



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# Factors Affecting Type II Error

- All else equal,
  - $\beta$ ↑ when the difference between hypothesized parameter and its true value ↓
  - $\beta$ ↑ when $\alpha$ ↓
  - $\beta$ ↑ when $\sigma$ ↑
  - $\beta$ ↑ when $n$ ↓


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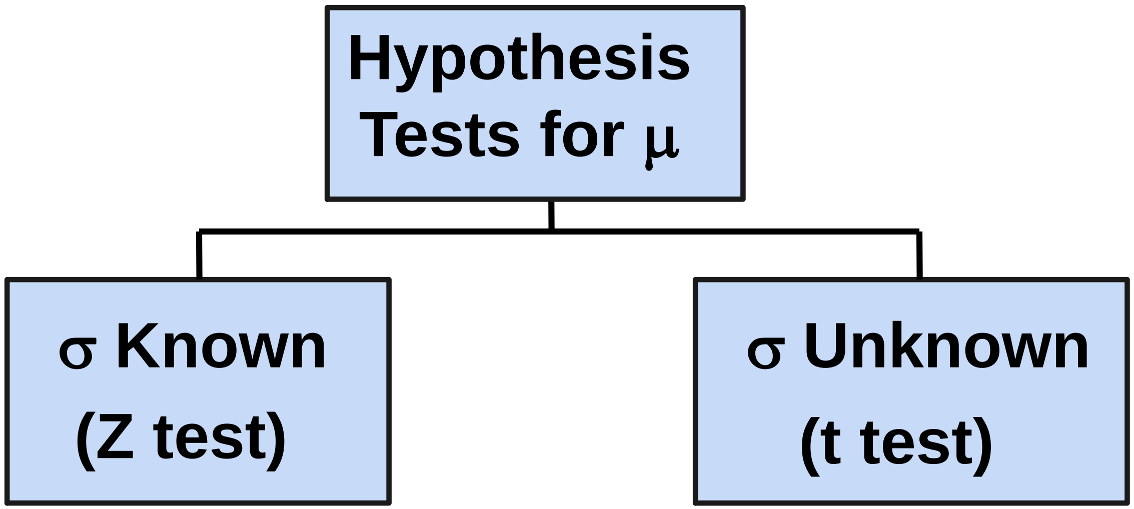
# Hypothesis Tests for the Mean





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# Z Test of Hypothesis for the Mean (σ Known)

- Convert sample statistic ( $\bar{X}$ ) to a Z test statistic

Hypothesis Tests for μ

σ Known (Z test)

σ Unknown (t test)

The test statistic is:

$$Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}}$$


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# Critical Value Approach to Testing

- For a two-tail test for the mean, σ known:
- Convert sample statistic ( $\bar{X}$ ) to test statistic (Z statistic )
- Determine the critical Z values for a specified level of significance $\alpha$ from a table or computer
- Decision Rule: If the test statistic falls in the rejection region, reject $H_0$ ; otherwise do not reject $H_0$



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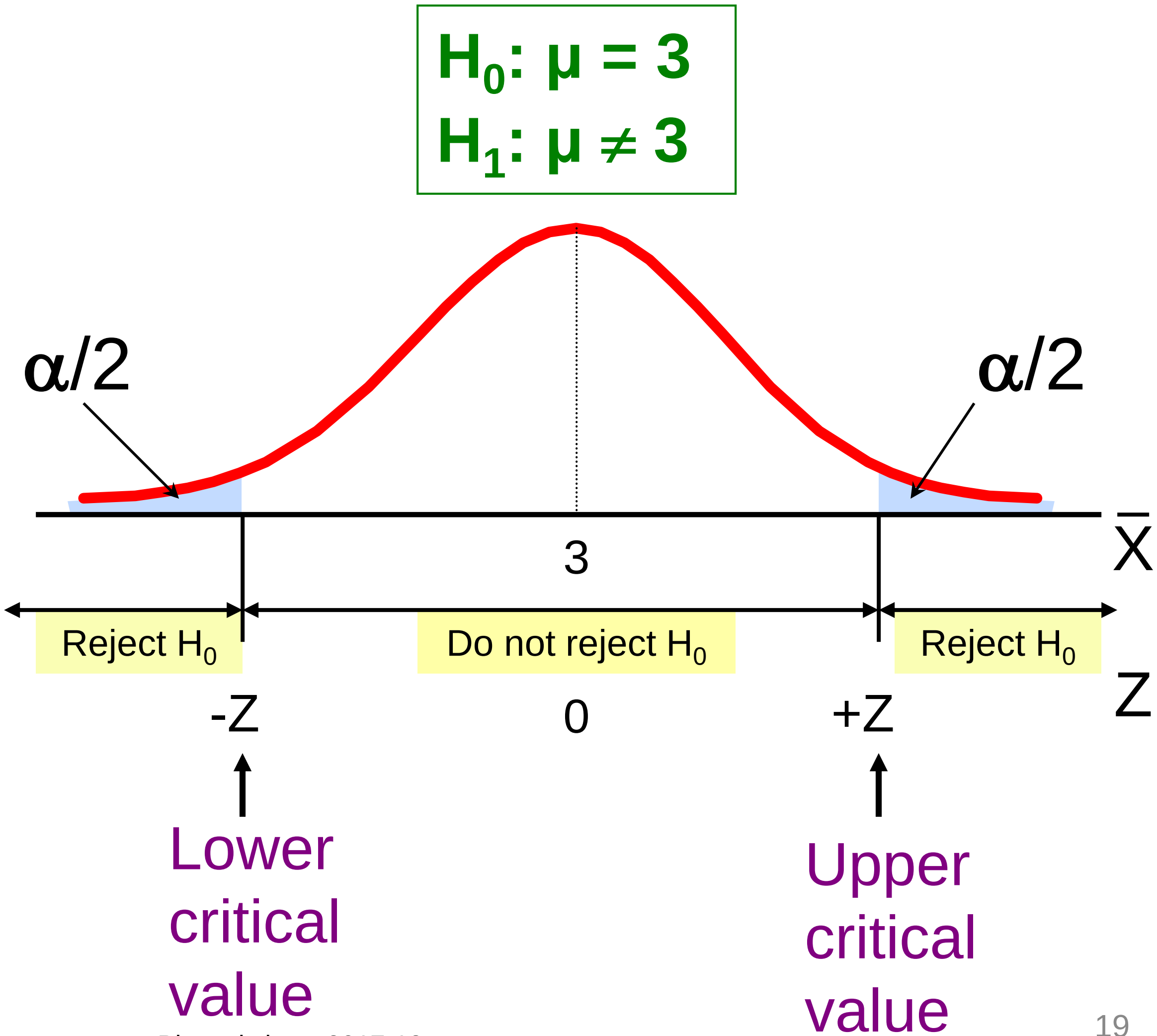
# Two-Tail Tests

- There are two cutoff values (critical values), defining the regions of rejection



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# 6 Steps in Hypothesis Testing

1. State the null hypothesis, $H_0$ and the alternative hypothesis, $H_1$
2. Choose the level of significance, $\alpha$, and the sample size, n
3. Determine the appropriate test statistic and sampling distribution
4. Determine the critical values that divide the rejection and nonrejection regions


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# 6 Steps in Hypothesis Testing

*(continued)*

5. Collect data and compute the value of the test statistic
6. Make the statistical decision and state the managerial conclusion.
   - If the test statistic falls into the non-rejection region, do not reject the null hypothesis $H_0$.
   - If the test statistic falls into the rejection region, reject the null hypothesis.
   - Express the managerial conclusion in the context of the problem



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# Hypothesis Testing Example

**Test the claim that the true mean of children in NTT woman is # equal to 3. (Assume $\sigma = 0.8$)**

1. State the appropriate null and alternative hypotheses
   - $H_0$: $\mu = 3$ $H_1$: $\mu \neq 3$ (This is a two-tail test)
2. Specify the desired level of significance and the sample size
   - Suppose that $\alpha = 0.05$ and $n = 100$ are chosen for this test


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# Hypothesis Testing Example

*(continued)*

3. Determine the appropriate technique
   - σ is known so this is a Z test.
4. Determine the critical values
   - For $\alpha = 0.05$ the critical Z values are ±1.96
5. Collect the data and compute the test statistic
   - Suppose the sample results are

     $n = 100$, $\bar{X} = 2.84$ ($\sigma = 0.8$ is assumed known)

So the test statistic is:

$$Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}} = \frac{2.84 - 3}{\frac{0.8}{\sqrt{100}}} = \frac{-.16}{.08} = -2.0$$



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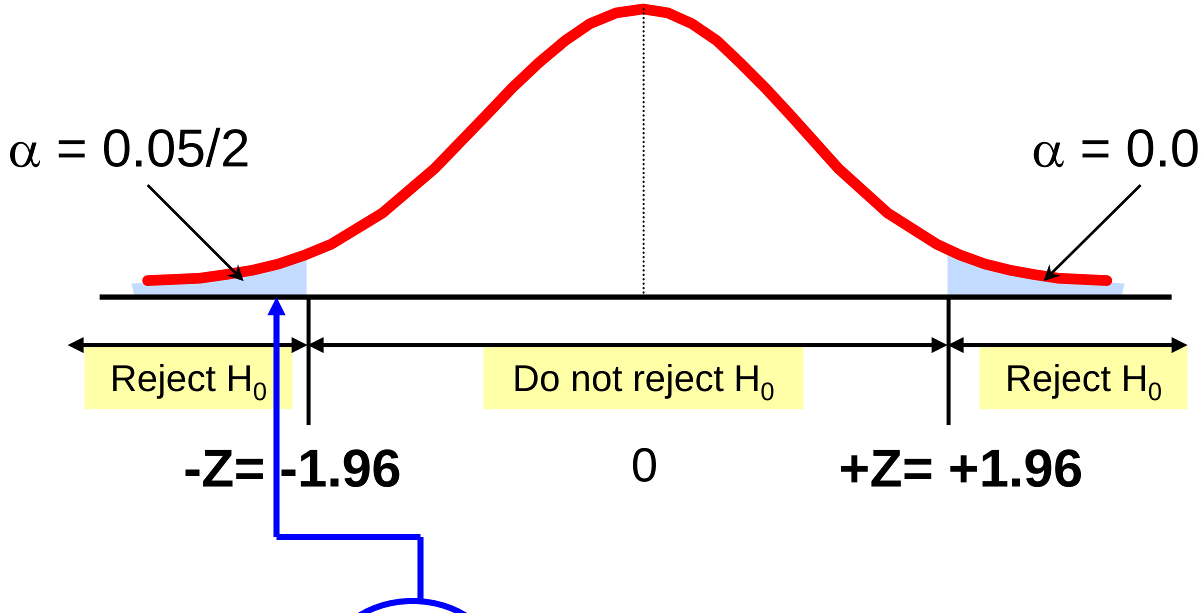
# Hypothesis Testing Example

*(continued)*

## 6. Is the test statistic in the rejection region?




Reject $H_0$ if $Z < -1.96$ or $Z > 1.96$; otherwise do not reject $H_0$

Here, $Z = -2.0 < -1.96$, so the test statistic is in the rejection region

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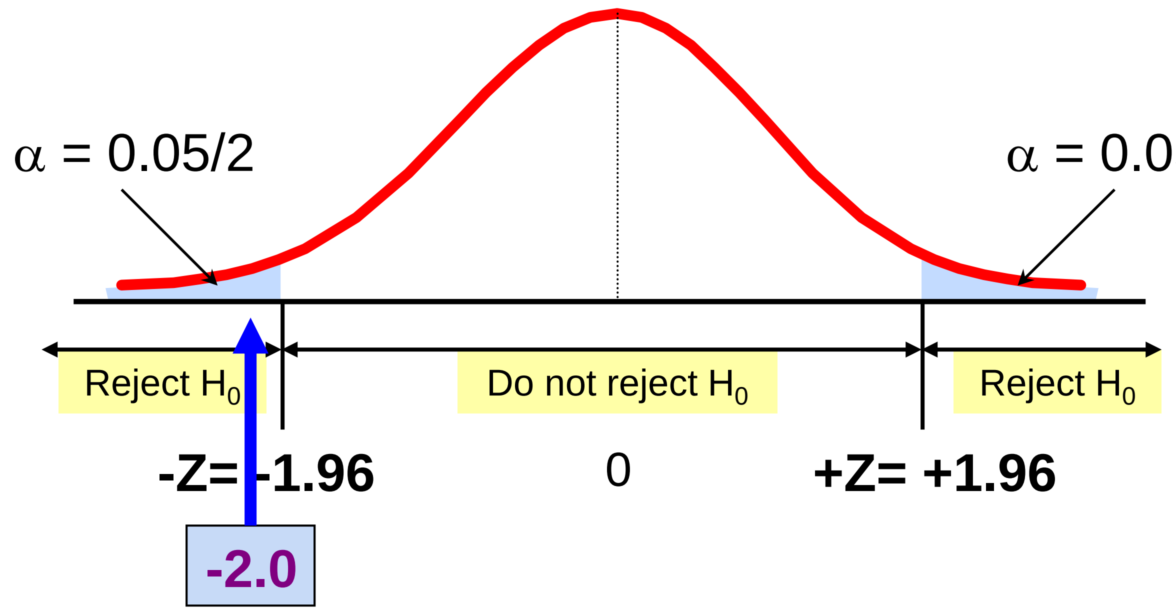
# Hypothesis Testing Example

*(continued)*

## 6(continued). Reach a decision and interpret the result




Since Z = -2.0 < -1.96, we <u>reject the null hypothesis</u> and conclude that there is sufficient evidence that the mean number of children of NTT woman is not equal to 3



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# p-Value Approach to Testing

- p-value: Probability of obtaining a test statistic more extreme ( $\leq$ or $\geq$ ) than the observed sample value given $H_0$ is true
  - Also called observed level of significance
  - Smallest value of $\alpha$ for which $H_0$ can be rejected


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# p-Value Approach to Testing

*(continued)*

- Convert Sample Statistic (e.g., $\bar{X}$) to Test Statistic (e.g., Z statistic )
- Obtain the p-value from a table or computer
- Compare the p-value with $\alpha$
  - If p-value $< \alpha$ , reject $H_0$
  - If p-value $\geq \alpha$ , do not reject $H_0$



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# p-Value Example

- **Example:** **How likely is it to see a sample mean of 2.84 (or something further from the mean, in either direction) if the true mean is $\mu$ = 3.0?**

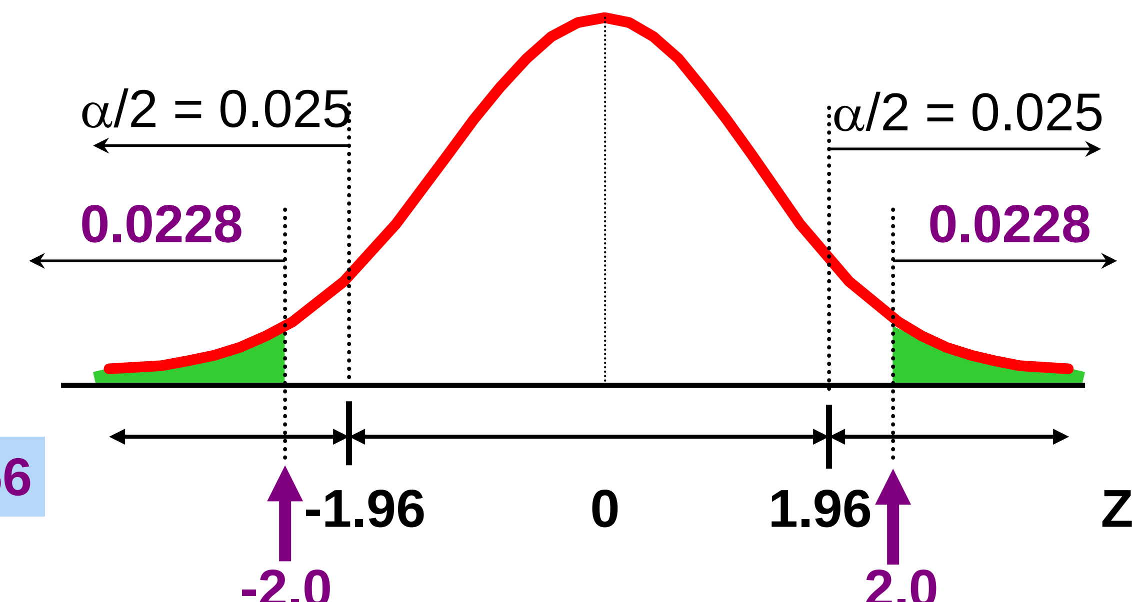
$\overline{X}$ = 2.84 is translated to a Z score of Z = -2.0

$$P(Z < -2.0) = 0.0228$$

$$P(Z > 2.0) = 0.0228$$

**p-value**

**= 0.0228 + 0.0228 = 0.0456**



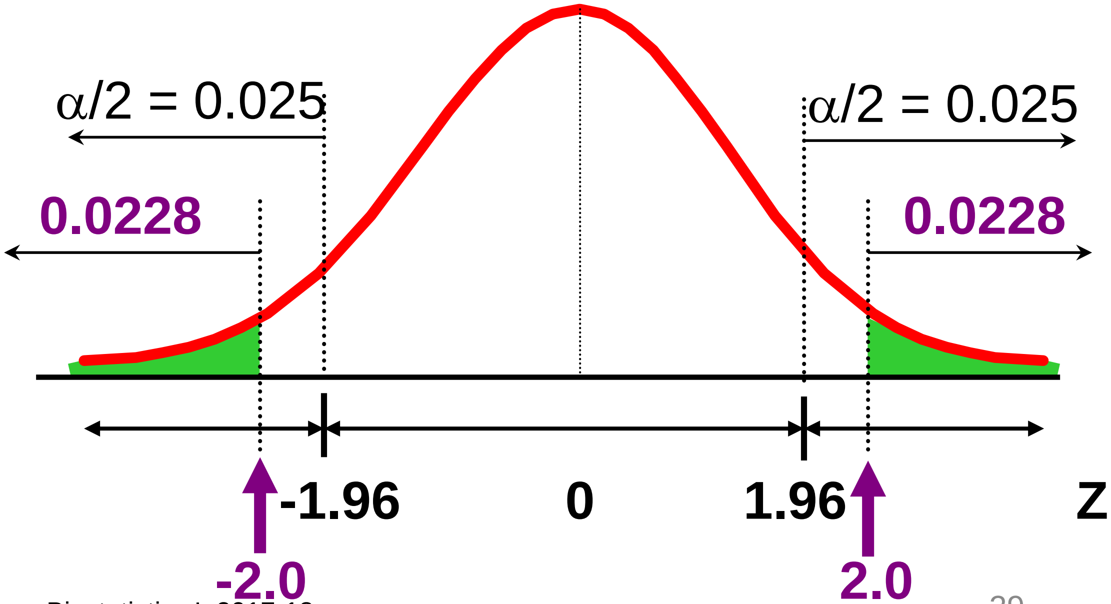
# p-Value Example

*(continued)*

- Compare the p-value with $\alpha$
  - If p-value $<$ $\alpha$ , reject $H_0$
  - If p-value $\geq$ $\alpha$ , do not reject $H_0$

Here: p-value = 0.0456
$\alpha$ = 0.05

**Since 0.0456 < 0.05, we reject the null hypothesis**







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# Connection to Confidence Intervals

- For $\bar{X} = 2.84$, $\sigma = 0.8$ and $n = 100$, the 95% confidence interval is:

$$2.84 - (1.96)\frac{0.8}{\sqrt{100}} \quad \text{to} \quad 2.84 + (1.96)\frac{0.8}{\sqrt{100}}$$

$$2.6832 \leq \mu \leq 2.9968$$

- Since this interval does not contain the hypothesized mean (3.0), we reject the null hypothesis at $\alpha = 0.05$


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# One-Tail Tests

- **In many cases, the alternative hypothesis focuses on a particular direction**

| |
|---|
| **$H_0: \mu \geq 3$** |
| **$H_1: \mu < 3$** |

→ This is a lower-tail test since the alternative hypothesis is focused on the lower tail below the mean of 3

| |
|---|
| **$H_0: \mu \leq 3$** |
| **$H_1: \mu > 3$** |

→ This is an upper-tail test since the alternative hypothesis is focused on the upper tail above the mean of 3


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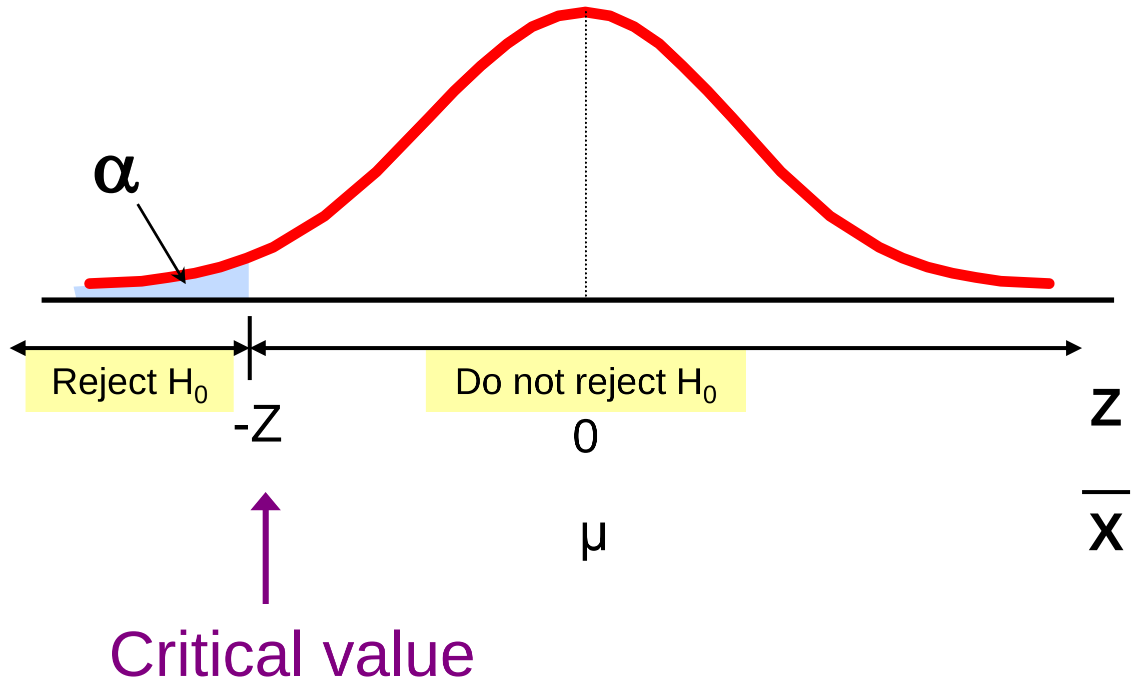
# Lower-Tail Tests

- There is only one critical value, since the rejection area is in only one tail

$H_0: \mu \geq 3$

$H_1: \mu < 3$





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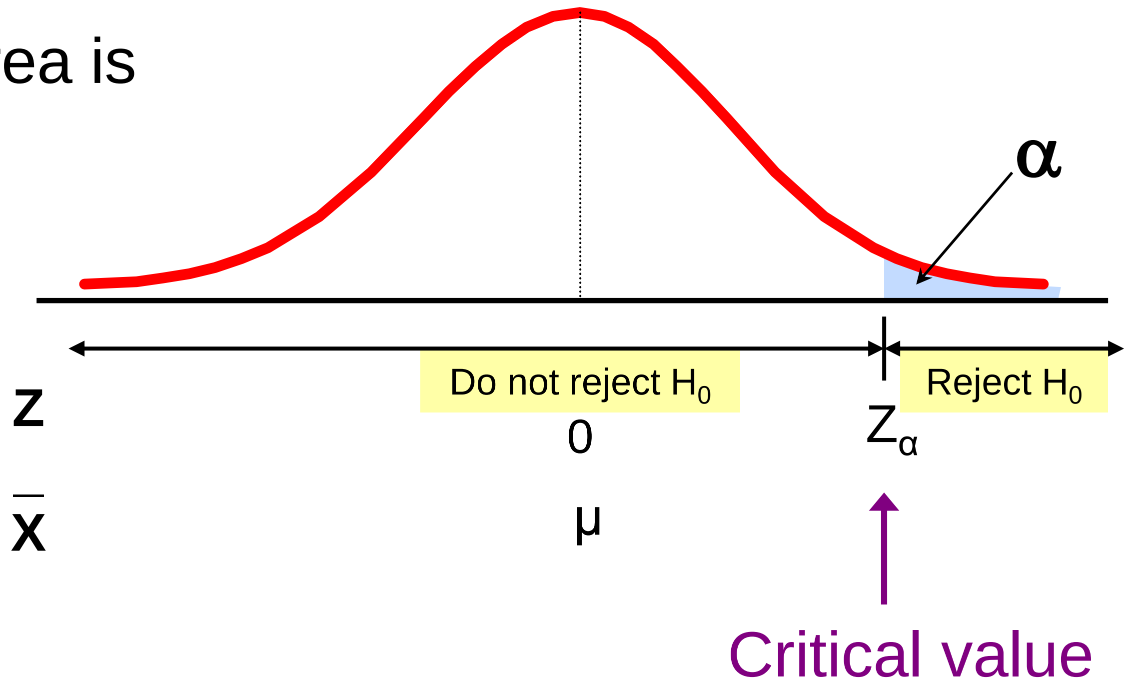
# Upper-Tail Tests

- There is only one critical value, since the rejection area is in only one tail

$H_0: \mu \le 3$

$H_1: \mu > 3$



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# Example: Upper-Tail Z Test for Mean ($\sigma$ Known)

**An investigator thinks that annual health expenditure have increased, and now average over $52 per year. The investigator wishes to test this claim. (Assume $\sigma = 10$ is known)**

Form hypothesis test:

| | |
|---|---|
| $H_0$: $\mu \leq 52$ | the average is not over $52 per month |
| $H_1$: $\mu > 52$ | the average **is** greater than $52 per year (i.e., sufficient evidence exists to support the invitagotor's claim) |



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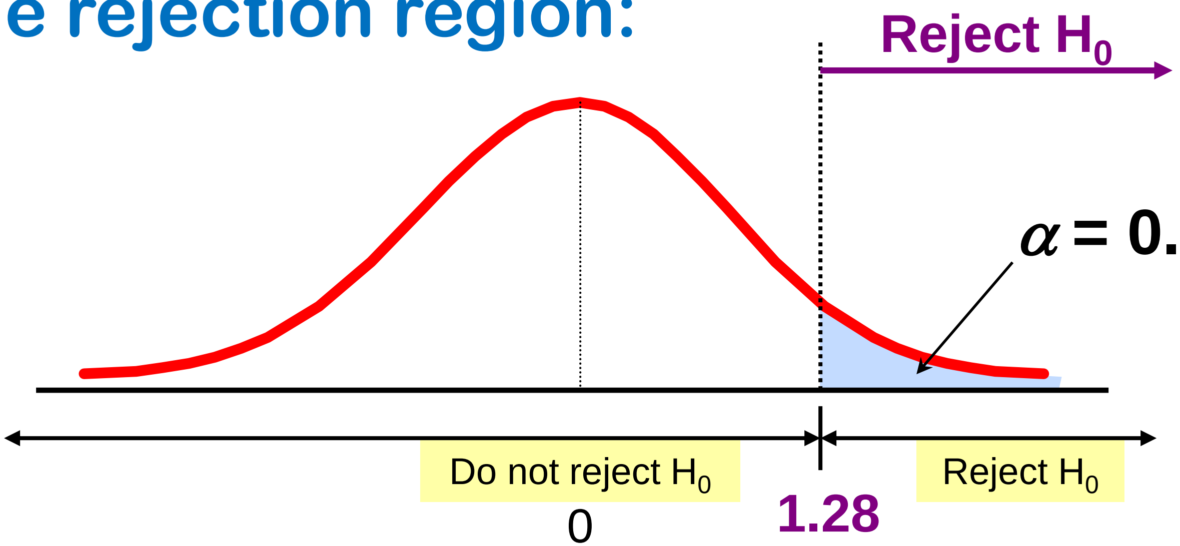
# Example: Find Rejection Region

*(continued)*

- **Suppose that α = 0.10 is chosen for this test**

**Find the rejection region:**




Reject $H_0$ if $Z > 1.28$



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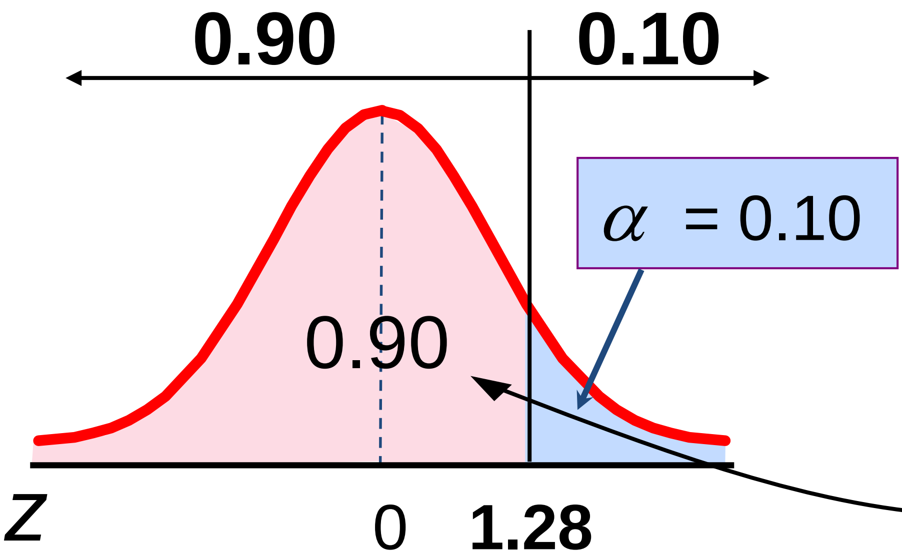
# Review: One-Tail Critical Value

What is Z given $\alpha = 0.10$?




**Critical Value = 1.28**

Standardized Normal Distribution Table (Portion)

| Z | .07 | .08 | .09 |
|---|---|---|---|
| 1.1 | .8790 | .8810 | .8830 |
| **1.2** | .8980 | .8997 | .9015 |
| 1.3 | .9147 | .9162 | .9177 |



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# Example: Test Statistic

*(continued)*

**Obtain sample and compute the test statistic**

**Suppose a sample is taken with the following results: $n = 64$, $\bar{X} = 53.1$** ($\sigma$=10 was assumed known)

- **Then the test statistic is:**

$$Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}} = \frac{53.1 - 52}{\frac{10}{\sqrt{64}}} = 0.88$$



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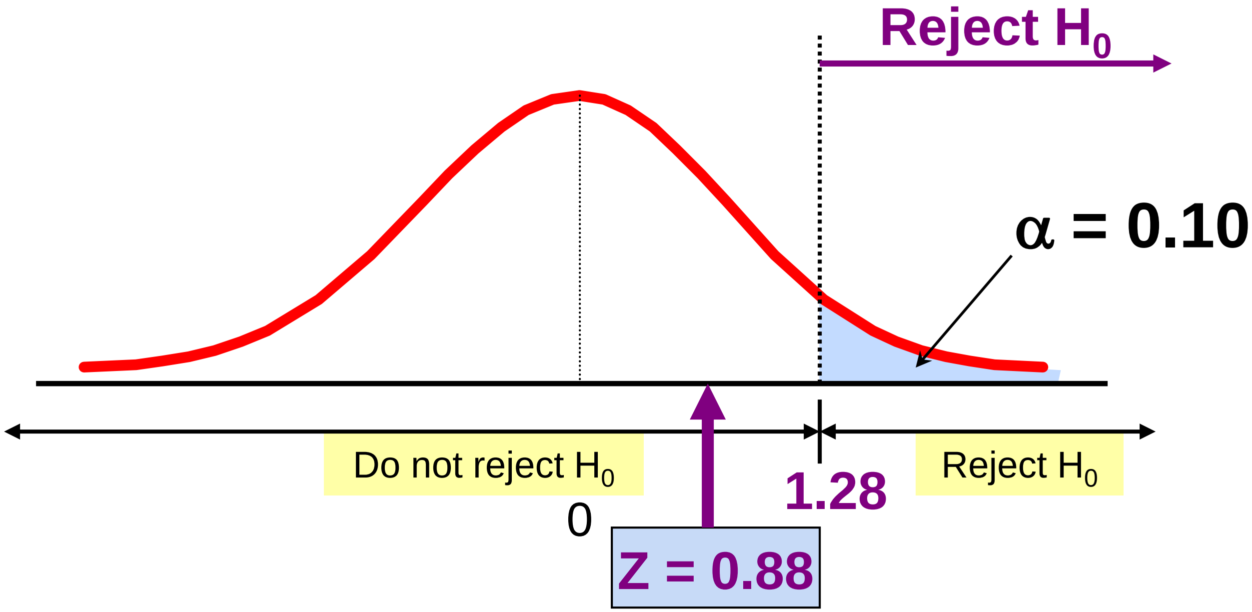
# Example: Decision

*(continued)*

## Reach a decision and interpret the result:




**Do not reject $H_0$ since $Z = 0.88 \leq 1.28$**

i.e.: there is not sufficient evidence that the mean bill is over $52

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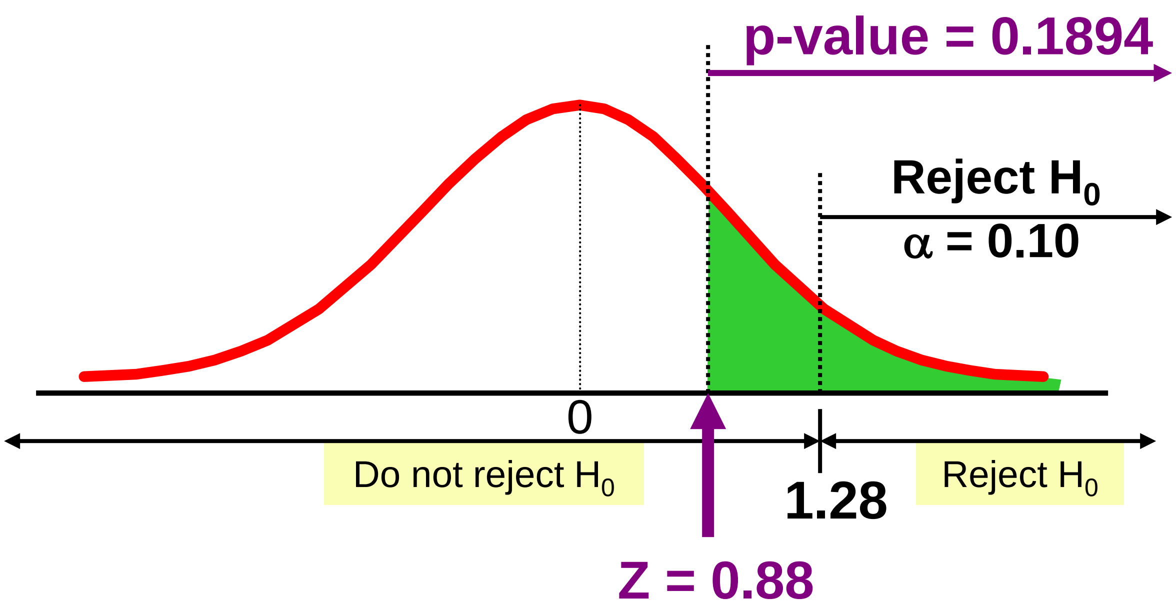
# *p*-Value Solution

*(continued)*

## Calculate the p-value and compare to α

**(assuming that μ = 52.0)**




$$P(\bar{X} \geq 53.1)$$

$$= P\left(Z \geq \frac{53.1 - 52.0}{10/\sqrt{64}}\right)$$

$$= P(Z \geq 0.88) = 1 - 0.8106$$

$$= 0.1894$$

**Do not reject $H_0$ since p-value = 0.1894 > α = 0.10**

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# t Test of Hypothesis for the Mean (σ Unknown)

- Convert sample statistic ( $\bar{X}$ ) to a t test statistic

Hypothesis Tests for μ

σ Known (Z test)

σ Unknown (t test)

The test statistic is:

$$t_{n-1} = \frac{\bar{X} - \mu}{\frac{S}{\sqrt{n}}}$$


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# Example: Two-Tail Test ($\sigma$ Unknown)

The average height of male in Indonesia is said to be 168 cm. A random sample of 25 male resulted in

$\bar{X}$ = 172.50 cm and

S = 15.40 cm.

Test at the $\alpha = 0.05$ level.

(Assume the population distribution is normal)

$H_0$: $\mu = 168$

$H_1$: $\mu \neq 168$



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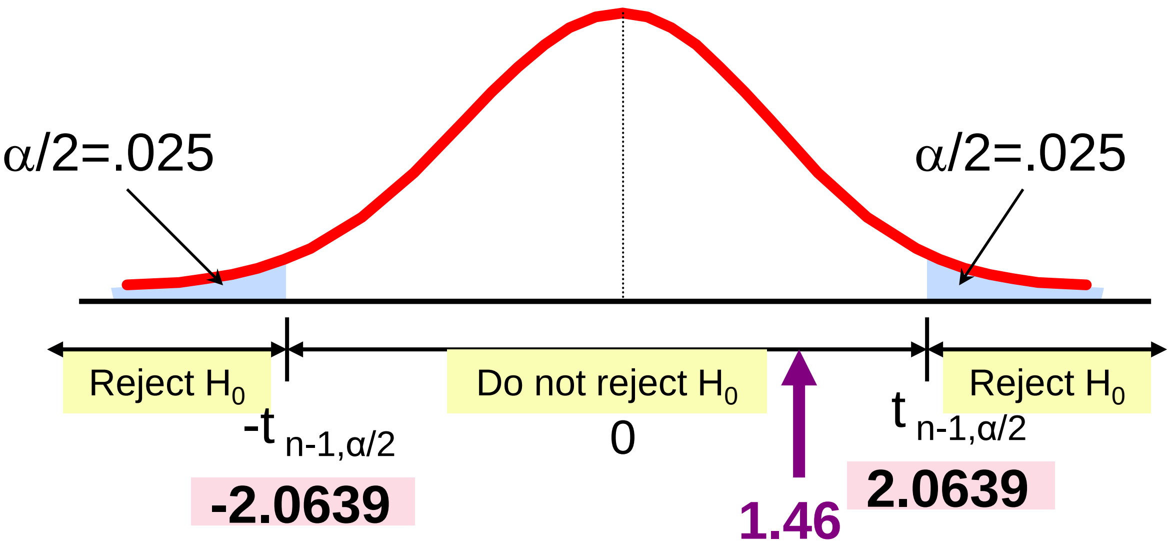
# Example Solution: Two-Tail Test

$H_0: \mu = 168$
$H_1: \mu \neq 168$

- $\alpha = 0.05$
- $n = 25$
- $\sigma$ is unknown, so use a **t statistic**
- Critical Value:




$$t_{n-1} = \frac{\bar{X} - \mu}{\frac{S}{\sqrt{n}}} = \frac{172.50 - 168}{\frac{15.40}{\sqrt{25}}} = 1.46$$

**Do not reject $H_0$:** not sufficient evidence that true mean height is different than 168 cm



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# Connection to Confidence Intervals

- For $\bar{X} = 172.5$, $S = 15.40$ and $n = 25$, the 95% confidence interval is:

$$172.5 - (2.0639)\ 15.4/\sqrt{25} \quad \text{to} \quad 172.5 + (2.0639)\ 15.4/\sqrt{25}$$

$$166.14 \leq \mu \leq 178.86$$

- Since this interval contains the Hypothesized mean (168), we do not reject the null hypothesis at $\alpha = 0.05$



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# Hypothesis Tests for Proportions

- Involves categorical variables
- Two possible outcomes
  - "Success" (possesses a certain characteristic)
  - "Failure" (does not possesses that characteristic)
- Fraction or proportion of the population in the "success" category is denoted by $\pi$


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# Proportions

*(continued)*

- **Sample proportion in the success category is denoted by p**
  - $$p = \frac{X}{n} = \frac{\text{number of successes in sample}}{\text{sample size}}$$
- **When both nπ and n(1-π) are at least 5, p can be approximated by a normal distribution with mean and standard deviation**
  - $$\mu_p = \pi \qquad \sigma_p = \sqrt{\frac{\pi(1-\pi)}{n}}$$



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# Hypothesis Tests for Proportions

- The sampling distribution of p is approximately normal, so the test statistic is a Z value:

$$Z = \frac{p - \pi}{\sqrt{\frac{\pi(1-\pi)}{n}}}$$

Hypothesis Tests for p

$n\pi \geq 5$ and $n(1-\pi) \geq 5$

$n\pi < 5$ or $n(1-\pi) < 5$

Not discussed in this chapter



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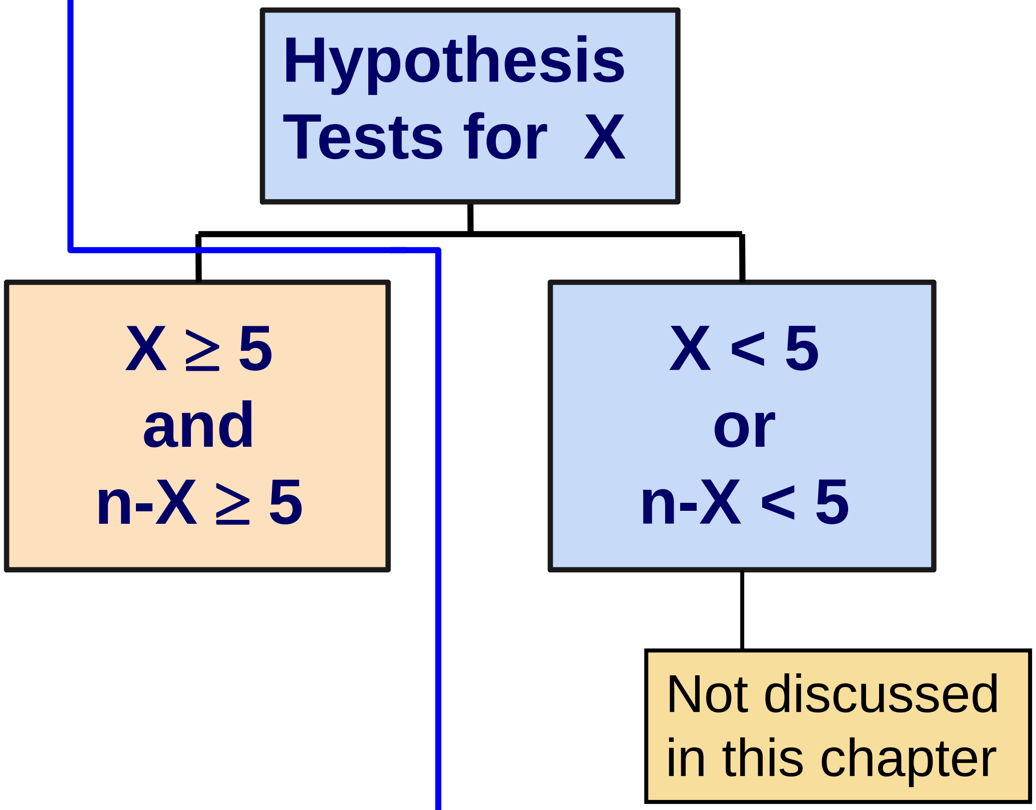
# Z Test for Proportion in Terms of Number of Successes

- An equivalent form to the last slide, but in terms of the number of successes, X:

$$Z = \frac{X - n\pi}{\sqrt{n\pi(1-\pi)}}$$



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# Example: Z Test for Proportion

A researcher claims that it receives 8% responses from its mailing. To test this claim, a random sample of 500 were surveyed with 25 responses. Test at the $\alpha = 0.05$ significance level.

Check:

$$n\pi = (500)(.08) = 40$$

$$n(1-\pi) = (500)(.92) = 460$$

✓


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# Z Test for Proportion: Solution

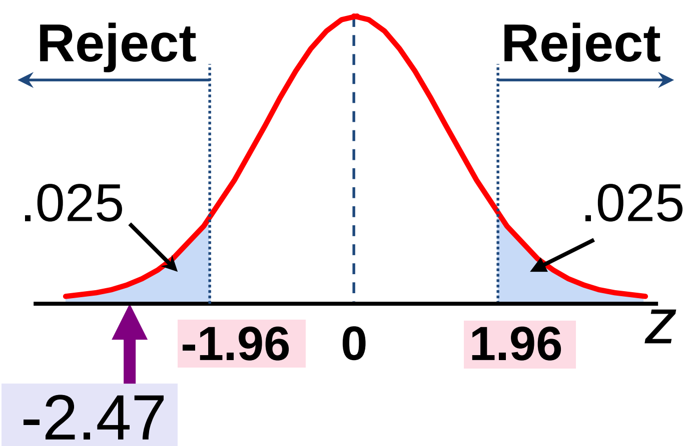
$H_0: \pi = 0.08$

$H_1: \pi \neq 0.08$

$\alpha = 0.05$

$n = 500, \quad p = 0.05$

**Critical Values: ± 1.96**




**Test Statistic:**

$$Z = \frac{p - \pi}{\sqrt{\frac{\pi(1-\pi)}{n}}} = \frac{.05 - .08}{\sqrt{\frac{.08(1-.08)}{500}}} = -2.47$$

**Decision:**

Reject $H_0$ at $\alpha = 0.05$

**Conclusion:**

There is sufficient evidence to reject the researcher claim of 8% response rate.



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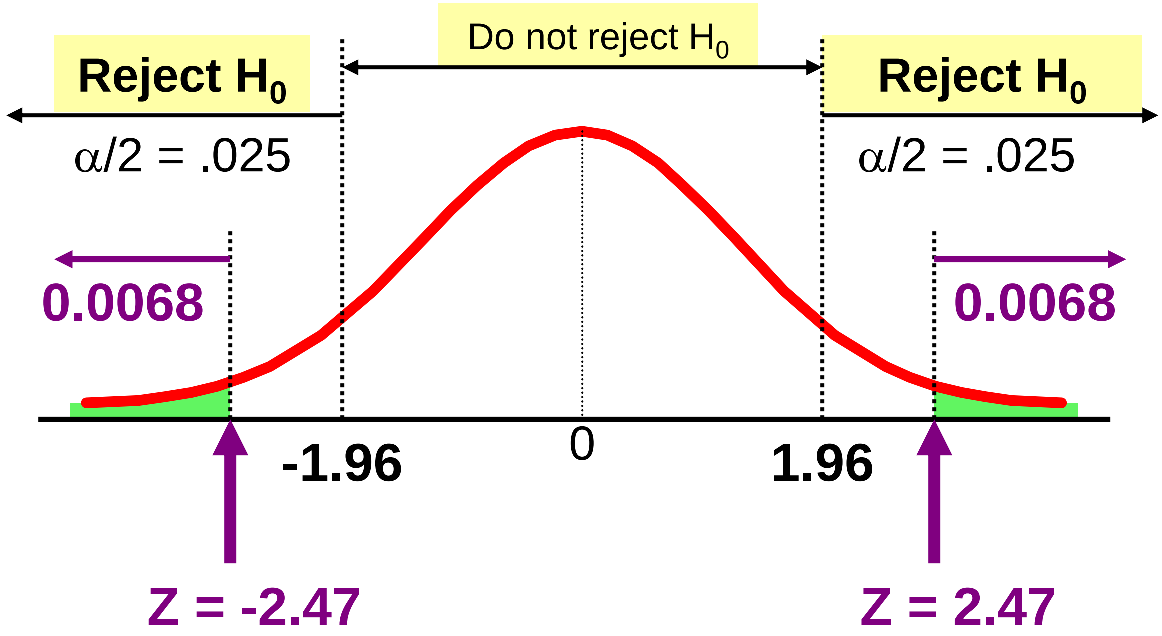
# p-Value Solution

*(continued)*

## Calculate the p-value and compare to α

**(For a two-tail test the p-value is always two-tail)**




**p-value = 0.0136:**

$$P(Z \le -2.47) + P(Z \ge 2.47)$$

$$= 2(0.0068) = 0.0136$$

**Reject $H_0$ since p-value = 0.0136 < α = 0.05**



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# Potential Pitfalls and Ethical Considerations

- Use randomly collected data to reduce selection biases
- Do not use human subjects without informed consent
- Choose the level of significance, $\alpha$, and the type of test (one-tail or two-tail) before data collection
- Do not employ "data snooping" to choose between one-tail and two-tail test, or to determine the level of significance
- Do not practice "data cleansing" to hide observations that do not support a stated hypothesis
- Report all pertinent findings


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# Chapter Summary

- Addressed hypothesis testing methodology
- Performed Z Test for the mean (σ known)
- Discussed critical value and p–value approaches to hypothesis testing
- Performed one-tail and two-tail tests


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# Chapter Summary

*(continued)*

- Performed $t$ test for the mean ($\sigma$ unknown)
- Performed $Z$ test for the proportion
- Discussed pitfalls and ethical issues



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