Remise en cause de l'échelle logarithmique pour les diagrammes en bar

Challenging the Logarithmic Scale for Bar Charts with Orders of Magnitude Values

Katerina Batziakoudi, Stéphanie Rey, and Jean-Daniel Fekete

English Abstract—In this work, we question the widespread use of logarithmic scales for communicating values spanning multiple orders of magnitude—Orders of Magnitude Values (OMVs)—to general audiences. Focusing on bar charts, we draw on cognitive insights to better match how people perceive large numerical ranges. Research in cognitive psychology shows that people tend to reason in a piecewise linear way: they group values by scale words (e.g., millions, billions) and apply linear reasoning within each group. Building on the recently introduced EplusM scale, we adapt it to bar charts—EplusM bar charts—and propose two new variants: Bricks, inspired by subitizing and round-number perception, and Multi-Magnitude, which uses faceting to encode scale words. We evaluate four bar chart designs—Logarithmic, EplusM, Bricks, and Multi-Magnitude—in a crowdsourced study across value retrieval and comparison tasks. Results show that EplusM bar charts are preferred over logarithmic ones, boost user confidence, and reduce perceived effort, while preserving performance. These results position EplusM-based bar charts as compelling alternatives for visualizing OMVs to the public.

1 Introduction

In this work, we challenge the use of logarithmic scales for the visualization of bar charts, and we validate designs that better align with the numerical perception of large value ranges. From public health data to national budgets, we are regularly exposed to numbers that span from thousands to millions and billions. These large value ranges—referred to as Orders of Magnitude Values (OMVs)—are cognitively demanding for the general public to interpret [3] and difficult to represent effectively with common visualization techniques [1]. For example, in the French national budget (see Figure 1), where allocations range from tens of thousands to hundreds of billions, a linear bar chart hides smaller values. While a logarithmic bar chart can display all budget categories, it hinders quantitative comparisons between them [1], [9] and is difficult for the general public to interpret [6], [15], [18].

Researchers in cognitive psychology have explored this difficulty, suggesting that people don't have a logarithmic mental representation for large numbers [12], [13]. Instead, humans use meaningful categories—such as "millions" and "billions"—and organize values into these discrete categories, applying linear reasoning within each. This *piecewise linear* interpretation of OMVs also aligns with how large numbers are expressed both verbally and symbolically. In verbal communication, large values consist of two parts: a numeric component (ranging linearly from 1 to 999) and a scale word (e.g., millions). Similarly, in scientific notation, large numbers are represented as the product of two components, the *mantissa* (which increases linearly) and the *exponent*, which indicates the scale. For example, the value 8,000,000 is written as 8×10^6, where 8 is the *mantissa* and 6 the *exponent*.

Visualization researchers have proposed novel designs for OMVs that separately encode the mantissa and exponent, similar to scientific notation [1], [2], [4], [5], [9], [10]. In a previous study [1], we systematically explored the design space of mantissa-exponent visualizations, proposing positional encodings—such as the *EplusM* scale— that align with the piecewise linear interpretation of OMVs. The only visual distinction between EplusM and logarithmic scales lies in the linear positional encoding of the mantissa between two consecutive exponents.

In this article, we aim to empirically validate visualization designs that effectively communicate OMVs to the general public. To that end, we focus on bar charts—the most commonly used idiom— and pursue two objectives: 1) provide significant evidence for using EplusM (Figure 1 (3)) and not logarithmic bar charts (Figure 1 (2)) for communicating OMVs datasets to a broad audience, and 2) explore improvements to EplusM bar charts by incorporating insights from cognitive psychology. We design and evaluate two novel bar charts based on the EplusM scale:

1) **Bricks:** Leveraging the linearity of EplusM between exponents, this design divides the mantissa into units, drawing inspiration from round numbers [16] and *subitizing*—the ability to quickly and accurately recognize small quantities of items without the need for counting [11] (Figure 1 (4)).
2) **Multi-Magnitude:** Inspired by the categorical interpretation of OMVs [12] this design separates values by magnitude category (e.g., millions, billions) using faceting (Figure 1 (5)).

- *Katerina Batziakoudi: Berger-Levrault, Université Paris-Saclay, CNRS, Inria*
  E-mail: a.batziakoudi@berger-levrault.com.
- *Stéphanie Rey: Berger-Levrault*
  E-mail: Stephanie.REY@berger-levrault.com.
- *Jean-Daniel Fekete: Université Paris-Saclay, CNRS, Inria.*
  E-mail: Jean-Daniel.Fekete@inria.fr.

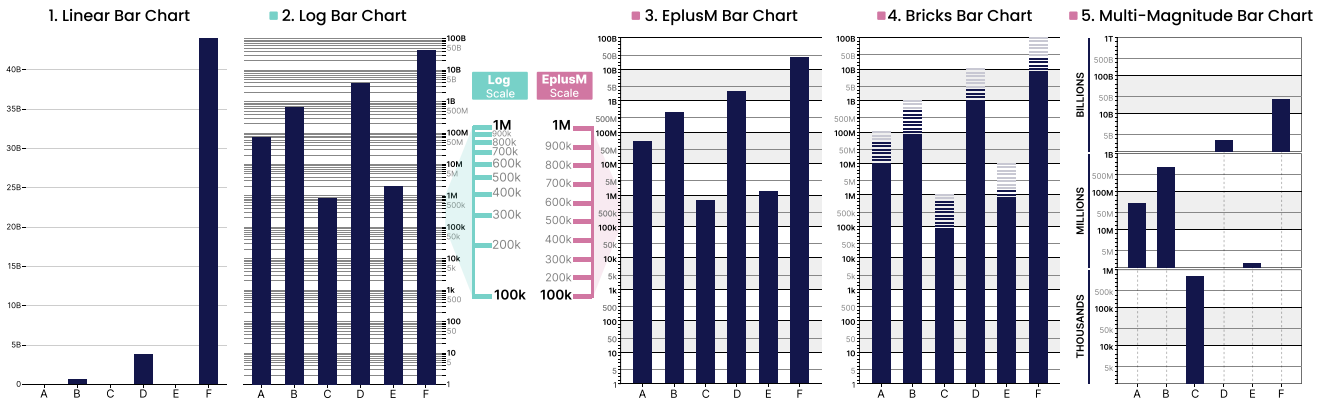

Fig. 1. Bar chart designs illustrating a sample of the French government's budget allocations, showcasing differences in orders of magnitude. On the left are the common (1) Linear and (2) Logarithmic bar charts. On the right are three bar chart designs that use the EplusM (Exponent plus Mantissa) scale—a piecewise linear scale that separates the axis into pieces based on exponent values, with values within each piece distributed linearly. (3) is a bar chart using the EplusM scale, referred to as the EplusM bar chart. (4) Bricks and (5) Multi-Magnitude introduce two variations in the original EplusM bar chart inspired by the numerical perception literature.

To validate the effectiveness of EplusM over logarithmic bar charts and assess the effectiveness of the novel designs, we conducted a crowdsourced user study with 112 participants. In summary, we make the following contributions:

- We empirically validate that EplusM bar charts outperform logarithmic ones, resulting in higher user preference, lower mental demand, and greater confidence.
- We extend the corpus of OMV visualizations, by introducing and evaluating two cognitively informed designs: Bricks and Multi-Magnitude.

2 Evaluation

To address the objectives of our study, we designed a within-subjects experiment to compare different visualizations. This design choice allowed us to statistically confirm our hypothesis and complement our initial findings [1], with user-centered quantitative and qualitative insights into perceived workload and user preference. Participants, recruited through a crowdsourced experiment on Prolific.co [17], completed a series of tasks using four bar chart designs: Log, EplusM, Bricks, and Multi-Magnitude. Additionally, to reduce the duration and facilitate deeper task analysis, a between-subjects approach was used to divide participants into two separate task groups: (1) *Value Retrieval and Difference Estimation*, and (2) *Ratio Estimation*. Since the analysis is performed separately for each task, we do not directly compare participants across the two groups.

We formulated the following hypotheses:

- **H$_1$**: *The EplusM bar chart performs as well as or better than the Log bar chart across key effectiveness metrics, in tasks involving OMV visualizations.*
- **H$_2$**: *The Bricks Bar Chart reduces perceived workload and improves response time and confidence compared to the EplusM Bar Chart, in tasks involving OMV visualizations.*
- **H$_3$**:*The Multi-Magnitude improves accuracy compared to the EplusM Bar Chart, in tasks involving OMV visualizations.*

3 Results

In summary, our findings show that all piecewise linear designs performed as well as, or better than, the logarithmic bar chart, providing additional support for the idea that people perceive OMVs in a piecewise linear manner [6], [7], [12], [13]. Our results suggest that the Bricks visualization, which incorporates rounded numbers and supports subitizing, can significantly boost user confidence compared to the original EplusM. However, it may introduce novelty effects that could require training or further refinement. Multi-Magnitude, while performing well in terms of accuracy, was less preferred by participants, likely due to challenges in comparing values across magnitude categories. Among the designs evaluated, the EplusM bar chart stood out for its consistency across tasks, measures, and individual characteristics, such as subjective numeracy. It was perceived as the easiest and, notably, even the most familiar by many participants—despite using a novel scale. Based on this evidence, we advocate for the adoption of the EplusM bar chart as a default alternative to the logarithmic one for OMVs visualizations for the general public.

4 Conclusion

Our findings challenge the dominant use of logarithmic scales in OMV bar charts and offer significant evidence for replacing them with the EplusM scale. We advocate moving beyond scales defined purely by mathematical properties, and toward designs that better reflect our cognitive representation of large numbers. Cognitive insights have long informed visualization—for example, by improving color scales based on color perception [8], [14]. Similarly, our work brings insights from numerical perception to the design of positional encodings for OMVs.

References

[1] K. Batziakoudi, F. Cabric, S. Rey, and J.-D. Fekete. Lost in Magnitudes: Exploring Visualization Designs for Large Value Ranges.

In *CHI 2025 - ACM Conference on Human Factors in Computing Systems*, Yokohama, Japan, Apr. 2025.

[2] R. Borgo, J. Dearden, and M. W. Jones. Order of magnitude markers: An empirical study on large magnitude number detection. *IEEE Trans. Vis. Comput. Graph.*, 20(12):2261–2270, Dec. 2014.

[3] C. Boyce-Jacino, E. Peters, A. P. Galvani, and G. B. Chapman. Large numbers cause magnitude neglect: The case of government expenditures. *Proceedings of the National Academy of Sciences*, 119(28):e2203037119, 2022.

[4] D. Braun, R. Borgo, M. Sondag, and T. von Landesberger. Reclaiming the horizon: Novel visualization designs for time-series data with large value ranges. *IEEE Trans. Vis. Comput. Graph.*, 30(1):1161–1171, 2024.

[5] D. Braun, K. Ebell, V. Schemann, L. Pelchmann, S. Crewell, R. Borgo, and T. von Landesberger. Color coding of large value ranges applied to meteorological data. In *Visualization and Visual Analytics (VIS)*, pages 125–129, USA, 2022. IEEE.

[6] L. Ciccione, M. Sablé-Meyer, and S. Dehaene. Analyzing the Misperception of exponential growth in graphs. *Cogn.*, 225:105112:1–105112:11, Aug. 2022.

[7] B. H. Engler, F. Hutzler, and S. Hawelka. An extended logarithmic visualization improves forecasting accuracy for exponentially growing numbers, but residual difficulties remain. *International Journal of Forecasting*, page to appear, 2024.

[8] C. G. Healey. Choosing effective colours for data visualization. In R. Yagel and G. M. Nielson, editors, *7th IEEE Visualization Conference, IEEE Vis 1996, San Francisco, CA, USA, October 27 - November 1, 1996, Proceedings*, pages 263–270. IEEE Computer Society and ACM, 1996.

[9] M. Hlawatsch, F. Sadlo, M. Burch, and D. Weiskopf. Scale-stack bar charts. *Computer Graphics Forum*, 32(3pt2):181–190, June 2013.

[10] M. Höhn, M. Wunderlich, K. Ballweg, and T. v. Landesberger. Width-Scale Bar Charts for Data with Large Value Range. In A. Kerren, C. Garth, and G. E. Marai, editors, *EuroVis 2020 - Short Papers*. The Eurographics Association, 2020.

[11] E. L. Kaufman and M. W. Lord. The discrimination of visual number. *Am J Psychol*, 62(4):498–525, Oct. 1949.

[12] D. Landy, A. Charlesworth, and E. Ottmar. Categories of Large Numbers in Line Estimation. *Cognitive Science*, 41(2):326–353, 2017.

[13] D. Landy, N. Silbert, and A. Goldin. Estimating Large Numbers. *Cognitive Science*, 37(5):775–799, July 2013.

[14] S. Lin, J. Fortuna, C. Kulkarni, M. Stone, and J. Heer. Selecting semantically-resonant colors for data visualization. *Computer Graphics Forum*, 32(3pt4):401–410, 2013.

[15] D. N. L. Menge, A. C. MacPherson, T. A. Bytnerowicz, A. W. Quebbeman, N. B. Schwartz, B. N. Taylor, and A. A. Wolf. Logarithmic scales in ecological data presentation may cause misinterpretation. *Nature Ecology & Evolution*, 2(9):1393–1402, 2018.

[16] H. A. Nguyen, J. M. Hofman, and D. G. Goldstein. Round numbers can sharpen cognition. In *CHI '22: CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA, 29 April 2022 - 5 May 2022*, pages 375:1–375:15. ACM, 2022.

[17] Prolific. Prolific. https://https://www.prolific.com/, 2024. Accessed on 08-Sep-2024.

[18] A. Romano, C. Sotis, G. Dominioni, and S. Guidi. The scale of COVID-19 graphs affects understanding, attitudes, and policy preferences. *Health Econ.*, 29(11):1482–1494, Nov. 2020.