Research through Design
- what is hard core science -

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Thinker versus Tinker

“There is nothing so practical as a good theory.”

"Don't worry about what anybody else is going to do... The best way to predict the future is to invent it. Really smart people with reasonable funding can do just about anything that doesn't violate too many of Newton's Laws!"

(1971)

Ludwig Boltzmann (1884-1906)

Alan C. Kay (1940-)
How do we get theories?

positivism:

\{\text{theory, model}\} \not\in \text{reality}

reality (t_1) \approx \text{reality (t_2)}

constructionism:

\{\text{theory, model}\} \in \text{reality}

reality (t_1) \neq \text{reality (t_2)}

What kind of knowledge?

Model-T

Test → Theory → Design → Test

Model-D

Theory → Design → Theory → Test
Paradigm and novelty

*Paradigm* is an unquestioned theory or set of beliefs, existing worldview (concept introduced by Thomas Kuhn in 1962).

Novel results outside the present paradigm are mainly rejected by the scientific community.
Three paradigms and major barriers

Science

Design

Engineering

Explaining the world

Changing the world

Objective

Subjective

Human Oriented

Technology Oriented
These persons really changed our world…

René Descartes (1596-1650)

Galileo Galilei (1564-1642)

Nikolaus Kopernikus (1473-1543)

Leonardo Da Vinci (1452-1519)

Christopher Columbus (1451-1506)

*most remarkable people*
“The task is not so much to see what no one yet has seen, but to think what nobody yet has thought about that which everybody sees…

But life is short, and truth works far and lives long: let us speak the truth.”

(1818)

Arthur Schopenhauer [1788 – 1860]
1492 – Conquest of paradise – the new world
So, what is TRUTH?

The meaning of the word truth extends from honesty, good faith, and sincerity in general, to agreement with fact or reality in particular.

The term has no single definition about which a majority of professional philosophers and scholars agree, and various theories of truth continue to be debated.

There are differing claims on such questions as what constitutes truth; how to define and identify truth; the roles that revealed and acquired knowledge play; and whether truth is subjective, relative, objective, or absolute.

From Wikipedia, the free encyclopedia
Correspondence theories state that true beliefs and true statements correspond to the actual state of affairs. This type of theory posits a relationship between thoughts or statements on the one hand, and things or objects on the other.

For coherence theories in general, truth requires a proper fit of elements within a whole system. Very often, though, coherence is taken to imply something more than simple logical consistency; often there is a demand that the propositions in a coherent system lend mutual inferential support to each other.

Social constructivism holds that truth is constructed by social processes, is historically and culturally specific, and that it is in part shaped through the power struggles within a community. Constructivism views all of our knowledge as "constructed," because it does not reflect any external "transcendent" realities (as a pure correspondence theory might hold).

Consensus theory holds that truth is whatever is agreed upon, or in some versions, might come to be agreed upon, by some specified group. Such a group might include all human beings, or a subset thereof consisting of more than one person.

Although there are differences in viewpoint among proponents of pragmatic theory, they hold in common that truth is verified and confirmed by the results of putting one's concepts into practice.

A logical truth (also called an analytic truth or a necessary truth) is a statement which is true in all possible worlds or under all possible interpretations, as contrasted to a synthetic claim (or fact) which is only true in this world as it has historically unfolded. Logical truths are necessarily true. A proposition such as “If p and q, then p.” and the proposition “All husbands are married.” are considered to be logical truths because they are true because of their meanings and not because of any facts of the world. They are such that they could not be untrue.

There are two main approaches to truth in mathematics. They are the model theory of truth and the proof theory of truth.
“But life is short, and truth works far and lives long…” Schopenhauer

“Time Saving Truth from Falsehood and Envy” François Lemoyne, 1737

<table>
<thead>
<tr>
<th>Ontological Reference</th>
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</thead>
<tbody>
<tr>
<td><strong>Real Being</strong></td>
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<tr>
<td><strong>Formal Being</strong></td>
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<tr>
<td><strong>Ideal Being</strong></td>
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<tr>
<td>Epistemo-logical Method</td>
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<td>Inference Concept</td>
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<td>Academic Paradigm</td>
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Analysis & Synthesis, Deduction & Induction

*Analysis* (reduction): Separating of any material or abstract entity into its constituent elements.

*Synthesis*: Combining of the constituent elements or separate material or abstract entities into a single or unified entity.

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*Deduction*: A form of inference; if the premises are true, the conclusion must be true, i.e., deduction preserves the truth (equivalent to analysis).

*Scientific induction*: a form of inference in which the conclusion, though supported by the premises, does not follow from them necessarily, i.e., induction does not necessarily preserve the truth (equivalent to synthesis).
Bloom's Taxonomy

A Taxonomy for Learning, Teaching, and Assessing — A Revision of Bloom's Taxonomy of Educational Objectives;
Causation, science and common sense

• We have a somewhat problem free handle on talk about causes, effects and causal explanations.

• Example: The beer got me so drunk that I fell down the stairs causing a fracture in my leg. That explains why I am moving around using these crutches.

• In science, acknowledging causes and effects is central!
What are causes and effects?
Are there causes and effects?

- We would normally not question that there are causes and effects.

- There seems to be an apparent necessity in causal relationships.

- Causation reduces to spatiotemporal contiguity, succession and constant conjunction.

- Regularities are just things or processes that we see repeated in nature.

- We have no epistemic justification for saying that they are necessary.
The regularity view of causation

- \( c \) causes \( e \) iff
  1. \( c \) is spatiotemporally contiguous to \( e \)
  2. \( e \) succeeds \( c \) in time, and
  3. all events of type \( C \) (i.e., events that are like \( c \)) are regularly followed by or constantly conjoined with events of type \( E \) (i.e. events like \( e \))

  (This formulation can be found in Psillos, 2002, p.19)

- Our ‘received view’ of causation tells us that causation happens in virtue of ‘something else’.

- If \( c \) causes \( e \), it is because there is some real connection between \( c \) and \( e \) (that necessitates \( e \) happening when \( c \) happens).
Similarity between worlds and causation

- We evaluate worlds with regard to matters of fact and laws.
- Some of these matters of fact will be causal.
- Laws of nature are sometimes considered to be causal.
  - Whether objects fall to the ground will depend on whether they are supported.
  - How far you can jump will depend on whether the laws of gravitation hold.
- So, when we determine the truth conditions for certain counterfactuals we already have to assume that certain causal facts either obtain or do not obtain in the worlds we evaluate with regard to their similarity.
Three kinds of causality

- **weak causality**
  - same causes
  - same effects

- **strong causality**
  - similar causes
  - similar effects

- **chaotic behaviour**
  - similar causes
  - different effects

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To explain the world, we need to know...

- The cause(s) -- effect(s) relationship(s)
- Factors altering functional relationships
- Systematic context for that information
The basic idea in explaining the world...

Positivistic sciences

• An assumption of linear causality; there are no effects without causes and no causes without effects.  
  
  [Causality]

• A single, tangible reality "out there" that can be broken apart into pieces capable of being studied independently.  
  
  [Reductionism]

• The separation of the observer from the observed.  
  
  [Objectivity]
  
  – So that the results of an inquiry are essentially free from beliefs, interpretations, etc.

• What is true at one time and place will also be true at another time and place.  
  
  [Universality]
Principle of the minimum

“Ockham’s razor”:

- Elimination of superfluous concepts
  \(\text{pluralitas non est podenda sine necessitate}\)

- Scepticism

- Omnipotence principle

William of Ockham (c.1280 - c.1348)
Criteria for scientific theories

Agreement with data
- Falsifiability (hypothetico-deductive method)
- Repeatability and reproducibility

Coherence or unity
- Internal and external coherence (deductive structure)

Generality
- Parsimony or economy (Occam’s razor to find the simplest theory)

Fertility
- New implied discoveries
A scientific method is…

“a method of research, in which a problem is identified, relevant data are gathered, a hypothesis is formulated [= discovery], and the hypothesis is empirically tested [= verification]” [Random House 1999]

- **Problem** is a question proposed for solution or discussion.

- **Hypothesis** is a provisional theory suggested as a solution to the problem: either a causal or a non-causal correlation between variables.
Scientific methods

Nomothetic research (in natural sciences and engineering): the aim is to find general causal laws to explain phenomena, theories are usually axiomatic (deductive) systems or sets of models.

Constructive research (in engineering and design): the solution of the problem is not only shown to exist but it is also constructed.

Idiographic (ideographic) research trying to provide all possible explanations of a particular case, for example in history.
Scientific methods (cont’d)

**Action research** (in design sciences): the problem is solved by certain actions whose consequences are evaluated and new actions are specified (iterative improvement, trial and error).

**Case study** (in design sciences): an in-depth, longitudinal examination of a single instance or event, which is called a case.

**Questionnaire study** (in social sciences): a series of questions are used for the purpose of gathering information, which is usually analyzed statistically.
From question to answer

- Experience (analogies)
- Question (problem)
- Answer (hypothesis)
- Criticism (testing)

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>Problem</td>
<td>Conjecture</td>
</tr>
<tr>
<td>Science</td>
<td>Problem</td>
<td>Hypothesis</td>
</tr>
<tr>
<td>Engineering research</td>
<td>Problem</td>
<td>Solution</td>
</tr>
<tr>
<td>Engineering research</td>
<td>Objective</td>
<td>Goal</td>
</tr>
<tr>
<td>Development</td>
<td>Requirement</td>
<td>System specification</td>
</tr>
</tbody>
</table>
Now the big question is…

How to distinguish between
a causal correlation
and
a non-causal correlation?

**Answer:** the controlled experiment!
Experimental settings

Laboratory experiment

Experiments conducted in a controlled setting.

Field experiment

Tests conducted outside the laboratory in an actual environment, such as a marketplace.
Experiments have to demonstrate validity

Internal validity

The extent to which competing explanations for the results observed can be ruled-out.

External validity

The extent to which causal correlations measured can be generalized to outside persons, settings, and times.
What is an experiment?

An experiment:
A research approach in which one [or more] variable[s] are manipulated and the effect[s] on other variable[s] are observed.

Key variables:

Independent (IV): variables one controls directly such as price, packaging, distribution, product features, etc.;

Treatment (T): the independent variable manipulated during an experiment to measure its effect on the dependent variable;

Dependent (DV): variables one does not directly control such as sales or customer satisfaction - (might control them by manipulating the independent variable);

Extraneous (EF): factors one does not control but has to live with such as the weather.
Extraneous variables

**History:**
Intervention, between the beginning and end of an experiment, of outside variables that might change the dependent variable.

**Maturation:**
Changes in subjects occurring during the experiment that are not related to the experiment but which might affect subjects’ response to the treatment factor.

**Instrument variation:**
Changes in measurement instruments (*e.g.*, interviews or observers) that might affect measurements.

**Selections bias:**
Systematic differences between the test group and the control group due to a biased selection process.
Extraneous variables (cont’d)

Mortality:
Loss of test units or subjects during the course of an experiment - which might result in a nonrepresentativeness.

Testing effect:
An effect that is a by-product of the research process itself (e.g. ‘Hawthorne effect’).

Regression to the mean:
Tendency of subjects with extreme behavior to move towards the average for that behavior during the course of the experiment.
Controlling extraneous variables

Randomization:
The random assignment of subjects to treatment conditions to ensure equal representation of subject characteristics.

Physical control:
Holding constant the value or level of extraneous variables throughout the course of an experiment.

Test-design control:
Use of experimental design to control extraneous causal factors.

Statistical control:
Adjusting for the effects of extraneous variables by statistically adjusting the value or the dependant variable for each treatment condition.
Population

Definition

A population consists of all elements – individuals, items, or objects – whose characteristics are being studied.

The population that is being studied is also called the target population.

A portion of the population selected for study is referred to as a sample.
The random sample

Definition
A sample drawn in such a way that each element of the population has a chance of being selected is called a random sample. If the chance of being selected is the same for each element of the population, it is called a simple random sample.

An element or member of a sample or population is a specific subject or object (for example, a person, firm, item, state, or country) about which the information is collected.

A variable is a characteristic under study that assumes different values for different elements. In contrast to a variable, the value of a constant is fixed.

The value of a variable for an element is called an observation or measurement.
**Random sampling method**

<table>
<thead>
<tr>
<th>Population</th>
<th>Sample Method</th>
<th>Resulting Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>The population identified uniquely by number</td>
<td>Selection by random number</td>
<td>Every member of the population has an equal chance of being selected into the sample</td>
</tr>
</tbody>
</table>
Systematic sampling method

<table>
<thead>
<tr>
<th>Population</th>
<th>Sample Method</th>
<th>Resulting Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directory of the population (sample frame)</td>
<td>Selection via skip interval with a random starting point</td>
<td>Every member of the sample frame has an equal chance of being selected into the sample</td>
</tr>
</tbody>
</table>

- Skip interval
- Random start point

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Cluster sampling method

<table>
<thead>
<tr>
<th>Population</th>
<th>Sample Method</th>
<th>Resulting Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>The population in groups (clusters)</td>
<td>Random selection of 2 clusters with random selection of members of these clusters (2-stage)</td>
<td>Every cluster (A, B, C, D, or E) in the population has an equal chance of being selected into the sample, and every cluster member has an equal chance of being selected from that cluster</td>
</tr>
</tbody>
</table>
From sample to population

- Here is the problem: different samples \((S_x)\) drawn from the same population \((P)\) can have different properties.

- When you take a sample from a population, you only have a subset of the population--a piece of what you’re trying to understand.

The solution to this problem is called statistics, in particular inferential statistics!
What is statistics?

Definition

Statistics is a group of methods used to collect, analyze, present, and interpret data and to make decisions.

Types of Statistics:

Descriptive Statistics consists of methods for organizing, displaying, and describing data by using tables, graphs, and summary measures.

Inferential Statistics consists of methods that use sample results to help make decisions or predictions about a population.
What is a hypothesis?

We like to think of statistical hypothesis testing as the data analysis stage of an experiment, in which the scientist is interested, for example, in comparing the means of a population to a specified value (e.g. mean ‘usability’).

A statistical hypothesis is a statement about the parameters of one or more populations.
Testing statistical hypotheses

Figure 4-4 The critical region for $H_0: \mu = 50$ versus $H_1: \mu \neq 50$ and $n = 10$. 

$\alpha/2 = 0.0288$
One-sided and two-sided hypotheses

Two-Sided Test:

\[ H_0: \mu = \mu_0 \]
\[ H_1: \mu \neq \mu_0 \]

One-Sided Tests:

\[ H_0: \mu = \mu_0 \]
\[ H_1: \mu > \mu_0 \]

or

\[ H_0: \mu = \mu_0 \]
\[ H_1: \mu < \mu_0 \]
Outcomes of a statistical analysis

<table>
<thead>
<tr>
<th>H₀ True</th>
<th>H₁ True</th>
</tr>
</thead>
<tbody>
<tr>
<td>(no correlation)</td>
<td>(correlation)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision</th>
<th>Type II (beta error)</th>
<th>Correct decision</th>
<th>Type I (alpha error)</th>
<th>Correct decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not reject H₀ (not stat. sig.)</td>
<td>Correct decision</td>
<td>Type II (beta error)</td>
<td>Correct decision</td>
<td>Correct decision</td>
</tr>
<tr>
<td>Reject H₀ (stat. sig.)</td>
<td>Correct decision</td>
<td>Type II (beta error)</td>
<td>Correct decision</td>
<td>Correct decision</td>
</tr>
</tbody>
</table>
Errors in inference

- **Type I error**: Erroneously rejecting the null hypothesis. Your result is significant \((p < .05)\), so you reject the null hypothesis, but the null hypothesis is actually true.

- **Type II error**: Erroneously accepting the null hypothesis. Your result is not significant \((p > .05)\), so you don’t reject the null hypothesis, but it is actually false.
The analysis of variability…

Correlation is knowledge

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How to measure?

\[ N_x^c \quad \text{Nominal scale:} \quad = , \neq \]

\[ O_x \quad \text{Ordinal scale:} \quad = , \neq , > , < \]

\[ I_x \quad \text{Interval scale:} \quad = , \neq , > , < , - , + \]

\[ R_x \quad \text{Rational scale:} \quad = , \neq , > , < , - , + , \times , \div \]

Representing data as graphs

- Frequency Distribution Graph presents all the info available in a Frequency Table (can be fitted to a grouped frequency table)

- Uses Histograms
  - Bar width corresponds to real limits of intervals
  - Histograms can be modified to include blocks representing individual scores
Normal distribution

- Bell-shaped: specific shape that can be defined as an equation
- Symmetrical around the mid point, where the greatest frequency if scores occur
- Asymptotes of the perfect curve never quite meet the horizontal axis
- Normal distribution is an assumption of parametric testing
Different distribution shapes

Symmetrical distributions

Skewed distributions

Positive skew

Negative skew
Measures of central tendency

- A way of summarising the data using a single value that is in some way representative of the entire data set
  - It is not always possible to follow the same procedure in producing a central representative value: this changes with the shape of the distribution

- **Mode** [recommended for N-scale]
  - Most frequent value
  - Does not take into account exact scores
  - Unaffected by extreme scores
  - Not useful when there are several values that occur equally often in a set
Measures of central tendency (cont’d)

– **Median** [recommended for O-scale]
  • The values that fall exactly in the midpoint of a ranked distribution
  • Does not take into account exact scores
  • Unaffected by extreme scores
  • In a small set it can be unrepresentative

– **Mean** (Arithmetic average) [recommended for I-scale]
  • Sample mean: $M = \frac{\sum X}{n}$  
    Population mean: $\mu = \frac{\sum X}{N}$
  • Takes into account all values
  • Easily distorted by extreme values
Central tendencies and distribution shape

(a) Skewness

(b) Skewness
Describing variability

- Describes in an exact quantitative measure, how spread out/clustered together the scores are
- Variability is usually defined in terms of distance
  - How far apart scores are from each other
  - How far apart scores are from the mean
  - How representative a score is of the data set as a whole
In order to know whether a difference between two means is important, we need to know how much the scores vary around the means.
• Holding the difference between the means constant
• With high variability the two groups nearly overlap
• With low variability the two groups show very little overlap
Significance test: T-test

- The logic of the T-Test is simple
- The T statistic = the difference between the two group’s means divided by standard deviation of the difference.
T-test (cont’d)

- The formula for the standard deviation of the difference is very straightforward:

\[
\text{SE}(\bar{X}_T - \bar{X}_C) = \sqrt{\frac{\text{var}_T}{n_T} + \frac{\text{var}_C}{n_C}}
\]
T-test (cont’d)

- The final formula for the T statistic is:

\[ t = \sqrt{\frac{\text{var}_T}{n_T} + \frac{\text{var}_C}{n_C}} \]
Choosing a significance level

• In general
  – Pilot program and intervention evaluations use liberal significance levels (.2 - .1) to avoid discarding effective interventions.
  – Pure research uses conservative significance levels (.01-.001) to avoid wide dissemination of erroneous results.
Choosing a significance level (cont’d)

• The more conservative the Significance Level
  – The *less likely* we are to commit an Alpha Error
    (rejecting a true Null Hypothesis)
  – The *more likely* we are to commit a Beta Error
    (failing to detect a real difference)
Overview over inference tests

- $N^2 \times N^2$: Fisher’s exact test; Odds Ratio
- $N^x \times N^y$: CHI$^2$ (with $x>2$ and/or $y>2$)
- $N^2 \times O$: Mann-Whitney-U-test
- $N^2 \times I$: T-test
- $N_x^y \times I$: [M]Anova (with $x>1$ and/or $y>2$)
- $I_x \times N$: Discriminant analysis (with $x>1$)
- $O \times O$: Spearman’s rank correlation
- $I \times I$: Pearson correlation
- $N_x$: Cluster analysis (with $x>2$)
- $O_x$: Multidimensional scaling (with $x>2$)
- $I_x$: Factor analysis (with $x>2$)
Overview over the scientific approach

Problem

Initial data collection (literature review)

Tentative solution (hypothesis)

Analysis/simulations/experiments

System model (prototype)

Theory/paper (new knowledge)

Google scholar, Digital libraries, etc.

Your own conference or journal publication!
Thank you for your attention…

“Traditional scientific method has always been at the very best 20-20 hindsight. It’s good for seeing where you’ve been. It’s good for testing the truth of what you think you know, but it can’t tell you where you ought to go.”

Robert Pirsig, 1974
“Zen and the art of motorcycle maintenance”
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