CS 598 ACK
Experimental HCI & Interactive Technologies

Text Chapter 5

Statistics (6 of 6)
REMINDER: “In the final optional analysis step, the effect of factors other than the independent variable can be investigated.”

**STEP 4:** Split the data so as to investigate more specific research questions (factor analysis).

The analysis so far has focused on determining whether the set of predefined conditions (the independent variables) have had any effect on the dependent variable. But results plus experience gained from running the experiment may prompt us to investigate the data in a more detailed way.

If so, we now consider extending the definition of “independent variables” to include other variables or factors. In doing so, we define the primary independent variable as the set of conditions relating to the original research question to distinguish it from these other (new) factors.
Post-hoc Extension of Independent Variables to Include Other Factors:

This is “Factor Analysis” – In contrast with the statistical techniques to be discussed on forthcoming slides, note it is post-hoc, and we have discussed two ways of going about it:

1. Focusing on the primary research question first, and then investigating all possible statistics for all combinations of factors, to find those that are interesting (i.e., performing a multiway factor analysis).

2. Focusing on the primary research question first, and then investigating other factors as necessary (i.e., performing a selective factor analysis).

   This approach entails devising appropriate and interesting secondary research questions, and investigating each of these in turn, producing those statistics relevant to these secondary research questions.
First, we distinguish (linear) regression from the other techniques:

In regression, the goal is to create a statistical model that best describes the effect of multiple independent variables, which are typically (but not always – hang on!) real-valued, on a real-valued dependent variable. The format is:

\[ y_i = \sum_{j=0}^{M} \beta_j x_{ij} + \varepsilon_i \]

- \( y_i \): dependent variable
- \( \beta_j \): regression coefficients
- \( x_{ij} \): the \( j \)'th variable at observation \( i \)
- \( \varepsilon_i \): residual variable

\( i = 1 \ldots N \) (number of observations)
\( j = 0 \ldots M \) (number of ind. variables)
First, we distinguish (linear) regression from the other techniques:

For a single independent variable, we can intuitively see the nature of the technique – minimization of the sum of least squared error:
Regression, Factor Analysis, ANOVA, ANCOVA, MANOVA, MANCOVA

In contrast to Regression, the goal of all of the remaining techniques is to create a statistical model that best describes the effect of multiple independent variables, which are typically (but not always – hang on!) categorical (levels of a factor), on a real-valued dependent variable.

The foundation for all these techniques is ANOVA.

Both Factor Analysis and the remaining techniques rely on ANOVA, yet Factor Analysis is distinguished from the others in that it’s a sequential process for investigating the effect of factors in addition to the central independent variable of interest that were identified in a post-hoc fashion. All the others are single-pass techniques for investigating the effects of multiple factors or independent variables identified to be of interest prior to experimentation.
ANOVA comes in “N-way” varieties:

**One-way ANOVA Example**

- College Degree
- Graduate Degree
- High School

**Two-way ANOVA Example**

- High School
- Graduate Degree

**ONE-WAY ANOVA** has one continuous response variable (e.g. test score) compared by three or more levels of a factor variable (e.g. level of education).

**TWO-WAY ANOVA** has one continuous response variable (e.g. test score) compared by more than one factor variable (e.g. level of education and zodiac sign).
Regression, Factor Analysis, ANOVA, ANCOVA, MANOVA, MANCOVA

ANCOVA:

The difference between ANOVA and ANCOVA is the letter "C", which stands for 'covariance'. Like ANOVA, "Analysis of Covariance" (ANCOVA) has a single continuous response variable.

Unlike ANOVA, ANCOVA compares a response variable by both a factor and a continuous independent variable (e.g. comparing test score by both 'level of education' and 'number of hours spent studying'). The term for the continuous independent variable (IV) used in ANCOVA is "covariate".
ANC OV A EX A M P L E

**Independent Variables**

(Factor)
- Level of Education (High School, College Degree, or Graduate Degree)

(Covariate)
- Number of Hours Spent Studying

**Dependent Variable**

(Response)
- Test Score

ANCova compares a continuous response variable (e.g., test score) by levels of a factor variable (e.g., level of education), controlling for a continuous covariate (e.g., number of hours spent studying).
Regression, Factor Analysis, ANOVA, ANCOVA, MANOVA, MANCOVA

MANOVA:

The difference between ANOVA and a "Multivariate Analysis of Variance" (MANOVA) is the “M”, which stands for multivariate.

In basic terms, A MANOVA is an ANOVA with two or more continuous response variables. Like ANOVA, MANOVA has both a one-way flavor and an N-way flavor.

The number of factor variables involved distinguish a one-way MANOVA from a two-way MANOVA.
Statistics (6 of 6)

Regression, Factor Analysis, ANOVA, ANCOVA, MANOVA, MANCOVA

ONE-WAY MANOVA EXAMPLE

Independent Variable
(Factor)
Level of Education
(High School, College Degree, or Graduate Degree)

Dependent Variables
(Response)
Test Score
Annual Income

TWO-WAY MANOVA EXAMPLE

Independent Variables
(Factor)
Level of Education
(High School, College Degree, or Graduate Degree)
Zodiac Sign

Independent Variables
(Factor)
Level of Education
(High School, College Degree, or Graduate Degree)
Zodiac Sign

Dependent Variables
(Response)
Test Score
Annual Income

ONE-WAY MANOVA COMPARES TWO OR MORE CONTINUOUS RESPONSE VARIABLES (E.G. TEST SCORE AND ANNUAL INCOME) BY A SINGLE FACTOR VARIABLE (E.G. LEVEL OF EDUCATION).

TWO-WAY MANOVA COMPARES TWO OR MORE CONTINUOUS RESPONSE VARIABLES (E.G. TEST SCORE AND ANNUAL INCOME) BY TWO OR MORE FACTOR VARIABLES (E.G. LEVEL OF EDUCATION AND ZODIAC SIGN).
MANCOVA:

Like ANOVA and ANCOVA, the main difference between MANOVA and MANCOVA is the “C,” which again stands for “covariance.”

Both a MANOVA and MANCOVA feature two or more response variables, but the key difference between the two is the nature of the IVs.

While a MANOVA can include only factors, an analysis evolves from MANOVA to MANCOVA when one or more covariates are added to the mix.
Regression, Factor Analysis, ANOVA, ANCOVA, MANOVA, MANCOVA

MANCOVA EXAMPLE

Independent Variables
(Factor)

Level of Education
(High School, College Degree, or Graduate Degree)

(Covariate)

Number of Hours Spent Studying

Dependent Variables
(Response)

Test Score

(Response)

Annual Income

MANCOVA COMPARES TWO OR MORE CONTINUOUS RESPONSE VARIABLES (E.G. TEST SCORES AND ANNUAL INCOME) BY LEVELS OF A FACTOR VARIABLE (E.G. LEVEL OF EDUCATION), CONTROLLING FOR A COVARIATE (E.G. NUMBER OF HOURS SPENT STUDYING).
However, a source of confusion arises, due to the fact that Regression is able to also accommodate (somewhat), in addition to the typically real-valued independent variables, categorical independent variables as well. These are typically called “dummy variables” where, for example, a value of 0 could stand for one level of an independent variable and a value of 1 could stand for a second value of the independent variable: e.g., 2 treatment levels of an I.D.
Regression, Factor Analysis, ANOVA, ANCOVA, MANOVA, MANCOVA

Also, a SECOND source of confusion arises, due to the fact that Regression is able to also accommodate (somewhat) categorical dependent variables as well. For example, the dependent variable \((y\) below) could be a 1 if it rains on a given day and 2 if it does not, and the independent \((x\) below) or “predictor” variables are numerical encodings of meteorological conditions the day prior.

Here, one uses LOGISTIC regression to handle non-normality in the D.V.
Regression, Factor Analysis, ANOVA, ANCOVA, MANOVA, MANCOVA

Which to Use When? From the following, Michelle Paret writes:

I personally prefer [ANCOVA, MANOVA, MANCOVA] because it offers multiple comparisons, which are useful if you have a significant categorical X with more than 2 levels. For example, suppose activity prior to sleep is significant. Comparisons will tell you which of the 4 levels—none, read a book, watch TV, surf the Internet—are significantly different from one another. [Unstated: with a real valued co- variate of activity duration].

Do people who watch TV sleep, on average, the same as people who surf the Internet, but significantly less than people who do nothing or read? Or, perhaps, are internet surfers significantly different from the other three categories? Comparisons help you detect these differences.

Previous Material Drawn From: http://www.statsmakemecry.com
Qualitative data obtained by interview or questionnaire, or by observation of the participants, can help in guiding the analysis by:

**Identifying potential outliers.** For example, a participant who was particularly confused about how to perform the tasks may say so in an interview. It may then be reasonable to eliminate these data.

**Revealing potentially important secondary factors.** For example, if participants said they found one task more difficult than the others, then selective factor analysis can be guided by knowledge of what factors (in this case, the task) might produce interesting results.

**Revealing possible confounding factors.** For example, if some participants reported that the light in the experimental room made it difficult to see the images on the screen in early morning sessions, then a factor analysis could reveal whether the results were affected by the confound.
It is unlikely that a full statistical analysis will be required for an evaluation that takes place as part of an iterative design cycle. Indeed, the analyses presented in this chapter assume the presence of an independent variable and a comparison between the values of the dependent variables associated with a set of conditions.

In the case where the system designers are interested in comparing different binary design decisions then the evaluation may include a comparative method and analysis.

It is unlikely, however, that a full and rigorous statistical experiment will be required for such software design decisions. Qualitative feedback from participants can in some cases be more useful than statistical analysis in informing subsequent design decisions.
It is easy to let getting statistical significance become the most important goal of your study, and to celebrate when the hard numerical data give you the magic $p < .05$ value.

However, a small significant effect should be treated with caution: if there is a statistically significant difference between the mean error rate of two conditions of 0.03 (say, 0.90 vs. 0.87), then although this shows that condition A may be better than condition B, it is only a small improvement.

This may not mean that condition A should always be recommended over B because any gains will be minimal. Similarly, a significant correlation coefficient of 0.15 represents only a small relationship between the two variables (even if it is significant).

STATISTICAL and PRACTICAL significance are related, but not identical (!)