STAT 305: Lecture 1

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Why Engineers Study Statistics

Chapter 1: Introduction

Course page:
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A Little Background

Deterministic Relationships

Most of the mathematical concepts that you have encountered in your education can (very broadly) be considered **determinisitic** meaning that there is an exact mathematical relationship between variables.

For example, Newton's 2nd Law of Motion,

$$F = m \cdot a$$

is a deterministic relationship.

If we know all the values on one side (for instance $m = 3kg$ and $a = 5m/s^2$) then we know the force (10 N).

A Terrible Lab Experiment

Materials:

- One sheet of Iowa State Engineering Graph Paper (balled up).
- Two students with stop watches.
- An instructor of roughly 71 inches (1.80 m) in height.

Procedure:

1. Position the paper ball at top of instructors head.
2. Count 1-2-3-Drop.
3. (careful) On "drop" simultaneously release the ball and begin the stop watch.
4. When the ball strikes the ground, stop the stop watch.

Results:

$$h(t) = h(0) + \frac{1}{2} g \cdot t^2 \rightarrow g = \frac{2 \cdot (0m - 1.80m)}{t^2}$$

Why this experiment didn't work

Very obvious issues:

- I am not exactly 1.80 meters tall.
- The stopwatch timing is difficult.

Less (?) obvious issues:

- Gravity is not the only force acting on the racquetball.
- ???

Conclusion:

- Our experiment is fraught with error

Suggested Improvements:

- Control more parts of the experimental environment and we will get a more accurate result.

How much can we really control though?

As science has progressed, we've gotten more and more precise with our measurements. Still though, we only have to measure two things in this experiment and we ultimately circle back to the same problems:

- How accurately can we really measure the time? Can we be accurate to 10 decimals? Are we actually measuring the true time if we are accurate up to 10 decimals? 100 decimals?

- How accurately can we really measure a height? Again, 10 decimals? 100 decimals?

My hunch:

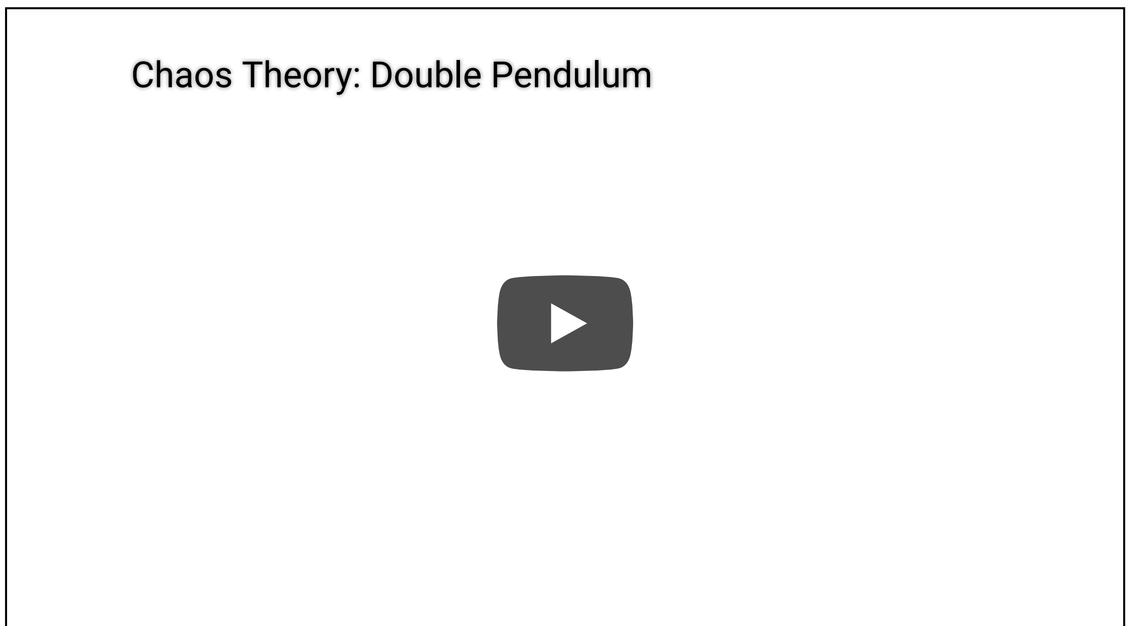
The relationship between distance, travel time, and acceleration is pretty simple - surely to 10 decimal places, we should be pretty accurate for g as well.

But what if the relationship is even a little more complicated?

Chaos Theory and Determinism

A **Chaotic System** is one for which minuscule differences in the system's conditions (possibly even below our ability to detect) can result in wildly different (essentially random) results. Even though the laws governing the system are deterministic, our inability to truly *know* the initial conditions can lead to unexpected outcomes.

Example: a double pendulum (credit to Bassam Jalgha)



What's My Point

Deterministic laws may govern the results of an experiment

but...

1. You can not know all the laws
2. You can not control everything in the system
3. What you don't control may be altering your results in chaotic ways

Section 1.1

Engineering Statistics: What and Why

What Do Engineers Do?

- Design/build/operate/improve some system
- Use both **quantitative theories** (i.e., mathematical) and **scientific principles** (i.e., physics, chemistry, psychology(?)) as a guide
- Obvious issue - math/science vast, no one knows everything.
- Additionally, engineers must work outside of "lab conditions" - there is no control over the environment, the users, the timing, ...

So, here's the situation:

The "system" you want to improve is essentially unique

There are competing theories that all seem equal

Experts disagree bitterly about what to do

What's an engineer to do???

Option 1: Just Give Up

A few drawbacks to this one

Option 2: Gather Some Data

Figure Out What Really Matters in the System

What Do I Mean Data?

Data is **essentially just information** we can record.

Examples are incredibly easy to come up with:

- Students with majors and courses they enrolled in

```
student   major         course
John      Philosophy    EASY 101
Kate      Engineering   SMRT 500
Mike      Mathematics   MATH 000
```

- Amount I can bench over time

```
Date     Weight
08/01    55 lbs.
08/02    56 lbs.
08/03    57 lbs.
08/04    59 lbs.
...      ...
12/21    345 lbs.
```

Really trivial to come up with examples

Getting Data is Easy

Getting Good Data is Hard

What and Why

Engineers In General

Data?

Example 1

Two Competing Theories

Goal: Load gears into a continuous carburizing furnace to minimize distortion during heat treating

- **Theory 1**: Load the gears laid in a stack
- **Theory 2**: Hang the gears from a bar
- **Complications**: No two gears exactly the same - if we test it how do we decide what was the effect of the gear and what was the effect of the loading method?
- **Good engineer**: tried it both ways and collected the distortion measures from multiple attempts

```
Method    Distortion measure (.0001 in.)
Hung      7, 8, 8, 10, 10, 10, 10, 11, 11, ..., 31, 36
Laid      5, 8, 8,  9,  9,  9,  9, 10, 10, ..., 19, 27
```

What and Why

Engineers In General

Data?

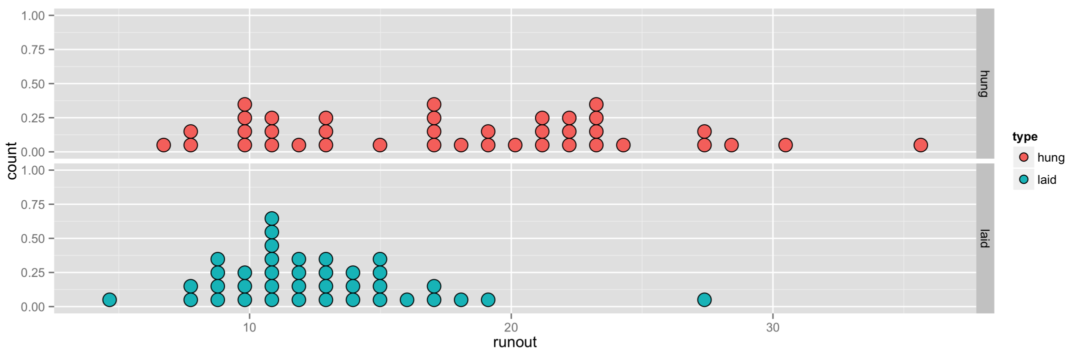
Example 1

Two Competing Theories

Goal: minimize distortion

```
Method    Distortion measure (.0001 in.)
Hung      7, 8, 8, 10, 10, 10, 10, 11, 11, ..., 31, 36
Laid      5, 8, 8,  9,  9,  9,  9, 10, 10, ..., 19, 27
```

Plots and summary values help us see what's going on:




```
Mean hung runout:  17.9
Mean laid runout:  12.6
```

Looks like laying gears in a stack is best

Engineering Statistics

Collecting good data is part of what engineering statistics is concerned with, but of course that's only the first part.

Our text book defines it this way:

> **Engineering Statistics** is the study of how *best* to
>
> 1. Collect engineering data
> 2. summarize or describe engineering data, and
> 3. draw formal inferences and practical conclusions on the basis of engineering data
>
> all while recognizing the reality of variation

Recognizing the "reality of variation" in the distortion example led the engineer to run multiple tests. This helped rules out the possibility that hanging gears is better: if hanging the gears were actually the right approach, it would be astronomically unlikely that it would have led to that many comparatively large distortions.

All good engineers use statistical tools

The only question is whether they will use good ones

Section 1.2

Basic Terminology

Types of Statistical Studies

An **observational study** is one in which the investigator's role is basically passive. A process or phenomenon is watched and data are recorded, but there is no intervention on the part of the person conducting the study.

An **experimental study** (or, more simply, an experiment) is one in which the investigator's role is active. Process variables are manipulated, and the study environment is regulated.

- Experiments: faster, more reliable results, helps determine causal relationships.
- These are the "perfect world" scenarios - most studies blend both.
- Even under ideal circumstances, some variables can not be controlled.

What and Why

Terms

Types of Studies

Extent to Which Results Can be Applied

An **enumerative study** is one in which there is a particular, well-defined, finite group of objects under study. Data are collected on some or all of these objects, and conclusions are intended to apply only to those objects.

A **population** is the entire group of objects about which one wishes to gather information in a statistical study.

A **sample** is a group of objects on which one actually gathers data. In the case of an enumerative investigation, the sample is a subset of the population (and can in some cases include the entire population).

- Example: If I am ordering 5000 microprocessors from Intel, I may test a few to see how well they actually work. In this case, the shipment is my population and the ones I test make the sample. I hope to use the sample to make a judgement about the entire shipment (so if 3/4 don't work, I should probably send the shipment back).

What and Why

Terms

Types of Studies

Extent to Which Results Can be Applied

An **analytical study** is one in which a process or phenonmeon is investigated at one point in space and time with the hope that the data collected will be representative of a system behavior at other places and times under similar conditions. In this kind of study, there is rarely, if ever, a particular well-defined group of objects to which conclusions are thought to be limited.

- **Analytical studies** tend to be the most important in engineering.
- Ex: Stock prices are dropping. I may determine if something doesn't change in the trading environment, they will continue dropping.
- Ex: The gear distortion example (Chapter 1, Example 1).

Telling the Difference

Observation vs. Experiment

- If things are being manipulated by the researcher, it's more of an experiment than an observational study.

Enmerative vs. Analytical

- We generally frown on people discussing **conceptual populations** - populations consisting of "all widgets that have heretofore existed or could one day exist in this universe or some other" type stuff
- Basically, if the population isn't well described, concrete thing, it's an analytical study.

Types of Data: Qualitative

Qualitative or **categorical** data are the values of basically nonnumerical characteristics associated with items in a sample.

- Ex: Eye color, choice of major, hometown, response to the question "have you ever been to Europe"

Qualitative variables can have a natural ordering - it's just that the ordering doesn't translate to an amount of something. Only by aggrigation and counting can we get meaningful numerical values from qualitative variables.

- Example: Classifying parts as (1) Conforming (it works), (2) Rework (fixable) and (3) Scrap (broken forever)

Types of Data: Quantitative

Quantitative or **numerical** data are values of numerical characteristics associated with items in a sample.

- Ex: Counts of the number of times some phenomenon occurs, measurements like weight/height

We can further describe **continuous** variables (where the actual result could be any value in a continuous interval) from **discrete** variables (where the number of values the variable could take are countable).

Example: Machine Parts

Suppose we get a shipment of 5000 machine parts and would like to verify that the shipment meets the standards the machinist agreed to. We take out 100 parts and examine them carefully. To verify that the parts are as strong as we anticipated, we measure the "Rockwell hardness" with a machine that is accurate to the first decimal place. We also examine each part for scratches and record it weight. Further, we run the part in a test machine to determine if it works correctly.

Question: How many data values are we collecting from each part and what type of data values are they?

Number of Measurements

Univariate data arise when only a single characteristic of each sample item is observed.

Multivariate data arise when observations are made on more than one characteristic of each sampled item.

Bivariate data are a special case of multivariate data where two characteristics are observed for each sampled item.

Repeated measures data arise when a sample item is being measured on the same characteristic but in multiple contexts (either with different instruments or in different scenarios).

Paired data are a special case of repeated measures data where the sample item is measured twice on the same characteristic.