COMP5310: Principles of Data Science

W6: Hypothesis Testing and Evaluation

Presented by

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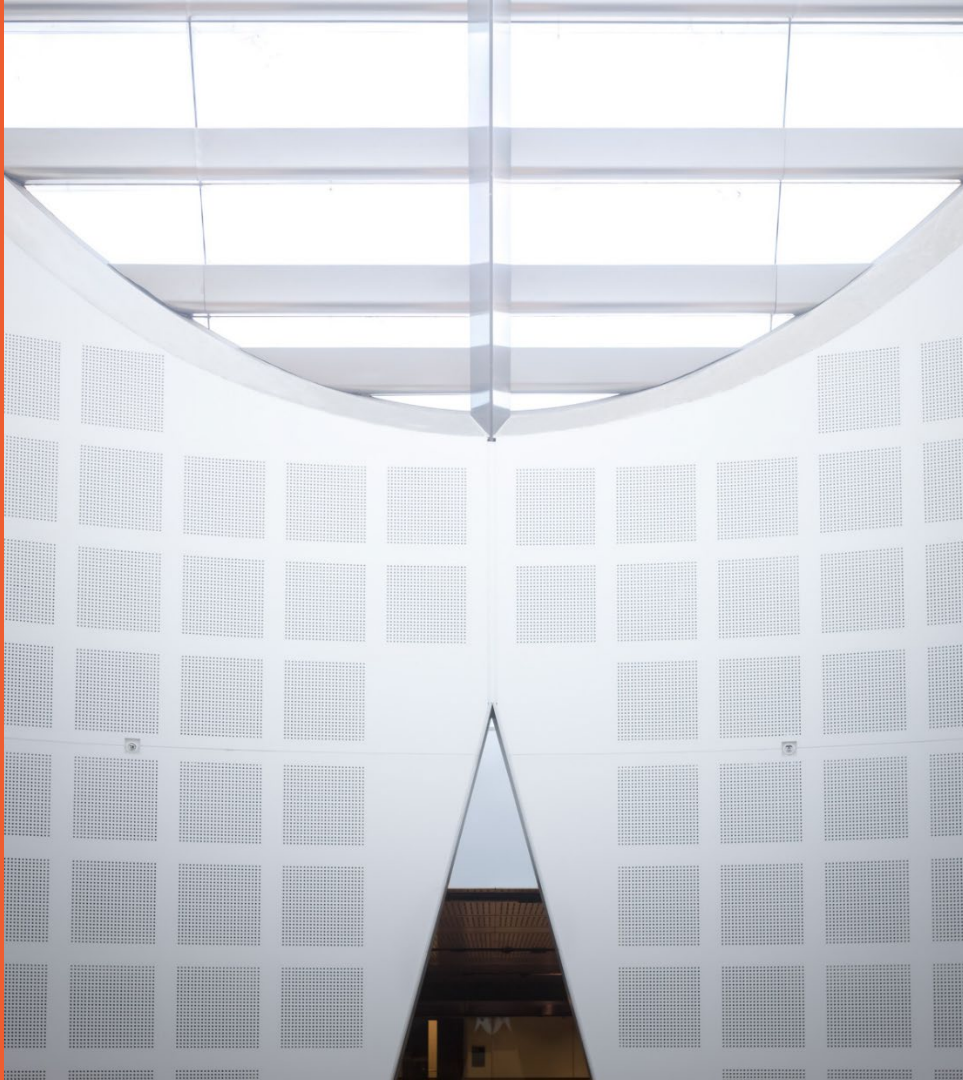
Based on slides by previous lecturers of this unit of study

THE UNIVERSITY OF SYDNEY



Last week: Querying and summarising data

Objective

- To be able to extract a data set from a database, as well as to leverage on the SQL capabilities for in-database data summarisation and analysis.

Lecture

- Data gathering reprise.
- SQL querying.
- Summarising data with SQL.
- Statistic functions support in SQL.

Readings

- Data Science from Scratch: Ch 24.

Exercises

- Data Loading.
- SQL Querying.
- Python DB Querying.
- Data Summarization using SQL.

TO-DO in W5

- Finish Ed Lessons Python modules.
- Finish Ed Lessons SQL modules.

Goal of today's lecture

– High-level overview of statistical tests (not a deep dive)

– Provide some guidance on selecting appropriate statistical tests for evaluating a predictive model, and justifying the choice of tool, in Assignment Stage 2A

– Help you seek details of how to use a statistical method or tool in the data analytic process

TYPES OF STATISTICAL STUDIES

Types of statistical studies

Observational Study

- Simply observing what happens.
- Records information about subjects without applying any treatments to subjects (passive participation of researcher).

Experimental Study

- Records information about subjects while applying treatments to subjects and controlling study conditions to some degree (active participation of researcher).

Observational studies

Sample survey

- Provide information about a population based on a sample at a specific point in time.
- Only establish correlation not causality!

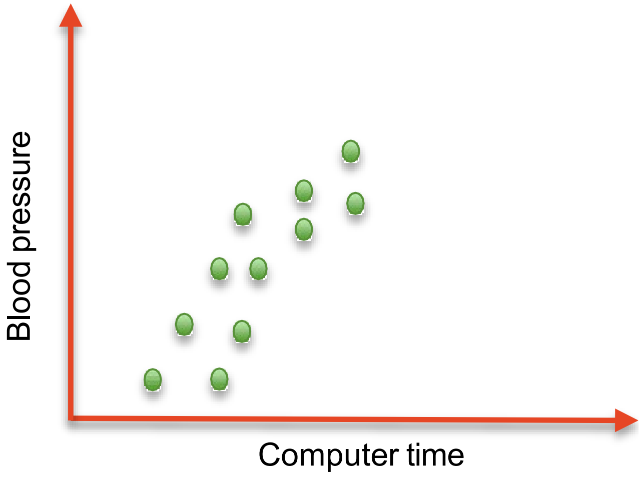
Obs

  - **Study 1:** Tanning and Skin Cancer.
    - The observational study involved 1,500 people.
    - Selected a group of people who had skin cancer and another group of people who did not have skin cancer.
    - Asked all participants whether they used tanning beds.
    - Wanted to see if there was an association between tanning beds and skin cancer prevalence.

Observational studies

obs

- **Study 2:** Average Computer Time vs Blood Pressure.
  - Enrol 100 individuals in the observational study.
  - Ask them about the average computer time they spent each day.
  - Measure their blood pressure.



Experimental studies

- Strong hypotheses, sample size for desired power and controlled data collection per specified protocols.
- Establish causality.
- **Example:** randomized control trials.
  - 100 subjects.
  - Factor: Average Computer Time.
  - Treatments:
    - Control group (computer time: max. 30 minutes).
    - Treatment group (computer time: 2 hours).
  - 50 subjects randomly assigned to each treatment.
  - Response: we measure the blood pressure for each group.

which statistical study looks more suitable to apply in your assignment

Experimental vs observational

- Main difference between observational studies and experiments
  - Most experiments use random assignment while observational studies do not.
- Observational studies typically only establish correlation but not causality
- Experimental studies establish causality

STATISTICAL SIGNIFICANCE TESTING

Types of variables

Dependent variable

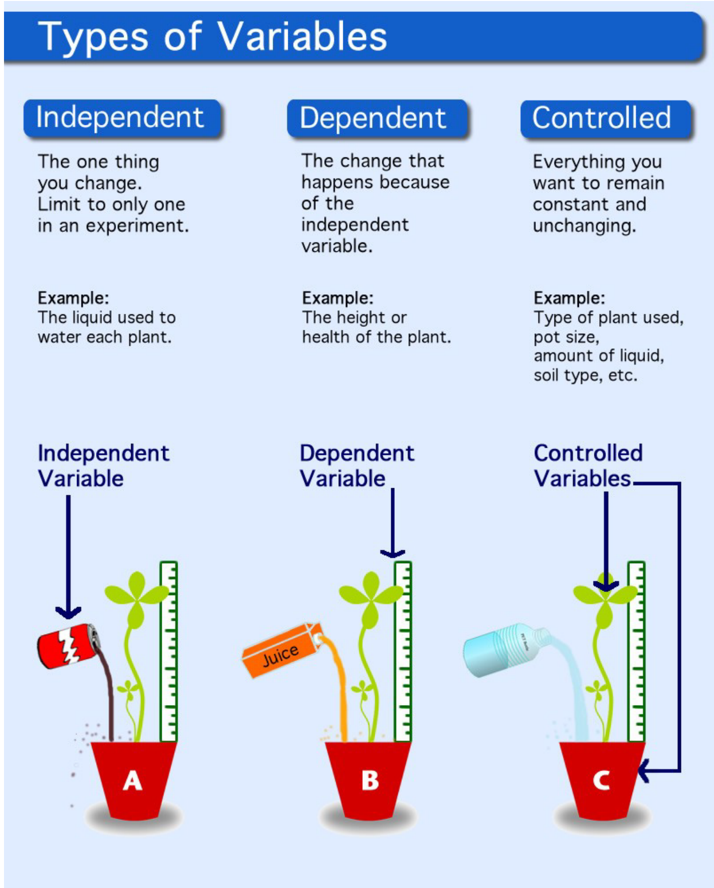
– Measure of interest.

Independent variable

– Manipulated to observe the effect on dependent variable

Controlled variables

– Materials, measurements and methods that don't change.



http://edtech2.boisestate.edu/angelacovil/506/procedure.html

Research question

Research question (Q)

– Asks whether the independent variable has an effect.
– "If there is a change in the independent variable, will there also be a change in the dependent variable?"

Null hypothesis (H0)

– The assumption that there is no effect.
– "There is no change in the dependent variable when the independent variable changes."

Hypothesis testing

- We use hypothesis testing to specify whether to accept or reject a claim about a population depending on the evidence provided by a sample of data.
- A hypothesis test examines two opposing hypotheses about a population parameter (e.g. the mean):
  - The **null hypothesis** and the **alternative hypothesis**.
  - The null hypothesis represents our **initial assumption** about the parameter, and we **collect evidence** to possibly **reject the null hypothesis** in favour of the alternative hypothesis.
- **Example:** Determine whether the mean of a population differs significantly (this has a special meaning) from a specific value or from the mean of another population.

Testing reliability with p-values

- Most tests calculate a p-value for measuring observation extremity, to measure whether or not the Null Hypothesis (H_0) is correct.
- Compare to significance level threshold α.
  - α is the probability of (wrongly) rejecting H_0 given that it is true (Type I error rate, i.e., false positive).
  - Commonly use α of 5% or 1%.

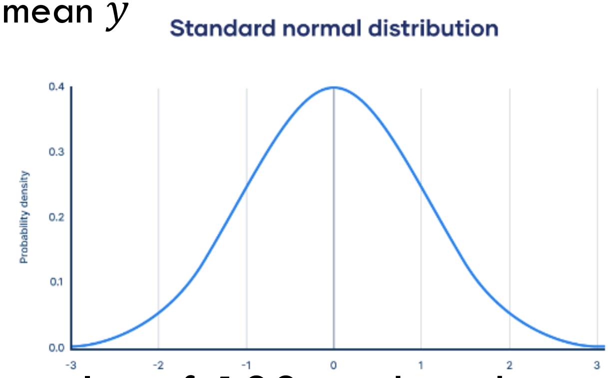
Test results

Actual Condition	Accept H_0	Reject H_0
H_0 (H_0 is True) - No difference	Right Decision	Type I error
H_1 (H_0 is False) - Difference exists	Type II error	Right Decision

P-value	Indicates	Reject H_0?
<α	Strong evidence against the null hypothesis	Yes
>α	Weak evidence against the null hypothesis	No
=α	Marginal	NA

General idea

- Suppose we have two normal random variables X and Y with the same known variance, we want to test whether they have the same mean
  - Sample 100 random numbers from X, and calculate its mean $\bar{x}$
  - Sample 100 random numbers from Y, and calculate its mean $\bar{y}$
  - Let μ_x and μ_y be the mean of X and Y, respectively
  - How do we conclude whether $\mu_x = \mu_y$ from the value of $\bar{x} - \bar{y}$
- **null hypothesis:** $\mu_x = \mu_y$
- **alternative hypothesis:** $\mu_x \neq \mu_y$



- P-value: probability of generating two sets of samples of 100 each such that the difference between their empirical means is at least $|\bar{x} - \bar{y}|$, under the assumption that the null hypothesis is true

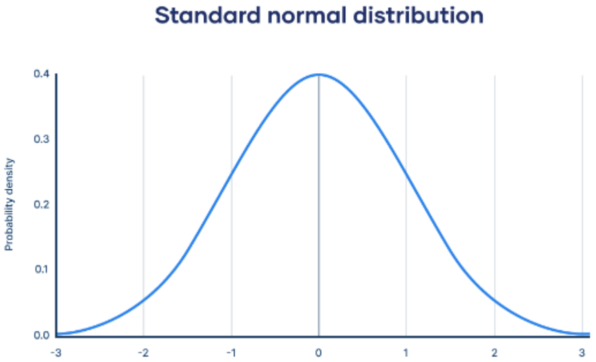
Not every test result is correct

- $\alpha=0.05$ will erroneously reject H_0 5% of the time
- Perform enough tests and you will get a false result (p-hacking)
- Good science:
  - Determine hypotheses before looking at data
  - Perform hypothesis-agnostic data cleaning
  - Remember that p-values do not replace common sense
- https://sites.uw.edu/stlab/2016/03/09/the-arbitrary-magic-of-p-0-05/

One-side test

- Suppose we want to test whether $\mu_x > \mu_y$
  - **null hypothesis:** $\mu_x = \mu_y$
  - **alternative hypothesis:** $\mu_x > \mu_y$
  - P-value: probability of generating two sets of samples of 100 each such that the difference between their empirical means is at least $\bar{x} - \bar{y}$, under the assumption that the null hypothesis is true

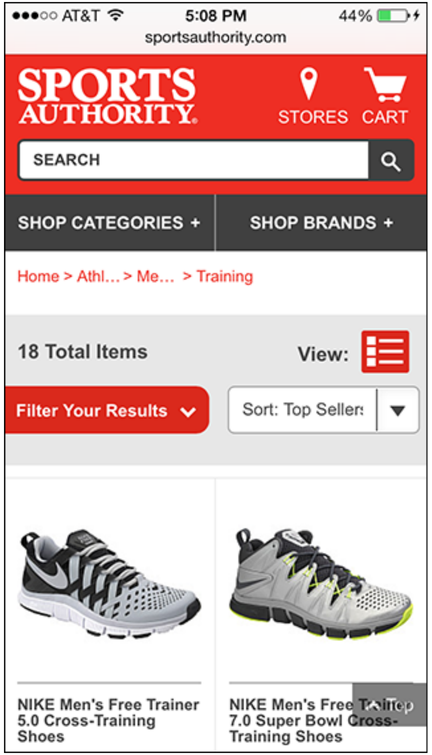
- P-value (in general):
  - P(observed or more extreme outcome | H0 true)

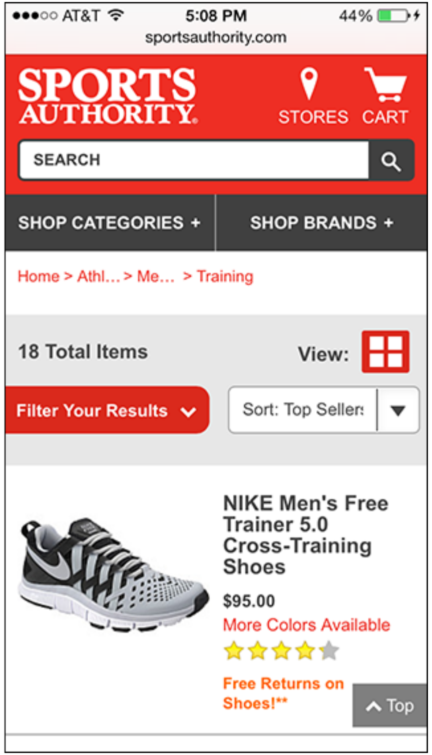


TESTING WHICH APPROACH IS BETTER BETWEEN SUBJECTS

Scenario: Comparing visual layouts

Grid view





List view

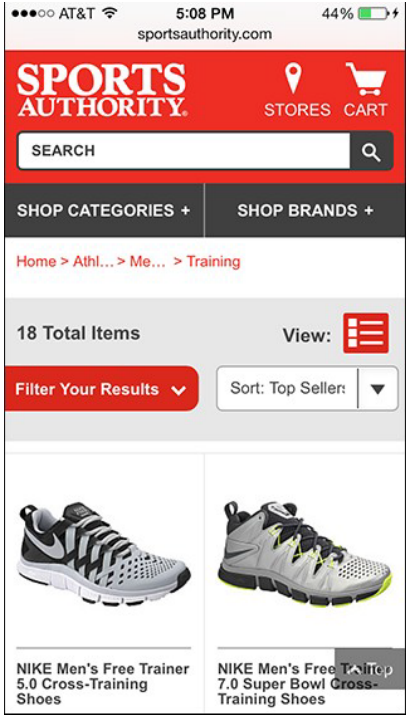
https://www.nngroup.com/articles/image-vs-list-mobile-navigation/

Research question

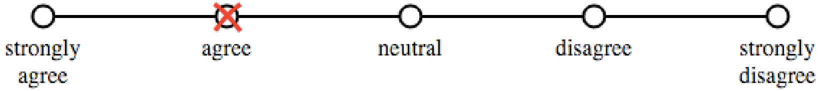
Do users prefer grid view?

Data/Measurement: User ratings of layouts

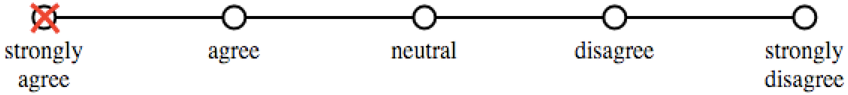
Example response from User Group A



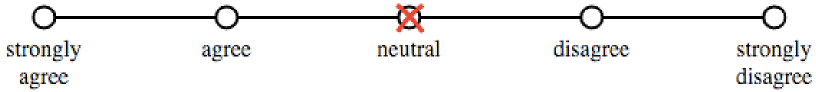
Page is easy to use.



Page gives good overview.

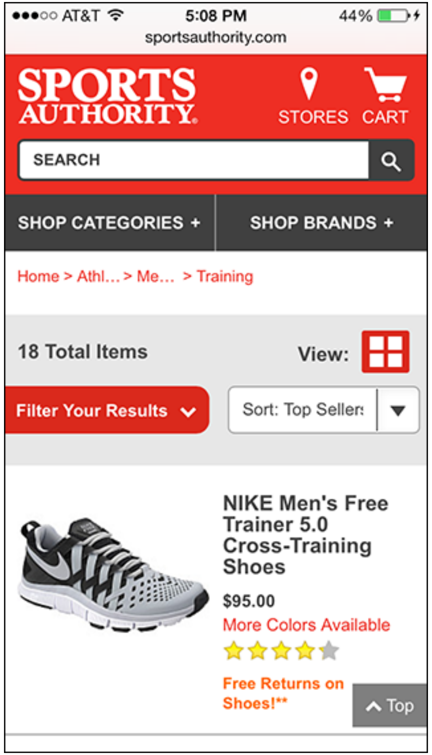


Page gives sufficient detail.



Data/Measurement: User ratings of layouts

Example response from User Group B



Page is easy to use.

strongly agree — agree — neutral — disagree — strongly disagree

Page gives good overview.

strongly agree — agree — neutral — disagree — strongly disagree

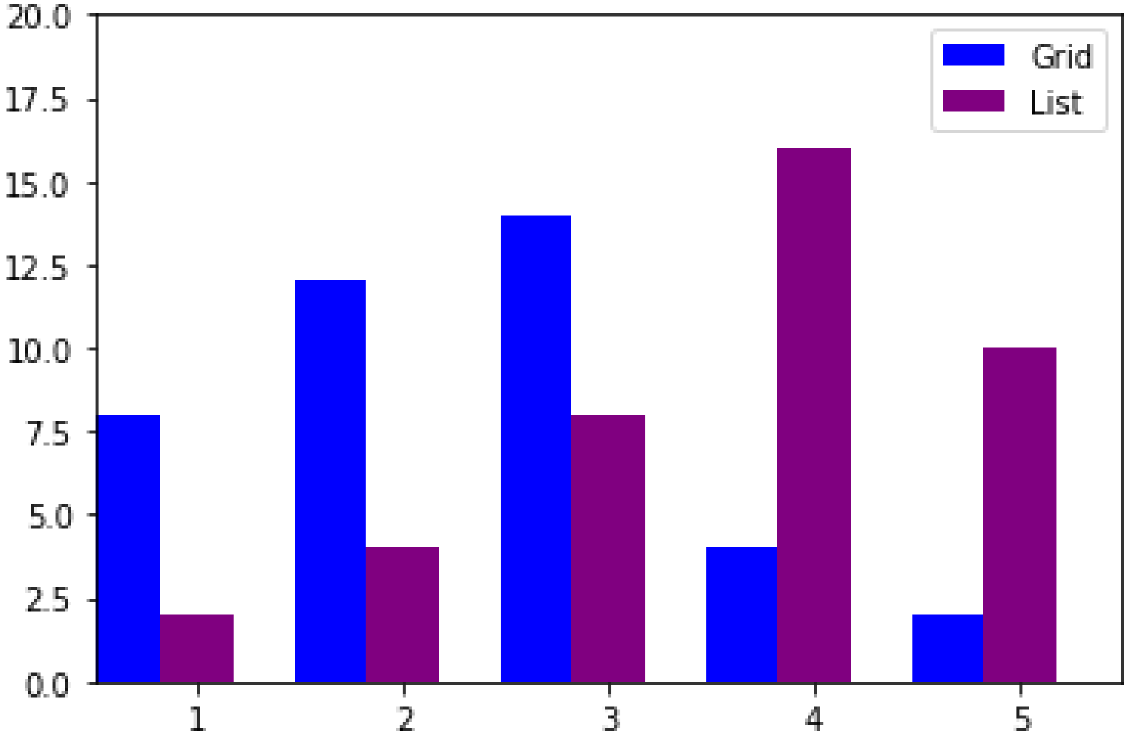
Page gives sufficient detail.

strongly agree — agree — neutral — disagree — strongly disagree

Generate ratings data

- We assume different subject groups for each condition.
- Each subject sees one of the layouts and is asked to rate on a 5-point Likert scale how strongly he agree or disagree with the statement:
- Question to subjects: Page gives a good overview?
- 1=strongly agree; 2=agree; 3=neutral; 4=disagree; 5=strongly disagree.
  - **G_data** = [1, 3, 3, 2, 4, 2, 3, 3, 1, 5, 2, 3, 4, 2, 1, 3, 2, 2, 1, 3, 2, 3, 4, 2, 1, 3, 2, 2, 1, 3, 1, 3, 3, 2, 4, 2, 3, 3, 1, 5]
  - **L_data** = [4, 5, 2, 4, 4, 3, 5, 4, 3, 5, 1, 4, 5, 3, 4, 4, 2, 3, 4, 5, 1, 4, 5, 3, 4, 4, 2, 3, 4, 5, 4, 5, 2, 4, 4, 3, 5, 4, 3, 5]
- **G_data** corresponds to ratings from users that see the **grid view**.
- **L_data** corresponds to ratings from users that see the **list view**.

Visualise ratings data



Setup: Comparing two versions of a display

- Subjects are users of the display (or summary, interface, etc).
  - **Dependent variable** is user rating (or comprehension, etc).
  - **Independent variable** is the version of the display.

- **Problem:** Find out which version of a display is better.
- **Question:** Do users prefer Grid view?
- **Null hypothesis (H_0):** there is no difference between Grid view and List view.

Significance: Unpaired Student's t-test

- Tests the null hypothesis that two population means are equal.
- **Assumptions:**
  - The samples are *independent*.
  - Populations are *normally distributed.*
  - Standard deviations are *equal (by default)*.
- https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.ttest_ind.html#scipy.stats.ttest_ind

Significance: Mann-Whitney U test

- Nonparametric version of unpaired t-test.
  - Test the null hypothesis that the distribution underlying sample x is the same as the distribution underlying sample y.
- **Assumptions:**
  - The samples are *independent*.
- **Note**
  - N should be at least 20.
- https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.mannwhitneyu.html#scipy.stats.mannwhitneyu

Exercise: Comparing visual layouts

- Test for difference
  - Run the code cell under “Test whether grid view is preferred”
  - Do users prefer grid view?

TESTING WHETHER MULTI-GROUPS DIFFER

Scenario: Mobile use by generation

Talking a different language

	Maturists (pre-1945)	Baby boomers (1945-1960)	Generation X (1961-1980)	Generation Y (1981-1995)	Generation Z (Born after 1995)
Formative experiences	Wartime rationing Rock'n'roll Nuclear families Defined gender roles - particularly for women	Cold War 'Swinging Sixties' Moon landings Youth culture Woodstock Family-orientated	Fall of Berlin Wall Reagan/Gorbachev/ Thatcherism Live Aid Early mobile technology Divorce rate rises	9/11 terrorists attacks Social media Invasion of Iraq Reality TV Google Earth	Economic downturn Global warming Mobile devices Cloud computing Wiki-leaks
Attitude toward career	Jobs for life	Organisational - careers are defined by employees	"Portfolio" careers - loyal to profession, not to employer	Digital entrepreneurs - work "with" organisations	Multitaskers - will move seamlessly between organisations and "pop-up" businesses
Signature product	Automobile	Television	Personal computer	Tablet/smartphone	Google glass, 3-D printing
Communication media	Formal letter	Telephone	E-mail and text message	Text or social media	Hand-held communication devices
Preference when making financial decisions	Face-to-face meetings	Face-to-face ideally but increasingly will go online	Online - would prefer face-to-face if time permitting	Face-to-face	Solutions will be digitally crowd-sourced

https://ihumanmedia.com/2015/09/14/gen-x-millennials-vs-baby-boomer-real-estate-baby-work-travel-politics-shopping/

Research question

Does mobile use differ across generations?

Data/Measurement: Survey of mobile use

- May be collected by survey or user data.
- **Dependent variable:**
  - Number of texts per day.
- **Independent variable:**
  - Generation {B,G,M}.

Texting survey

1. What year were you born?

2. How many texts do you send per day?

Significance: Analysis of variance (ANOVA)

- Tests the null hypothesis two or more groups have the same population mean.
- **Assumptions:**
  - The samples are *independent*.
  - Populations are *normally distributed*.
  - Standard deviations are *equal*.
- https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.f_oneway.html#scipy.stats.f_oneway

Significance: Kruskall-Wallis H-test

- Nonparametric version of ANOVA.
  - Test the null hypothesis that the population median of all of the groups are equal
- **Assumptions:**
  - Samples are *independent*.
- **Note:**
  - Not recommended for samples smaller than 5.
  - Not as statistically powerful as ANOVA.
  - Both ANOVA and Kruskall-Wallis H-test are extensions of the Unpaired Student's t-test and Mann-Whitney test used to compare the means of more than two populations.
- https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.kruskal.html#scipy.stats.kruskal

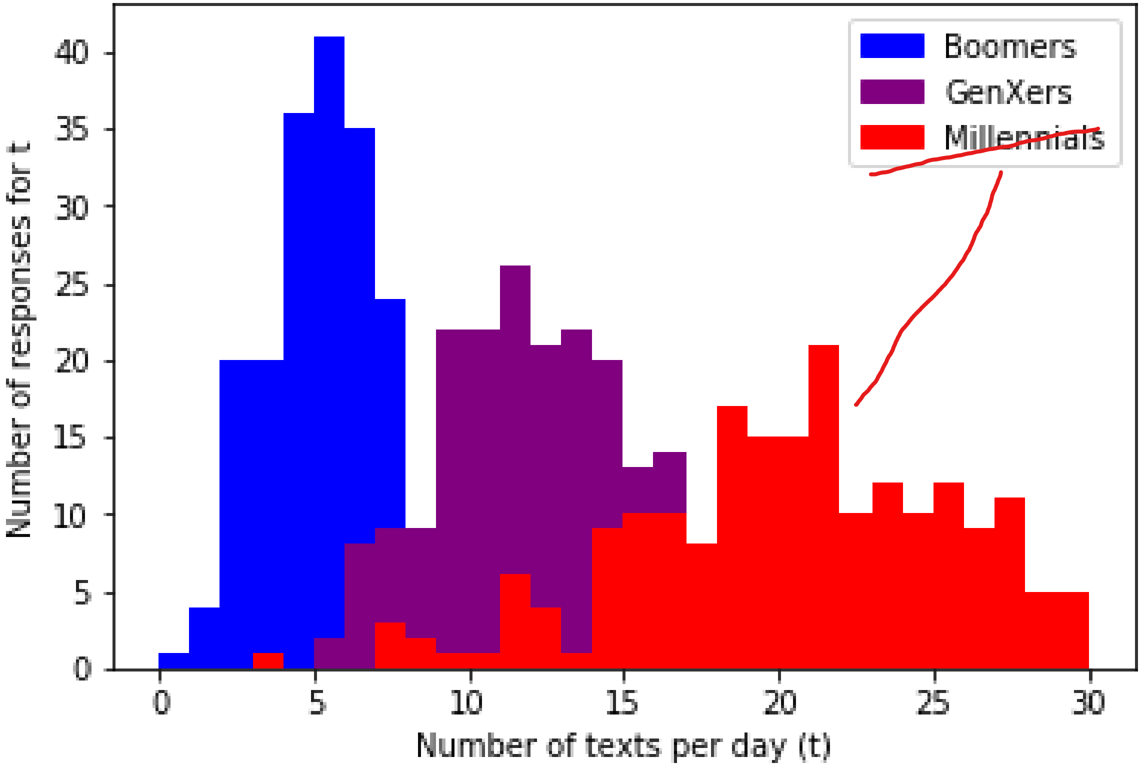
Setup: Comparing behaviour across groups

- Subjects are rows of data.
  - **Dependent variable** is number of texts per day.
  - **Independent variable** is generation {B,G,M}.
- **Q:** Is there any difference between groups?
- **H_0:** Group means (or medians, for nonparametric methods) are the same

Generate generation data

- Imagine we conducted a survey of **200 baby boomers** (born 1945-1960), **200 generation Xers** (born 1961-1980) and **200 millennials** (born 1981-1995).
- For the purposes of this exercise, let's generate some simulated samples. We assume:
  - **Baby Boomers** send 5 texts per day on average with standard deviation 2.
  - **GenXers** send 12 texts per day on average with standard deviation 3.
  - **Millennials** send 20 texts per day on average with standard deviation 5.

Visualise generation data

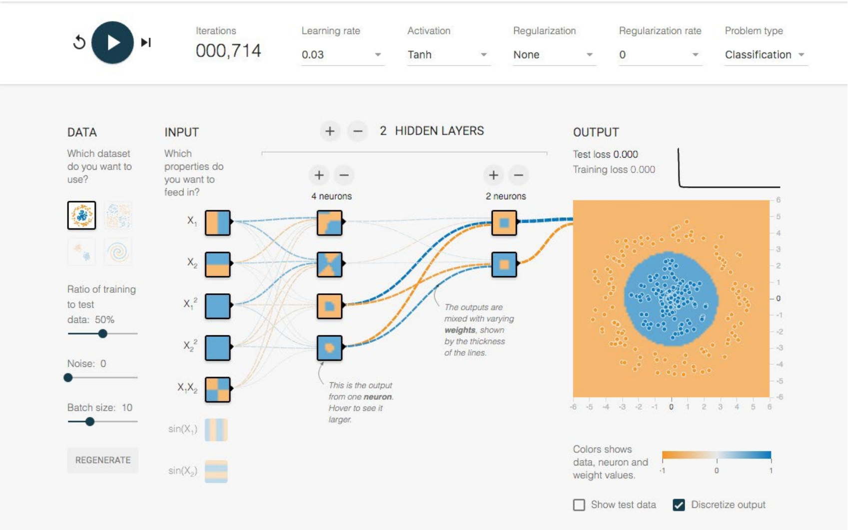


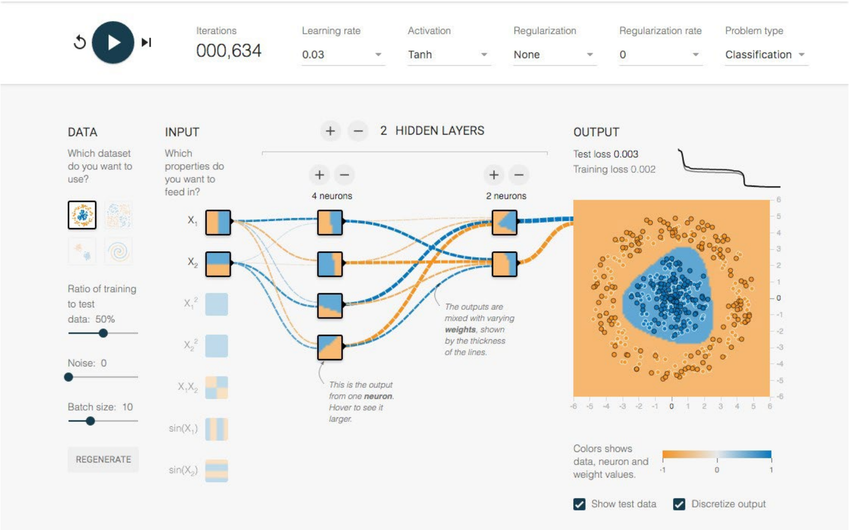
Exercise: Comparing mobile behaviour

- Test for difference
  - Run the code cell under "Testing for differences"
  - Does the data satisfy ANOVA assumptions?

TESTING WHICH APPROACH IS BETTER WITHIN SUBJECTS

Example scenario: Comparing classifiers





http://playground.tensorflow.org/

Research question

Does my new model perform better?

Task: Spam/ham detection

- Let's assume our classifiers predict whether an email is:
  - 1: spam.
  - 0: ham.
- Features are words, e.g.:
  - .P.a.Y.p.a.l, bitcoin_up, iphone.14.Pro, winner, Settlement4U.

Measurement: Model evaluation

- Need to measure accuracy of system output S.
- Compare to gold-standard labelling G.
- Define evaluation measure: score(S, G).
- https://scikit-learn.org/stable/modules/model_evaluation.html

Measurement: Accuracy, precision, recall, f1

Model prediction

Actual results	Spam (s=1)	Ham (s=0)
Spam (g=1)	*TP* (true positives)	*FN* (false negatives)
Ham (g=0)	*FP* (false positives)	*TN* (true negatives)

- **Accuracy**: percentage of correct over all instances.
  - (TP+TN) / N
- **Precision**: percentage of correct system predictions.
  - TP / (TP+FP)
- **Recall**: percentage of correct gold labels.
  - TP / (TP+FN)
- **F1**: Harmonic mean of Precision and Recall.
  - 2PR / (P+R)

Confusion matrix for more than two classes

- E.g. iris data classification - confusion matrix:

```
  a  b  c   <-- classified as
 50  0  0 |  a = Iris-setosa
  0 44  6 |  b = Iris-versicolor
  0  3 47 |  c = Iris-virginica
```

	Setosa +	Versicolor-	Virginica-
Setosa+	50 tp	0 fn	0 fn
Versicolor-	0 fp	44	6
Virginica-	0 fp	3	47

- accuracy =?

accuracy= (tp+tn)/(tp+fn+fp+tn)

- accuracy = (50+44+47)/(50+0+0+0+44+6+0+3+47) =141/150 =94%

Evaluating classifier accuracy: Holdout & cross-validation methods

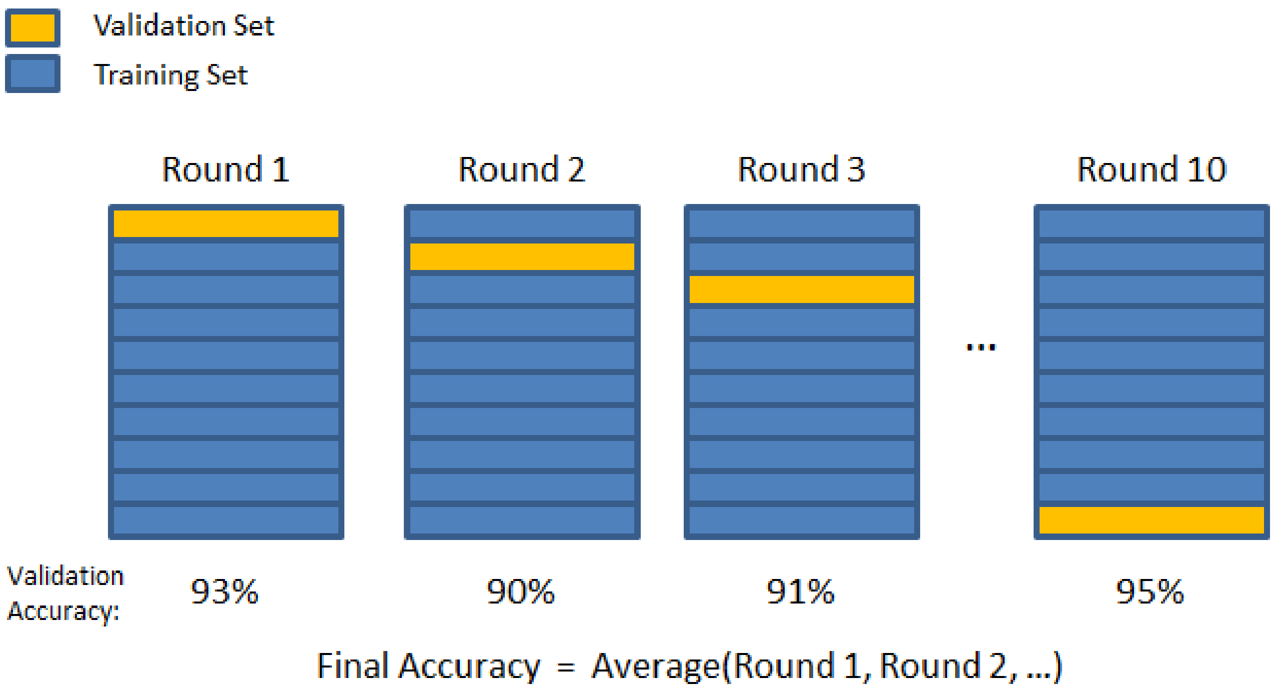
Holdout method

- Splits the data randomly into two independent sets.
  - Training set (e.g., 2/3) for model construction.
  - Test set (e.g., 1/3) for accuracy estimation.
  - Repeat holdout k times, accuracy = avg. of the accuracies obtained.

Cross-validation (*k*-fold, where k = 10 is most popular)

- Randomly partition the data into k mutually exclusive subsets, each approximately equal size.
- Leave-One-Out is a particular form of cross-validation:
  - *k* folds where *k* = # of tuples, for small sized data.

Data: Cross validation



https://chrisjmccormick.wordpress.com/2013/07/31/k-fold-cross-validation-with-matlab-code/

Significance: Paired Student's t-test

- Tests the null hypothesis that two population means are equal.
- **Assumptions:**
  - The samples are *paired* (e.g. before and after a treatment).
  - Populations are *normally distributed*.
  - Standard deviations are *equal*.
- https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.ttest_rel.html#scipy.stats.ttest_rel

Significance: Paired tests for non-parametric data

- Nonparametric version of paired t-test.
- **Assumptions:**
  - The samples are *paired*.
- **Note:**
  - Often used for ordinal data, e.g., Likert ratings.
  - N should be large, e.g., ≥ 20.
- https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.wilcoxon.html#scipy.stats.wilcoxon

Generate gold and classifier labellings

- We generate **10,000 gold labels.**
  - Marking approximately **20% as spam** (1) based on a random number generator and the rest as ham (0).
    - 0: 8000 and 1: 2000
- **System 1** incorrectly marks 5% of ham as spam and fails to detect 20% of actual spam.
- **System 2** incorrectly marks 10% of ham as spam and fails to detect 10% of actual spam.

System 1		PREDICTED	
		1	0
ACTUAL	1	1600 (TP)	400 (FN)
	0	400 (FP)	7600 (TN)

System 2		PREDICTED	
		1	0
ACTUAL	1	1800	200
	0	800	7200

Setup: Comparing classifiers

- Subjects correspond to cross-validation folds.
  - **Dependent variable** is some measure of accuracy (precision, recall, f1, etc).
  - **Independent variable** is the algorithm, feature set, etc.
- **Q**: Is my shiny, new model better?
- **H_0**: Accuracy is not better for the new model.

Exercise: Comparing models

- Generate data
  - Run the code cell under “Generate gold and classifier labelling”
  - Run the code cell under “Split data into folds”
- Calculate accuracy
  - Run the code cell under “Calculate classifier accuracy”
  - Run the code cell under “Calculate scores across folds”

- Test for differences
  - Run the code cell under “Compute significance for sys1 and sys2”
  - How can we manage reliability?

REVIEW

Tips and tricks

- Statistical hypothesis testing ensures results are reliable.
- Experimental design includes:
  - Formulating a research question and null hypothesis.
  - Designing and running experiments.
  - Analysing results using appropriate statistics.
- Use textbooks and documentation to find the right stats.
- Sample representatively; Report p-value; Don’t hack p-value.
- Report precision, recall, f-score and significance.

Additional reading (not examinable)

Some great online resources:

- Hypothesis testing, power, sample sizes
  - https://online.stat.psu.edu/stat415/
- What does it all even mean?
  - https://plato.stanford.edu/entries/statistics/