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The Next Billion Users of Visualization

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We argue that visualization research has overwhelmingly focused on users from the economically developed world. However, billions of people around the world are rapidly emerging as new users of information technology. Most of the next billion users of visualization technologies will come from parts of the world that are extremely populous but historically ignored by the visualization research community. Their needs may be different to the types of users that researchers have targeted in the past, but, at the same time, they may have even more to gain in terms of access to data potentially affecting their quality of life. We propose a call to action for the visualization community to identify opportunities and use cases where users can benefit from visualization; develop universal design principles; extend evaluations by including the general population; and engage with a wider global population.

Data visualization is arguably a mature and respected field of research by many standards, having existed as a recognized topic in academia for several decades. It is a research "success story" in terms of the degree to which ideas originating in academic research have made their way into commercial software (from the likes of Tableau and Microsoft) and popular media (for example, the *New York Times* now famously has an information graphics department). These commercial interests have made further contributions, popularizing and making visualization successful in their respective markets. Some of this success may be attributed to firm research foundations, such as rigor around experimental methodologies, integration of theory from human–computer interaction and perceptual psychology, and technological tool-building. However, these foundations are limited by a skewed authorship from universities and industry in highly developed countries (especially the U.S. and Europe). Furthermore, the foundations are built upon studies with an inherent selection bias of participants from a highly educated subset of the populations of these highly privileged nations who have a high level of graphic and numeric literacy and access to the latest information communication technologies (ICT).

However, the divisions between the technological have- and have-nots are breaking down across the world, at least in terms of access to the Internet and basic mobile technologies. At the same time, we are seeing more and more examples of the relevance of

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data to the lives of every citizen of our planet. The COVID-19 pandemic is the most obvious, focusing the world's attention on time-series graphs like never before; but there are a host of other pressing issues that should be viewed from a data-centric perspective by a truly global audience.

In this article, we argue that data visualization researchers need to reconsider their assumptions about the audiences for visualization to include these emergent users of ICT. This new access to technology can bring many positives to peoples' lives, none the least of which is the potential to access information. However, as we have seen in recent times, information may be disseminated to people through media that are potentially destructive (Google bubbles, Facebook echo chambers, and so on). Visualization has an important role to play here in being a tool that allows people to explore data for themselves, rather than making them passive recipients of information.

But is our field of data visualization research able to provide or support the development of data communication and exploration tools that are suitable for emergent ICT users? Do the assumptions about the end users of visualization, in place throughout the development of our field, still apply to these new users? The numbers of people gaining access to basic Internet-enabled devices in the developing world is staggering. Furthermore, there is great potential for visualization to profoundly affect these peoples' lives providing (potentially) access to information and data in a form that may cross cultural, educational, geographical, and accessibility barriers. But there are as many research questions as there are opportunities. In this article, by an international and interdisciplinary team of visualization, design, and inclusive technology researchers, we reflect on the development of data visualization, and we compare the needs of emergent users in economically developing countries (primarily India) versus users (existing but also emerging) in developed countries. From this reflection, we call for action on a number of research but also organizational fronts.

EXPERIENCES OF EMERGENT ICT USERS IN INDIA

We are conscious that there are radical and rapid changes in ICT use occurring or about to occur in many places around the world. Our lived experience is of India, which is an archetypal example of a developing country with a large, emergent population of ICT users. 50% of India's population of 1.4 billion people is now connected to the Internet. With 1 billion mobile connections, close to 900 million of which are via smartphones, the majority of the new Internet users (emergent users) access information, services, and entertainment through a multitude of apps that are designed for users who are not like them. Less than 10%[12] of the Indian population can read and transact in the English language, yet nearly all apps are designed in English.[13] Language options in devices and automatic translation tools alleviate this problem to some extent, primarily at the user interface (UI) layer, but more sophisticated aspects of the apps remain inaccessible to the users because they are not designed with these users in mind.

Visualizations that enable users to solve complex numerical or spatial problems expeditiously and accurately are one such aspect we increasingly see in apps. For example, a banking app might allow an emergent user to perform simple transactions such as transferring money to a family member, paying a bill, or checking the balance. However, a set of visualizations in the app that could help analyze her finances would remain unused because the user does not know how to interpret charts. We have come across several instances of delivery persons from e-commerce vendors having little difficulty in picking up orders on delivery platforms such as Zomato or Swiggy, but who are unable to locate the customers' address using the navigational maps integrated with the shopping orders in their apps. We have seen parents unable to understand school report cards that presented visual analysis of their child's academic performance. School report cards using visualizations like the bar, line, pie charts were difficult to comprehend by the parents.

These examples point to the fact that access is a multilayered problem. The lack of formal education/training in numeracy and graphicacy for emergent users is the primary reason for their inability to comprehend and benefit from visualizations. However, computer-mediated visualizations that are personal, customized, adaptive, and progressively complex present us with an opportunity to address their needs.

Industry is already moving to deliver data-centric apps to this enormous new user base. One important example is Google's India-first payment app Tez, which was launched in September 2017. As an illustration of its success, over 22 million people and businesses used Tez to make over 750 million transactions that are collectively worth over USD 30 billion annually.[5] Now Tez has been taken beyond India and available as Google Pay worldwide, unifying all of Google's payment offerings globally.

In terms of digital civics, Aarogya Setu (see Figure 1) is a mobile application launched by the

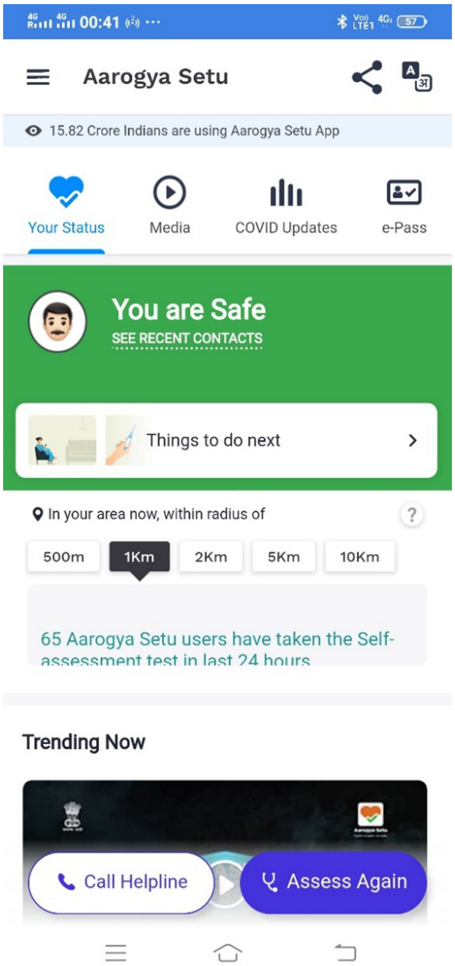

FIGURE 1. Aarogya Setu app launched by Government of India for Covid-19 contact tracing. It uses Bluetooth and GPS to show active cases near the user.

Government of India as a response to COVID-19 to connect essential health services with the people of India. It is available in 11 different languages. Aarogya Setu uses contact tracing to record details of all the people one may have come in contact with, as the person goes about normal activities. If any one of them, at a later point in time, tests positive for COVID-19, the user is immediately informed and proactive medical intervention is arranged for them.

ASSUMPTIONS ABOUT VISUALIZATION USERS

At present, the data visualization community has not considered the needs of emergent ICT users like those in India. Figure 2 shows an analysis of recent locations and types of participants studies reported at the IEEE VIS conference (InfoVis and VAST) 2019.[17] We did not consider SciVis as our focus was on papers with a user study component. As per the figure caption, the studies are almost exclusively conducted in developed countries, and the vast majority of participants are highly educated. In 2010, Henrich *et al.* [6] criticized behavioral science researchers for their disproportionate reliance on WEIRD (Western, Educated, Industrialized, Rich, and Democratic) participants in studies and the implicit but unwarranted assumption that findings from this group generalize to all populations. This criticism has also been leveled at human–computer interaction (HCI) research.[11] It seems this reliance on WEIRD participants is also true for data visualization research.

It seems very unlikely that findings from data visualization studies using WEIRD participants will generalize to non-WEIRD populations. We know from comparative studies that susceptibility to visual illusions such as the Mueller–Lyer Illusion[6] and visual preferences for websites[8] significantly vary between WEIRD and non-WEIRD participants. Thus, what is regarded as best practice in data visualization design may well only apply to Western developed countries.

One reason for this is cultural difference. An example is the difference in the significance of colors, for instance the color used for mourning is not consistent around the world. In Western cultures black is used; in India, it is white; in much of Asia, red, in South Africa and Egypt, it is yellow, and purple in Thailand. So, color coding may be interpreted differently depending on the culture of the users. In contrast, cultures can have shared color meaning, for example, warning signs around the world use a common color with red indicating stop or danger. In addition to color, icons have been used as an effective method for communication to bridge language and cultural barriers, but these are only effective if the objects and concepts are familiar and compatible across cultures.[19]

Probably, however, the most important reason for differences are different levels of familiarity with the information graphics used in data visualization. In Western developed countries, children are explicitly taught graphic literacy as an integrated part of the curriculum. For example, in Australia, maps are taught from the first year of school, with more sophisticated concepts like grid references taught in the fourth and fifth years of school. Graphs are progressively introduced with column graphs in the third year of school, pie graphs in the fourth year, line graphs in the seventh year, and scatter plots are not introduced until the eleventh year of schooling.[18] In addition, information graphics are common in educational materials and in the popular media, such as newspapers and

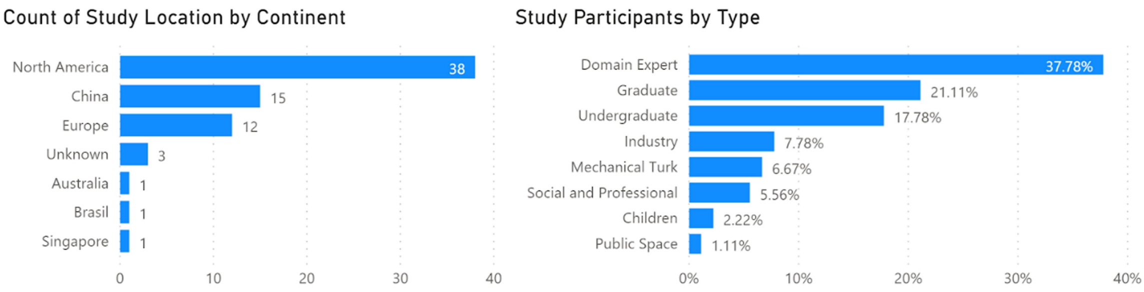

FIGURE 2. Analysis of the full papers published at the IEEE VIS 2019 conference (InfoVis and VAST)[17] that included human studies reveals the vast majority of studies are conducted in North America, Western Europe, or China. For three studies the location was not specified. Study participants were almost entirely domain experts or university students or staff. Less than a quarter could be considered to be representative of a broader public.

magazines. Thus, most citizens in Western developed countries have a high level of graphic literacy.

This was not always true. In the European Renaissance, most city maps used a birds-eye view. It was only later that people became accustomed to the use of top-down planimetric views. When William Playfair introduced bar charts and used them to show expenditure, he felt obliged to justify and explain that he was using a visual metaphor in which the bars in a bar chart represented piles of guineas. It was only in the late 20th century that educators began to realize that graphic literacy was also an important part of general education.[1]

In many developing countries, poorer people leave school at an early age and may not receive formal training in the use of graphics. Reflecting this, popular media designed for less educated audiences does not make use of data graphics. Thus, many emergent ICT users in such countries lack the knowledge or experience to comprehend and benefit from visualizations.

EMERGENT USERS OF COMPUTER-MEDIATED VISUALIZATIONS

In India, ICTs, in particular mobile phones, have reached beyond the traditional tech-savvy English educated users and have acted as an enabler toward

Population, mobile phone and internet user statistics				Internet users aged 16 to 64 who own each kind of device			
In 2020	Australia (in million)	India (in million)	India (in Australias)	In 2020	Australia (in million)	India (in million)	India (in Australias)
Total Population	25.35	1370	54	Mobile Phone of any type	15.13	815.82	54
Mobile Phone Connections	32.89	1060	32	Smart Phone	14.97	806.85	54
Internet Users	22.31	687.60	31	Non-smart Phone	0.71	125.51	177
Population between age 16 to 64	16.10	896.50	56	Laptop	13.37	555.83	42

FIGURE 3. Comparative analysis of India and Australia's population, mobile phone connections, Internet users, and population between age 16 to 64. We present the data on the number of Internet users aged between 16 to 64 who own mobile phones of any type, smart and nonsmart phones, and laptops. There are many users who own both a smart and nonsmart phone. To highlight the massive difference in size between the two countries, the right-most column shows statistics for India in units of the entire population of Australia.

human development at large by reaching new users. This is true in many parts of the developing world, for example, Avle *et al.*[20] described the effect of mobile phone adoption in "the Global South." Africa shows a similar mobile phone adoption trend to India.[23] In India, these new users of ICTs include people who may have been educated in an Indian vernacular language, work in low-income professions like farmers, are small business owners, daily wage laborers, urban poor, and culturally diverse, and may not have reached college.[4]

Today the majority of mobile phone and Internet users in India are Indian language users, and in 2020 this number stands at 688 million (see Figure 3). These emergent users are increasingly being exposed to visualizations through electronic and print media, embedded in various mobile apps, political campaigns, and through in-match sports visualizations, specifically cricket. But such visualizations are not useful unless they support these new users with varied visualization literacy, diversity in culture and language which changes every few kilometers, various usage contexts like mobile phone as a shared resource in the household, and different mental models.[16]

Emergent users are not limited to developing countries such as India. Developed nations also play host to a subset of underconsidered visualization users. For instance, Peck *et al.*[21] find personal differences in the perception and use of data visualizations by residents of rural Pennsylvania (USA). We are also aware of differences in individuals' ability to understand visualizations in our part of the developed world (Australia). While numeracy and graphicacy are now formally supported within the Australian education system, there are still groups of users who may not have had the opportunity to develop meaningful visualization literacy. Considering the elderly, visualization literacy would be expected to have been obtained through continued exposure, rather than formal education. Potentially more compromised, immigrants and refugees to developed nations such as Australia have widely varied education backgrounds as well as the possibility of limited exposure to visualizations more generally. In Australia, a significant proportion of the Australian Indigenous community resides in remote places where education opportunities may be more restricted, and a comprehensive education in numeracy and graphicacy may not be a given. Finally, for people with disabilities, education curriculum and materials are often tailored to best support the needs of the person in question. This again can lead to uncertainty regarding the exact nature of the visualization literacy they have had the opportunity to develop.

Although the numbers of affected people in a developed nation may be smaller relative to a developing nation such as India, assumptions regarding visualizations and their use can still be damaging. Not only is there compromised access, but a sense of isolation may emerge, of living in an information society and not being able to access that information. As such, the impact on these affected groups can be of major significance.

Characteristics of Emergent Users of Computer-Mediated Visualization

Considering both developing and developed nations, characteristics emerge that may define an emergent user. These include:

- lack of education opportunity, in particular with relation to numeracy and/or graphicacy;
- cultural backgrounds "outside the norm" for visualizations;
- limited prior exposure to visualizations;
- limited access to technology; and
- diverse specific needs, such as those arising from disability.

SUPPORTING EMERGENT USERS

As a visualization community, we need to assume the responsibility for designing and developing visual user interfaces that are inclusive and accessible to all potential end users, not only a select subset. While much existing research about low-level visual perception may hold across a broad range of end users, we argue that higher level considerations such as user experiences, task goals, and application contexts may diverge between emergent and proficient end users. We see several key areas in which visualization researchers can drive inclusivity and accessibility of visualization for emergent users.

Education for Emergent Users to Develop Graphical Literacy

While not solely being responsible for visualization education, we can contribute to graphical literacy through dedicated activities such as short courses and workshops that target specifically visualization education for emergent users. Currently, data visualization courses are often done in niche academic communities (e.g., major conferences such as VIS and CHI) and are unlikely to be accessible to people from most emergent user backgrounds. Not only is it important to teach how to understand graphical conventions

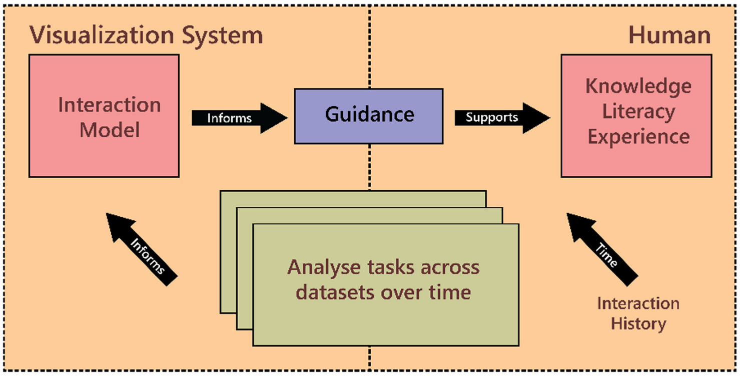

FIGURE 4. Guidance systems act as a responsive support to human capability as they interact with a visualization system.[2,3] We propose that guidance systems be informed by a rich longitudinal model of interaction by a particular user or population of users that fit a certain profile. The resulting visualization system will be able to provide guidance, and also potentially adapt styles of visualization or levels of detail, appropriate to their level of visual and numerical literacy, that will develop over time as they learn.

but also to discuss ethics and the need to critically evaluate data sources and presentation choices.[22]

Visualization and User Interface Design Inclusive of Emergent Users

We need to be more open minded in regard to the questions that we ask ourselves about how visualization and user interface design may influence users that have little to no graphical literacy. We need to consider a breadth of cultural and educational backgrounds that may potentially affect people's interpretation of and interaction with classic data visualization idioms and user interface paradigms. Is the way emergent users associate values with lengths/areas/color/etc. different to experienced users? Do emergent users prefer different interaction techniques as compared to experienced users? Dedicated user evaluations inclusive of emergent users may answer some of these questions and lead us to more inclusive user models.

Guidance for Emergent Users Capable of Longitudinal Support for a Wider Range of Users

We argue that carefully guiding emergent users through a visual analysis process is of critical importance. Dedicated user models of emergent users as well as adaptive systems that learn from user interactions may play an instrumental role here, but past suggestions of such systems[2,3] (see Figure 4) have focused on short-term use by domain experts such as scientists or analysts. Not assuming that emergent users have the same learning curve as more experienced users is among many aspects that need to be taken into account when we aim to design inclusive systems. We need to be able to meet emergent users at their current skill level and, where appropriate, encourage them to use more complex visualizations with the aim to build graphical literacy and interaction skills.

Ensure Visualization and Interaction Techniques are Compatible With the Devices Used by Emergent Users

While it is certainly appropriate for research to explore the capabilities of emerging (and expensive) technologies (such as large displays and mixed-reality), we must not neglect advancing what can be done with "low-end" devices such as mobile phones with small screens that are not necessarily either high resolution or particularly responsive. Can we do more with less?

CALL FOR ACTION

We have charted how visualizations have developed as being tools for experts who are graphically literate and have access to the latest computer technologies. Yet this can be exclusionary of emergent users, or indeed, the vast majority of the world's population. We therefore argue that an important next step is to take the rich history of visualization work and build upon it so it becomes relevant for the masses, including underrepresented minorities. Bringing this about involves a range of practical steps, that we propose the community adopt going forward.

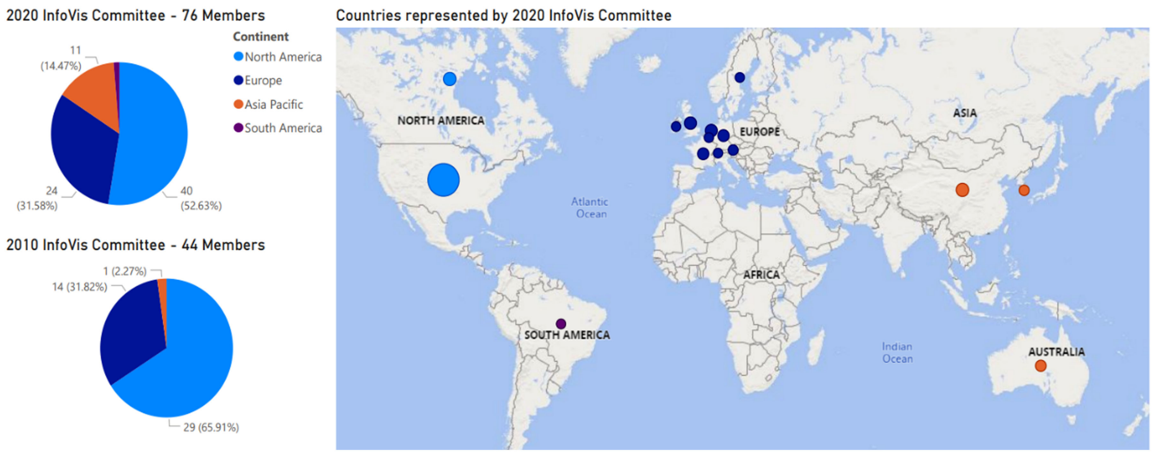

FIGURE 5. Geographic distribution of the 76 members of the 2020 InfoVis Conference Program Committee by continent (top-left), by country (bottom), and the continental make-up of the 2010 committee for historical comparison. The continent of Africa (1.216 billion people) is entirely unrepresented, as is India (1.353 billion), Southeast Asia (655 million) or the Middle East (411 million), Eastern Europe (293 million) and—apart from 1 member in Brazil—South America (423 million).

Identifying Opportunities and Use Cases

Ensuring that both underrepresented minorities and "non-experts" are included requires a focus on identifying the scenarios and purposes for which they might rely on visualizations. This is an issue that requires active investigation, to ensure that we do not overlook unusual or important use cases that apply in the real world. It also requires being active and ambitious, by considering novel (and hitherto unidentified) ways in which visualizations might be used in the future and ensuring that these opportunities can be rapidly reacted to as and when they arise (with COVID-19 perhaps being a striking example of this).

Developing and Evidencing Universal Design Principles

Universal design is about ensuring that systems are usable by a diverse range of people, including those with disabilities and emergent users. Yet there is no body of principles that explains how visualizations can be optimally designed to be fully inclusive of a wider constituency. These principles will especially need to address the lack of literacy and numeracy in many of these communities, as well as ensuring that inappropriate cultural assumptions are not made (e.g., color coding can have different interpretations in different societies). Addressing this might even mean taking a step back to the time of William Playfair (as mentioned above) and making graphs inherently more intuitive, rather than assuming any understanding on the part of users establishing this body of principles and practices is an important and necessary step for supporting everyone in benefiting from visualizations.

Asking the Right Questions (and Doing the Right Evaluations)

Visualization research has largely proceeded on the basis of an assumption of an idealized "expert" user who is WEIRD (Western, Educated, Industrialized, Rich, and Democratic). The trouble with this approach is that it is implicitly biased toward a minority of expert users, rather than the general population. This means that many of the presumptions and principles that have been built up over time are unlikely to generalize to most users, and may even lead toward biased systems that are easier to interact with by some groups compared with others. This is an important issue that other related academic communities have been grappling with—perhaps most notably "FATE" (Fairness, Accountability, Transparency, and Ethics) with respect to Artificial Intelligence (AI)—and with which the visualization research community should be engaging.

Engaging More Widely

The academic visualization community is not representative of the global population: while this might be somewhat improving, the community still remains heavily centered on North America (see Figure 5). We therefore need to find a way to involve a wider constituency in charting the path of visualization research going forward, to ensure that important concerns are not overlooked when shaping visualization research goals. As a starting point, it would be worth investigating the range of barriers that may exclude people from underrepresented groups from engaging in our community, be they geographic, language related, or disability related (a common challenge in academic circles[7,10]). We would add that it is not just a matter of "balancing" academic committees, but ensuring that end users are engaged and providing a full range of opportunities for emergent users to become stakeholders.

CONCLUSION

Addressing the issues raised in this article could have a profound and positive impact on the future, being both transformative to our research but also transformative for the lives of emergent users of visualizations. The four recommendations set out above, while only a beginning, are important first steps for our research community once we agree upon the importance of serving the entire world rather than a privileged few. We welcome wider debate in the community: this is the start, not the end. At the same time, we encourage visualization researchers to connect to other communities with similar goals, e.g., Fair AI and HCI, and see this as an opportunity to put data visualization at the forefront of systems used by most people.

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