Proposed title: The Noisy Work of Uncertainty Visualisation Research

Harriet Mason Dianne Cook Sarah Goodwin Emi Tanaka
Susan VanderPlas

1 Rationale

Better ways of including a representation of the uncertainty in a data visualisation is a focus of recent research activity. A problem with the current literature is that there is a lack of clarity in the definition of uncertainty, and what it means to represent it in a plot. This confusion can also be seen in literature describing experiments to test effectiveness of choices of different uncertainty representation. The purpose of this review article is to summarise the current literature, provide workable definitions, and illustrate with examples. It is hope that it will be useful to guide new graphics methodology and experimental work.

2 Outline

1. Common uses of the terms "uncertainty visualisation": Here we will provide some background to the use of the term "uncertainty visualisation" and tie it to statistical definitions of uncertainty.
2. Dangers of ignoring uncertainty representation in a visualisation. This part motivates the reason for the importance of this area of research.
3. Review of current approaches to representing uncertainty in plots, as gathered from discipline journals in information visualisation, statistics, environmental science and psychology.
4. Review of literature describing experiments testing effectiveness of different representations. The information visualisation literature is especially prolific in describing experiments assessing the relative merits of different uncertainty visualisations, and this section will critically summarise these efforts, and propose refining of procedures.
5. Examples:

- spatial data poses substantial challenges because of the difficulties of using the page for the map coordinates, and hence little room for representing uncertatinty. It also has been a place with useful recent work, providing some good solutions.
- comparing groups (boxplots, letter value plots, dotplots) OR
- confidence intervals, vs rainclouds, vs dotplots, vs transparency

6. Recommendations for research directions. Here we will gather the discussion into some suggestions for framing new work, developing methodology and designing experiments.

References

Boukhelifa, Nadia, Anastasia Bezerianos, Tobias Isenberg, and Jean Daniel Fekete. 2012. "Evaluating sketchiness as a visual variable for the depiction of qualitative uncertainty." *IEEE Transactions on Visualization and Computer Graphics* 18 (12): 2769–78. https://doi.org/10.1109/TVCG.2012.220.

Buja, Andreas, Dianne Cook, Heike Hofmann, Michael Lawrence, Eun Kyung Lee, Deborah F. Swayne, and Hadley Wickham. 2009. "Statistical inference for exploratory data analysis and model diagnostics." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 367 (1906): 4361–83. https://doi.org/10.1098/rsta.2009.0120.

Cleveland, William S., and Robert McGill. 1984. "Graphical perception: Theory, experimentation, and application to the development of graphical methods." *Journal of the American Statistical Association* 79 (387): 531–54. https://doi.org/10.1080/01621459.1984.10478080.

Correll, Michael, Dominik Moritz, and Jeffrey Heer. 2018. "Value-suppressing uncertainty Palettes." *Conference on Human Factors in Computing Systems - Proceedings* 2018-April: 1–11. https://doi.org/10.1145/3173574.3174216.

Hofman, Jake M., Daniel G. Goldstein, and Jessica Hullman. 2020. "How Visualizing Inferential Uncertainty Can Mislead Readers about Treatment Effects in Scientific Results." *Conference on Human Factors in Computing Systems - Proceedings*. https://doi.org/10.1145/3313831.3376454.

Hullman, Jessica. 2016. "Why evaluating uncertainty visualization is error prone." *ACM International Conference Proceeding Series* 24-October: 143–51. https://doi.org/10.1145/2993901.2993919.

———. 2020. "Why Authors Don't Visualize Uncertainty." *IEEE Transactions on Visualization and Computer Graphics* 26 (1): 130–39. https://doi.org/10.1109/TVCG.2019.2934287.

Hullman, Jessica, and Andrew Gelman. 2021. "Designing for Interactive Exploratory Data Analysis Requires Theories of Graphical Inference." *Harvard Data Science Review*, 1–70. https://doi.org/10.1162/99608f92.3ab8a587.

Kay, Matthew. 2023. "ggdist : Visualizations of Distributions and Uncertainty in the Grammar of Graphics k E." https://doi.org/10.5281/zenodo.7770984.Index.

Kinkeldey, Christoph, Alan M. MacEachren, and Jochen Schiewe. 2014. "How to assess visual communication of uncertainty? a systematic review of geospatial uncertainty visualisation

user studies." *Cartographic Journal* 51 (4): 372–86. https://doi.org/10.1179/1743277414Y.0000000099.

Li, Weihao, Dianne Cook, Emi Tanaka, and Susan VanderPlas. 2024. "A Plot Is Worth a Thousand Tests: Assessing Residual Diagnostics with the Lineup Protocol." *Journal of Computational and Graphical Statistics*, May, 1–19. https://doi.org/10.1080/10618600.2024.2344612.

Lucchesi, Lydia R., and Christopher K. Wikle. 2017. "Visualizing uncertainty in areal data with bivariate choropleth maps, map pixelation and glyph rotation." *Stat* 6 (1): 292–302. https://doi.org/10.1002/sta4.150.

Maceachren, Alan M., Robert E. Roth, James O'Brien, Bonan Li, Derek Swingley, and Mark Gahegan. 2012. "Visual semiotics & uncertainty visualization: An empirical study." *IEEE Transactions on Visualization and Computer Graphics* 18 (12): 2496–2505. https://doi.org/10.1109/TVCG.2012.279.

North, Chris. 2006. "Toward measuring visualization insight." *IEEE Computer Graphics and Applications* 26 (3): 6–9. https://doi.org/10.1109/MCG.2006.70.

Otsuka, Jun. 2023. *Thinking About Statistics: The Philosophical Foundations*. 1st ed. New York: Routledge. https://doi.org/10.4324/9781003319061.

Padilla, Lace, Ian Ruginski, and Sarah Creem-Regehr. 2017. "Effects of ensemble and summary displays on interpretations of geospatial uncertainty data." *Cognitive Research: Principles and Implications* 2 (1). https://doi.org/10.1186/s41235-017-0076-1.

Smart, Stephen, and Danielle Albers Szafir. 2019. "Measuring the separability of shape, size, and color in scatterplots." *Conference on Human Factors in Computing Systems - Proceedings*, 1–14. https://doi.org/10.1145/3290605.3300899.

Spiegelhalter, David. 2017. "Risk and uncertainty communication." *Annual Review of Statistics and Its Application* 4: 31–60. https://doi.org/10.1146/annurev-statistics-010814-020148.

Tierney, Nicholas, and Dianne Cook. 2023. "Expanding Tidy Data Principles to Facilitate Missing Data Exploration, Visualization and Assessment of Imputations." *Journal of Statistical Software* 105 (7): 1–31. https://doi.org/10.18637/jss.v105.i07.

Vanderplas, Susan, Dianne Cook, and Heike Hofmann. 2020. "Annual Review of Statistics and Its Application Testing Statistical Charts: What Makes a Good Graph?" https://doi.org/10.1146/annurev-statistics-031219-041252.

Vanderplas, Susan, and Heike Hofmann. 2015. "Signs of the Sine Illusion — Why We Need to Care Signs of the Sine Illusion — Why We Need to Care" 8600. https://doi.org/10.1080/10618600.2014.951547.

Wickham, Hadley, and Heike Hofmann. 2011. "Product plots." *IEEE Transactions on Visualization and Computer Graphics* 17 (12): 2223–30. https://doi.org/10.1109/TVCG.2011.227.

Wilkinson, Leland. 2005. *The Grammar of Graphics (Statistics and Computing)*. Berlin, Heidelberg: Springer-Verlag.