EXPERIMENTAL MEASUREMENT: METHODS AND METHODOLOGY

Strategies and Tactics for Measurements in 16.62x

16.621 Experimental Projects Lab I

BASIS FOR MEASUREMENT

- **Whatever exists, exists in some amount**

- **Our goals:**
  - **Measure the <u>appropriate</u> quantity,**
  - **Measure with the <u>appropriate</u> accuracy,**

  to allow us to assess our hypothesis

- **Some questions:**
  - **What data do we need?**
  - **What do we measure?**
  - **How do we measure?**
  - **How well do we need to measure?**
  - **What do we do with the data?**

ERROR AND UNCERTAINTY IN MEASUREMENT

- **This is the subject of a future class, but the idea is so important that I mention it today as well**
- **In engineering the word "error", when used to describe an aspect of measurement does not necessarily carry the connotation of mistake or blunder (although it can!)**
- **Error in a measurement means the inevitable uncertainty that attends all measurements**
- **We cannot avoid errors in this sense**
- **We can ensure that they are as small as reasonably possible and that we have a reliable estimate of how small they are**

[Adapted from Taylor, J. R, "An Introduction to Error Analysis; The Study of Uncertainties in Physical Measurements"]

SOME GENERAL MEASUREMENT CONCEPTS

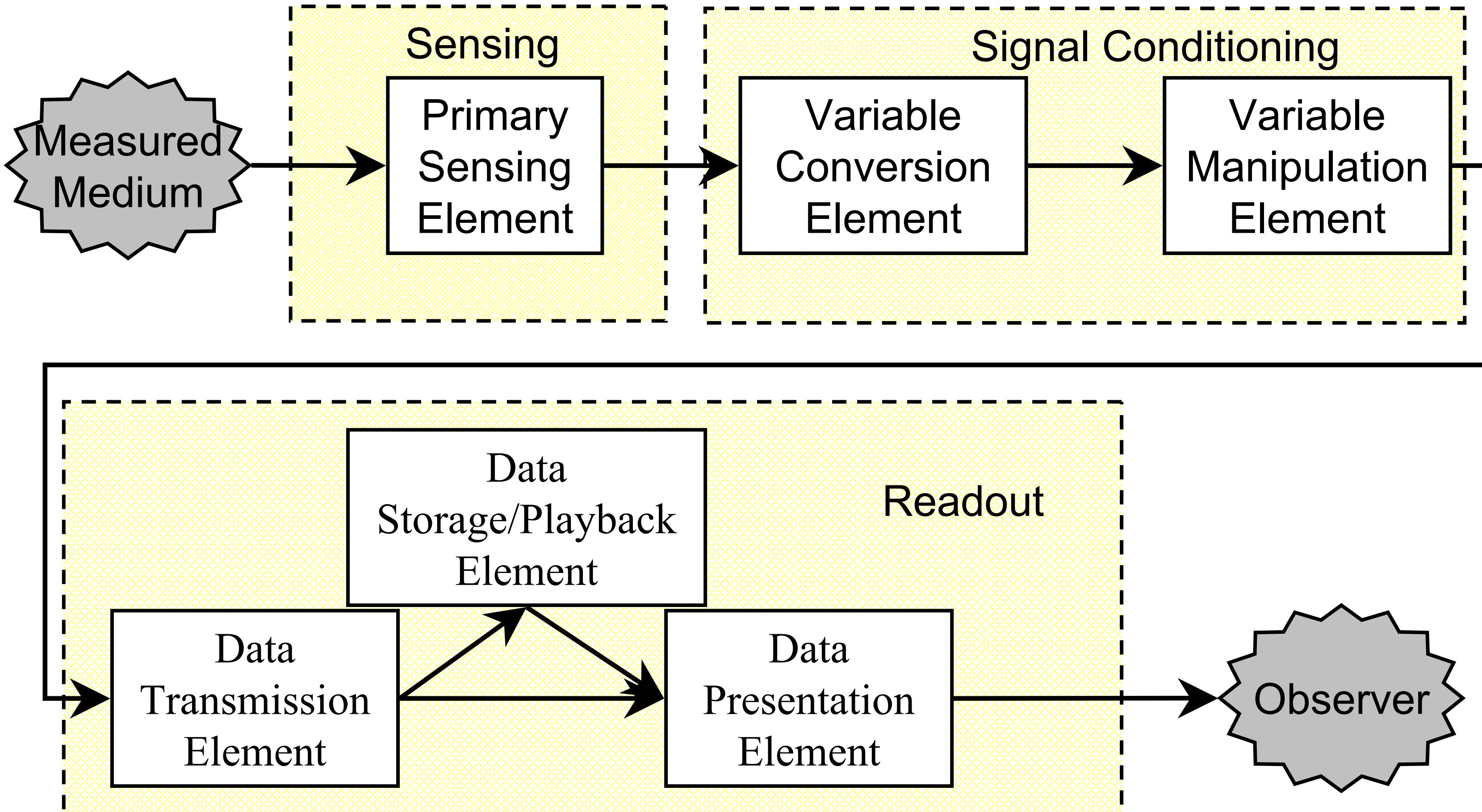
- **The measurement exists in some context**
  - **We want to do this measurement *because*…….**

- **The context (and objective) shapes the measurement strategy and tactics [“Begin with the end in mind”- Steven Covey]**

- **You generally do not directly measure the quantity you want**
  - **Most measurement devices are systems which translate the measured quantity (voltage, for example) into the quantity you want (pressure)**

- **All measurements have some *uncertainty*, or *error*, connected with them**
  - **It is important to know not only the *result* of the measurement but also the *fidelity* of the result (how big is the uncertainty, how much can I trust the answer?)**

ELEMENTS OF A MEASUREMENT SYSTEM



Adapted from Ernest O. Doebelin, *Measurement Systems: Application and Design*, McGraw Hill

MEASUREMENT ELEMENT DEFINITIONS

- **Primary Sensing element**
  - **Retrieves energy from the measured system**
  - **Produces some form of output**
    - **Strain gage, thermometer tip**

- **Variable conversion element**
  - **Changes data from one physical form to another**
    - **Elongation to resistance, temperature to volume change**

- **Variable manipulation element**
  - **Performs mathematical operation on data**
    - **Amplifier, filter**

Adapted from Ernest O. Doebelin, *Measurement Systems: Application and Design*, McGraw Hill

MEASUREMENT ELEMENT DEFINITIONS

- Data transmission element
  - Gets data between measurement elements
    - Wire, speedometer cable, satellite downlink system
- Data storage/playback element
  - Stores data for later retrieval
    - Hard drive, RAM
- Data presentation element
  - Gets data to form detectable by human
    - Indicators, alarms, analog recording, digital recording

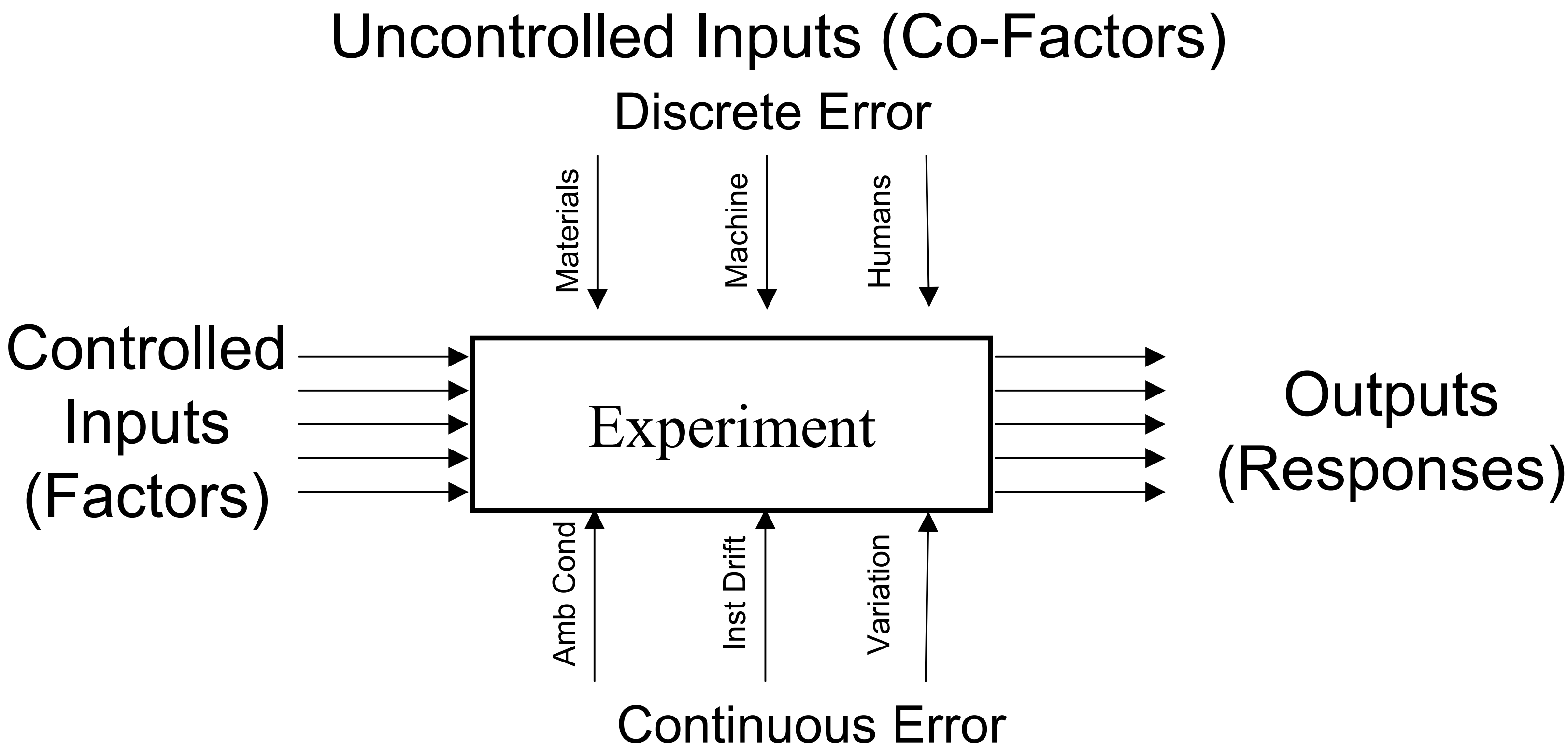
Adapted from Ernest O. Doebelin, *Measurement Systems: Application and Design*, McGraw Hill

OBSERVATIONS ABOUT THE ELEMENTS

- Two primary functions
  - Extract data
  - Present data
- Two points of <u>intended</u> contact with the “outside world”
- Functional blocks
  - Can have more than one of each type
  - Not all measurement systems have all functions
  - May be in any sequence (except primary sensing and data presentation)

ERROR ANALYSIS

– **Error is inherent in experimental process**



16.622 MEASUREMENT GOALS

Our goals:

- **Measure the <u>appropriate</u> quantity (DO THE RIGHT THING)**

- **Measure with the <u>appropriate</u> accuracy (DO THE THING RIGHT)**
  - **This is not only strategy (selecting the needed accuracy) but also implementation (being able to carry out the measurement)**
  - **To do this, you may have to learn something about differerent specific measurement methods**

16.622 MEASUREMENT GOALS?
[ONE SIZE DOES NOT FIT ALL]

Jonker/Yenson (Prototype Rowing Blades)

- **10% change in oar performance**

Diedrich/Smith (Vortex Breakdown)

- **10% agreement with predictions of theory**

Pigeon/Whitaker (Near Vacuum Hall Thruster)

- **Measureable thrust**
- **YES-NO Result, BUT result must be able to be demonstrably different than measurement uncertainties**

AN EXERCISE CONCERNING THE GREITZER-SPAKOVSZKY 16.62X TEAM PROJECT

Hypothesis proposed by our advisor, Murman: The thermodynamic loss in the flow through a blade row in a jet engine is less than 2% of the inlet dynamic pressure

Objective: Go to Pratt&Whitney, obtain a blade row, measure the loss

Success criterion: Establishing the loss through the blade row to an accuracy such that the hypothesis can be assessed

- What does all this mean for the measurements we need?
  - What would the final "slam dunk viewgraph" look like?

- We want to measure "*loss*". How do we do this?

- How well do we need to do it?

16.050 TO THE RESCUE

- **Entropy = loss (half of what I learned in 16.050)**
- **How do I measure entropy?**
  - **Who in the department has an entropy meter?**
- **What *do* I need to measure?**
- **Suppose my measurements have an "uncertainty" of ± 1% of the dynamic pressure**
  - **What would be a success?**
- **Suppose my measurements have an "uncertainty" of ± 0.1% of the dynamic pressure**
  - **What would be a success?**
- **Suppose my measurements have an "uncertainty" of ± 10% of the dynamic pressure**
  - ***Can* I succeed?**

A TURN TO YOUR PARTNER EXERCISE

- **For your project:**
  - **List the quantities you need to know to assess yourhypothesis**
  - **Define why these quantities are necessary**
- **Are these the actual quantities that you will measure? (Is measuring the voltage output of a pressure transducer the same as measuring the pressure directly?)**
  - **If not, what are the quantities that you will be measuring?**
  - **If not, what are the ideas, principles, etc. that you will use to connect the two**
- **How well does the measurement have to be made?**

A TURN TO YOUR PARTNER EXERCISE

- Pick a variable that is important for your experiment

- Describe the:
  - sensors
  - Instrumentation
  - measurement chain

you will need to obtain the data.

UNDERSTANDING MEASUREMENT DEVICES

Devices are specified by stating things such as…

- Accuracy and Precision
- Static Sensitivity
- Zero Drift and Sensitivity Drift
- Linearity
- Resolution
- Threshold
- Hysteresis (dead band)
- Readability
- Span
- Dynamic Performance

ACCURACY AND PRECISION

Accuracy of a measurement is a measure of how close the result of the experimen is to the true value

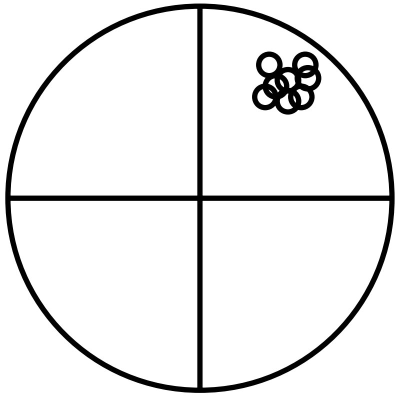
Accuracy is a measure of the correctness of the experiment

Precision is a measure of how well the result was determined, without reference to its agreement with the true value

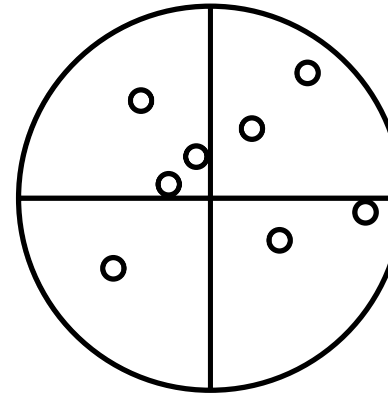
Bevington, P. R. and Robinson, D. K, 1992, “Data Reduction and Error Analysis for the Physical Sciences”

MEASUREMENT ACCURACY AND PRECISION

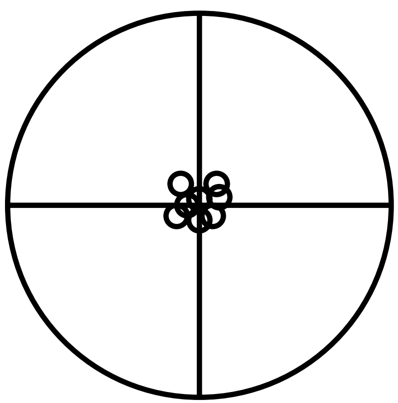
Accurate?___
Precise? ___



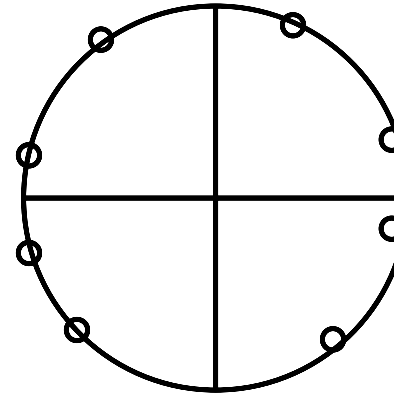
Accurate?___
Precise? ___



Accurate?___
Precise? ___



Accurate?___
Precise? ___



CALIBRATION

- **Once a measurement device is selected, it must be calibrated**
  - **Calibration – Comparison of instrument's reading to a calibration standard**
  - **Calibration standard created from a measurement**
    - **Inherent error**
  - **Rule of thumb: Calibration standard 10x accuracy of the instrument being calibrated**
- **Basic issue is how do we know that what we record has any relation to what we wish to measure?**

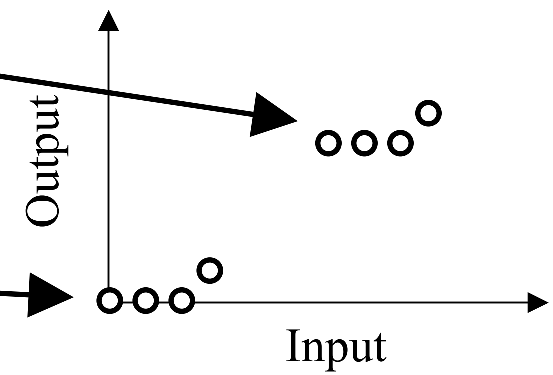
SENSITIVITY

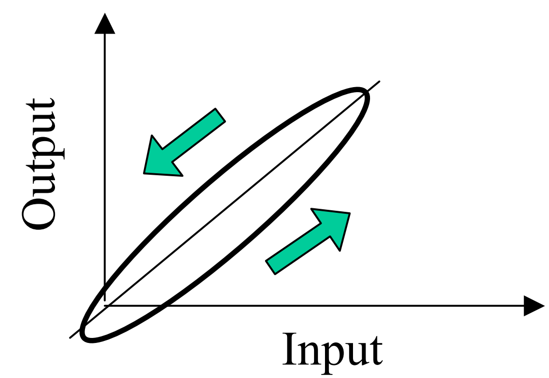
- Quantity of output for each unit of input
  - For 1 unit of input:
    - 10 units of output = more sensitivity
    - 1 unit of output = less sensitivity

- Sensitivity is <u>not</u> accuracy!

STILL MORE……….

- Resolution
  - Smallest smallest detectable change
- Threshold
  - Smallest detectable value
- Hysteresis (dead band)
  - Loop resulting from complete calibration using monotonically changing values





MEASUREMENT METHODS

- **Ask your advisor**
- **Ask lab staff**
- **Texts or articles**
  - ***e.g.*, Beckwith, T. G., *Mechanical Measurements*, Addison Wesley**
  - ***e.g.*, Ernest O. Doebelin, *Measurement Systems: Application and Design*, McGraw Hill**

MEASUREMENT METHODS: MIT Video Tapes

- Introduction to Measurement
- Calibration, Accuracy and Error
- Mass, Force, Strain, Torque and Pressure Measurement
- Measuring Dynamic Variables
- Fluid Quantity and Flow
- Infrared Temperature Measurement
- Contact Temperature Measurement

Available in Aero-Astro Library for Viewing

SOME GENERAL MEASUREMENT CONCEPTS

- **The measurement exists in some context**
  - **We want to do this measurement *because*…….**

- **The context (and objective) shapes the measurement strategy and tactics [“Begin with the end in mind”]**

- **You generally do not directly measure the quantity you want**
  - **Most measurement devices are systems which translate the quantity you measure (voltage, for example) into the quantity you want (pressure)**

- **All measurements have some *uncertainty*, or *error*, connected with them**
  - **It is important to know not only the *result* of the measurement but also the *fidelity* of the result (how big is the uncertainty, how much can I trust the answer?)**