Heterogeneous Visualization: A Call for Empirically Driven Technology Advancement and Adoption

Preprint

Kenny Gruchalla and Graham Johnson

National Renewable Energy Laboratory

Presented at the ASCR Workshop on Visualization for Scientific Discovery, Decision-Making, & Communication
Washington, D.C.
January 18-20, 2022

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-2C00-81684
September 2022

Heterogeneous Visualization: A Call for Empirically Driven Technology Advancement and Adoption

Preprint

Kenny Gruchalla and Graham Johnson

National Renewable Energy Laboratory

Suggested Citation
Gruchalla, Kenny, and Graham Johnson. 2022. *Heterogeneous Visualization: A Call for Empirically Driven Technology Advancement and Adoption; Preprint*. Golden, CO: National Renewable Energy Laboratory. NREL/CP-2C00-81684.
https://www.nrel.gov/docs/fy22osti/81684.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-2C00-81684
September 2022

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy National Renewable Energy Laboratory (NREL). The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.OSTI.gov.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Heterogeneous Visualization:
A Call for Empirically Driven Technology Advancement and Adoption

Kenny Gruchalla (kenny.gruchalla@nrel.gov), Graham Johnson (graham.johnson@nrel.gov)
Data, Analysis and Visualization Group, Computational Science Center,
National Renewable Energy Laboratory

Topics: 2b & 3b

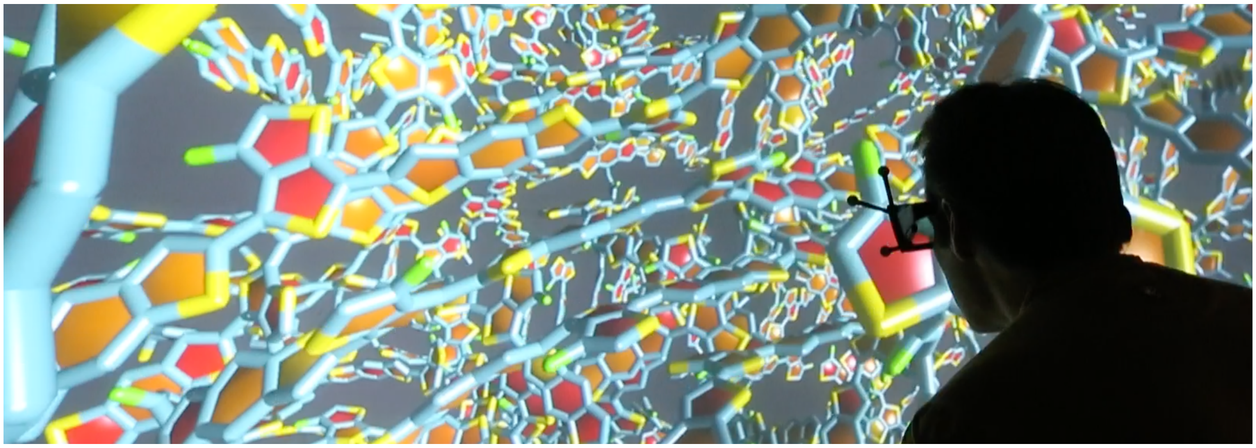

Figure 1: *A researcher investigating polymer stacking in the active layer of an organic photovoltaic device, using the large-scale immersive virtual environment at NREL. Through this immersive visual analysis, scientists were able to qualitatively distinguish stacking characteristics between materials that they had misinterpreted with more traditional desktop analyses. [3]*

Challenge & Opportunity

Our ability to generate data from simulations and experimental platforms is generally outpacing our ability to analyze those data efficiently and effectively. There are a growing number and variety of possible visualization display modalities, from commodity head-mounted displays to large-scale immersive environments, from desktop and touch displays to high-resolution display walls. Many of these visualization technologies and visual environments are rapidly evolving and could transform analysis for certain classes of complex scientific and engineering data. However, the choice of what technology or combination of technologies to use has historically been largely ad hoc and lacks a carefully validated understanding of how to best utilize different visualization technologies to advance the science. To maximize the impact of our data and analyses, it is imperative that we use the most effective visualization environments for the analysis task at hand.

Toward that goal, we need to develop an empirical understanding of how these technologies positively and negatively affect cognition, perception, and analytical processes for different types of analyses. In addition, we need to consider how we can combine multiple technologies to complement each other, improving ergonomics and better supporting both qualitative and quantitative analysis. There is growing evidence that advanced visualization technologies, such as immersive visualization and high-resolution display walls, benefit the visual analysis of complex data. We have repeatedly observed scientists discover features in their data or whole new insights into phenomena using immersive visualization, which had evaded them in prior examinations of the very same data on traditional desktop displays [3]. These observations are consistent with the theory of embodied cognition [4] where immersive visualization improves our understanding by supporting natural body movements and automatic brain function that facilitates reasoning about the data. Likewise, high-resolution display walls can support sensemaking, providing external memory and a semantic layer [1]. However, the applicability of these technologies is extremely data and task-dependent, and as such, more empirical research is critically needed to understand how and when to employ them. Moreover, not all visualization technologies are created equal: it is not at all clear if commodity head-mounted displays are capable of supporting the types of discoveries we have documented in our large-scale immersive environment. [3]

This report is available at no cost from the National Renewable Energy Laboratory at www.nrel.gov/publications.

Figure 2: *The combination of heterogeneous visualization technologies Left: In the background, an analyst is interacting with an immersive visualization of city-energy model data. In the foreground, another analyst works with representations of the same data in an R-Studio notebook. Selections and brushings on one platform translate to the other.[2] Right: Combining the fidelity of a 100 MPixel display wall with the fluid interactions on multi-touch table.*

Furthermore, most advanced visualization technologies come with serious trade-offs. For example, while immersive visualization can directly support qualitative evaluations, quantitative analyses are generally limited. Large high-resolution walls can provide the visual real estate for large amounts of information, but interaction becomes cumbersome and tedious. However, the combination of technologies holds promise to alleviate some of the most severe limitations. For example, we have had success combining immersive displays and statistical notebooks (Figure 2 Left), and integrating multi-touch control surfaces and high-resolution display walls (Figure 2 Right).

We assert that an empirically driven research program, designed to uncover how advanced visualization technologies affect ASCR-focused and related program analyses, could provide foundations, guidance, and frameworks for the scientific teams and ultimately promote better use of their resources and maximize the overall impact of projects with complex, extreme-scale data. More specifically, **we propose a program of empirical research targeted to investigate:**

- Advanced visualization technologies and their benefits for subsets of data and types of analyses
- How different visual environments provide distinct benefits for different analyses
- How different visual environments provide distinct benefits for teams and stakeholders
- How combinations of visualization technologies improve interaction, perception, and cognition

Timeliness

As our scientific research programs continue to expand, supported by DOE's leadership-class exascale high-performance computing resources, targeted large-scale empirical studies focused on the application of advanced visualization technologies and environments are notably needed. They will provide the basis for understanding how certain visualization technologies, their environments, and combinations thereof can properly support classes of analyses with complex data across scientific teams. Ultimately, these empirical findings will provide guiding lights for properly investing in the design, development, and deployment of next-generation visualization technologies that will provide comprehensive insights into our most complex systems.

Addressing our fundamental knowledge gaps around the development of advanced visualization ecosystems ***now*** *will enable us to replace ad hoc design approaches with empirically supported visualization technologies and associated environments - providing critical insights and advancing the science by choosing the right visualizations for the analyses of complex data on a given team.*

References

[1] Christopher Andrews, Alex Endert, and Chris North. "Space to Think: Large High-Resolution Displays for Sensemaking". In: *Proceedings of the SIGCHI*. CHI '10. Atlanta, Georgia, USA, 2010, pp. 55–64.

[2] Nicholas Brunhart-Lupo et al. "Collaborative Exploration of Scientific Datasets Using Immersive and Statistical Visualization". In: *Proceedings of the 2020 Improving Scientific Software Conference* (2020).

[3] Kenny Gruchalla and Nicholas Brunhart-Lupo. "The Utility of Virtual Reality for Science and Engineering". In: *VR Developer Gems*. Ed. by W.R. Sherman. 2019. Chap. 21, pp. 383–402.

[4] Edwin Hutchins. *Cognition in the Wild*. The MIT Press, 1996. DOI: 10.7551/mitpress/1881.001.0001.

This report is available at no cost from the National Renewable Energy Laboratory at www.nrel.gov/publications.