Lab 02

Hypothesis Testing

Applied statistics and experiments

September, 2024

Agenda

1. Terminology
2. Statistical hypothesis
3. Null and alternative hypothesis
4. Practices on formulating hypotheses
5. Hypothesis testing
6. Practices on hypothesis testing

Lecture Recap

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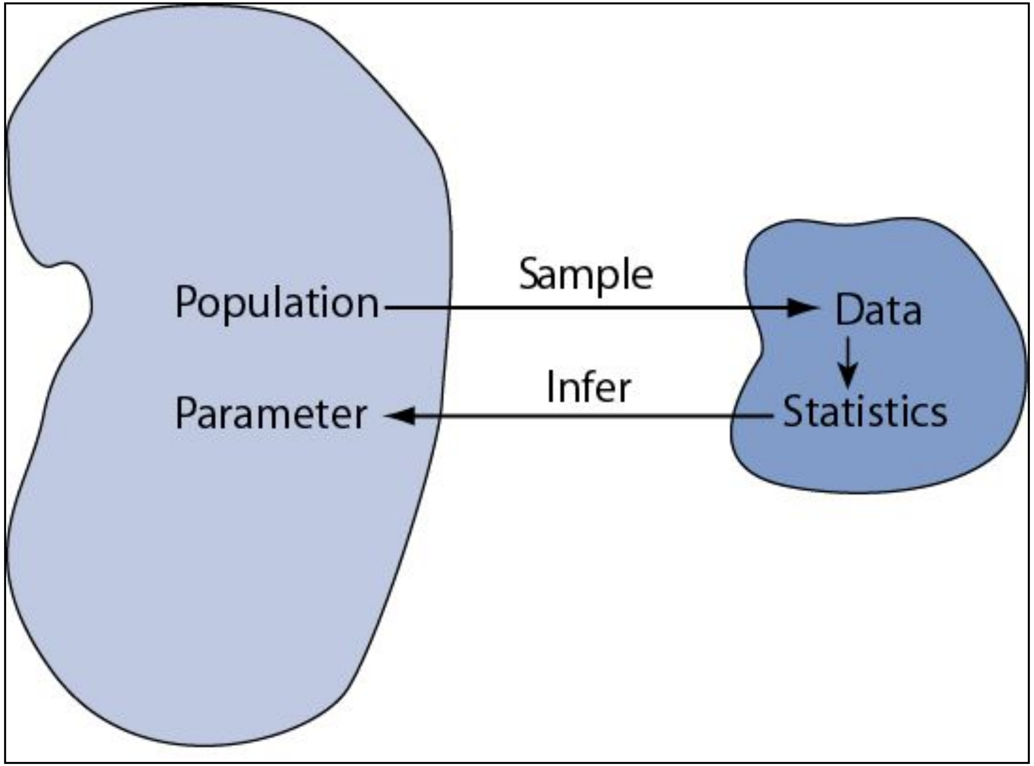
game code

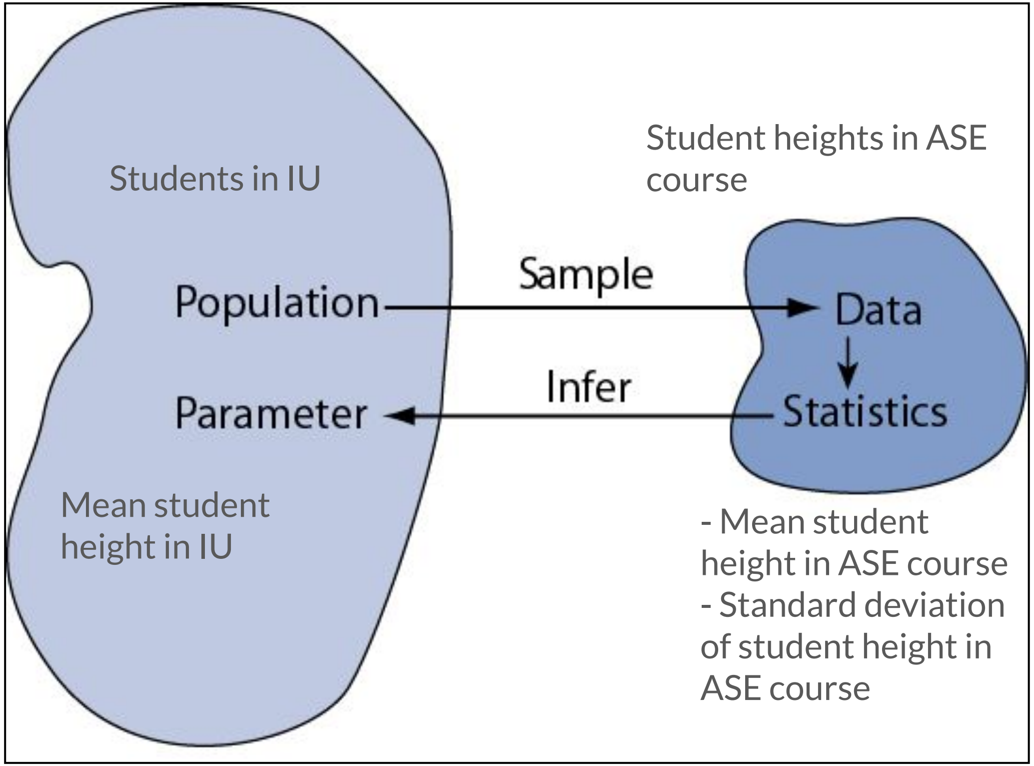
Terminology

- **Population**: all possible values.
    - All students in Innopolis university.
- **Sample**: a portion of the population.
    - The students in ASE course.
- **Statistical inference**: generalizing from a sample to a population with calculated degree of certainty
- Two forms of statistical inference
    - **Hypothesis testing**
    - **Estimation**
- **Parameter**: a characteristic of population, e.g., population mean μ. (mean height is 175 cm)
- **Statistic**: calculated value from sample data, e.g., sample mean x̄.(mean height is 172 cm)

Statistical inference



Statistical inference



Statistical hypothesis

- An unproven statement which can be tested. (hypothesis)
- A statement about the nature of a population
- An assertion or a claim about one or more population characteristics
- **Statistical hypotheses** are discussed in terms of the **population**, not the sample, yet tested on samples
- **Example:** The average height of students in the course did not change with respect to the last year.
  - How to test this claim?
- The null hypothesis, denoted H_0, is the hypothesis to be **tested**. This is the "**default**" assumption.
- The alternative hypothesis, denoted H_A is the alternative to the null.

Null Hypothesis: H_0

We consider that we are testing only population mean using one-sample (One-sample hypothesis testing)

- The **null hypothesis (denoted by** H_0) is a statement that the value of a population parameter (such as proportion, mean, or standard deviation) is equal to some claimed value.

$$H_0: \mu = \mu_0$$

  - μ_0 is the population mean assuming that H_0 is true
  - The population mean μ is equal to the null hypothesized value (μ_0).
- We test the null hypothesis directly.
- Either reject H_0 or fail to reject H_0.

Null Hypothesis: H_0 – Example

- A company records the mean time of employees working in a day. The mean comes out to be **475** minutes, with a standard deviation of 45 minutes. A manager recorded times of 20 employees and got the mean time as 470 minutes with a variance 25 minutes. Using a 5% level of significance, we want to determine if the mean time is more than 475 minutes.

$$H_0: \mu = \mu_0$$

Null Hypothesis: H_0 – Example

- A company records the mean time of employees working in a day. The mean comes out to be 475 minutes, with a standard deviation of 45 minutes. A manager recorded times of 20 employees and got the mean time as 470 minutes with a variance 25 minutes. Using a 5% level of significance, we want to determine if the mean time is more than 475 minutes.

$$H_0: \mu = \mu_0 = 475$$

We consider that we are testing only population mean using one-sample (One-sample hypothesis testing)

Alternative Hypothesis: H_A(or H_1)

- The **alternative** hypothesis **(denoted by H_1 or H_a or H_A)** is the statement that the parameter has a value that somehow differs from the Null Hypothesis.

$$H_1: \mu \neq \mu_0$$

$$H_1: \mu > \mu_0$$

$$H_1: \mu < \mu_0$$

Alternative Hypothesis: H_1 – Example

- A company records the mean time of employees working in a day. The mean comes out to be **475** minutes, with a standard deviation of 45 minutes. A manager recorded times of 20 employees and got the mean time as 470 minutes with a variance 25 minutes. Using a 5% level of significance, we want to determine if the mean time is more than 475 minutes.
  - Formulate null and alternative hypotheses.

$$H_0: \mu = 475$$

$$H_1: \mu > 475$$

Alternative Hypothesis: H_1 – Example

- A company records the mean time of employees working in a day. The mean comes out to be **475** minutes, with a standard deviation of 45 minutes. A manager recorded times of 20 employees and got the mean time as 470 minutes with a variance 25 minutes. Using a 5% level of significance, we want to determine if the mean time is less than 475 minutes.
  - Formulate null and alternative hypotheses

$$H_0: \mu = 475$$

$$H_1: \mu < 475$$

Alternative Hypothesis: H_1 – Example

- A company records the mean time of employees working in a day. The mean comes out to be **475** minutes, with a standard deviation of 45 minutes. A manager recorded times of 20 employees and got the mean time as 470 minutes with a variance 25 minutes. Using a 5% level of significance, we want to determine if the mean time changed.
  - Formulate null and alternative hypotheses.

$$H_0: \mu = 475$$

$$H_1: \mu \neq 475$$

Notes on Null & Alternative Hypotheses

1. H_0 always has a symbol with an equal in it. H_a never has a symbol with an equal in it.
2. The choice of symbol depends on the wording of the hypothesis test. However, be aware that many researchers use = in the null hypothesis, even with > or < as the symbol in the alternative hypothesis. This practice is acceptable **because we only make the decision to reject or not reject the null hypothesis.**

3. The possible cases for the hypotheses under taken considerations are as follows:

H_a

H_0

	$\mu \neq \mu_0$	$\mu < \mu_0$	$\mu > \mu_0$
$\mu = \mu_0$	Possible	Possible	Possible
$\mu \geq \mu_0$	Not possible	Possible	Not possible
$\mu \leq \mu_0$	Not possible	Not possible	Possible

Notes on Null & Alternative Hypotheses – examples

- On a state driver's test, the mean score is 40% on the first try in June. We want to test the claim that the mean score will be more than 40% on the first try next month.

H_0: $\mu = 0.4$

H_1: $\mu > 0.4$

Notes on Null & Alternative Hypotheses – examples

- We want to test if it takes fewer than 45 minutes to teach a lesson plan. State the null and alternative hypotheses.

$H_0: \mu \geq 45$

$H_1: \mu < 45$

Notes on Null & Alternative Hypotheses – examples

- We want to test whether the mean height of first year students is 170 cm. State the null and alternative hypotheses.

$$H_0: \mu = 170$$

$$H_1: \mu \neq 170$$

Notes on Null & Alternative Hypotheses – examples

- The average weight of a dumbbell in a gym is 90 lbs. However, a physical trainer believes that the average weight might be higher. A random sample of 5 dumbbells with an average weight of 110 lbs and a standard deviation of 18lbs. Using hypothesis testing check if the physical trainer's claim can be supported for a 95% confidence level.

$$H_0: \mu = 90$$

$$H_1: \mu > 90$$

Notes on Null & Alternative Hypotheses – examples

- Jasmine has just begun her new job on the sales force of a very competitive company. In a sample of 16 sales calls it was found that she closed the contract for an average value of 108 dollars with a standard deviation of 12 dollars. Test at 5% significance that the population mean is at least 100 dollars against the alternative that it is less than 100 dollars. Company policy requires that new members of the sales force must exceed an average of $100 per contract during the trial employment period. Can we conclude that Jasmine has met this requirement at the significance level of 95%?

$$H_0: \mu \leq 100$$

$$H_1: \mu > 100$$

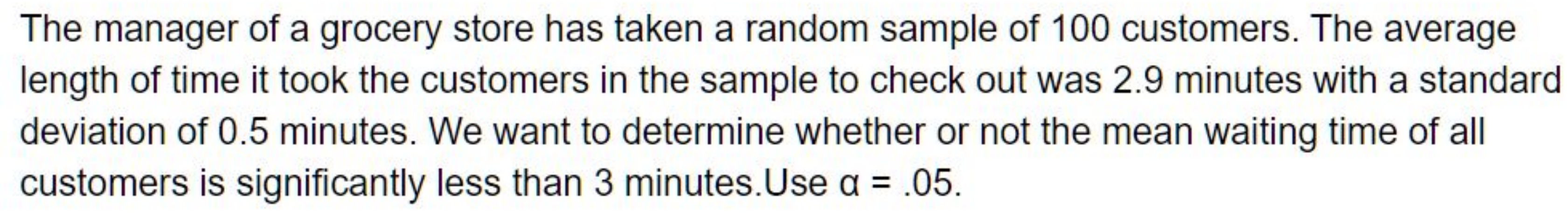
Notes on Null & Alternative Hypotheses – examples

- Jeffrey, as an eight-year old, established a mean time of 16.43 seconds for swimming the 25-yard freestyle, with a standard deviation of 0.8 seconds. His dad, Frank, thought that Jeffrey could swim the 25-yard freestyle faster using goggles. Frank bought Jeffrey a new pair of expensive goggles and timed Jeffrey for 15 25-yard freestyle swims. For the 15 swims, Jeffrey's mean time was 16 seconds. Frank thought that the goggles helped Jeffrey to swim faster than the 16.43 seconds. Conduct a hypothesis test using a preset α = 0.05. Assume that the swim times for the 25-yard freestyle are normal.

$$H_0: \mu = 16.43$$

$$H_1: \mu < 16.43$$

Statistical hypothesis – practice



The manager of a grocery store has taken a random sample of 100 customers. The average length of time it took the customers in the sample to check out was 2.9 minutes with a standard deviation of 0.5 minutes. We want to determine whether or not the mean waiting time of all customers is significantly less than 3 minutes.Use α = .05.

1. Specify the sample statistics (n, s, x̄) and population parameters (μ_0, σ).
2. Determine the null and alternative hypotheses.
3. Interpret the hypotheses in your own words.

Statistical hypothesis – practice

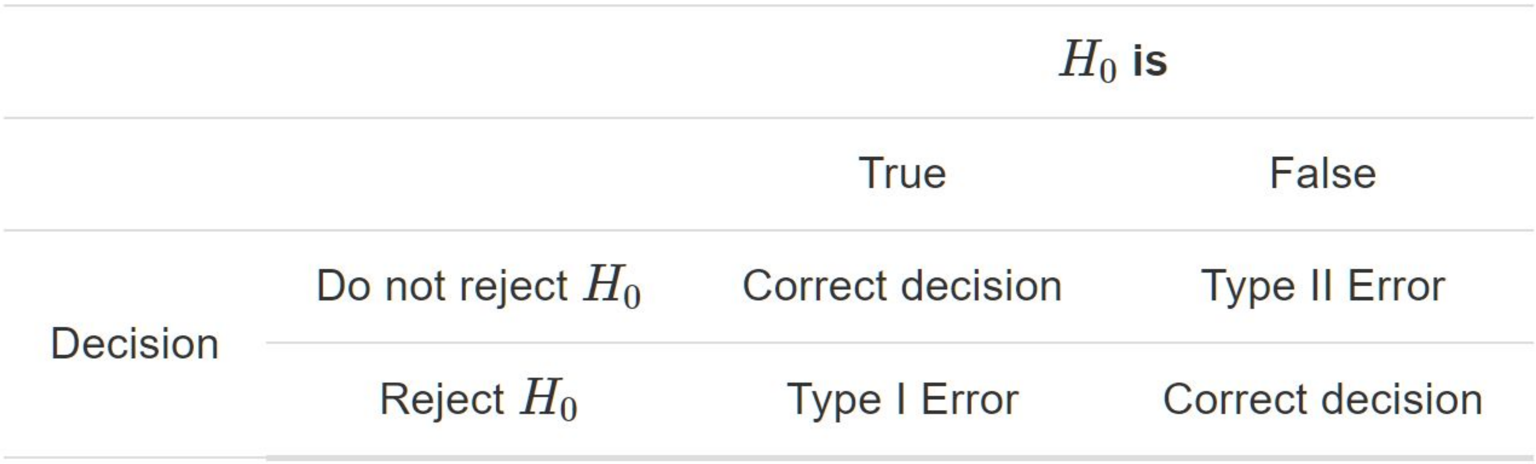
- Can you give an example of a Null and Alternative Hypothesis?

Hypothesis testing

We consider that we are testing only population mean using one-sample (One-sample hypothesis testing)

- Helps us decide whether the null hypothesis should be rejected in favor of the alternative.
- Tests a claim about a population parameter using evidence (data in a sample)
- The null hypothesis (H_0) is a claim of **“no difference in the population”**
- The alternative hypothesis (H_A) claims “H_0 **is false”**
- Collect data and seek evidence against H_0 as a way of bolstering H_A (deduction)

Hypothesis testing – Confusion matrix



		H_0 is	
		True	False
Decision	Do not reject H_0	Correct decision	Type II Error
	Reject H_0	Type I Error	Correct decision

We consider that we are testing only population mean using one-sample (One-sample hypothesis testing)

Choosing a proper test statistic

- A test statistic is a rule, based on sample data, for deciding whether to reject H_0.
- **Assuming that the population is normally distributed or samples are very large (CLT).**
- The standard deviation of the population **σ** is unknown:
    - We use **T statistic**
    - Replace **σ** with its sample estimate **S**
- The standard deviation of the population **σ** is known:
    - If $n \geq 30$: we use **Z statistic**
    - If $n < 30$: we use **T statistic**

Z-score vs. T-score

Hypothesis testing

$$s = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

df: Degrees of freedom

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

$$t = \frac{\bar{x} - \mu}{s / \sqrt{n}}$$

σ is known and n<30

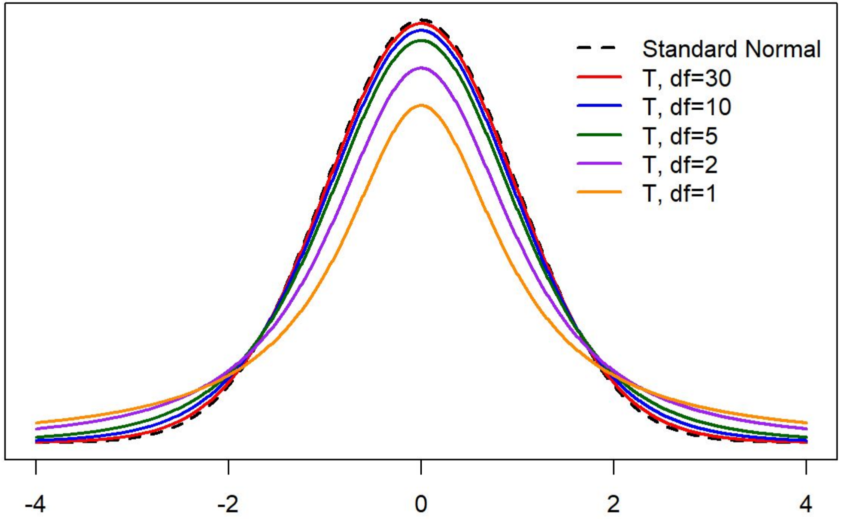
σ is known and n≥30

OR

σ is unknown ⇒ replace with its sample estimate **S**

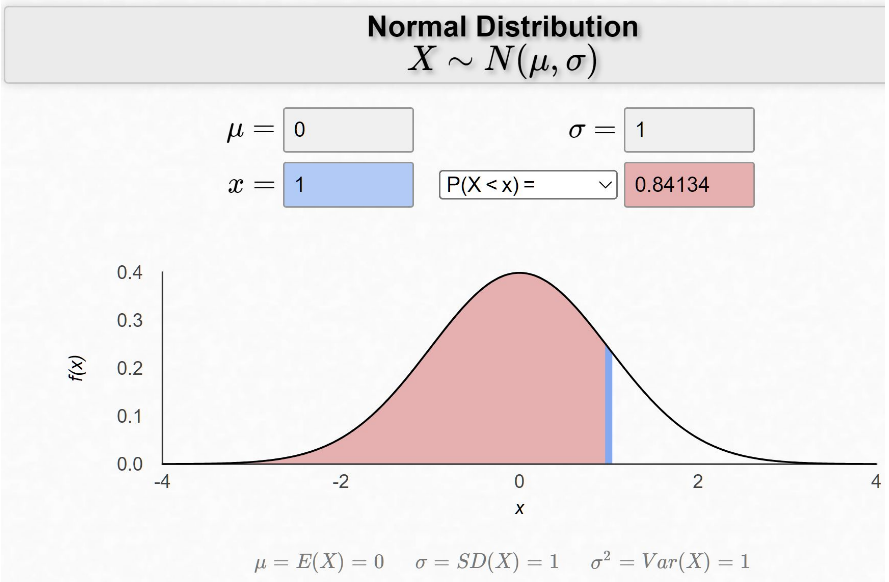
T-statistic & Z-statistic

- Think of T-score as an estimated Z-score
  - Estimation is due to the unknown population variance σ2
  - With large samples **(n>=30)**, the estimation is good and the T statistic is very close to Z.



- ***Degrees of freedom*** is used to describe how well T represents Z

T-statistic & Z-statistic



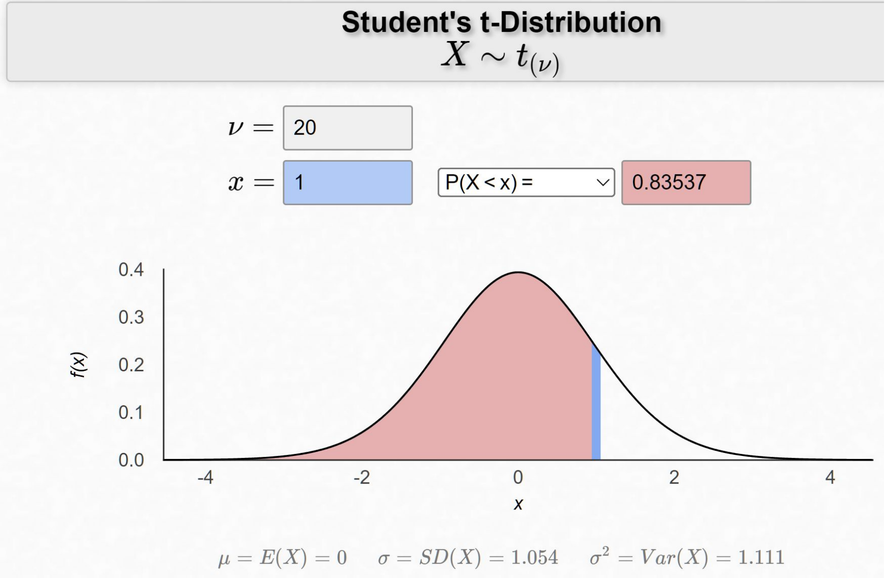
Normal Distribution

$X \sim N(\mu, \sigma)$

$\mu =$ 0 $\sigma =$ 1

$x =$ 1 P(X < x) = 0.84134

$\mu = E(X) = 0 \quad \sigma = SD(X) = 1 \quad \sigma^2 = Var(X) = 1$



Student's t-Distribution

$X \sim t_{(\nu)}$

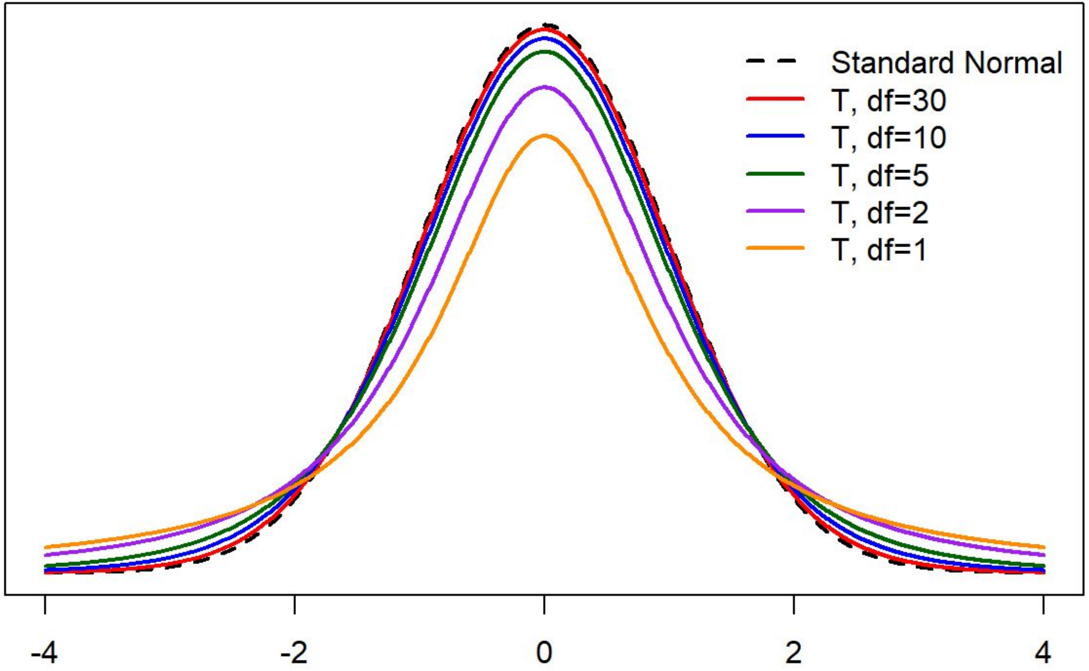
$\nu =$ 20

$x =$ 1 P(X < x) = 0.83537

$\mu = E(X) = 0 \quad \sigma = SD(X) = 1.054 \quad \sigma^2 = Var(X) = 1.111$

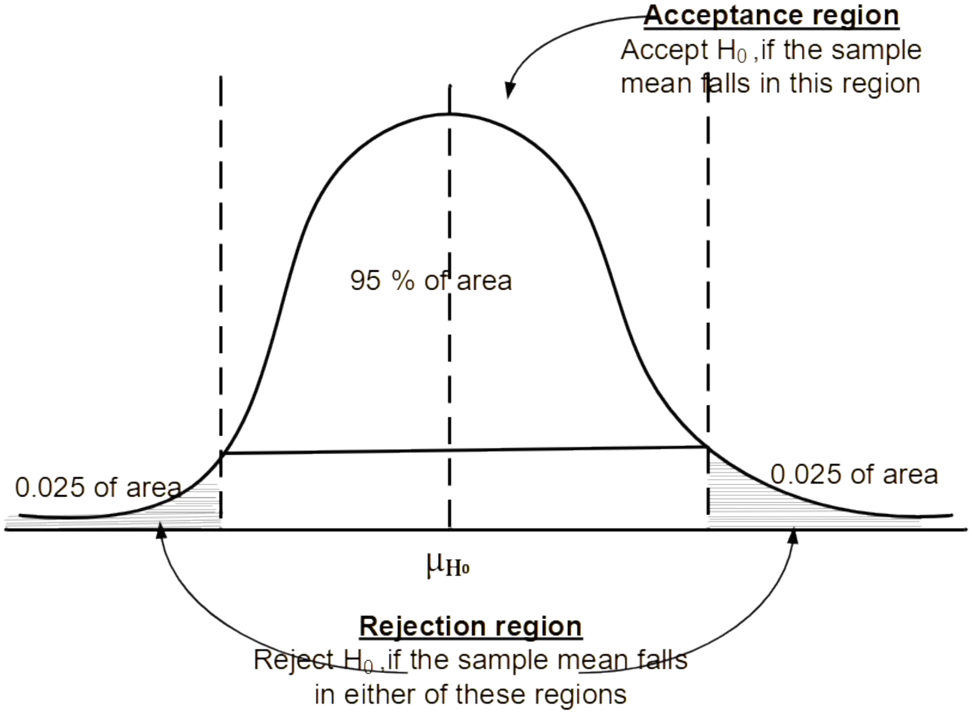
https://homepage.divms.uiowa.edu/~mbognar/applets/normal.html
https://homepage.divms.uiowa.edu/~mbognar/applets/t.html

Standard Normal (Z) & Student’s (T) distributions



Hypothesis testing

- The **critical region** (or **rejection** region) is the set of all values of the test statistic that cause us to reject the null hypothesis.



Acceptance and rejection regions in case of a two-tailed test with 5% significance level.

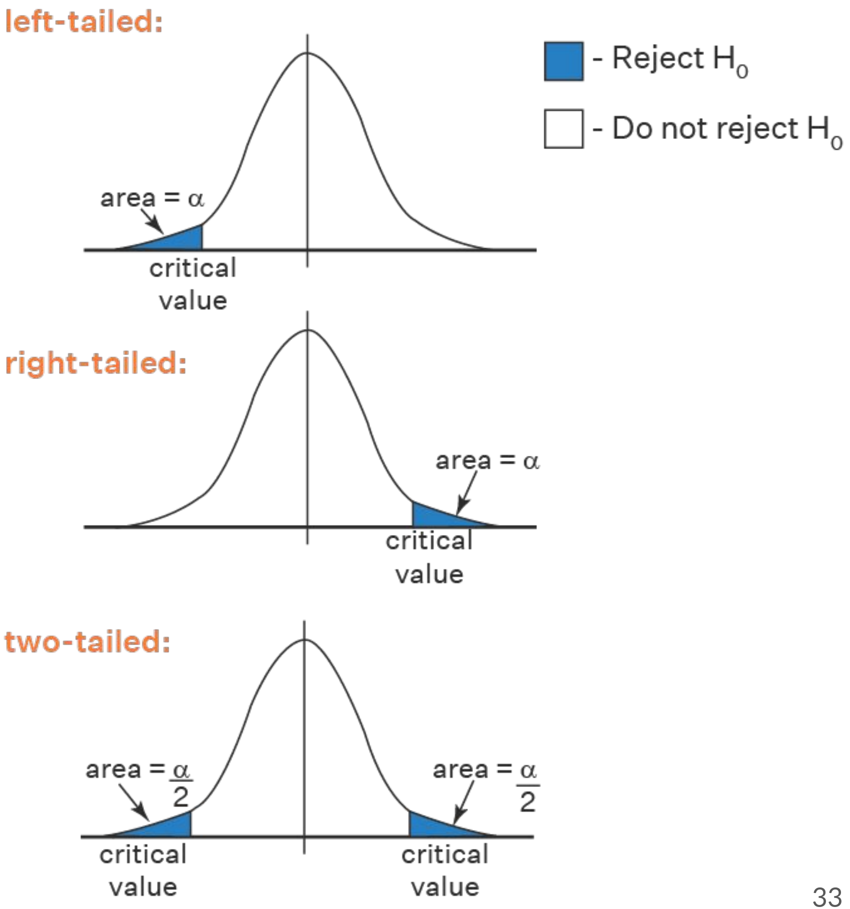
Hypothesis testing

- **Test statistic (T-score or Z-score)** is a value used in making a decision about the null hypothesis, and is found by converting the sample statistic to a score with the assumption that the null hypothesis is true.

$$z = \frac{\bar{X} - \mu}{\sigma / \sqrt{n}} \qquad t = \frac{\bar{x} - \mu}{s / \sqrt{n}}$$

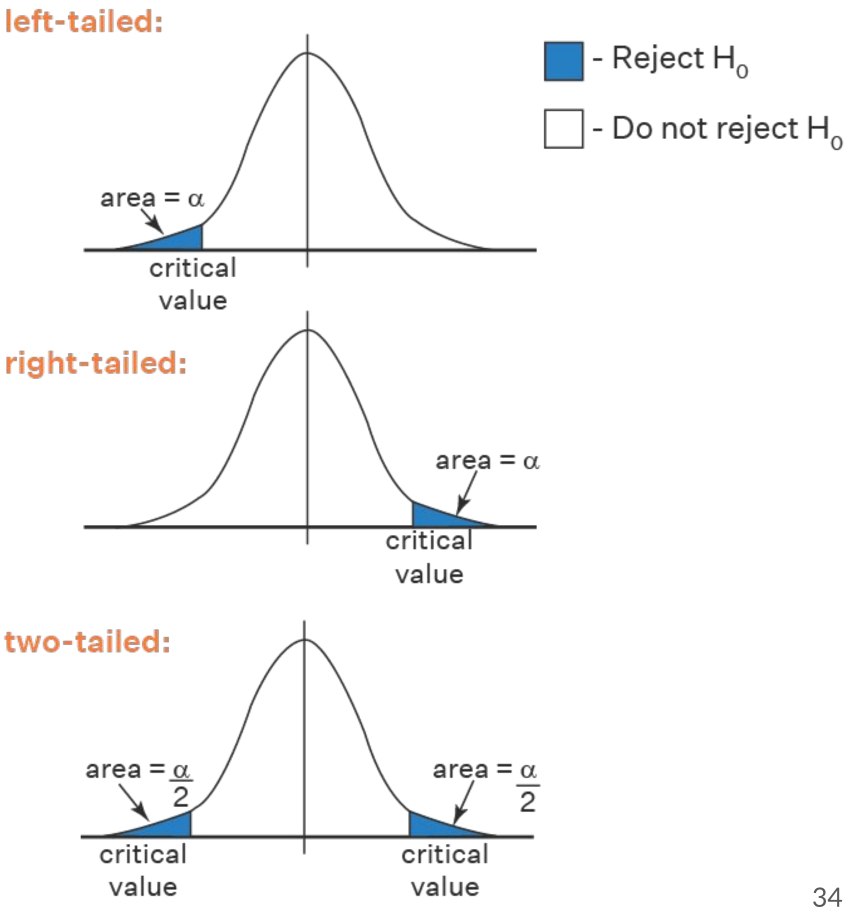
Hypothesis testing

- **Significance level** (denoted by **α**) is the probability that the test statistic will fall in the critical region when the null hypothesis is actually true. Common choices for are 0.05, 0.01, and 0.10.



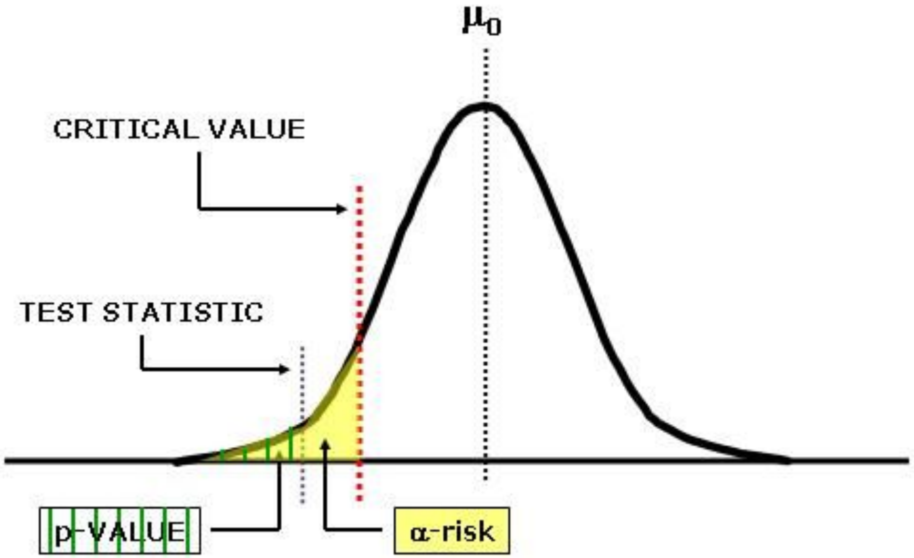
Hypothesis testing

- **A critical value** is any value that separates the critical region (where we reject the null hypothesis) from the values of the test statistic that do not lead to rejection of the null hypothesis.

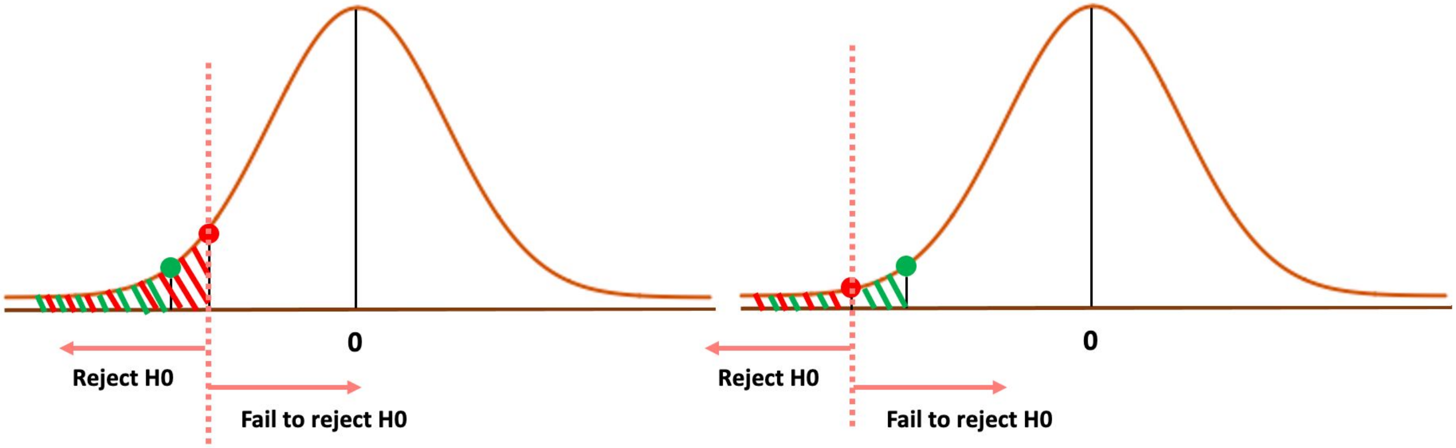


Hypothesis testing

- **The P-value** (or p-value or probability value) is the probability of getting a value of the test statistic that is at least as extreme as the one representing the sample data, assuming that the null hypothesis is true.
- The null hypothesis is rejected if the P-value is very small, such as 0.05 or less.



Hypothesis testing – alpha vs. p-value



Significant Level (α) = 0.05
p-value = 0.0062
p-value < significant level → Reject H0

Significant Level (α) = 0.005
p-value = 0.0062
p-value > significant level → Fail to reject H0

Two-tailed, Right-tailed, Left-tailed Tests

The **tails** in a distribution are the extreme regions bounded by critical values.

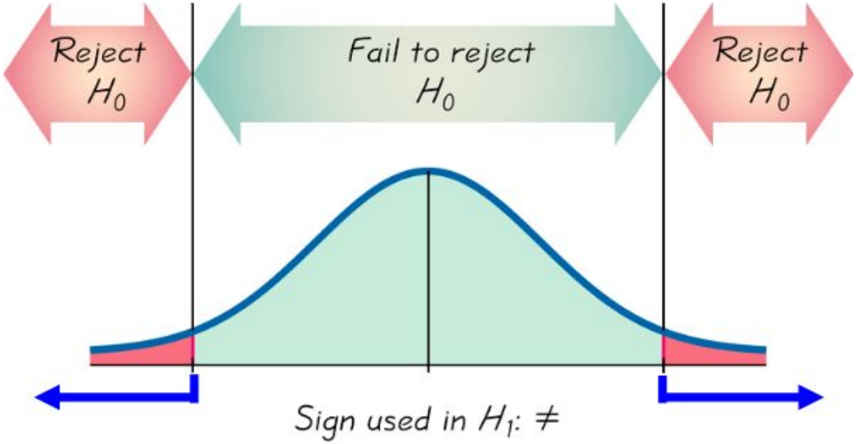
Two-tailed Test

H_0: =

H_1: ≠

Means less than or greater than

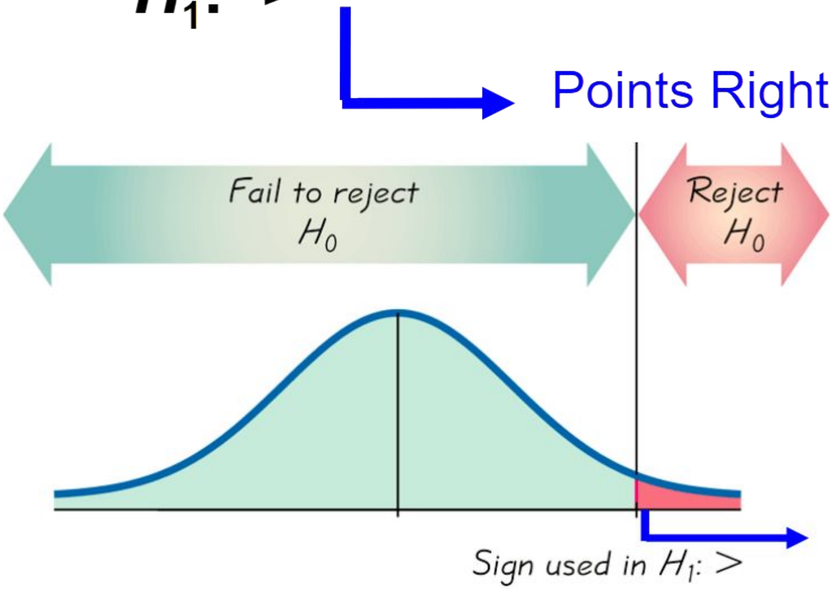
α is divided equally between the two tails of the critical region



Right-tailed Test

H_0: =

H_1: >

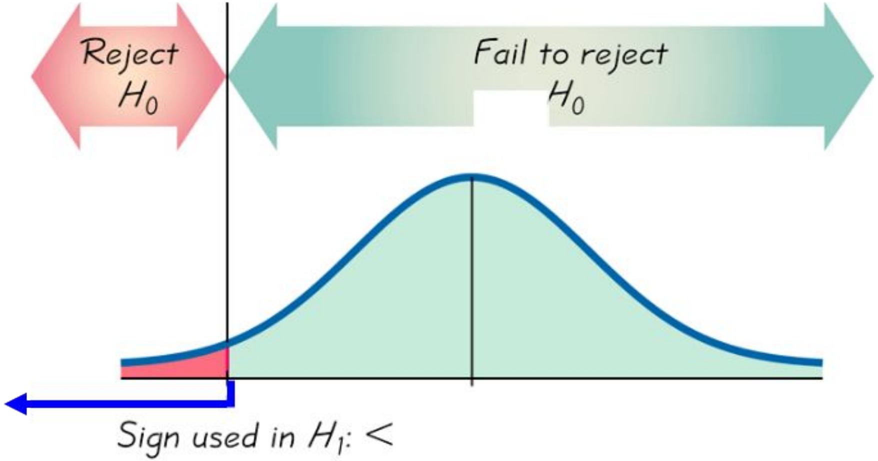


Left-tailed Test

H_0: =

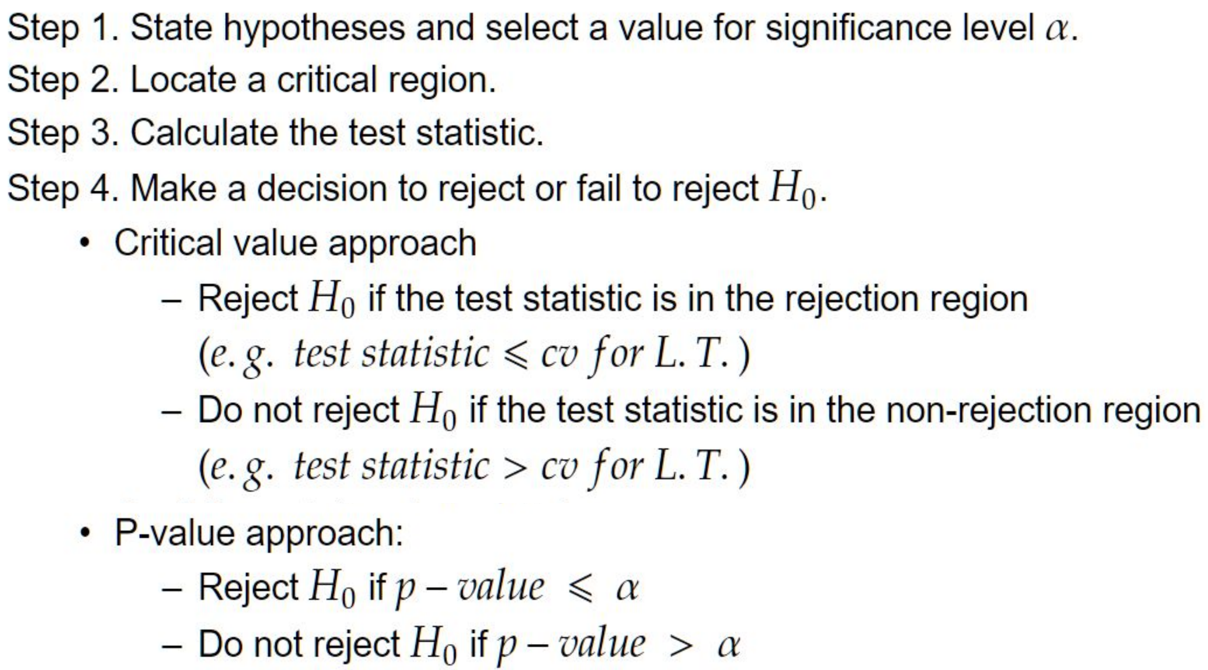
H_1: <

Points Left



NOTE: In the following examples, statistics are skipped.

Hypothesis Testing - 4 steps



Step 1. State hypotheses and select a value for significance level α.

Step 2. Locate a critical region.

Step 3. Calculate the test statistic.

Step 4. Make a decision to reject or fail to reject H_0.

- Critical value approach
  - Reject H_0 if the test statistic is in the rejection region $(e.g.\ \ test\ statistic \leqslant cv\ for\ L.T.)$
  - Do not reject H_0 if the test statistic is in the non-rejection region $(e.g.\ \ test\ statistic > cv\ for\ L.T.)$
- P-value approach:
  - Reject H_0 if $p - value\ \leqslant\ \alpha$
  - Do not reject H_0 if $p - value\ >\ \alpha$

Hypothesis testing – Making a Decision

We always test the null hypothesis. The initial conclusion will always be one of the following:

1. Reject the null hypothesis.

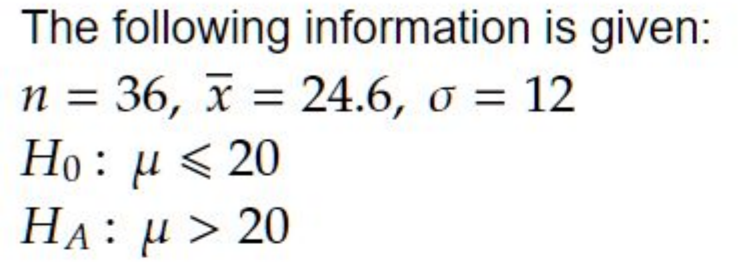
2. Fail to reject the null hypothesis.

Hypothesis testing – Interpreting a Decision

Example:

- A cigarette manufacturer claims that less than one-eighth of the US adult population smokes cigarettes.
    - If **H0 is rejected**, you should conclude “there is sufficient evidence to indicate that the manufacturer’s claim is false.”
    - If you **fail to reject H0**, you should conclude “there is no sufficient evidence to indicate that the manufacturer’s claim is false.”

Hypothesis testing – Example 1

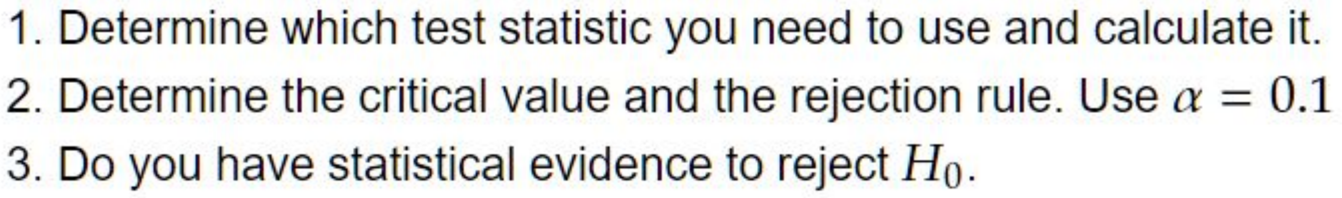


The following information is given:

$n = 36, \ \overline{x} = 24.6, \ \sigma = 12$

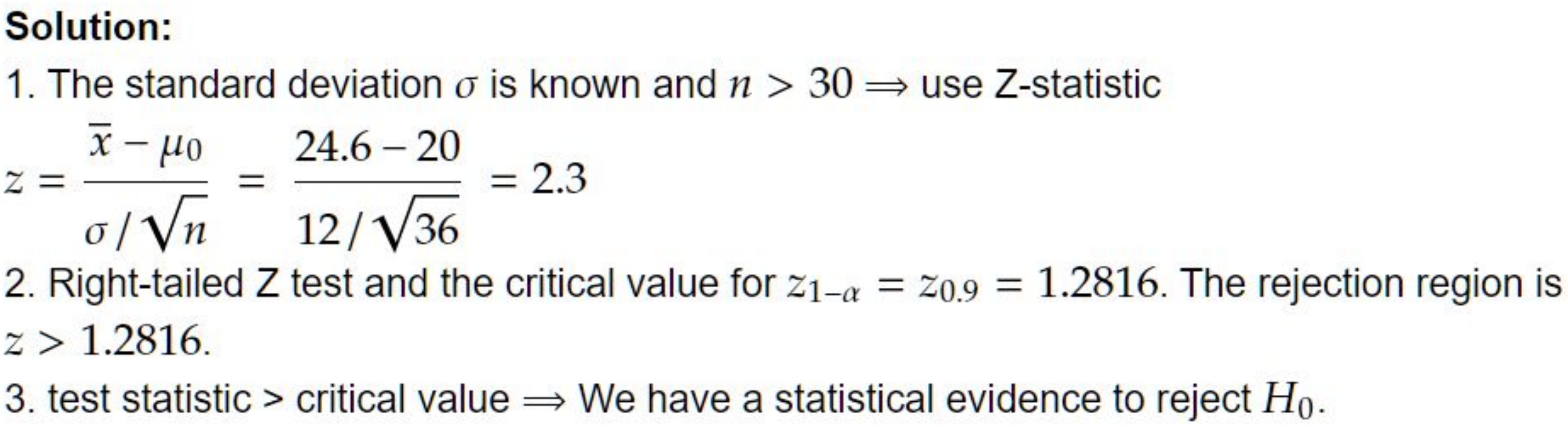
$H_0: \ \mu \leqslant 20$

$H_A: \ \mu > 20$



1. Determine which test statistic you need to use and calculate it.
2. Determine the critical value and the rejection rule. Use $\alpha = 0.1$
3. Do you have statistical evidence to reject H_0.

Hypothesis testing – Example 1



Solution:

1. The standard deviation σ is known and $n > 30 \Longrightarrow$ use Z-statistic

$$z = \frac{\overline{x} - \mu_0}{\sigma / \sqrt{n}} = \frac{24.6 - 20}{12 / \sqrt{36}} = 2.3$$

2. Right-tailed Z test and the critical value for $z_{1-\alpha} = z_{0.9} = 1.2816$. The rejection region is $z > 1.2816$.

3. test statistic > critical value $\Longrightarrow$ We have a statistical evidence to reject H_0.

[lab02.EM.Rcode.ipynb - Colaboratory (google.com)]()

One sample Z-test

Hypothesis testing – Example 1

R

```r
install.packages("BSDA")
library(BSDA)

sigma <- 12; mu <- 20; mean <- 24.6; n <- 36; alpha <-
0.1;

r = z.test(x = rep(c(x_mean), each=n), mu=mu,
alternative = "greater", sigma.x = pop_sigma)

p_val = r["p.value"]
if (p_val < alpha) {
    print(" We can reject the null hypothesis")
}
else{
    print("We fail to reject the null hypothesis")
}
```

Python

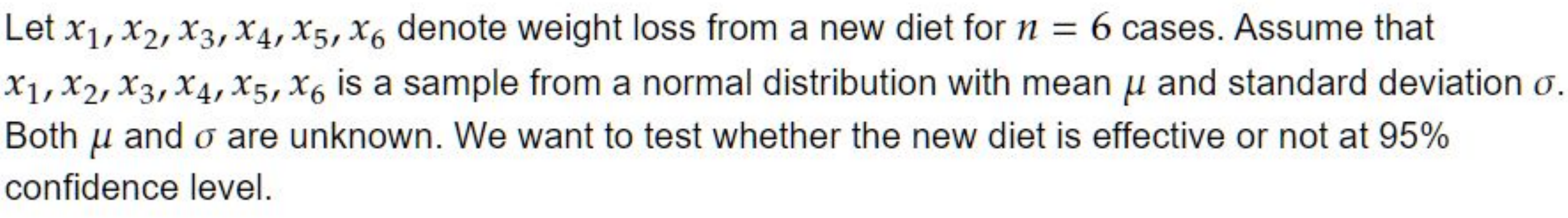
```python
pop_sigma = 12; mu = 20; x_mean = 24.6; n = 36;
alpha = 0.1;
data = n*[x_mean]

from statsmodels.stats.weightstats import ztest

ztest_Score, p_value= ztest(data, value = mu,
alternative='larger')

if p_val < alpha:
    print(" We can reject the null hypothesis")
else:
    print("We fail to reject the null
hypothesis")
```

Hypothesis testing – Example 2



Let $x_1, x_2, x_3, x_4, x_5, x_6$ denote weight loss from a new diet for $n = 6$ cases. Assume that $x_1, x_2, x_3, x_4, x_5, x_6$ is a sample from a normal distribution with mean μ and standard deviation σ. Both μ and σ are unknown. We want to test whether the new diet is effective or not at 95% confidence level.

1	2	3	4	5	6
2.0	1.0	1.4	-1.8	0.9	2.3

Hypothesis testing – Example 2

4	5	6
-1.8	0.9	2.3

Solution:

1.

$H_0: \ \mu \leqslant 0 \ \ (New\ diet\ is\ not\ effective)$

$H_A: \ \mu > 0 \ (New\ diet\ is\ effective)$

2. The standard deviation σ is unknown $\Longrightarrow$ use T-statistic

$$t = \frac{\overline{x} - \mu_0}{s / \sqrt{n}} = \frac{0.97 - 0}{1.46 / \sqrt{6}} = 1.62$$

3. Right-tailed T test, $df = n - 1 = 5$ and the critical value is $t_{1-\alpha,\, df} = t_{0.95,\, 5} = 2.015$. The rejection region is $t > 2.015$.

4. test statistic $\leqslant$ critical value $\Longrightarrow$ At the $\alpha = 5\%$ level of significance, the data does not provide sufficient evidence to support the alternative hypothesis that $\mu > 0$ and we fail to reject the null hypothesis.

5. $$\begin{aligned} p - value \ &= \ P(T_{df} > t) = 1 - P(T_5 < t) = 1 - P(T_5 < 1.62) = 1 - 0.9169 \\ &= 0.0831 \geqslant \alpha = 0.05 \end{aligned}$$

There is no enough evidence to conclude that new diet is effective.

lab02.EM.Rcode.ipynb - Colaboratory (google.com)

One sample T-test

Hypothesis testing – Example 2

R	Python

R

```r
data <- c(2, 1, 1.4, -1.8, 0.9, 2.3)
alpha = 0.05
r = t.test(data, mu = 0, alternative="greater")

p_val = r["p.value"]

if (p_val < alpha) {
    print(" We can reject the null hypothesis")
}
else{
    print("We fail to reject the null hypothesis")
}
```

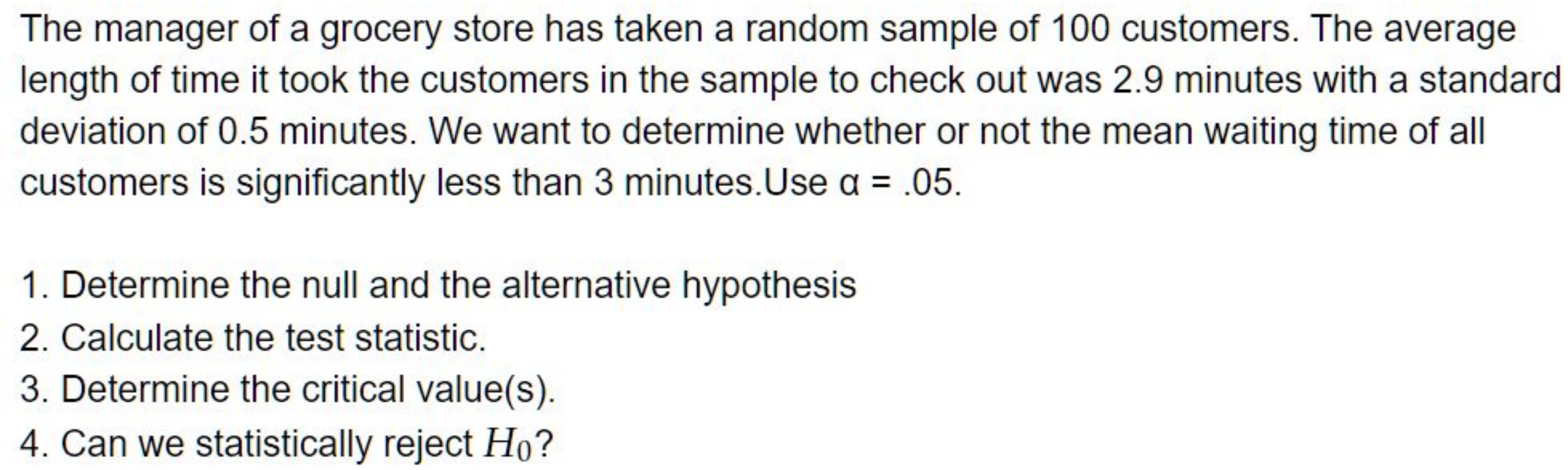
Python

```python
from scipy import stats
data = [2, 1, 1.4, -1.8, 0.9, 2.3]
alpha = 0.05

t_test, p_val = stats.ttest_1samp(data,
popmean=0, alternative="greater")

if p_val < alpha:
    print(" We can reject the null hypothesis")
else:
    print("We fail to reject the null
hypothesis")
```

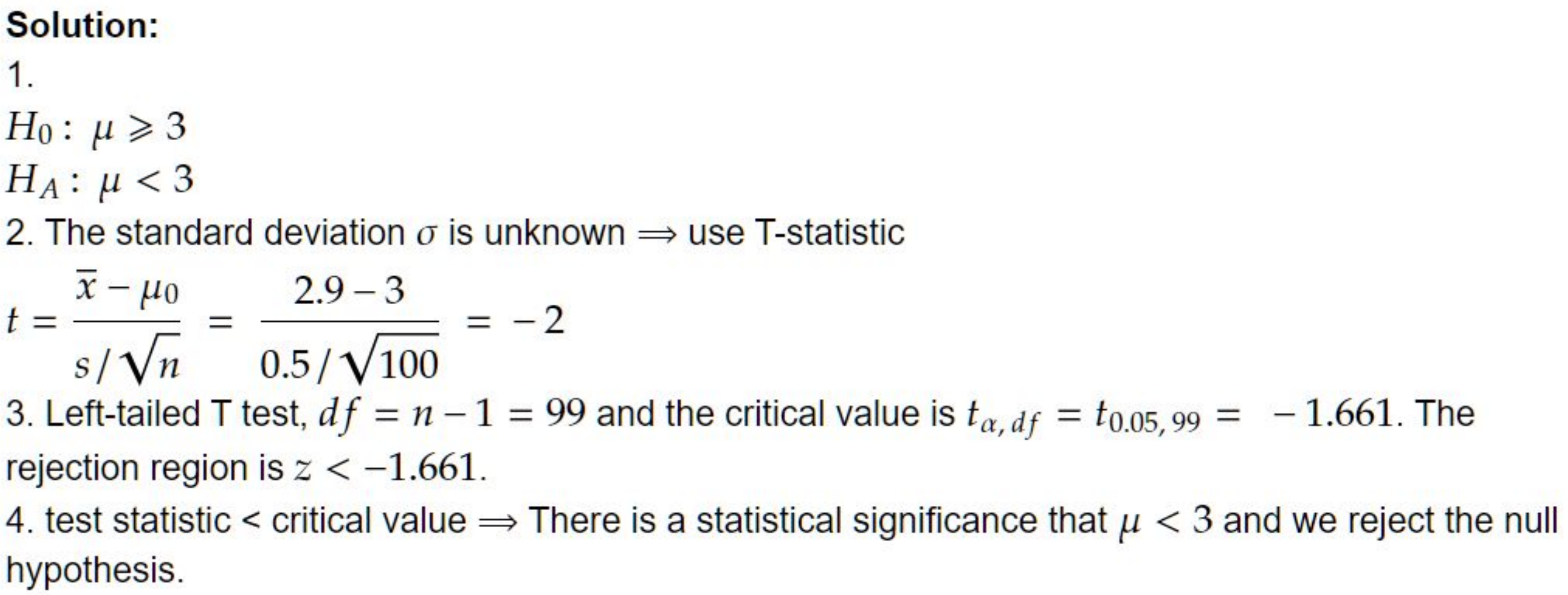
Hypothesis testing – Example 3



The manager of a grocery store has taken a random sample of 100 customers. The average length of time it took the customers in the sample to check out was 2.9 minutes with a standard deviation of 0.5 minutes. We want to determine whether or not the mean waiting time of all customers is significantly less than 3 minutes.Use α = .05.

1. Determine the null and the alternative hypothesis
2. Calculate the test statistic.
3. Determine the critical value(s).
4. Can we statistically reject H_0?

Hypothesis testing – Example 3



Solution:

1.

$H_0 : \ \mu \geqslant 3$

$H_A : \ \mu < 3$

2. The standard deviation σ is unknown $\Longrightarrow$ use T-statistic

$$t = \frac{\overline{x} - \mu_0}{s / \sqrt{n}} = \frac{2.9 - 3}{0.5 / \sqrt{100}} = -2$$

3. Left-tailed T test, $df = n - 1 = 99$ and the critical value is $t_{\alpha, df} = t_{0.05, 99} = -1.661$. The rejection region is $z < -1.661$.

4. test statistic < critical value $\Longrightarrow$ There is a statistical significance that $\mu < 3$ and we reject the null hypothesis.

Hypothesis testing – Example 4

Suppose the mean GPA of all students graduating from Innopolis University in 2022 was 4.05. The registrar plans to look at records of 100 students graduating in 2022 to see if mean GPA has changed. The sample mean is 4.15, while standard deviation is 1.5.

1. State the null and alternative hypotheses for this investigation.
2. Test the null hypothesis at the significance level 0.05.

Hypothesis testing – Example 4

Solution:

1.

$H_0: \mu = 4.05$

$H_A: \mu \neq 4.05$

2. The standard deviation σ is unknown $\Longrightarrow$ use T-statistic

$$t = \frac{\overline{x} - \mu_0}{s/\sqrt{n}} = \frac{4.15 - 4.05}{1.5/\sqrt{100}} = 0.667$$

3. Two-tailed T test, $df = n - 1 = 99$ and the critical values are $t_{1-\alpha/2,\,df} = t_{0.975,\,99} = 1.660$ and $t_{\alpha/2,\,df} = t_{0.025,\,99} = -1.660$. The rejection region is $t > 1.66$ *or* $t < -1.66$.

4. test statistic is not in the rejection region $\Longrightarrow$ At the $\alpha = 5\%$ level of significance, the data does not provide sufficient evidence to support the alternative hypothesis that $\mu \neq 4.05$ and we do not reject the null hypothesis.

5. $$p - value = 2 * P(T_{df} > |t|) = 2 - 2 * P(T_{99} < |t|) = 2 - 2 * P(T_{99} < 0.667) = 2 - 2 * 0.7478$$
$$= 0.5044 > \alpha = 0.05$$

There is no enough evidence to conclude that the average GPA is changed.

Hypothesis testing – Example 5

Test the hypothesis at confidence level 95% that the mean men weight increased to 191 pounds in some group during the winter with standard deviation $\sigma = 25.6$. We will assume the sample data are as follows: $n = 100, \ \overline{X} = 197.1$

Hypothesis testing – Example 5

Solution:

1.

$H_0: \ \mu = 191$

$H_A: \ \mu \ > \ 191$

2. The standard deviation σ is known and $n \geqslant 30 \Longrightarrow$ use Z-statistic

$$z = \frac{\bar{x} - \mu_0}{\sigma / \sqrt{n}} = \frac{197.1 - 191}{25.6 / \sqrt{100}} = 2.38$$

3. Right-tailed Z test and the critical value is $z_{1-\alpha} = z_{0.95} = 1.645$. The rejection region is $z > 1.645.$

4. test statistic > critical value $\Longrightarrow$ At the $\alpha = 5\%$ level of significance, the data provide sufficient evidence to support the alternative hypothesis that $\mu > 191$ and we reject the null hypothesis.

5. $p - value \ = \ P(Z > |z|) = 1 - P(Z < 2.38) = 1 - 0.9913 = 0.0087 \leqslant \alpha = 0.05$

There is enough evidence to conclude that there is an increase in the mean weight.

Homework 1

A company claims that their new training program will improve employee productivity. A random sample of 40 employees is taken, and their productivity scores before and after the training program are recorded. The average improvement in productivity is found to be 10 points, with a standard deviation of 5 points. Test the company's claim at a significance level of 0.01.

Homework 2

Suppose scores on an IQ test are normally distributed, with a population mean of 100. Suppose 20 people are randomly selected and tested. The standard deviation in the sample group is 15.

1. What is the probability that the average test score in the sample group will be at most 110?
2. Assume that the population mean 100 is not the true mean and it is the claim of the committee. Test the hypothesis that the population is less than 100 given the sample above with an average score of 110 and std. of 15.

References

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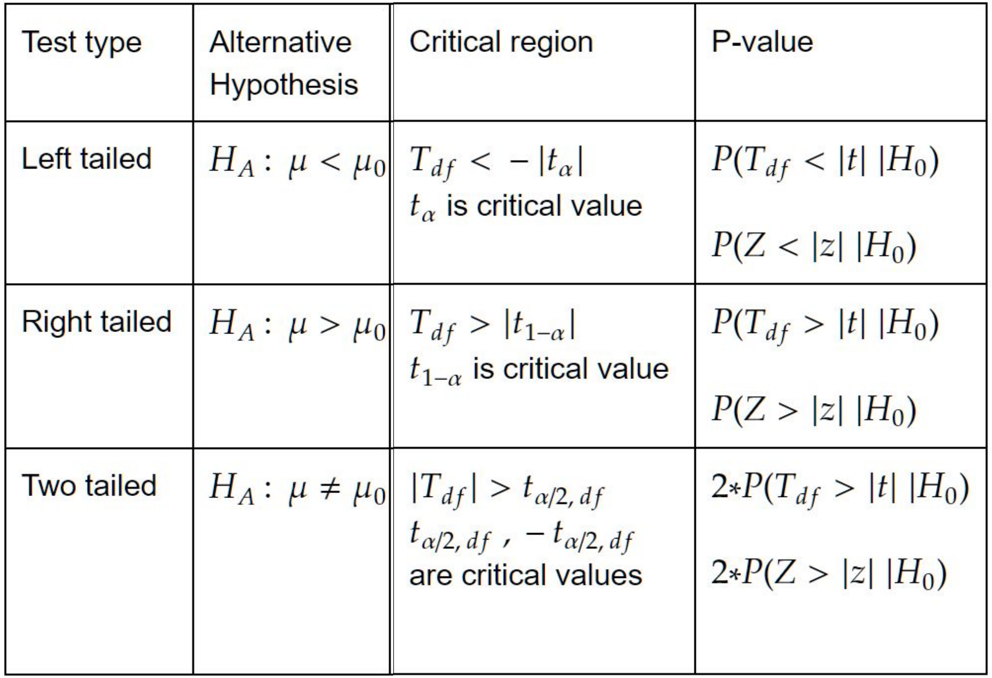
- https://www.scribbr.com/statistics/normal-distribution/
- https://www.visual-design.net/post/an-interactive-guide-to-hypothesis-testing-in-python
- https://online.stat.psu.edu/stat200/lesson/6/6.1
- https://bookdown.org/lgpcappiello/introstats/introduction-to-confidence-intervals.html
- Hypothesis Testing in Python.ipynb - Colaboratory (google.com)
- https://condor.depaul.edu/gandrus/428/docs/hyptest.html
- https://courses.lumenlearning.com/introstats1/chapter/null-and-alternative-hypotheses/
- …etc

Upcoming class

- Representational theory of measurement
- Measurement scales
  - Nominal
  - Ordinal
  - Interval
  - Ratio

Extra slides

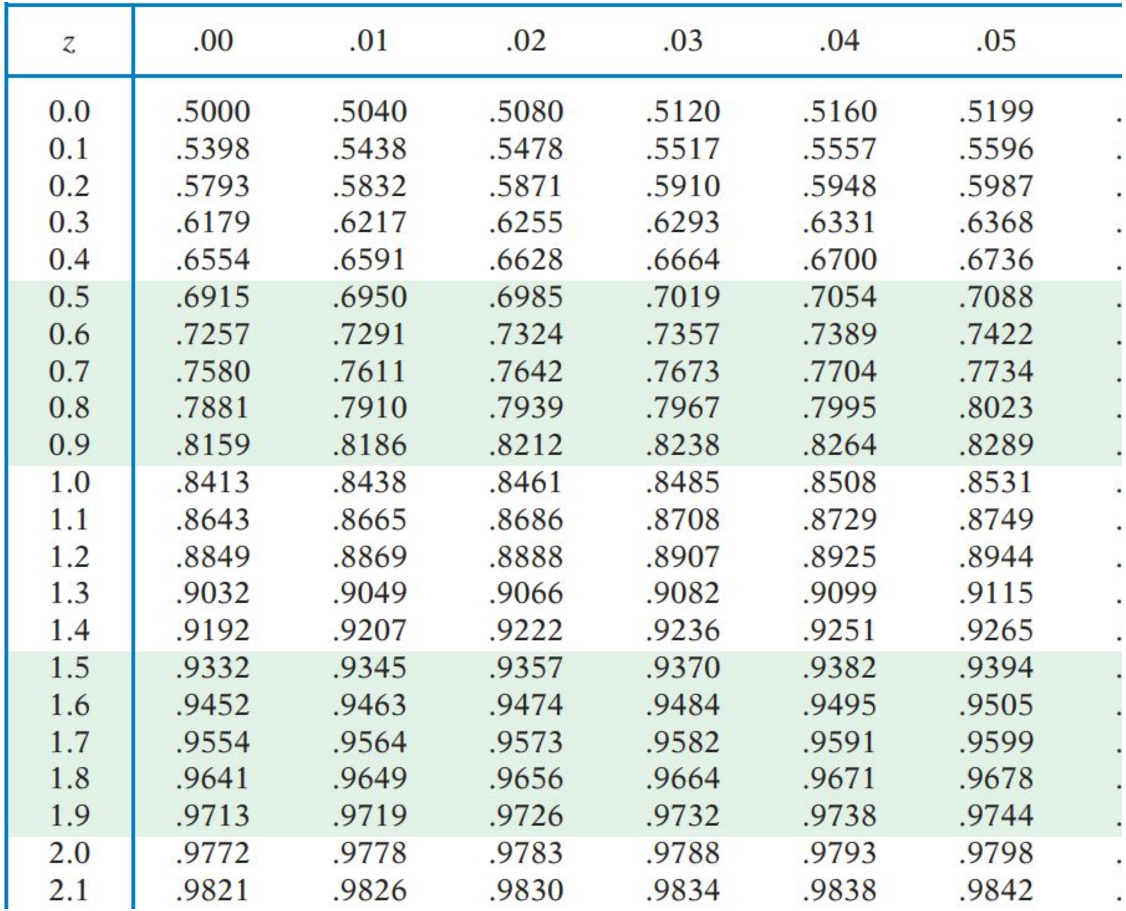
Critical regions & p values



Test type	Alternative Hypothesis	Critical region	P-value
Left tailed	$H_A : \mu < \mu_0$	$T_{df} < -\lvert t_\alpha \rvert$ t_α is critical value	$P(T_{df} < \lvert t \rvert\ \lvert H_0)$ $P(Z < \lvert z \rvert\ \lvert H_0)$
Right tailed	$H_A : \mu > \mu_0$	$T_{df} > \lvert t_{1-\alpha} \rvert$ $t_{1-\alpha}$ is critical value	$P(T_{df} > \lvert t \rvert\ \lvert H_0)$ $P(Z > \lvert z \rvert\ \lvert H_0)$
Two tailed	$H_A : \mu \neq \mu_0$	$\lvert T_{df} \rvert > t_{\alpha/2,\, df}$ $t_{\alpha/2,\, df}\ ,\ -t_{\alpha/2,\, df}$ are critical values	$2{*}P(T_{df} > \lvert t \rvert\ \lvert H_0)$ $2{*}P(Z > \lvert z \rvert\ \lvert H_0)$

Z & T tables

https://docs.google.com/spreadsheets/d/1P7KBaJNMnBF-eurP3t6t9pRud-SB7pHfoBT3yaKlU0o/edit?usp=sharing

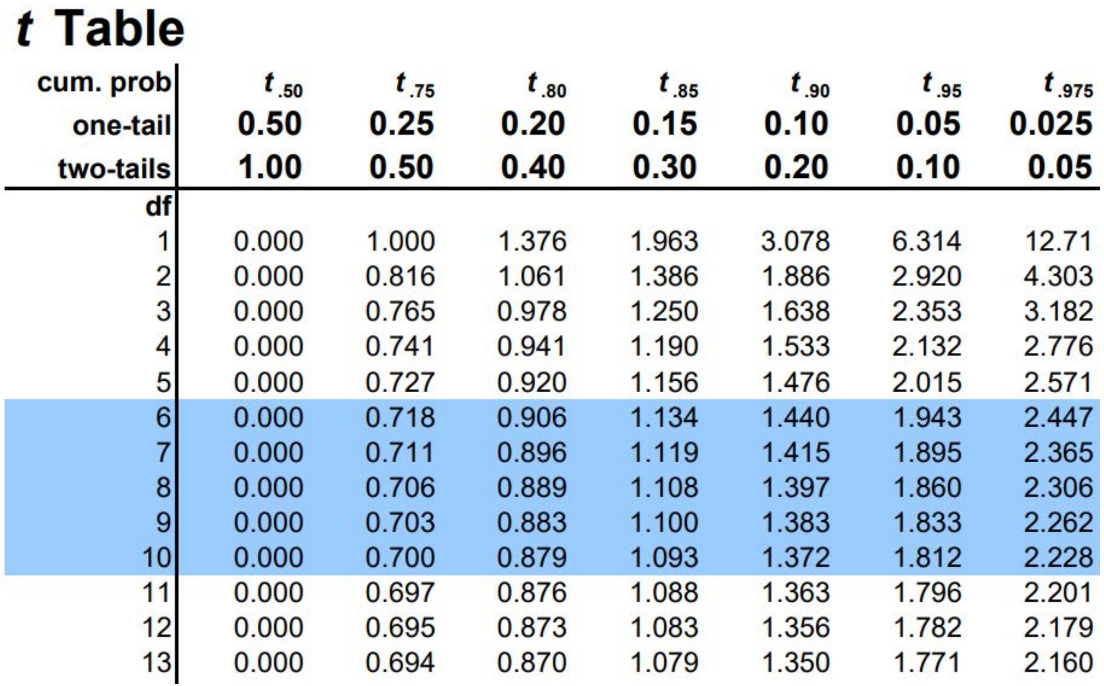


z	.00	.01	.02	.03	.04	.05
0.0	.5000	.5040	.5080	.5120	.5160	.5199
0.1	.5398	.5438	.5478	.5517	.5557	.5596
0.2	.5793	.5832	.5871	.5910	.5948	.5987
0.3	.6179	.6217	.6255	.6293	.6331	.6368
0.4	.6554	.6591	.6628	.6664	.6700	.6736
0.5	.6915	.6950	.6985	.7019	.7054	.7088
0.6	.7257	.7291	.7324	.7357	.7389	.7422
0.7	.7580	.7611	.7642	.7673	.7704	.7734
0.8	.7881	.7910	.7939	.7967	.7995	.8023
0.9	.8159	.8186	.8212	.8238	.8264	.8289
1.0	.8413	.8438	.8461	.8485	.8508	.8531
1.1	.8643	.8665	.8686	.8708	.8729	.8749
1.2	.8849	.8869	.8888	.8907	.8925	.8944
1.3	.9032	.9049	.9066	.9082	.9099	.9115
1.4	.9192	.9207	.9222	.9236	.9251	.9265
1.5	.9332	.9345	.9357	.9370	.9382	.9394
1.6	.9452	.9463	.9474	.9484	.9495	.9505
1.7	.9554	.9564	.9573	.9582	.9591	.9599
1.8	.9641	.9649	.9656	.9664	.9671	.9678
1.9	.9713	.9719	.9726	.9732	.9738	.9744
2.0	.9772	.9778	.9783	.9788	.9793	.9798
2.1	.9821	.9826	.9830	.9834	.9838	.9842

https://ux1.eiu.edu/~aalvarado2/z_table.pdf

Z & T tables

https://docs.google.com/spreadsheets/d/1P7KBaJNMnBF-eurP3t6t9pRud-SB7pHfoBT3yaKlU0o/edit?usp=sharing



t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$
one-tail	**0.50**	**0.25**	**0.20**	**0.15**	**0.10**	**0.05**	**0.025**
two-tails	**1.00**	**0.50**	**0.40**	**0.30**	**0.20**	**0.10**	**0.05**
df							
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160

https://www.sjsu.edu/faculty/gerstman/StatPrimer/t-table.pdf

Attendance

https://baam.duckdns.org

Questions?