Consistency plots – a simple graphical tool for investigating agreement in Key Comparisons

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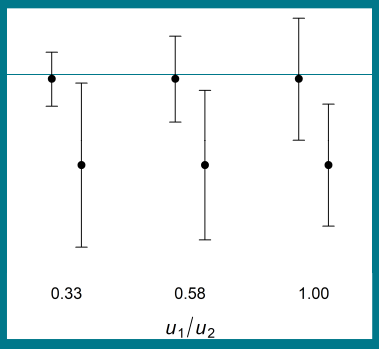
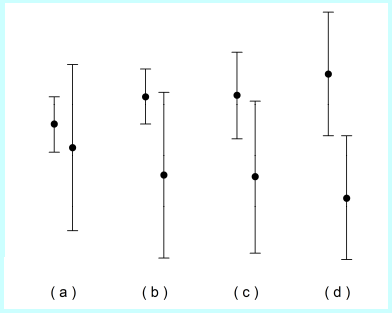
An introductory quiz

1) Which of these pairs of 95% error bars indicate a significant difference with 95% confidence?



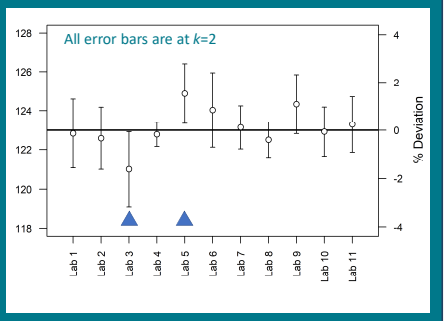
Answer: All differ with exactly 95% confidence (p=0.05)

2) Which of these pairs of 95% error bars show a significant difference with 95% confidence?



Answer: d) differs at approximately **99.5%** confidence

3) Which of these laboratories differ from each other or from the central value with 95% confidence?



Answer: None. In this simulation, all labs have the same mean value and all are shown with accurate uncertainties

The problem

Error bars with k=2 are a poor indicator of significance:

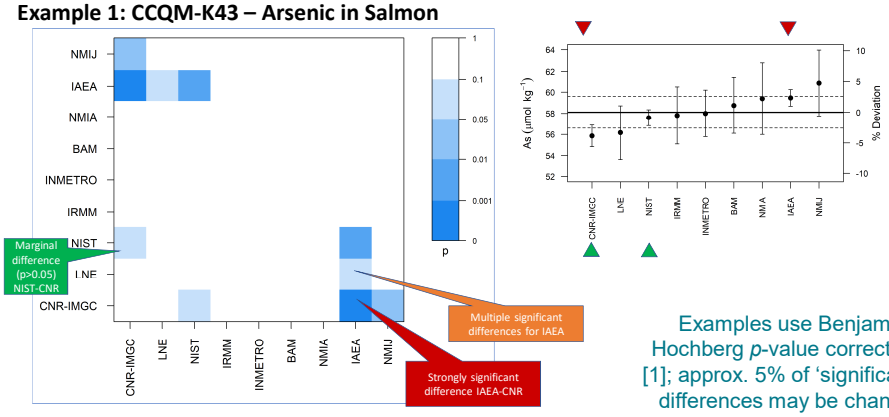
- The extent of overlap at exactly 95% confidence changes with the uncertainties;
- 95% error bars 'just touching' indicate much stronger significance than 95%;
- With more than two values, large differences appear in much more than 5% of data sets (the 'multiple comparison' problem).

Error bars at *k*=1 give even less useful information, and are almost useless for judging significance.

Consistency plots

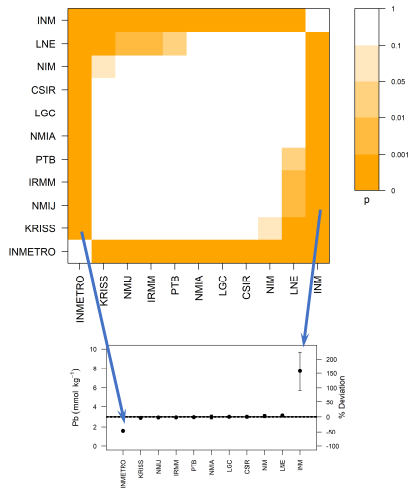
A consistency plot is a map of the *p*-values for pairwise differences in a data set, corrected for the $n(n-1)/2$ comparisons*.

Example 1: CCQM-K43 – Arsenic in Salmon



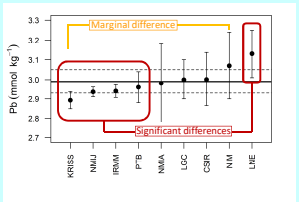
Examples use Benjamini-Hochberg *p*-value correction [1]; approx. 5% of 'significant' differences may be chance.

Example 2: CCQM-K30 – Lead in Wine



Example 2 shows that:

- Extreme uncertainty/location outliers (INMETRO and INM in this early study) show strongly in the consistency plot (*arrows, left*)
- Some additional inconsistency is due to significant disagreement between LNE (high) and **four** low results (below).



Conclusions

- Consistency plots give a relatively simple and reliable summary of significant differences between laboratories in metrology comparisons.
- Outlying value/uncertainty pairs show up strongly
- The summary does not depend on a reference value

Consistency plots can be produced easily using the `cplot` function in the metRology package [2] for R.

References

1. Hochberg, Y. (1988). A sharper Bonferroni procedure for multiple tests of significance. *Biometrika*, **75**, 800-803. doi: 10.2307/2336325.
2. Ellison, SLR: metRology: Support for Metrological Applications. R package version 0.9-29-1. https://r-forge.r-project.org/projects/metrology/