Learning Objectives

In this chapter, 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
- Pitfalls & ethical issues involved in hypothesis testing

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What is a Hypothesis?

DCOVA

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

Example: The mean monthly cell phone bill in this city is $\mu = \$42$

  - population proportion

Example: The proportion of adults in this city with cell phones is $\pi = 0.68$

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The Null Hypothesis, H_0

DCOVA

- States the claim or assertion to be tested

Example: The mean diameter of a manufactured bolt is 30mm $(H_0 : \mu = 30)$

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

$$H_0 : \mu = 30$$

$$\cancel{H_0 : \bar{X} = 30}$$

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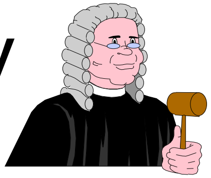
The Null Hypothesis, H_0

DCOVA
(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 or historical value
- Always contains "=", or "≤", or "≥" sign
- May or may not be rejected

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The Alternative Hypothesis, H_1

DCOVA

- Is the opposite of the null hypothesis
  - e.g., The average diameter of a manufactured bolt is not equal to 30mm ($H_1: \mu \neq 30$)
- Challenges the status quo
- Never contains the "=", or "≤", or "≥" sign
- May or may not be proven
- Is generally the hypothesis that the researcher is trying to prove

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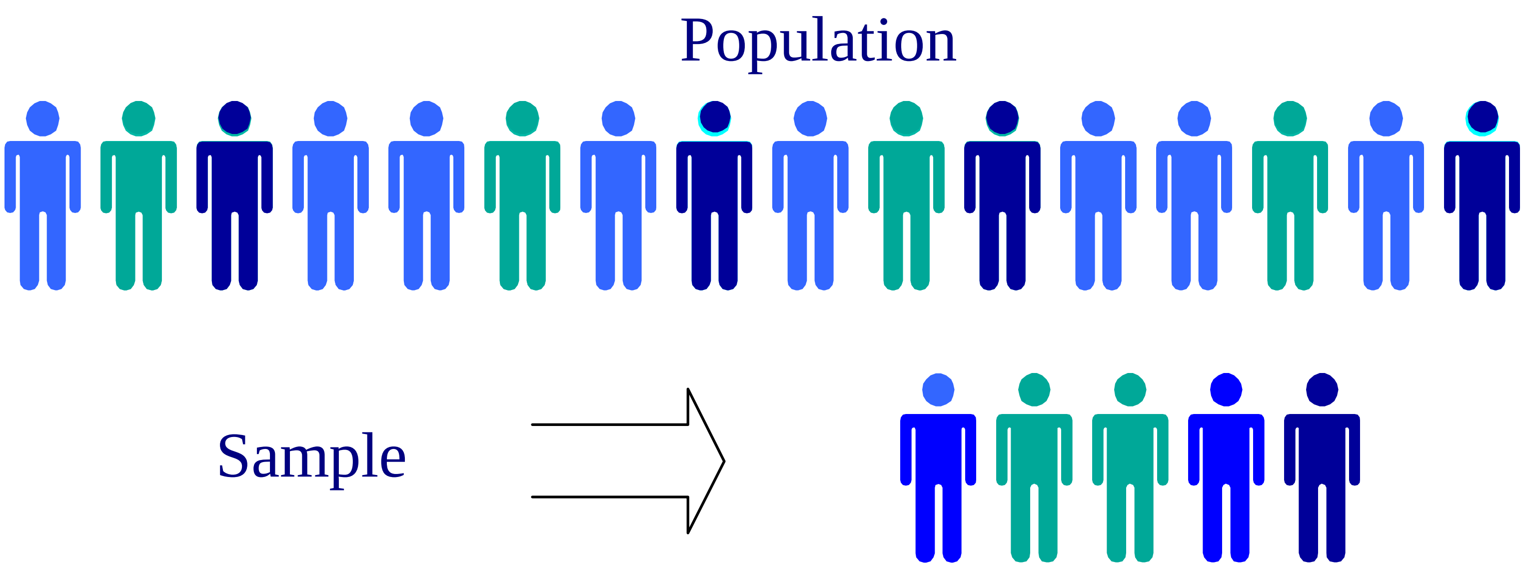
The Hypothesis Testing Process

DCOVA

- Claim: The population mean age is 50.
  - H_0: $\mu = 50$, H_1: $\mu \neq 50$
- Sample the population and find sample mean.



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The Hypothesis Testing Process

DCOVA
(continued)

- Suppose the sample mean age was $\bar{X} = 20$.
- This is significantly lower than the claimed mean population age of 50.
- If the null hypothesis were true, the probability of getting such a different sample mean would be very small, so you reject the null hypothesis .
- In other words, getting a sample mean of 20 is so unlikely if the population mean was 50, you conclude that the population mean must not be 50.

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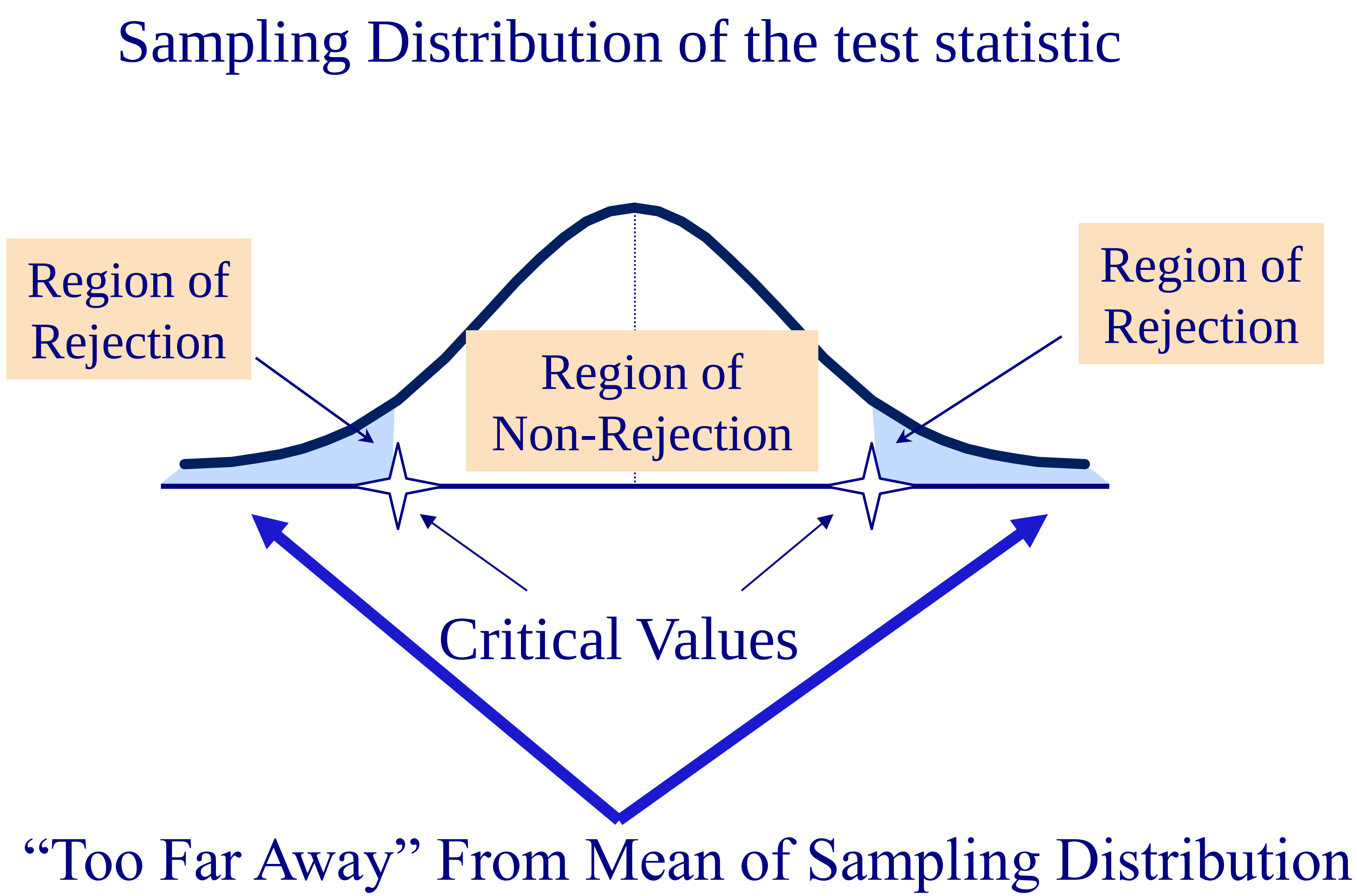
The Test Statistic and Critical Values

DCOVA



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Possible Errors in Hypothesis Test Decision Making

DCOVA

(continued)

Possible Hypothesis Test Outcomes		
	Actual Situation	
Decision	H_0 True	H_0 False
Do Not Reject H_0	No Error Probability 1 - α	Type II Error Probability β
Reject H_0	Type I Error Probability α	No Error Power 1 - β

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Possible Errors in Hypothesis Test Decision Making

DCOVA

(continued)

- The confidence coefficient (1-α) is the probability of not rejecting H_0 when it is true.

- The confidence level of a hypothesis test is (1-α)*100%.

- The power of a statistical test (1-β) is the probability of rejecting H_0 when it is false.

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Type I & II Error Relationship

DCOVA

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

If Type I error probability (α) ⬆, then

Type II error probability (β) ⬇

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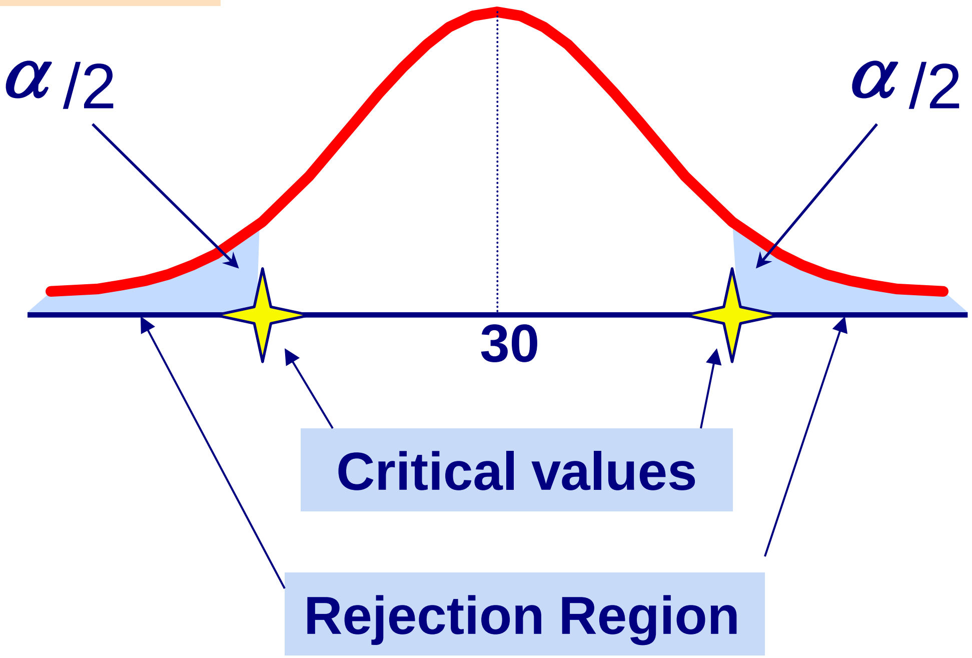
Level of Significance and the Rejection Region

DCOVA

H_0: μ = 30
H_1: μ ≠ 30

Level of significance = α



This is a two-tail test because there is a rejection region in both tails

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Hypothesis Tests for the Mean

DCOVA

Hypothesis Tests for μ

- **σ Known (Z test)**
- **σ Unknown (t test)**

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Z Test of Hypothesis for the Mean (σ Known)

DCOVA

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

Hypothesis Tests for μ

σ Known (Z test)

σ Unknown (t test)

The test statistic is:

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

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Critical Value Approach to Testing

DCOVA

- For a two-tail test for the mean, σ known:
- Convert sample statistic ($\bar{X}$) to test statistic (Z_{STAT})
- Determine the critical Z values for a specified level of significance α 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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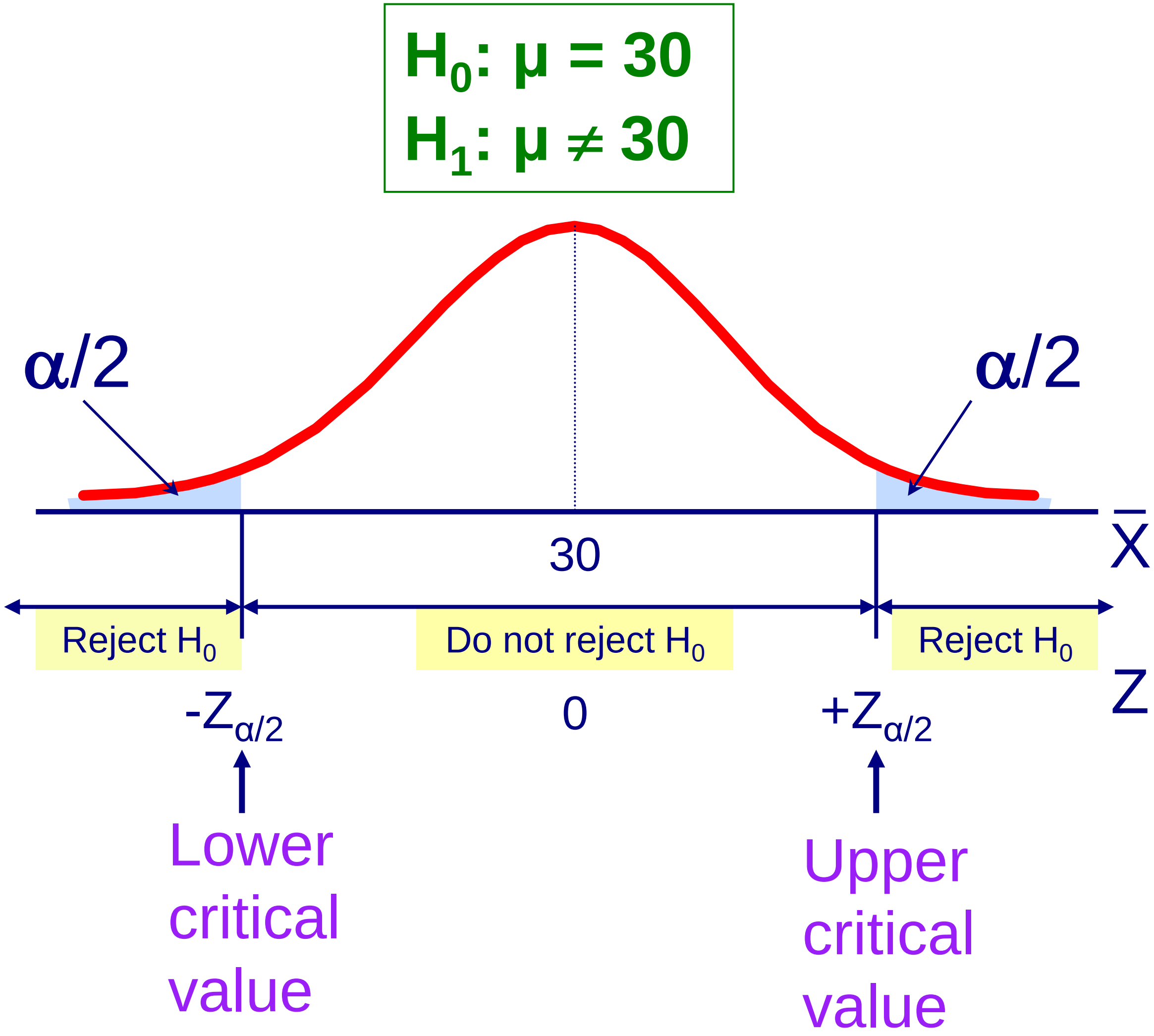
Two-Tail Tests

DCOVA

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



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Hypothesis Testing Example

DCOVA

Test the claim that the true mean diameter of a manufactured bolt is 30mm. (Assume $\sigma = 0.8$)

1. State the appropriate null and alternative hypotheses
   - $H_0: \mu = 30$ $H_1: \mu \neq 30$ (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

DCOVA

(continued)

3. Determine the appropriate technique
   - σ is assumed known so this is a Z test.
4. Determine the critical values
   - For α = 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, $\bar{X}$ = 29.84 (σ = 0.8 is assumed known)

So the test statistic is:

$$Z_{STAT} = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}} = \frac{29.84 - 30}{\frac{0.8}{\sqrt{100}}} = \frac{-.16}{0.08} = -2.0$$

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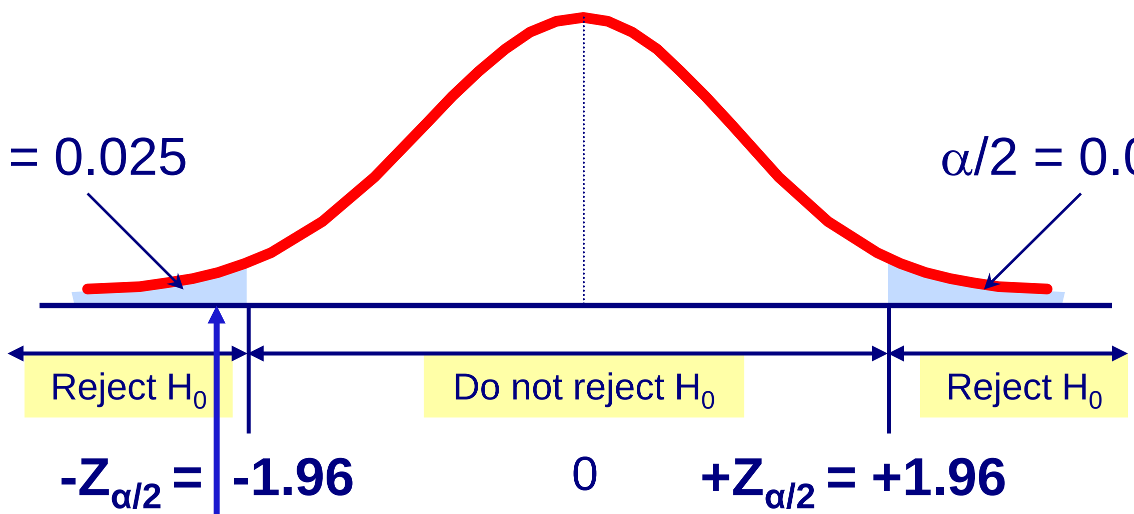
Hypothesis Testing Example

DCOVA
(continued)

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



Reject H_0 if $Z_{STAT} < -1.96$ or $Z_{STAT} > 1.96$; otherwise do not reject H_0

Here, $Z_{STAT} = -2.0 < -1.96$, so the test statistic is in the rejection region

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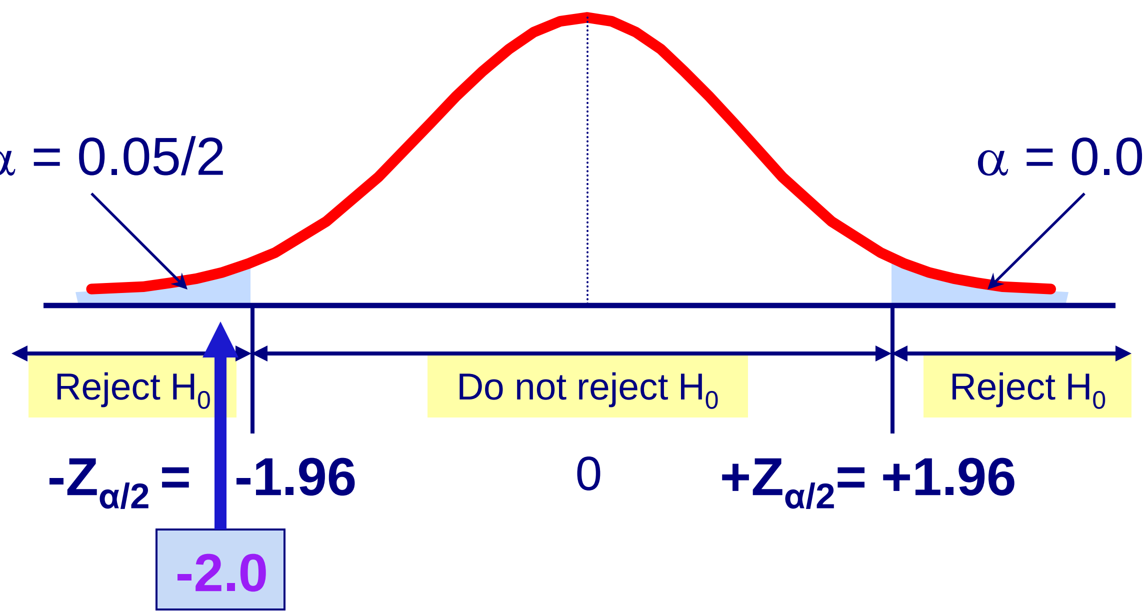
Hypothesis Testing Example

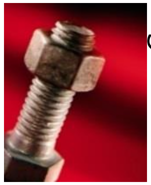
DCOVA

(continued)

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



Since Z_{STAT} = -2.0 < -1.96, reject the null hypothesis and conclude there is sufficient evidence that the mean diameter of a manufactured bolt is not equal to 30



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p-Value Approach to Testing

DCOVA

- p-value: Probability of obtaining a test statistic equal to or more extreme than the observed sample value given H_0 is true
  - The p-value is also called the observed level of significance
  - It is the smallest value of α for which H_0 can be rejected

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p-Value Approach to Testing: Interpreting the p-value

DCOVA

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

- Remember
  - If the p-value is low then H_0 must go

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The 5 Step p-value approach to Hypothesis Testing DCOVA

1. State the null hypothesis, H_0 and the alternative hypothesis, H_1
2. Choose the level of significance, α, and the sample size, n
3. Determine the appropriate test statistic and sampling distribution
4. Collect data and compute the value of the test statistic and the p-value
5. Make the statistical decision and state the managerial conclusion. If the p-value is < α then reject H_0, otherwise do not reject H_0. State the managerial conclusion in the context of the problem

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p-value Hypothesis Testing Example

DCOVA

Test the claim that the true mean diameter of a manufactured bolt is 30mm. (Assume σ = 0.8)

1. State the appropriate null and alternative hypotheses
   - H_0: $\mu = 30$ H_1: $\mu \neq 30$ (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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p-value Hypothesis Testing Example

DCOVA

(continued)

3. Determine the appropriate technique
   - σ is assumed known so this is a Z test.
4. Collect the data, compute the test statistic and the p-value
   - Suppose the sample results are

     n = 100, $\bar{X}$ = 29.84 (σ = 0.8 is assumed known)

   So the test statistic is:

$$Z_{STAT} = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}} = \frac{29.84 - 30}{\frac{0.8}{\sqrt{100}}} = \frac{-0.16}{0.08} = -2.0$$

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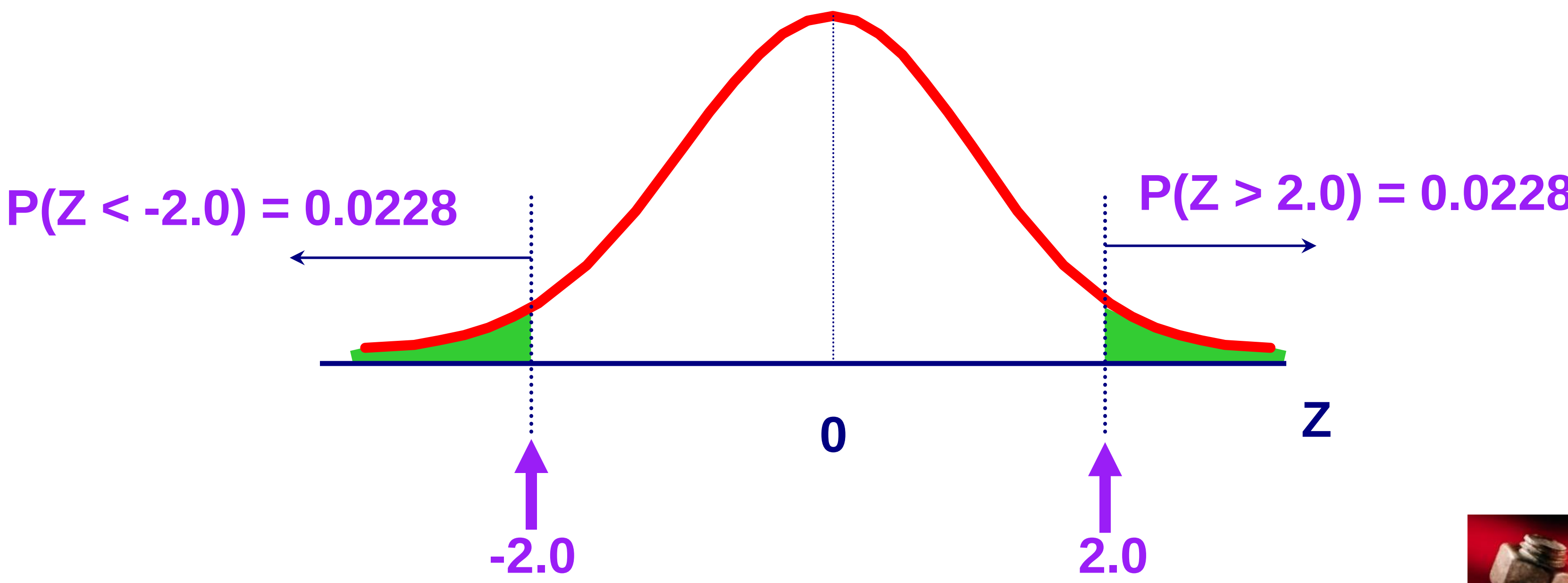
p-Value Hypothesis Testing Example: Calculating the p-value

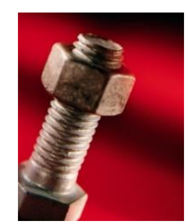
DCOVA

4. (continued) Calculate the p-value.

- How likely is it to get a Z_{STAT} of -2 (or something further from the mean (0), in either direction) if H_0 is true?



p-value = 0.0228 + 0.0228 = 0.0456



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p-value Hypothesis Testing Example

DCOVA

(continued)

- 5. Is the p-value < α?
  - Since p-value = 0.0456 < α = 0.05 Reject H_0
- 5. (continued) State the managerial conclusion in the context of the situation.
  - There is sufficient evidence to conclude the average diameter of a manufactured bolt is not equal to 30mm.

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Connection Between Two Tail Tests and Confidence Intervals

DCOVA

- For $\bar{X}$ = 29.84, σ = 0.8 and n = 100, the 95% confidence interval is:

$$29.84 - (1.96)\frac{0.8}{\sqrt{100}} \quad \text{to} \quad 29.84 + (1.96)\frac{0.8}{\sqrt{100}}$$

$$29.6832 \le \mu \le 29.9968$$

- Since this interval does not contain the hypothesized mean (30), we reject the null hypothesis at $\alpha = 0.05$

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Do You Ever Truly Know σ?

DCOVA

- Probably not!
- In virtually all real world business situations, σ is not known.
- If there is a situation where σ is known then μ is also known (since to calculate σ you need to know μ.)
- If you truly know μ there would be no need to gather a sample to estimate it.

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Hypothesis Testing: σ Unknown

DCOVA

- If the population standard deviation is unknown, you instead use the sample standard deviation S.
- Because of this change, you use the t distribution instead of the Z distribution to test the null hypothesis about the mean.
- When using the t distribution you must assume the population you are sampling from follows a normal distribution.
- All other steps, concepts, and conclusions are the same.

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t Test of Hypothesis for the Mean (σ Unknown)

DCOVA

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

Hypothesis Tests for μ

σ Known (Z test)

σ Unknown (t test)

The test statistic is:

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

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Example: Two-Tail Test (σ Unknown)

DCOVA

The average cost of a hotel room in New York is said to be $168 per night. To determine if this is true, a random sample of 25 hotels is taken and resulted in an $\bar{X}$ of $172.50 and an S of $15.40. Test the appropriate hypotheses at $\alpha = 0.05$.

(Assume the population distribution is normal)

H_0: $\mu = 168$

H_1: $\mu \neq 168$

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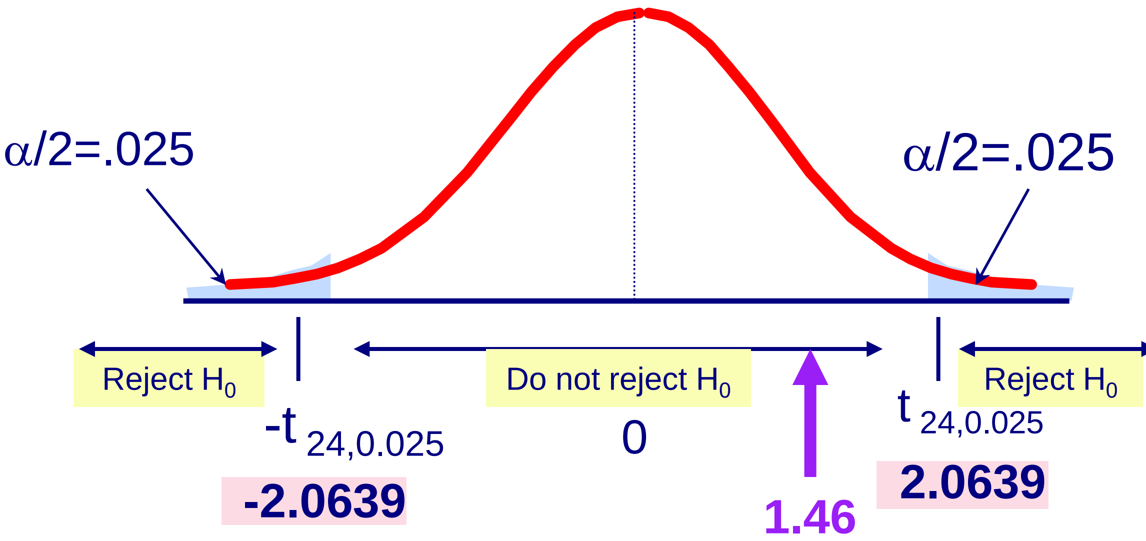
Example Solution: Two-Tail t Test

DCOVA

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

- $\alpha = 0.05$
- $n = 25$, $df = 25-1=24$
- σ is unknown, so use a **t statistic**
- Critical Value:

$\pm t_{24,0.025} = \pm\ 2.0639$



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

Do not reject H_0: insufficient evidence that true mean cost is different from \$168

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Example Two-Tail t Test Using A p-value from Excel

DCOVA

- Since this is a t-test we cannot calculate the p-value without some calculation aid.
- The Excel output below does this:

t Test for the Hypothesis of the Mean

Data			
Null Hypothesis	**μ=**	**$**	**168.00**
Level of Significance			**0.05**
Sample Size			**25**
Sample Mean		**$**	**172.50**
Sample Standard Deviation		**$**	**15.40**

Intermediate Calculations			
Standard Error of the Mean	$	3.08	=B8/SQRT(B6)
Degrees of Freedom		24	=B6-1
t test statistic		**1.46**	=(B7-B4)/B11

Two-Tail Test		
Lower Critical Value	-2.0639	=-TINV(B5,B12)
Upper Critical Value	2.0639	=TINV(B5,B12)
p-value	0.157	=TDIST(ABS(B13),B12,2)
Do Not Reject Null Hypothesis		=IF(B18<B5, "Reject null hypothesis", "Do not reject null hypothesis")

p-value > α
So do not reject H_0

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Connection of Two Tail Tests to Confidence Intervals

DCOVA

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

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

$$\boxed{166.14 \le \mu \le 178.86}$$

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

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One-Tail Tests

DCOVA

- 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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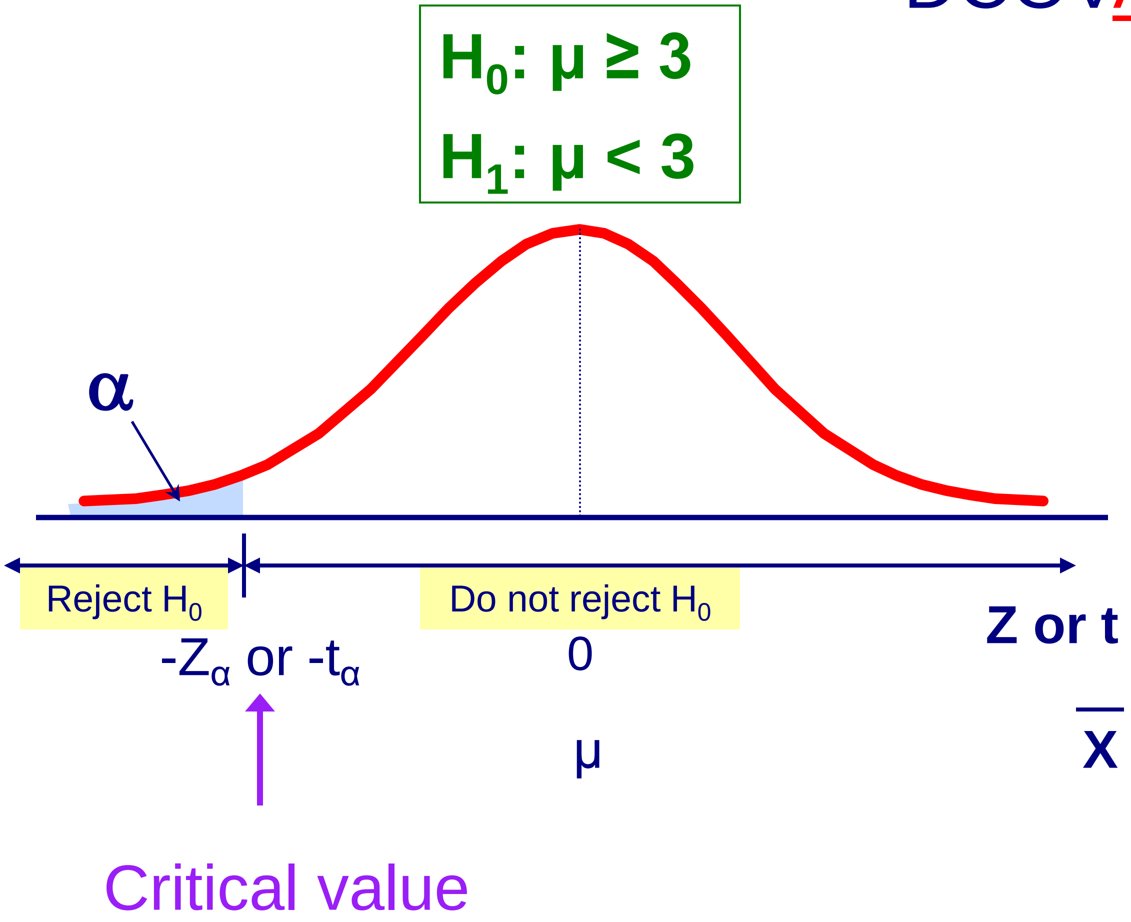
Lower-Tail Tests

DCOVA

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



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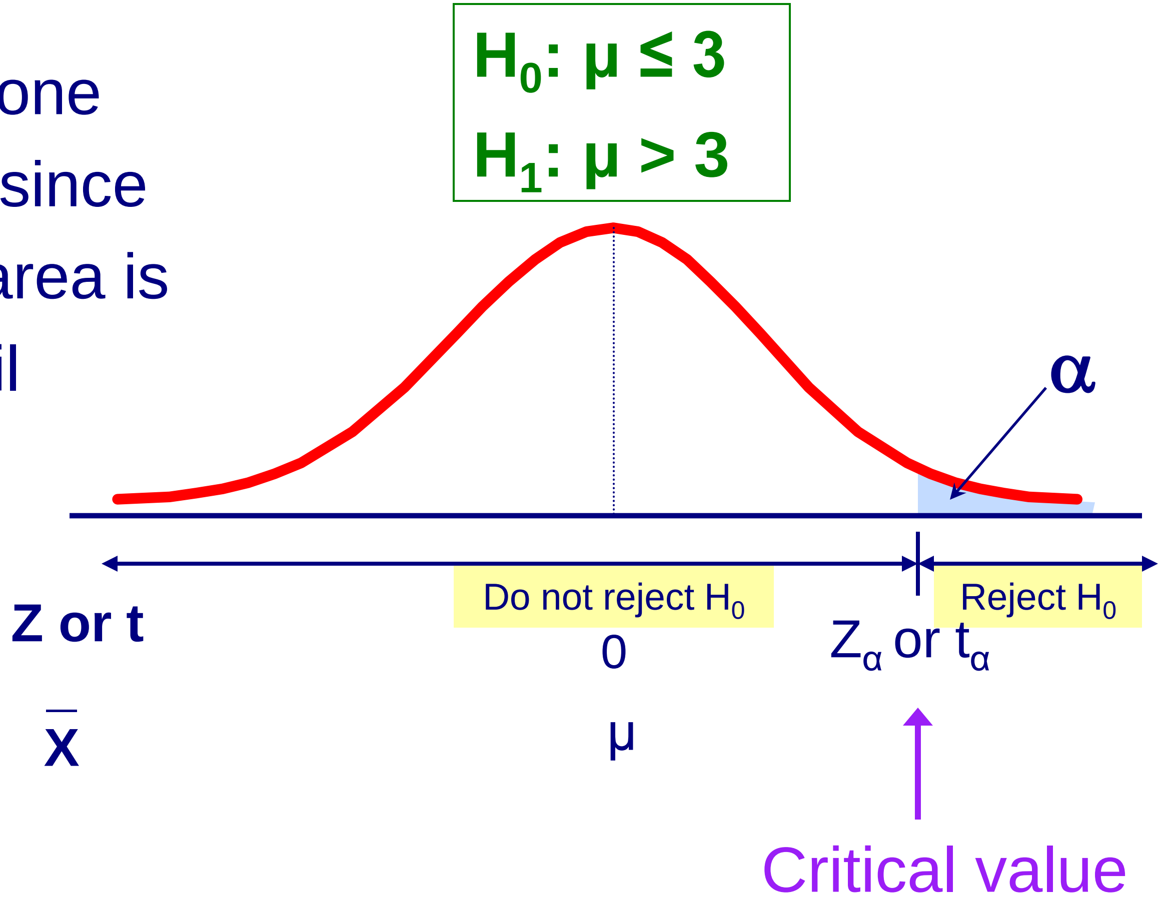
Upper-Tail Tests

DCOVA

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



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Example: Upper-Tail t Test for Mean (σ unknown)

DCOVA

A phone industry manager thinks that customer monthly cell phone bills have increased, and now average over $52 per month. The company wishes to test this claim. (Assume a normal population)

Form hypothesis test:

H_0: $\mu \le 52$ the average is not over $52 per month

H_1: $\mu > 52$ the average **is** greater than $52 per month (i.e., sufficient evidence exists to support the manager's claim)

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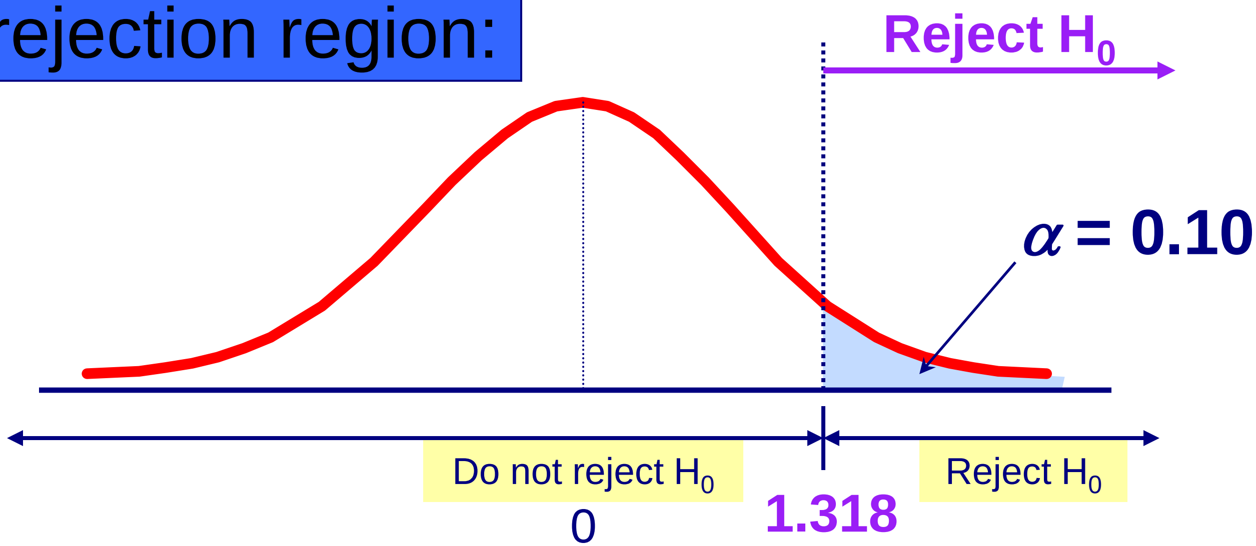
Example: Find Rejection Region

DCOVA
(continued)

- Suppose that $\alpha = 0.10$ is chosen for this test and $n = 25$.

Find the rejection region:



Reject H_0 if $t_{STAT} > 1.318$

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Example: Test Statistic

DCOVA

(continued)

Obtain sample and compute the test statistic

Suppose a sample is taken with the following results: $n = 25$, $\bar{X} = 53.1$, and $S = 10$

- Then the test statistic is:

$$t_{STAT} = \frac{\bar{X} - \mu}{\frac{S}{\sqrt{n}}} = \frac{53.1 - 52}{\frac{10}{\sqrt{25}}} = 0.55$$

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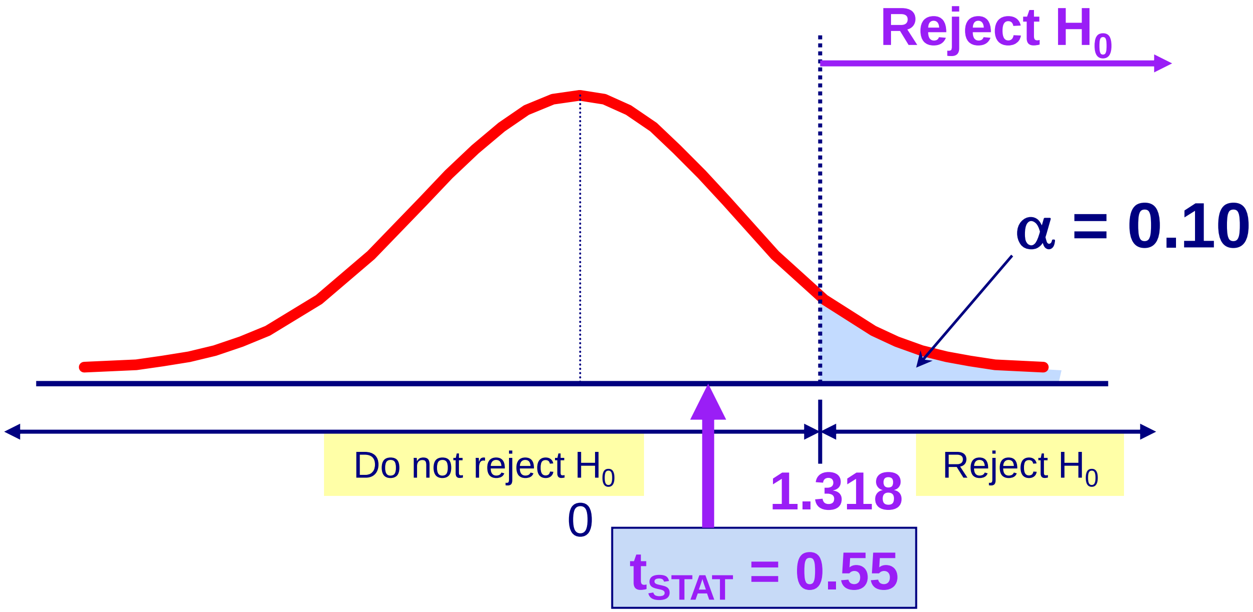
Example: Decision

DCOVA

(continued)

Reach a decision and interpret the result:



Do not reject H_0 since $t_{STAT} = 0.55 \leq 1.318$

there is not sufficient evidence that the mean bill is over $52

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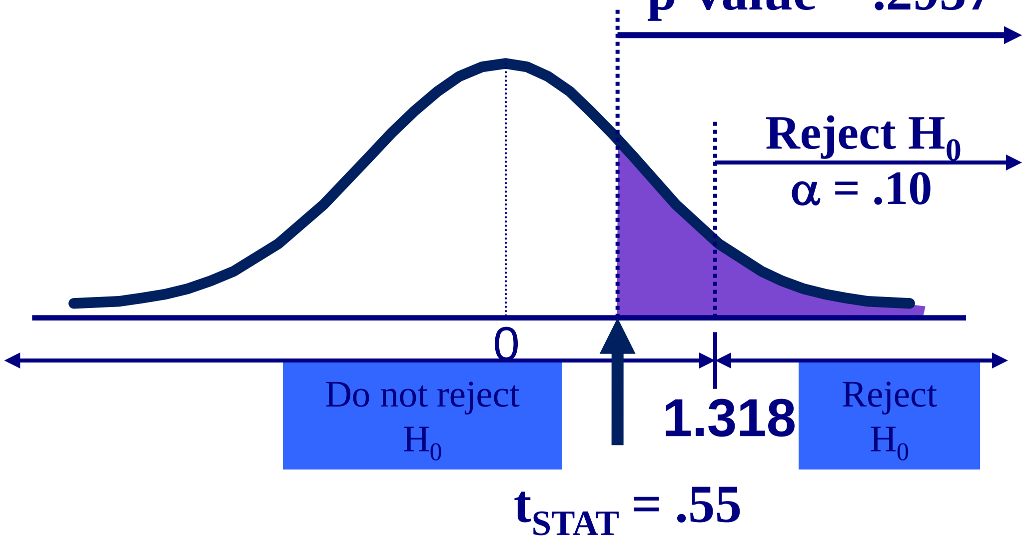
Example: Utilizing The p-value for The Test

DCOVA

- Calculate the p-value and compare to α (p-value below calculated using excel spreadsheet on next page)



Do not reject H_0 since p-value = .2937 > α = .10

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Excel Spreadsheet Calculating The p-value for An Upper Tail t Test

DCOVA

	A	B	
1	t Test for the Hypothesis of the Mean		
2			
3	Data		
4	Null Hypothesis μ=	184.2	
5	Level of Significance	0.05	
6	Sample Size	25	
7	Sample Mean	170.8	
8	Sample Standard Deviation	21.3	
9			
10	Intermediate Calculations		
11	Standard Error of the Mean	4.2600	=B8/SQRT(B6)
12	Degrees of Freedom	24	=B6 - 1
13	*t* Test Statistic	-3.1455	=(B7 - B4)/B11
14			
15	Lower-Tail Test		
16	Lower Critical Value	-1.7109	=-T.INV.2T(2 * B5, B12)
17	*p*-Value	0.0022	=IF(B13 < 0, E11, E12)
18	Reject the null hypothesis		=IF(B17 < B5,"Reject the null hypothesis", "Do not reject the null hypothesis")

	D	E	
10	One-Tail Calculations		
11	T.DIST.RT value	0.0022	=T.DIST.RT(ABS(B13), B12)
12	1-T.DIST.RT value	0.9978	=1 - E11

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Hypothesis Tests for Proportions

DCOVA

- Involves categorical variables
- Two possible outcomes
  - Possesses characteristic of interest
  - Does not possess characteristic of interest
- Fraction or proportion of the population in the category of interest is denoted by π

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Proportions

DCOVA

(continued)

- Sample proportion in the category of interest is denoted by p

$$p = \frac{X}{n} = \frac{\text{number in category of interest in sample}}{\text{sample size}}$$

- When both nπ and n(1-π) are at least 5, p can be approximated by a normal distribution with mean and standard deviation
  - $\mu_p = \pi$

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

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Hypothesis Tests for Proportions

DCOVA

- The sampling distribution of p is approximately normal, so the test statistic is a Z_{STAT} value:

$$Z_{STAT} = \frac{p - \pi}{\sqrt{\dfrac{\pi(1-\pi)}{n}}}$$

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 in Category of Interest

DCOVA

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

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

Hypothesis Tests for X

$X \geq 5$ and $n\text{-}X \geq 5$

$X < 5$ or $n\text{-}X < 5$

Not discussed in this chapter

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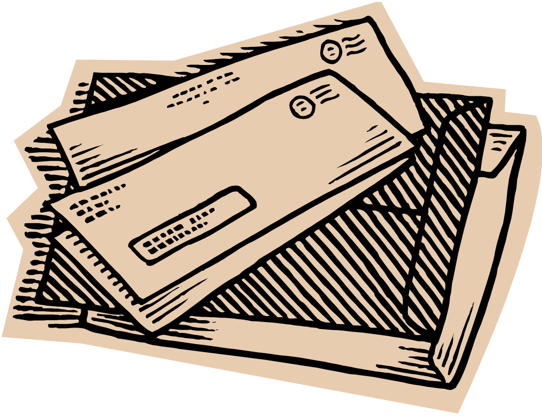
Example: Z Test for Proportion

DCOVA

A marketing company 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

DCOVA

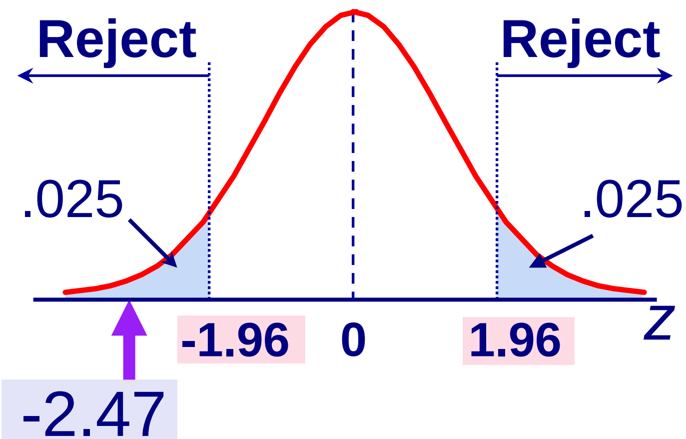
H_0: $\pi = 0.08$

H_1: $\pi \neq 0.08$

$\alpha = 0.05$

$n = 500$, $p = 0.05$

Critical Values: ± 1.96



Test Statistic:

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

Decision:

Reject H_0 at $\alpha = 0.05$

Conclusion:

There is sufficient evidence to reject the company's claim of 8% response rate.

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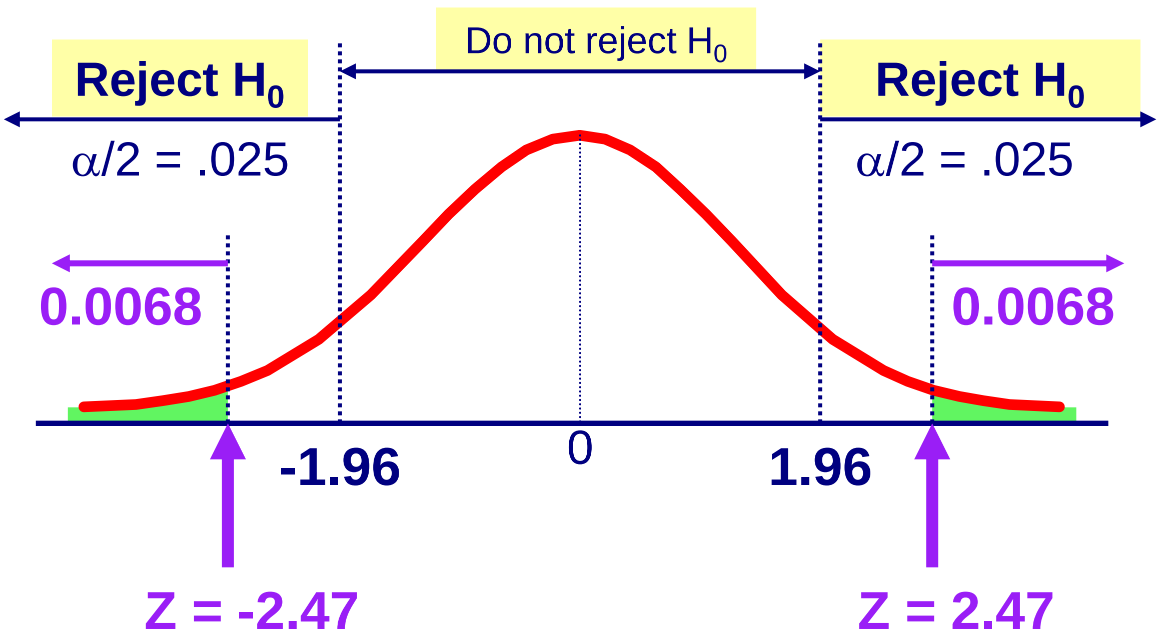
p-Value Solution

DCOVA

(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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The Power Of A Test Is An Important Part Of Planning

- The power of a hypothesis test is included as an on-line topic

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Online Topic

Power of a Test

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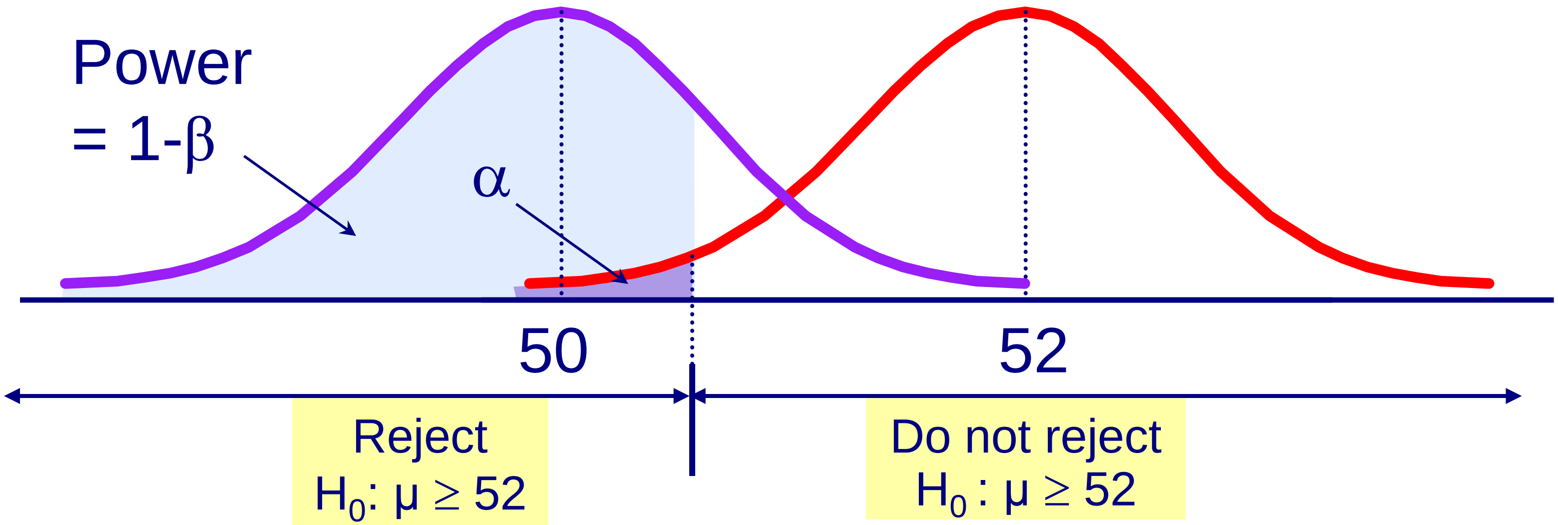
The Power of a Test

DCOVA

- **The power of the test is the probability of correctly rejecting a false H_0**

Suppose we correctly reject **H_0: μ ≥ 52** when in fact the true mean is **μ = 50**



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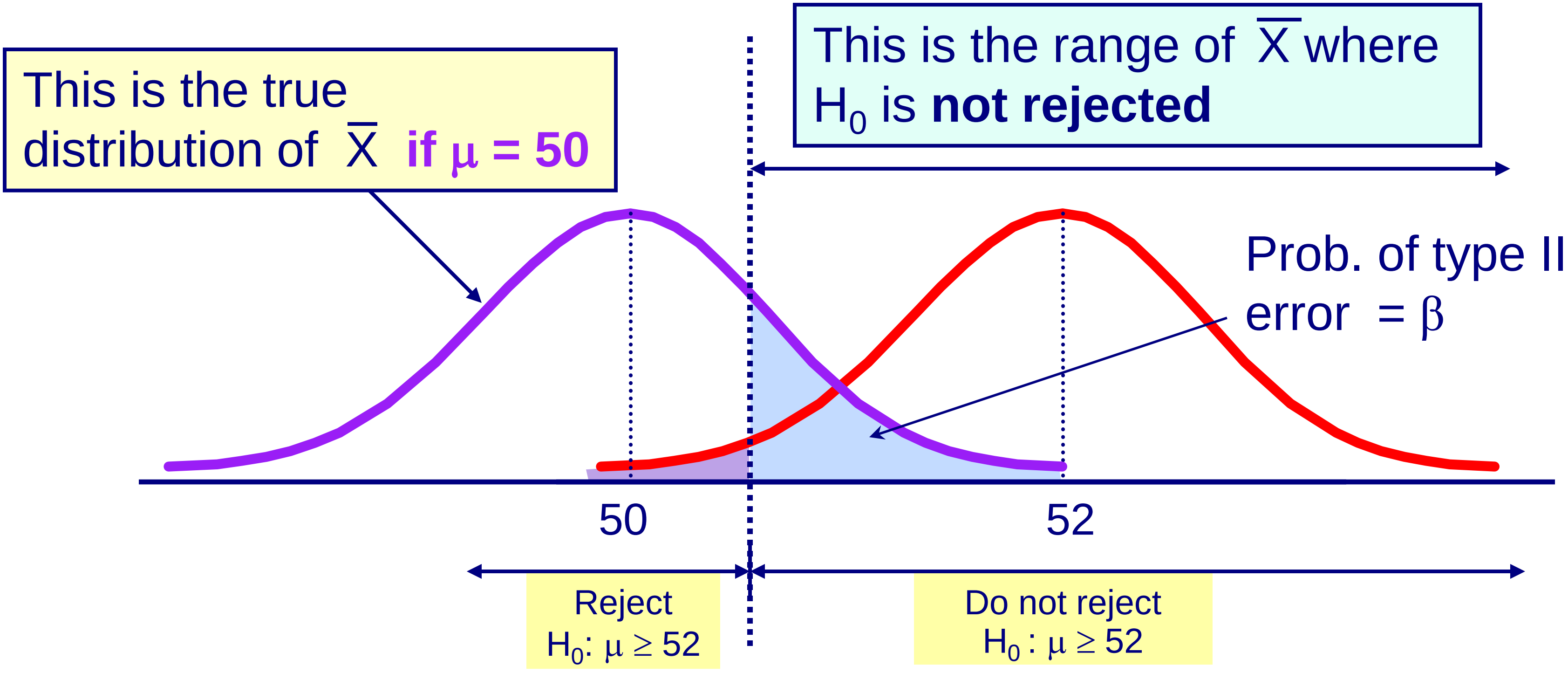
Type II Error

DCOVA

- Suppose we do not reject H_0: $\mu \geq 52$ when in fact the true mean is $\mu = 50$



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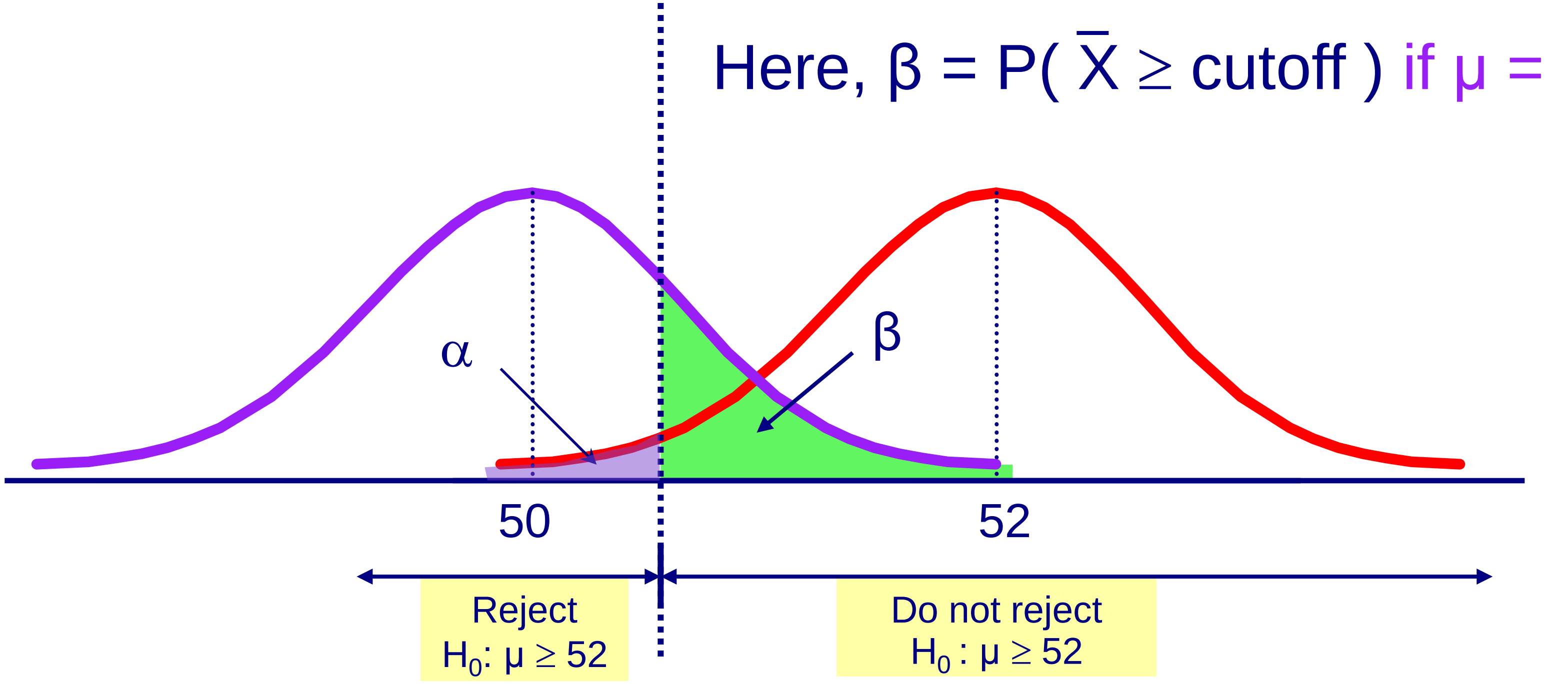
Type II Error

DCOVA

(continued)

- Suppose we do not reject H_0: $\mu \geq 52$ when in fact the true mean is $\mu = 50$



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Calculating β

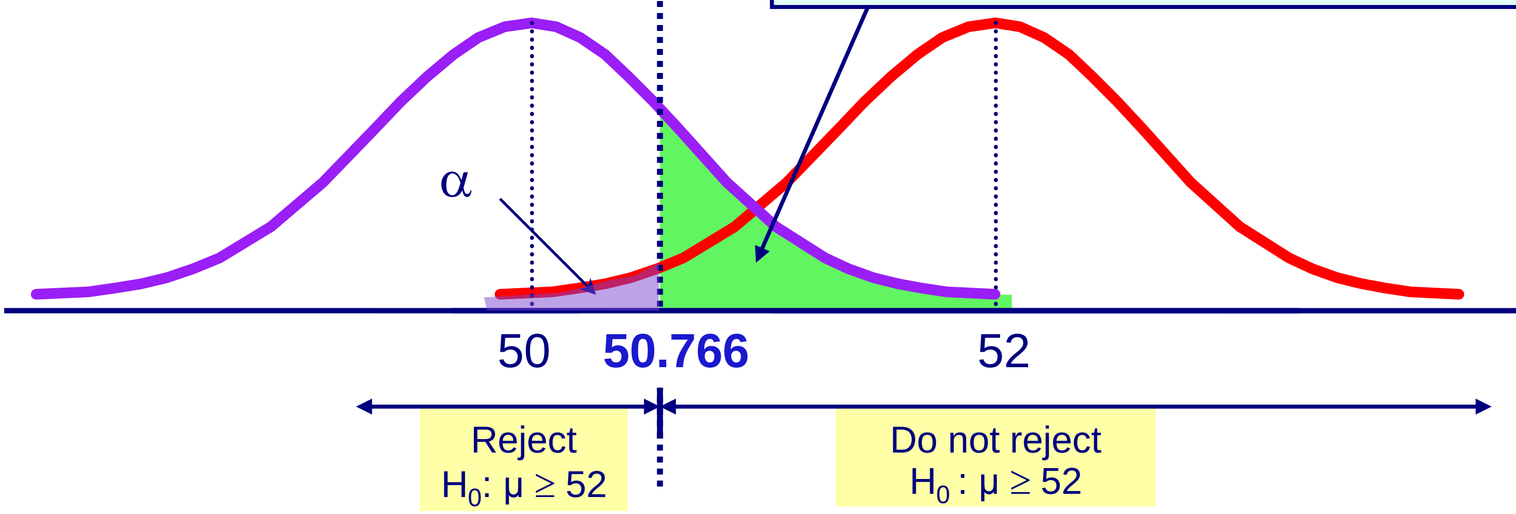
DCOVA

- Suppose $n = 64$, $\sigma = 6$, and $\alpha = .05$

$$\text{cutoff} = \bar{X}_{\alpha} = \mu - Z_{\alpha}\frac{\sigma}{\sqrt{n}} = 52 - 1.645\frac{6}{\sqrt{64}} = \boxed{50.766}$$

(for $H_0 : \mu \geq 52$)

So $\beta = P(\bar{x} \geq 50.766)$ if $\mu = 50$



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Calculating β and Power of the test

DCOVA

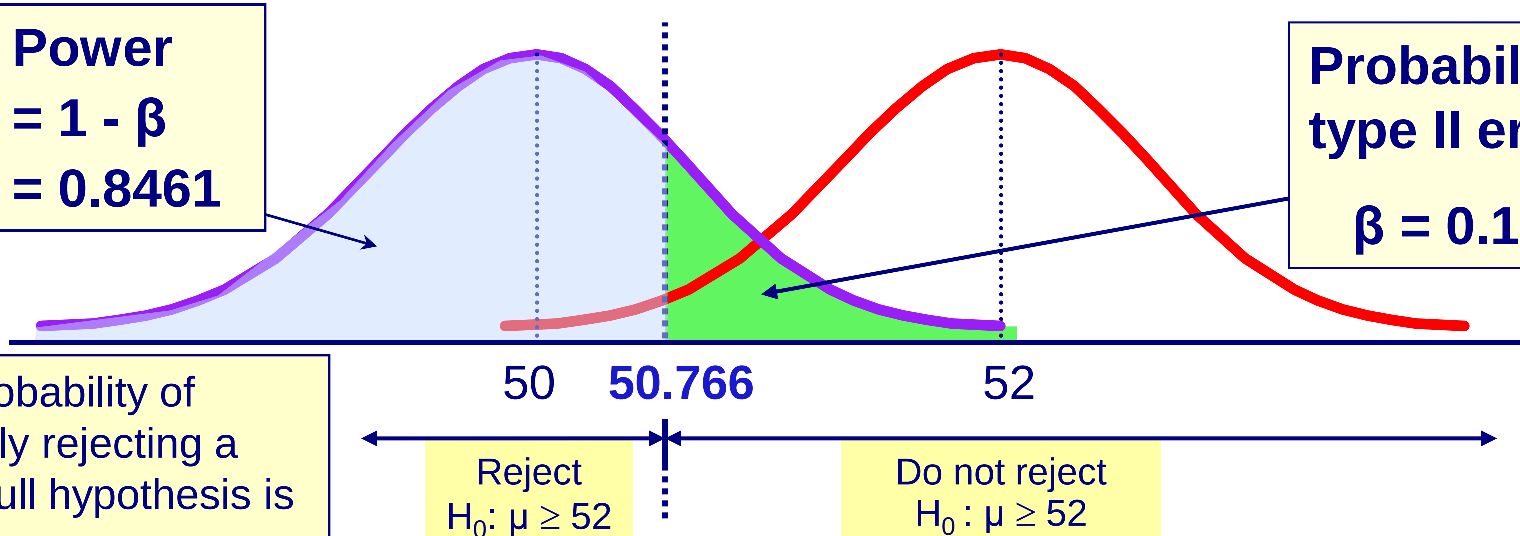
(continued)

- Suppose n = 64 , σ = 6 , and α = 0.05

$$P(\bar{X} \geq 50.766 \mid \mu = 50) = P\left(Z \geq \frac{50.766 - 50}{6/\sqrt{64}} \right) = P(Z \geq 1.02) = 1.0 - 0.8461 = \boxed{0.1539}$$

Power
= 1 - β
= 0.8461

The probability of correctly rejecting a false null hypothesis is 0.8641



Probability of type II error:

β = 0.1539

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Power of the Test

- Conclusions regarding the power of the test:
  - A one-tail test is more powerful than a two-tail test
  - An increase in the level of significance (α) results in an increase in power
  - An increase in the sample size results in an increase in power

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