Data Exploration

Machine Learning for Behavioral Data

February 25, 2025

Today's Topic

Week	Lecture/Lab
1	Introduction
2	**Data Exploration**
3	Regression
4	Classification
5	Model Evaluation
6	Time Series Prediction
7	Time Series Prediction
8	Time Series Prediction

Complete pipeline for one use case:

- **Data exploration**
- **Prediction**
- **Model evaluation**

Getting ready for today's lecture…

- **If not done yet**: clone the repository containing the Jupyter notebook and data for today's lecture into your Noto workspace..
- SpeakUp room for today's lecture:

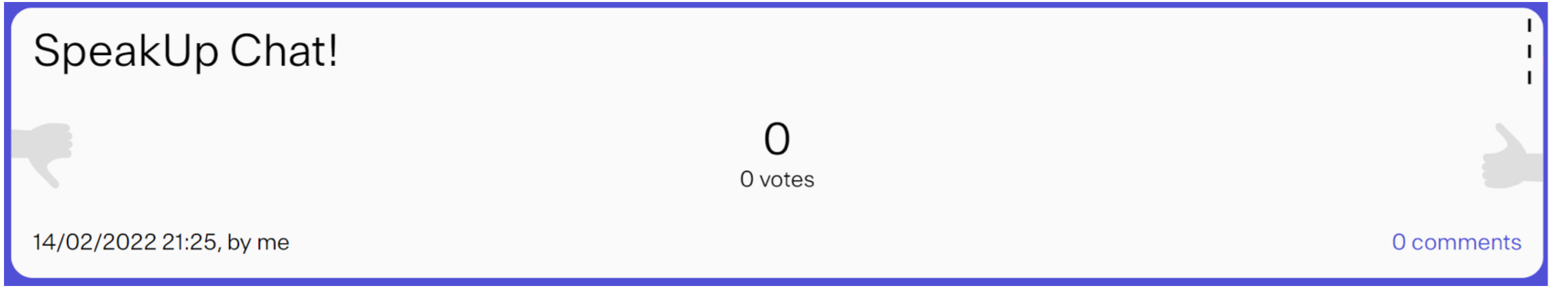
https://go.epfl.ch/speakup-mlbd2025

Noto: Student notebook

- Go to https://noto.epfl.ch/
- Login with your GASPAR
- Go to Git → Clone
- Clone the course repository: https://github.com/epfl-ml4ed/mlbd-2025

Why is data handling important?

- Why do we not just use the *raw data*?



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0 comments

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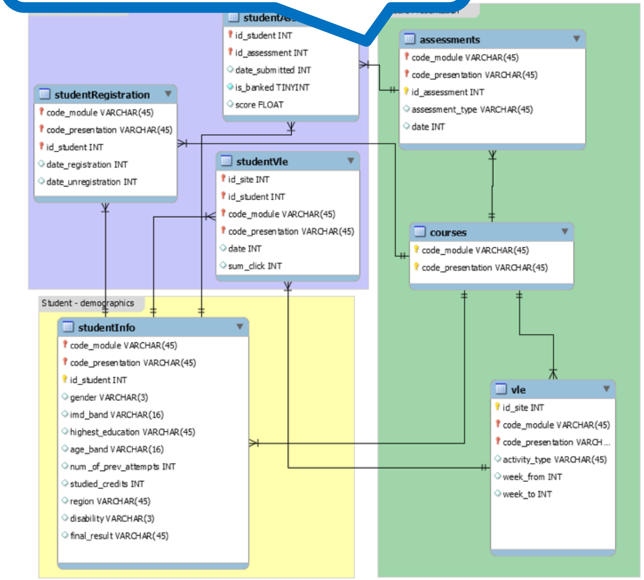
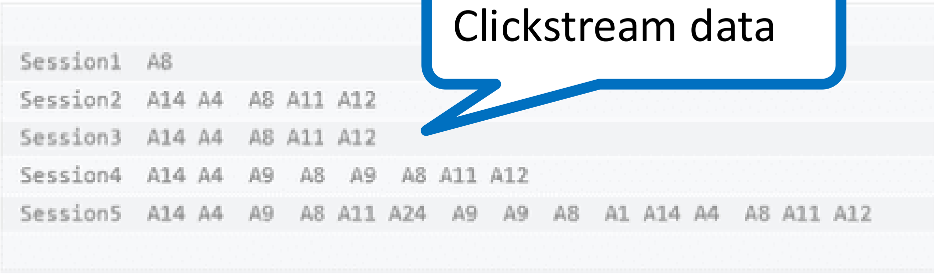
Different types of input data

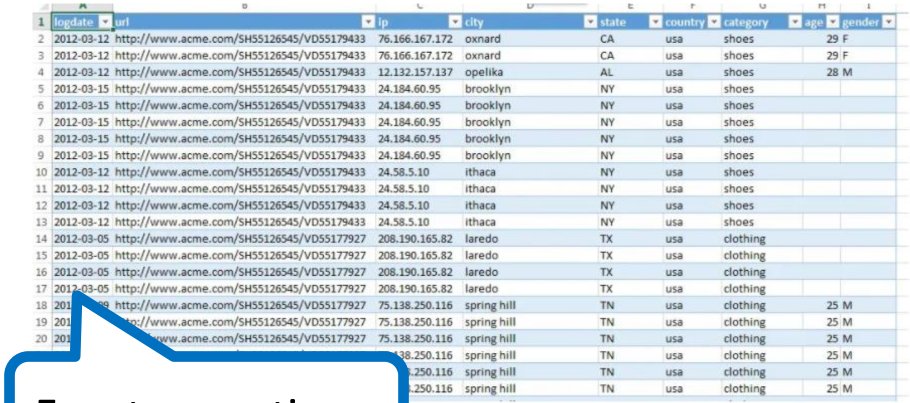
Relational databases



Clickstream data



```
Session1  A8
Session2  A14  A4   A8  A11  A12
Session3  A14  A4   A8  A11  A12
Session4  A14  A4   A9   A8   A9   A8  A11  A12
Session5  A14  A4   A9   A8  A11  A24   A9   A9   A8   A1  A14  A4   A8  A11  A12
```



	logdate	url	ip	city	state	country	category	age	gender
2	2012-03-12	http://www.acme.com/SH55126545/VD55179433	76.166.167.172	oxnard	CA	usa	shoes	29	F
3	2012-03-12	http://www.acme.com/SH55126545/VD55179433	76.166.167.172	oxnard	CA	usa	shoes	29	F
4	2012-03-12	http://www.acme.com/SH55126545/VD55179433	12.132.157.137	opelika	AL	usa	shoes	28	M
5	2012-03-15	http://www.acme.com/SH55126545/VD55179433	24.184.60.95	brooklyn	NY	usa	shoes		
6	2012-03-15	http://www.acme.com/SH55126545/VD55179433	24.184.60.95	brooklyn	NY	usa	shoes		
7	2012-03-15	http://www.acme.com/SH55126545/VD55179433	24.184.60.95	brooklyn	NY	usa	shoes		
8	2012-03-15	http://www.acme.com/SH55126545/VD55179433	24.184.60.95	brooklyn	NY	usa	shoes		
9	2012-03-15	http://www.acme.com/SH55126545/VD55179433	24.184.60.95	brooklyn	NY	usa	shoes		
10	2012-03-12	http://www.acme.com/SH55126545/VD55179433	24.58.5.10	ithaca	NY	usa	shoes		
11	2012-03-12	http://www.acme.com/SH55126545/VD55179433	24.58.5.10	ithaca	NY	usa	shoes		
12	2012-03-12	http://www.acme.com/SH55126545/VD55179433	24.58.5.10	ithaca	NY	usa	shoes		
13	2012-03-12	http://www.acme.com/SH55126545/VD55179433	24.58.5.10	ithaca	NY	usa	shoes		
14	2012-03-05	http://www.acme.com/SH55126545/VD55177927	208.190.165.82	laredo	TX	usa	clothing		
15	2012-03-05	http://www.acme.com/SH55126545/VD55177927	208.190.165.82	laredo	TX	usa	clothing		
16	2012-03-05	http://www.acme.com/SH55126545/VD55177927	208.190.165.82	laredo	TX	usa	clothing		
17	2012-03-05	http://www.acme.com/SH55126545/VD55177927	208.190.165.82	laredo	TX	usa	clothing		
18	201	http://www.acme.com/SH55126545/VD55177927	75.138.250.116	spring hill	TN	usa	clothing	25	M
19	201	p://www.acme.com/SH55126545/VD55177927	75.138.250.116	spring hill	TN	usa	clothing	25	M
20	201	www.acme.com/SH55126545/VD55177927	75.138.250.116	spring hill	TN	usa	clothing	25	M
			38.250.116	spring hill	TN	usa	clothing	25	M
			.250.116	spring hill	TN	usa	clothing	25	M
			.250.116	spring hill	TN	usa	clothing	25	M

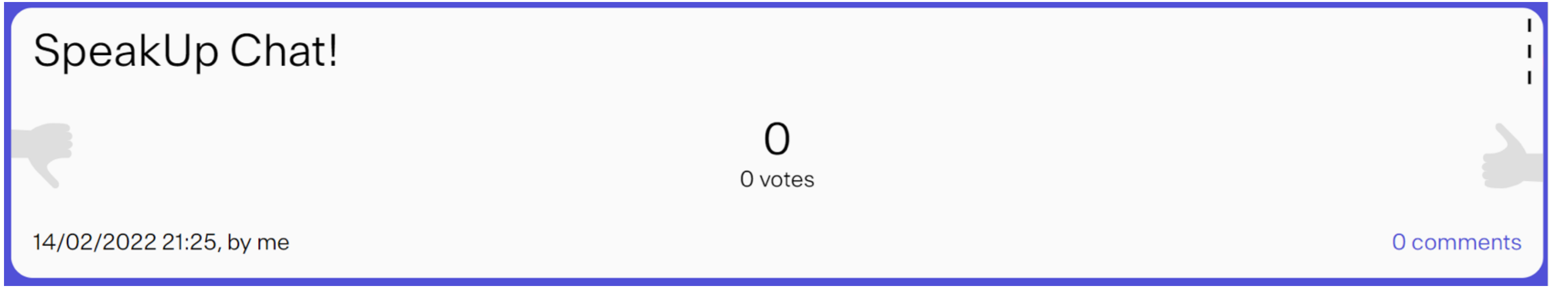
Events over time

Data Problems

- Incorrect data
- Duplicates
- Inconsistent data
- Missing data
- Outliers

Why is data handling important?

- What is the purpose of *data exploration*?



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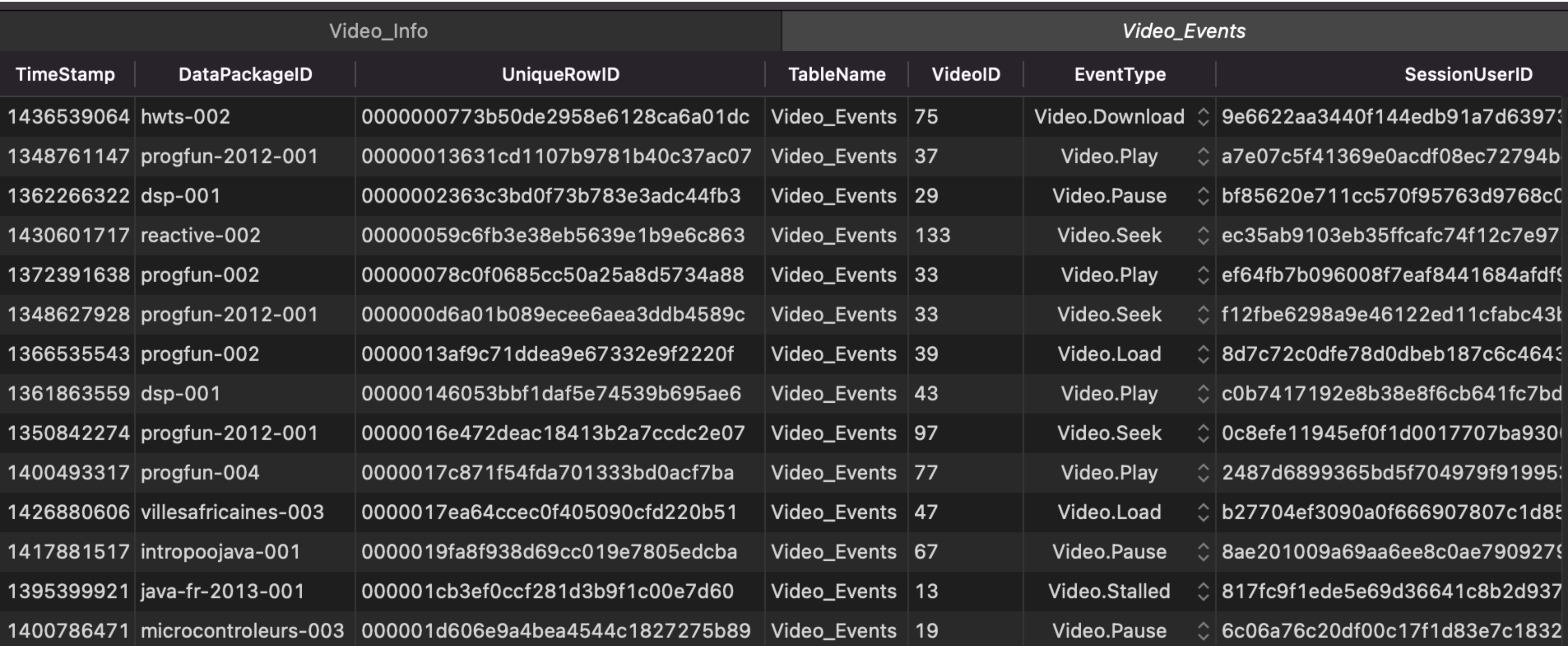
Today: Data Exploration

- **Univariate Analysis**
- Multivariate Analysis
- Time Series

Today’s Use Case: Flipped Classroom Course

- Participants: 157 EPFL students of a course taught in *flipped classroom* mode with a duration of 10 weeks
- Structure:
  - Preparation: watch videos (and solve simple quizzes) on **new content** at home as a preparation for the lecture
  - Lecture: discuss open questions and solve more complex tasks
  - Lab session: solve paper-and-pen assignments
- Data: clickstream data (all interactions of the student with the system)

Today's Use Case: The Data



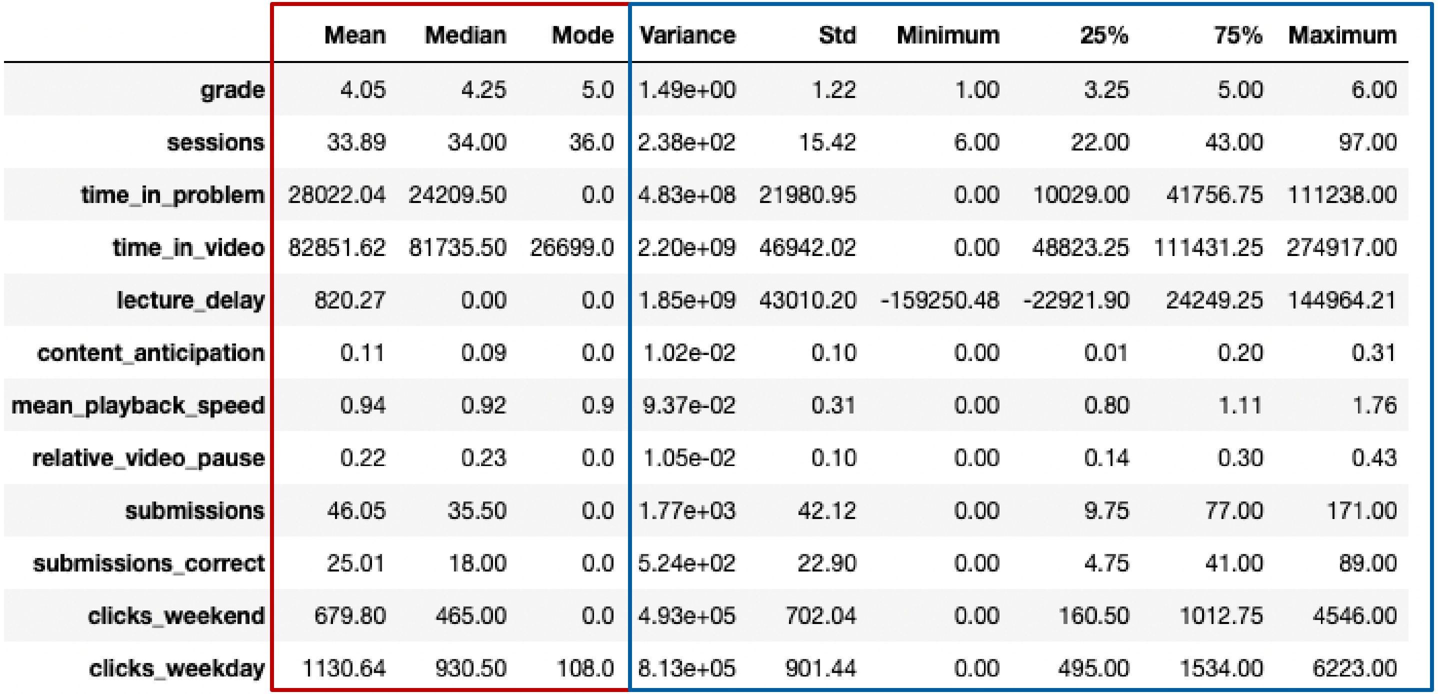
TimeStamp	DataPackageID	UniqueRowID	TableName	VideoID	EventType	SessionUserID
1436539064	hwts-002	0000000773b50de2958e6128ca6a01dc	Video_Events	75	Video.Download	9e6622aa3440f144edb91a7d63973
1348761147	progfun-2012-001	00000013631cd1107b9781b40c37ac07	Video_Events	37	Video.Play	a7e07c5f41369e0acdf08ec72794b
1362266322	dsp-001	0000002363c3bd0f73b783e3adc44fb3	Video_Events	29	Video.Pause	bf85620e711cc570f95763d9768c0
1430601717	reactive-002	00000059c6fb3e38eb5639e1b9e6c863	Video_Events	133	Video.Seek	ec35ab9103eb35ffcafc74f12c7e97
1372391638	progfun-002	00000078c0f0685cc50a25a8d5734a88	Video_Events	33	Video.Play	ef64fb7b096008f7eaf8441684afdf
1348627928	progfun-2012-001	000000d6a01b089ecee6aea3ddb4589c	Video_Events	33	Video.Seek	f12fbe6298a9e46122ed11cfabc43
1366535543	progfun-002	0000013af9c71ddea9e67332e9f2220f	Video_Events	39	Video.Load	8d7c72c0dfe78d0dbeb187c6c4643
1361863559	dsp-001	00000146053bbf1daf5e74539b695ae6	Video_Events	43	Video.Play	c0b7417192e8b38e8f6cb641fc7bd
1350842274	progfun-2012-001	0000016e472deac18413b2a7ccdc2e07	Video_Events	97	Video.Seek	0c8efe11945ef0f1d0017707ba930
1400493317	progfun-004	0000017c871f54fda701333bd0acf7ba	Video_Events	77	Video.Play	2487d6899365bd5f704979f91995
1426880606	villesafricaines-003	0000017ea64ccec0f405090cfd220b51	Video_Events	47	Video.Load	b27704ef3090a0f666907807c1d85
1417881517	intropoojava-001	0000019fa8f938d69cc019e7805edcba	Video_Events	67	Video.Pause	8ae201009a69aa6ee8c0ae790927
1395399921	java-fr-2013-001	000001cb3ef0ccf281d3b9f1c00e7d60	Video_Events	13	Video.Stalled	817fc9f1ede5e69d36641c8b2d937
1400786471	microcontroleurs-003	000001d606e9a4bea4544c1827275b89	Video_Events	19	Video.Pause	6c06a76c20df00c17f1d83e7c1832

Characteristics of a Variable/Feature

ID	Grade	Gender	Category	# Sessions	Time in videos	Time in problems	# clicks on weekdays	# clicks on weekends	Content alignment	Mean pause duration	Mean playback speed	# problem sub-missions	# correct sub-missions
1	4.5	M	Suisse. Autres	57	9227	1698	179	4	0.75	50	1.1	9	5.9
2	5.25	M	Suisse. Autres	41	10801	2340	129	95	0.35	231	0.8	6.1	3
3	4.5	F	Suisse. PAM	33	8185	2737	46	14	0.37	92	0.5	4.6	3.2
4	4.75	F	France	47	7040	3787		58	0.03	62	0.85	0.3	0.1

- Center of the data?
- Spread of the data?
- Shape/distribution of the data?

Descriptive Statistics



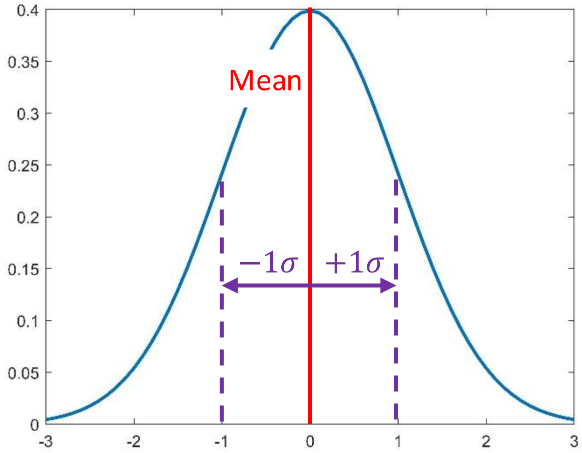
	Mean	Median	Mode	Variance	Std	Minimum	25%	75%	Maximum
grade	4.05	4.25	5.0	1.49e+00	1.22	1.00	3.25	5.00	6.00
sessions	33.89	34.00	36.0	2.38e+02	15.42	6.00	22.00	43.00	97.00
time_in_problem	28022.04	24209.50	0.0	4.83e+08	21980.95	0.00	10029.00	41756.75	111238.00
time_in_video	82851.62	81735.50	26699.0	2.20e+09	46942.02	0.00	48823.25	111431.25	274917.00
lecture_delay	820.27	0.00	0.0	1.85e+09	43010.20	-159250.48	-22921.90	24249.25	144964.21
content_anticipation	0.11	0.09	0.0	1.02e-02	0.10	0.00	0.01	0.20	0.31
mean_playback_speed	0.94	0.92	0.9	9.37e-02	0.31	0.00	0.80	1.11	1.76
relative_video_pause	0.22	0.23	0.0	1.05e-02	0.10	0.00	0.14	0.30	0.43
submissions	46.05	35.50	0.0	1.77e+03	42.12	0.00	9.75	77.00	171.00
submissions_correct	25.01	18.00	0.0	5.24e+02	22.90	0.00	4.75	41.00	89.00
clicks_weekend	679.80	465.00	0.0	4.93e+05	702.04	0.00	160.50	1012.75	4546.00
clicks_weekday	1130.64	930.50	108.0	8.13e+05	901.44	0.00	495.00	1534.00	6223.00

Center of the data

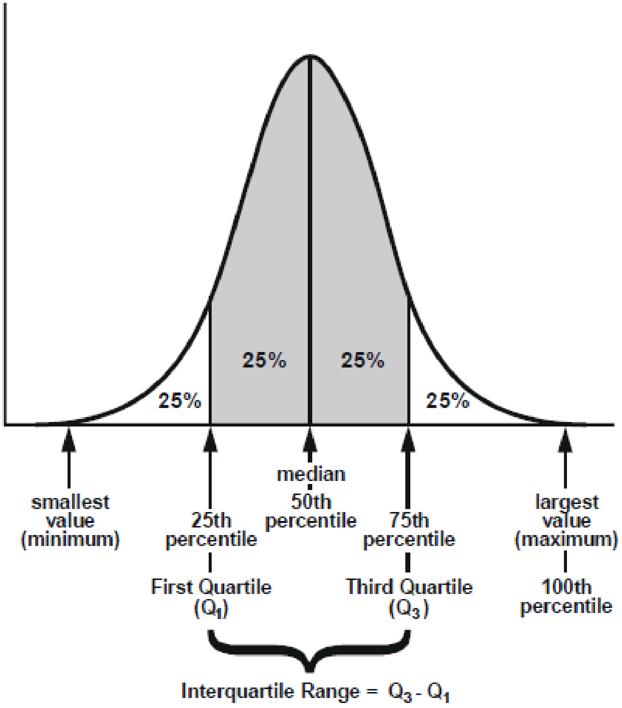
Spread of the data

Example: Normal Distribution

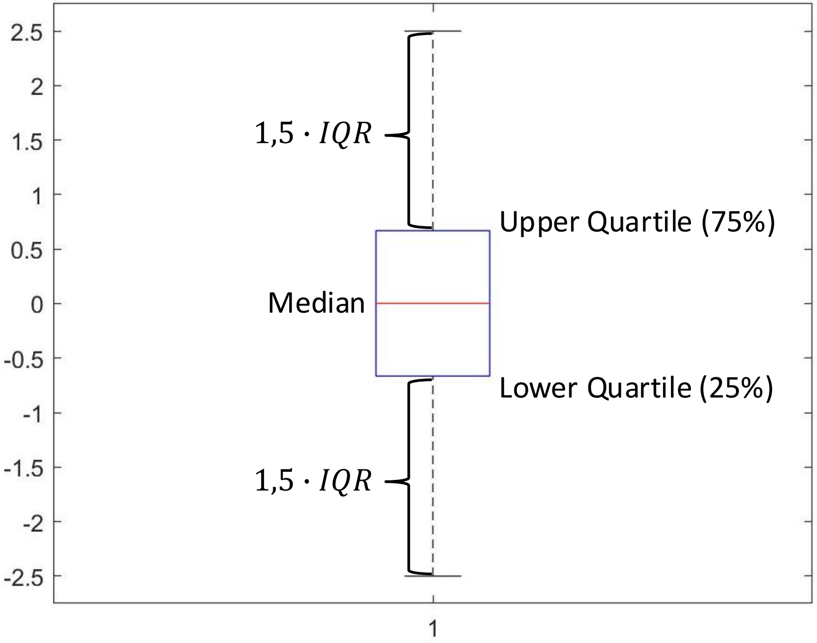
- Sample mean: $\mu_{\bar{x}} = \frac{1}{n}\sum_{i=1}^{n} x_i$
- Sample variance: $\sigma_{\bar{x}}{}^2 = \frac{1}{n}\sum_{i=1}^{n} (x_i - \mu_{\bar{x}})^2$
- Mode: most frequent value in data set
- Median: separates the lower and upper half of the data (1, 2, 2, **3**, 4, 7, 9)



Example: Normal Distribution

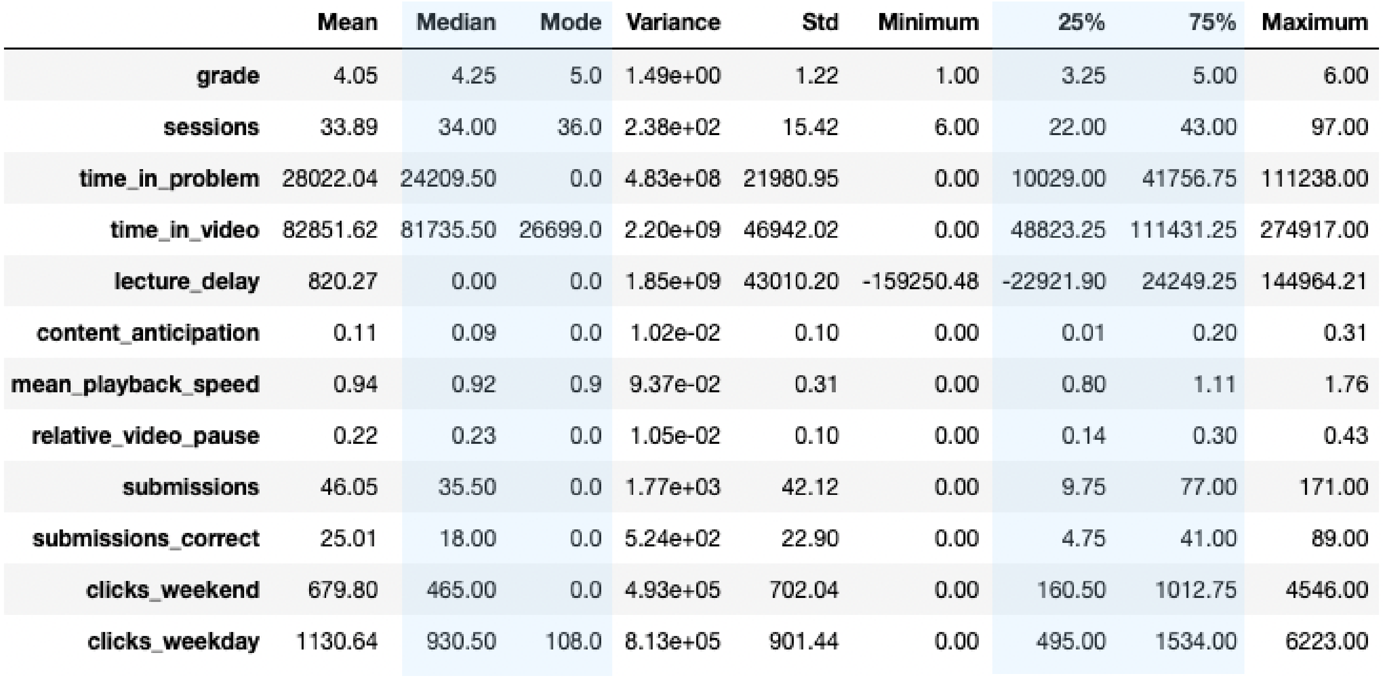


Boxplot



2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
1
$1{,}5 \cdot IQR$
Upper Quartile (75%)
Median
Lower Quartile (25%)
$1{,}5 \cdot IQR$

Descriptive Statistics



	Mean	Median	Mode	Variance	Std	Minimum	25%	75%	Maximum
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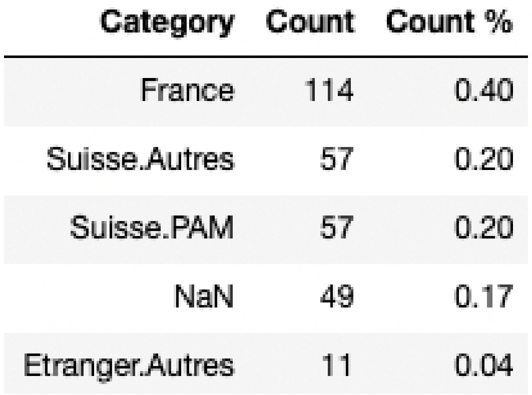
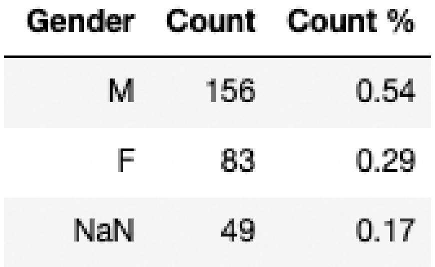
Variable Types

- Categorical
- Ordinal
- Numerical

Categorical Variables

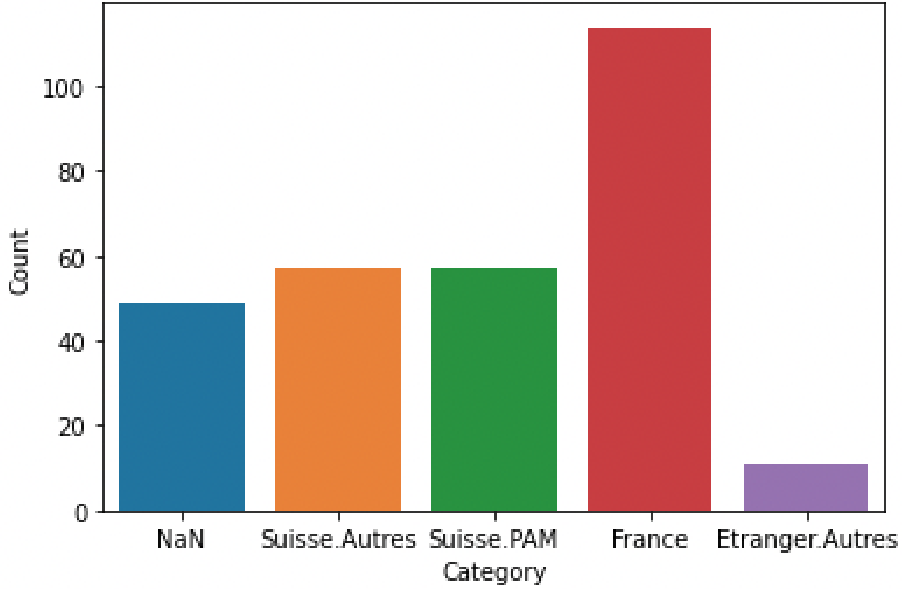


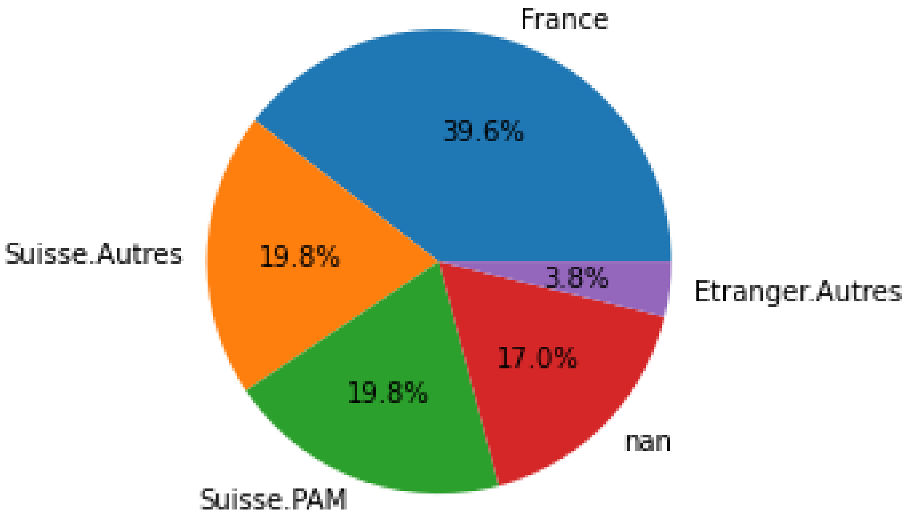
Category	Count	Count %
France	114	0.40
Suisse.Autres	57	0.20
Suisse.PAM	57	0.20
NaN	49	0.17
Etranger.Autres	11	0.04



Gender	Count	Count %
M	156	0.54
F	83	0.29
NaN	49	0.17

Number of students per category





https://seaborn.pydata.org/tutorial/categorical.html

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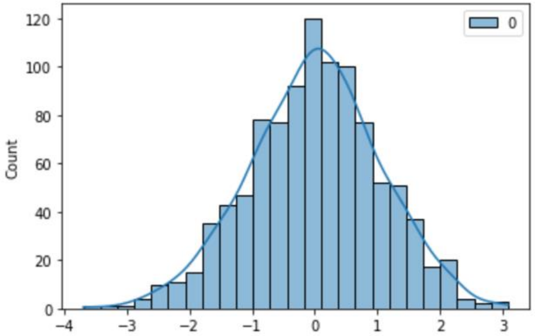
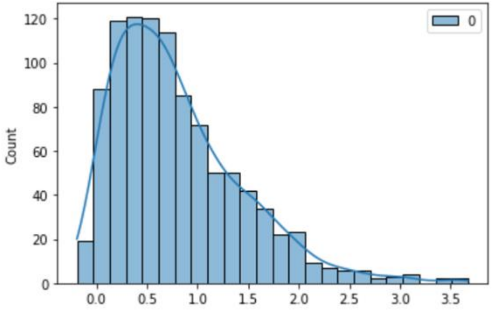
- Center of the data?
- Spread of the data?
- Shape/distribution of the data?

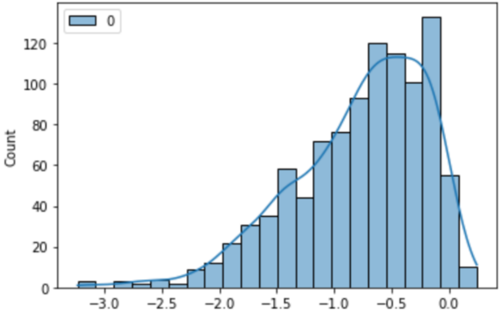
Does my data follow a normal distribution?



symmetric



right skewed



left skewed

Normal test p = 0.39

Normal test p = 8.7e-43

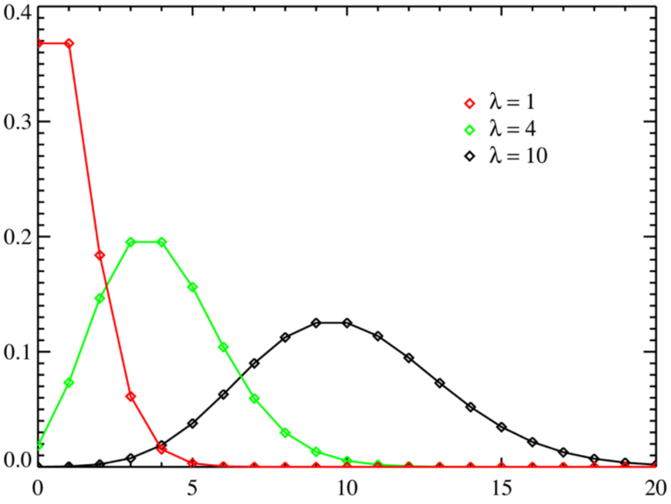
Normal test p = 6.0e-26

Important Distributions

- **Normal distribution :** *(continuous)* see previous slides
- **Poisson distribution:** *(discrete)* expresses the probability of a given number of events occurring in a fixed interval of time or space
- **Exponential distribution** *(continuous)* distribution of times between events in a Poisson process
- **Binomial distribution**: *(discrete)* models the number of successes in a sequence of independent experiments
- **Bernoulli distribution**: *(discrete)* special case of binomial distribution (n=1)

Important Distributions | Poisson

Models the number of events occurring within a given time interval.



Properties:

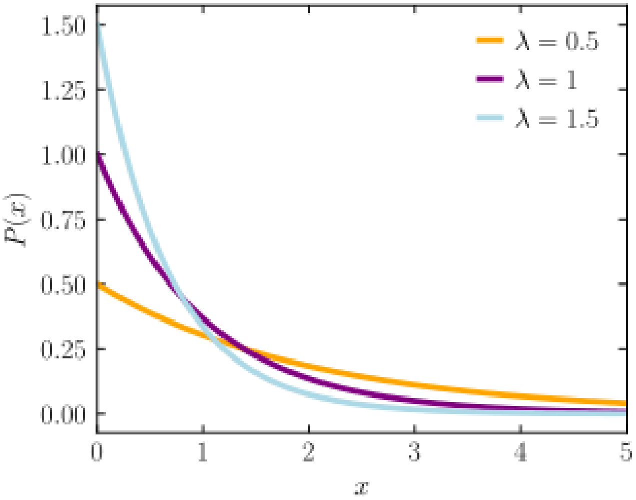
- Discrete (not continuous)
- Greater or equal to zero.

Examples:

- Number of calls a call center receives per minute
- Number of students that join the zoom meeting per minute during the first 15 minutes of the class

Important Distributions | Exponential

Probability distribution of time between events of a **Poisson** process.



Properties:

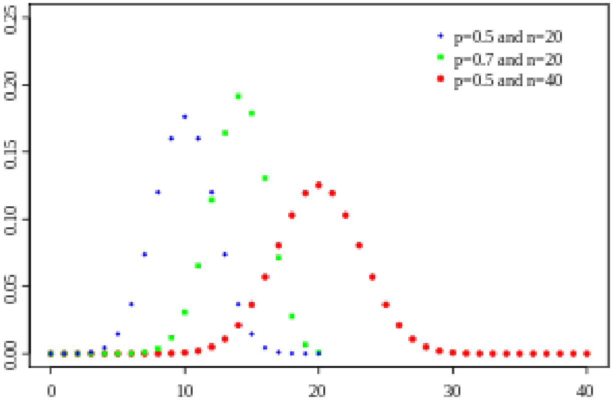
- Continuous
- Greater or equal to zero.

Examples:

- The time before the next telephone call in a call center.
- The time before the next student joins the zoom call.

Important Distributions | Binomial

Models the number of successes in a sequence of independent experiments.



Properties:

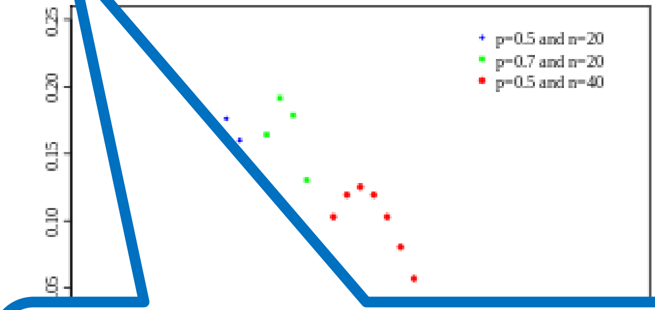
- Discrete (not continuous)
- Greater or equal to zero.

Examples:

- Number of passed tests in a course with 20 tests.
- Number of customers that redeemed a coupon.

Important Distributions | Binomial

Models the number of successes in a sequence of independent experiments.



Bernoulli is a special case of the Binomial distribution with one experiment: n = 1

Properties:

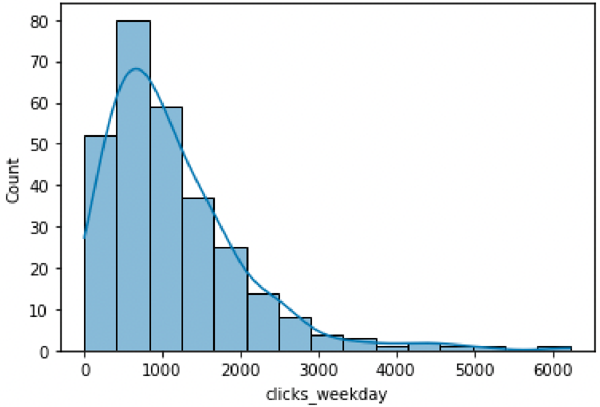
- Discrete (not continuous)
- Greater or equal to zero.

Examples:

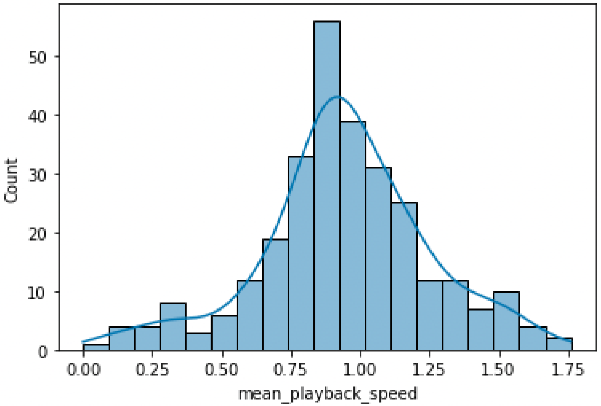
- Number of passed tests in a course with 20 tests.
- Number of customers that redeemed a coupon.

Visual Inspection

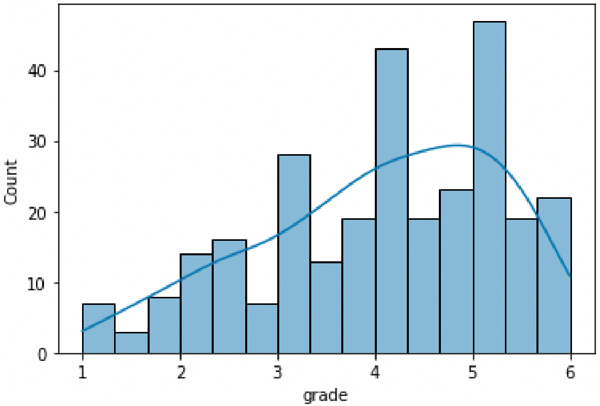
```
p = 6.20579e-29
The null hypothesis can be rejected
```



```
p = 0.0216998
The null hypothesis cannot be rejected
```



```
p = 5.78191e-05
The null hypothesis can be rejected
```

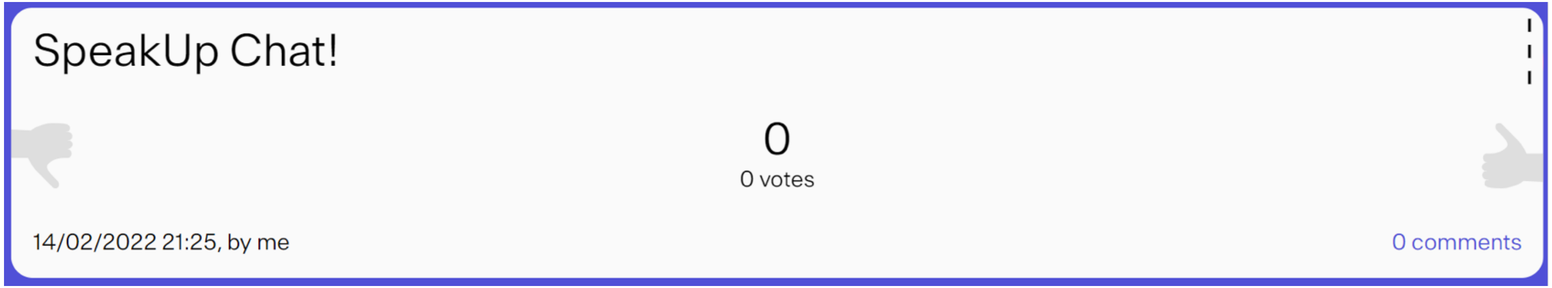


Data Exploration

- Univariate Analysis
- **Multivariate Analysis**
- Time Series

Multivariate Analysis

How can we explore the relationship between two variables?



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0 votes

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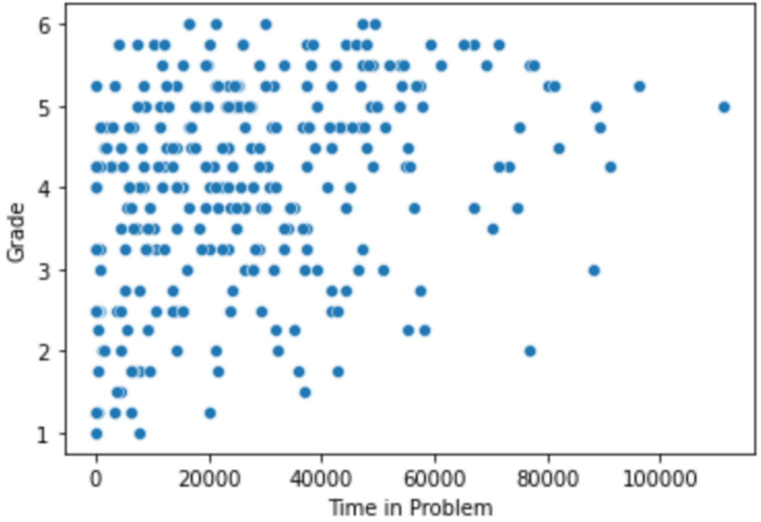
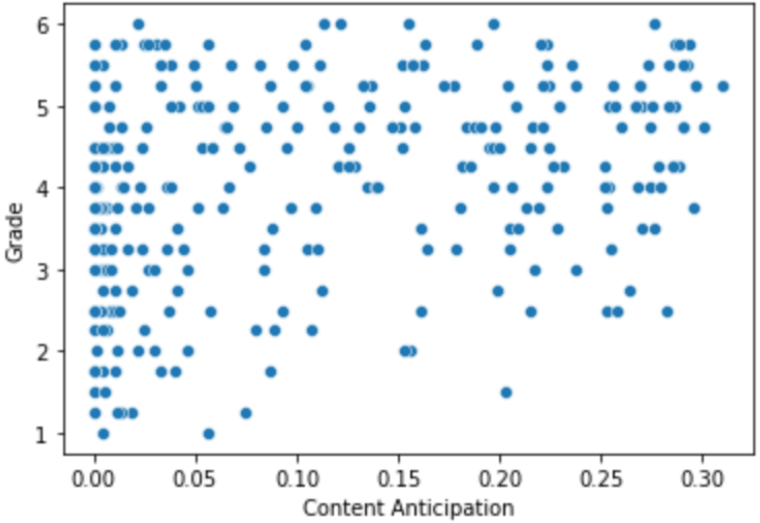
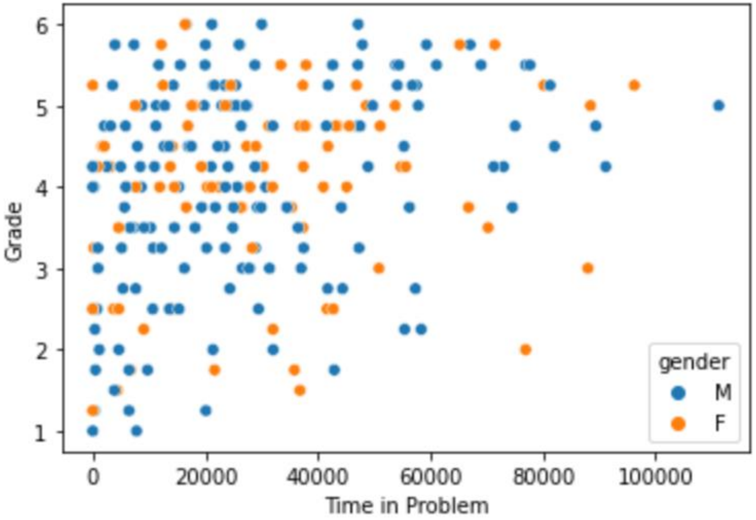
https://go.epfl.ch/speakup-mlbd2025

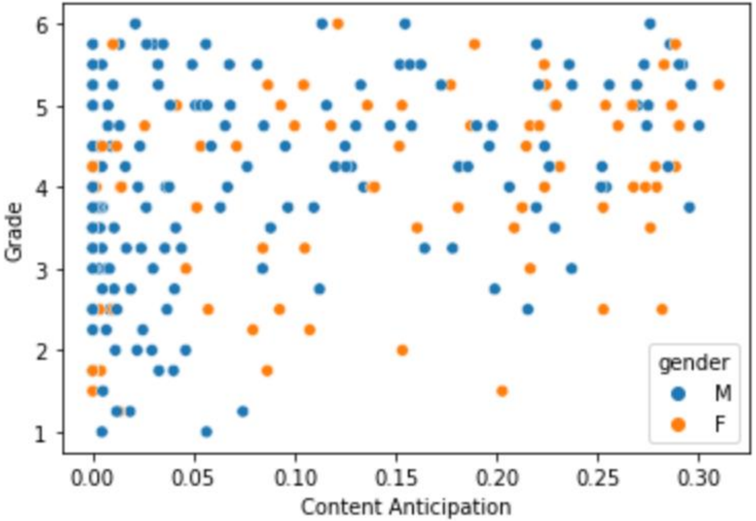
Relation between numerical variables



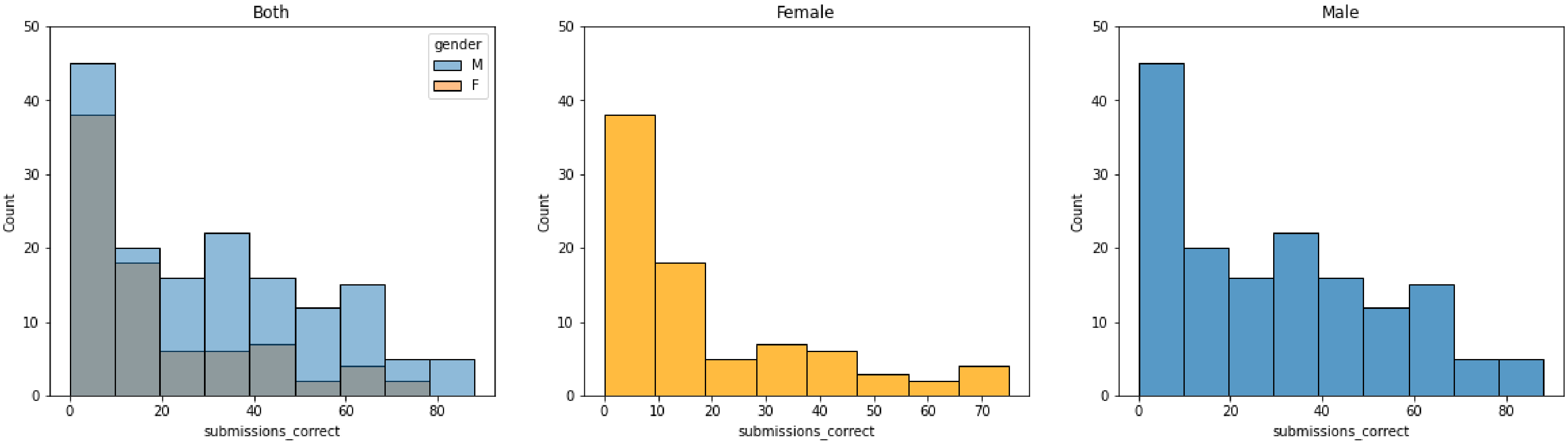


Relation between numerical & categorical variables

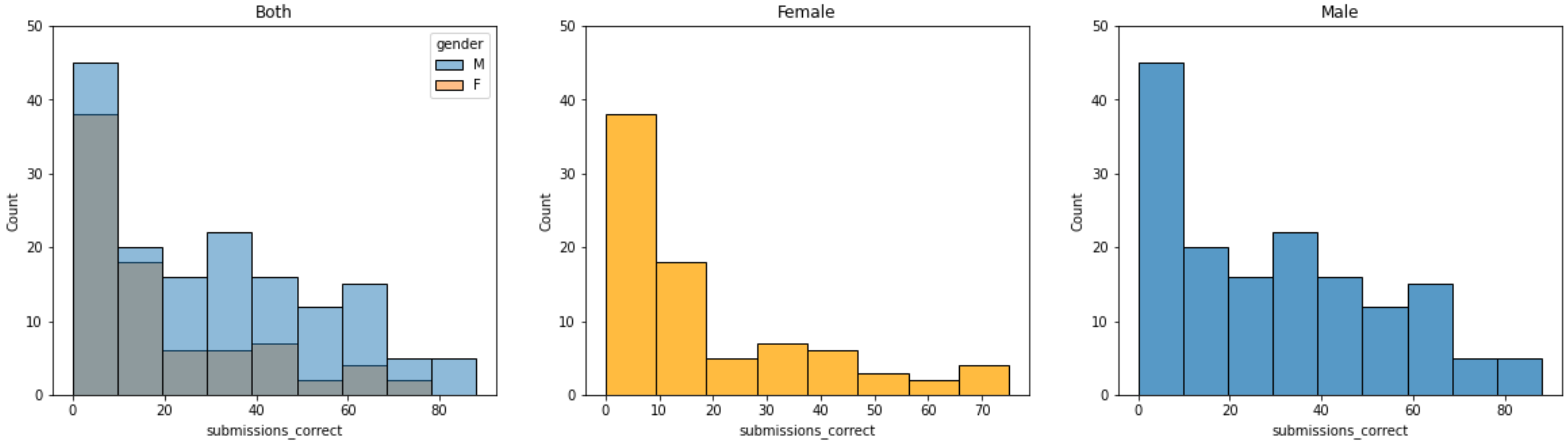




Submissions Correct by Gender



Who is more likely to have correct submissions?



a) Students identifying as male are more likely to have a correct submission.

b) Students identifying as female are more likely to have a correct submission.

c) I cannot answer based on the visualization.

SpeakUp Poll!

0

0 votes

14/02/2022 21:26, by me

0 comments

https://go.epfl.ch/speakup-mlbd2025

Pearson's Correlation

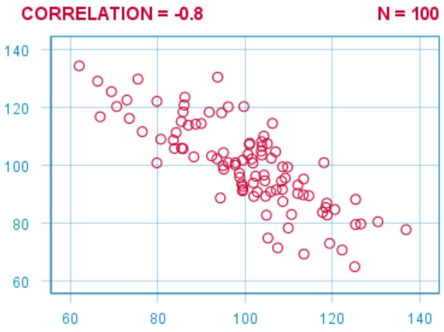
Linear correlation between two sets of data.

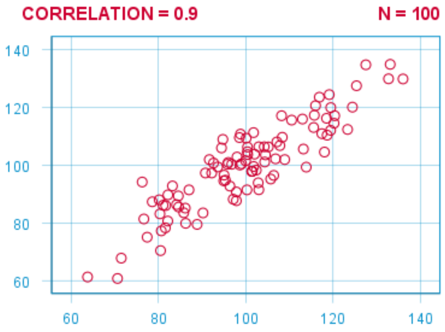
$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$$

Where $cov(X,Y)$ is the covariance

σ_X is the standard deviation on X

σ_Y is the standard deviation on Y





Pearson’s Correlation

Linear correlation between two sets of data.

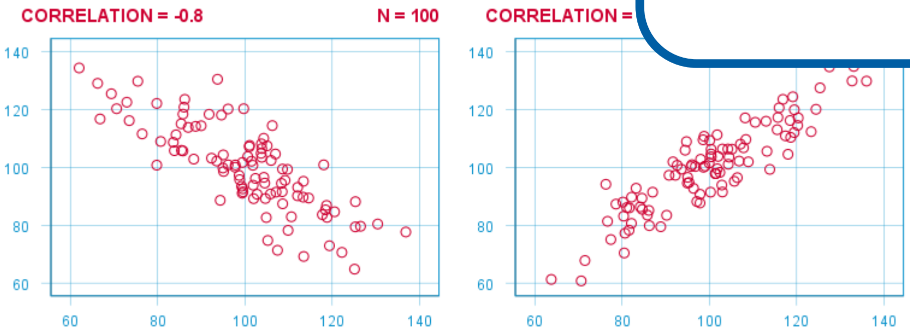
$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$$

Where cov

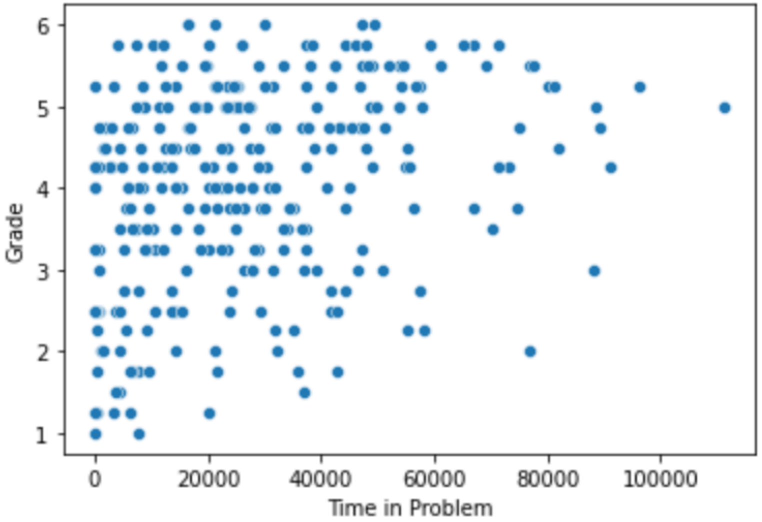
σ_X is the st

σ_Y is the st

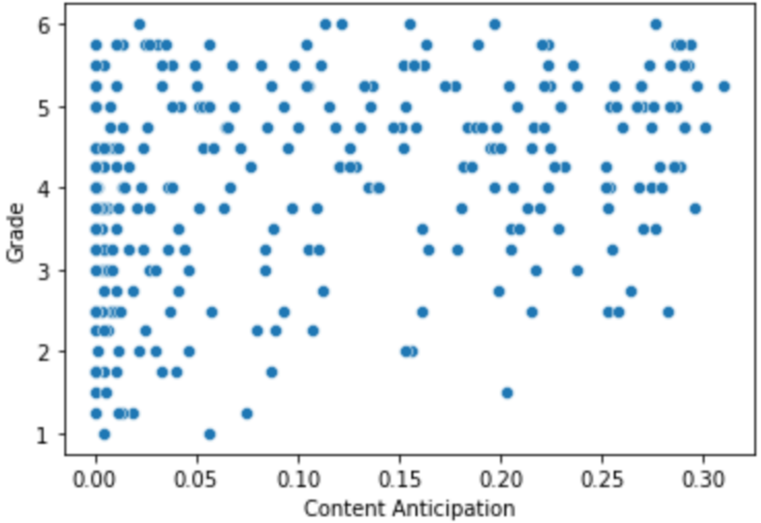
X and Y need to be numerical or at least ordinal variables



Correlation between variables



$\rho = 0.31\ (p = 6.8e - 8)$



$\rho = 0.32\ (p = 1.5e - 08)$

Pearson’s Correlation

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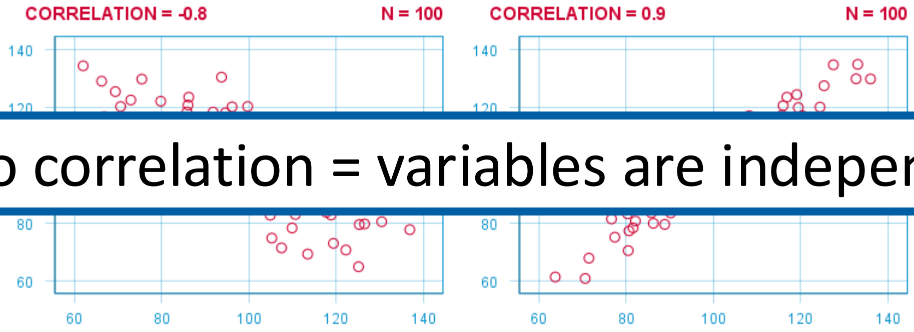


No correlation = variables are independent?

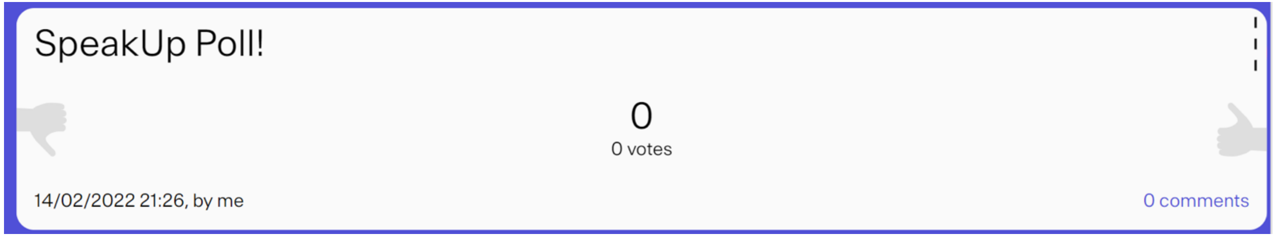
Pearson’s Correlation

Linear correlation between two sets of data.

No correlation = variables are independent?

a) Yes

b) No



SpeakUp Poll!

0

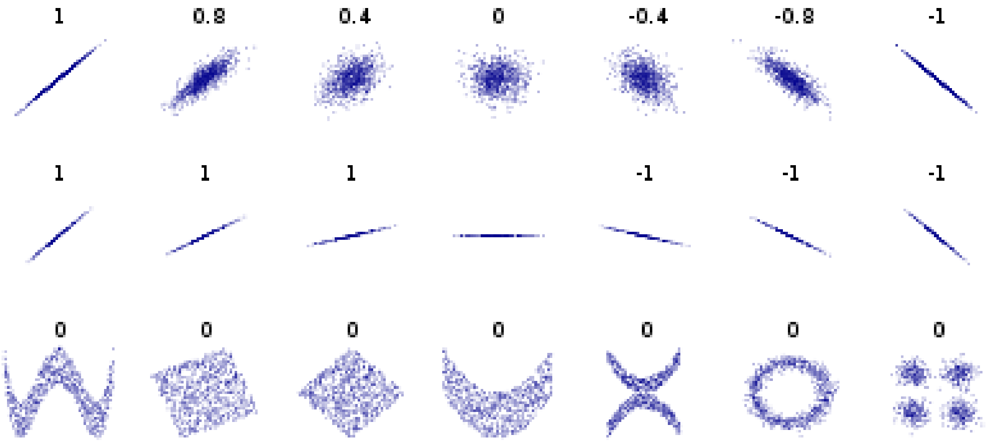
0 votes

14/02/2022 21:26, by me

0 comments

https://go.epfl.ch/speakup-mlbd2025

Pearson’s Correlation



$$X, Y \text{ independent } \rightarrow \ \rho_{X,Y} = 0$$

$$\rho_{X,Y} = 0 \ \nrightarrow X, Y \text{ independent}$$

Image Source: https://en.wikipedia.org/wiki/Pearson_correlation_coefficient

Mutual Information

- Dependence between two random variables: “Amount of information” obtained about one random variable through observing the other random variable

$$I(X;Y) = D_{KL}(P_{(X,Y)}||P_X \otimes P_Y)$$

where X and Y are random variables, $P_{(X,Y)}$ is their joint distribution, P_X and P_Y are the marginal distributions, and D_{KL} is the Kullback-Leibler divergence.

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- For discrete distributions

$$I(X;Y) = \sum_{x \in \mathrm{X}} \sum_{y \in \Upsilon} p(x,y) \cdot \log(\frac{p(x,y)}{p(x) \cdot p(y)})$$

Mutual Information - Motivation

- For discrete distributions

$$I(X;Y) = \sum_{x \in \mathrm{X}} \sum_{y \in \Upsilon} p(x,y) \cdot \log(\frac{p(x,y)}{p(x) \cdot p(y)})$$

- If X and Y are *independent,* then $p(x,y) = p(x) \cdot p(y)$ and therefore:

$$\log\left(\frac{p(x,y)}{p(x) \cdot p(y)}\right) = \log(1) = 0$$

Pearson Correlation vs Mutual Information

Pearson’s Correlation Coefficient

Mutual Information

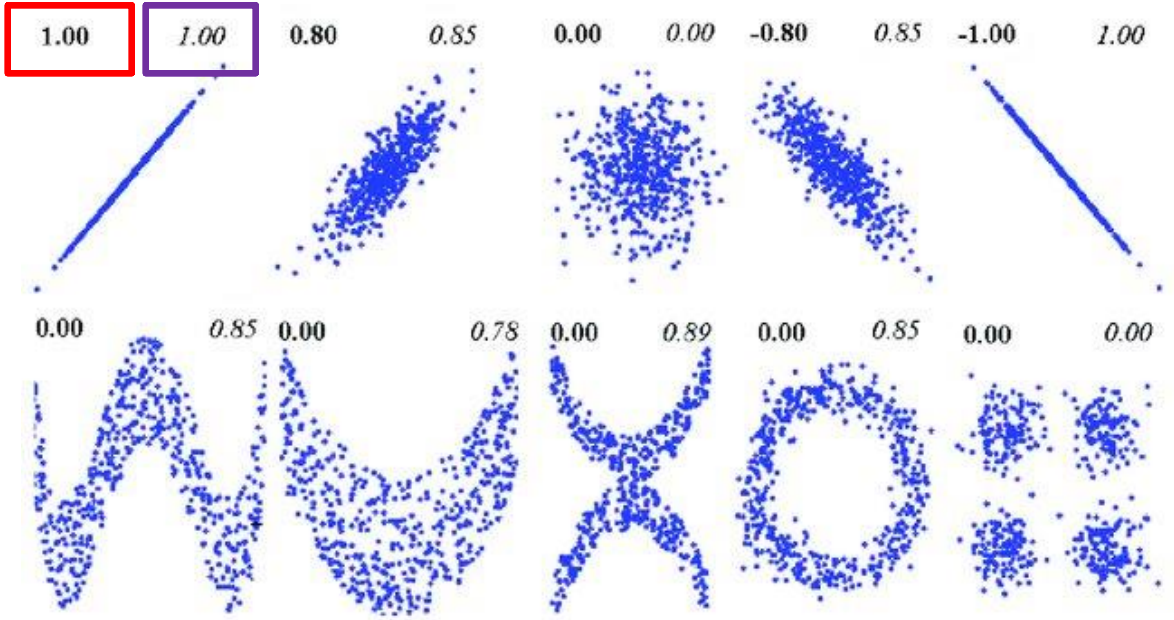
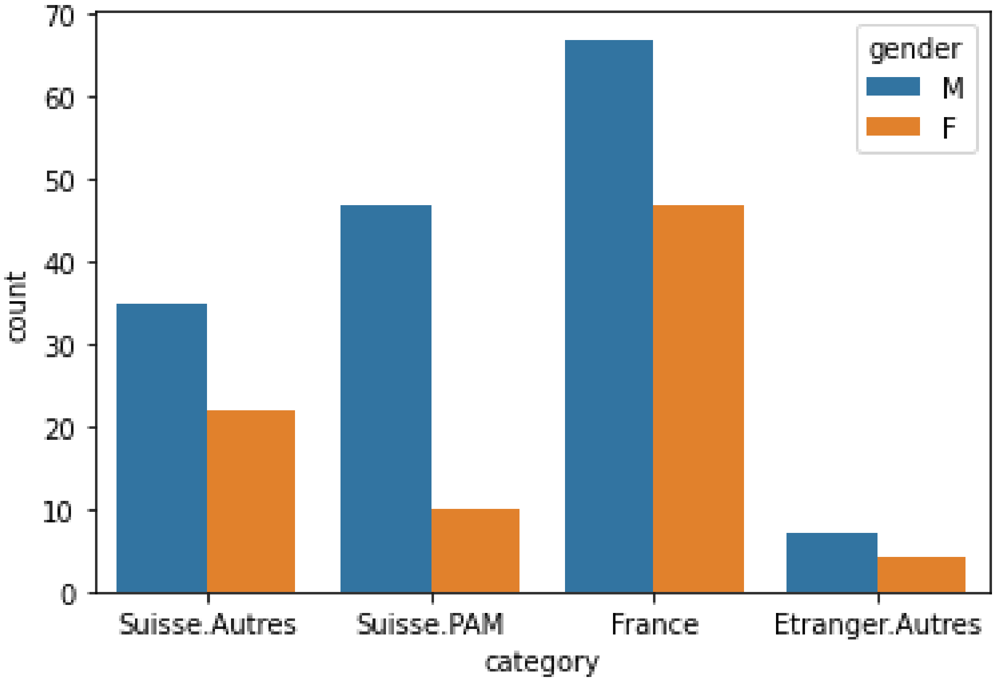


Image Source: https://www.researchgate.net/publication/322349267_Information_Entropy_Suggests_Stronger_Nonlinear_Associations_between_Hydro-Meteorological_Variables_and_ENSO

Mutual Information – Discrete



Mutual Information - Discrete

$P(X,Y)$

Y: Category

X: Gender

	France	Suisse.PAM	Suisse. Autres	Etranger.Autres
Male	0.28	0.20	0.15	0.02
Female	0.20	0.04	0.09	0.02

Mutual Information - Discrete

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$P(Y)$

France	Suisse.PAM	Suisse. Autres	Etranger.Autres
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$P(X)$

Female	Male
0.35	0.65

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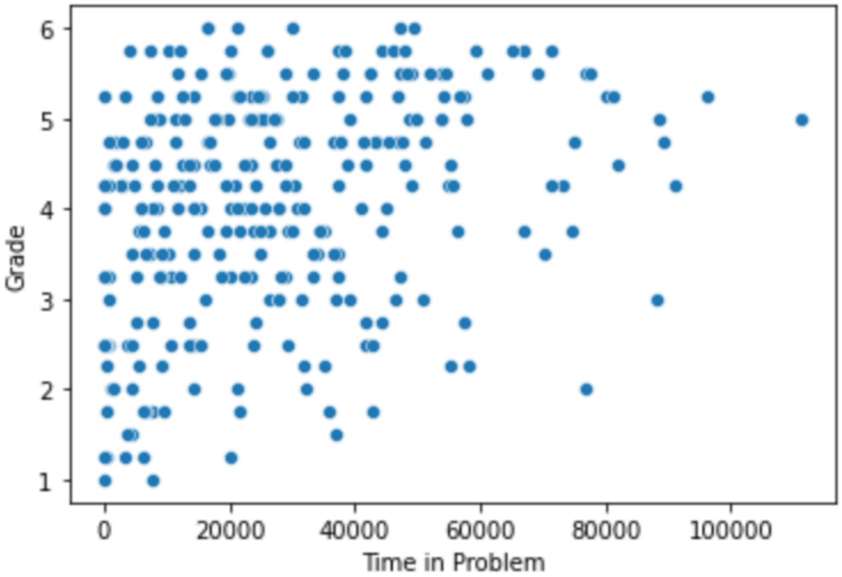
$P(X)$

Female	Male
0.35	0.65

$$\boxed{I(X;Y) = 0.02}$$

Mutual Information - Continuous



$$I(X;Y) = 0.12$$

$$\rho = 0.31\ (p = 6.8e - 8)$$

Data Exploration

- Univariate Analysis
- Multivariate Analysis
- **Time Series**

Time Series Data

Records, which are measured sequentially over time:

- **Business**: sales figures, production numbers, customer frequencies, ...
- **Economics**: stock prices, exchange rates, interest rates, ...
- **Official Statistics**: census data, personal expenditures, road casualties, ...
- **Natural Sciences**: population sizes, sunspot activity, chemical process data, ...
- **Environmetrics**: precipitation, temperature or pollution recordings, ...

Time Series – Behavioral Data

Records of user behavior, which are measured sequentially over time:

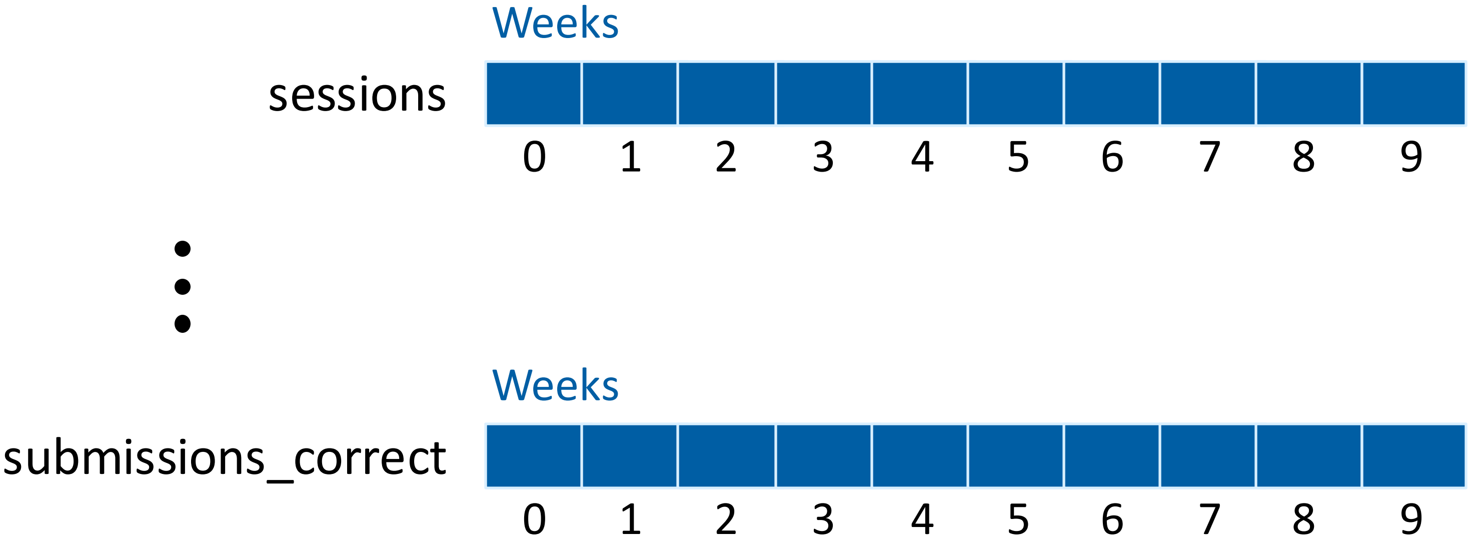
- we usually deal with multiple time series (i.e. one time series per user u)
- a record $r_{u,t}$ of a user u at time t can consists of multiple variables

We might be interested in representing, analyzing, and predicting behavior of single users or of group of users:

- Visualization and exploration of time series data (this lecture)
- Modeling time series data (later…)

Time Series – Our flipped classroom case

Student n



Weeks

sessions

0 1 2 3 4 5 6 7 8 9

⋮

Weeks

submissions_correct

0 1 2 3 4 5 6 7 8 9

Hypothesis 1

The number of sessions will decrease over the course of the semester.

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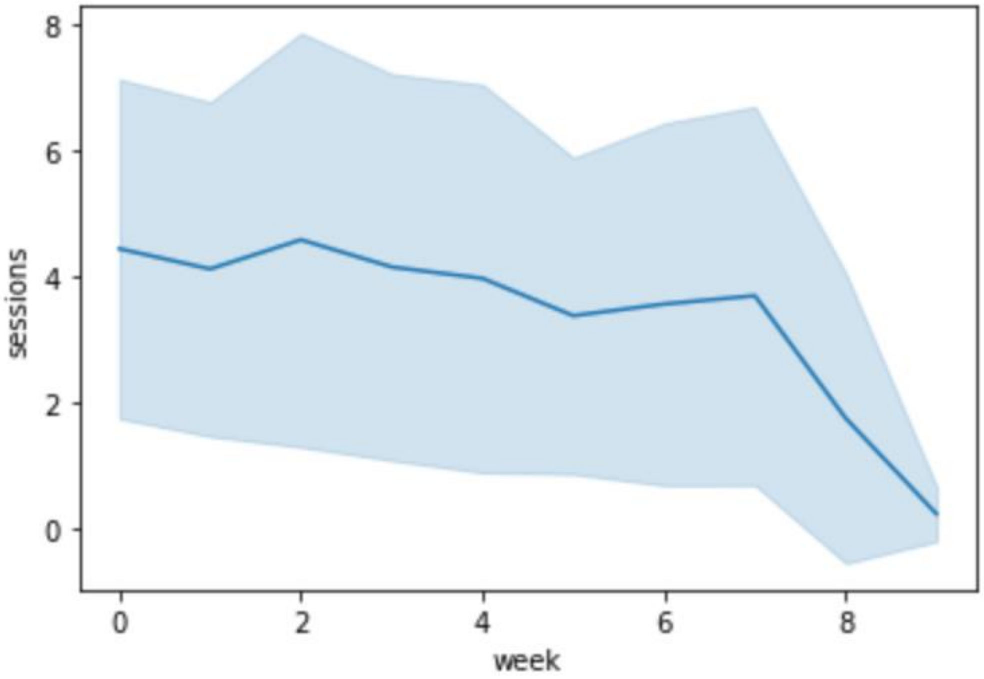

Hypothesis 2

There is no difference between males and females in terms of the number of sessions.

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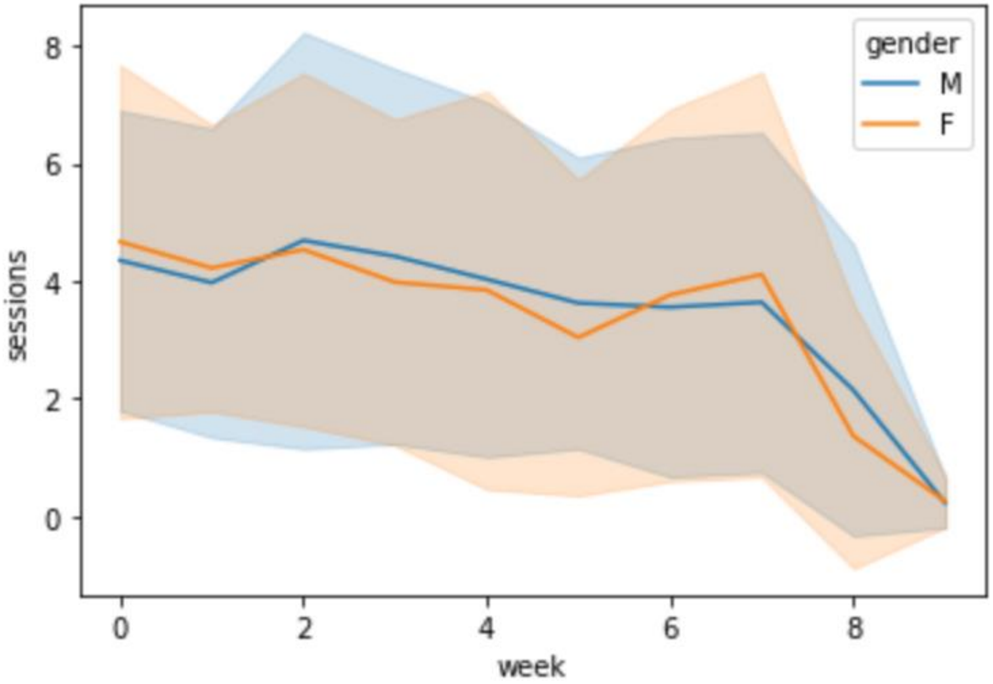

Your turn!

- Come up with a hypothesis on your own
- Produce a visualization
- Describe: what do you observe? Can your hypothesis be confirmed?

Your turn!

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Do you want feedback or have questions?
(Optional) Upload your Jupyter Notebook here:
https://go.epfl.ch/notebooks-mlbd

Summary

- Compute descriptive statistics
- Visualize, visualize, visualize,…
  → Different types of visualizations or representations help to identify different types of problems

  → Different types of visualizations help to identify different patterns/properties in the data
- Try to gain as much knowledge as possible about the domain and the data collection

Up next…

- Exercises on data exploration [lab session today]
- Introduction to tasks for M2 [project hours today]

Remember

Deadline for **M1** is today at 23:59.

Sign-up for the project here (as a team or alone): https://go.epfl.ch/mlbd-m1-2025