Research through Design

- what is hard core science -

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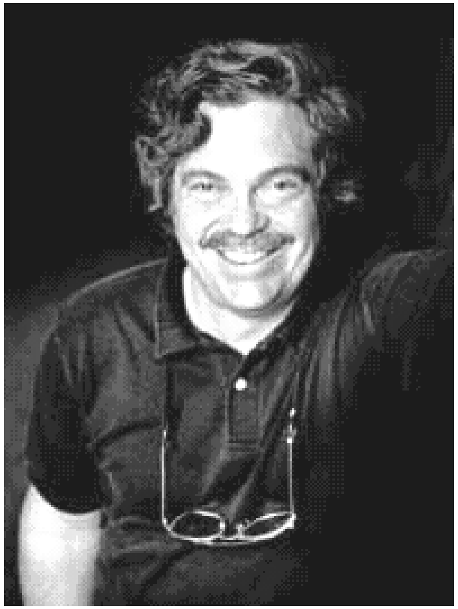
2011

Thinker versus Tinker

Ludwig Boltzmann (1884-1906)

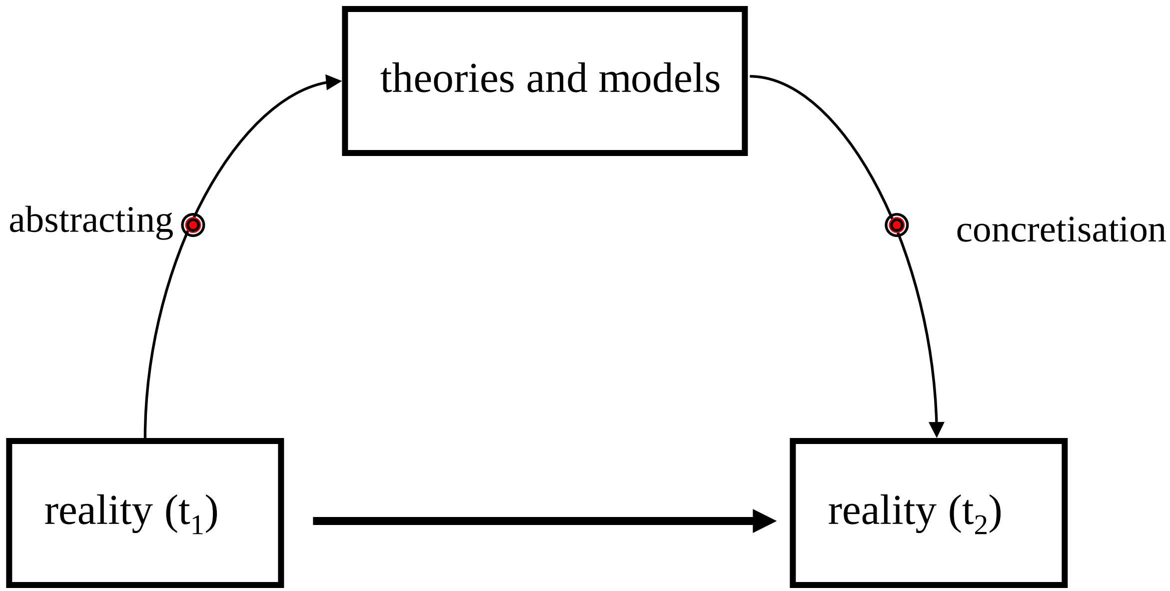
“There is nothing so practical as a good theory."

"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)



Alan C. Kay (1940-)

How do we get theories?



positivism :

$\{\text{theory, model}\} \notin \text{reality}$

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

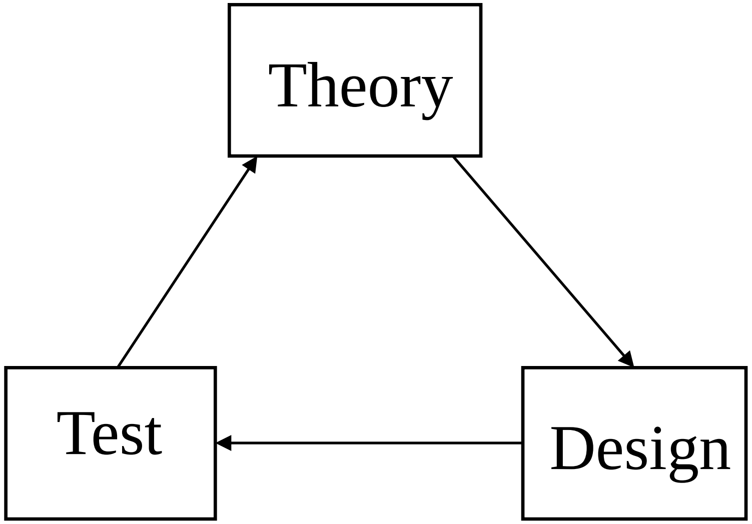
constructionism :

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

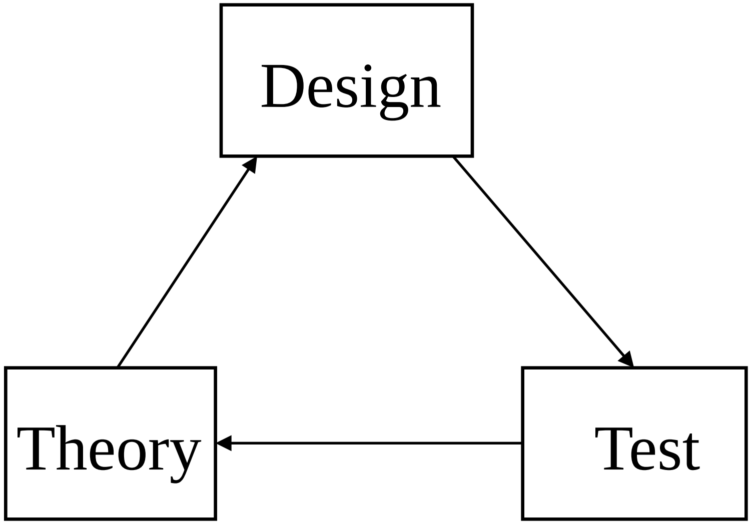
$\text{reality } (t_1) \neq \text{reality } (t_2)$

[REFERENCE: Rauterberg M. (2006). HCI as an engineering discipline: to be or not to be!?. *African Journal of Information and Communication Technology*, vol. 2, no. 4, pp. 163-184]

What kind of knowledge?

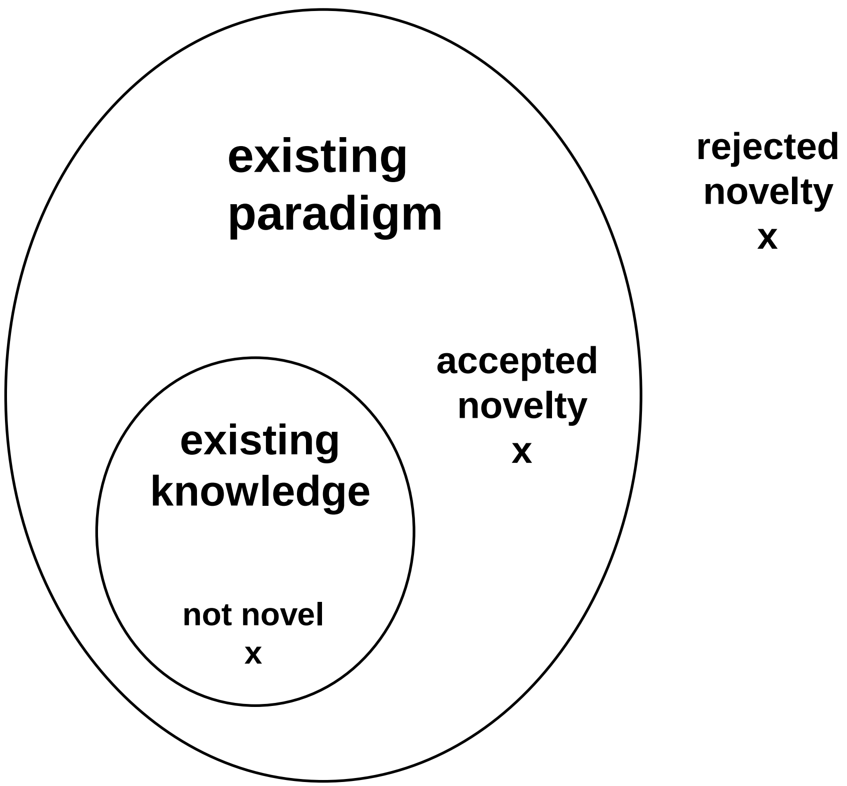


Model-T



Model-D

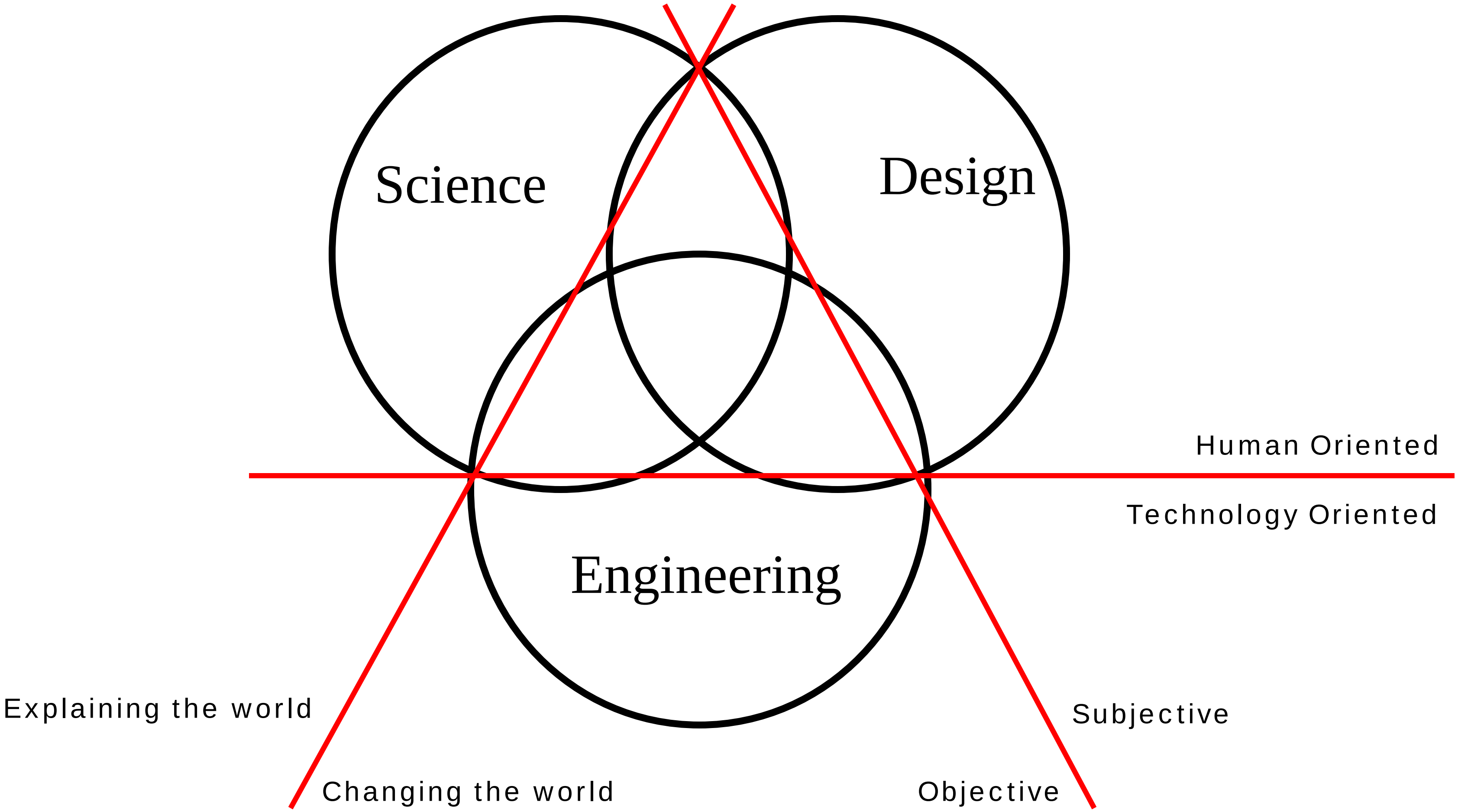
Paradigm and novelty



Paradigm is an un-questioned theory or set of beliefs, existing world-view (concept introduced by Thomas Kuhn in 1962).

Novel results outside the present paradigm are mainly rejected by the scientific community.

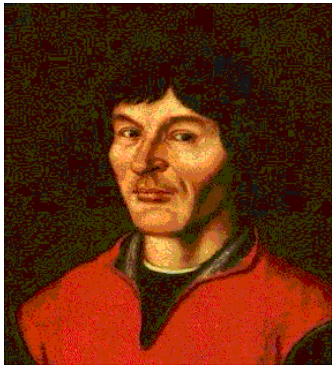
Three paradigms and major barriers



These persons really changed our world…

Christopher Columbus
(1451-1506)

Leonardo Da Vinci
(1452-1519)



Nikolaus Kopernikus
(1473-1543)

Galileo Galilei
(1564-1642)

René Descartes
(1596-1650)

most remarkable people

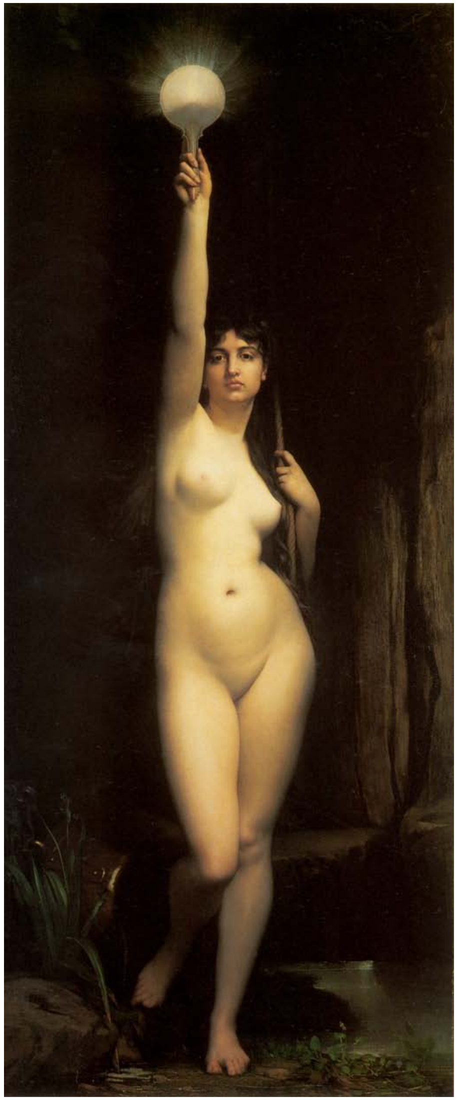
A deep insight…

Arthur Schopenhauer [1788 – 1860]

“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)

1492 – Conquest of paradise – the new world



La Vérité ("Truth")
Jules Joseph Lefebvre, 1870

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

	Ontological Reference		
	Real Being	**Formal Being**	**Ideal Being**
Epistemo-logical Method	Observation of Reality	Formal proof	Belief based on intuition
Inference Concept	Inductive logic	Deductive logic	Value system
Academic Paradigm	Natural Sciences	Mathe-matics	Humane Sciences

Analysis & Synthesis, Deduction & Induction

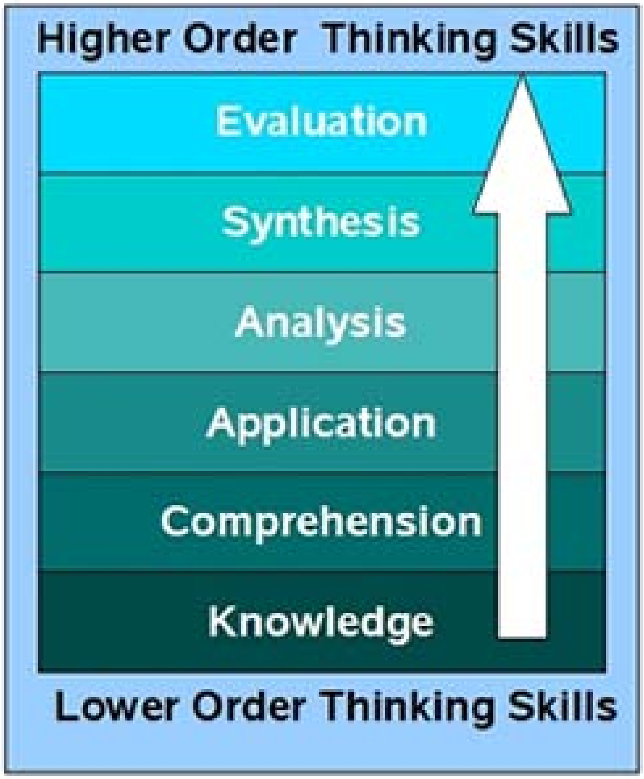
Analysis (reduction): Separating of any material or abstract entity into its constituent elements.

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

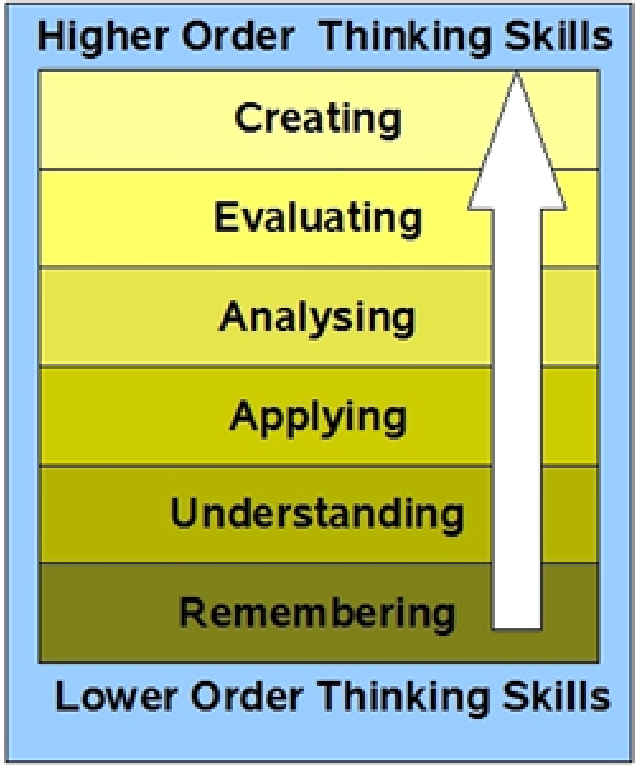
Deduction: A form of inference; if the premises are true, the conclusion must be true, i.e., deduction preserves the truth (equivalent to analysis).

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



Bloom's Revised Taxonomy



Taxonomy of Educational Objectives: The Classification of Educational Goals; pp. 201–207; B. S. Bloom (Ed.) Susan Fauer Company, Inc. 1956.

A Taxonomy for Learning, Teaching, and Assessing — A Revision of Bloom's Taxonomy of Educational Objectives; Lorin W. Anderson, David R. Krathwohl, Peter W. Airasian, Kathleen A. Cruikshank, Richard E. Mayer, Paul R. Pintrich, James Raths and Merlin C. Wittrock (Eds.) Addison Wesley Longman, Inc. 2001

Causation, science and common sense

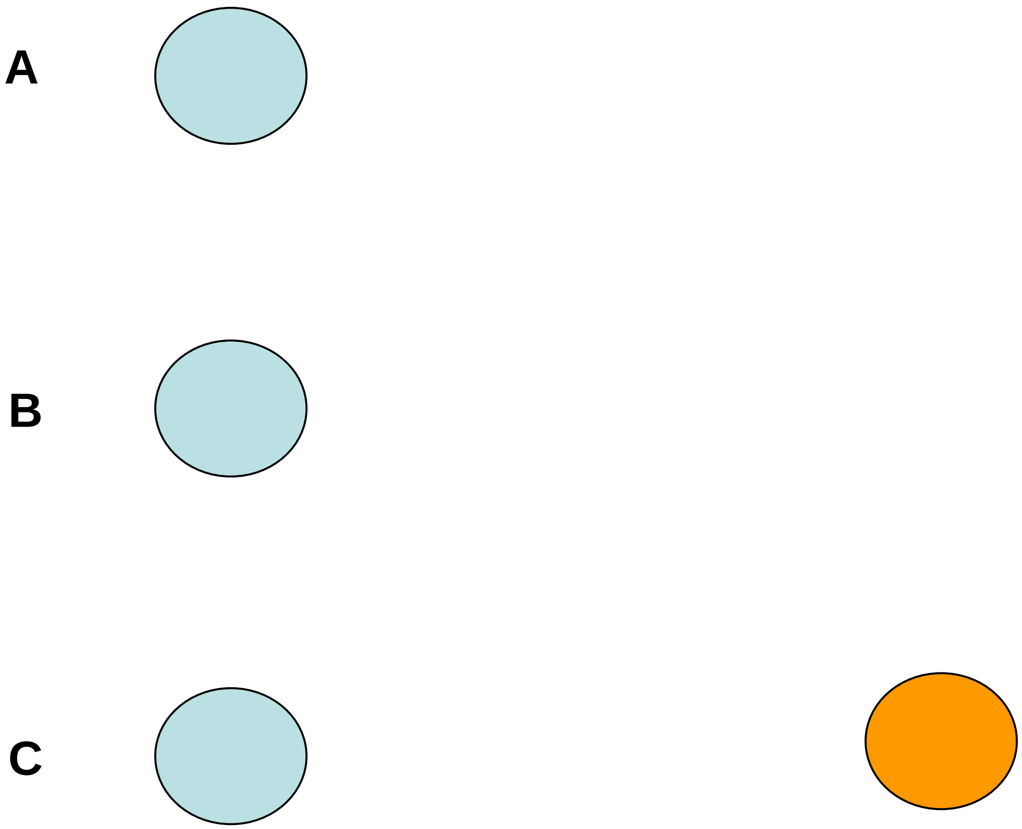
- We have a somewhat problem free handle on talk about causes, effects and causal explanations.

- 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

  (I) *c* is spatiotemporally contiguous to *e*

  (II) *e* succeeds *c* in time, and

  (III) 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’.

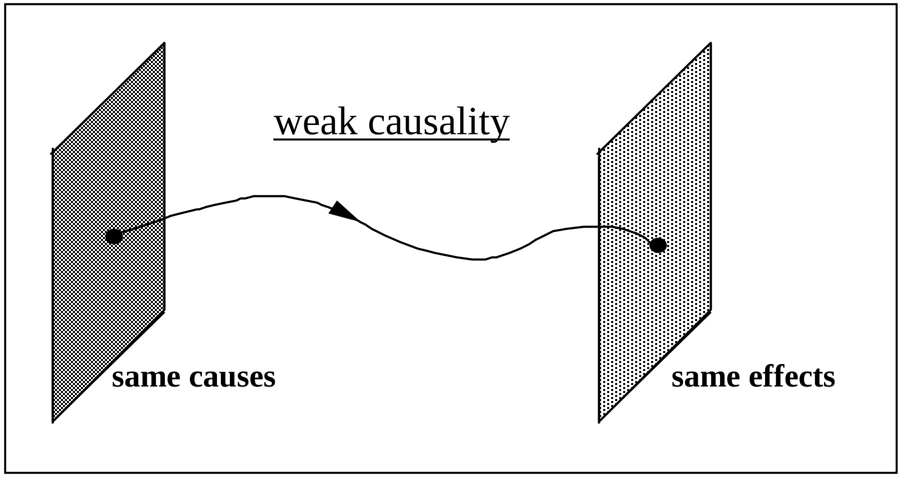
- If *c* causes *e*, it is because there is some real connection between *c* and *e* (that necessitates *e* happening when *c* happens).

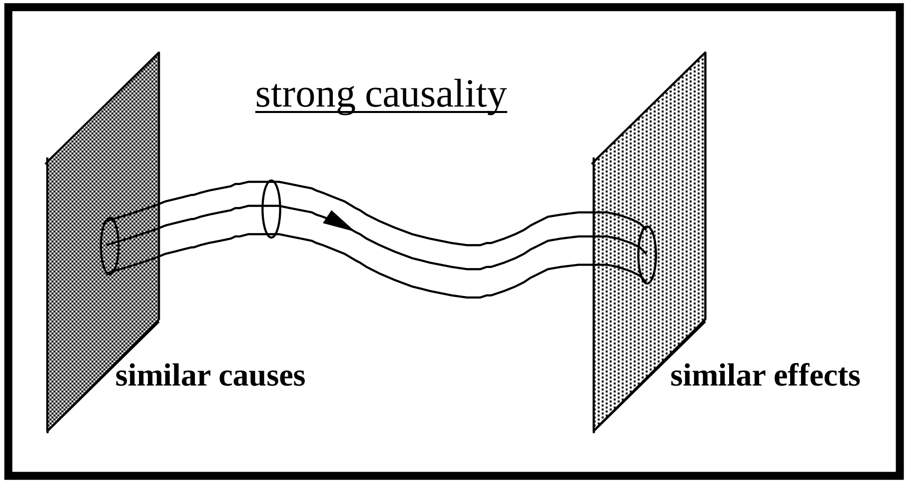
Similarity between worlds and causation

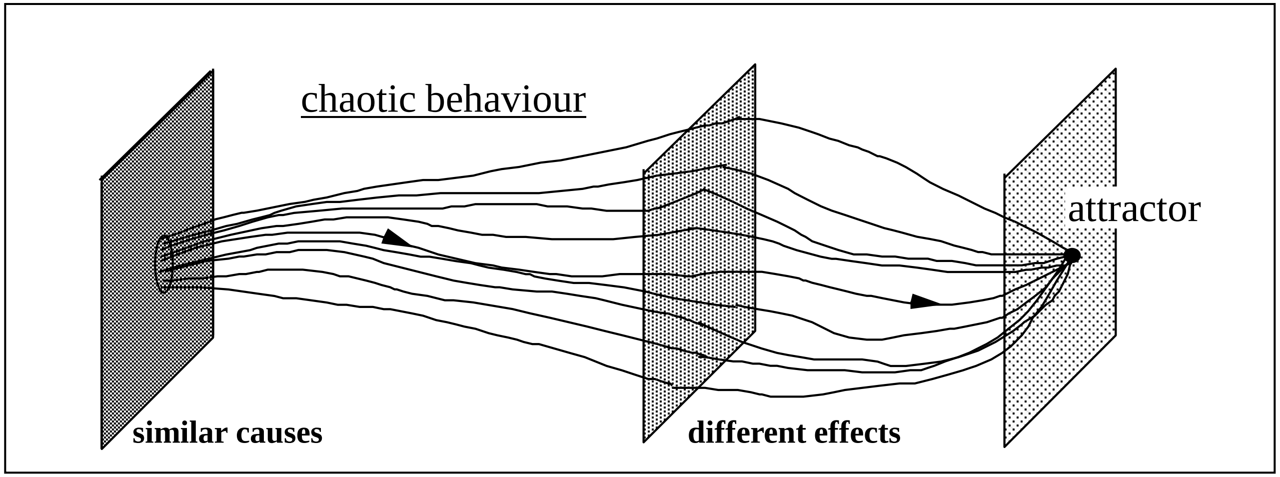
- We evaluate worlds with regard to matters of fact and laws.
- Some of these matters of fact will be causal.
- Laws of nature are sometimes considered to be causal.
  - Whether objects fall to the ground will depend on whether they are supported.
  - How far you can jump will depend on whether the laws 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

[Walter Seifritz (1987), Wachstum, Ruckkopplung und Chaos:
Eine Einfuhrung in die Welt der Nichtlinearitat und des Chaos . Carl Hanser]



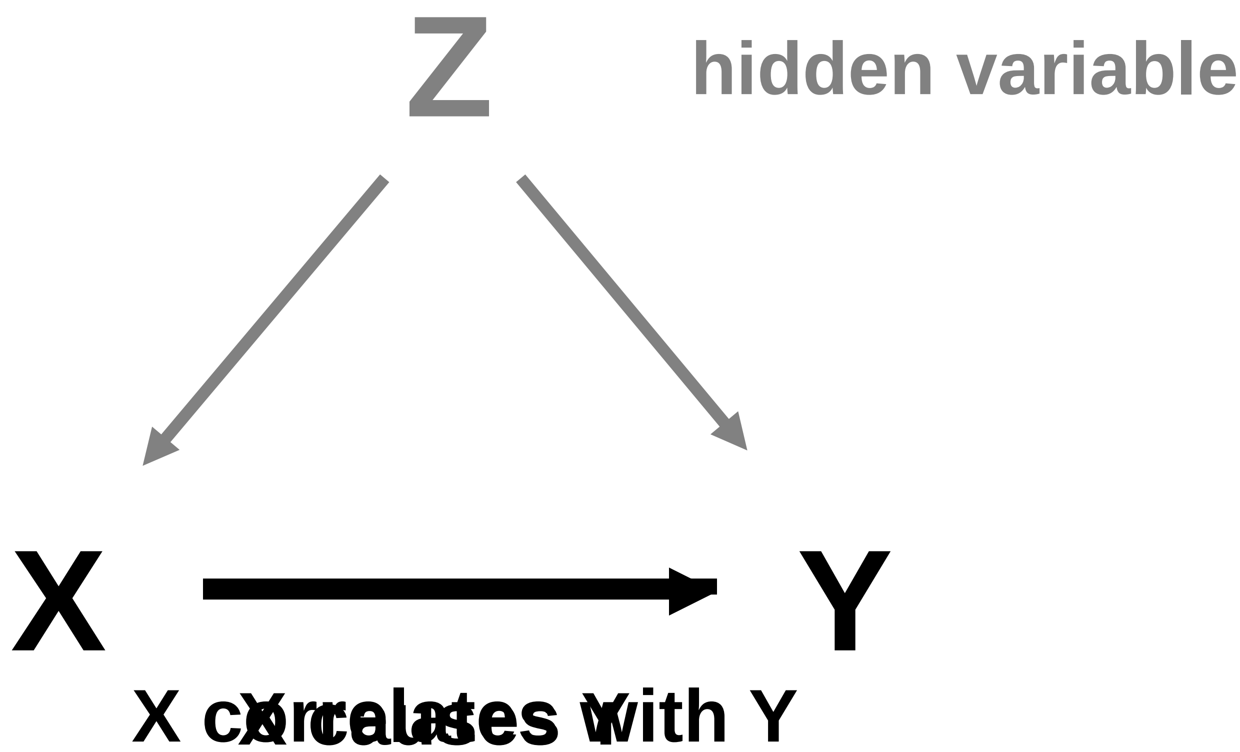




To explain the world, we need to know…

- The cause(s) -- effect(s) relationship(s)
- Factors altering functional relationships
- Systematic context for that information

The basic idea in explaining the world…



REF: Robert Mauro, Understanding L.O.V.E. (Left Out Variables Error): A Method for Estimating the Effects of Omitted Variables. *Psychological Bulletin*, Volume 108, Issue 2, September 1990, Pages 314-329

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

  (*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.

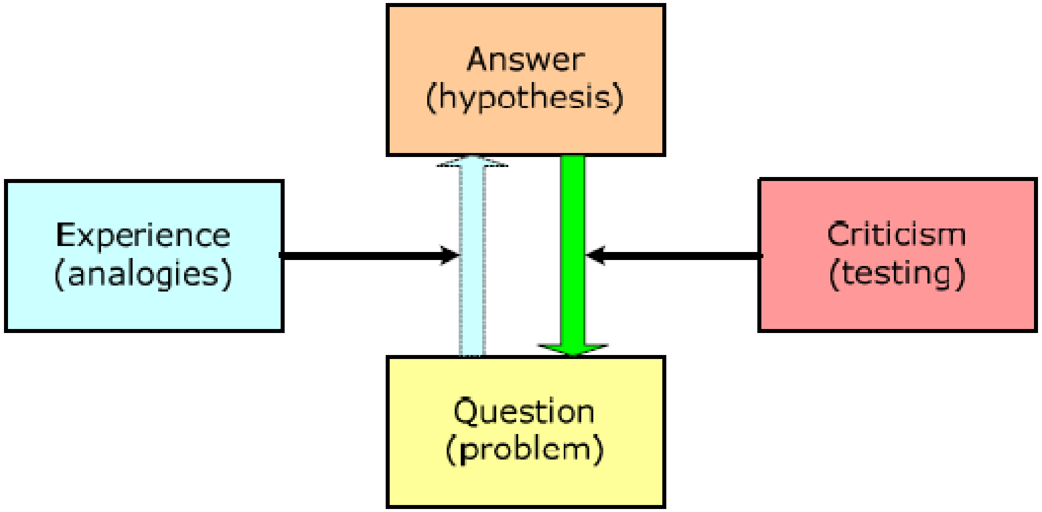
Scientific methods (cont'd)

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



Discipline	Question	Answer
Mathematics	Problem	Conjecture
Science	Problem	Hypothesis
Engineering research	Problem	Solution
Engineering research	Objective	Goal
Development	Requirement	System specification

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.

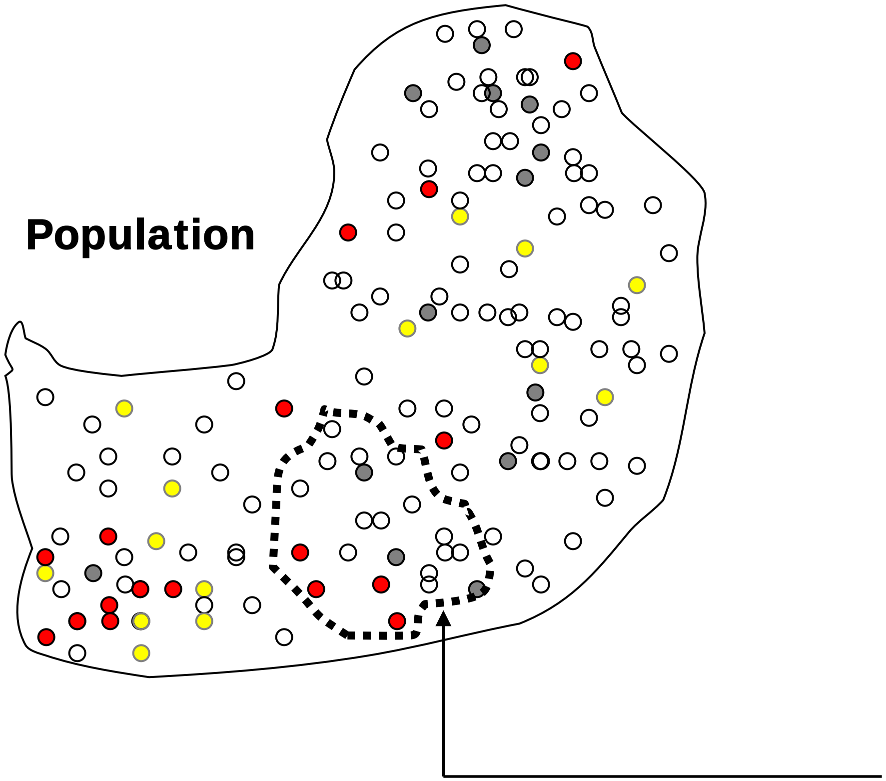
Test-design control:

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

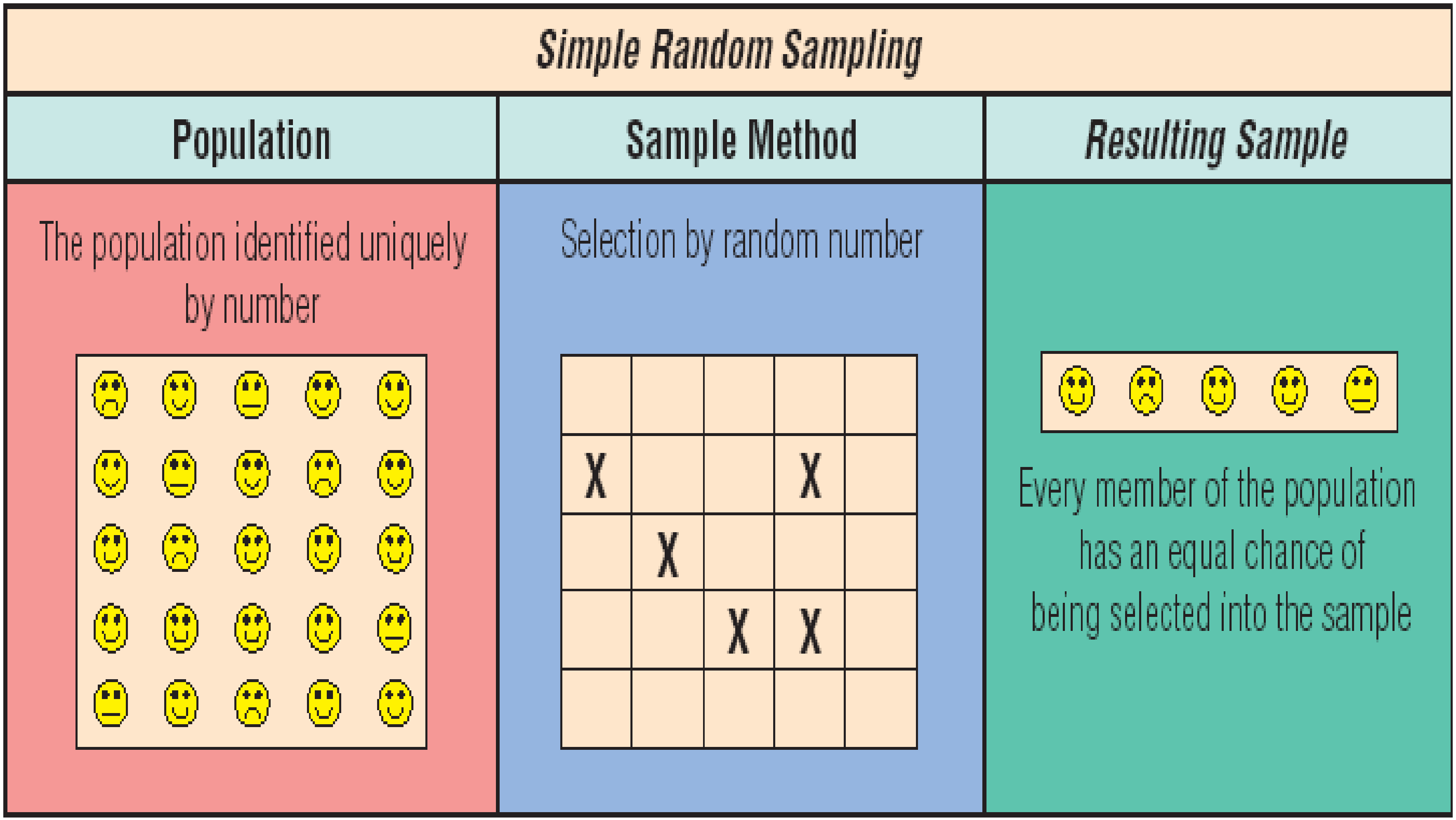
A sample drawn in such a way that each element of the population has a chance of being selected is called a ***random sample***. If the chance of being selected is the same for each element of the population, it is called a ***simple random sample***.

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.

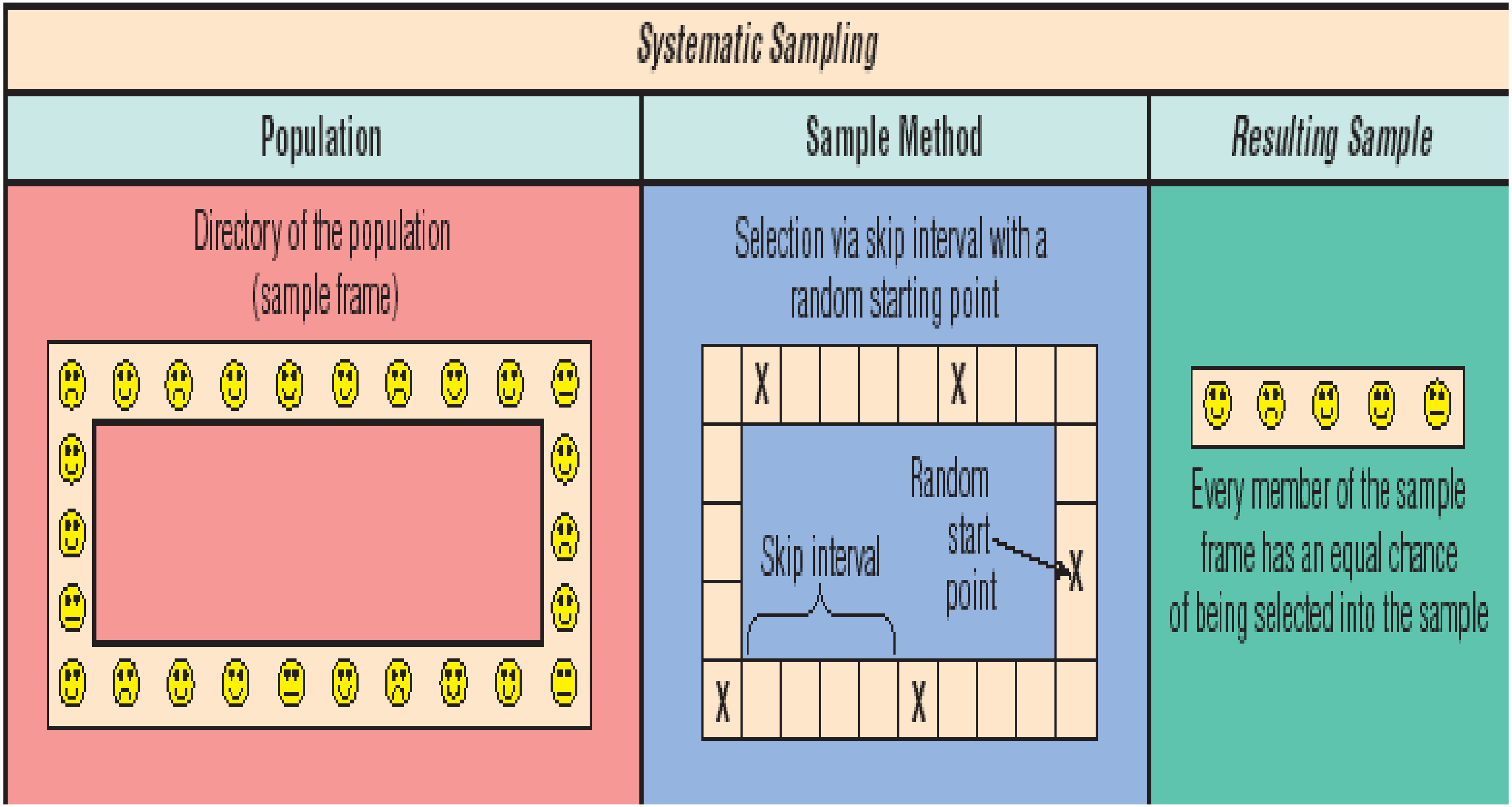
A ***variable*** is a characteristic under study that assumes different values for different elements. In contrast to a variable, the value of a ***constant*** is fixed.

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

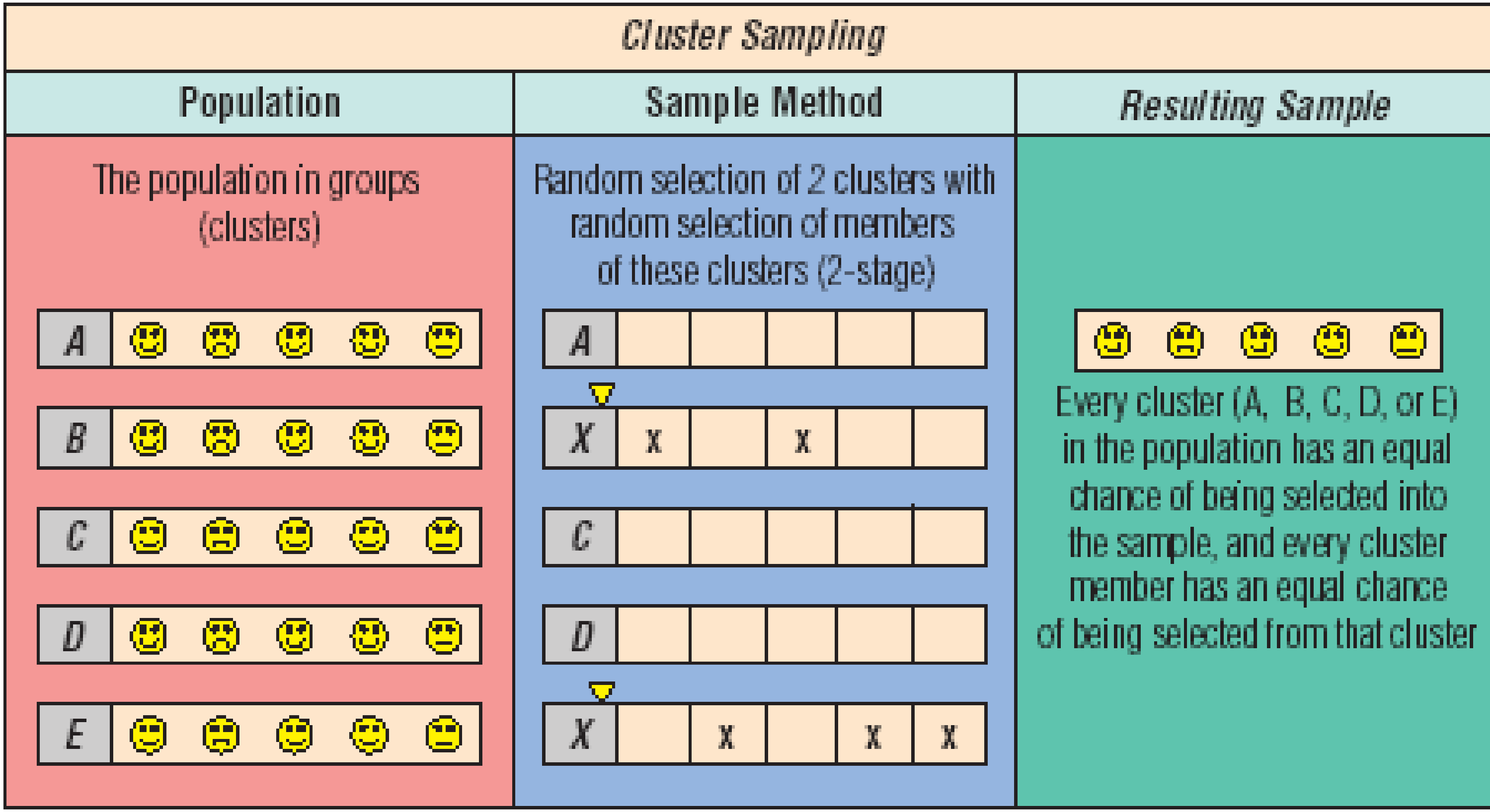
Random sampling method



Systematic sampling method



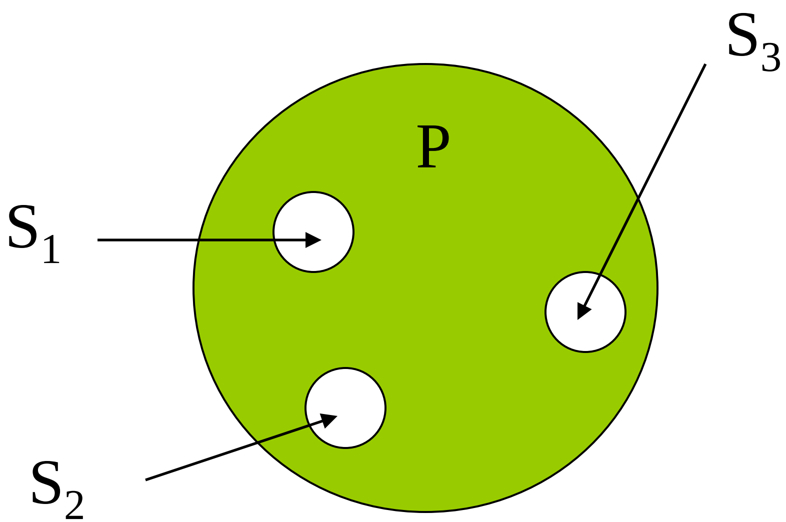
Cluster sampling method



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

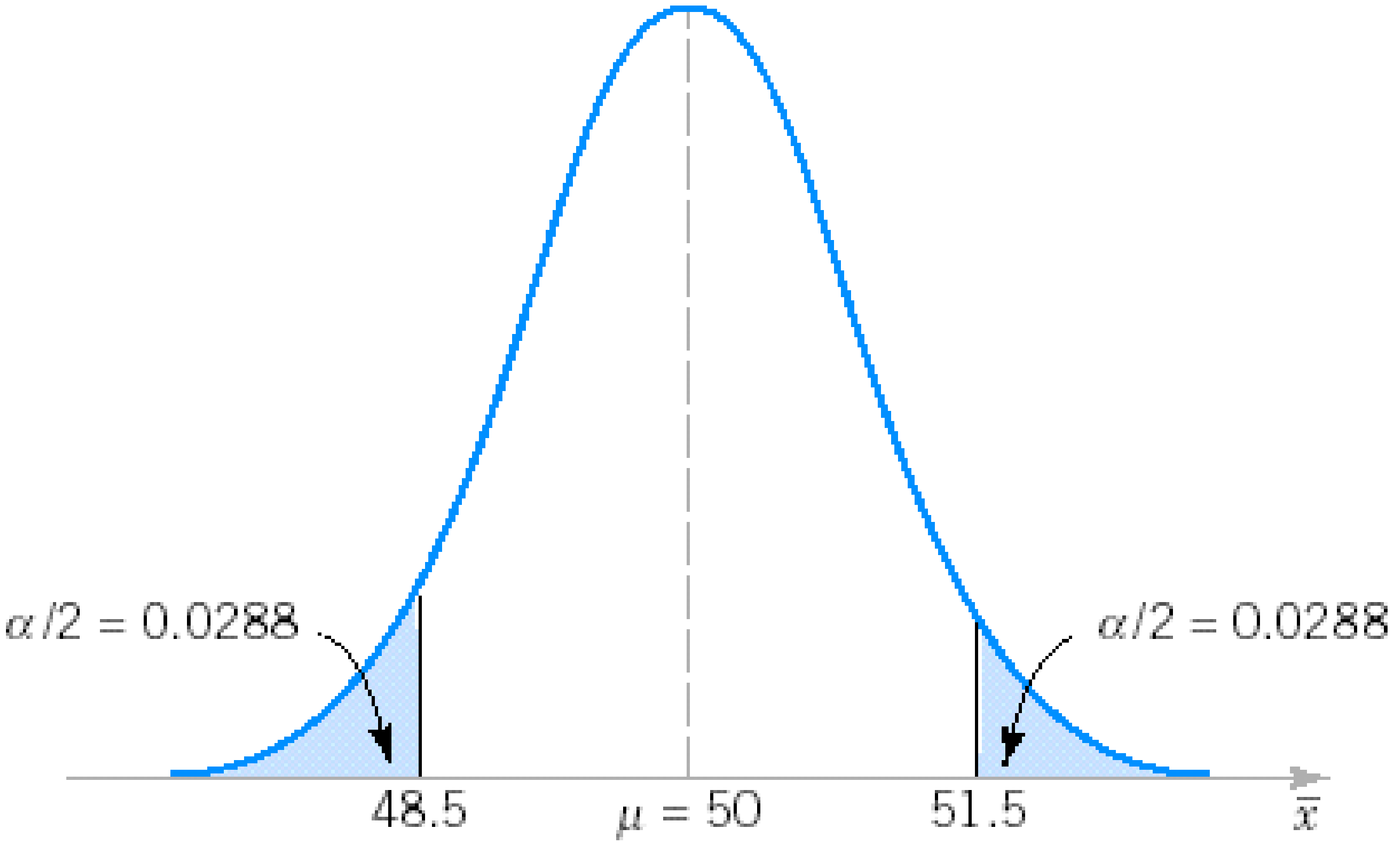


Figure 4-4 The critical region for H_0: $\mu = 50$ versus H_1: $\mu \neq 50$ and $n = 10$.

One-sided and two-sided hypotheses

Two-Sided Test:

$$H_0: \mu = \mu_0$$

$$H_1: \mu \neq \mu_0$$

One-Sided Tests:

$$H_0: \mu = \mu_0 \qquad\qquad H_0: \mu = \mu_0$$
$$\text{or}$$
$$H_1: \mu > \mu_0 \qquad\qquad H_1: \mu < \mu_0$$

Outcomes of a statistical analysis

	H_0 True (no correlation)	H_1 True (correlation)
Do not reject H_0 (not stat. sig.)	Correct decision	Type II (beta error)
Reject H_0 (stat. sig.)	Type I (alpha error)	Correct decision

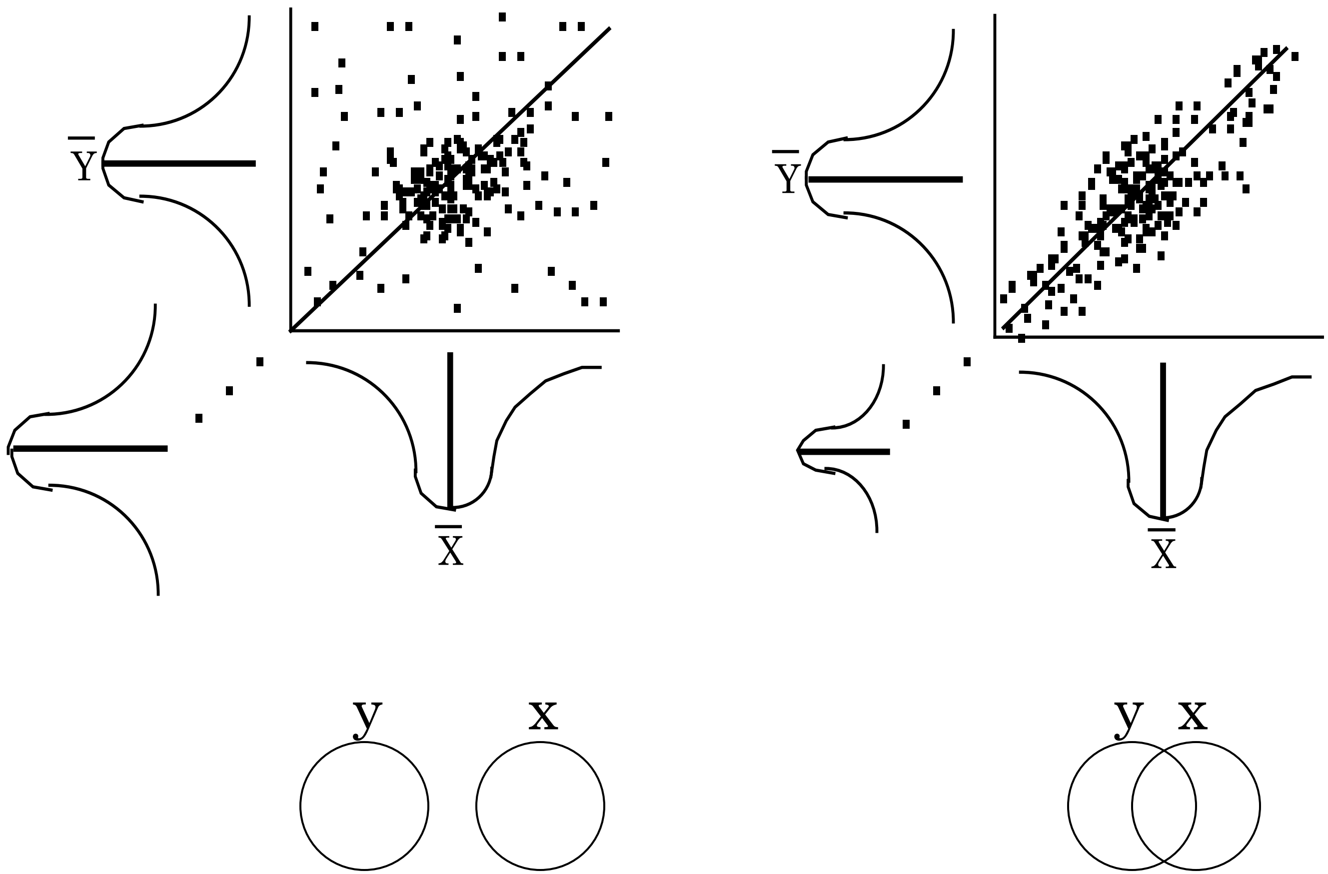
Errors in inference

- **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



How to measure?

N_x^c **N**ominal scale: **= , ≠**

O_x **O**rdinal scale: **= , ≠ , > , <**

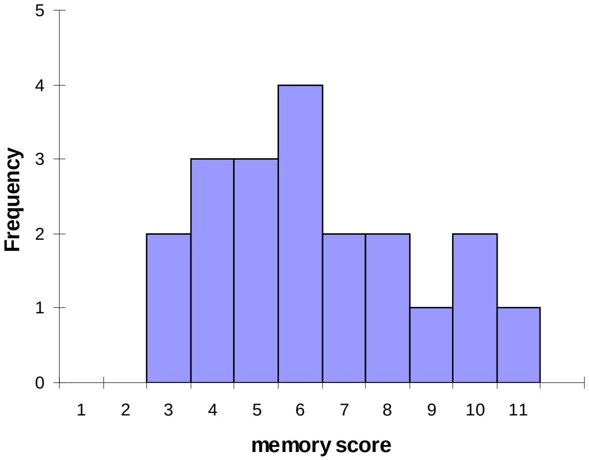
I_x **I**nterval scale: **= , ≠ , > , < , – , +**

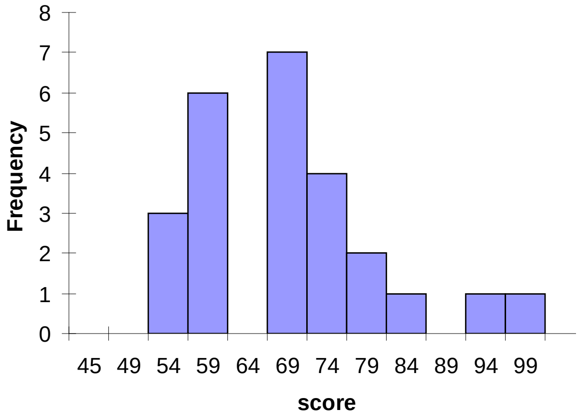
R_x **R**ational scale: **= , ≠ , > , < , – , + , × , ÷**

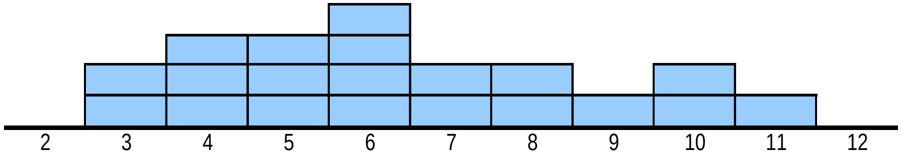
See further at ftp://ftp.sas.com/pub/neural/measurement.html

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

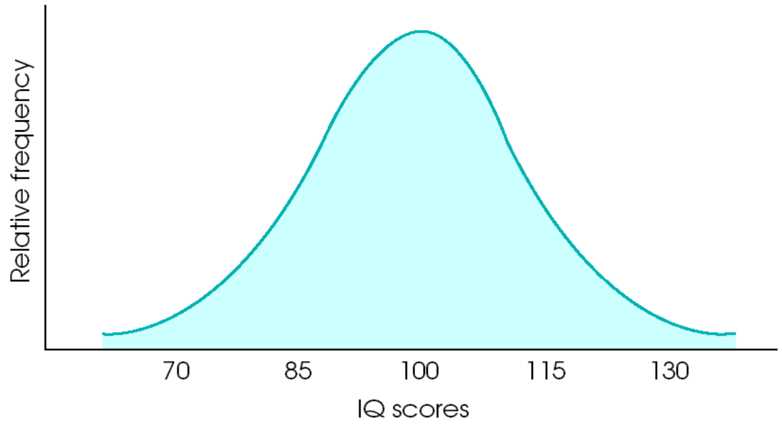






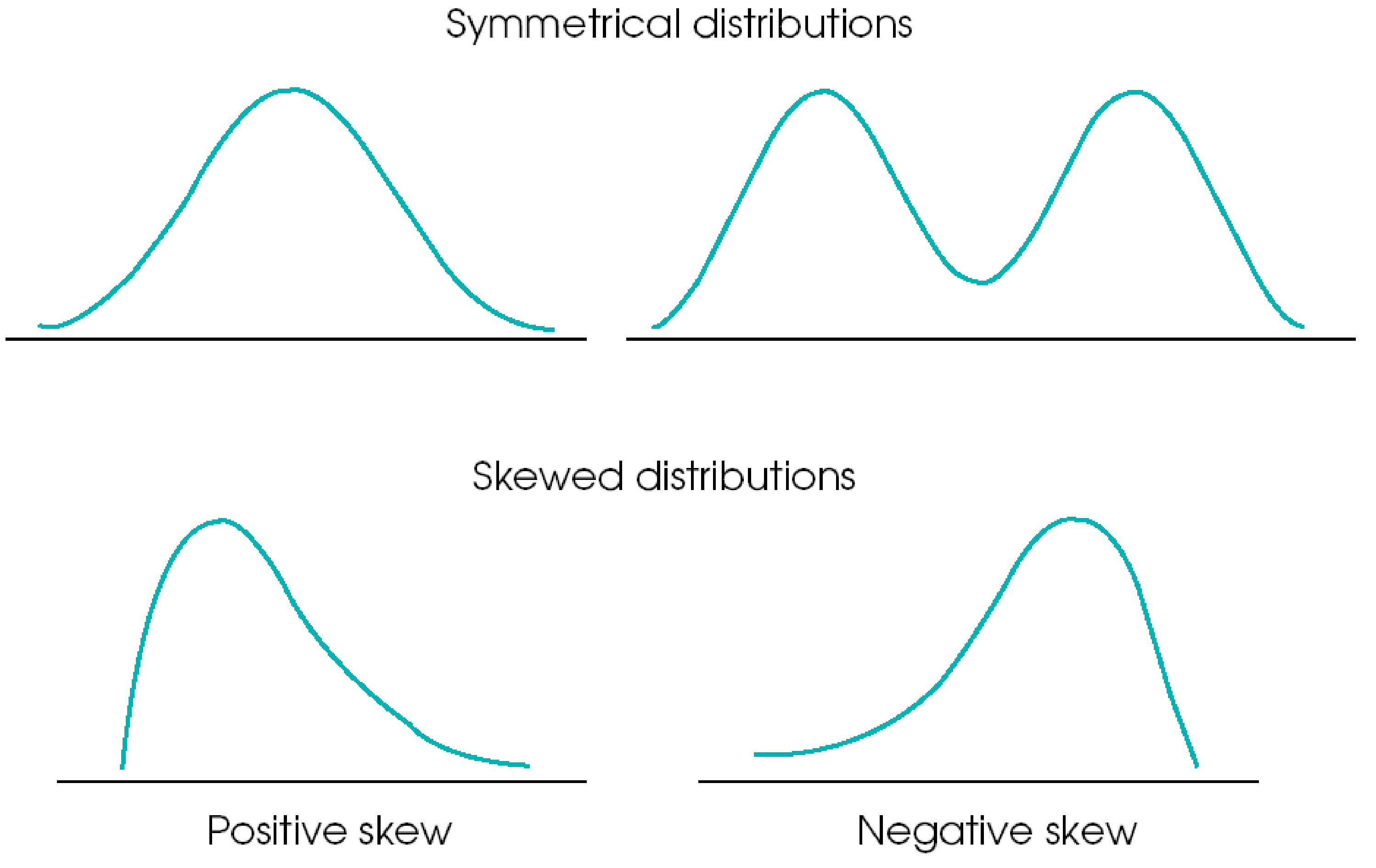
Normal distribution

– 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



Measures of central tendency

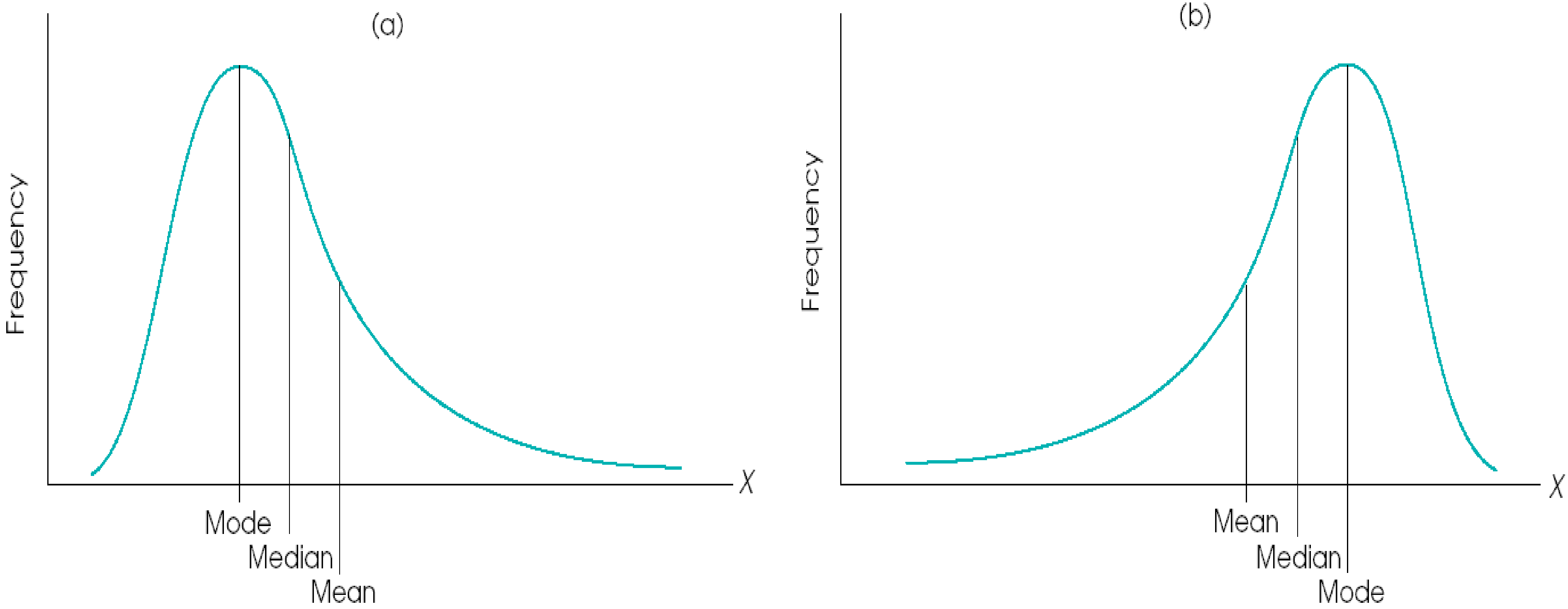
- A way of summarising the data using a single value that is in some way representative of the entire data set
  - It is not always possible to follow the same procedure in producing a central representative value: this changes with the shape of the distribution

- **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 falls 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: $M = \frac{\Sigma X}{n}$ Population mean: $\mu = \frac{\Sigma X}{N}$
  - Takes into account all values
  - Easily distorted by extreme values

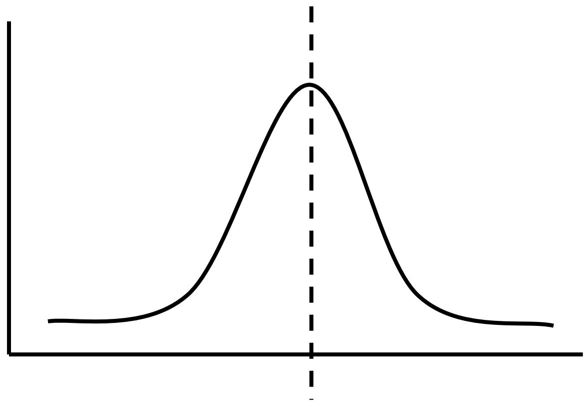
Central tendencies and distribution shape

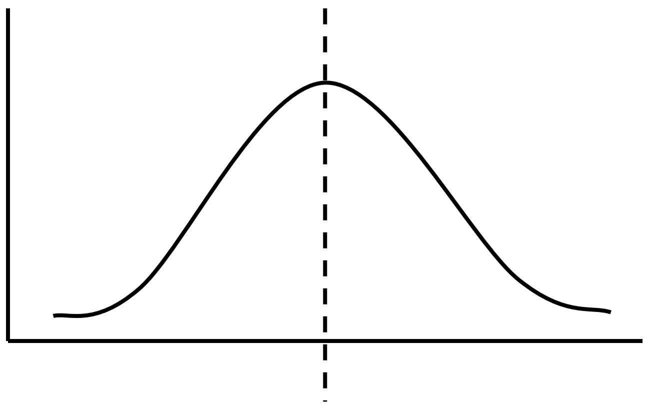


‘Skewness’

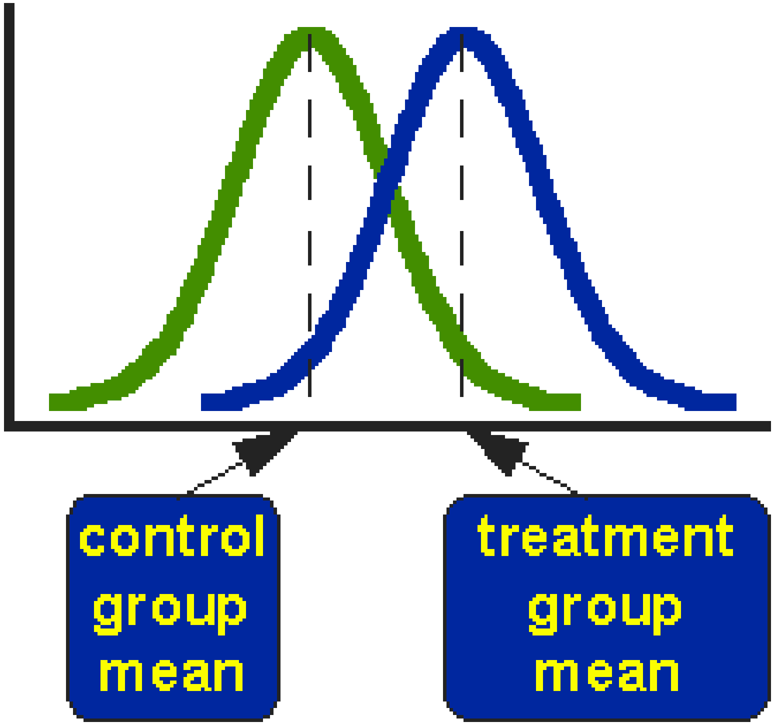
Describing variability

- 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



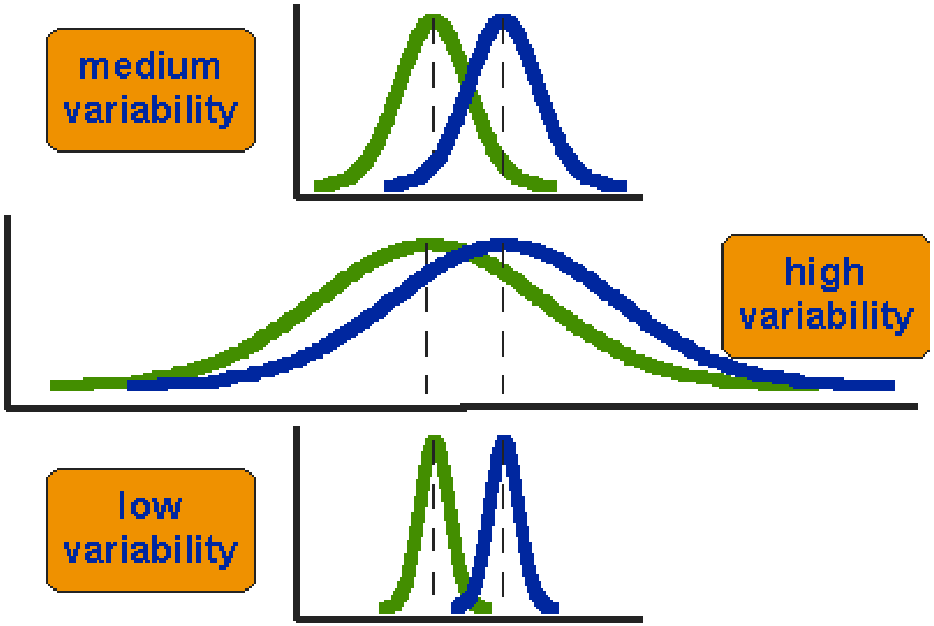


[N^2 * I] Differences in means



- In order to know whether a difference between two means is important, we need to know how much the scores vary around the means.

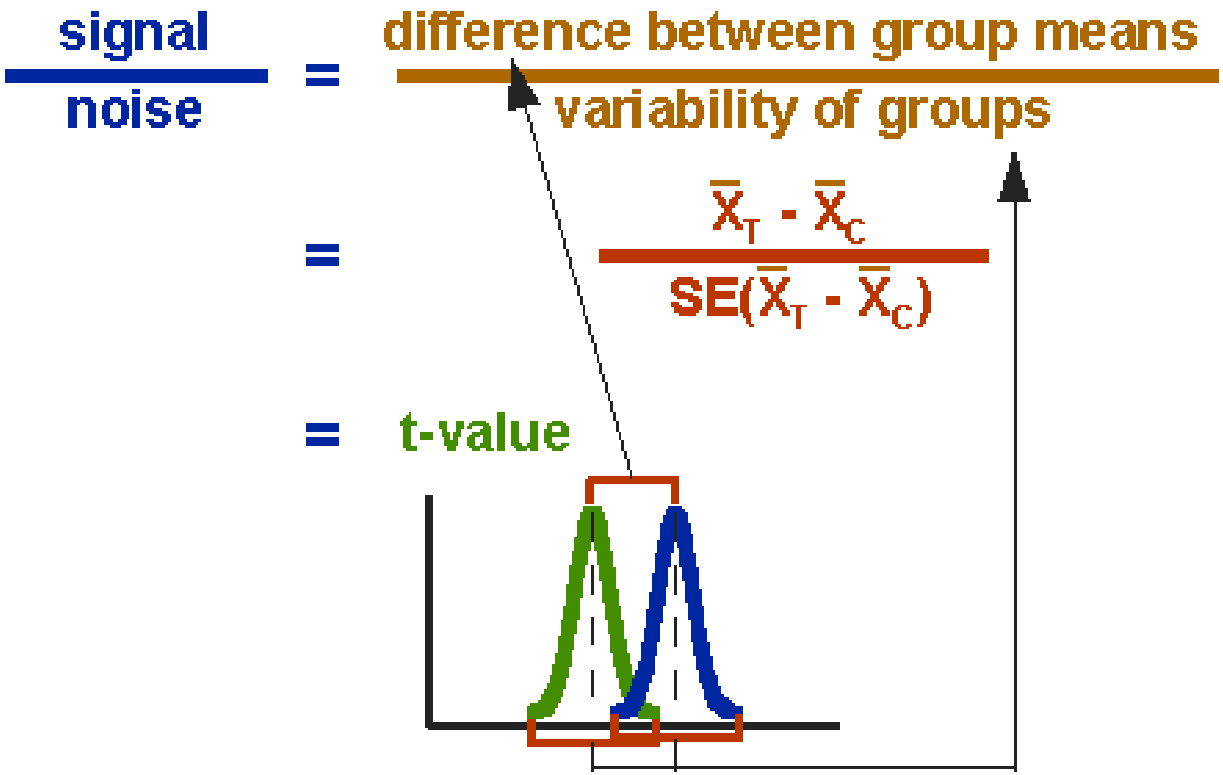
[N^2 * I] Differences in means (cont'd)



- 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:

$$SE(\bar{X}_T - \bar{X}_C) = \sqrt{\frac{var_T}{n_T} + \frac{var_C}{n_C}}$$

T-test (cont'd)

- The final formula for the T statistic is:

$$t = \frac{\bar{x}_T - \bar{x}_C}{\sqrt{\dfrac{var_T}{n_T} + \dfrac{var_C}{n_C}}}$$

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.

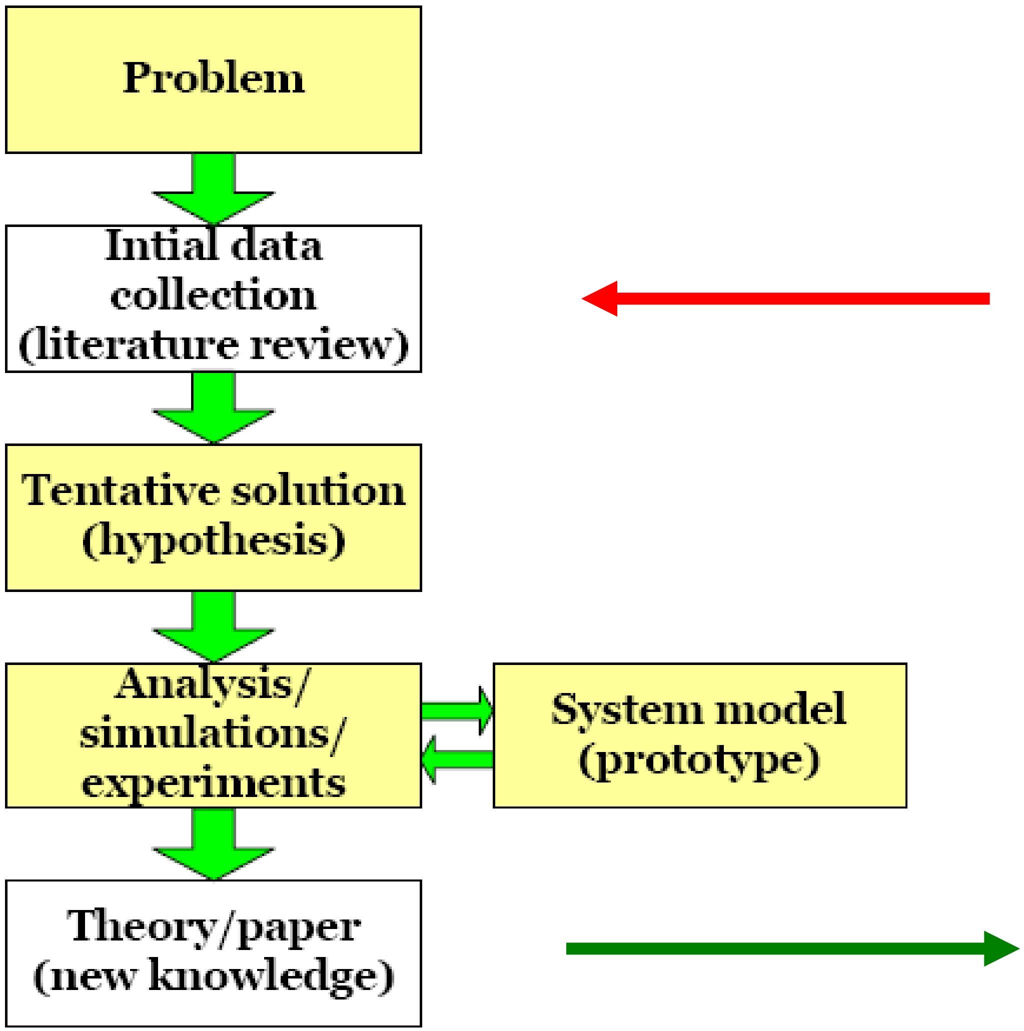
Choosing a significance level (cont'd)

- 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

$N^2 * N^2$	Fisher's exact test; Odds Ratio
$N^x * N^y$	CHI^2 (with $x>2$ and/or $y>2$)
$N^2 * O$	Mann-Whitney-U-test
$N^2 * I$	T-test
$N_x^y * I$	[M]Anova (with $x>1$ and/or $y>2$)
$I_x * N$	Discriminant analysis (with $x>1$)
$O * O$	Spearman's rank correlation
$I * I$	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



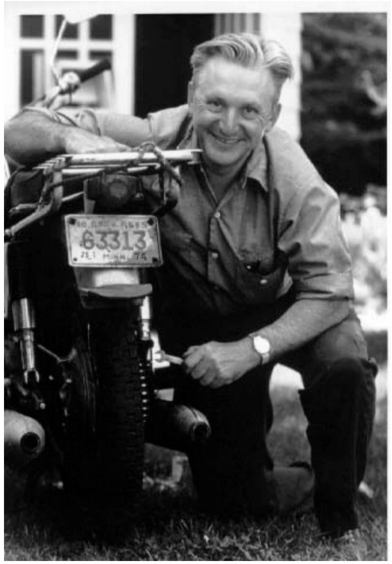
Google scholar, Digital libraries, etc.

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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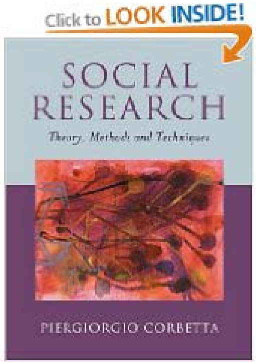

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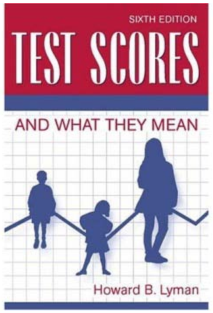

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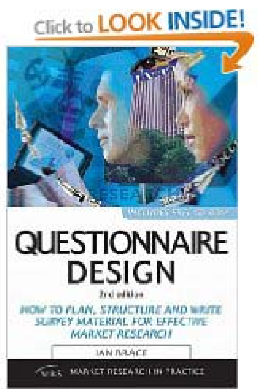

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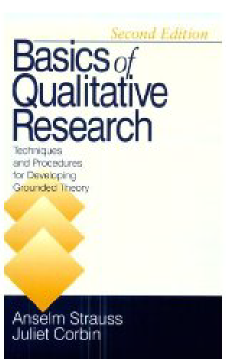

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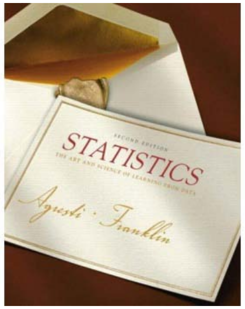

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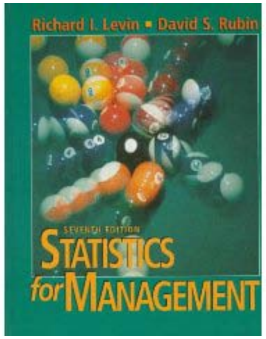

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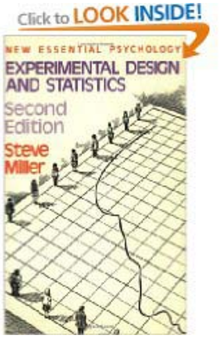

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