Broadening Intellectual Diversity of Visualization Research Papers

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Promoting a wider range of contribution types can facilitate healthy growth of the visualization community, while increasing intellectual diversity of visualization research papers. In this article, we discuss the importance of contribution types and summarize contribution types that can be meaningful in visualization research. We also propose several concrete next steps we can and should take to ensure a successful launch of the contribution types.

We as a visualization research community increasingly see the need for and use of visualization not only for exploring or analyzing data, but also for communicating insights extracted from the data or for explaining concepts and phenomena in the real world. However, we seem to be stuck in a narrow scope when evaluating contributions that a visualization research project can and should make. For example, papers presenting novel interaction techniques for visualization often appear in non-visualization conferences after (or with the fear of) being turned away from visualization venues, being labeled as "out of scope." We suggest that the current lens of five paper types used by several top visualization conferences[1] is a narrow view of possible contributions that hinders us from demonstrating and realizing the full potential of visualization research. It may well be inhospitable to the people from other research communities or industries who successfully leverage visualizations in their research and practice.

In this article, we discuss a broader range of contribution types than is currently accepted, with aims to promote healthy growth of the visualization community, to increase intellectual diversity, and to better demonstrate the value and impact of visualization research. We fully acknowledge the value of the visualization paper types,[2] particularly with respect to the paper writing and reviewing process. However, we also note that paper types are frequently applied as prescriptive: they tend to specify much of the paper structure and may not be well-suited to papers with less common contributions (e.g., those outlining new problem spaces) or paper that do not comply with the existing structures (e.g., practitioner-oriented applications). We assert that the lens of

contribution types can give a broader scope to the types of papers that are considered acceptable (e.g., exciting and emerging research that does not fit exactly into a paper type) and can offer more transient and flexible criteria to evaluate visualization research.

After discussing the importance of contribution types, we describe five examples of contribution types that are rarely seen in visualization conferences. We offer the descriptions of these contribution types along with example papers, as well as a broader collection of contribution types that are seen more widely. We also argue that looking at visualization research through the contribution type lens would support the intellectual evolution and expansion of our community, opening up the possibility of seeing new contribution types we may not yet have imagined. We conclude with the discussion of concrete next steps the visualization community can take to ensure a successful implementation and application of the research contribution types.

THE ROLE AND VALUE OF CONTRIBUTION TYPES

We consider a contribution to be some unit of knowledge that advances our understanding of visualization as a community that can facilitate the growth of our field in new directions. This knowledge can be expressed through several forms including ideas, results, and discussions. The broad scope of a contribution can make it difficult to recognize and communicate knowledge across the community. Inspired by the paper summarizing seven research contribution types in HCI,[3] we aim to clarify contributions both within the visualization research community and to newcomers through the discussion and articulation of contribution types.

We posit that considering contribution types would help our community in the following ways:

1. Enumerating types of contributions can familiarize community members with lines of research we do not normally produce or read, helping us recognize those contributions when we come across them.
2. Categorizing work into contribution types allows for greater flexibility in crafting academic papers. In particular, newcomers to the visualization community can more freely craft papers that combine typical visualization contributions with less-known ones, especially when they are bringing new methods from another research community.
3. Clearly stating contribution types in research papers can benefit both authors and reviewers by providing shared expectations. It can help authors measure their contributions more objectively, and help reviewers more appropriately evaluate the work.
4. A wider range of contribution types can foster intellectual diversity by providing a more accessible method for integrating new kinds of research and perspectives on visualization both for newcomers and for established researchers.
5. Thinking about known contribution types may identify gaps and underrepresented lines of inquiry, and reveal new forms of contribution for the community to consider.

We note that a contribution type is separate from a paper or a paper type. A paper may present a single type of contribution, for example, a new algorithm, or it may provide several types of contributions that are related to solving a single problem, such as the task and data abstractions, techniques, and evaluation that make up a design study.

FIVE EXAMPLE CONTRIBUTION TYPES

We identified 26 contribution types reflective of visualization research (Table 1), building on our own observations and conversations with the visualization community. We began discussing contribution types at a breakout session at the BIRS Workshop, "Restructuring IEEE VIS for the Future," focused on broadening intellectual diversity in visualization research. We continued our discussion after the workshop and held a meetup at IEEE VIS 2018 to continue the conversation with a broader audience. While many of these contribution types capture common threads in current visualization research, several reflect new kinds of intellectual diversity often underrepresented or seen as outside of the scope offered by conventional paper types. This list is not comprehensive and we believe no list ever could be. Our goal is to present a broad set of contributions that reflect the intellectual diversity present in the field, but spread across multiple venues and communities of practice. These contribution types illustrate growing interdisciplinary areas that provide promising avenues for broadening the intellectual knowledge base that serves as the foundation for our community.

Table 1. Types of Contributions for Visualization Research.

Contribution Type	Description
Algorithmic simplification	simplification or explanation of techniques and algorithms to make them easier to understand and reproduce
Artistic design	practices and evaluative reflection on expressiveness of visualization
Data abstraction	mapping of data from a domain/problem to abstract data and dataset types, including identification or clarification of new dataset types, data types, or facets of data not previously articulated in the literature
Data structure	improvements or new uses of existing ones to support visualization
Dataset	publicly available dataset for use in understanding visualizations, e.g., their construction, consumption, design, or interpretation
Deployment	discussion of insights gained from real world deployment of a tool or technique
Design methodology	methodologies that help people take a structured and formalized approach to visualization design or that help people be more creative in devising possible visualization approaches
Evaluation methodology	methodologies that enable new ways in evaluating visualization solutions
Formalism	generalized theoretical, algorithmic, or mathematical formalisms of visualization concepts
Guideline	generalized advice for the design and use of visualizations and visualization techniques, including theoretical and practical evidence to challenge an existing (design) guideline
Interaction technique	novel interaction techniques or components, or combinations of existing interaction techniques in new ways to support visualization
Lessons from failure	discussion of unsuccessful ideas and negative results, including identification of pitfalls to be avoided
Mechanism	foundational understanding of perception and cognition to explain how visualization works
New problem and domain	thorough discussion of previously unaddressed or undiscussed visualization problems, including descriptions of domains and their research challenges that have not previously appeared in the visualization literature
Visual representation	encoding of a dataset type different from previous representations of that dataset type
Performance analysis	analysis of running visualizations and visualization algorithms efficiently on real devices
Presentation	methodology or discussion of insights for storytelling and expository applications such as data journalism and education
Qualitative empirical finding	findings from ethnographic and other deeply qualitative methods; understanding of how people approach or use tools in situ
Replication	reproduction of previously-published research and comparison of results
Survey	summary and enumeration of the state of the art, with synthesis and reflection
Systematic review	structured review and synthesis of the available literature grounded in a well-defined methodology
Task abstraction	mapping of tasks performed by domain users to abstract tasks, either newly identified or from existing taxonomies
Taxonomy and conceptual model	systematic characterizations of a particular space that scaffold thinking within that topic
Toolkit / Language / Architecture	design and implementation of a novel platform for developing visualizations
Vision	well-argued and well-supported visions of the future of visualization
Visual data analysis methodology	novel combination of established visualization and interaction techniques to perform data analysis
Yet unlisted contributions	ideas, results, discussions, or yet undiscovered units of effort that help the community solve visualization problems but have not been listed here

We here describe five examples of these contribution types---Lessons from Failure, Mechanism, Interaction Technique, Dataset and Problem, and Vision---that visualization research frequently contributes to but that currently have limited representation at visualization conferences.

Lessons from Failure Contributions

Visualization papers typically report only successes (e.g., visualization techniques that successfully solve problems, empirical studies with statistically significant results). Failures rarely see the light of day, even though some failed experiences can provide incredibly useful insight for future design and research. Other disciplines routinely analyze and report on their failures. One example is Civil Engineering (e.g., Collings, 2008). There would be a public outcry if engineers did not investigate and report the causes of a bridge failure. We argue that we should do the same, welcoming the papers with valuable lessons from the failed experiences.

Closer to our own discipline, there is clear evidence of the value in learning from failures (e.g., popularity of this topic in recent workshops.[4-6] We note that not all unsuccessful projects are worthy of being shared; for example, if they did not adhere to known design guidelines and principles or they repeated well-known mistakes. Good lessons from failure contributions should document the reasoning behind the research and why it could reasonably have been expected to succeed, and then analyze the reasons behind the failure and lessons for future projects.

Examples:

- D. Collings, "Lessons from historical bridge failures," *Proceedings of the Institution of Civil Engineers-Civil Engineering*, 2008, pp. 20–27.
- T. Lau, "Why programming-by-demonstration systems fail: Lessons learned for usable AI," *AI Magazine*, vol. 30, no. 4, 2009, pp. 65–67.
- D. Balfanz, G. Durfee, D.K. Smetters, and R.E. Grinter, "In Search of Usable Security: Five Lessons from the Field," *IEEE Security & Privacy*, vol. 2, no. 5, 2004, pp. 19–24.
- S.H. Kim, J.S. Yi, and N. Elmqvist, "Oopsy-daisy: failure stories in quantitative evaluation studies for visualizations," *Proceedings of the Fifth Workshop on Beyond Time and Errors: Novel Evaluation Methods for Visualization*, 2014, pp. 142–146.

Mechanism Contributions

Traditional graphical perception studies focus on trying to determine the right visualization for a given data type and task. However, this perspective excludes understanding why a particular visualization might work well in some scenarios (and why it may not work well in others). Such generalizable insight requires contributions that enumerate the perceptual and cognitive mechanisms at play in a visualization. These contributions hypothesize why people interpret visualized data the way they do. They provide designers with generalizable insight into what makes a visualization effective grounded in the ways people process visualized data, and enable designers to predict what might make a new design effective for a given task.

Crossovers with vision science (e.g., Borkin et al., 2013) and cognitive science (e.g., Padilla et al., 2018) offer theories and methods that enable mechanism contributions. However, these kinds of experiments are traditionally seen as external to visualization as they often require studies that exchange complexity for control, using smaller datasets, short timespans, more systematic modeling, or other techniques more closely correlated with cognitive science than HCI. We argue that these contributions are central to visualization research: they differ from traditional evaluations by connecting experimental outcomes with analyst capabilities.

Examples:

- S. Haroz and D. Whitney, "How capacity limits of attention influence information visualization effectiveness," *IEEE Transactions on Visualization and Computer Graphics*, vol. 18, no. 12, 2012, pp. 2402–2410.
- M.A. Borkin, A.A. Vo, Z. Bylinskii, P. Isola, S. Sunkavalli, A. Oliva, and H. Pfister, "What makes a visualization memorable?," *IEEE Transactions on Visualization and Computer Graphics*, vol. 19, no. 12, 2013, pp. 2306–2315.

- R.A. Rensink, "On the prospects for a science of visualization." *Handbook of Human-Centric Visualization*, Springer, 2014, pp. 147–175.
- L.M. Padilla, S.H. Creem-Regehr, M. Hegarty, and J.K. Stefanucci, "Decision making with visualizations: a cognitive framework across disciplines," *Cognitive research: principles and implications*, vol. 3, no. 1, 2018, pp. 29–53.
- D.A. Szafir, S. Haroz, M. Gleicher, and S. Franconeri, "Four types of ensemble coding in data visualizations," *Journal of Vision*, vol. 16, no. 5, 2016, 11:1–19.

Interaction Technique Contributions

User interaction is a central component of many visualizations. People reason and communicate through interaction with data, fostering cognitive processes of knowledge generation.[7] Interaction is particularly important when we engage with large and complex datasets because many tasks can no longer be completed using static images alone. Several researchers have explicitly advocated more careful interaction design, further research about novel visualization interactions, and the characterization of successful interaction.[8,9] Due to the importance of user interaction, the visualization community would benefit from more clearly articulating when contributions are made based on interaction rather than a novel visual encoding technique.

Characterizing contributions made by an interaction technique enables papers to articulate novel methods, paradigms, user tasks, modalities, and implementations. While interaction in visualizations depends on the visual representation being interacted with, this contribution type focuses less on the novelty of the representation, but more on novel ways that people can interact with data through these representations. We posit that interaction technique contributions can lead to new discoveries in helping people make sense of data through the lens of interactivity.

Examples:

- H. Xia, N. Henry Riche, F. Chevalier, B. De Araujo, and D. Wigdor, "DataInk: Direct and Creative Data-Oriented Drawing," *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 2018, Paper No. 223.
- M. Cordeil, A. Cunningham, T. Dwyer, B.H. Thomas, and K. Marriott, "ImAxes: Immersive axes as embodied affordances for interactive multivariate data visualization," *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology*, 2017, pp. 71–83.
- J. Jo, S. L'Yi, B. Lee, and J. Seo, "TouchPivot: blending WIMP & post-WIMP interfaces for data exploration on tablet devices," *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 2017, pp. 2660–2671.
- T. Gao, M. Dontcheva, E. Adar, Z. Liu, and K.G. Karahalios, "DataTone: Managing ambiguity in natural language interfaces for data visualization," *Proceedings of the 28th Annual ACM Symposium on User Interface Software and Technology*, 2015, pp. 489–500.
- B. Kondo and C. Collins, "DimpVis: Exploring time-varying information visualizations by direct manipulation," *IEEE Transactions on Visualization and Computer Graphics*, vol. 20, no. 12, 2014, pp. 2003–2012.

Dataset and Problem Contributions

As any field matures, the work published in that field gradually evolves from large, exciting strides to incremental improvements. Yet, visualization has a history of successful continuous growth through the introduction of new data types and new problems. For example, the advent of scientific visualization correlates with the introduction of spatial data from science and engineering into the landscape of graphics applications, and the advent of information visualization correlates with the introduction of tabular, tree, hierarchical, and text data into the landscape of spatial data. In contrast, resistance to the introduction of new data types and problems can truly limit growth. Moreover, the unconditional acceptance of a particular theory or guideline can further stunt the growth of a field. For example, the unconditional adoption of the overview-first design paradigm can alienate domain scientists and journalists who operate under a details-first workflow (Luciani et al., 2019).

We argue that the introduction of new data types and problems is a valuable contribution to our field and should be recognized as such. A new problem contribution would describe the problem and the domain in which the problem appears. For example, consider the problem of visualizing sets of data that have a semantically significant spatial organization, yet are not spatially adjacent (Collins et al., 2009), with instantiations in machine translation, geospatial applications, or sets of research articles on a timeline. As another example, consider the search-first paradigm (van Ham and Perer, 2009) and its instantiation in large citation networks. While these two examples were published in the visualization literature, they were accepted at the time on the basis of the technical solutions they proposed.

We also argue that the intellectual effort involved in creating and curating datasets suitable for visualization research should be rewarded with publication credit. A new dataset contribution would provide a description of the dataset and its challenges, and make at least one example dataset public. A few examples exist in our field, including the Scientific Visualization Contest datasets, the VAST Challenge datasets, and, rarely, datasets in the visualization literature (e.g., Isenberg et al., 2017); explicit consideration of this contribution type may inspire more examples, as it did in other fields (e.g., MacKenzie and Soukoreff, 2003).

Examples:

- C. Collins, G. Penn, and S. Carpendale, "Bubble sets: Revealing set relations with iso-contours over existing visualizations," *IEEE Transactions on Visualization and Computer Graphics*, vol. 15, no. 6, 2009, pp. 1009–1016.
- F. van Ham and A. Perer, "Search, show context, expand on demand: Supporting large graph exploration with degree-of-interest," *IEEE Transactions on Visualization and Computer Graphics*, vol. 15, no. 6, 2009, pp. 953–960.
- T. Luciani, A. Burks, C. Sugiyama, J. Komperda, and G.E. Marai, "Details-First, Show Context, Overview Last: Supporting Exploration of Viscous Fingers in Large-Scale Ensemble Simulations," *IEEE Transactions on Visualization and Computer Graphics*, vol. 25, no. 1, 2019, pp. 1225–1235.
- P. Isenberg, F. Heimerl, S. Koch, T. Isenberg, P. Xu, C.D. Stolper, M. Sedlmair, J. Chen, T. Möller, and J. Stasko, "vispubdata. org: A metadata collection about IEEE Visualization (VIS) publications," *IEEE Transactions on Visualization and Computer Graphics*, vol. 23, no. 9, 2017, pp. 2199–2206.
- I.S. MacKenzie and R.W. Soukoreff, "Phrase sets for evaluating text entry techniques," *CHI '03 extended abstracts on Human factors in computing systems*, 2003, pp. 754–755.

Vision Contributions

Another way of giving a boost to a mature research community, which is in danger of being stagnant, is to provide well-argued and well-supported visions of the future of the community to inspire the people in the community by providing new research agenda and forward-thinking ideas. Based on the combination of experience, imagination, and wisdom, they can cover non-traditional topics, viewpoints, and perspectives that bring something new to visualization research and practice without reporting a new research project.

We acknowledge that papers with vision contributions may not be as common as those with other research contributions. On the other hand, they tend to become seminal papers, making a high impact to the community. For example, the Illuminating the Path book (Cook and Thomas, 2005) played a critical role in establishing the Visual Analytics research and has been cited more than 2,300 times (as of January 2019).

Examples:

- G.D. Abowd, "What next, ubicomp?: celebrating an intellectual disappearing act," *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, 2012, pp. 31–40.
- M. Weiser, "The computer for the 21st century," *Mobile Computing and Communications Review*, vol. 3, no. 3, 1999, pp. 3–11.
- K.A. Cook and J.J. Thomas, "Illuminating the path: The research and development agenda for visual analytics," *National Visualization and Analytics Center*, 2005.

- A. van Dam, "Post-WIMP user interfaces," *Communications of the ACM*, vol., 40, no. 2, 1997, pp. 63–67.
- C. Plaisant, "The challenge of information visualization evaluation," *Proceedings of the working conference on Advanced visual interfaces*, 2004, pp. 109–116.

THE POSSIBILITY OF NEW CONTRIBUTION TYPES

We argue that considering visualization research through the lens of contribution types is likely to facilitate a more receptive and open attitude in how we, as visualization researchers, reflect on the contributions of our research. Thinking in terms of contributions prompts us to clearly articulate how a piece of research advances our current understanding of visualization and empowers us in arguing explicitly for the diverse ways that our research contributes to the field. The flexible nature of contribution types also enables researchers to combine multiple types of contributions in a single paper with varying levels of significance.

We expect that this open-ended, flexible attitude will also foster a culture where visualization researchers are empowered to think broadly in terms of how a piece of research can advance visualization science. An open attitude towards contributions will make the community more receptive and agile in proposing and recognizing new contribution types, and more proactive in investigating how other scientific disciplines articulate their contributions and to learn from them. We argue that such dynamic, adaptive, and responsive mechanisms are critical in building a research discipline that evolves and advances organically as new challenges and scientific questions emerge.

NEXT STEPS

Here are several concrete next steps we, as a community, can take to implement and apply a wider range of contribution types:

1. Allow (or encourage) authors to declare their contributions, including under PCS (Precision Conference Solutions), the conference management system adopted by several visualization conferences. The conference management system should also allow the introduction of new contribution types from the authors.
2. Agree on criteria for evaluating papers that have multiple types of contributions and follow those criteria during the review process. Embrace an openness to novel and different types of contributions and explicitly discourage quick rejects that are based on the grounds of a bad fit with the current paper types.
3. Educate reviewers about a wider range of possible contributions and about the criteria for evaluating papers with diverse contribution types. Where possible, route papers with non-standard contributions to a trained pool of reviewers, including reviewers from outside of the traditional research community.
4. Monitor the path of papers with non-standard contributions during the review process, and where necessary, appoint shepherd reviewers to work with first-time paper authors to help establish and bridge expectations around such contributions.
5. Monitor papers with visualization contributions published in non-visualization-centric conferences (e.g., ACM CHI, ACM UIST, PACM IMWUT) or less prestigious conferences and workshops to identify and refine enumerated contribution types.
6. Incorporate contribution types into student training and education. Encourage students to think about contributions at the time of conceiving research ideas and incorporate the discussion of contributions in visualization and research methods courses.
7. Encourage the visualization community to contribute to the ongoing discussion started with this viewpoint article.

With restructuring IEEE VIS efforts underway, further consideration of the contribution types and next steps is particularly timely. We invite the visualization community both as authors and as reviewers to reflect on what contribution types are present, how they can be better communicated and evaluated, and other possible steps we can take to continue healthy growth of the visualization community.

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