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A "Design First" Approach to Visualization Innovation

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Current approaches to visualization have resulted in many engaging and useful visualization techniques for a variety of data and tasks. As we begin to encounter new visualization problems, such as those with Big Data, we propose considering alternatives to traditional approaches. We suggest an approach influenced by the artistic and creative design community to help drive innovation in visualization research. The design-first approach focuses on the human, without influence from the data or the user requirements until a visual concept is developed. This approach offers a fresh perspective that can enhance or be an alternative to traditional visualization approaches, particularly for difficult visualization problems. We describe two case studies that used this approach to generate creative visualization solutions for a particularly difficult visual analytics challenge.

Visualization Process

The traditional visualization process is well established in the literature.[1] Nearly every version of this process includes these five key elements:

- *data*, the artifact the human uses to understand the world;
- *analytics*, the transformation of the data (such as through statistics) into more meaningful relationships;
- *visualization*, the visual transformation of the data and relationships for human consumption;
- *context of use*, the conditions under which the visualization is consumed; and
- *human*, the consumer of the data through the visualization.

The traditional visualization process begins with the data. There are many definitions of data, but in this context, we refer to raw bits, bytes, text, and images typically used in analytics rather than higher-level representations. The data is processed, such as through abstraction, statistics, summarization, or some other type of analytic. The relationships provided by the analytics are matched to visualization techniques suited to show those types of relationships. The final visualization is a combination of visualization techniques, analytics, and data that support human tasks. This *data-first approach* is the most common and accepted practice for visualization.

Alternatively, the influence of human-computer interaction (HCI) research and design practices has led to an alternative *data-human approach*.[2] Decisions about what data to use, which analytics to apply, and the best visualization technique are made earlier in the process and are influenced by a person's tasks and context of use. Although user research can be a source of requirements, the designer is limited by the available data, analytics, and system capabilities. These requirements often limit the amount of creativity that can be used to solve a problem. Furthermore, the data-first approach requires designers to be familiar with the characteristics and processing of data, thus limiting the pool of designers who have this expertise.

Design-First Visualization Process

Visualizing particularly large and complex datasets for analysis is one of several current research challenges in the visualization community.[3] Displaying an attractive graph with a million data points is not the same as providing a visual analytic that helps a human make sense of relationships in an attractive graph.

A common solution for data visual analytics is to create a meaningful abstraction of the data, rather

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than trying to visualize it all at once. Current abstraction strategies focus on characteristics of the data. This has proved to be a challenge. For example, Big Data is so big that there are many ways that data can be abstracted. Knowing which way is the most effective for the visualization and ultimately the human is a different type of problem than simply processing data. Using abstractions and maintaining context is challenging. Abstractions tend to result in a loss of context. The goal is to abstract data in a way that avoids skewing or losing context.

The design-first visualization process focuses on the human without influence from the data or the user's current work processes until a visual concept is developed. Design first differs from the data-human process (HCI) in that design first lacks the constraints from HCI engineering requirements while maintaining the problem's context.

Think of data as a type of ground truth for a problem. One of the challenges of using ground truth in system design is unintentionally designing to the answer rather than designing to solve the problem. The data-first approach is at risk of designing to the data, and the mixed data-human approach is at risk of introducing data too soon, for the same reason. The design-first approach focuses on first completely solving the visualization problem visually before constraining to the data or requirements. Let's start by thinking about the context of use:

- What high-level goal is the user trying to accomplish?
- What types of analytic questions is the user trying to answer?
- What types of relationships can provide answers to these questions?
- How can these types of relationships be visually represented?
- How well do these visual representations scale (for the case of Big Data)?
- Can the user answer analytic questions using these visual representations?

These questions sound similar to a task analysis from the HCI methodology, but there's an important difference. There are no questions about the data or the user's current work processes (yet). That is not to say that questions about the data will remain unanswered. Data is necessary to create a complete visualization. However, the absence of data removes engineering constraints that may limit visualization design possibilities.

Once a visualization concept is created, more data- and task-focused questions can be considered:

- What data does this visualization need?
- What data is available?
- What does the data look like?
- Which algorithms can process the data?
- How do users utilize the data to accomplish their goals/tasks?

These questions must be considered early in the engineering process, but it's important to not think about them too soon in the design process. You may wonder how these two lists of questions differ or why it matters to ask them in a certain way. Consider the questions "What types of relationships can provide answers to my questions?" versus "What types of relationships exist in my data?" The question focused on the user's questions and answers is a less constrained problem to solve. In contrast, the question focused on the data has already constrained potential design possibilities to what exists in the data. Constraints are necessary when the goal is to engineer a usable system, but they can also be limiting when the research goal is innovation.

The benefit of the design-first approach is that it can lead to new visualization innovations that are not constrained by data.

In some ways, the design-first process is a *human-first process*: an inversion of the current data-first visualization practice. The benefit of the design-first approach is that it can lead to new visualization innovations that are not constrained by data. The drawback is a greater risk of generating visualization concepts that are not implementable, practical, or possible. However, provocative visualization concepts that are not yet possible may drive future technology requirements. Stretching the limits of what we can do today and what we might be able to do tomorrow will lead to new innovations in visualization research.

Case Studies

We conducted two studies to explore how the design-first approach can be applied to real visual analytics challenges and to foster innovation in visualization. The first study was a small workshop in which we invited four design-oriented individuals and teams to develop visual designs using no data—only a scripted scenario. The second study was a public research contest that recruited participants from the visualization, computer science, and design communities to also develop visual designs using only a scripted scenario.

A challenge of the design-first approach is presenting enough information about the context of use to be useful while not providing details about data that may bias or constrain the design process. We wanted people who were good at human-centered visual design to not get bogged down by the size, complexity, or domain of the data problem. Imagine how a scene in a movie script might describe how an actor uses a high-tech or futuristic visual interface. The script provides context and motivation, but no data. Your job would be to create a visualization that is compelling, inspiring, and believable.

The challenge is determining how to transform that low-level data into a human-understandable format without losing meaning.

We chose cyber situation awareness as a topic to frame two design-first activities because of the visual analytics challenges the domain faces. Cyber data is high-volume, low-level data that needs to be interpreted for high-level tasks, such as situation awareness. The challenge is determining how to transform that low-level data into a human-understandable format without losing meaning.

A fictional scenario was developed to provide participants with context about the people and environment for the design. No other information or data was provided to participants; however, they were free to conduct their own background research in order to better understand the context of the problem. The scenario described the daily life and data challenges of a manager in a network operations center, including the role of the visualization designer:

> A large company has hired you to create an innovative visual design for a future situation awareness display of their network. The network is global and consists of several hundred thousand computers. The company wants the display to help them understand the overall health and status of the network. Your goal is to design a visualization for the large computer display that will provide operators with situation awareness for the company's large network.

This is a summarized version of the scenario; see the IEEE Visual Analytics Science and Technology (VAST) Challenge 2013 Mini-Challenge 2 for the full scenario, http://vacommunity.org/VAST Challenge 2013: Mini-Challenge 2.

The setting was chosen because of the real-life challenges of visualizing Big Data of large computer networks in a way that managers can operationally use. The scenario did not include specific details about the users, tasks, network, or data—this was left up to the designer.

Study 1: Visualize This!

The first study was a workshop called Visualize This! (no association with the book by Nathan Yau) that explored the design-first approach. We recruited two individuals and two teams (for a total of four work groups) to attempt the design scenario. The first individual was a mixed-media artist who specialized in the use of technology in art but had no related subject matter expertise in cyber or situation awareness. The second individual was a traditional graphic designer with some subject matter expertise in business analytics and risk management. The third was a user experience design team with comprehensive experience in cyber situation awareness. The fourth was a user experience design team from a national laboratory with comprehensive experience in emergency management and cyber situation awareness.

Each group spent approximately 40 hours working on the design scenario. Participants provided graphics and storyboards to document their designs. At the workshop, participants presented their design solutions and described their design processes. As a group, we discussed how they felt about the design scenario, the challenges of having no data, what worked, and what needed improvement.

All the participants created aesthetically pleasing and usable visualization designs while meeting the requirements of the design scenario. The two user experience teams produced familiar design concepts. However, it was the artists and designers who had the least amount of subject matter expertise who produced what we thought were the most creative solutions to the design scenario.

In particular, the graphic designer developed an interesting design concept that was thought-provoking and feasible. His process included reviewing the design scenario and then reaching out to friends in the cyber security industry. He asked

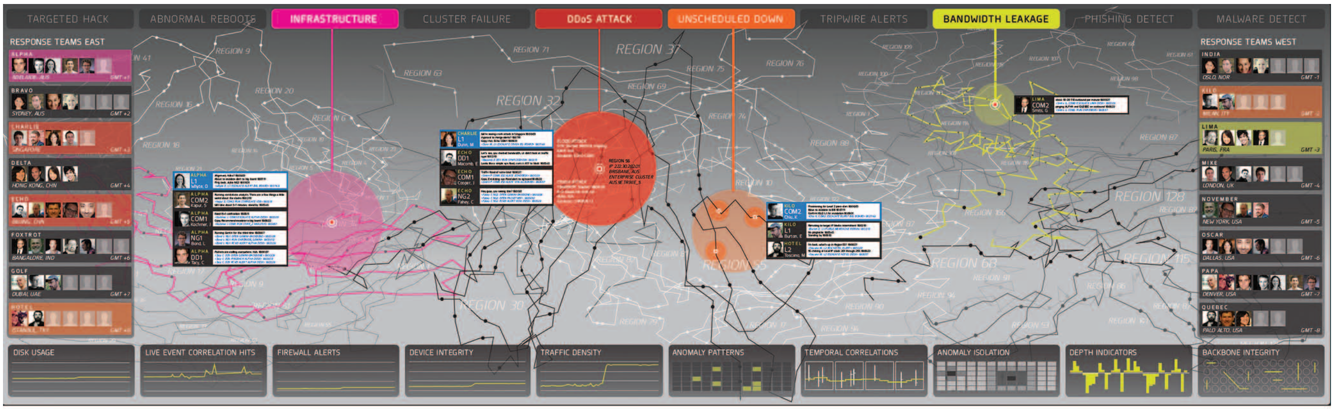

Figure 1. Visualizing situational-awareness in a very large-scale federated network.[4] Rather than representing the physical structure of the network, the graphic designer felt that an abstracted view of the subnetworks provided the same sense of "networkiness," without the noise of a large messy graph.

them, "What are the top five things that keep you up at night?" From their answers, he established a theory that managing the work of people in the context of the network was most important for solving the presented cyber situation awareness challenge. That is, it was through the people that you would be able to know which events were being investigated, which events needed more coverage, and which people were available to assist. The physical network was not as important as the concept of network places and the events happening at those places.

This visualization design provides a view of a large network, with color coded events linked with people who are investigating those events (see Figure 1).[4] Rather than representing the physical structure of the network (which can get messy in a large graph), he felt that an abstracted view of the subnetworks provided the same sense of "networkiness," without the noise of a large messy graph. Selecting an event provided insight into where on the network that event was happening and a visual link to the people who were working on that event. Additional details, such as computer information, communication between people, and general network trends, were supplementary but not necessary for a high-level awareness of the overall health and status of the network.

The next step would be to take this visualization concept and implement it with real data to evaluate the effectiveness of the design.

Interestingly, the two user experience teams with the most relevant subject matter expertise expressed that they had a difficult time completing the design scenario. Another factor about the two user experience teams was that they subscribed to the user-centered design (UCD) process, which is a software engineering process that focuses on the user's needs and requirements. Having no user requirements to work from, such as specific user tasks and data they would work with, was counter to the process they were familiar with.

One of the user experience teams repeatedly asked for additional details. We declined to provide these details, reminding them that they could draw from their own experiences and intuition. Although they developed requirements on their own, as the graphic designer did, they expressed discomfort and insecurity in not having "real" requirements to work from. This feedback leads us to wonder if it was the UCD method—essentially an engineering process—that lead to "safe" designs exhibited by the user experience teams. User-centered design supports the development of many useful visualization solutions, but it may leave the full range of creative and innovative solutions unexplored

Study 2: IEEE VAST Challenge

The second study was a public contest marketed to academics, researchers, and students. The IEEE VAST Challenge is an annual contest that aims to advance visual analytics through a series of competitions.[5] The contest is traditionally data oriented, with real and simulated datasets provided to participants to solve challenge scenarios. In 2013, we introduced a design-first challenge scenario based on the Visualize This! workshop scenario.[6] The purpose of this new challenge format was twofold: first, to get visualization researchers thinking about the human aspects of visualization and, second, to make the VAST Challenge accessible to the design community.

The scenario used in the workshop study was updated (based on workshop feedback) and used as the contest scenario. The challenge was open to the public for four months and participants could spend as much time as they needed to work on their design solutions. Submissions required participants to provide graphics, storyboards, and a

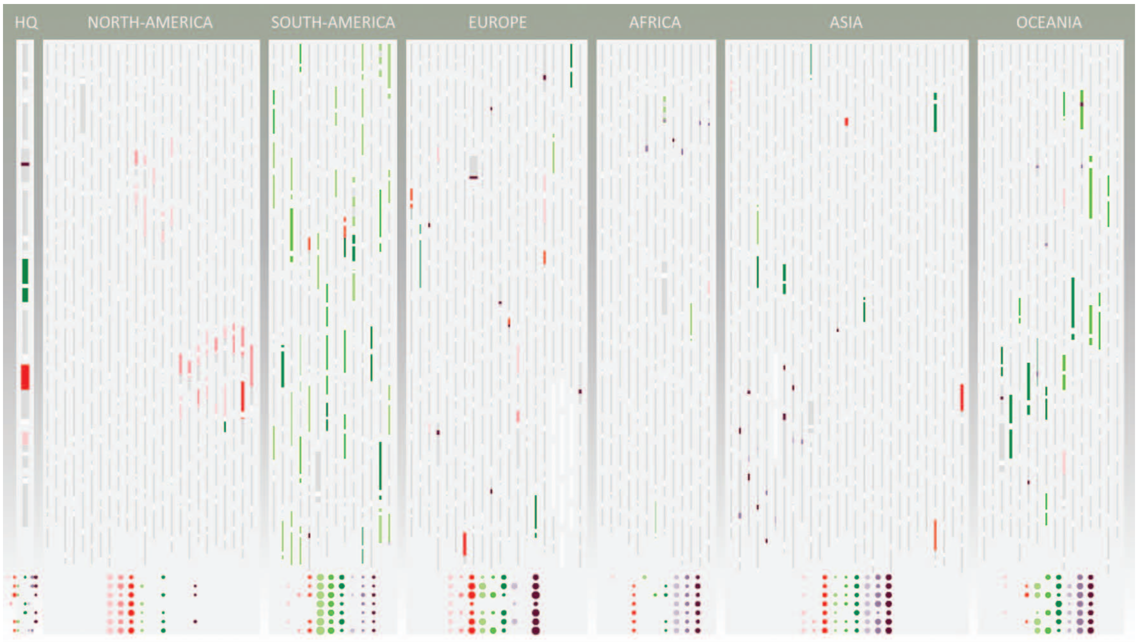

Figure 2. Spring Rain.[7] Inspired by nature, the designers used a large ambient display on which each vertical line represents a section in a large network. The lines are color coded by issue, and color density or brightness also represents issue severity.

short video explaining their design concept (a replacement for the presentations given during the Visualize This! workshop).

The challenge received 10 submissions from individuals, students, researchers, and companies. Submissions were evaluated based on the creativity of the visualization concept, scale of data supported, and perceived effectiveness from subject matter experts. All the submissions presented concepts that were technically feasible. Several submissions provided insightful iterations on existing visualization techniques that offered something new to the cyber situation awareness problem space. However, two submissions in particular exemplified the design-first ideal: creative, thought-provoking, and fresh ideas.

Both of these submissions were from teams of visualization scientists and interaction designers from the Purdue University. These designs were striking because they both managed to solve the scenario by transferring concepts from outside the visualization field in a way we had not seen before while still being technically feasible.

Spring Rain was inspired by shapes in nature as a way to represent a large computer network on a large ambient display (see Figure 2).[7] Each vertical line represents a section (such as a subnet) in a large network. The lines are color coded by issue and use color density or brightness to represent issue severity. Event history is represented by coordinated color dots at the bottom of a network that show the summative volume (size of dot) of an issue over a week. They also describe how smart glasses (such as Google Glass) could provide additional details on demand based on viewing context. The ambient information display of Spring Rain is a potential way to provide on-going, high-level situation awareness. This is an appropriate design concept for a user such as a network operations manager who does not have time for in-depth analysis and must quickly make decisions and allocate resources.

Inspired by objects in a solar system, Solar Wheels provides a collaborative and interactive wall display to support situation awareness (see Figure 3).[8] The rings in each system represent different types of issues, such as health, performance, or security status. The colored planets on the rings represent the severity of issue (color) and the number of issues at the time (size). The level of detail presented in the visualization changes based on how physically close the user is to the display. Specific details are shown when the user is within reading/touching distance, and an overview is shown when the user is several steps away from the display. The contextual zoom through physical navigation in Solar Wheels is an interesting design concept that could support the collaborative, multiuser environment in an operations center.

Both Spring Rain and Solar Wheels were rated higher than the other submissions because of their ability to creatively apply concepts from outside the cyber security domain. As VAST Challenge committee members from 2011–2013, we felt that there was a noticeable difference between the 2013 VAST Challenge results and those of the previous 2011 and 2012 VAST Challenges that also focused on cyber situation awareness.[9,10] The past challenge solutions were technically competent and usable, and they improved over the course of the three years but lacked the creative breakthrough shown by the results of the 2013 design challenge. However, we do point out that evaluating conceptual visual designs is not directly comparable with a functional prototype. Despite no formal evaluation, the potential of these designs is great, and we look forward to seeing how the practice of designing first will influence future visualization technology.

Designers are critical to the visualization process. Although it is not uncommon for engineers to be multidisciplinary and have design skills, teams that included designers did better in both the Visualize This! workshop and 2013 VAST Challenge. One of the greatest challenges we had while running the VAST Challenge was promoting the traditionally engineering-focused contest to less-technical design communities. The teams who integrated designers produced more innovative visualization solutions, but there were no designer-only teams.[6]

Getting more designers involved in visualization, especially in the early stages, will not be easy. Designers are not new to visualization, but they have traditionally been involved in the design after much of the data processing, back-end services, interactive software, and generally speaking, engineering has been completed. We believe that visualization would benefit greatly from more early designer participation. While panels, workshops, and art shows targeted at artists and designers have become more common at the annual visualization conference IEEE VIS (http://ieeevis.org),[11,12] additional outreach to this community is necessary. If anything, our case studies show how we as a visualization research community should strive to become more interdisciplinary in engineering and design.

We by no means suggest that the design-first approach replace the traditional visualization process. For example, the design-first approach may not be appropriate for visualization problems that already have strong solutions and require only incremental improvement. Additionally, the design-first approach risks the creation of visualization concepts that are simply not implementable because they may require data and analytics that are not currently available. In a way, this is an opportunity for innovation in that new data and analytic technology requirements that solve user needs may be derived directly from the design.

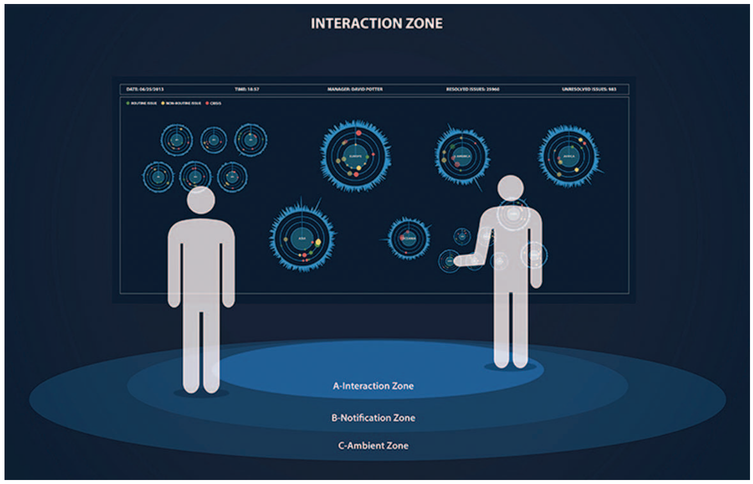

Figure 3. Solar Wheels.[8] The rings represent different types of issues, such as health or security status, and the colored planets represent the severity of issue (color) and the number of issues at the time (size).

We believe there are classes of problems for which the design-first approach will yield better results than traditional approaches. The design-first approach is especially promising for new problems that do not yet have strong visualization solutions. It provides an opportunity to consider a broad spectrum of solutions potentially leading to innovation beyond the visualization. Similarly, the design-first approach is a great way to reexamine visualization problems that have been investigated for years without a suitable solution or significant improvement. The design-first approach to visualization has yielded creative solutions for a challenging visual analytic problem in the situational awareness in cyberspace domain. Further work in this area will help assess the effectiveness of this approach as compared with other visualization design methods. We look forward to the use of the design-first approach by others so that the value to the visualization community can be further explored.

References

1. M. Ward, G. Grinstein, and D. Keim, *Interactive Data Visualization: Foundations, Techniques, and Applications*, AK Peters, 2010, p. 25.
2. M. Sedlmair, M. Meyer, and T. Munzer, "Design Study Methodology: Reflections from the Trenches and the Stacks," *IEEE Trans. Visualization and Computer Graphics*, vol. 18, no. 2, 2012, pp. 2431–2440.
3. D. Keim, H. Qu, and K.L. Ma, "Big Data Visualization," *IEEE Computer Graphics and Applications*, vol. 33. no. 4, 2013, pp. 20–21.
4. G. Szeto, "Visualization Situational-Awareness in a Very Large Scale Federated Network," Visualize This! Workshop, US Dept. of Defense, 2013.

5. C. Plaisant et al., "Evaluating Visual Analytics at the 2007 VAST Symposium Contest," *IEEE Computer Graphics and Applications*, vol. 28, no. 2, 2008, pp. 12–21.
6. M. Whiting et al., "VAST Challenge 2013: Situation Awareness and Prospective Analysis," IEEE Visual Analytics Science and Technology (VAST), 2013; http://ieeevis.org/year/2013/workshop/vast-challenge.
7. M. Promann et al., "Spring Rain," IEEE Visual Analytics Science and Technology (VAST) Challenge 2013, Mini-Challenge 2, Award for Outstanding Creative Design; http://hcil2.cs.umd.edu/newvarepository/VAST%20Challenge%202013/challenges/MC2%20-%20Situation%20Awareness%20Display%20Design/entries/Purdue%20University%20-%20Promann/.
8. S.K. Chang et al., "Solar Wheels," IEEE Visual Analytics Science and Technology (VAST) Challenge 2013, Mini-Challenge 2, Award for Outstanding Creative Design; http://hcil2.cs.umd.edu/newvarepository/VAST%20Challenge%202013/challenges/MC2%20-%20Situation%20Awareness%20Display%20Design/entries/Purdue%20University%20-%20Chang/.
9. K. Cook et al., "VAST Challenge 2012: Visual Analytics for Big Data," *Proc. IEEE Conf. Visual Analytics Science and Technology* (VAST) 2012, pp. 251–255.
10. G. Grinstein et al., "VAST 2011 Challenge: Cyber Security and Epidemic," *Proc. IEEE Conf. Visual Analytics Science and Technology* (VAST) 2011, pp. 299–301.
11. M. Chen et al., "Quality of Visualization: The Bake Off," panel discussion, IEEE VIS 2012.
12. F. Samsel, "Scheherazade's Toolbox: Artists Meet Visualization," *Proc. IEEE VIS Workshop*, 2012, http://ieeevis.org/year/2012/workshop/visweek/scheherazades-toolbox-artists-meet-visualization.

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