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Humans have used technology to improve their capabilities and overcome their limitations since the beginning of time. Interactive computing is just a tool in a long line of tools, but its potential for supporting people in processing vast amounts of information is unparalleled. My research within *human-computer interaction* (HCI) and *information visualization* builds on this idea with the goal of **amplifying human capabilities**: using interactive visual tools to improve the perceptual, cognitive, and analytical capabilities of people, allowing them to solve tasks that were previously too large or too complex to manage efficiently. My work is thus applicable to a wide range of domains and problems.

One gratifying aspect of visualization is that it is by its very nature interdisciplinary, since we are almost always visualizing someone else's data. So far, I have had the opportunity to work with data from domains ranging from biology and business to safety and social science. As a Co-PI of the DHS-funded VACCINE center for visual analytics at Purdue [G3], I have been heavily involved with stakeholders in public safety, emergency management, and cybersecurity, including local police, the U.S. Coast Guard, and TSA. Furthermore, my industry contacts at NVidia [EG2], Google [G1, G5], and SAP have given rise to research projects on business intelligence, collaborative data analytics, and portfolio mining. In addition, my recent NSF awards on sketching [G12], cyber-enabled design [G13], and STEM education [G8] have yielded collaboration opportunities with a broad set of colleagues from different disciplines. In general, I like to work closely with collaborators from other domains.

My research methodology is a mix of theory, design, and evaluation. The problems I attack are real problems posed by real users, and I strive to involve these users in the design process in a user-centered, participatory fashion. Because the problems are real and need practical solutions, all of my work is characterized by software and hardware engineering components aimed at implementing and deploying the results of our research. Finally, new HCI techniques must be empirically evaluated, and for this to be possible we need prototype implementations. After iterative design and development, my approach is to evaluate the new idea using a blend of qualitative and quantitative methods.

I have spent the last six years at Purdue University, where I was recently promoted to associate professor with tenure. During this time, I have built an independent and successful research program as well as a corresponding research group (Pivot) currently numbering six Ph.D. students. In the below treatment, I go into detail on my research on both the visual and interactive computing aspects of my work. I also discuss real-world applications within cyber-enabled learning, social and citizen science and awareness, public safety and emergency management, and creative design.

Visual Computing: Making Sense of Big Data

Visualization creates graphical representations of data that aid cognition, allowing a user to view, analyze, and understand datasets larger than would be possible with less visual formats. However, for truly big data, we invariably reach a point when there are simply not enough pixels to go around (large displays can help here, but only to a certain degree). In my research, I have taken an aggregation approach for handling this situation, where we recursively combine several data points into a hierarchy of discrete zoom levels to create a multiscale representation of the data. The problem is then twofold: (1) visually representing these aggregate entities that consist of potentially thousands of data cases [J12], and (2) providing the powerful techniques for navigating this multiscale space.[1] In the ZAME graph visualization tool [C12], my collaborators and I attacked these problems by employing programmable shaders (that we generalized later to be utilized for any visualization technique and data type [J10]) to effectively render visual aggregates in real time, and designed a set of interaction techniques tailored at traversing the multiscale environment.

[1] [J10] and [C12] have been cited 143 times; this and subsequent citation counts are from Google Scholar.

Computing has today reached a point where we must go beyond the confines of a single monitor and look at display spaces consisting of multiple heterogeneous displays. My work poses the fundamental question of how we can leverage the ecosystems of digital devices (smartphones, tablets, music players, laptops, head-mounted displays, etc.) in our surroundings into shared display environments that allow the seamless transfer and display of data. By being embedded into the real world, these display spaces will support a ubiquitous form of visual analytics [J30] at a system level, as opposed to at the level of individual devices and artifacts. Our Munin [W6] framework has been under development for more than three years, and provides a peer-to-peer distributed scene graph that is independent of graphics API, network protocol, or operating system. Using Munin, my students and I are exploring visual representations that make full use of these ubiquitous analytics environments to provide high-resolution, adaptable, and scalable visual displays. For example, the Hugin toolkit [C18] (Figure 1) connects two or several digital tabletops in geographically distributed locations into a shared display space, enabling synchronous collaboration.

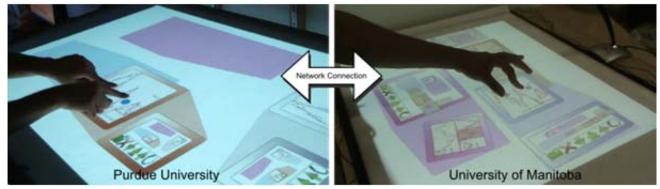

Figure 1: Hugin toolkit [C18] connecting two remote tabletop displays.

Other efforts within the visualization theme of my work focus on particular applications and data types. For example, large text corpora are often intractable to analyze due to their scale, particularly for data collections such as news stories and corporate press releases that change dynamically. In the WordBridge project [C19], we used node-link diagrams overlaid with tag clouds to display such data. The VisTwit system [W11] aggregates and analyzes Twitter messages, using an interactive web-based visualization as an index to access the tweets. Furthermore, for text corpora associated with spatial information, our automatic typographic maps [J25] can use type to visually represent the data. My students and I have also studied dynamic graphs [J14, J21], time-series data [J15, J27][2], web-based visualization [J28, J29], visualization in games [J23], and social networks [C12, J32].

Interactive Computing: Action as Cognitive Catalyst

While traditionally receiving scant attention in visualization research compared to representations, it is quickly becoming clear that interaction is much more than the interface used to control our visualization tools. Instead, interaction serves as a critical catalyst for understanding because it places direct control of the data into the hands of the user [J19]. In fact, post-cognitivist frameworks like *socially distributed cognition*[3] model information flow in a cognitive system—such as an analyst using a computational device to view and understand data—as the transfer of internal and external representational states across different media—such as a screen, your mind, and a piece of paper used to take notes—through *interactions* between them. Humans do not think in a vacuum; rather, we surround ourselves with surfaces, spaces, artifacts, and other people that support the cognitive task. Consider spreading financial reports on your kitchen table when working on your stock portfolio; annotating, stacking, and organizing bills in your office when balancing your checkbook; or gathering your family around a dining room table littered with catalogues, maps, and notepads when planning your vacation. Action is clearly a catalyst for understanding.

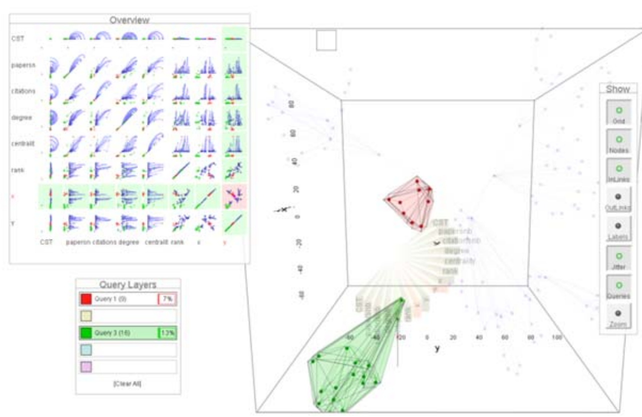

Figure 2: GraphDice [J13] used to visualize a social network.

[2] Cited 46 times since 2010.

[3] E. Hutchins. *Cognition in the Wild*. MIT Press, Cambridge, MA, 1995.

In particular, interaction plays a vital role in analyzing big data. As stated earlier, there is a very clear limit to how many pixels, colors, and individual graphical entities the human perceptual system can handle; after this limit has been exceeded, we must look beyond mere visual representations to be able to manage the massive datasets given to us. One of my research goals is thus to design interactive tools and techniques that scaffold and support human cognition in managing large and complex data. This fits into the research area of *visual analytics*, where computational methods such as machine learning and data mining are integrated in the sensemaking loop to support human users in their analysis process rather than attempting to replace them. My approach is based on providing smooth and seamless interaction techniques to allow for selecting, filtering, and combining the data, not only within a visualization but also between several different views [C25]. In the DataMeadow [J6, C10], I extended traditional dynamic query sliders to a hierarchical structure and provided a set of rich interaction techniques to allow for iterative refinement of queries. In ScatterDice [J8],[4] I designed a new method for exploring multidimensional data by navigating in the data space itself. In GraphDice [J13][5] (Figure 2), we applied this navigation technique to multivariate graphs, such as a social network from Facebook or LinkedIn, where vertices represent people and their as age, gender, and location, and edges between them represent their relations.

Figure 3: Branch-explore-merge on a digital tabletop and mobile tablet.

My recent work has gone beyond traditional computers equipped with mouse and keyboard and into the space of novel platforms such as touch, gestures, and tangibles, which provide unparalleled opportunities for applying the action-as-catalyst concept to augment human abilities. In the last few years, I have built a menagerie of novel devices in my lab, including an 81-inch FTIR/DSI tabletop display, a 3×2 tiled-LED display wall, a Kinect-based gestural input system [C28], and multiple smartphones and tablets. Several of our focus on practical solutions for using such devices for analysis and sensemaking: text entry on touch displays [C24], managing occlusion between physical objects and virtual objects on the screen [C23], and integrating tangible lenses with digital content [J22]. Furthermore, the branch-explore-merge protocol [C30] (Figure 3) scaffolds varying degrees of coupling between multiple collaborators by providing a real-time adaptation of a version control system.

Applications and Impact

True impact can only be measured by applying technology to real-world problems. My work is characterized by participatory collaboration with domain users that inspire and drive my work. Below are some of the problem domains I am particularly interested in:

- Public safety and emergency management: As a Co-PI of Purdue's DHS-funded VACCINE center on visual analytics for supporting homeland security, I have had the opportunity to work with a range of stakeholders in public safety and emergency management, including local police, the TSA, and the Coast Guard. Our work is being applied to spatial and temporal forecasting [C29], law enforcement in both mobile and desktop settings [C32], and intelligence analysis [J24]. My future work is to support decision-making through interactive steering and visualization of large-scale simulation results within critical infrastructure, food safety, and emergency mitigation.
- Social networks: Working with social scientists from Purdue's school of communication, I have found visualization to be a particularly effective tool to support social network analysis (SNA). Our

[4] Best paper at IEEE InfoVis 2008 and cited 161 times.
[5] Cited 54 times since 2010.

work on dynamic graphs [J14, J21] was conducted in close collaboration with these social scientist colleagues and led to a design study on the use of visual analytics for SNA [J32].

- Cyber-enabled learning: Formal learning is a data-intensive cognitive activity where the learner is potentially exposed to many and complex inputs and needs to form a mental representation of these. This is a perfect setting for my work on ubiquitous analytics, and my plan is to study how to build cyber-enabled learning environments using the students' own mobile devices for interactive media, multiple ways to engage with concepts, and backchannel communication channels.

  I already have a track record in integrating my research with educational activities. The Environopoly [J23] urban planning game combines tangible bricks with a tabletop display, and has been targeted for K-12 students as part of Purdue's Women In Engineering Program (WIEP). Another effort focuses on portfolio mining [J26] for research in STEM undergraduate education.

- Early engineering design: Creative design is an intrinsically collaborative, highly visual, and highly fluid process with applications across a range of disciplines, including mechanical engineering, interaction design, and industrial design and ergonomics. For this reason, my work in visual and interactive computing, particularly using novel touch-based devices that can mimic the affordances of traditional pen and paper, has been particularly effective at supporting these settings. Thus, some recent NSF awards [G12, G13] focus on supporting design and sketching.

- Citizen of the future: Visual communication has unparalleled potential for conveying large amounts of information in an effective, intuitive, and easily understandable manner. Building on my previous work on casual data exploration, I plan to launch a large-scale research program on providing data delivery and analysis platforms that help normal citizens to manage their life more efficiently through information, focusing on aspects such as health, consumerism, and politics.

Future Work and Outlook

My goal is to have both short-term as well as long-term impact. In the short term, I will continue to take an active role in the research community for HCI and visualization. In the longer term, I will work towards disseminating my research to industry and society, as well as integrating new techniques and tools in real interactive systems. My ultimate goal is to enable real users to solve real tasks—such as understanding large-scale multidimensional data, seeing the structure of huge hierarchies, or navigating large information spaces—that were previously beyond their reach. Another of my goals is to contribute to the theoretical foundations of HCI and visualization beyond today's empiricism.

More concretely, my future research efforts in visual computing will be to study how to link devices together on the level of the web browser. This will allow us to bypass differences in hardware and operating system between devices and leverage the power of today's web standards for co-located display environments consisting of multiple heterogeneous devices. Furthermore, I am also interested in novel applications of these multi-device spaces, such as using a dynamically changing collection of pico-projectors to automatically assemble large displays. Finally, I have begun exploring storytelling for data analysis, particularly using existing visual narration and communication techniques from well-established fields such as comics, sketching, and cinematography.

Countless research challenges remain for harnessing the power of interaction as a catalyst for cognition. For example, is it possible to harvest one person's work to not only provide a tangible visual history of their interaction, but also to provide social navigation cues for other people trying to solve the same problems? Another aspect of my future work is to leverage the fact that web-based visualizations already exist in a networked ecosystem, making interaction harvesting and feedback trivial. I also plan to work on interactions that faciliate collaboration, consensus, and deixis.

In summary, I am well on my way towards harnessing visual and interactive computing—anywhere, anytime—for helping people make sense of data. However, much work remains to be done, and I look forward to continue tackling these problems together with colleagues and students in the future.