Precision, Accuracy and Uncertainty in Data

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Podcast: Fun from the Sun
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This month Michael (that’s me), Doug and Mike get together on Skype to discuss the Sun.

If I may have a moment, the Sun is unquestionably the most important thing in our universe. Every scrap of energy we have on this planet comes from the Sun. It’s big, bright and hugely important to the evolution of Man and our fate in the future. It’s also a cauldron of convecting plasma that behaves, in ways, like a big, boiling pot of water.

In the podcast we talk specifically about aurora and their source — sun spots, solar flares and coronal mass ejections. And we go off-topic and make jokes and stuff, too. An abbreviated version of this podcast is available at The 365 Days of Astronomy Podcast.

http://www.slackerastronomy.org/
Accuracy

Precision

Uncertainty
A datum (or plural data) is a measured value.

It’s a “fact”.

It’s the output of a sensor, an algorithm or an observation.

It is always uncertain to some extent.
Data is reduced

- For example, my CCD detector has 765 x 510 pixels at 16 bits/pixel so a single image is 6,242,400 bits (6.2MB) of data.

- My reported variable star measurement from that single image is approximately 200 bits of data.

- The data in this case was reduced by a factor of 30,000!
Think about it.

The whole point of science is to reduce data -- to take petabytes of data and turn it into a few key insights.

Statistics, in a sense, is the language of progress.
Thus

Understanding the quality of your data is just as important as understanding the data itself.
How many units apart are these dots?

*A little experiment*

*http://www.lolife.com/experiment1/*
What do we expect?

A somewhat normal distribution around the correct value.

Values near the true value should be more frequent than values far from the true value.
What do we get?

A somewhat normal distribution around the correct value.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>min</td>
<td>3.00</td>
</tr>
<tr>
<td>max</td>
<td>9.00</td>
</tr>
<tr>
<td>average</td>
<td>4.69</td>
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<tr>
<td>median</td>
<td>4.63</td>
</tr>
<tr>
<td>mode</td>
<td>5.00</td>
</tr>
<tr>
<td>stddev</td>
<td>0.97</td>
</tr>
</tbody>
</table>

**Histogram**

- True value 4.89

**Estimate of Distance**

- Number of Answers
- Up To 3.5
- 3.5 To 4.5
- 4.5 To 5.5
- 5.5 To 6.5
- 6.5 To 7.5
- 7.5 To 8.5
- 8.5 To 9.5
Accuracy
The degree to which a measured value agrees with the “true value”.

Precision
The degree to which repeated measurements agree with each other.

Uncertainty
The range of values that can confidently said to contain the true value of a measurement.
Accuracy vs. Precision

Accuracy is external agreement.
Precision is internal agreement.
Example: photometry

Photometric measurements have uncertainty due to precision (e.g. how many digits after the decimal point on the measurement) and due to accuracy (how well the zero-point of the system matches the standard system).
Example: photometry

\[ V = 11.07 \pm 0.01 \text{ magnitudes} \]
Uncertainty

The range of values that can confidently said to contain the true value of a measurement.
Signal-to-Noise Ratio

- aka S/N, SNR
- A statistic of the quality of a measurement.
- A ratio of the data to the uncertainty.
Whence *uncertainty*?

- **Systematic** uncertainty (you unknowingly have a 13-inch ruler).

- **Random** uncertainty: An infinite number of low-amplitude processes and effects that you have no chance of ever physically understanding.
Systematic Uncertainty

“Errors” related to the system, apparatus or analysis specific to your setup.

Bad news: they are your fault.

Good news: they are (usually) fixable.

But you have to identify them first!
Random Uncertainty

- If the noise is dominated by the Poisson noise from the star being measured, the uncertainty is given simply by:

\[ \delta q = \sqrt{N} \]

- …where \( N \) is the number of electrons (or photons) in the measurement. It is important to note that this does not work for analog-to-digital units (ADUs) – your counts must be in electrons (or photons).
Poisson Statistics

✧ It is fairly simple to see that this also gives an estimate of the SNR ratio:

\[
\frac{S}{N} = \frac{N_\ast}{\sqrt{N_\ast}} = \sqrt{N_\ast}
\]

✧ For example, if the net counts, measured in electrons, for a given star was 64,000 the uncertainty is +/- 253 counts and the SNR is 253. In this case the uncertainty is usually stated as 1/SNR or 0.004 in this example. This is a fractional uncertainty in that it is the noise divided by the signal. Thus, the uncertainty in this example is 0.4%.
Calculating Uncertainty

✧ Two primary methods:

1. Additive (think of everything and add it up).

\[
\frac{S}{N} = \frac{N_*}{\sqrt{N_* + n_{pix}(1 + \frac{n_{pix}}{n_B})(N_S + N_D + N_R^2 + G^2\sigma_f^2)}}
\]

2. Statistics.

\[
\sigma_{K-C} = \sqrt{\frac{1}{N-1} \sum (x - \bar{x})^2}
\]
Error Bars

An easy and effective way to report uncertainty.
A Very Real Example
(although it is fabricated)
A Very Real Example
(although it is fabricated)
A Very Real Example
(although it is fabricated)
A Very Real Example
(that is actually real)
A Very Real Example
(that is actually real)
The purpose of a plot is to assist thinking.
<table>
<thead>
<tr>
<th>Cancer Type</th>
<th>5 year</th>
<th>10 year</th>
<th>15 year</th>
<th>20 year</th>
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</thead>
<tbody>
<tr>
<td>Prostate</td>
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<td>95</td>
<td>87</td>
<td>81</td>
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<tr>
<td>Hodgkin's disease</td>
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<td>80</td>
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<tr>
<td>Corpus uteri, uterus</td>
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<td>83</td>
<td>81</td>
<td>67</td>
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<tr>
<td>Urinary, bladder</td>
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<td>70</td>
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<tr>
<td>Cervix, uteri</td>
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<td>64</td>
<td>63</td>
<td>60</td>
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<tr>
<td>Larynx</td>
<td>69</td>
<td>57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectum</td>
<td>63</td>
<td>46</td>
<td></td>
<td></td>
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<td>Kidney, renal pelvis</td>
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<td>55</td>
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<td>38</td>
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<tr>
<td>Colon</td>
<td>62</td>
<td>54</td>
<td>50</td>
<td>47</td>
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<tr>
<td>Non-Hodgkin's</td>
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<td>55</td>
<td>54</td>
<td>52</td>
</tr>
<tr>
<td>Oral cavity, pharynx</td>
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<td>46</td>
<td>38</td>
<td>34</td>
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<tr>
<td>Ovary</td>
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<td>49</td>
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<tr>
<td>Leukemia</td>
<td>43</td>
<td>49</td>
<td>50</td>
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<td>Brain, nervous system</td>
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<td>30</td>
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<td>Multiple myeloma</td>
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<td>26</td>
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<tr>
<td>Stomach</td>
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<td>13</td>
<td>7</td>
<td>5</td>
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<tr>
<td>Lung and bronchus</td>
<td>15</td>
<td>19</td>
<td>19</td>
<td>15</td>
</tr>
</tbody>
</table>
unnecessary precision
weird “x” range
reversed “y” range
small labels
background
point shape
point color
shadows
grid lines
legend
no error bars
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Thank You!

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