The plan

- What do you need to survive physics? Thrive?
  - math
  - critical thinking / problem solving
  - experiments ...

- What are we going to do?
  - not PH105/106 ...
  - the ‘flavor’ of physics
  - some tools you will need
  - some background as to how we think
How?

- We’ll mostly do experiments.
  - Experiments similar to PH105/106
- Hypothesis + reality check ...
  - have an idea, then test it
  - how good was the test?
- math is the language we use for this
Specifically?

• Each session has one key idea
• This idea is *testable* ... or it is not science
• So we test it.

• How good is our test? How well did it work?
  • a measure of the result & accuracy
  • does it make any sense? predict something else ...
Example

• Your reaction time is better than mine ...  
• Every time? By how much?  
• What is the variability?  
• How good is the measurement anyway?
<table>
<thead>
<tr>
<th>Session</th>
<th>Lab</th>
<th>Math-related things</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tues 7 July 3:45-5:45</td>
<td>intro / Error analysis</td>
<td>uncertainty, basic statistics (mean, std. dev)</td>
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<tr>
<td>Fri 10 July 3:45-5:45</td>
<td>Coefficient of restitution</td>
<td>sequence &amp; series, logarithms, power laws</td>
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<tr>
<td>Tues 14 July 4-6</td>
<td>Atomic spectroscopy</td>
<td>trigonometry</td>
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<tr>
<td>Thu 16 July 1:30-3:30</td>
<td>dc circuits</td>
<td>linear relationships</td>
</tr>
<tr>
<td>Tue 21 July 3:45-5:45</td>
<td>resistive circuits (resistor networks)</td>
<td>systems of linear equations</td>
</tr>
<tr>
<td>Wed 22 July 1:30-3:30</td>
<td>Planck’s constant determination</td>
<td>trigonometry, exponential behavior, linear regression</td>
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<tr>
<td>Tue 28 July 1:30-3:30</td>
<td>RC circuits</td>
<td>exponential behavior, non-linear regression, logarithms</td>
</tr>
<tr>
<td>Fri 31 July 1:30-3:30</td>
<td>mutual inductance / wireless power</td>
<td>linearization, rate of change, trig functions</td>
</tr>
<tr>
<td>Mon 3 Aug 1:30-3:30</td>
<td>homopolar motors</td>
<td>vector relationships (cross product)</td>
</tr>
<tr>
<td>Wed 5 Aug 1:30-3:30</td>
<td>remote controls</td>
<td>time-dependent behavior, trig functions, 3D geometry in spherical coordinates</td>
</tr>
</tbody>
</table>

http://faculty.mint.ua.edu/~pleclair/EMAP_09/
Format

Quick (10-20min) intro to the idea / experiment

Do the experiment!
  groups of 5 or so

Analyze the data
  was the idea right? put numbers on that ...

Repeat if necessary

What would you do next?

Follow-up ... homework!
So: let’s get at it!

- Today: gauging reaction time
- one measurement vs. many
- how does accuracy improve?
- how to measure accuracy?
- care & feeding of data ...
Homework for next time

• Bring in a small rubber ball of some kind
• Which sort bounces the ‘best’
• What do we mean by ‘best’
My experiment: picking cards

• give each one a number
• Ace = 1, 2 = 2 ... Jack = 11 ... King = 13
• what is the average card?
  - we expect it must be 7 ...
• what is the spread? how to define this?
equal number of each average must be 7, if one chooses enough cards takes \(\sim 50\) before ‘luck’ is moot!

**Average of cards chosen**

expected average: 7.0

initial run is low!
**standard deviation** is a measure of the variability dispersion in a population or data set

low standard deviation: data tends to lie close to the average (mean)
high standard deviation: data spread over a large range

**data set:** data clustered about average

**many trials:** follow a distribution

~68% within +/- 1 standard deviation
~95% within +/- 2 standard deviations
~99.7% within +/- 3...
so what?

- knowing the standard deviation tells you
  - if subsequent measurements are outliers
  - what to expect next
  - *accuracy* of a set of data
  - variability in a large batch

- “six sigma” - quality control
  - means one out of 500 million!
so what?

if the mean of the measurements is too far away from the prediction, then the theory being tested probably needs to be revised!

particle physics: 3-sigma standard typical

more than that ... probably a new effect!
expect 75% of cards within 2 standard deviations of average

or, 75% are within about 4 cards from the average after 100 trials

or, 75% of cards should be between 3 and Jack (inclusive)

It works!

flip side: we could estimate the distribution of cards without prior knowledge (e.g., remove all 2’s and 3’s ... we could tell!)
now you try ...

\[ \sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2} \]

say your data is 11.0, 11.5, 12.0

\[ \bar{x}_3 = \frac{1}{n} \sum_{i}^{n} x_i = \frac{1}{3} [11.0 + 11.5 + 12.0] = 11.5 \]

\[ \sigma_3 = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2} = \sqrt{\frac{1}{3} \sqrt{(11.0 - 11.5)^2 + (11.5 - 11.5)^2 + (12.0 - 11.5)^2}} \approx 0.41 \]

\[ \sigma_3 = \frac{1}{3} \sqrt[3]{3 \cdot (11.0^2 + 11.5^2 + 12.0^2) - (11.0 + 11.5 + 12.0)^2} \approx 0.41 \]
Now plot the standard deviation $\sigma$ as a function of $n$ either on paper or using Excel.

After a series of measurements and subsequent analysis, you now have two sources of error to report: the statistical error due to measurement fluctuations and the systematic or instrument error reflecting the accuracy of individual measurements. You can report your final result as $x = \bar{x} \pm \delta_x \pm \sigma_g$.

Questions:
- Does the uncertainty change as the number of points increases?
- Does your data confirm the stated hypothesis?
- How could you reduce the systematic error?
- Is the systematic error small or large compared to the statistical error?
- Compare data with neighboring groups. Is the human to human variation larger or smaller than the measurement errors?

Homework
- Can you figure out how to do this in Excel?
- Bring in a rubber ball for the next session (Fri, Jul x).

<table>
<thead>
<tr>
<th>point point $i$</th>
<th>distance $x_i$</th>
<th>running average $\bar{x}$</th>
<th>running $\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.1</td>
<td>28.1</td>
<td>–</td>
</tr>
<tr>
<td>2</td>
<td>28.5</td>
<td>28.3</td>
<td>0.20</td>
</tr>
<tr>
<td>3</td>
<td>28.7</td>
<td>28.4</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>28.3</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>5</td>
<td>28.0</td>
<td>...</td>
<td>...</td>
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<tr>
<td>...</td>
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