Future Directions in Computer Graphics and Visualization:

From CG&A's Editorial Board

L. Miguel Encarnação
ACT Inc.

With many new members joining the *CG&A* editorial board over the past year, and with a renewed commitment to not only document the state of the art in computer graphics research and applications but to anticipate and where possible foster future areas of scientific discourse and industrial practice, we asked editorial and advisory council members about where they see their fields of expertise going. The answers compiled here aren't meant to be all encompassing or deterministic when it comes to the opportunities computer graphics and interactive visualization hold for the future. Instead, we aim to accomplish two things: give a more in-depth introduction of members of the editorial board to the *CG&A* readership and encourage cross-disciplinary discourse toward approaching, complementing, or disputing the visions laid out in this compilation.

We asked the participants these questions:

- What's your field of interest, and what makes it important?
- What are some recent developments in this field, and why are they important?
- What new developments should people be looking for in your field?
- Where do you see your field five years from now?

Here's what *CG&A* editorial and advisory council members had to say.

Yung-Yu Chuang, *National Taiwan University*

Associate Editor, *IEEE Computer Graphics and Applications*

Field of Interest

Computational photography refers to computational techniques for capturing, displaying, and manipulating images that produce a richer, more vivid representation beyond what traditional cameras can record. It enhances or extends the capabilities of traditional digital photography, such as resolution, dynamic range, viewpoint, and frame rate. The wide deployment of mobile devices makes cameras accessible to everyone. People carry and use cameras all the time to record precious moments. With computational photography, they can better record and enhance those moments.

Recent Developments

Cameras' underlying principles have pretty much stayed the same over time; they produce 2D images recoding the scene's visual appearance from a single view. Recently, several new types of cameras have emerged, such as RGB-D (RGB-depth), binocular, light-field, and high-speed cameras. These cameras record more information about the scene and offer additional capabilities. With them, you can either capture a new type of image or leverage the additional information to obtain better conventional 2D images.

Upcoming Developments

These new types of cameras aren't just lab pro-

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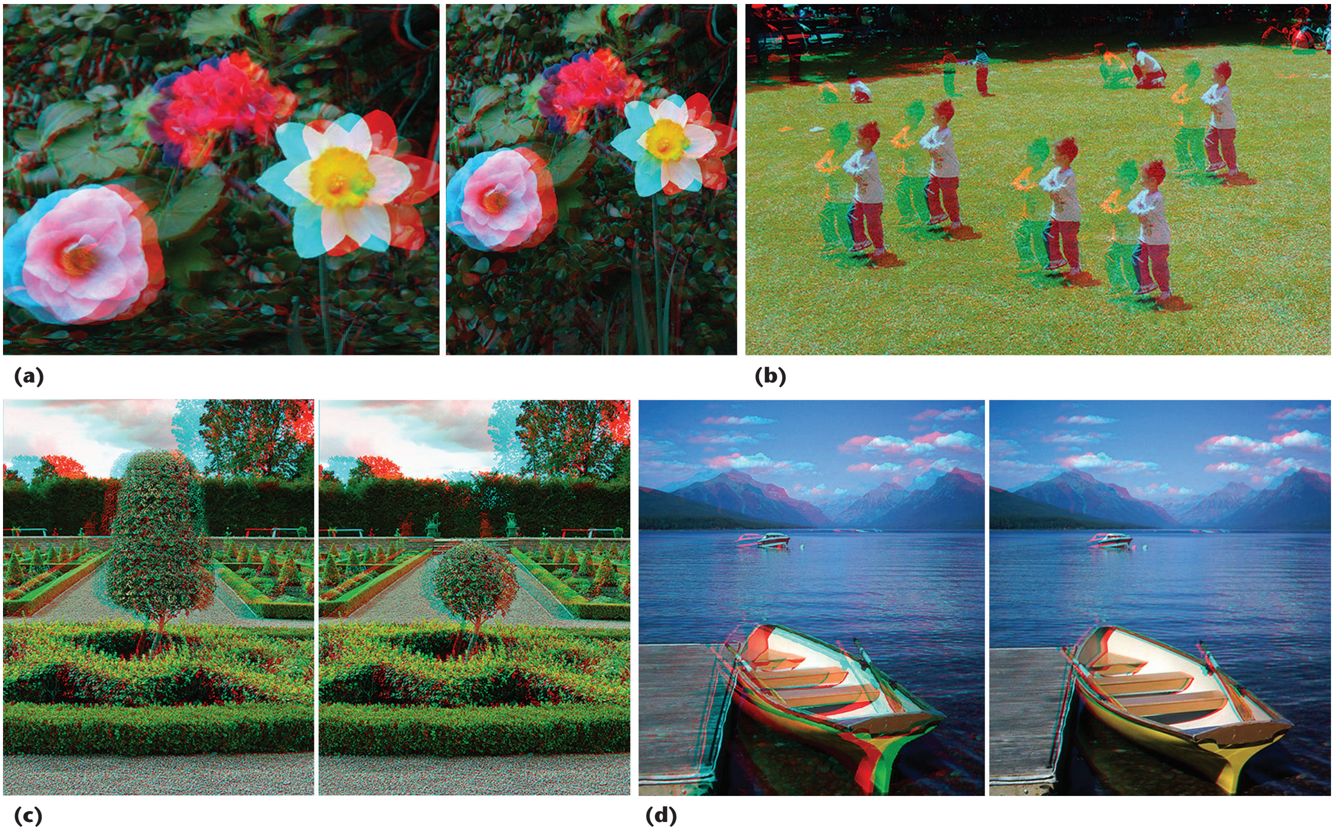

Figure 1. New types of cameras capture new types of images. Examples of (a) resizing, (b) cloning, (c) editing, and (d) depth adjustment for stereoscopic images.

totypes but real products accessible to everyday users. For example, Lytro and Pelicam offer consumer light-field cameras that record multiview images and allow refocusing. Microsoft Kinect records RGB-D images and has initiated many new applications. Google Glass enables first-person experience recording. Also, many stereoscopic cameras and displays are already on the market. These cameras will bring tremendous opportunities to both research and industry.

Five Years from Now

A few of these new types of cameras will become widely accessible. They'll provide better means for recording visual experiences and enable new applications in interaction, life logging, education, augmented reality (AR), and so on. The new types of cameras will capture new types of images and thus create new editing needs. For example, Figure 1 shows examples of resizing, cloning, editing, and depth adjustment for stereoscopic images.

André Stork, *Technische Universität Darmstadt, Germany*

Associate Editor, *IEEE Computer Graphics and Applications*

Field of Interest

My field of interest for a long time has been the convergence of modeling, simulation, and visualization—more specifically, geometric modeling and processing, interactive simulation, and real-time visualization. These are "traditional" application areas for computer graphics and computer vision in industrial value creation chains covering design, analysis, and interpretation in branches such as automotive, aerospace, and the corresponding software industry (CAD, CAx, and so on). The Interactive Engineering Technologies Department at the Technische Universität Darmstadt pursues research to support users' and engineers' workflows and to simplify decision making during workflow execution so that operation sequences can become more reliable and efficient.

Recent Developments

Three trends and recent developments have had a considerable impact and will probably have even bigger impact in the future.

Customization. An increasing demand for more individual and customized products has had a large impact on industry—how it communicates, involves customers, and produces goods. These demands largely affect the processes, hardware, and software needed to support them.

GPGPU computing, big data, cloud computing, and HPCCs. Programmable GPUs have not only revolutionized graphics effects for films and computer games but also established themselves as effective number crunchers on desktop machines and even found their way into high-performance compute clusters (HPCCs). GPGPU computing (general-purpose computing on GPUs) has accelerated many algorithms, and its potential probably isn't fully leveraged yet in simulation applications. This is because GPUs require specific programming approaches and additional advances in the field will push their development further in the future.

Big data is a term (and trend) not typically associated with data stemming from industrial processes. However, industry always has struggled, and probably always will, with the increasing amounts of data that are being produced, whether in the design, simulation, production, or use phases.

Up to now, cloud computing has been concerned mainly with data sharing. Recently, services have appeared that provide cloud-based functionality and compute capacity for engineering applications—for example, Autodesk 360. Cloud-computing services for the engineering domain are still in their infancy. The future will enable end-user small and medium enterprises to access services they can't afford today, letting them develop better products, for example, by using rented high-performance-computing (HPC) resources.

High-performance computers broke the 1-Tflop margin 15 years ago. Today, our machines have GPUs with more than 1 Tflop. Still, high-performance computers are indispensable for solving large problems in finite time. Cloud computing will also make HPC capacities more accessible and affordable. It could immensely impact how we generate graphics. Virtualization of GPU power could move us toward interactive server-side rendering. Also, we need new hybrid approaches to balance the rendering load between the server, network, and client side, while covering Web-client rendering.

3D printing and rapid manufacturing. Although 3D printing is at least 20 years old, only recently have consumers been able to buy 3D printers for less than US$1,000. Five to 10 years from now, we might all have a 3D printer on our desktop, and we'll want to print things that are nice and robust. In 2013, Siggraph for the first time dedicated sessions to 3D printing, appearance printing, and simulation for printing. The future will bring more tools for the prosumer—people such as you and I, sitting in front of their PC, tablet, and so on, wanting to design a piece of jewelry and 3D print it. We'll have sketch-based modeling and reshaping tools that let us design our customized products by touch or even in 3D.

Upcoming Developments

In this field, two strategies are especially important.

Advanced manufacturing, Industry 4.0. Advanced manufacturing, often called "the fourth industrial revolution," or Industry 4.0 in Europe, is considered the next big game changer for industrial engineering and manufacturing. Computer graphics and computer vision (visual computing) will be key enabling technologies to implement smart and cognitive behavior in the product customization, engineering, and manufacturing stages as envisioned by the Advanced Manufacturing Initiative (www.manufacturing.gov/advanced_manufacturing.html).

Internet-based services. Google Docs has changed how teams write documents when collaboration is of paramount importance. Engineering is highly collaborative by definition. Teams of engineers work together at one place, in different countries, and in different time zones, and they share their data via special databases (through product- data-management and product-lifecycle-management systems). Various approaches to collaborative CAD haven't been fully accepted yet. Cloud-based engineering applications and services can change this and allow better cooperation even beyond the boundaries of individual companies. Still, a few challenges remain.

Five Years from Now

We'll see further convergence of functionality from the user's viewpoint. As the user designs or customizes a product, a high-performance computer might execute a simulation that's fully transparent to the user to check whether the design can be 3D printed, or it might optimize the design for 3D printing. "Simple" simulations might even execute on a mobile device, given an onboard GPUs' increasing power.

But 3D printing certainly won't be the only driver in this field. The need to produce more flexibly and individually will drive the development of high-end product development and production planning tools. Self-organizing, decentralized planning will involve new disciplines (robotics, AI, and computer vision) in the traditional mechanical and now mechatronic domain.

Dave Kasik, *Boeing*

Advisory Council, *IEEE Computer Graphics and Applications*

Field of Interest

My general field is visualization and interactive techniques. Specifically, I deal with visualizing the complex 3D geometry needed to design, engineer, manufacture, and maintain aerospace products and with visual analytics (VA) for nongeometric aerospace data. The payoff is effective, improved communications during analysis and storytelling.

Recent Developments

The advent of GPUs and parallel computing for HPC clearly improves the end-user experience because of improved performance. A more profound development is in mobility because of the basic convenience and the systemic impact on interaction that highly portable touch interfaces enable. The impact is twofold: it's reasonably painless to develop new applications that exploit mobile devices and unreasonably painful to adapt existing applications for mobile interaction.

Upcoming Developments

In the near future, mobile device enabled AR will finally become a reality, and GPUs and CPUs will consume far less power. Back-end compute capabilities (the cloud and HPC centers) will also become far easier to access as interactive services. Finally, additional interaction techniques will make it easier to replace WIMP (windows, icons, menus, pointer) interfaces on conventional and mobile devices.

Five Years from Now

Further down the road, demand will increase for mobile, with little-to-no progress on figuring out what to do with older, graphics-intensive, WIMP applications. We need breakthroughs in transforming those apps to new interfaces, and I don't see much research in this area. Sensors will become omnipresent, further driving the need for analytics. I also believe 3D will become the lingua franca across the design, engineer, manufacture, and support value stream.

Theresa-Marie Rhyne, *Visualization Consultant*

Associate Editor, *IEEE Computer Graphics and Applications*

Field of Interest

My interest and passion is computer-generated visualization. Visualization is the study of the transformation of data into visual representations that help provide insight about the domain or problem under study.

There are many visualization techniques for many forms of data, including, but not limited to, texts and documents; trees, graphs, and networks; image collections and videos; time series data; tabular and multivariate data; geospatial data; scale, vector, and tensor fields; isosurfaces; geometric, mathematical, numerical, and statistical models, historical events, and census records; dynamic data streams, algorithms, and computational logs; and a range of domain-specific data from disciplines such as archaeology and medicine.

People frequently perceive visualization as a way to present beautiful computer-generated images and animations to the general public or specialized audiences. Key evidence obtained through perceptual studies and user evaluations confirms that

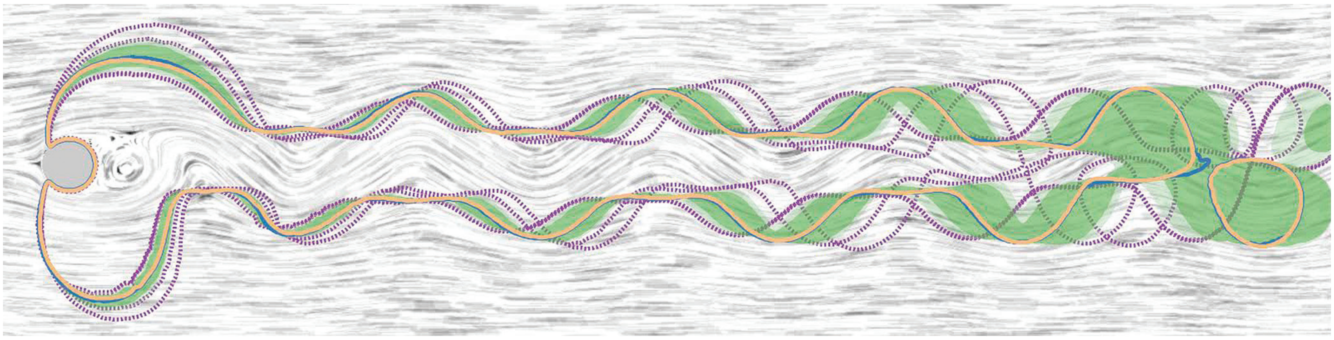

Figure 2. Color study of Contour Boxplot visualization prepared by Mahsa Mirzargar and Theresa-Marie Rhyne.[1]

visualization has additionally enabled researchers and decision makers to more efficiently make observations and establish plans of action. Figure 2 shows one such example. (The visualization method and data were originally published in earlier work.[1])

Recent Developments

The visualization field has evolved over the years to encompass three major subfields—scientific visualization, information visualization, and visual analytics—as well as many domain-specific areas, such as geoinformation visualization, biological data visualization, and software visualization. In the past five years, visualization has begun emerging as a potential ubiquitous technology, impacting almost every walk of life. This was exemplified by the 2013 initial public offering of Tableau Software and the release of general industrial reports on visual analytics by the SAS Institute, IBM, and other commercial companies.

Upcoming Developments

The visualization field has recently teamed up with cognitive researchers to develop objective methods to evaluate how our brain senses and processes information when we view and interact with different visual designs. This research will greatly advance meaningful and memorable visualization methods and techniques.

Regarding scientific computation, scientists can now execute alternative simulation models in parallel, creating an *ensemble* of possible outcomes for an event of interest. The visual analysis of ensemble data is becoming one of the more significant arenas of scientific visualization.

Five Years from Now

I hope that visualization will continue to evolve as a ubiquitous technology for scientific visualization, information visualization, and visual analytics.

Lisa Avila, *Kitware*

Associate Editor, *IEEE Computer Graphics and Applications*

Field of Interest

Volume visualization was an active field of research in the early 1990s, when I was in graduate school, and it remains an active field of research. Sure, 20 years ago, a typical dataset was 16 Mbytes, and we were happy to render it in under a minute, whereas today we render gigabytes of data at interactive rates. However, the demand for advanced visualization techniques applied to an ever-increasing amount of complex volumetric data keeps researchers busy developing new techniques.

Each application domain for volume visualization, including medical imaging, seismic data exploration, cosmology, computational fluid dynamics, and computational chemistry, just to name a few, has its own challenges. These challenges include irregular data, hierarchical data, time-varying data, large data, multivariate data, overlapping data, and even uncertain data. Also, each domain has its own visualization goals ranging from slow, deliberate investigation in order to gain insight from the unknown to speedy assessment based on some known criteria. No single technique for volume visualization meets every application domain's needs, which ultimately is what keeps this research area active.

Recent Developments

Many recent developments in this field aim to apply volume visualization to a particular domain. These advances focus on the effective visualization of data, letting domain experts gain a deeper understanding of their data or locate and assess anomalies with better speed and accuracy. A tailored volume visualization method that's developed with the target audience's needs in mind will gain greater acceptance. Also, reporting on the results for one scientific domain can lead to advances in other domains facing similar challenges. Other research focuses on fundamental rendering improvements that might be applicable across all domains. These advances help add the visual cues to volume rendering that are critical for understanding complex structure in a static image.

Upcoming Developments

It's interesting to see techniques that were popular more than a decade ago being revived owing to the push for volume visualization on mobile devices. Although we again face similar limitations in memory and processing power, we can now approach the problem from a more knowledgeable starting point.

Five Years from Now

With an increasing emphasis on open science and reproducible results, the community will need to come together to establish volume visualization standards. This will be important not only within the field for quantitatively comparing rendering methods but also in other fields such as computational fluid dynamics and medical image analysis. In those fields, the research produces volumetric data and data visualization becomes one way to validate the research.

Mobile devices will become powerful enough to truly support volume visualization applications. This will create opportunities in diverse areas such as medicine, education, and industrial inspection. On a mobile device with limited or imprecise interaction capabilities, the goals of "automatic" and "easy to use" will move to the forefront because users won't be able to effectively edit complex transfer functions or set numerous rendering parameters.

Jörn Kohlhammer, *Fraunhofer IGD*

Associate Editor, *IEEE Computer Graphics and Applications*

Field of Interest

My field of interest for the last 10 years has been visual analytics (VA) and its application areas. VA combines information visualization and automated methods to allow the interactive analysis of massive amounts of data. The overabundance of data leaves practically all industry areas struggling with using this data for business goals. The same is true for various scientific areas, medicine, or policy modeling. At Fraunhofer IGD, we look at both the basic research and the application experts to create solutions that help users make decisions based on such big data.

Recent Developments

A few years ago, the VA field might have been called a recent development. Today, IEEE VAST (Visual Analytics Science and Technology) has grown from a symposium to a conference, and there are more application areas that follow VA approaches. VA has been an interdisciplinary field from the start. The increasing outreach to not only connected research communities such as data mining and machine learning but also cognitive and perceptual science has provided additional insight into VA approaches' benefits. It's highly important

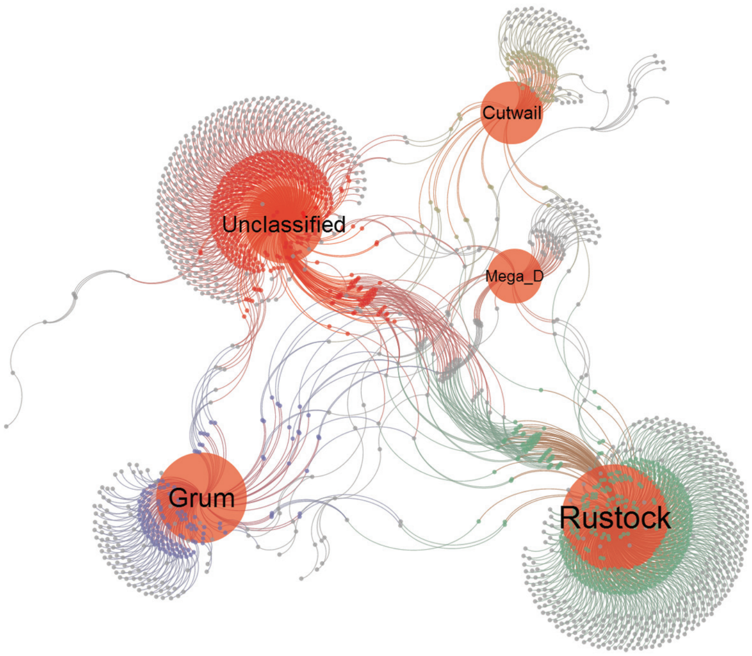

Figure 3. A result from the European Union project VIS-SENSE that shows spam botnet ecosystems. It visualizes a large amount of spam campaigns with a significant number of interconnections. This visualization aids cybersecurity analysts in understanding botnet activities.

for the field that experts from other disciplines are showing interest in VA and contributing to joint research.

Upcoming Developments

Big data challenges seem to be everywhere these days. Governments and funding agencies across Europe have created research programs to address these challenges in a more cross-disciplinary way. VA will have to show its benefits more strongly in competition with purely automated approaches, as advocated by a large part of the machine-learning community. In the business intelligence domain, software companies have understood this benefit. SAS offers a VA tool that combines its long-standing expertise in statistics and data mining with visual interfaces. Tableau has been adding interfaces to combine its strong visualization functionality with analytics capabilities.

Application solutions will be among the most interesting developments in VA. One gap on this path, especially for smaller companies, is a more elaborate software infrastructure and a platform for VA applications.

Five Years from Now

The next five years will continue to showcase many excellent VA solutions for particular applications and domains. The field is just starting to consolidate approaches to establish toolkits that flexibly integrate both automated and visual approaches. KDD (knowledge discovery in databases) and information visualization are relatively close, and we'll see a tighter integration in five years. Evaluation will be a major task as industry and general users of VA technologies look for verifiable benefits before starting larger projects on big data. At the same time, even more niche players will offer successful (in a business sense) VA solutions for specific data and applications, including medicine, genomics, finance, business analytics, and cybersecurity.

L. Miguel Encarnação, *ACT Inc.*

Editor in Chief, *IEEE Computer Graphics and Applications*

Field of Interest

I'm particularly interested in visual thinking, analytics literacy, and new ways to make data accessible and comprehensible to large populations with little to no formal education in the (visual) analysis of data. The ubiquity of data and the associated expectations that everybody will be able to improve their decision making by tapping into personalized and contextualized data is hampered by the fact that most of the public has little to no training and thus the means to understand, effectively analyze, and thus benefit from the data and information provided. Thus, data and information (and at closer sight, STEM [science, technology, engineering, and mathematics] disciplines that rely on effective data analysis) remain a mystery to large parts of the population, instilling fear and confusion into the audiences who should benefit from it.

Recent Developments

Approaches to resolving the challenge I just described must be multifaceted and span many research areas, including graphics and analytics education, information design, communication, and human-computer interaction. Recent activities in related fields such as data democratization provide access to large amounts of data, which is crucial to providing context for much personalized information provisioning. However, effectively handling data privacy and security in the new world of big data analytics remains a challenge.

Also, new user-centered analytics tools can provide better means for laypeople to analyze data.

A few colleges have identified the rising shortage in qualified data analysts and created master's programs to meet this need.

Furthermore, the field of social and casual visualization could overcome some of the mystique surrounding data and related analytic processes.

Finally, in a few application areas such as personal health, data analytics' potential to improve individuals' lives has already found recognition and ignited Quantified Self, a grassroots movement in which personal data collection, community data aggregation, and peer-to-peer exchange of insight have become a lifestyle. This is changing the perception of data from foe to friend and creating analytics literacy in the process.

Upcoming Developments

Visual narratives and other types of data-driven storytelling are on the rise and will provide interdisciplinary research opportunities at the intersection of the computer sciences, the humanities, and the arts. What journalism has explored in the form of info charts and similar visual presentations will now require additional personalization, individualized interaction, and longitudinal narration.

Context-adaptive information display will let individuals reduce the complexity of decision making by adapting it to data from other sources. Working together, mobile technology, location-based services, and augmented reality (AR) will provide a platform for users to access, comprehend, and effectively respond to data for individual and group decision making.

Serious games are increasingly recognized as compelling platforms to explore and understand complex environments as well as collect and analyze data on player behavior as it relates to performance and learning. As such, serious games seem uniquely suited to develop analytics literacy by connecting complex problem-solving gaming environments to real-world (and possibly real-time) data feeds, while maintaining the risk-free entertainment character that persuades players to spend significant time and energy competing at challenging tasks.

AR has the unique ability to connect analytics to the real world, whether for pleasure, entertainment, learning, scientific research, business, or other applications. This connectedness puts displayed data and information into context, providing another means to increase relevance and literacy in the process. Although AR is far from new, its utilization as rich public data displays provides new presentation and interaction challenges while requiring increased consideration of individual privacy.

When talking about public audiences, however, accommodation of groups with different ability levels remains an additional challenge. This is especially true for data analysis, which relies much on good visual perception, fine motor skills, and advanced problem-solving skills. To provide analytics access to such an audience, which relies on information possibly more than the general public, researchers will explore new ways to display, communicate, and interact with information, including, but not limited to, sonification, haptics, and automatic narration.

Five Years from Now

Data analytics literacy will become a fundamental discipline in K–12 education and an additional emphasis in postsecondary education. In K–12, it will gain ground through interactive visual-analysis tools creating increased interest and access to STEM subject areas. Learning analytics will have progressed to the point that teachers start benefitting from performance data being streamed into the classroom and that students can better understand and develop their potential. Browser-based handheld AR will have become a commodity for strolling the world, while heads-up AR will remain limited to special-purpose applications such as engineering and gaming.

Working together, mobile technology, location-based services, and augmented reality (AR) will provide a platform for users to access, comprehend, and effectively respond to data for individual and group decision making.

Many serious games will draw additional challenges from providing complex data displays for decision making, which (intentionally or not) will increase the avid player's analytics literacy. Many stakeholders in the educational system will recognize and accept the potential of serious games and integrate them with traditional classroom and after-class activities, while still struggling to exploit the data exhaust produced by the students' interaction with the games.

Information display and presentation will have progressed to the point at which information can be effectively communicated on the basis of context, individual abilities, preferences, and information access mediums in a multitude of ways, ranging from well-designed dashboards, to interactive analytics environments, to written or spoken narratives. However, effective interactive analysis of data for the general public will still face challenges, aside from early adopters and the first generation of students coming from a K–12 system that has elevated analytics literacy to a fundamental skill.

Similarly, screen readers will have advanced, and a few prototype systems will exhibit accommodations for various disabilities. However, there will still be significant research in making information provisioning ubiquitous and affordable to differently abled audiences.

Joseph J. LaViola Jr., *University of Central Florida*

Associate Editor, *IEEE Computer Graphics and Applications*

Field of Interest

My general field of interest is the study, development, and analysis of interactive technologies and systems as they relate to overall user experience. Specifically, I explore how to use different input modalities such as 3D gestures, touch, speech, and eye gaze, along with associated recognition algorithms to improve the user interface in applications in VR and AR, videogames and entertainment, robotics and teleoperation, and STEM education. This field of interest is important because there's a critical need to make computers and the power they give people easier to use and enjoy.

Recent Developments

Some of the most recent developments are the miniaturization and commoditization of hardware platforms that support 3D spatial interaction, such as the Nintendo Wii, Microsoft Kinect, PlayStation Move, and Leap Motion. These devices have made my field much more relevant to people because their commercial success gives researchers a greater opportunity to have a positive impact on society, in which their innovations and discoveries can make a difference by improving the user experience.

Upcoming Developments

We need research examining how to use these technologies to better interact with the physical world. For years, 3D spatial interaction and other input modalities have focused on interaction in virtual environments. With the proliferation of robotics technology, including inexpensive sensors and actuators as well as ubiquitous computing, the ability to interact directly with physical objects in the world through gestures and speech, for example, represent an up-and-coming area in user interface innovation. This research will significantly affect games and entertainment, eldercare, medicine, and many other domains.

Five Years from Now

I expect to see the continued commoditization of various hardware platforms and input device technologies that support more natural user interaction in a variety of domains. This continued innovation, coupled with advances in sensor networks, new unobtrusive tracking systems, improvements in modeling and acquisition of the physical world, and improved recognition algorithms that exploit these advances, will blur the lines between the virtual and the real and establish richer augmented and mixed-reality environments in a variety of applications.

Melanie Tory, *University of Victoria*

Associate Editor, *IEEE Computer Graphics and Applications*

Field of Interest

I'm interested in visualization, broadly defined. Visualization supports data analysis in a variety of application domains and is particularly valuable for supporting exploratory analysis.

Recent Developments

There are many recent developments, but I'll focus on two that are closely related to my own interests: sensemaking tools, collaboration, and the combination of both. Sensemaking involves gathering information, organizing it into a schematic structure, and deriving insights by manipulating this representation. Recently, researchers have introduced tools to support sensemaking; these tools help analysts organize their findings, hypotheses, and evidence. This is important because it extends visualization beyond just the visual representation of data, recognizing the need to support the entire analysis process from initial information gathering through to insight and action.

Meanwhile, the field is recognizing the importance of collaborative data analytics and the need for specially designed tools to support collaboration. The support needed varies dramatically, depending what the collaborative task is, whether the collaboration is synchronous or asynchronous, whether the participants are colocated, and what roles the participants play. However, one common need is for awareness: people need to know what their collaborators are working on so that they can effectively coordinate their efforts.

Taking sensemaking and collaboration together identifies an emerging area of collaborative sensemaking: how can we design tools that help collaborative teams share their hypotheses, insights, and evidence so they can come to a collective understanding of data?

Upcoming Developments

In the coming years, I expect that we'll see visualization and visual analytics applied to an increasingly wider variety of people, tasks, and domains. For example, I see these technologies moving into the personal domain. People are starting to employ visualization techniques in their everyday lives to understand themselves and their communities and to make personal decisions. This leads to a new set of interesting research challenges: making visualization technologies fit into people's environments and daily routines, supporting visualization novices, enabling personalization, and so on.

I also expect to see more overlap between the various visualization subfields. The boundaries between different areas will blur to a greater degree. For example, we'll see more visualization tools that merge spatial visualization, nonspatial visualization, and data mining to solve domain-specific problems.

John Dill, *Simon Fraser University, Surrey*

Advisory Council, *IEEE Computer Graphics and Applications*

Field of Interest

My field of interest is visualization, generally (I actually started some of this back in the early days of computer graphics). My current research areas are information visualization and visual analytics. One reason I like visual analytics is that it pays significant attention to real problems of real users, and it uses that to drive research questions.

Recent Developments

Investigators are paying more attention to better understand the analysis process itself, developing the notion of analytic provenance. At the output end, some researchers are looking more seriously at the notion of "story," especially as a way to communicate analysis results.

Upcoming Developments

I hope we'll see a better understanding of how to integrate the human-in-the-loop with big computing and big data.

Five Years from Now

I hope we'll see more flexible visual analytics systems with fewer "point" solutions and possibly with some kind of friendly end-user programming capability. It would also be nice to see more progress toward understanding the underlying science of how we use and interact with complex visualizations.

Gitta Domik, *University of Paderborn,* **and G. Scott Owen,** *Georgia State University*

Associate Editors, *IEEE Computer Graphics and Applications*

Field of Interest

Textbooks can't keep up with the rapid advances in the dynamic and exciting fields of computer graphics and interactive techniques. Focusing on education in computer graphics and interactive techniques and their applications, we support university educators in updating their courses. We do this by incorporating the new developments, enabling educators to realize what other educators are doing, and providing examples of

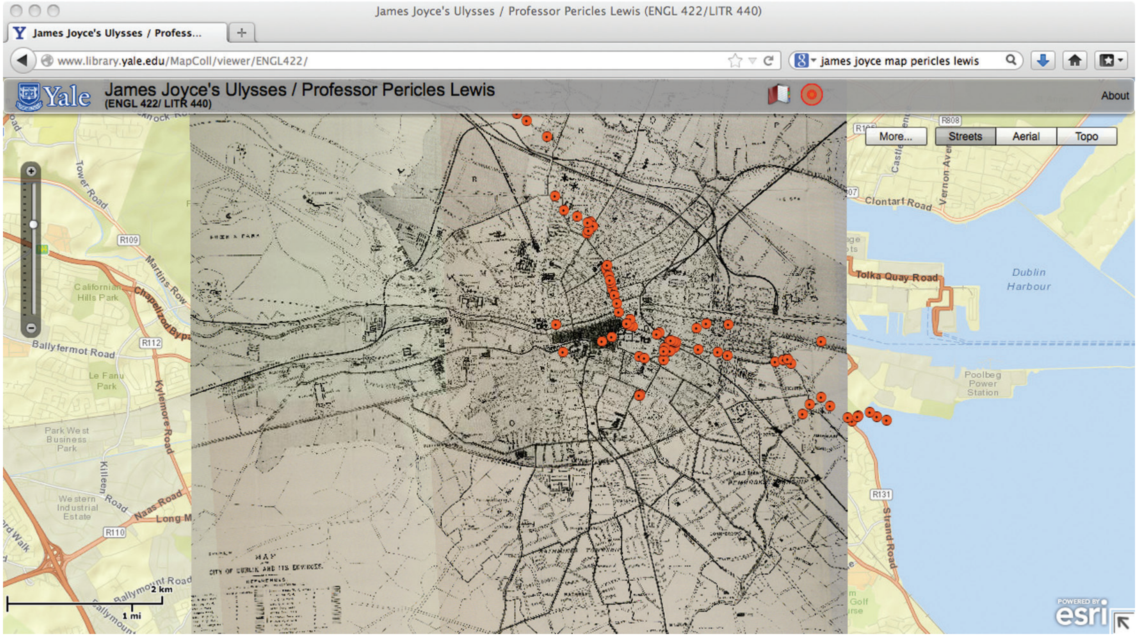

Figure 4. Teaching visualization in the context of Yale University's liberal arts education.[2] Students in Pericles Lewis's Ulysses seminar at Yale mapped major events in the novel using the addresses in Google, cross-referenced with a map of Dublin from the time of James Joyce.

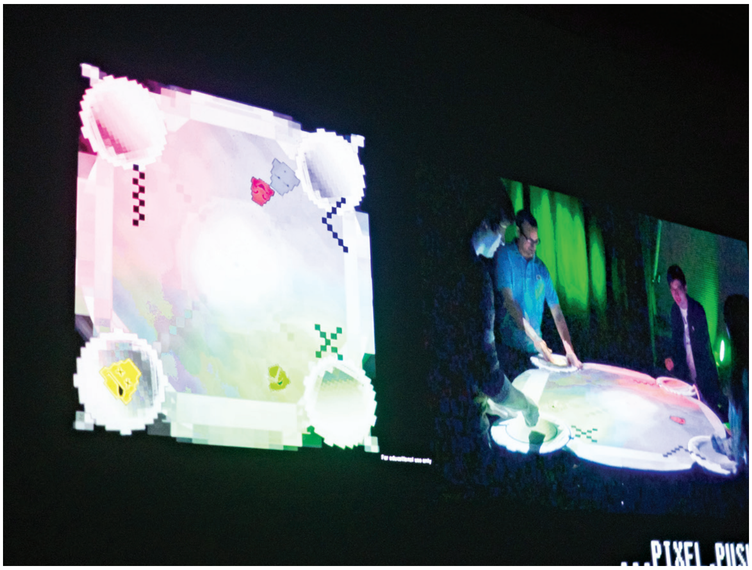

Figure 5. Pushing students to rapidly create inventive digital experiences.[3] A team of students playtests the Pixel Pushers world on the tabletop Jam-O-Drum platform. A key tenet of the course is that students are more innovative when forced to develop for unfamiliar future-oriented platforms.

the innovative uses of new techniques in other educational areas.

Recent Developments

New mobile and interactive devices as well as game engines capture the interest of computer science students. Educators can use them to teach both computer graphics fundamentals and the newest challenges of graphics scalability and novel interaction methods. By reading our Education department in *CG&A*, educators can pick up teaching tools, methods to share devices in the classroom, or ideas to deal with the complexity of these devices or engines. For example, Figure 4 gives an example of teaching students visualization in the context of Yale University's liberal arts education, where application domains sometimes need to relate to literature or art or politics as well as to science.[2]

In another example. Randy Pausch made Carnegie Mellon University's course on Building Virtual Worlds famous in his "Last Lecture," as an example of how to push students to rapidly create inventive digital experiences seemingly beyond their own abilities. Jesse Schell and Chris Klug give a more detailed presentation of this course. In Figure 5, a team of students playtests the Pixel Pushers world on the tabletop Jam-O-Drum platform. A key tenet of the course is that students are more innovative when forced to develop for unfamiliar future-oriented platforms.[3]

Upcoming Developments

For computer graphics educators, the challenges of the next five years (at least) will be to prepare university graduates for these changes: highly interactive graphics and especially novel interaction methods becoming more prevalent, scalable graphics from mobile devices to large screens and VR environments, interdisciplinarity in the classroom, the need for graphics in the professions, and the need to evaluate the produced graphics' quality.

Pak Chung Wong, *Pacific Northwest National Laboratory*

Associate Editor in Chief, *IEEE Computer Graphics and Applications*

Field of Interest

My primary field of interest is visual analytics (VA) applied to the physical, social, and life sciences. VA is often called "the science of analytical reasoning facilitated by interactive visual interfaces." The definition was deliberately chosen to be broad enough to encompass a range of established research and fill the gaps that individual research disciplines didn't adequately cover. VA has remained one of the fastest-growing disciplines that has evolved from computer graphics.

Recent Developments

Researchers have attempted to use bigger computers, larger screens with more pixels, and faster networks to tackle today's big data VA challenges. The ability to bring a large amount of data to users and graphically display this data on their computers represents the first and foremost step toward VA's success.

Upcoming Developments

As more VA technologies continue to penetrate new applications and platforms, new and more complex challenges in the social sciences will arise, such as personal information privacy and transaction security. For example, Figure 6 shows how the emergency management community is using precision information environments (PIEs, http://precisioninformation.org) to manage complex emergencies and change the way people interact with each other and information.

Five Years from Now

VA will be gradually embedded in our everyday

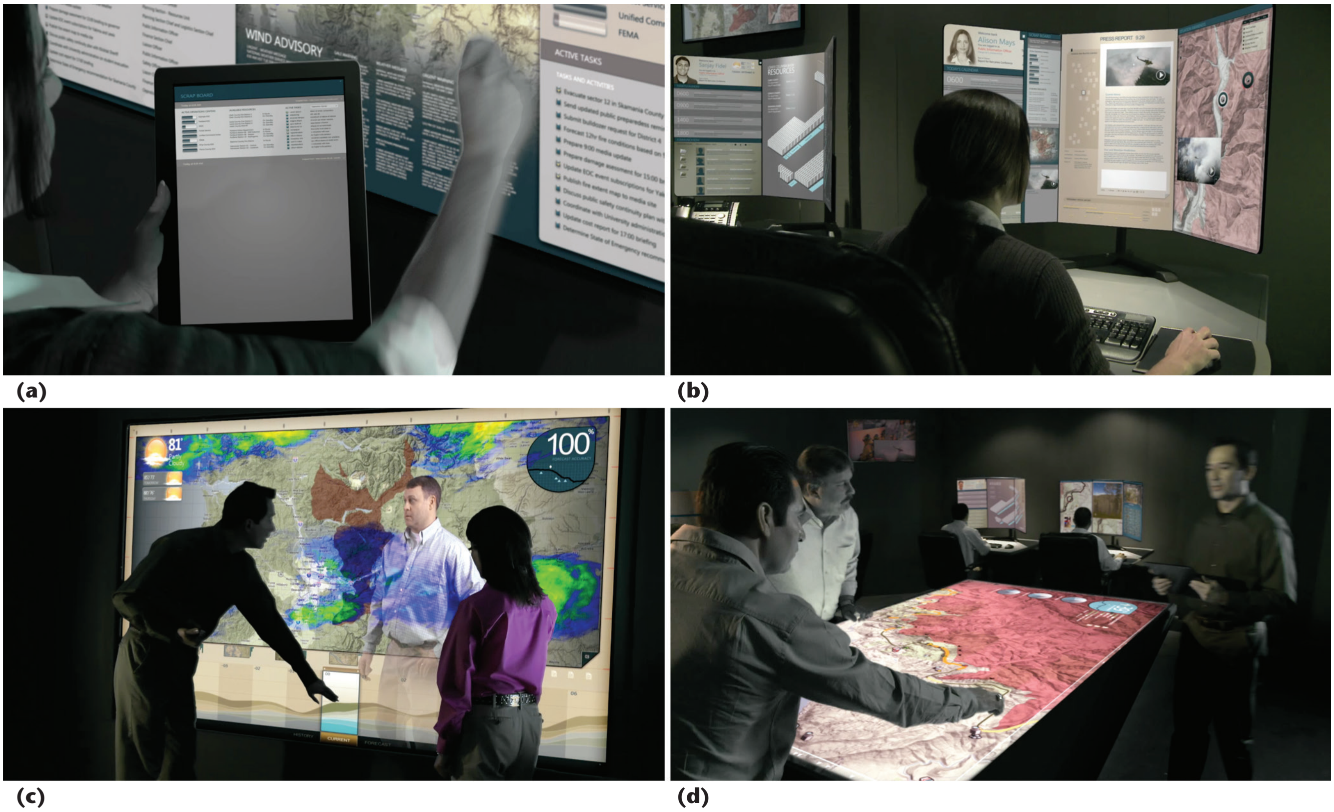

Figure 6. Visual analytics applications. (a) Unified access control and the Internet of things affords sharing information across devices through simple gesture techniques. (b) Provenance or analytics and source is maintained during report generation using a strong ontology similar to the Semantic Web. (c) LiveWall affords enhanced collaboration from remote locations by overlaying interaction, visualization, and forecast models alongside video conference capabilities. (d) Natural user interfaces improve collaborative analytics and decision support through large touch displays as situation awareness evolves into what if analysis.

New Editorial Board Members

Aditi Majumder is an associate professor in the Department of Computer Science at the University of California, Irvine (UCI). Her research interests include novel display technologies, computational camera and projectors, image and video processing, and computer graphics and visualization. Her work in color calibration of multiprojector displays at Argonne National Laboratories and the University of North Carolina is the earliest work on camera-based approaches for color seamlessness in tiled displays. Majumder has a PhD in computer science from the University of North Carolina. She received the NSF CAREER Award in 2009. She was also the program chair for IEEE Virtual Reality 2011 and received the IEEE Service Award for hosting IEEE VR 2012. Contact her at majumder@ics.uci.edu.

Michael Neff is an associate professor of Computer Science and Cinema & Technocultural Studies at the University of California, Davis, where he directs the Motion Lab, an interdisciplinary research effort in character animation and embodied input. He is also a Certified Laban Movement Analyst. His interests include character animation tools, especially modeling expressive movement, physics-based animation, gesture and applying performing arts knowledge to animation. At Davis, he is working to bridge the art and technology communities on campus, collaborating with computer scientists, dancers, choreographers and geologists. Neff has a PhD in computer graphics from the University of Toronto. He received an NSF CAREER Award in 2009, the Alain Fournier Award for his dissertation in 2005, a best paper award from Intelligent Virtual Agents in 2007, and the Isadora Duncan Award for Visual Design in 2009. Contact him at mpneff@ucdavis.edu.

lives. All of our smart appliances will have some sort of VA features and capabilities. We'll see a new generation of dedicated computer chips that support both computer graphics and information analytics applications.

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