Evaluation - Controlled Experiments

- What is experimental design?
- What is an experimental hypothesis?
- How do I plan an experiment?
- Why are statistics used?
- What are the important statistical methods?

Quantitative evaluation of systems

Quantitative:
- precise measurement, numerical values
- bounds on how correct our statements are

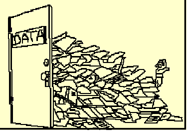
Methods
- user performance data collection
- controlled experiments

Collecting user performance data

Data collected on system use (often lots of data)

Exploratory:
- hope something interesting shows up
- but difficult to analyze

Targeted
- look for specific information, but may miss something
  - frequency of request for on-line assistance
    - what did people ask for help with?
  - frequency of use of different parts of the system
    - why are parts of system unused?
  - number of errors and where they occurred
    - why does an error occur repeatedly?
  - time it takes to complete some operation
    - what tasks take longer than expected?

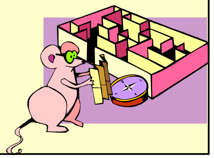


Controlled experiments

Traditional scientific method

Reductionist
- clear convincing result on specific issues

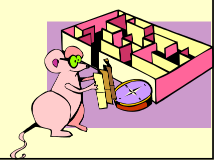
In HCI:
- insights into cognitive process, human performance limitations, ...
- allows system comparison, fine-tuning of details ...



Controlled experiments

Strives for

- lucid and testable hypothesis
- quantitative measurement
- measure of confidence in results obtained (statistics)
- replicability of experiment
- control of variables and conditions
- removal of experimenter bias



A) Lucid and testable hypothesis

State a lucid, testable hypothesis

- this is a precise problem statement

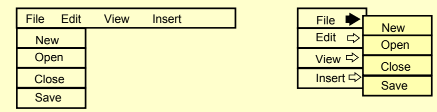
Example 1:

There is no difference in the number of cavities in children and teenagers using crest and no-teeth toothpaste when brushing daily over a one month period

A) Lucid and testable hypothesis

Example 2:

There is no difference in user performance (time and error rate) when selecting a single item from a pop-up or a pull down menu of 4 items, regardless of the subject’s previous expertise in using a mouse or using the different menu types”



Independent variables

b) Hypothesis includes the **independent variables** that are to be altered

- the things you manipulate independent of a subject’s behaviour
- determines a modification to the conditions the subjects undergo
- may arise from subjects being classified into different groups

Independent variables

in toothpaste experiment

- toothpaste type: uses Crest or No-teeth toothpaste
- age: <= 11 years *or* > 11 years

in menu experiment

- menu type: pop-up or pull-down
- menu length: 3, 6, 9, 12, 15
- subject type (expert or novice)

Dependant variables

c) Hypothesis includes the **dependent variables** that will be measured

- variables dependent on the subject's behaviour / reaction to the independent variable
- the specific things you set out to quantitatively measure / observe

Dependant variables

in menu experiment

- time to select an item
- selection errors made
- time to learn to use it to proficiency

in toothpaste experiment

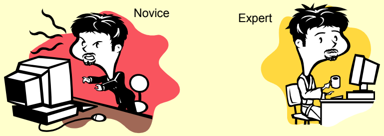
- number of cavities
- frequency of brushing
- preference

Subject Selection

d) Judiciously select and assign subjects to groups

ways of controlling subject variability

- reasonable amount of subjects
- random assignment
- make different user groups an independent variable
- screen for anomalies in subject group
  - superstars versus poor performers



Controlling bias

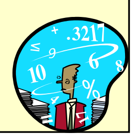
e) Control for bias

- unbiased instructions
- unbiased experimental protocols
  - prepare scripts ahead of time
- unbiased subject selection

Statistical analysis

f) Apply statistical methods to data analysis

- confidence limits:
  - the confidence that your conclusion is correct
  - "the hypothesis that computer experience makes no difference is rejected at the .05 level" means:
    - a 95% chance that your statement is correct
    - a 5% chance you are wrong

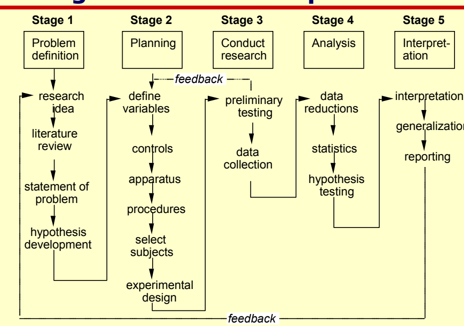


Interpretation

g) Interpret your results

- what you believe the results really mean
- their implications to your research
- their implications to practitioners
- how generalizable they are
- limitations and critique

Planning flowchart for experiments



Copied from an early ACM CHI tutorial, but I cannot recall which one

Statistical analysis

Calculations that tell us

- mathematical attributes about our data sets
  - mean, amount of variance, ...
- how data sets relate to each other
  - whether we are "sampling" from the same or different distributions
- the probability that our claims are correct
  - "statistical significance"

Statistical vs practical significance

When *n* is large, even a trivial difference may show up as a statistically significant result

- eg menu choice:
  mean selection time of menu a is 3.00 seconds;
  menu b is 3.05 seconds

Statistical significance **does not imply** that the difference is important!

- a matter of interpretation
- statistical significance often abused and used to misinform

Example: Differences between means

Condition one: 3, 4, 4, 4, 5, 5, 5, 6
Condition two: 4, 4, 5, 5, 6, 6, 7, 7

Given:

- two data sets measuring a condition
  - height difference of males and females
  - time to select an item from different menu styles ...

Question:

- is the difference between the means of this data statistically significant?

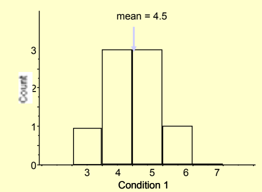
Null hypothesis:

- there is no difference between the two means
- statistical analysis:
  - can only reject the hypothesis at a certain level of confidence

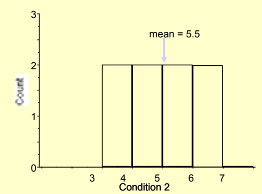
Example:

Is there a significant difference between these means?

Condition one: 3, 4, 4, 4, 5, 5, 5, 6

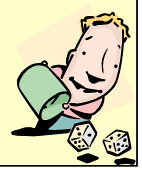


Condition two: 4, 4, 5, 5, 6, 6, 7, 7



Problem with visual inspection of data

Will almost always see variation in collected data
- Differences between data sets may be due to:
  - normal variation
    - eg two sets of ten tosses with different but fair dice
      - » differences between data and means are accountable by expected variation
  - real differences between data
    - eg two sets of ten tosses for with loaded dice and fair dice
      - » differences between data and means are not accountable by expected variation



T-test

A simple statistical test
- allows one to say something about differences between means at a certain confidence level

Null hypothesis of the T-test:
- no difference exists between the means of two sets of collected data

possible results:
- I am 95% sure that null hypothesis is rejected
  - (there is probably a true difference between the means)
- I cannot reject the null hypothesis
  - the means are likely the same

Different types of T-tests

Comparing two sets of independent observations
- usually different subjects in each group
- number per group may differ as well

Condition 1	Condition 2
S1–S20	S21–43

Paired observations
- usually a single group studied under both experimental conditions
- data points of one subject are treated as a pair

Condition 1	Condition 2
S1–S20	S1–S20

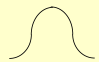
Different types of T-tests

Non-directional vs directional alternatives
- non-directional (two-tailed)
  - no expectation that the direction of difference matters
- directional (one-tailed)
  - Only interested if the mean of a given condition is greater than the other

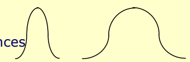
T-test…

Assumptions of t-tests

- data points of each sample are normally distributed
  - but t-test very robust in practice



- population variances are equal
  - t-test reasonably robust for differing variances
  - deserves consideration



- individual observations of data points in sample are independent
  - must be adhered to

Significance level

- decide upon the level before you do the test!
- typically stated at the .05 or .01 level

Two-tailed unpaired T-test

N: number of data points in the one sample
ΣX: sum of all data points in one sample
X: mean of data points in sample
Σ(X²): sum of squares of data points in sample
s²: unbiased estimate of population variation
t: t ratio
df = degrees of freedom = N1 + N2 – 2

Formulas

$$s^2 = \frac{\Sigma(X_1^2) - \frac{(\Sigma X_1)^2}{N_1} + \Sigma(X_2^2) - \frac{(\Sigma X_2)^2}{N_2}}{N_1 + N_2 - 2} \qquad t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s^2}{N_1} + \frac{s^2}{N_2}}}$$

Level of significance for two-tailed test

df	.05	.01
1	12.706	63.657
2	4.303	9.925
3	3.182	5.841
4	2.776	4.604
5	2.571	4.032
6	2.447	3.707
7	2.365	3.499
8	2.306	3.355
9	2.262	3.250
10	2.228	3.169
11	2.201	3.106
12	2.179	3.055
13	2.160	3.012
14	2.145	2.977
15	2.131	2.947

df	.05	.01
16	2.120	2.921
18	2.101	2.878
20	2.086	2.845
22	2.074	2.819
24	2.064	2.797

Example Calculation

x_1 = 3 4 4 4 5 5 5 6
x_2 = 4 4 5 5 6 6 7 7

Hypothesis: there is no significant difference between the means at the .05 level

Step 1. Calculating s^2

	1	2
N	8	8
Σx	36	44
$\overline{x}$	4.5	5.5
$\Sigma(x^2)$	168	252
$(\Sigma x)^2$	1296	1936

df = 14

$$s^2 = \frac{\Sigma x_1^2 - (\Sigma x_1)^2/N_1 + \Sigma x_2^2 - (\Sigma x_2)^2/N}{N_1 + N_2 - 2}$$

$$= \frac{168 - 1296/8 + 252 - 1936/8}{8+8-2}$$

$$= 1.1429$$

Example Calculation

Step 2. Calculating *t*

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s^2/N_1 + s^2/N_2}} = \frac{4.5 - 5.5}{\sqrt{2 \cdot (1.1429/8)}} = \frac{-1}{.5345} = -1.871$$

Two-tailed Unpaired T-test

Or, use a statistics package (e.g., Excel has simple stats)

Condition one: 3, 4, 4, 4, 5, 5, 5, 6
Condition two: 4, 4, 5, 5, 6, 6, 7, 7

Unpaired t-test

DF:	Unpaired t Value:	Prob. (2-tail):
14	-1.871	.0824

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
one	8	4.5	.926	.327
two	8	5.5	1.195	.423

Example Calculation

Step 3: Looking up critical value of *t*
- Use table for two-tailed *t*-test, at *p*=.05, *df*=14
- critical value = 2.145
- because *t*=1.871 < 2.145, there is no significant difference
- therefore, we cannot reject the null hypothesis
  i.e., there is no difference between the means

df	*.05*	*.01*
1	12.706	63.657
…		
14	**2.145**	2.977
15	2.131	2.947

Significance levels and errors

Type 1 error
- reject the null hypothesis when it is, in fact, true

Type 2 error
- accept the null hypothesis when it is, in fact, false

Effects of levels of significance
- high confidence level (eg p<.0001)
  - greater chance of Type 2 errors
- low confidence level (eg p>.1)
  - greater chance of Type 1 errors

You can ‘bias’ your choice depending on consequence of these errors

Type I and Type II Errors

Type 1 error
- reject the null hypothesis when it is, in fact, true

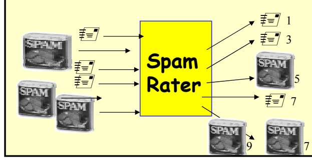
Type 2 error
- accept the null hypothesis when it is, in fact, false

		Decision	
		False	*True*
"Reality"	*True*	Type I error	✓
	False	✓	Type II error

Example: The SpamAssassin Spam Rater

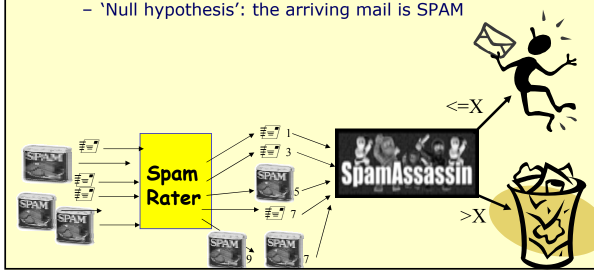
A SPAM rater gives each email a SPAM likelihood
- 0: definitely valid email…
- 1:
- 2:
  …
- 9:
- 10: definitely SPAM

SPAM likelihood



Example: The SpamAssassin Spam Rater

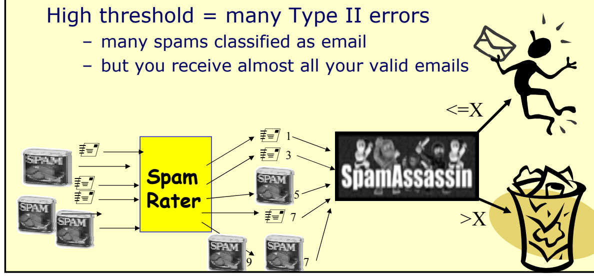
A SPAM assassin deletes mail above a certain SPAM threshold
- what should this threshold be?
- 'Null hypothesis': the arriving mail is SPAM



Example: The SpamAssassin Spam Rater

Low threshold = many Type I errors
- many legitimate emails classified as spam
- but you receive very few actual spams

High threshold = many Type II errors
- many spams classified as email
- but you receive almost all your valid emails



Which is Worse?

Type I errors are considered worse because the null hypothesis is meant to reflect the incumbent theory.

BUT

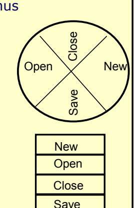
you must use your judgement to assess actual risk of being wrong in the context of your study.

Significance levels and errors

There is no difference between Pie and traditional pop-up menus

What is the consequence of each error type?

- Type 1:
  - extra work developing software
  - people must learn a new idiom for no benefit
- Type 2:
  - use a less efficient (but already familiar) menu



Which error type is preferable?

1. Redesigning a traditional GUI interface
   - Type 2 error is preferable to a Type 1 error
2. Designing a digital mapping application where experts perform extremely frequent menu selections
   - Type 1 error preferable to a Type 2 error

Scales of Measurements

Four major scales of measurements

- Nominal
- Ordinal
- Interval
- Ratio

Nominal Scale

Classification into named or numbered **unordered** categories

- country of birth, user groups, gender…

Allowable manipulations

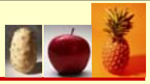
- whether an item belongs in a category
- counting items in a category

Statistics

- number of cases in each category
- most frequent category
- *no means, medians…*

With permission of Ron Wardell

Nominal Scale



Sources of error
- agreement in labeling, vague labels, vague differences in objects

Testing for error
- agreement between different judges for same object

Ordinal Scale

Classification into named or numbered **ordered** categories
- no information on magnitude of differences between categories
- e.g. preference, social status, gold/silver/bronze medals

Allowable manipulations
- as with interval scale, plus
- merge adjacent classes
- transitive: if A > B > C, then A > C

Statistics
- median (central value)
- percentiles, e.g., 30% were less than B

Sources of error
- as in nominal

Interval Scale

Classification into **ordered** categories with equal differences between categories
- zero only by convention
- e.g. temperature (C or F), time of day

Allowable manipulations
- add, subtract
- cannot multiply as this needs an absolute zero

Statistics
- mean, standard deviation, range, variance

Sources of error
- instrument calibration, reproducibility and readability
- human error, skill…

Ratio Scale

Interval scale with absolute, non-arbitrary zero
- e.g. temperature (K), length, weight, time periods

Allowable manipulations
- multiply, divide

Example: Apples

Nominal:

- apple variety
  - Macintosh, Delicious, Gala…

Ordinal:

- apple quality
  - US. Extra Fancy
  - U.S. Fancy,
  - U.S. Combination Extra Fancy / Fancy
  - U.S. No. 1
  - U.S. Early
  - U.S. Utility
  - U.S. Hail

Example: Apples

Interval:

- apple ‘Liking scale’

  Marin, A. Consumers’ evaluation of apple quality. Washington Tree Postharvest Conference 2002.

After taking at least 2 bites how much do you like the apple?

Dislike extremely   Neither like or dislike   Like extremely

Ratio:

- apple weight, size, …

Correlation

Measures the extent to which two concepts are related

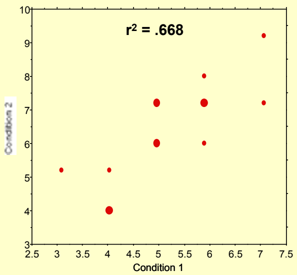
- eg years of university training *vs*
  computer ownership per capita

How?

- obtain the two sets of measurements
- calculate correlation coefficient
  - +1: positively correlated
  - 0: no correlation (no relation)
  - –1: negatively correlated

Correlation

condition 1	condition 2
5	6
4	5
6	7
4	4
5	6
3	5
5	7
4	4
5	7
6	7
6	6
7	7
6	8
7	9



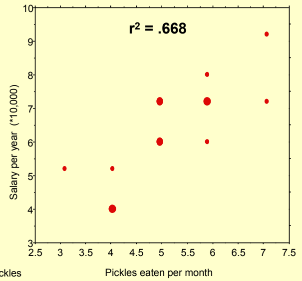
Correlation

Dangers

- attributing causality
  - a correlation does not imply cause and effect
  - cause may be due to a third “hidden” variable related to both other variables
- drawing strong conclusion from small numbers
  - unreliable with small groups
  - be wary of accepting anything more than the direction of correlation unless you have at least 40 subjects

Correlation

Pickles eaten per month	Salary per year (*10,000)
5	6
4	5
6	7
4	4
5	6
3	5
5	7
4	4
5	7
6	7
6	6
7	7
6	8
7	9



Which conclusion could be correct?
-Eating pickles *causes* your salary to increase
-Making more money *causes* you to eat more pickles
-Pickle consumption *predicts* higher salaries *because* older people tend to like pickles better than younger people, and older people tend to make more money than younger people

Correlation

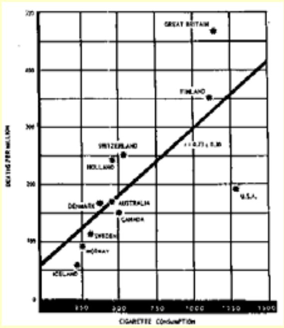
Cigarette Consumption

Crude Male death rate for lung cancer in 1950 per capita consumption of cigarettes in 1930 in various countries.

While strong correlation (.73), can you *prove* that cigarette smoking causes death from this data?

Possible hidden variables:

- age
- poverty



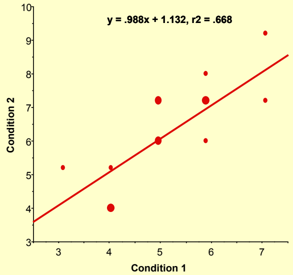
Other Tests: Regression

Calculates a line of “best fit”

Use the value of one variable to predict the value of the other

- e.g., 60% of people with 3 years of university own a computer

condition 1	condition 2
5	6
4	5
6	7
4	4
5	6
3	5
5	7
4	4
5	7
6	7
6	6
7	7
6	8
7	9



Single Factor Analysis of Variance

Compares three or more means

e.g. comparing mouse-typing on three keyboards:

Qwerty	Alphabetic	Dvorak
S1-S10	S11-S20	S21-S30

- Possible results:
  - mouse-typing speed is
    - fastest on a qwerty keyboard
    - the same on an alphabetic & dvorak keyboards

Analysis of Variance (Anova)

Compares relationships between many factors

- Provides more informed results
  considers the interactions between factors
- example
  - beginners type at the same speed on all keyboards,
  - touch-typist type fastest on the qwerty

	Qwerty	Alphabetic	Dvorak
cannot touch type	S1-S10	S11-S20	S21-S30
can touch type	S31-S40	S41-S50	S51-S60

You know now

Controlled experiments can provide clear convincing result on specific issues

Creating testable hypotheses are critical to good experimental design

Experimental design requires a great deal of planning

You know now

Statistics inform us about

- mathematical attributes about our data sets
- how data sets relate to each other
- the probability that our claims are correct

There are many statistical methods that can be applied to different experimental designs

- T-tests
- Correlation and regression
- Single factor Anova
- Anova