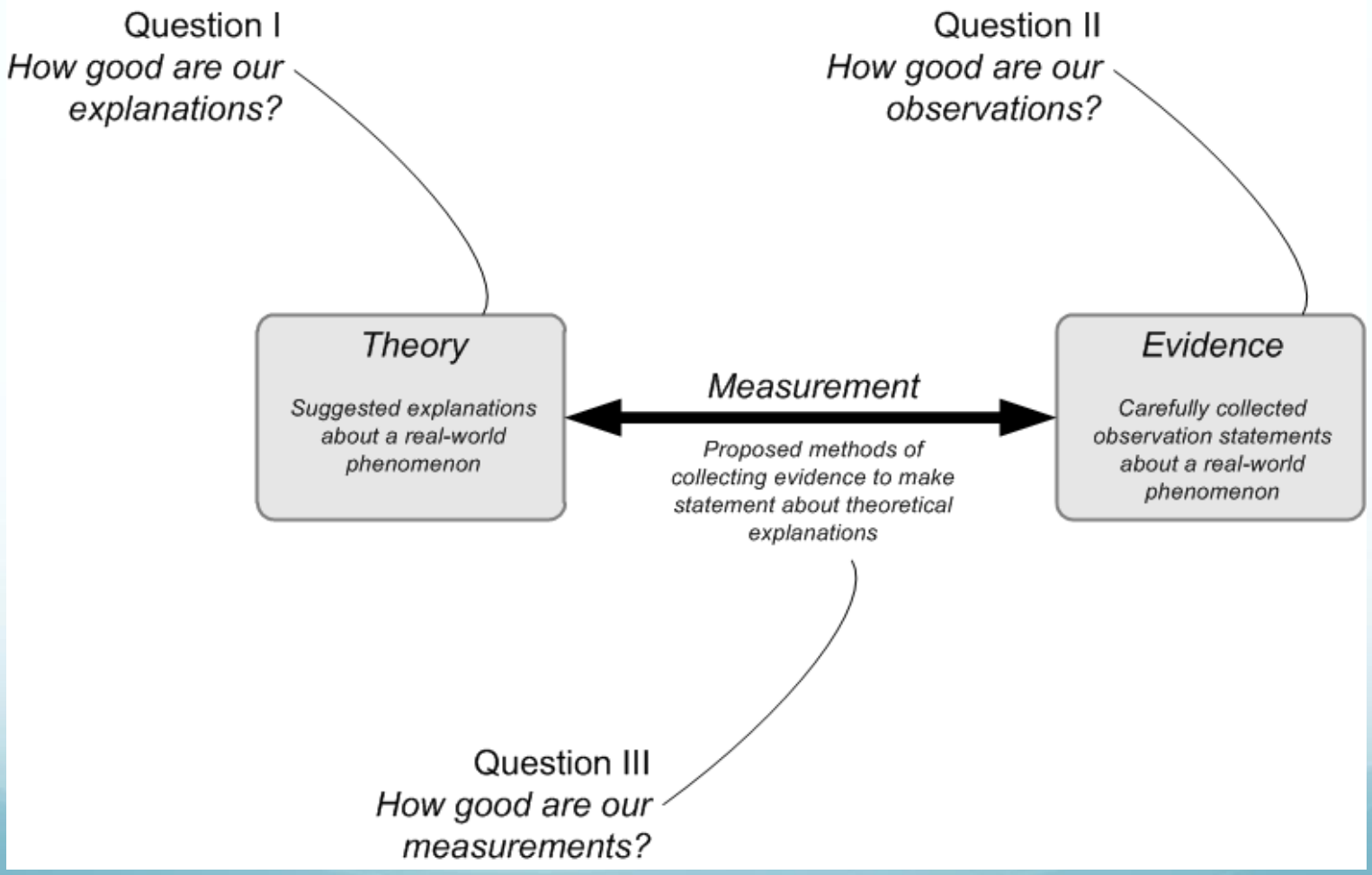
Scientific Method and Experimental Design

Introduction to Scientific Processing

What is the body of knowledge?



What is the Scientific Method?

What is the Scientific Method?

- The Process by which scientists try to construct an accurate representation world
- It's a PROCESS
- It has 6 steps

What are the steps?

What are the steps?

- Ask a question
  - State the problem that you are trying to find an answer to

What are the steps?

- Ask a question
- Research
  - Do your background research
  - Figure out what specifically you want to test
    - What is your independent variable

What are the steps?

- Ask a question
- Research
- Construct a Hypothesis
  - Formulate a hypothesis to explain the phenomena,
  - If the …IV… is modified in this way, then this will happen to the …DV…
  - Used to predict the existence of other phenomena, or predict the results of new observations

What are the steps?

- Ask a question
- Research
- Construct a Hypothesis
- Test your hypothesis by doing an experiment
  - Experimental Design
  - Leads to either the confirmation of the hypothesis or ruling out of the hypothesis

What are the steps?

- Ask a question
- Research
- Construct a Hypothesis
- Test your hypothesis by doing an experiment
- Analyze your data and Draw conclusions
  - Data can be presented graphically, through lab reports, mini-posters, or power point presentations

What are the steps?

- Ask a question
- Research
- Construct a Hypothesis
- Test your hypothesis by doing an experiment
- Analyze your data and Draw conclusions
- Report your results
  - Participate in a poster session
  - Give a presentation at a conference
  - Submit your findings to an established journal

What are the steps?

- Ask a question
- Research
- Construct a Hypothesis
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Experimental Design

- Ask a question
- Research
- Construct a Hypothesis
- Test your hypothesis by doing an experiment
- Analyze your data and Draw conclusions
- Report your results

What is a experimental Design?

What is a experimental Design?

- An EXPERIMENT deliberately imposes a treatment on a group of objects or subjects in the interest of observing the response

What is the difference between experimental Design and observational Study?

What is the difference between experimental Design and observational Study?

- Observational Study
  - Involves collecting and analyzing data without changing existing conditions
- An EXPERIMENT deliberately imposes a **treatment** on a group of objects or subjects in the interest of observing the response

Experimental Design

- We are concerned with the analysis of data generated from an experiment. It is wise to take time and effort to organize the experiment properly to ensure that the right type of data, and enough of it, is available to answer the questions of interest as clearly and efficiently as possible. This process is called ***experimental design***.

What is a treatment

What is a treatment

- **Treatment** is something that researchers administer to experimental units. For example, a corn field is divided into four, each part is 'treated' with a different fertiliser to see which produces the most corn
- Example:
  - a corn field is divided into four, each part is 'treated' with a different fertilizer to see which produces the most corn

- The specific questions that the experiment is intended to answer must be clearly identified before carrying out the experiment.
- We should also attempt to identify known or expected sources of variability in the experimental units since one of the main aims of a designed experiment is to reduce the effect of these sources of variability on the answers to questions of interest.
- That is, **we design the experiment in order to improve the precision of our answers**.

What are sources of variability?

What are sources of variability?
Bias

- ***experimental bias***
  - the favoring of certain outcomes over others.
- ***placebo effect***.
  - Since many patients are confident that a treatment will positively affect them, they react to a control treatment which actually has no physical affect at all, such as a sugar pill.

What are ways to eliminate sources of variability?

- ***double-blind*** experiments
  - are generally preferable. In this case, neither the experimenters nor the subjects are aware of the subjects' group status. This eliminates the possibility that the experimenters will treat the placebo group differently from the treatment group, further reducing experimental bias.
- ***placebo effect***.
  - it is important to include control, or placebo, groups in experiments to evaluate the difference between the placebo effect and the actual effect of the treatment.

What are ways to eliminate sources of variability?

- ***Randomization***
  - objects or individuals are randomly assigned (by chance) to an experimental group. Using randomization is the most reliable method of creating homogeneous treatment groups, without involving any potential biases or judgments.
- ***Replication***
  - the repetition of an experiment on a large group of subjects, is required. If a treatment is truly effective, the long-term averaging effect of replication will reflect its experimental worth.

What are the Groups in an Experiment?

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- Control

What are the Groups in an Experiment?

- Control
  - used as a baseline measure.
  - identical to all other items or subjects that you are examining with the exception that it does not receive the treatment or the experimental manipulation that the treatment group receives.
  - Example: when examining test tubes for catalytic reactions of enzymes when added to a specific substrate, the control test tube would be identical to all other test tubes with the exception of lacking the enzyme.

What are the Groups in an Experiment?

- Control
- Treatment Groups

What are the Groups in an Experiment?

- Control
- Treatment Groups
  - The treatment group is the item or subject that is manipulated. In our example, all other test tubes containing enzyme would be part of the treatment group.

What are Variables?

What are Variables?

- An element, feature, or factor that is liable to vary or change.

What types of Variables are there?

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- Three Categories of Variables:

What types of Variables are there?

- Three Categories of Variables:
  - Independent
  - Dependent
  - Control

What types of Variables are there?

- Three Categories of Variables:
  - Independent
    - is what is varied during the experiment; it is what the investigator thinks will affect the dependent variable.
    - For example, the investigator may want to study coffee bean growth. possible independent variables include: amount of fertilizer, type of fertilizer, temperature, amount of H_2O, day length, all of these may affect the number of beans, weight of the plant, leaf area, etc.

What types of Variables are there?

- Three Categories of Variables:
  - Independent
  - Dependent
    - is what will be measured; it's what the investigator thinks will be affected during the experiment.
    - For example, the investigator may want to study coffee bean growth. Possible dependent variables include: number of beans, weight of the plant, leaf surface area, time to maturation, height of stem.

What types of Variables are there?

- Three Categories of Variables:
  - Independent
  - Dependent
- **Key :** Since you need to know which factor is affecting the dependent variable(s), there may be only one independent variable. The investigator must choose the one that he/she thinks is most important. But the scientist can measure as many dependent variables as he/she thinks are important indicators of coffee bean growth.

What types of Variables are there?

- Three Categories of Variables:
  - Independent
  - Dependent
  - Control
    - the variables held constant. Since the investigator wants to study the effect of one particular independent variable, the possibility that other factors are affecting the outcome must be eliminated.
    - For example, the above scientist must ascertain that no differences in the type of fertilizer used exists, or amount of H_2O, variations of temperature, or day length exist.

Engineering Experiments

- Reduce **time** to design/develop new products & processes
- Improve **performance** of existing processes
- Improve **reliability** and performance of products
- Achieve product & process **robustness**
- **Evaluation** of materials, design alternatives, **setting** component & system tolerances, etc.

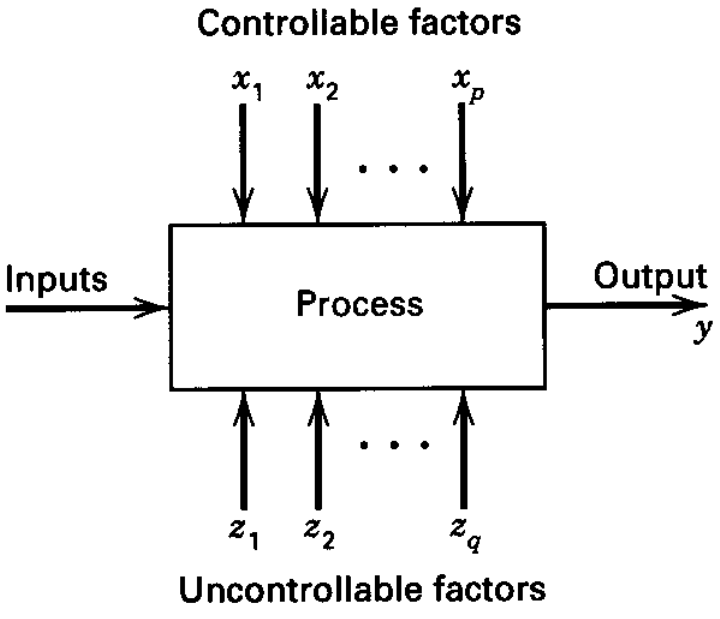


Figure 1-1 General model of a process or system.

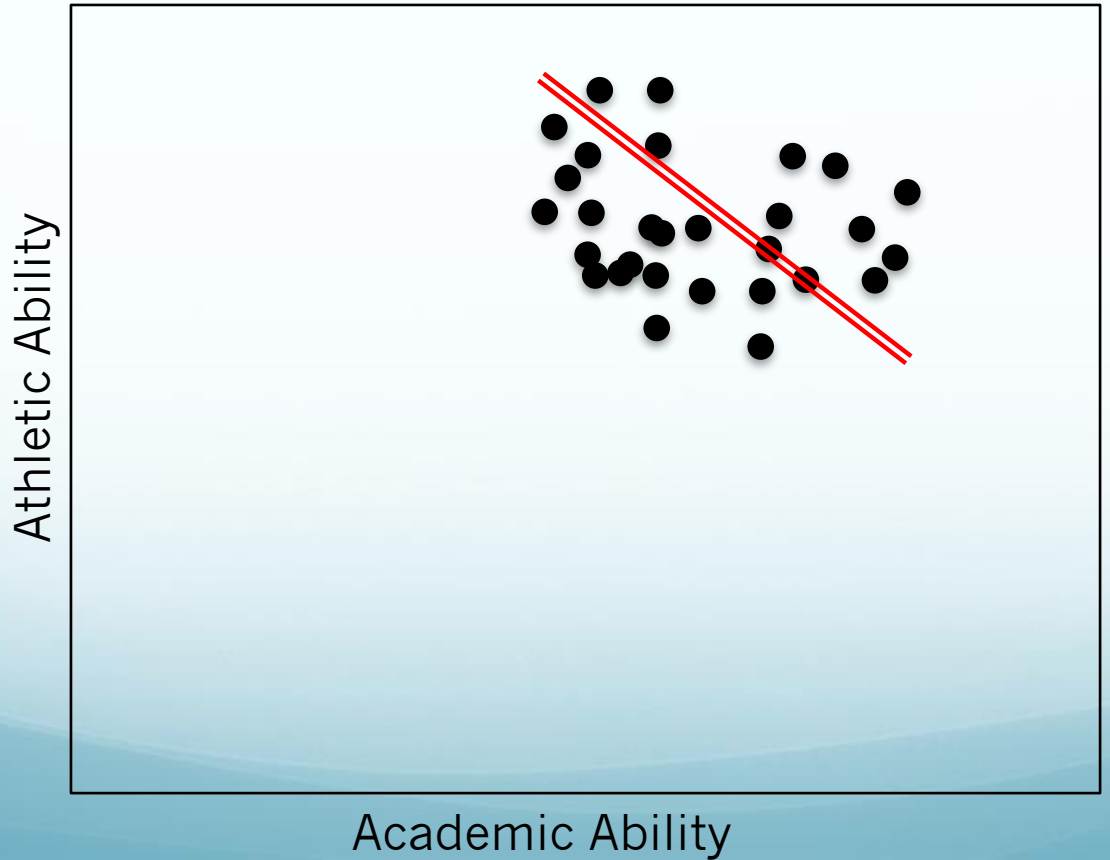
Strategy of Experimentation

- **“Best-guess” experiments**
  - Used a lot
  - More successful than you might suspect, but there are disadvantages…
- **One-factor-at-a-time (OFAT) experiments**
  - Sometimes associated with the “scientific” or “engineering” method
  - Devastated by interaction, also very inefficient
- **Statistically designed experiments**
  - Based on Fisher’s factorial concept

A Collision of Sampling and Regression

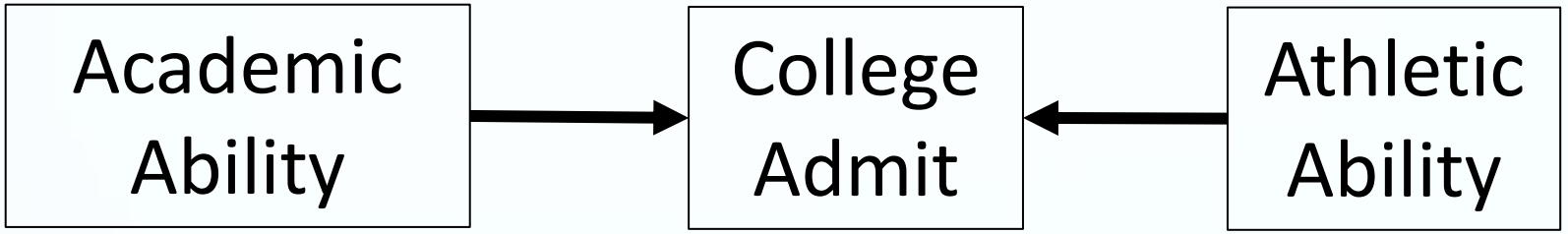
Consider the following:

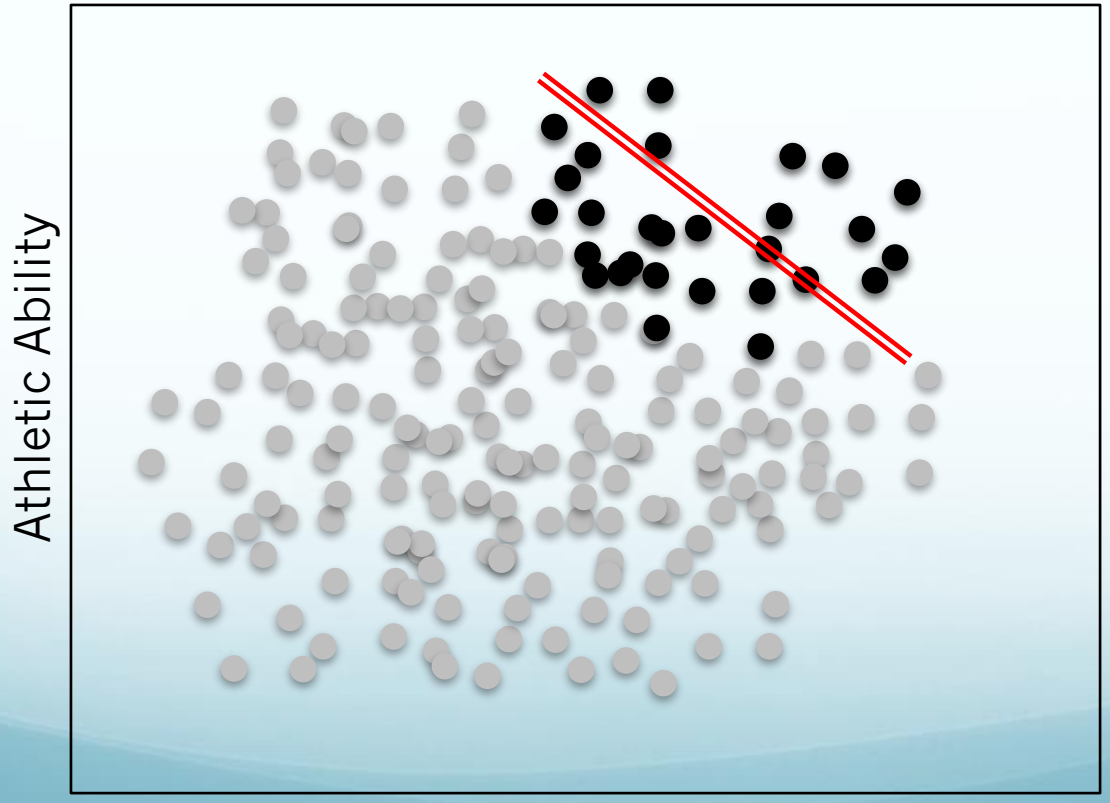
You are interested to see if academic ability and athletic ability are correlated. So, you sample students at your university.



A Collision of Sampling and Regression

But how do you get into college?





Factorial Designs

- In a factorial experiment, **all possible combinations** of factor levels are tested
- The golf experiment:
  - Type of driver
  - Type of ball
  - Walking vs. riding
  - Type of beverage
  - Time of round
  - Weather
  - Type of golf spike
  - Etc, etc, etc…

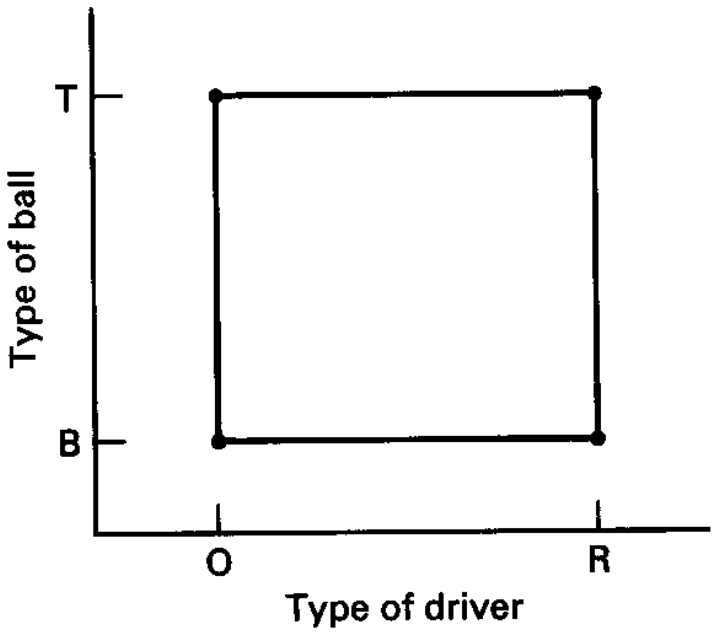
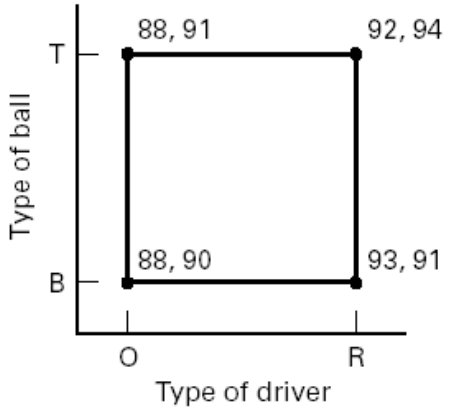
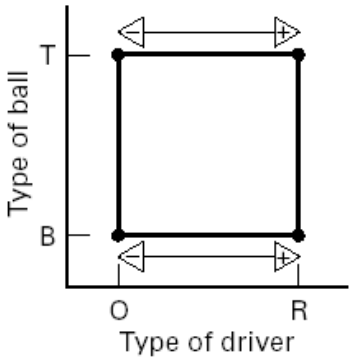


Figure 1-4 A two-factor factorial experiment involving type of driver and type of ball.

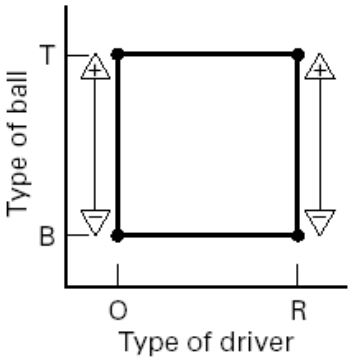
Factorial Designs with Several Factors



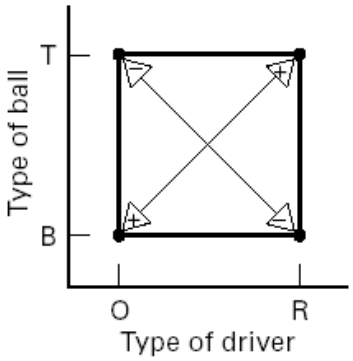
(*a*) Scores from the golf experiment



(*b*) Comparison of scores leading to the driver effect



(*c*) Comparison of scores leading to the ball effect



(*d*) Comparison of scores leading to the ball-driver interaction effect

Figure 1-5 Scores from the golf experiment in Figure 1-4 and calculation of the factor effects.

Factorial Designs with Several Factors

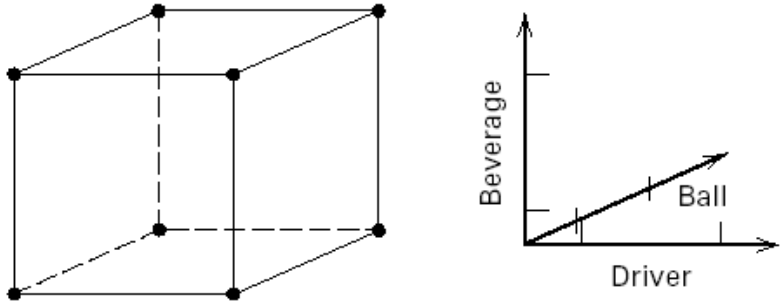


Figure 1-6 A three-factor factorial experiment involving type of driver, type of ball, and type of beverage.

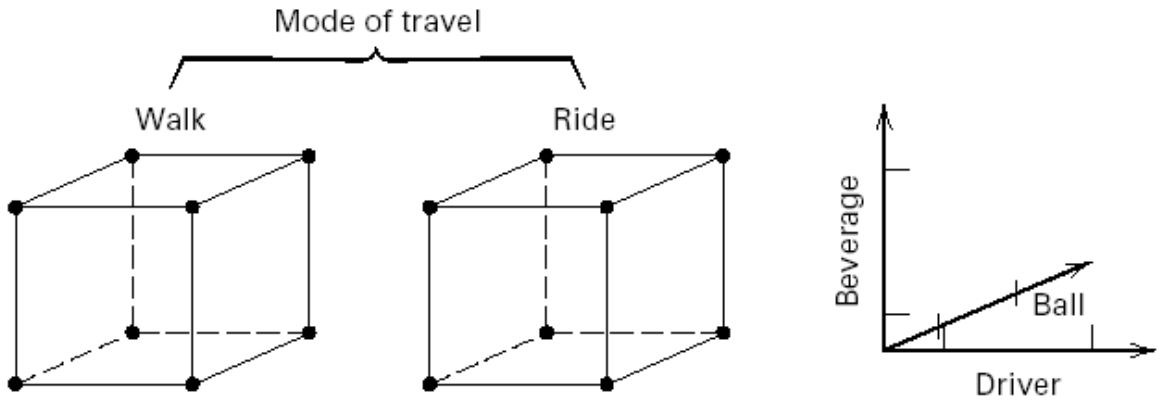


Figure 1-7 A four-factor factorial experiment involving type of driver, type of ball, type of beverage, and mode of travel.

Factorial Designs with Several Factors

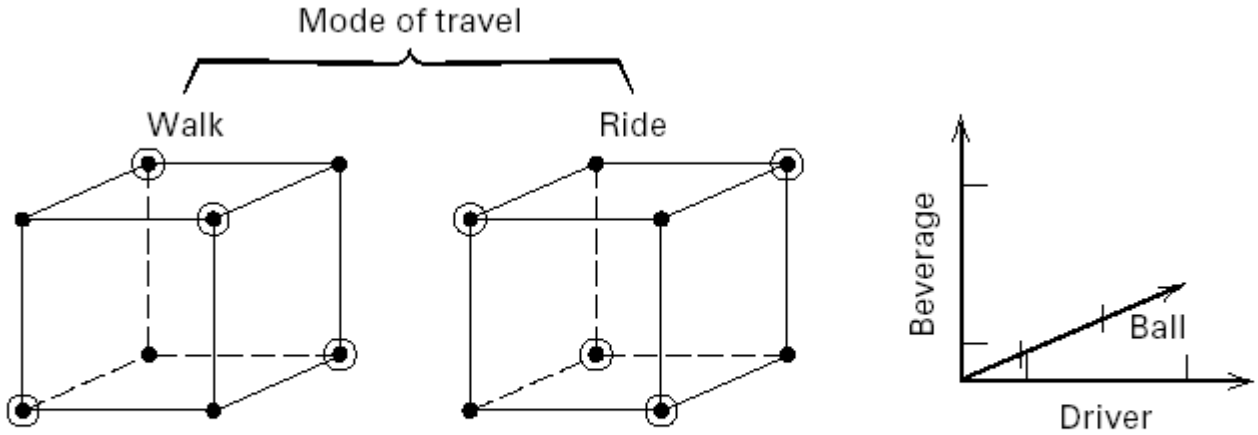


Figure 1-8 A four-factor fractional factorial experiment involving type of driver, type of ball, type of beverage, and mode of travel.

What is primary requirement?

- The ability to vary all the important input parameters to the desired levels
  - Many types of experiments do not allow you to set the inputs, rather, you can only observe the inputs.

So, what is DOE?

- "…the process of planning the experiment so that the appropriate data that can be analyzed by statistical methods will be collected, resulting in valid and objective conclusions."

◦ Douglas Montgomery, Design and Analysis of Experiments, 5th ed, pg. 11.

So, what is DOE?

- "...a planned approach for determining cause and effect relationships."
  - Mark Anderson & Patrick Whitcomb, DOE Simplified, pg ix.

So, what is DOE?

- "…consists of purposeful changes of the inputs (factors) to a process in order to observe the corresponding changes in the outputs (responses)."

◦ Stephen Schmidt and Robert Launsby, Understanding Industrial Designed Experiments, 3rd ed, pg 1-2.

So, what is DOE?

- "The generation of response data from systematically selected combinations of input factors that are used to create mathematical models (equations) from which valid and objective conclusions about the inputs and outputs can be inferred."

◦ Stephen Schmidt and Robert Launsby, Understanding Industrial Designed Experiments, 3rd ed, pg 1-2.

Goals of DOE?

- To identify (screening)
- To predict
  - “Prediction is very hard, especially when it is about the future.” Yogi Berra
- To do so with minimum resources

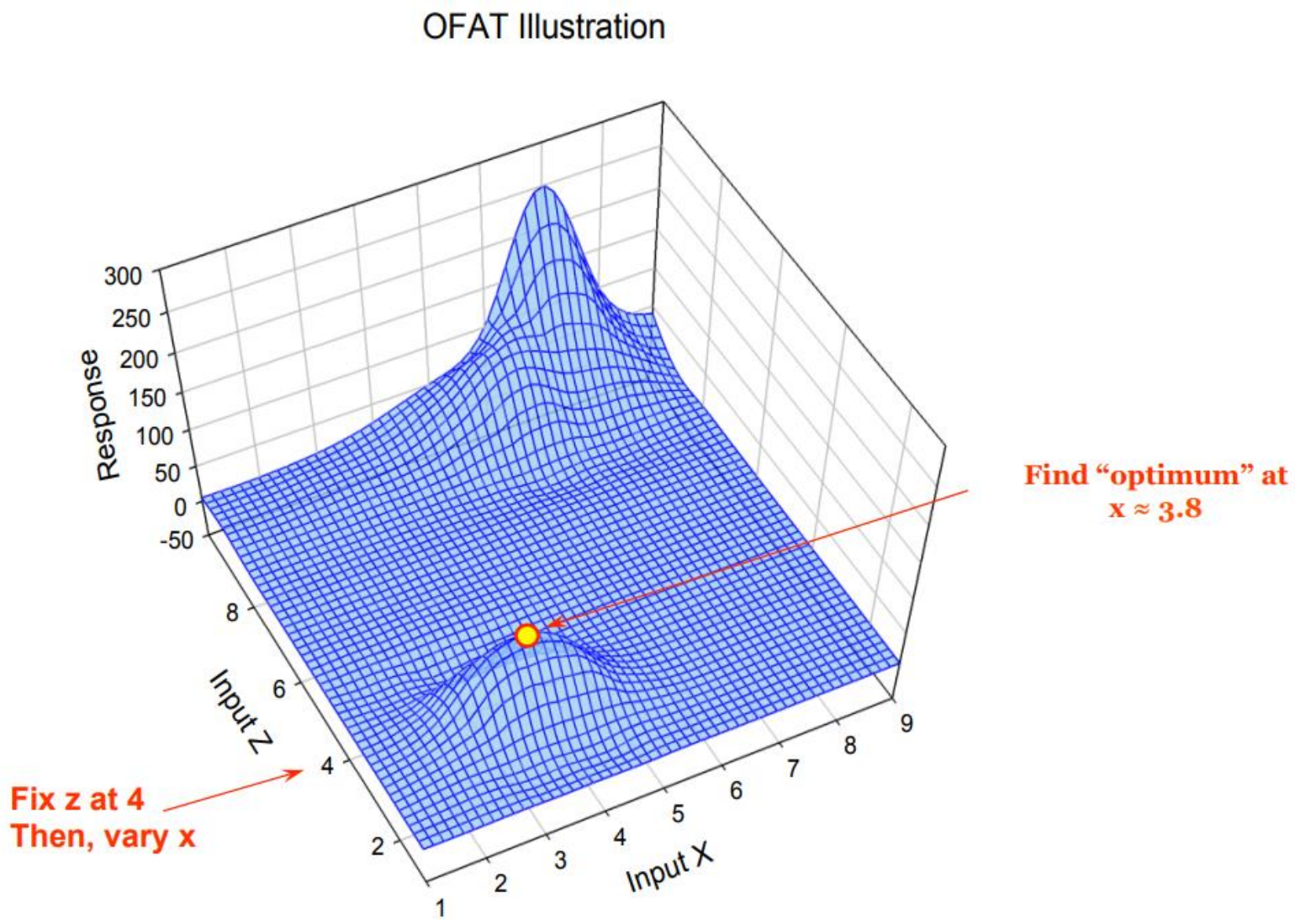
Why DOE?

- Best to explain by way of contrast to OFAT
  - Not how you respond to your significant other's question about how her new dress makes her look!
- **O**ne-**f**actor-**a**t-a-**t**ime (OFAT): the time honored, traditional way of doing experiments via the scientific method

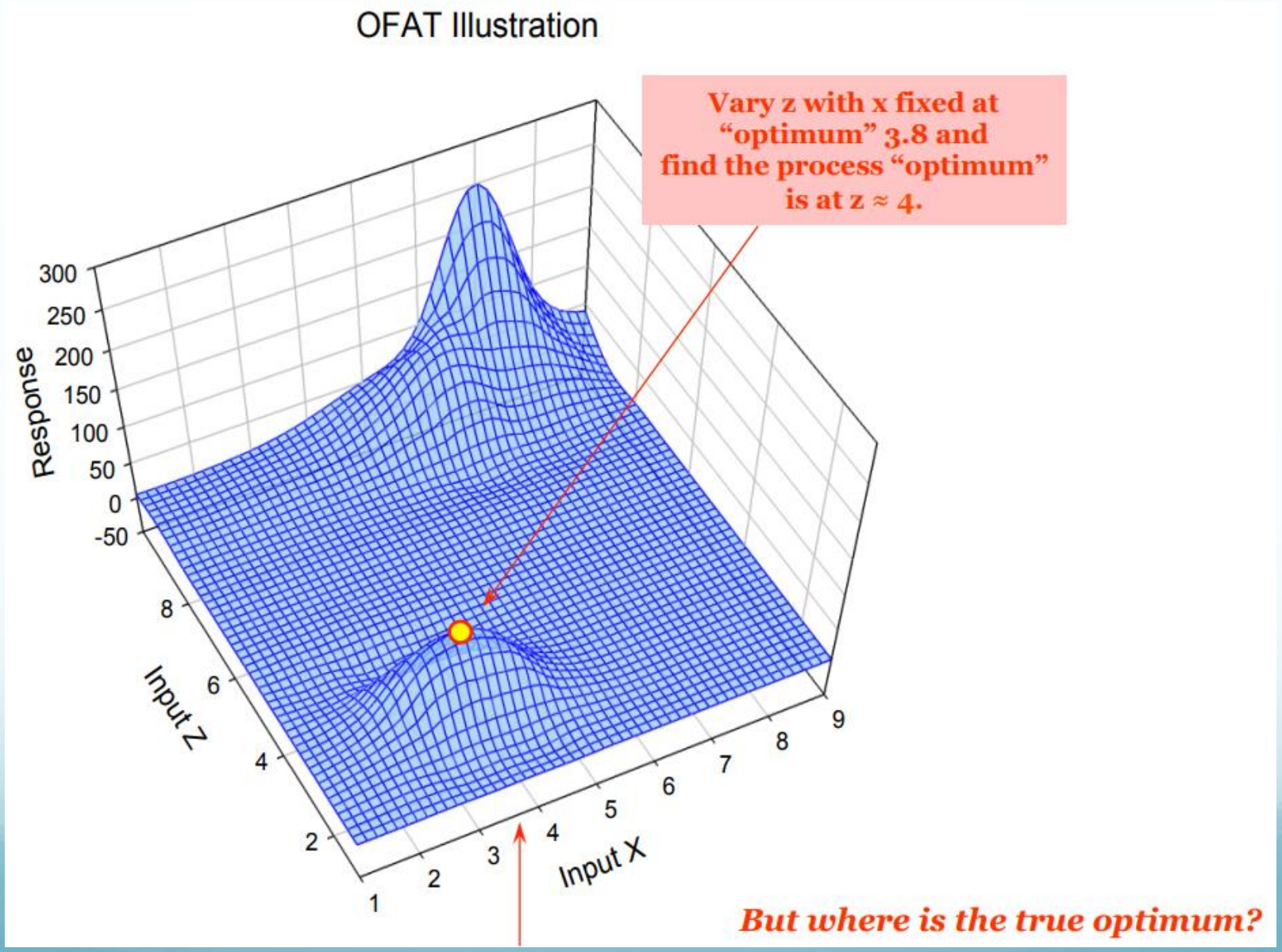
Why DOE?

- What's wrong with OFAT…?
  - Can miss the true optimum
  - Does not account for interactions
  - Has lower statistical power of analysis

DOE?

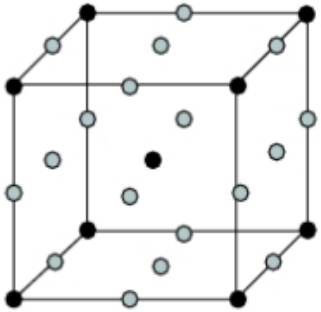

OFAT Illustration
Response
300
250
200
150
100
50
0
-50
Input Z
8
6
4
2
Input X
1
2
3
4
5
6
7
8
9
Fix z at 4
Then, vary x
Find "optimum" at
x ≈ 3.8

DOE?

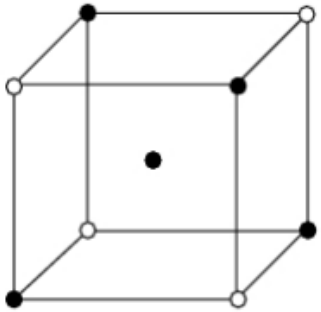

OFAT Illustration
Vary z with x fixed at "optimum" 3.8 and find the process "optimum" is at z ≈ 4.
Response
300
250
200
150
100
50
0
-50
Input Z
8
6
4
2
Input X
1
2
3
4
5
6
7
8
9
But where is the true optimum?

Design selection?

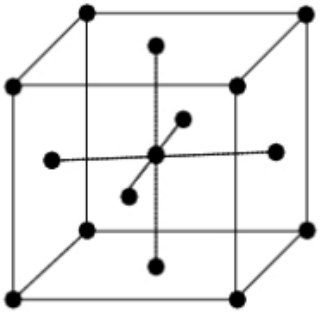
- Determining what combinations of factors to run



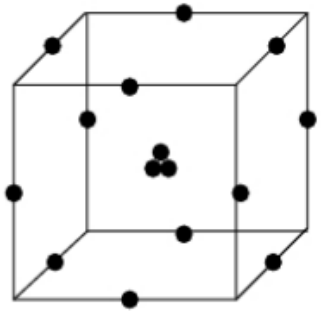
Full factorial



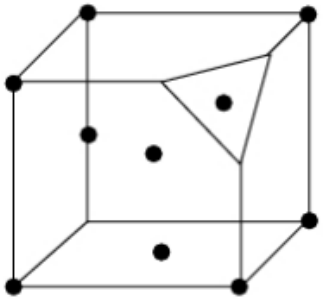
Fractional factorial



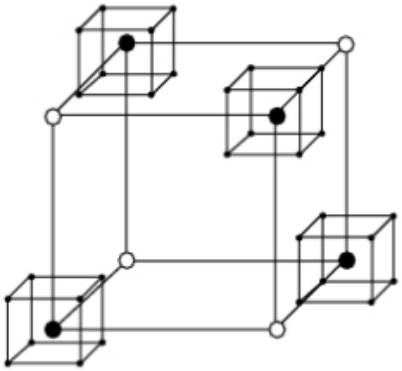
Central composite



Box Behnken



D-optimal design



Taguchi design

Planning, Conducting & Analyzing an Experiment

1. Recognition of & statement of problem
2. Choice of factors, levels, and ranges
3. Selection of the response variable(s)
4. Choice of design
5. Conducting the experiment
6. Statistical analysis
7. Drawing conclusions, recommendations