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A Gentle Introduction to the Chi-Squared Test for Machine Learning

Brownlee on June 15, 2018 in Statistics

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Last Updated on October 31, 2019

A common problem in applied machine learning is determining whether input features are relevant to the outcome to be predicted.

the problem of feature selection.

In the case of classification problems where input variables are also categorical, we can use statistical tests to determine whether the output variable is dependent or independent of the input variables. If independent, then the input variable is a candidate for a feature that may be irrelevant to the problem and removed from the dataset.

The Pearson's chi-squared statistical hypothesis is an example of a test for independence between categorica

In this tutorial, you will discover the chi-squared statistical hypothesis test for quantifying the independence of pairs of categorical variables.

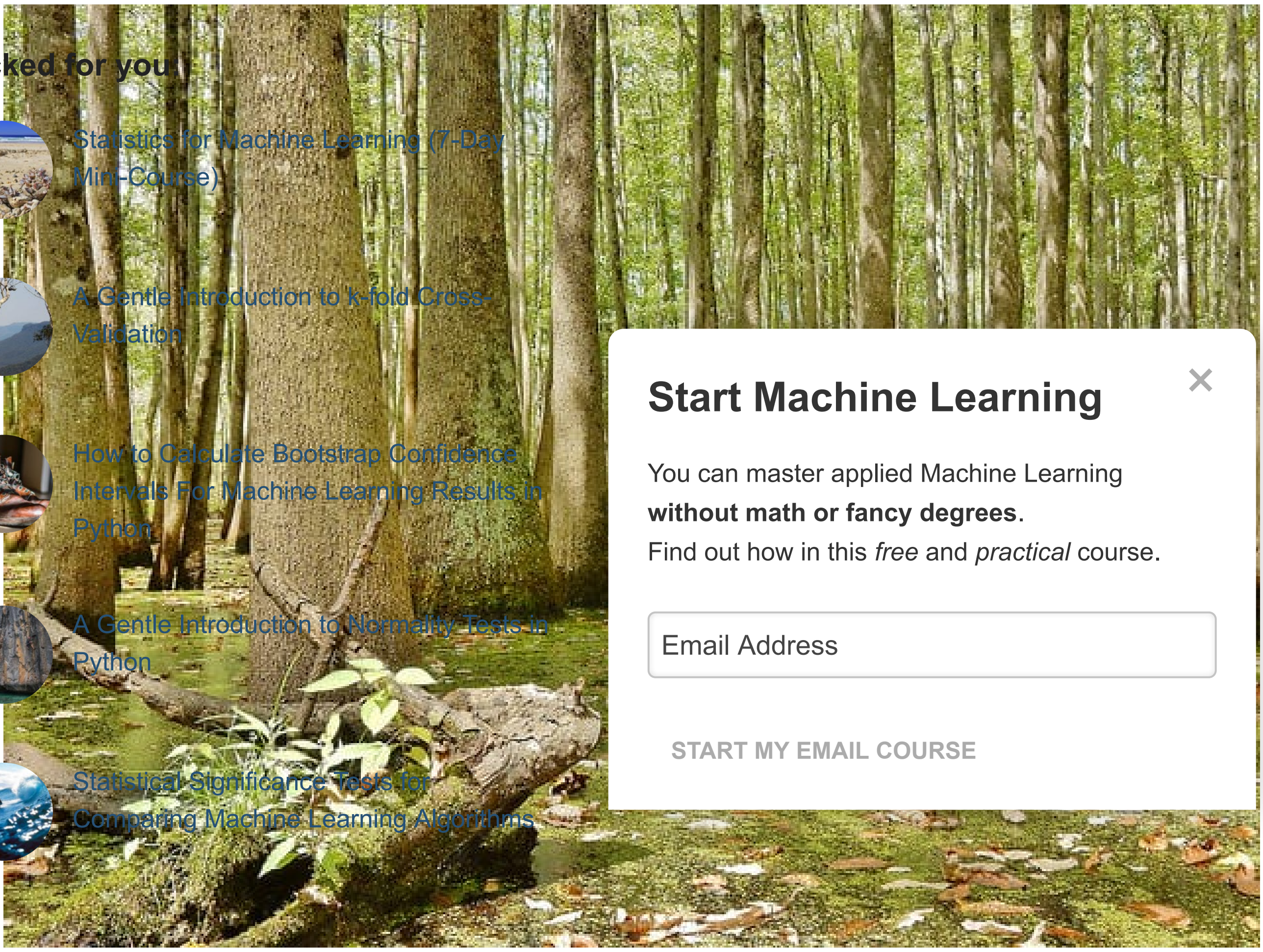
After completing this tutorial, you will know:

- Pairs of categorical variables can be summarized using a contingency table.
- The chi-squared test can compare an observed contingency table to an expected table and determine if the categorical variables are independent.
- How to calculate and interpret the chi-squared test for categorical variables in Python.

Kick-start your project with my new book Statistics for Machine Learning, including *step-by-step tutorials* and the *Python source code* files for all examples.

Let's get started.

- **Update Jun/2018**: Minor typo fix in the interpretation of the critical values from the test (thanks Andrew).
- **Update Oct/2019**: Fixed language around factor/levels (thanks Marc)



A Gentle Introduction to the Chi-Squared Test for Machine Learning
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Tutorial Overview

This tutorial is divided into 3 parts; they are:

1. Contingency Table
2. Pearson's Chi-Squared Test
3. Example Chi-Squared Test

Contingency Table

A categorical variable is a variable that may take on one of a set of labels.

An example might be sex, which may be summarized as male or female. The variable or factor is '*sex*' and the labels or levels of the variable are '*male*' and '*female*' in this case.

We may wish to look at a summary of a categorical variable as it pertains to another categorical variable. For example, sex and interest, where interest may have the labels '*science*', '*math*', or '*art*'. We can collect observations from people collected with regard to these two categorical variables; for example:

```
Sex,    Interest
Male,   Art
Female, Math
Male,   Science
Male,   Math
...
```

We can summarize the collected observations in a

and another variable corresponding to rows. Each

cy of observations that correspond to the r

Historically, a table summarization of two categoric ble.

For example, the *Sex=rows* and *Interest=columns* table with contrived counts might look as follows.

```
        Science,   Math,   Art
Male         20,     30,    15
Female       20,     15,    30
```

The table was called a contingency table, by Karl Pearson, because the intent is to help determine whether one variable is contingent upon or depends upon the other variable. For example, does an interest in math or science depend on gender, or are they independent?

This is ch m the table alone; instead, we can use a statistical method called the Pearson's Chi-Squared test.

Pearson's Chi-Squared Test

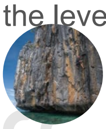
The Pearson's Chi-Squared test, or just Chi-Squared test for short, is named for Karl Pearson, although there are variations on the test.

The Chi-Squared test is a statistical hypothesis test that assumes (the null hypothesis) that the observed frequencies for a categorical variable match the expected frequencies for the categorical variable. The test calculates a statistic that has a chi-squared distribution, named for the Greek capital letter Chi (X) pronounced "ki" as in kite.

Given the Sex/Interest example above, the number of observations for a category (such as male and female) may or may not the same. Nevertheless, we can calculate the expected frequency of observations in each Interest group and see whether the partitioning of interests by Sex results in similar or different frequencies.

The Chi-Squared test does this for a contingency table, first calculating the expected frequencies for the groups, then determining whether the division of the groups, called the observed frequencies, matches the expected frequencies.

The result of the test is a test statistic that has a chi-squared distribution and can be interpreted to reject or fail to reject the assumption or null hypothesis that the observed and expected frequencies are the same.



> *When observed frequency is far from the expected frequency, the corresponding term in the sum is large; when the two are close, this term is small. Large values of X^2 indicate that observed and expected frequencies are far apart. Small values of X^2 mean the opposite: observeds are close to expecteds. So X^2 d*
> *observed and expected frequencies.*

— Page 525, Statistics, Fourth Edition, 2007.

The variables are considered independent if the ob
the levels of the variables do not interact, are not c

> *The chi-square test of independence works*
> *you have collected (known as the observed*
> *expected to get in each cell of a table by char*

— Page 162, Statistics in Plain English, Third Edition, 2010.

We can interpret the test statistic in the context of the chi-squared distribution with the requisite number of degress of freedom as follows:

- **If Statistic >= Critical Value**: significant result, reject null hypothesis (H0), dependent.
- **If Statistic < Critical Value**: not significant result, fail to reject null hypothesis (H0), independent.

The degrees of freedom for the chi-squared distribution is calculated based on the size of the contingency table as:

```
degrees of freedom: (rows - 1) * (cols - 1)
```

In terms of a p-value and a chosen significance level (alpha), the test can be interpreted as follows:

- **If p-value <= alpha**: significant result, reject null hypothesis (H0), dependent.
- **If p-value > alpha**: not significant result, fail to reject null hypothesis (H0), independent.

For the test to be effective, at least five observations are required in each cell of the contingency table.

Next, let's look at how we can calculate the chi-squared test.

Example Chi-Squared Test

The Pearson's chi-squared test for independence c
chi2_contingency() SciPy function.

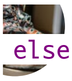
The function takes an array as input representing the contingency table for the two categorical variables. It returns the calculated statistic and p-value for interpretation as well as the calculated degrees of freedom and table of expected frequencies.

```
stat, p, dof, expected = chi2_contingency(table)
```

We can interpret the statistic by retrieving the critical value from the chi-squared distribution for the probability and number of degrees of freedom.

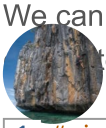
For example, a probability of 95% can be used, suggesting that the finding of the test is quite likely given the assumption of the test that the variable is independent. If the statistic is less than or equal to the critical value, we can fail to reject this assumption, otherwise it can be rejected.

```
# interpret test-statistic
prob = 0.95
critical = chi2.ppf(prob, dof)
if abs(stat) >= critical:
    print('Dependent (reject H0)')
else:
    print('Independent (fail to reject H0)'
```



We can also interpret the p-value by comparing it t

ted by inverting the 95% probability used in



```
# interpret p-value
alpha = 1.0 - prob
if p <= alpha:
    print('Dependent (reject H0)')
else:
    print('Independent (fail to reject H0)')
```

We can tie all of this together and demonstrate the chi-squared significance test using a contrived contingency table.

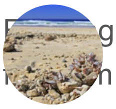
A contingency table is defined below that has a different number of observations for each population (row), but a similar proportion across each group (column). Given the similar proportions, we would expect th ps are similar and that the variables are independent (fail to reject the null hy

```
table = [   [10, 20, 30],
            [6,  9,  17]]
```

The complete example is listed below.

```
# chi-squared test with similar proportions
from scipy.stats import chi2_contingency
from scipy.stats import chi2
# contingency table
table = [   [10, 20, 30],
            [6,  9,  17]]
print(table)
stat, p, dof, expected = chi2_contingency(table)
print('dof=%d' % dof)
print(expected)
# interpret test-statistic
prob = 0.95
critical = chi2.ppf(prob, dof)
print('probability=%.3f, critical=%.3f, stat=%.3f' % (prob, critical, stat))
if abs(stat) >= critical:
    print('Dependent (reject H0)')
```

```
else:
    print('Independent (fail to reject H0)')
# interpret p-value
alpha = 1.0 - prob
print('significance=%.3f, p=%.3f' % (alpha, p))
if p <= alpha:
    print('Dependent (reject H0)')
else:
    print('Independent (fail to reject H0)')
```



g the example first prints the contingency table. The test is calculated and the degrees of n (dof) is reported as 2, which makes sense given:

```
degrees of freedom: (rows - 1) * (cols - 1)
degrees of freedom: (2 - 1) * (3 - 1)
degrees of freedom: 1 * 2
degrees of freedom: 2
```

Next, the calculated expected frequency table is pr ency table does appear to match via an eye

The critical value is calculated and interpreted, finc l to reject H0). The interpretation of the p-value makes

```
[[10, 20, 30], [6, 9, 17]]

dof=2

[[10.43478261 18.91304348 30.65217391]
 [ 5.56521739 10.08695652 16.34782609]]

probability=0.950, critical=5.991, stat=0.272
Independent (fail to reject H0)

significance=0.050, p=0.873
Independent (fail to reject H0)
```

Extensions

This secti ending the tutorial that you may wish to explore.

- Update the chi-squared test to use your own contingency table.
- Write a function to report on the independence given observations from two categorical variables
- Load a standard machine learning dataset containing categorical variables and report on the independence of each.

If you explore any of these extensions, I'd love to know.

Further Reading

This section provides more resources on the topic if you are looking to go deeper.

Books

- Chapter 14, The Chi-Square Test of Independence, Statistics in Plain English, Third Edition, 2010.
- Chapter 28, The Chi-Square Test, Statistics, Fourth Edition, 2007.

API

- scipy.stats.chisquare() API
- scipy.stats.chi2_contingency() API
- sklearn.feature_selection.chi2() API

Articles

- Chi-squared test on Wikipedia
- Pearson’s chi-squared test on Wikipedia
- Contingency table on Wikipedia
- How is chi test used for feature selection in machine learning? on Quora

Summary

In this tutorial, you discovered the chi-squared stat
independence of pairs of categorical variables.

Specifically, you learned:

- Pairs of categorical variables can be summari
- The chi-squared test can compare an observe
determine if the categorical variables are inde
- How to calculate and interpret the chi-squared test for categorical variables in Python.

Do you have any questions?

Ask your questions in the comments below and I will do my best to answer.

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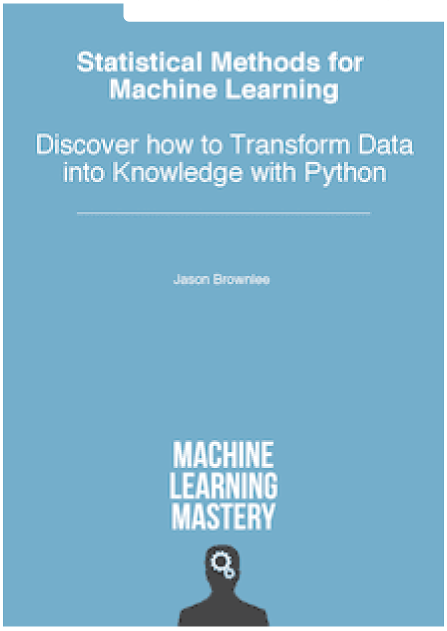
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About Jason Brownlee

Jason Brownlee, PhD is a machine learning specialist who teaches developers how to get results with modern machine learning methods via hands-on tutorials.

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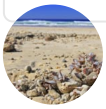
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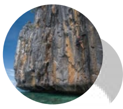
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Elie Kawerk June 19, 2018 at 5:27 am #

Hi Jason,

nks for this nice post.

at statistical test should be used to test the dependence of a continuous variable on a categorical variable (ex: weight and gender).

Best,
Elie

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ne 19, 2018 at 6:38 am # REPLY ↰

Good question. I have not seen a test that can do this directly.

Often, the continuous variable is made discrete/ordinal and the chi-squared test is used. It will give a results, but I'm not sure how statistically valid this would be.

DearML July 2, 2019 at 8:37 pm # REPLY ↰

Is there any way to get the correlation between all the input features only but with binary values which is 0 and 1 (converted from true and false)?

Jason Brownlee July 3, 2019 at 8:33 am # REPLY ↰

Perhaps if you convert input f

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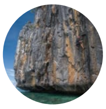


DearML July 3, 2019 at 3:00 pm #

its a discrete variables like for example

df = pd.DataFrame({
'y1': [1,1,1,1,1,1,1,1,0,1,0,0],
'y2': [1,1,1,1,1,1,1,1,0,1,1,0],
y3: [0,1,0,0,0,1,0,0,0,1,1,0],
y4: [0,1,1,1,0,0,1,1,0,0,1,0],
})

Here it should be a strong correlati
this all are features (independent/i
Is there any methods I can use to f
Please help.

Jason Brownlee July 4, 2

Chi squared might be a g

DearML July 5, 2019 at 2:24 pm #

Chi squared is about input and output. isn't it? What about cosine similarity? i think it will work.

rownlee July 6, 2019 at 8:22 am #

Chi squared is only concerned with two categorical variables. They may or may not be inputs or outputs to a model.

What about cosine similarity exactly?

DearML July 8, 2019 at 1:55 pm #

cosine similarity can give me the similarity of two different vectors. here in my example above, it will say that y1 and y2 are related with some more than ~95%

Jason Brownlee July 9, 2019 at 8:04 am #

Details here:
https://en.wikipedia.org/wiki/Cosine_similarity

Judith Vazquez June 26, 2018 at 1:09 am # REPLY

Hi Elie,

You might try using the binning technique. Please see below

http://www.saedsayad.com/binning.htm

Hope it helps ☺

Olutobi Adeyemi October 15, 2018

Analysis of variance will work for t

Adi June 16, 2019 at 6:24 pm #

A 2 sample KS test (https://docs.scipy 0.14.0/reference/generated/scipy.stats.ks_2samp.html)

Jason Brownlee June 17, 2019 at 8:19 am # REPLY

Nice!

Rishabh March 31, 2020 at 5:15 am # REPLY

Independent two sample t test

ana July 1, 2020 at 2:59 am # REPLY

https://en.wikipedia.org/wiki/Correlation_ratio

Andrew V. June 21, 2018 at 3:36 am # REPLY

Hi Jason, great article! One quick thing: shouldn't the above read: "If statistic > critical value then significant result" and "If statistic <= critical value then non-significant result"? The statistic's value and p-value should be inversely related.

June 21, 2018 at 6:22 am # REPLY

Yes, thanks. That was a typo in the explanation. Fixed.

Hani December 25, 2018 at 10:51 pm # REPLY

Hi ,

can I loop the chisq to check the Target vs. all other variables in one step and will let me know the p-value dof etc… of any co

I tried and it didnt work out….

ks !

Jason Brownlee December 26, 2018 at 6

Perhaps write a for-loop to check all v

SK January 24, 2019 at 10:12 pm # REPLY

How do we perform chi-squared test for finding terms that are the most correlated with each class ?

uary 25, 2019 at 8:44 am # REPLY

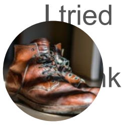
Perhaps calculate the test for each term, then rank order the results?

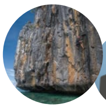
Cody March 8, 2019 at 3:43 am # REPLY

Very helpful and easy to understand. Thank you very much.

Jason Brownlee March 8, 2019 at 7:55 am # REPLY

Thanks, I'm glad it helped.





Sachin April 20, 2019 at 5:23 am # REPLY

Such nice written article! Thanks for your time!

Jason Brownlee April 20, 2019 at 7:43 am # REPLY

Thanks, I'm glad it helped.

Vaishali Bhadwaj June 11, 2019 at 7:28 pm #

Hi ,

I have 3 categorical variables in my data set:
Happiness, Income and Degree

I need to find below :

Survey was conducted among 2800 customers o
status, sex, age, age-group, race, happiness, no. c
income group etc. had been captured for that purp
there any relationship in between labour force

educational qualification is somehow controlling the marital status? c. Is happiness is driven by earnings or marital status?

Jason Brownlee June 12, 2019 at 7:55 am # REPLY

Perhaps try using the chi squared test?

BM August 18, 2019 at 3:53 am # REPLY

How to creat the cotingency table in python

Jason Brownlee August 18, 2019 at 6:49 am # REPLY

See this:
https://www.statsmodels.org/stable/contingency_tables.html

Patrick C. September 12, 2019 at 8:44 am # REPLY

You could also have a look at the pandas crosstab functions ~ https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.crosstab.html

Jason Brownlee September 12, 2019 at 1:48 pm # REPLY

Thanks for the note Patrick.

Bruno Ambrozio September 30, 2019 at 3:15 am # REPLY

Great content! Thanks!

Doubt:

If I understood well, with this chi-squared test you
ng the group categories, but if so, how to find c
Eg.: Let's say that you managed to reject the null h
significant differences?

Do we have to apply a Fisher exact test in each ca
ngency tables?

Thanks!

Jason Brownlee September 30, 2019 at 6:17 am # REPLY

What do you mean group? Do you mean the categories for a given variable?

Bruno Ambrozio September 30, 2019 at 7:58 pm # REPLY

our example you have 3 categories been tested: Science, Math and Art. Let's say your result concludes you have evidence enough to reject the null hypothesis (the variables are dependent). But, how do you know which one (or whether all of them) account for such result?

Let's consider another example, where you have 34 categories (Degrees of Freedom = 33). You also manage to reject the null hypothesis. So, how do you know which of those 34 categories were responsible for the final result (p <= alpha)?

Jason Brownlee October 1, 2019 at 6:50 am # REPLY

Yes, that is one discrete random variable that has 3 states or events.

The test comments on the random variable, not the states.

Does that help?

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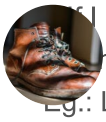

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Yogesh Naicker October 9, 2019 at 8:24 pm #

REPLY

Can I need ... please provide python code for the below 4 categorical variables???

The table shows the contingency table of marital status by education. Use Chi-Square test for testing Homogenity contingency table of marital status by education.

View the table by executing the following command python

from prettytable import PrettyTable
t = PrettyTable(['Marital Status','Middle school', 'High School','Bachelor','Masters','PhD'])
t.add_row(['Single',18,36,21,9,6])
t.add_row(['Married',12,36,45,36,21])
t.add_row(['Divorced',6,9,9,3,3])
t.add_row(['Widowed',3,9,9,6,3])
print (t)
exit()

Hypothesis

Null Hypothesis: There is no difference in distributi
marital status.

Alternate Hypothesis: There is a Difference

Coding

1.Import chi2_contingency and chi2 from scipy.stat

2.Declare a 2D array with the values mentioned in the contingency table of marital status by education.

3.Calculate and print the values of

– Chi-Square Statistic
– Degree of Freedom
– P value
– Hint: Use chi2_contingency() function

4.Assume the alpha value to be 0.05

5.Compare the P value with alpha and decide whether or not to reject the null hypothesis.

– If Rejected print "Reject the Null Hypothesis"
– Else print "Failed to reject the Null Hypothesis"

Sample output 2.33 4.5 8.9 Reject the Null Hypothesis

Jason Brownlee October 10, 2019 at 6:57 am #

REPLY

Looks like homework. Perhaps try posting to stackoverflow?

Sachin Ladhad October 17, 2019 at 1:22 pm #

REPLY

from scipy.stats import chi2_contir
from scipy.stats import chi2

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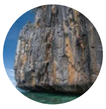
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table= [[18,31,21,9,6],[12,36,45,36,21], [6,9,9,3,3],[3,9,9,6,3]]

stat,p,dof,expected = chi2_contingency(table)

prob = 0.95

critical = chi2.ppf(prob, dof)

if abs(p) <= 0.05:

print(stat, dof ,p ,'Reject the Null Hypothesis')

else:

print(stat, dof ,p ,'Failed to reject the Null Hypothesis')

output

21.032858433297882 12 0.0499013559023993 Reject the Null Hypothesis

Help needed : Please let me know why the

Jason Brownlee October 17, 2

I have some suggestions here
https://machinelearningmastery.com/fa
work-for-me

REPLY

Mary November 29, 2019 at 7:48 am #

Your table indicates that for the “Single” road the values are 18,36,21,9,6

and for your code you have 18,*31*,21…

That 31 should be 36

```
from scipy.stats import chi2_contingency
from scipy.stats import chi2
table = [[18,36,21,9,6],[12,36,45,36,21],[6,9,9,3,3],[3,9,9,6,3]]
stat,p,dof,expected = chi2_contingency(table)
prob = 0.95
critical = chi2.ppf(prob, dof)
if abs(stat) >= 0.05:
    print(stat, dof, p, ‘Reject the Null Hypothesis’)
else:
    print(stat, dof, p, ‘Failed to reject the Null Hypothesis’)
```

Jason Brownlee November 29, 2019 at 1:40 pm #

Thanks for sharing.

REPLY

Marc Hansen October 31, 2019 at 7:12 am #

Thank you for the clear explanations.

In the text you say: “The variable is ‘sex‘ and the labels or factors of the variable are ‘male‘ and ‘female‘ in this case.”

on’ m “Th riab factor is ‘sex‘ and the labels or levels of the variable are ‘male‘ and ‘female‘ in this case.”

ref: https://stattrek.com/statistics/dictionary.aspx?definition=factor

Jason Brownlee October 31, 2019 at 7:32 am # REPLY

Yes, you’re right. Fixed, thanks.

Sandeep December 29, 2019 at 6:18 am #

Thanks Jason. Good read it is.

Jason Brownlee December 30, 2019 at 5

You’re welcome.

James Tizard February 12, 2020 at 2:23 pm # REPLY

Great tutorial, thanks!

I’m wondering how to do chi2 test where survey respondents could select multiple answers.

For example: which OS do you use? A) Windows B) Linux C)Mac

Results ey, 500 say windows, 400 say Mac and 200 say linux. Total is greater than the number of respondents.

Can I compare windows and mac by creating the following contingency table and running the test?

OS, Not OS
Mac 400, 600
Windows 500, 500

Jason Brownlee February 13, 2020 at 5:36 am # REPLY

Good question, I’m not sure off the cuff when it comes to multiple answers. It messes up the contingency table.

You might have to hit the books or ping a statistician / post on crossvalidated.

Eric Ren June 6, 2020 at 2:30 am # REPLY

Hi J n,

Very nice article, clearly explained the Chi2 test. I have one question to ask. When reading the sklearn feature selection using the Chi2 test here: https://scikit-learn.org/stable/modules/feature_selection.html, I am confused by the example, in which the Iris data is used to demo the Chi 2 test on non categorical which is not even frequency or count. Is it wrong?

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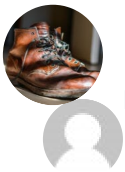
Jason Brownlee June 6, 2020 at 7:58 am # REPLY

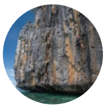
Probably.



How to Calculate Bootstrap Confidence Intervals For Machine Learning Results in Python

Saurabh Agarwal August 12, 2020 at 5:28 pm

A very clearly written article.



A Gentle Introduction to Normality Tests in Python

Statistical Significance Tests for Comparing Machine Learning Algorithms

Jason Brownlee August 13, 2020 at 6:08

Thank you!

Dhruv Modi August 20, 2020 at 8:01 pm # REPLY

Hi Jason,

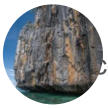
Does c independent variables of an imbalanced data having bad rate just 1%?

Jason Brownlee August 21, 2020 at 6:27 am # REPLY

The test requires at least 20 examples in each cell of the contingency table I believe.

Hridaya Saboo June 11, 2021 at 4:04 pm # REPLY

Thank you. It is a really important and very practical question. Can you please provide more insights into this?



Jason Brownlee June 12, 2021 at 5:23 am #

REPLY

n't any more insight to give, perhaps check some of the references in the further reading section.

Fidan September 23, 2020 at 10:26 am #

REPLY

Hi Jason.

t article. I have one question. If we done the chi-square test on a sample dataset and the result een two categorical variables are dependent.

population?

Jason Brownlee September 23, 2020 at

Yes and No. It is a statistical estimate.

confidence.

Kenny October 20, 2020 at 11:14 pm #

REPLY

Thanks Jason for the Good and informative article.
Sometimes I get mixed up between chi-square Goodness of fit and chi-square Tests of Independence.
Can we use the terms interchangeably or are they different to each other?

ober 21, 2020 at 6:40 am #

REPLY

Same thing I believe, different use case.

Kenny October 22, 2020 at 8:43 pm #

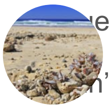
REPLY

Thanks Jason for the clarification.
In scipy there are 2 different function for chi-square-
1)scipy.stats.chisquare
2)scipy.stats.chi2_contingency
Do you mind telling which one to use for which use-case, please?

Jason Brownlee October 23, 2020 at 6:09 am #

REPLY

Perhaps check the API docun



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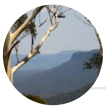

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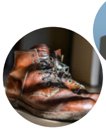

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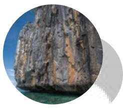

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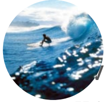

Statistical Significance Tests for Comparing Machine Learning Algorithms

Cu sly din xah November 5, 2020 at 7:31 am #

REPLY

Hey JB,

Have you ever explored the reason why sklearn's chi2 gives different values for the test statistic and p-
e compared to performing the test by hand or using chi2_contingence from scipy?

n't seem to find a satisfactory answer, and I'm hoping the good doctor (you) might have some insight.

Cheers

Jason Brownlee November 5, 2020 at 7:

I have not.

Hamed November 19, 2020 at 9:57 pm #

Hey,

very new in this area.
ve x_1 and x_2 and y. How can I see the dependence of y to x_1 and x_2?
x=[[1,0],[1,0],[0,1],[1,1],[1,0],[1,0],[1,0],[1,1],[0,1],[0,1]]
y=[0,0,1,1,0,0,0,1,1,1]

Jason Brownlee November 20, 2020 at 6:45 am #

REPLY

e tutorial to calculate the dependence?

Rara July 10, 2021 at 3:01 am #

REPLY

Hi! I'm new to data science. Would like to understand like how do you decide which test to use if chi-square or one-sample t-test, independent sample t-test, paired sample t test in A/B testing?

Jason Brownlee July 10, 2021 at 6:12 am #

REPLY

Good question, see this:
https://machinelearningmastery.com/statistical-hypothesis-tests-in-python-cheat-sheet/

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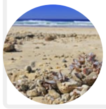
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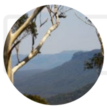
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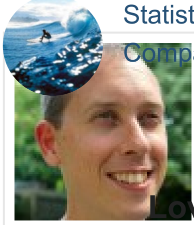
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and I **help developers** get results with **machine learning**.
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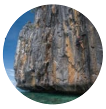
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