Marshalling the Many Facets of Diversity

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CHAPTER 1

Marshalling the Many Facets of Diversity

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1.1 INTRODUCTION

Diversity is not a goal unto itself. Increasing the count of people from different genders, races and geographies is important, but the real goal is to create communities that are substantially better because their diverse members share benefits and opportunities equally. To achieve real inclusion requires sharing responsibility, prestige, recognition,and power. We have learned from natural ecosystems that diversity is critical for sustainability and health, and that different populations need to contribute to the collective gene pool [171]. A healthy academic ecosystem depends on the introduction of new ideas and connections, and on the diverse voices that carry them.

Many factors contribute to the diversity of an academic ecosystem, such as the diversity of topics and disciplines, the gender, racial and geographic make-up of its membership, and the dynamics of international research funding. There are many ways to measure individual empowerment, such as authorship, leadership, and recognition. In this chapter, we examine a range of diversity vectors through the lens of the IEEE VIS family of conferences, and explore how these interact with measures of recognition. To do so, we have analyzed data on many facets of our organization and its participants. We explore how the evolution of topics has created opportunities for the inclusion of new academic disciplines, and how topic diversity can promote gender diversity. We analyze how our members become empowered through their participation as authors and program committee members, and through awards for technical achievement. We examine patterns of international research and development spending as a backdrop for understanding the factors that contribute to geographical diversity, in general, and in our ecosystem, specifically. Our goal is

[1] Authors ordered by contribution.

to provide insight into the diversity of our ecosystem and how it has evolved, and to increase awareness of the sociological factors that underpin our future success.

Chapter Overview. This chapter focuses on sociological factors influencing diversity in visualization. Our observations are based on the analysis of data about the IEEE family of VIS conferences (IEEE Visualization (IEEE Vis), Information Visualization (InfoVis), Scientific Visualization (SciVis), and Visual Analytics Science and Technology (VAST)), and on data from external sources.

The field of visualization grew primarily out of computer science and data-rich experimental sciences, and the population characteristics and traditions of these disciplines still play a dominant role. Since the 1990s, the field has grown to include a wider range of disciplines and research topics, enriching the scientific ecosystem. The first section of this chapter looks at the growth and structural evolution of the IEEE VIS family of conferences and symposia, and at the evolution of topics revealed through the analysis of keywords used in papers and in calls-for-participation in the various conferences. We look at census data to shed light on the relationship between topic diversity and gender diversity. Our hypothesis is that new topics can expand our diversity by attracting scientists from different disciplines, which may have very different intrinsic gender distributions. To get a handle on this, we present data on how the proportion of male and female professionals has evolved in different disciplines over time and identify opportunities for increasing diversity by embracing different disciplines. We observe, for example, that the proportion of women professionals in computer science is steady, or decreasing, yet, the proportion of VIS program committee members from computer science is increasing.

Next, we examine gender diversity in the leadership of our community. To set the stage, we looked at the gender diversity of our authors over time, examining number and proportion of authors who are women, and also, the proportion of papers with at least one female author. Both these measures have increased over the past 30 years. To get a measure of the degree to which male and female members are valued and esteemed, we then looked at two measures of recognition. First, we studied the make-up of the program committees of the various conferences. Only members of the community with excellent credentials and judgment are invited to serve on the program committees, since their main job is to evaluate the conference manuscripts, which later become archival publications of the IEEE Transactions on Visualization and Computer Graphics (TVCG). We also looked at the gender-distribution of awards, which are our society's way of recognizing technical achievement, and discuss the relationship between participation and recognition in our community.

The IEEE VIS family of conferences has broad international participation, integrating diverse intellectual and cultural experiences into our community. In this section, we examine sociological and financial factors that drive funding for international research and diversity programs. We look at R&D funding across a wide range of countries, discuss different funding patterns in developed and emerging countries, and explore programs through which the richest countries support international research and diversity. We explore different funding patterns in developed and emerging countries and its impact on research publication in peer-reviewed journals. We also look at how research outlay influences the flow of researchers around the world, show the growth of international participation in VIS program committees.

This chapter, thus, looks at diversity from a number of different angles and perspectives, to examine how topics, participants, and geography interact to affect our ecosystem. We conclude with observations, suggestions for improvement, and aspirations for the future.

Data Caveats and Limitations. Visualization-specific data in this chapter revolves around the IEEE VIS family of conferences and symposia. There are other important venues such as the EG/VGTC Conference on Visualization (EuroVis), the IEEE Pacific Visualization Symposium (PacificVis), and the IS&T Visualization and Data Analysis Conference (VDA), plus many journals serving the visualization community. Data about their topics and participants would help expand our understanding of diversity in visualization.

Much of the data in this chapter was painstakingly culled, by hand, and small errors may have been introduced. The IEEE has not tracked authors, program committee members, or recognition by gender, race, ethnicity, country of origin or seniority. We scraped data from past programs and calls-for-papers. We collected gender information based on first names, personal knowledge, searches of web pages, use of his/her pronouns in posted biographies, and photos on LinkedIn. We specify where we were not able to determine gender from these sources. Although we recognize the importance of respecting gender identity, we did not have access to clarifying metadata. We did not address race and ethnicity directly, since we were not able to compile data on how individuals self identify. Although the population of underrepresented minorities (URMs) in visualization is very low, it would be important to understand their representation among authors, committee members and award winners. Data on geography, funding and migration were extracted from governmental and private web sites. We looked at country of origin for program committee members, largely by combing through online biographies. There are enormous subtleties in their collection and curation that may have eluded our scrutiny. Many of our analyses are not specific to visualization. Through our analysis of funding programs, we can provide some indication of how funding is being allocated to gender diversity, worldwide, but we do not have data on how well these programs have done in driving a more diverse research population. Our hope is that our work will help frame this discussion of diversity within a larger sociological context, and will provide motivation for creating more complete data sets, which will enable more sophisticated analyses.

1.2 TOPIC DIVERSITY AT IEEE VISUALIZATION

IEEE Visualization was launched in 1990 [162] and has changed significantly over its history, not only in size, but also in diversity. Inspired by this 25th Anniversary, Isenberg and her colleagues created a database of its published papers and authors, plus a search tool, and two papers analyzing topic evolution [155, 156]. This section draws on their work, and also explores topic diversity through keywords used in the calls for the major conferences.

Figure 1.1 shows the evolution of the IEEE VIS family of conferences, from a small conference with fifty-five papers in 1990 to a symposium with three major tracks and seven specialized symposia in 2018. Over that time, the number of papers has almost tripled. In 2015, the symposium published over 120 papers, which all appeared in the Proceedings of the IEEE Transactions in Visualization and Computer Graphics (TVCG). In 1995, there was a major expansion, with the introduction of InfoVis and two scientific visualization symposia, Volume Visualization (VolVis), and Parallel Rendering, which evolved into PGV (Parallel and Large-Data Visualization and Graphics. In 2006, VAST was launched, supporting the visual analytics community. Several major symposia and workshops have developed since. BELIV was introduced in 2006 to address the evaluation of visualizations. In 2011, the BioVis conference emerged from a series of conference workshops on biological data visualization dating back to the 1990s, and the LDAV symposium on Big Data Analysis and Visualization arose to address the astounding growth in large-scale data. In recent years, there has been an upsurge in new symposia, including Visualization for Cyber Security (VizSec), the Visualization Arts Program (VisAp), and Visualization in Practice (ViP).

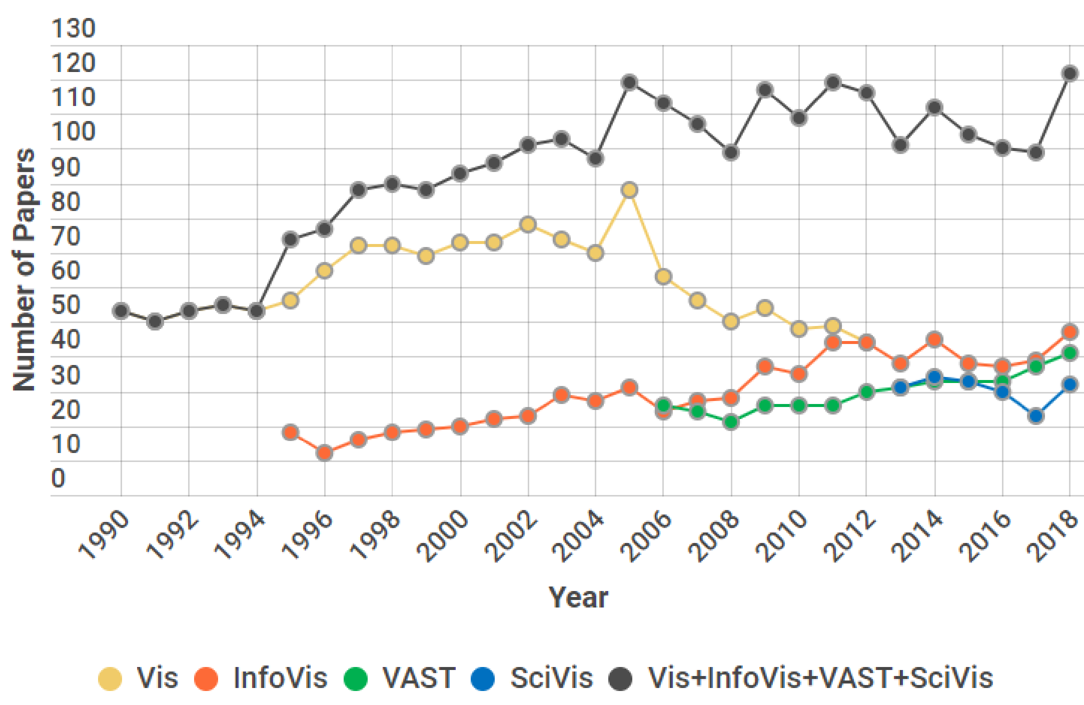
In their 2014 paper, Isenberg, et al [158] remarked on the intrinsic diversity of the visualization field, its roots in many disciplines, in the research methods it embraces, and in the application areas it explores. It is clear just looking at this structure, that the major conferences, and perhaps especially, the associated symposia, draw from a large pool of scientists and practitioners from diverse disciplines.

The diversity of topics has evolved. In the early 1990s, the main focus was on algorithms and scientific visualization. The creation of the Information Visualization conference in 1995 reflected a change in focus, welcoming new topics and participants from adjacent disciplines, such as perception, human computer interaction, and statistics. VAST provided introduced new topics in visual analytics and modeling, and welcomed disciplines where visualization is used as an analysis methodology. The biology, art and cybersecurity symposia expanded the envelope of disciplines, enabling the growth of new topics such as gene expression analysis, aesthetics, and network analysis.

Two analyses give us a deeper look into the evolution of topics at VIS. Isenberg et al. examined keywords for the ~4300 papers submitted to the annual IEEE VIS meeting, including InfoVis, SciVis and VAST. They found a significant increase in “interaction techniques,” and "evaluation," plus in keywords related to "time-varying data" and "multidimensional/multivariate data," including "machine learning" and "statistics." The author-generated keywords that declined most were those relating to "volume visualization," "meshes, grids, and lattices" as well as "numerical methods / mathematics." It is possible that papers in these areas have been subsumed by the associated LDAV symposium.

Data from the KeyVis database (Isenberg, 2017), Figure 1.2 illustrate the time-course of four topics over the span of our history. We see, for example, “interaction” and “evaluation” first appeared in paper titles in the early 2000’s, and have been gaining momentum since, reflecting the growing emphasis on human-computer interaction. Popular topics in scientific visualization, such as “isosurface” and “volume visualization,” have declined.

To complement this analysis, we examined raw text from conference calls-for-participation for the three major IEEE VIS conferences in the most recent decade,



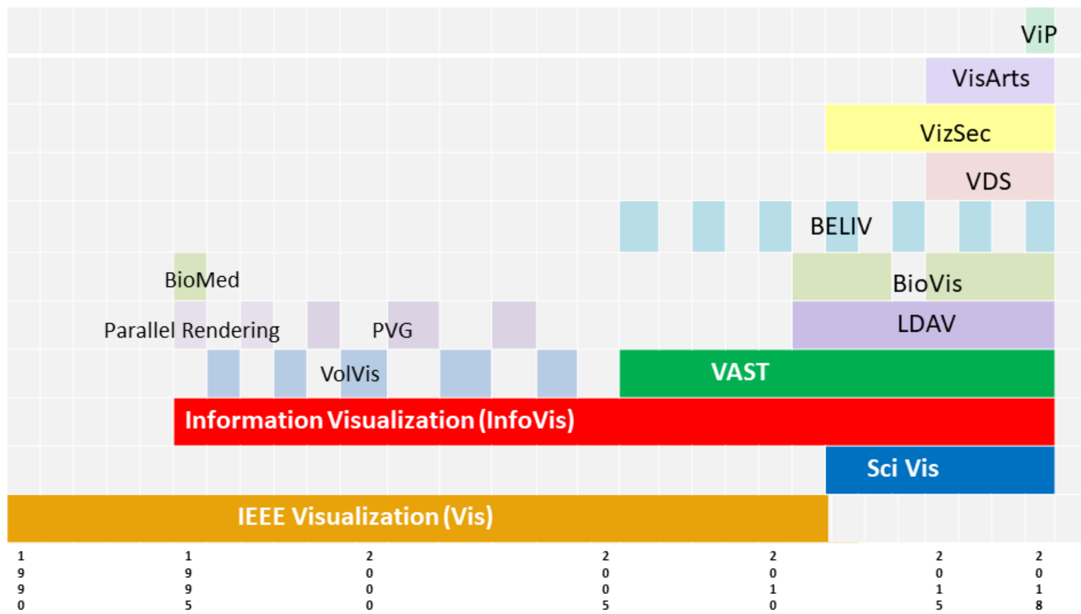


Figure 1.1: The evolution of IEEE Visualization family of conferences. The top panel, from Isenberg, et. al [155] shows the steady growth in technical papers in the major VIS conferences since the inception of IEEE Visualization (Vis) in 1990. *This image is in the public domain.* The bottom time chart, updated from that paper, depicts changes in the major conferences and also depicts the expanding set of symposia associated with the conference.

from 2009 to 2018. Word-frequency clouds for individual words in these texts are shown in Figure 1.3. InfoVis, VAST and SciVis are shown in the rows. We stratified the data into two time periods as a way of identifying major changes over this period. For InfoVis and VAST, the two intervals are 2009-2013 and 2014-2018. Since SciVis was launched in 2012, the first word cloud contains two years of keywords, from 2012 and 2013. These word clouds share a common scale, so that the counts across conferences are preserved. For example, "studies" was mentioned 20 times in the InfoVis calls from 2009-2013, "methods" was mentioned 20 times in VAST in that same

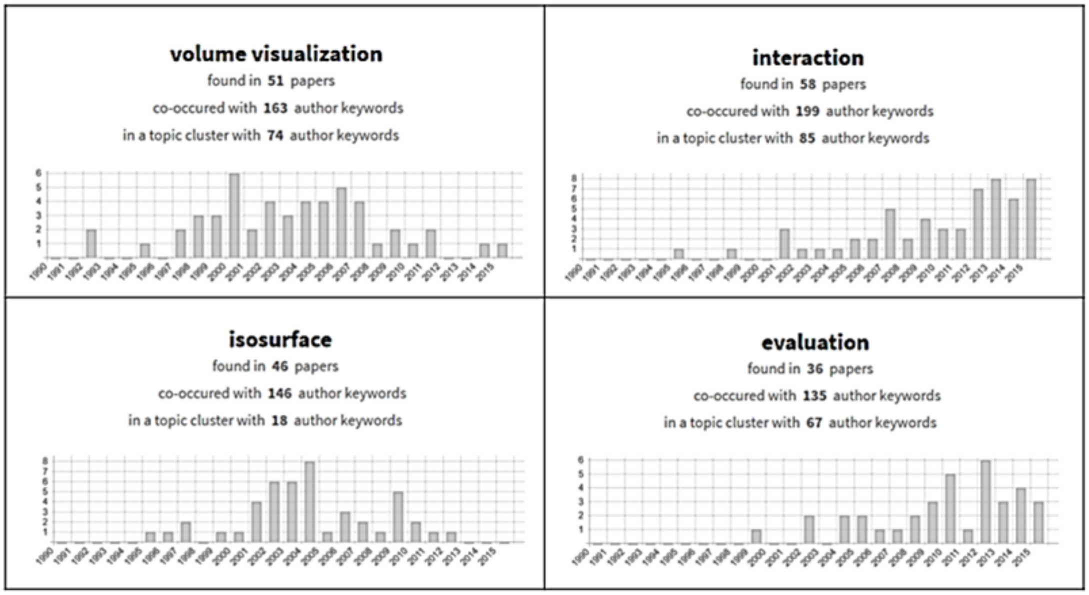


Figure 1.2: The evolution of four topics at IEEE Visualization, 1990-present. These examples reflect the ebb and flow of diversification and extinction over time.

time frame, and thus are the same size. The SciVis 2012-2013 data have been scaled up proportionately. Common words such as "visualization," "data," and "information" were removed from all visualizations to better reveal the fine structure.

The conferences have distinct flavors, with InfoVis focused on user studies, evaluation, and design, VAST focused on analytics and representation, and SciVis on "science," "hardware," and "devices," "perception" and "interaction." Some topic shifts, cross-referenced against the actual counts in the data, can be observed. Some InfoVis topics that appeared frequently in 2009-2013, such as "mathematics" (8 mentions) and "interaction" have dropped out in the most recent five years; other topics, such as "context" (15 mentions), "analysis," design" and "integration" have appeared, or have grown significantly. This rotation shows topic diversity and evolution. VAST terms have not changed much over the past decade, but this may, however, reflect the re-use of text year over year, not stagnation in the topics being addressed. Using the same methodology, of iteratively filtering out terms that appear equally in both periods, the strongest difference was the increase in the term "algorithms" which grew from from 5 mentions to 10. In SciVis, cornerstones of the 2012-2103 period, such as "hardware," "techniques" and "volume-rendering" have all but dropped out, new

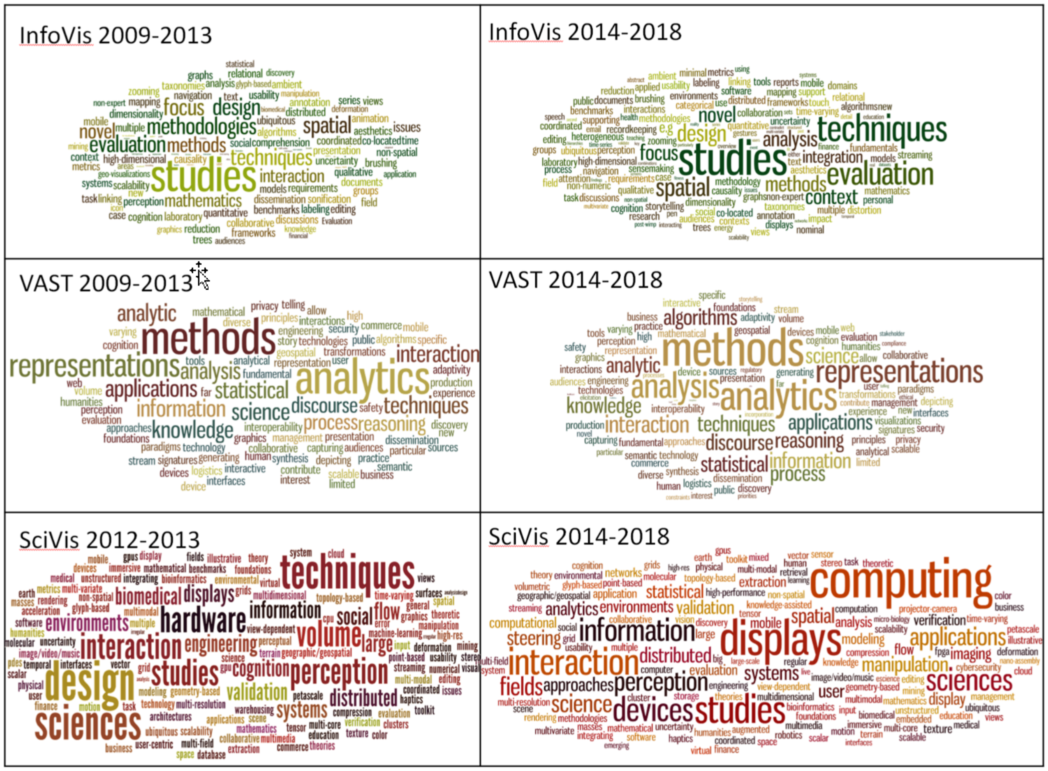


Figure 1.3: Call-for-Papers Text Analysis. Word clouds show high-frequency keywords for VIS conferences over the most recent decade, divided into two time intervals. InfoVis and VAST are separated into two 5-year intervals, from 2009-2013 and from 2014-2018. Since SciVis was created in 2012, its first interval covers 2012-2013 only.

terms such as "computing" (26 mentions) and "displays" have become prominent, and new topics such as "cybersecurity," "robotics" have appeared.

The above analysis is a first step toward understanding the dynamics of topic diversity and evolution in visualization. It would be fascinating to look at other visualization conferences, explore richer datasets, and conduct more sophisticated analyses. For example, we would like to study the co-located conferences and workshops at VIS, since they seem to bring enormous diversity into our ecosystem. On the analysis side, Isenberg, et al. (2017) clustered visualization papers into 186 categories based on several keyword types associated with each paper. It would be fascinating to examine how topic clusters have formed, morphed, and declined over our history, and relate these dynamics to changes in the demographics of our population.

1.3 TOPIC DIVERSITY CAN DRIVE GENDER DIVERSITY

In this section, we look at topic diversity as a possible on-ramp to population diversity. We focus on gender diversity because we were able to find relevant data that bear on this question. The basic idea is that some intellectual disciplines may have intrinsically higher proportions of women, underrepresented minorities, and international researchers, so, by embracing these disciplines, we include more diverse populations in our ecosystem. Our analysis focuses on professional women, since this is the only group for which we were able to obtain sufficient data.

Figure 1.4: **The proportion of women in fields relevant to Visualization.** Three panels show the growth of women professionals in "computer science and statistics," "soft sciences and the arts" and "hard sciences. Data since 1990 are summarized in the bottom right panel. Women make up 25% in computer science disciplines (red and yellow bars) compared with roughly 50% in statistics, the arts, life and social sciences. In chemistry/materials and geography, 35% are women. Only physics/astronomy has a smaller proportion of women professionals than computer science.

Figure 1.4 shows the proportion of women professionals in disciplines closely allied with visualization, such as computer science, compared with their participation in fields that are related to the emerging topics we have described. These data are extracted from Nathan Yau's Flowing Data site [170], which joins two sources of labor data from the Census Bureau (1950-2000) and from the American Community Survey (2010 and 2015), coded according to the 2010 ACS job classification system. The top-left panel shows how the proportion of women has varied in professions most closely related to Visualization fields. Roughly 25% of computer programmers (red) and computer and systems analysts (yellow) are women, and there has been a sizable drop in female programmers since 1990. There there has been a consistently high rate of female statisticians (purple), with representation steady around 50% since 1980. The graph in the bottom left panel shows womens' participation in fields that have more recently been integrated into the visualization community. Social sciences (blue), medical and life sciences(green), and art (magenta) have nearly equal participation by men and women, and these numbers have been consistent over the span of measurement, which in many cases reaches back to 1950.

We often hear language suggesting that the low participation of women in scientific visualization is a direct consequence of the low participation of women in the "hard sciences." The fields shown in the top right panel tell a more nuanced story. While, indeed, female participation in physics and astronomy (violet) have made very slow increases from their low levels half a century ago, there has been a steady increase in female participation in chemistry and materials science (azure). The job category that includes environmental science and geography has experienced a remarkable leap in female participation, rising from less than 10% in 1950 to 40% at the most recent measurement in 2015.

The chart in the lower right quadrant of Figure 1.4 distills these data, showing average participation rates for women since 1990, when IEEE Visualization was launched. Each color-coded bar corresponds to a discipline in one of the other graphs. To explicitly compare computer science fields with the disciplines, their colors (red and yellow) are more saturated. Also, a red horizontal line at just over 25%, depicts the average proportion of women in these two fields. The representation of women in computer-science fields over the past thirty years is half that of their proportion in statistics, art, and life sciences, which are all around 50%. The proportion of women in the social sciences is also near parity. Women professionals make up nearly 35% of environmental scientists, geographers, chemists and materials scientists. Across all these fields, the proportion is lower in just one category, physics and astrophysics.

The decreasing proportion of women in computer science is a danger sign for the growth of gender diversity at VIS. If the number of female CS graduate students is

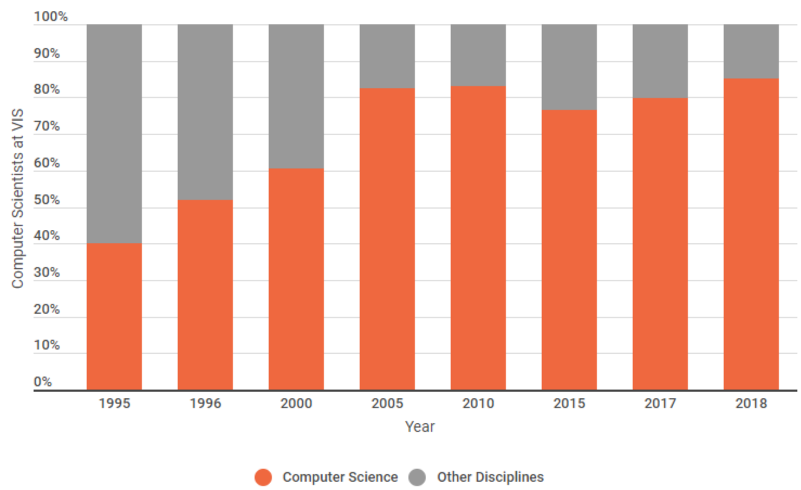


Figure 1.5: Computer Science background of VIS Program Committee Members The percentage of computer scientists has increased from about 40% to over 80% since 1995, during which time, the proportion of women in computer science has been falling.

not increasing, then continuing to draw members from that pool will not contribute to increasing the female/male ratio of our population. We did a short analysis to understand how this decrease may affect the visualization ecosystem. We compiled background on the disciplines of VIS program committee members. Figure 1.5 shows the proportion of computer scientists, sampled every 5 years from 1995 to 2015, plus the two most recent years, 2017 and 2018. Two decades ago, roughly half the program committee members were computer scientists. That proportion has grown steadily since, and is currently near 80%. So, not only is the pool of female computer scientists decreasing, but our program committees are increasing drawing from that pool. If our goal is to attract a more diverse population, it's clear that we need to encourage participation from fields outside of computer science.

We see topic diversity as an important lens through which to examine growth drivers for diversity in visualization. Many of the disciplines examined in Figure 1.4, not only dovetail with new and diverse topic areas for visualization, but could also increase the participation of women, since these professions have higher proportions of women scientists and practitioners. Our community has already embraced many of these topics, and they have been an important vehicle for keeping ideas fresh and responsive. For example, the enormous growth in data for biological and genetic analysis has attracted doctors and biologists to visualization. Statisticians, geographers, and social scientists are increasingly using visualization to analyze the vast pool of geo-located social data now coming available. The important goal of providing evaluation methods and guidelines for visual representation have drawn new members to our community from psychology and human computer interaction fields. The arts program has attracted artists as well as other professionals interested in visual representation, semiology, and expression. New topics add to our diversity, and also attract practitioners from other fields with higher intrinsic proportions of women, and perhaps other minority groups, creating a virtuous cycle.

Looking forward, why not develop visualization symposia that explicitly tap disciplines with higher proportions of women scientists? For example, the EnviroVis symposium at EuroVis draws on disciplines related to the environment and geography, and there are definitely large data analysis and representation issues in chemistry and materials science that could benefit from visualization. Topics could also be promoted that tap visualization opportunities for data journalism and advocacy, attracting social scientists, graphic artists and writers.

1.4 GENDER AND RECOGNITION AT IEEE VISUALIZATION

A hallmark of a healthy social ecosystem is one where individual merit is acknowledged and recognized. In this section, we take a look at three levers of intellectual recognition through the lens of diversity. To begin this exploration, we examine the number of women authors at IEEE Visualization. Next, we look at gender diversity in program committee composition and in recognition through awards.

Women Authors at IEEE VIS. The number of papers at VIS has been increasing steadily. An analysis of all VIS paper authors from 1990-2016 is shown in Figures 1.6 and 1.7. These data were coded by hand, and include as "unlabeled" the 1 or 2 authors per year for whom we were not able to definitively ascribe gender.

The number of women authors rose quickly from 8 in 1990 to 37 by 1996. In the following decade, however, the number of women authors leveled out (solid red line), while the number of male authors grew monotonically (dotted red line). In the most recent decade, the rate of male authorship has continued to increase 50 percent per decade. During this decade, the rate of women authors has doubled, owing largely to participation in InfoVis and VAST. Although the number of women authors is still small, the recent growth rate points to growth in ecosystem diversity.

Program Committee Membership. Program committee members' main responsibility is the review of technical papers. This is a very competitive process, with roughly 20% of the papers accepted, and these accepted papers appear as full publications in the Transactions on Visualization and Computer Graphics (TVCG), a highly

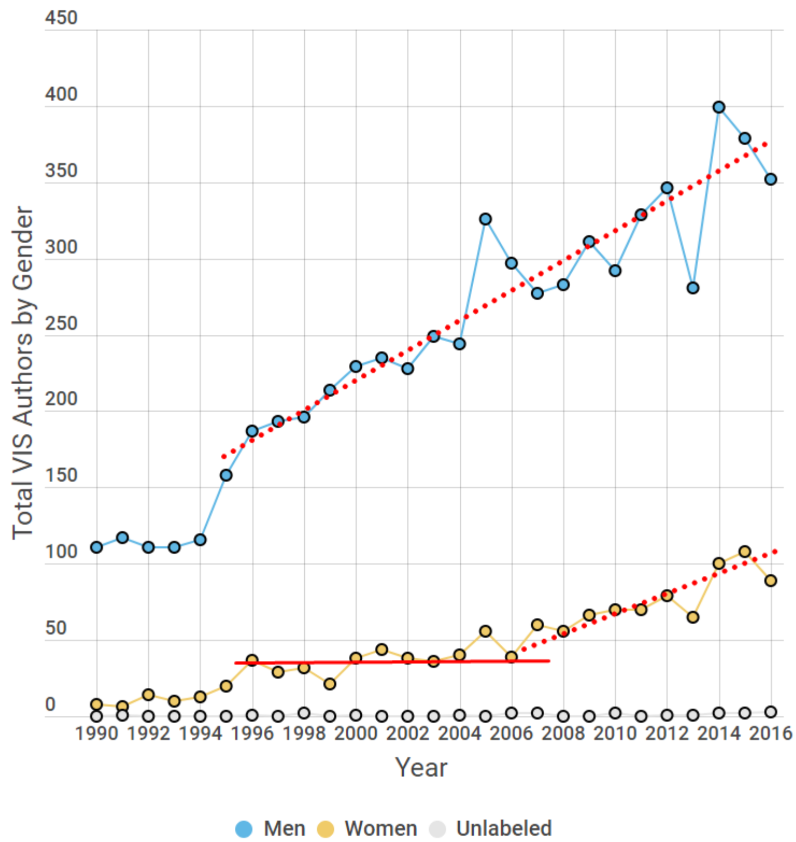


Figure 1.6: Men and Women Authors at IEEE VIS. The number of authors has risen steadily over the history of VIS. The number of male authors has increased at a rate of roughly 20 per year since 1996. The number of female authors began growing steadily in 2006.

prestigious journal of the IEEE Computer Society. Program committee members provide in-depth technical reviews, solicit additional reviewers, and adjudicate over often-conflicting reviews. Program committee members are recognized for their excellent credentials, judgment and knowledge, and play an integral role in maintaining the quality and intellectual integrity of the organization.

Figure 1.8 shows the male vs. female composition of the program committees for the major conferences, sampled irregularly from 1995-2018. We are missing data from the first five years, but from 1995-2005, women made up roughly 10% of the program committees. This number jumped to just under 20% in 2006, driven by the

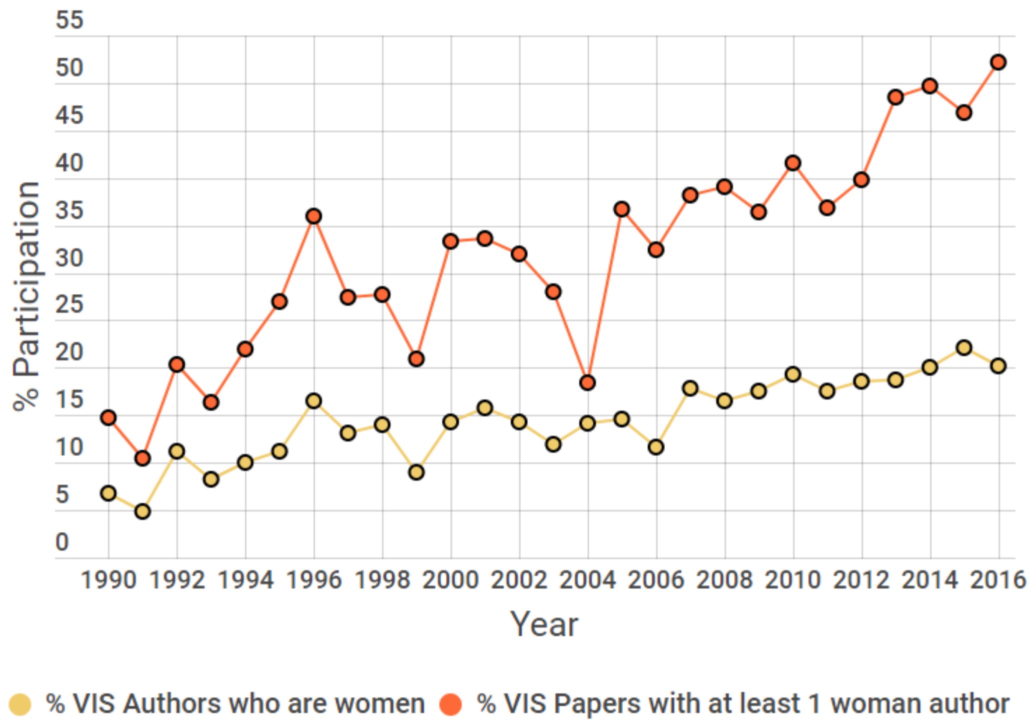


Figure 1.7: Proportion of Women Authors and Papers with Women Authors. The proportion of papers with at least one woman author has increased faster than the proportion of authors who are women, reaching 50% in 2016.

steadily increasing proportion of women on the InfoVis program committee. The overall proportion is now over 20%, driven by the continued increase in female participation in InfoVis, and a significant growth in SciVis, as well. Figure 1.9 explores these data more closely, plotting the percentage of women on the program committee as a function of the percentage of women authors, for the same years from 1995-2016 depicted above. The correlation between the percentage of women authors and the percentage of women on the program committee is 0.475 (r-square). That is, authorship is related to leadership at VIS. However, the proportion of women on the program committee is roughly 2% lower than would be predicted by the proportion of women authors (dotted red line). That is, the rate that women are invited to a leadership position on a program committee does not keep up with their level of scientific contribution.

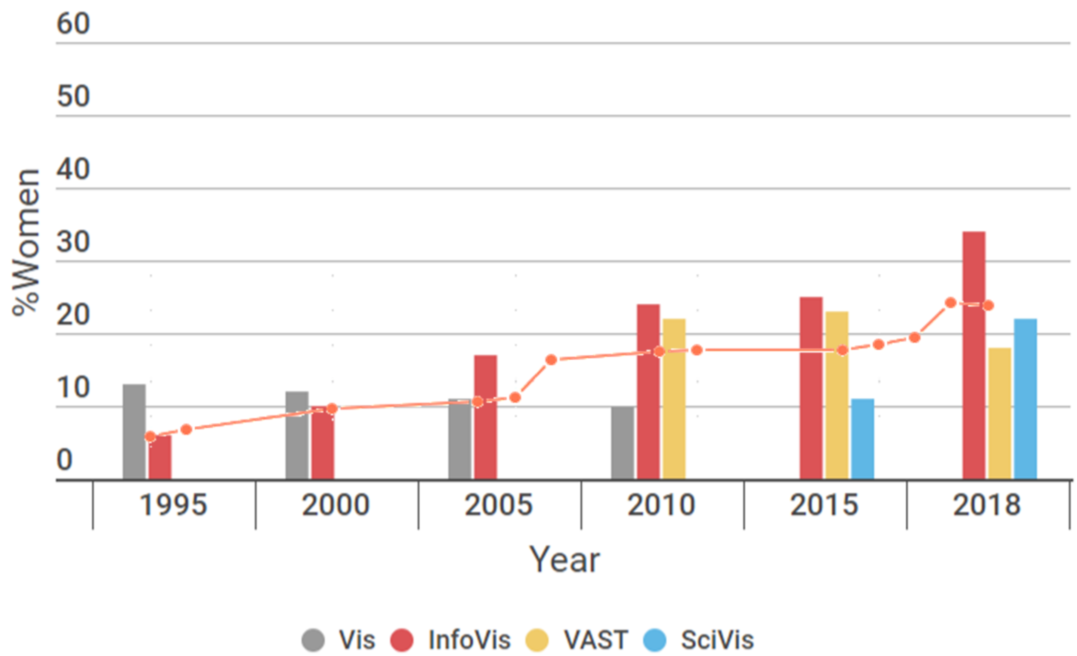


Figure 1.8: Program committee composition. On average, the percentage of women serving on program committees has grown monotonically (red line), led by the InfoVis conference.

Society Awards. Each year, the IEEE and individual conferences provide recognition of intellectual achievement through an annual awards process. Awards serve as a mechanism for validating members' value in an organization, and add to their prestige and influence. Figure 1.10 shows the recognition structure at VIS, comparing how frequently men vs. women receive awards for their intellectual contribution to the community. In the 14 years from 2004-2017 there have been yearly awards for Technical Achievement and for Career recognition. During this 14-year period, the annual Technical Achievement Award was awarded to a man every year, but one. Up through 2017, no woman received the Career Award. (Although not included in this graph, 2018 marked the first year that a woman was bestowed a Career Award, raising the proportion from 0 to 6.7%.

Starting in 2013, the three major conferences, InfoVis, SciVis, and VAST have awarded best paper awards. These awards reflect our current award dynamics, not a reminder of behavior in decades past. Of these 15 awards, three papers with female authors have been recognized. For the first time ever, in 2018, two papers with at least one woman author were awarded a best paper award, bringing the percentage

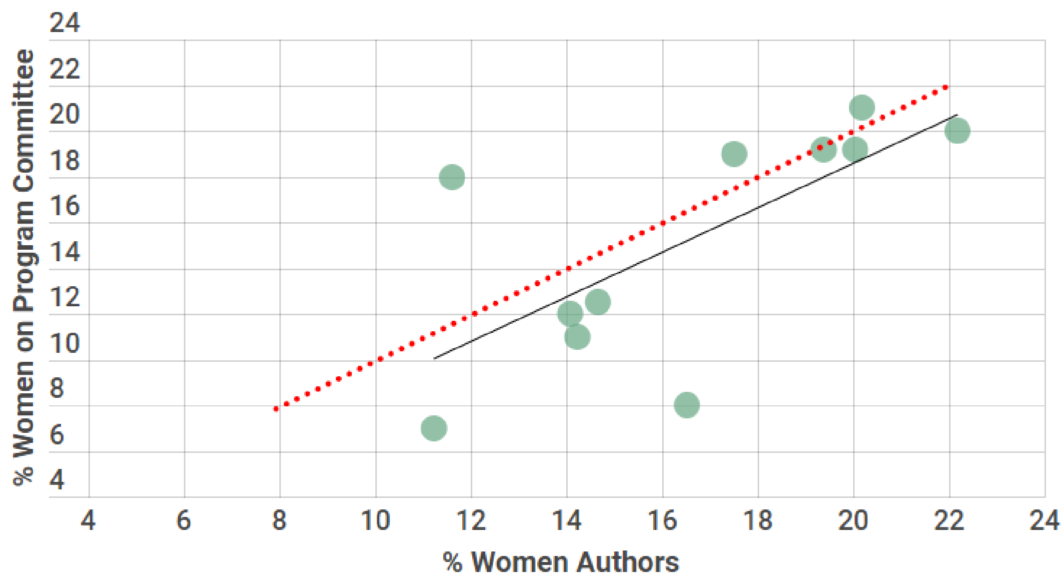


Figure 1.9: PC Representation of Women relative to authorship. Participation on a program committee is related to authorship (r-squared = .475), shown as the black line. The red line, however, shows the prediction if being selected for a PC were at parity with authorship.

from 8% to 20%. However, of the 54 authors who have been recognized by a Best Paper award, only four have been women (7.4%).

Across all these opportunities for intellectual recognition, there have only been five instances, counting 2018, where a woman received a major honor. There are certainly reasons why this finding may not reflect bias, such as the longevity of women in the field, the number of students they may have had to contribute to their success, etc. Still, the absence of yellow on this chart is breathtaking.

Since 2014, the proportion of women authors has grown to 20%, and as has the proportion serving on program committees (PCs) for the major conferences. Although this is not a large percentage, this growth reflects growing recognition. The same cannot be said for the awards process. A much more thorough study would be required to delve into the many factors that drive recognition in a society. This is important to explore, because participation and recognition make people feel respected, acknowledged and admired in an organization, giving them authority, voice, and status. Also, awards and recognition provide valuable line items on resumes, which can increase the chance of getting a job or a grant, which can also have economic implications. We hope that these data will spark discussion and awareness.

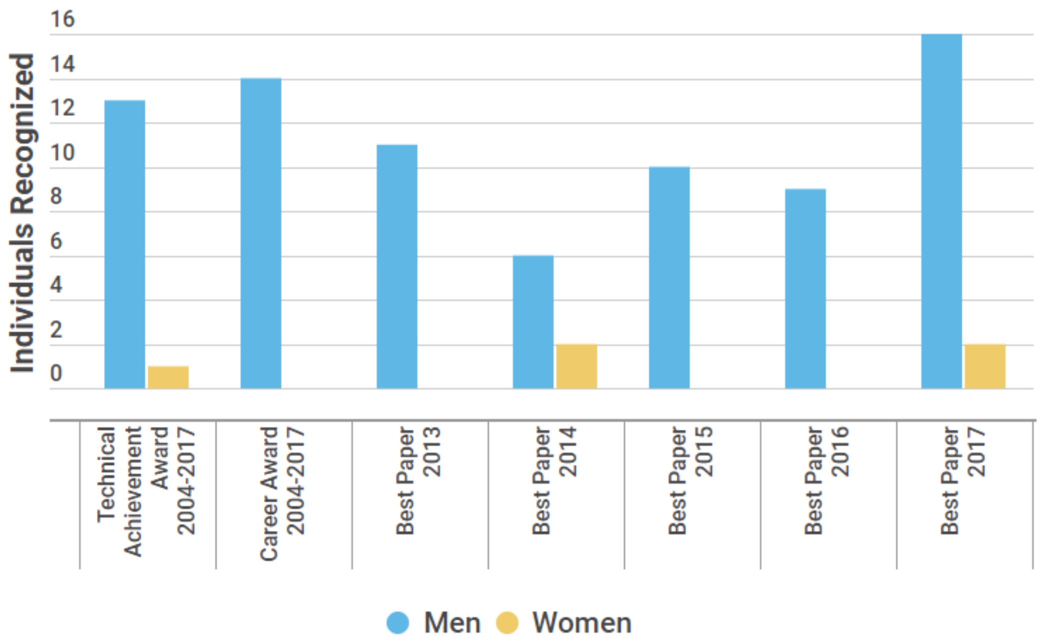


Figure 1.10: Awards Recognition. Recognition by men and women via conference-wide Technical Achievement Career awards and Conference-specific Best Paper Awards. Recognition of women is far below their representation as authors.

1.5 GEOGRAPHICAL DIVERSITY AND FUNDING

Another important facet of diversity in visualization is geographic diversity. In the Arts, Philosophy, and Politics, differences between cultures are explicitly considered. In Visualization, too, different world experiences contribute differently to the field. Rene Descartes and Jacques Bertin were French, William Playfair and James Clerk Maxwell, who sculpted the first 3-D visualization, were Scottish, S.S. Stevens and John Tukey were American, Herman von Helmholtz was German, to name a few. Each brought a very different flavor to the fabric of visualization.

So, how is that geographical diversity driven? A step toward understanding geographical diversity is to understand the distribution of research funding. Governments differ significantly in terms of the amount of money they allocate for research, which has a strong influence on the magnitude of research activity. Figure 1.11 shows the distribution of gross domestic expenditure on research and development $R\&D$. The countries with the biggest R&D budgets are the US, China, the European Union,

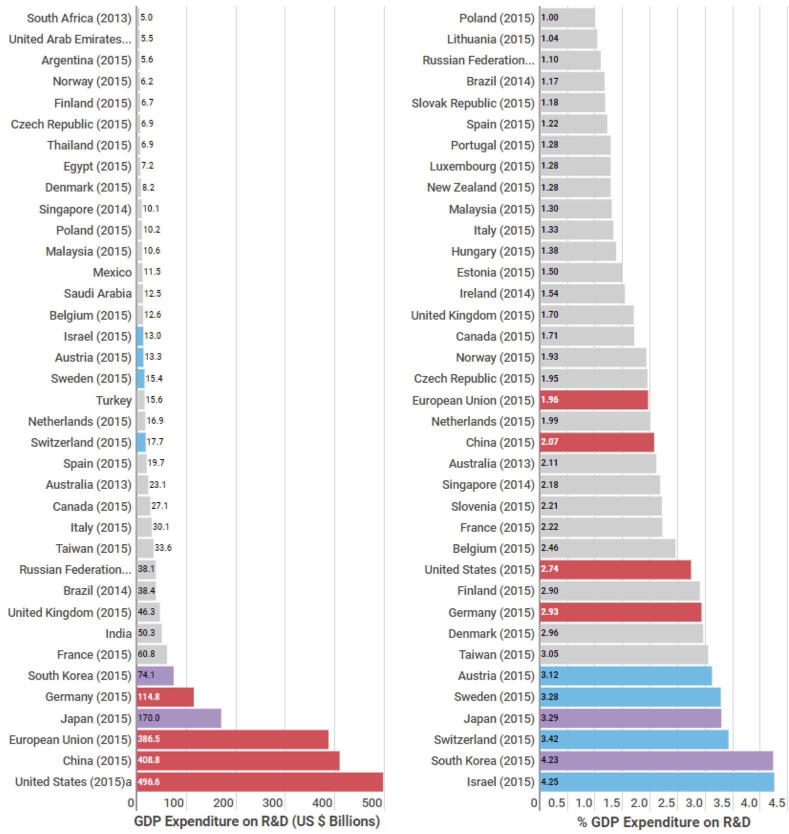


Figure 1.11: Research Funding by Country. The chart on the left shows R&D funding by country, with the US topping the charts at $500B, and China close behind at over $400B. The right-hand chart depicts R&D funding as a proportion of gross domestic expenditure (GDP). Countries with the highest absolute spending on R&D are shown in red; countries with the highest R&D expenditure relative to GDP are highlighted in blue. Countries with highest absolute spending *and* highest spending on R&D relative to GDP are shown in purple. Data come from the 2018 NSF report [132]

Japan, and Germany. The amount spent by these countries dwarfs the investment by other developed and developing countries. The chart to the right re-plots these data as a pro portion of overall GDP, providing insight into the Research appetite for each country. In order, the countries with largest expenditure in R&D relative to their GDP are Israel, South Korea, Japan, Switzerland, and Sweden. The colorcoding in the graph shows that the countries with the largest R&D budgets (red) are not necessarily the ones with the highest expenditure relative to GDP, and vice versa.

Richer, more developed countries can support more research and can attract students from all over the world. As we will see, some are more generous toward foreign students, and others spend their research funding to support their own populations. Developing or emerging countries can offer fewer opportunities, and students often leave to study in richer environments. Whether they stay in their adopted countries or return home, this exchange expands scientific borders and increases diversity.

1.5.1 THE FLOW OF INTERNATIONAL RESEARCH FUNDING

To better understand how research funding is allocated across the world, we collected public data on agencies and universities that provide grants to support international research and diversity programs. Since governmental funding agencies in each country drive the research agenda, the fields they choose to fund may differently affect funding for visualization research. In richer countries, the diversity of funded topics is very large. We included grants that are targeted for specific countries as well as opportunities that are open to all international researchers. This compilation is not comprehensive; it is intended to provide a glimpse into the magnitude and scope of programs that support international collaboration and diversity.

Figure 1.12 provides a high-level overview of our findings. This tree-map shows international-focused research funding and diversity programs for the countries that devote the most money to research and development. Rectangle size represents total R&D budget, coloring depicts the number of international or diversity programs we identified, and title bar color codes the continent.

The US and The European Union. In this figure, we see that the United States(US) and the European Union are the largest contributors to worldwide research, and this wealth translates into a wide array of programs to support funding for developing countries, international collaborations, and diversity. The US has the largest R&D budget. Major funding goes to support international collaboration and research in developing countries, including joint collaboration initiatives between Asia and the US (such as the ASEAN Research Program), and between Africa and the US. There are also many programs supporting diversity, including the National Academy of Sciences PEER Women in Science Mentoring Program [140], plus non-profit international organizations such as Anita Borg [141], Women Techmakers [142], and the ACM Council on Women in Computing (ACM-W) [143].

The European Union offers many funding opportunities including Horizon 2020 [163],the European Research Council, and the European Neighborhood Instrument (ENI). There are several programs supporting research between Asia and

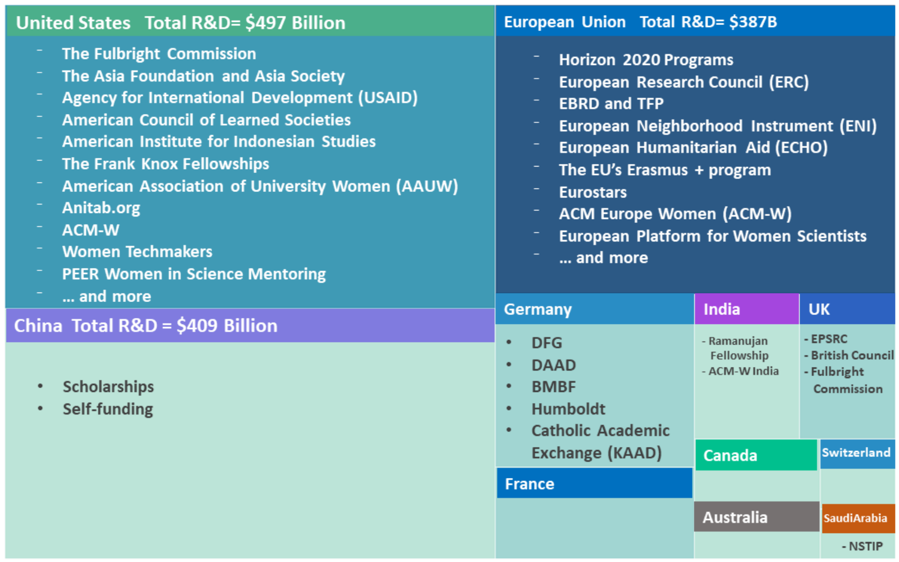


Figure 1.12: Research Funding for International and Diversity Programs. A sample of the international research and diversity programs funded by the richest countries. Area is proportion to R%D spending. The more research programs we were able to discover, the darker the color.

Europe, such as the EUforAsia Programme, the Trans-Eurasia Information Network (TEIN), and the Asia-Europe Foundation (ASEF) as well as the partnership programs between Africa and Europe [167]. Recently, the European Commission (EC) opened its funding to any country of the world that wants to apply [144]. In 2021 they will launch Horizon Europe, with a budget of 100 billion euro, the biggest research budget in history. On the surface, this initiative seems to be a great opportunity for non-European countries, but is not clear how much it will cost to participate, and what proportion of funding will be allocated outside the EU.

Other Developed Countries. Individual countries in Europe, especially Germany, Switzerland, and the UK, also have active programs supporting gender equality, research collaborations and student fellowships in developing countries [131]. Germany has the largest R&D budget of the European countries, and is one of the strongest contributors to research funding in developing countries. The Deutsche Forschungsgemeinschaft (DFG) has specific cooperation programs for 90 countries in Africa, North and South America, Europe and Oceana. Moreover, the DFG strongly supports gender-equality programs [147]. In the UK, the Engineering and Physical Sciences Research Council (EPSRC) funds programs for International collaboration with China, India, Japan, and the US [148]. They also support programs that fund equality and diversity, including gender, place of origin, and other factors. Since the announcement of Brexit, the UK has suffered significant losses in funding from EU projects, such as Horizon2020 [166]. An inflection point will come in 2019, when the UK leaves the EU, jeopardizing its right to participate in the research budget.

Emerging Countries. During this past decade, emerging economies such as Saudi Arabia and China have significantly increased their engagement in the international academic community. This shift can be understood within the context of a new theory on the Economics of Innovation [168], in which countries are changing their economic paradigm from trade- or oil-based to knowledge-based. [151]. In this context, countries are investing in increasing their research and patent portfolios and bootstrapping their research programs. Their main mechanism is to send their students to the US, Europe and Australia for advanced degrees. China has the second largest research and development budget, worldwide, which they focus mainly on the development of their citizens. China invests in scientific programs for its students, including international research visits for undergraduates and support for Chinese students to earn their masters' degrees in the US and the EU. From 2001 to 2011, China has increased funding for research from 1.0% of GDP to 1.8% of GDP, with a target of 2.07% in 2015 [149]. A recent report from the National Science Foundation (NSF) [132], shows a direct correlation between the investment in science and the quantity of published papers. Figure 1.13 shows the increase in peer-reviewed papers in the European Union, the US and in China. The results are breathtaking. China's output has quadrupled since 2003, and in 2018, it surpassed the US as the country with the most peer-reviewed papers.

In Saudi Arabia, the National Science, Technology and Innovation Plan (NSTIP) is dedicated to increasing scientific publishing and patents. To do so, Saudi Arabia recruits researchers to institutions such as the King Abdullah University of Science and Technology (KAUST). Its main investment is in sending Saudi students abroad for post-graduate study, to increase their knowledge and their international networks. India, Japan, and South Korea have also been increasing their R&D expenditure [149].

Other Developing regions such as Latin America vary greatly depending on the economic fluctuations on the region. We found one regional effort, FRIDA [159], that funds Digital Innovation in Latin America and the Caribbean. Also, there are private efforts made by companies such as Google, Microsoft Research, and Facebook to increase the mobility of undergraduate and PhD students from Latin America to the US and Europe.

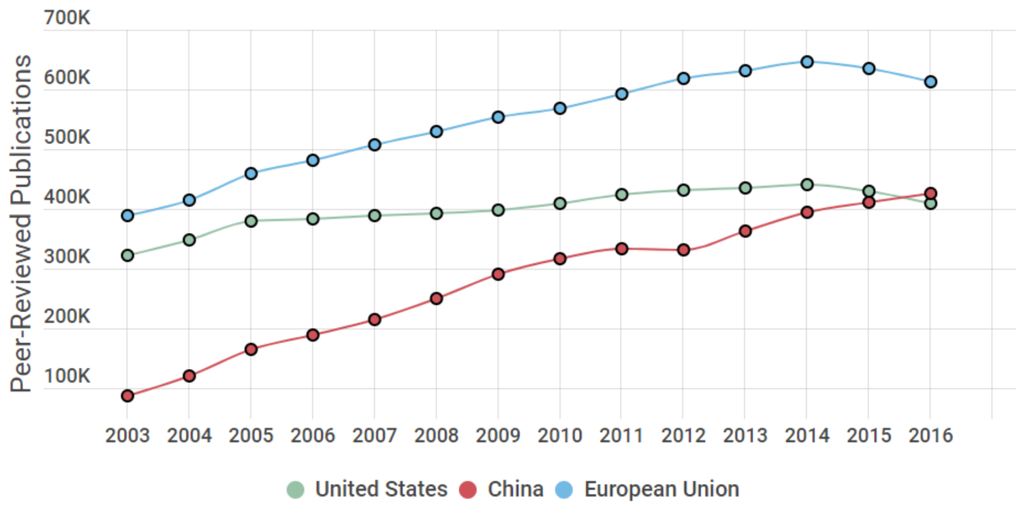


Figure 1.13: Peer-reviewed publications for the European Union (EU), China, and the US. Data are courtesy of NSF 2018 Report [132]

1.5.2 PATTERNS OF MIGRATION

Abel and Sander [160] analyzed migrants demographics to understand contemporary trends in international migration. They identified some interesting trends that are relevant to our analysis of international diversity in research, including, (1) the attractiveness of North America, (2) significant movement from South Asia to the Gulf states, (3) diverse flow dynamics within Europe, and (4) North America and Europe as the principal flow sinks; Asia, Africa, and Latin America as the main sources of migration.

Many of these patterns can be explained by the funding dynamics we outlined in the previous section. Wealthy regions like North America and Europe, invest in high-quality graduate education that attracts students from Asia, Africa and Latin America. This, coupled with fellowship and scholarship programs, provides a powerful magnet. Iconic programs such as the German Marie Sklodowska-Curie Fellowships [152], the American Fulbright scholarships [153], and the English IAESTE [154], for example, promote mobility of researchers in the early stages of their careers, independent of their age and country. Likewise, countries that see education as a strategy for growth, such as Saudi Arabia and China, have generous programs that provide funding for their citizens to study abroad.

Mobility is very important for international collaboration, research exchange, and diversification of ideas. The literature investigating mobility patterns among scientists and PhD students is vast [169]. Recently, Bohannon [165] analyzed a set of 741,000 public CVs to understand migratory patterns of scientists. This research was based on the ORCID datasets [164], an important collection of worldwide scientists' profiles, collected by Dryad, a nonprofit repository for scientific data. Although the data are incomplete, comprising only 10% of scientists profiles in which Europe is overreprsented, the results are intriguing. For example, 15% of the scientists in the dataset had migrated.

International Participation at VIS. It would be interesting to study migration patterns in VIS, where it seems, anecdotally, that there is a growing population of international students who are graduate students or post-docs in the US and Europe, especially in Germany. Figure 1.14 shows our first attempt in this direction. These data show the country-of-origin of program committee members for the three VIS conferences, irregularly sampled from 1995 to 2018. Data were hand-coded based on personal knowledge and on information gleaned from individuals' CVs.

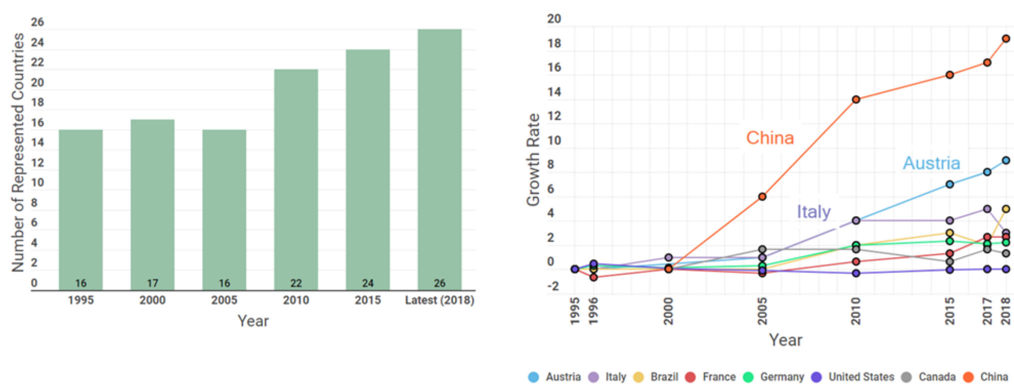


Figure 1.14: Geographic Distribution of PC members. The left-hand graph shows the number of different countries-of-origin of VIS program committee members. The right-hand graph illustrates the growth rate in PC participation for selected countries.

Looking at the left figure, we see that VIS has always been an international conference, with at minimum 16 countries represented in the program committees. This number grew in 2010, and has been increasing steadily since. Although this is a 60% increase, in many cases, the country is represented by one person. The graph to the right shows the growth rate by country. Here we show the countries with the highest growth rates plus the US, for comparison. There has been a 20% increase in PC members from China since 2000, an 8% increase in participants from Austria, and moderate growth in the other countries shown. By contrast, although scientists born in the US comprise 60% of the program committees, their growth rate is near zero.

1.6 SPRINGBOARD FOR FUTURE DIRECTIONS

Studying an ecosystem is a difficult task, since there are many dimensions, influences, and interaction effects. Taking this first step has shown us how much we don't know. One big factor in tackling the unknown is the lack of data. IEEE, for example, could capture more information about VIS participants, such as the conferences and symposia they attend, their demographics (e.g., race, gender, ethnicity, where they were born, trained, and work), and their discipline of study. This repository could be joined with information the IEEE already has about participants' membership, publication/presentation history, leadership roles, and awards. The society could also mine funding information provided by authors, which could give us a handle on the geographic flow of funding specifically focused on visualization research.

More ambitiously, we think it would be valuable to understand the generation of new ideas in our ecosystem, and what drives their introduction. Do these new ideas germinate because we have a vibrant system that rewards and encourages diversity? Looking at the calls for papers over the last decade, we did find topic evolution. However, we had to look hard to find dramatically new ideas and directions. Our hunch is that a lot of new and innovative ideas at VIS are coming from the panels, workshops, symposia, and Meet-ups, which seem to be bursting with new topics and ideas. If this is true, is it because there's a lower barrier to entry for papers in these venues, widening the entry portal? Or, is it because they explicitly draw from fields outside of computer science? Are they more gender- and race-diverse? and if so, can this diversity be tied to differences in the demographic populations from which they draw? These events are part of the fabric of VIS, and contribute to its appeal and success. Explicitly studying their role in encouraging diversity in visualization would be an interesting way to explore some of the hypotheses raised in this paper.

We also need to build reward mechanisms that will encourage diverse voices. Fellowships and travel grants could encourage women and minority scientists and build our geographic footprint. Awards committees could be asked to explicitly add people from diverse backgrounds to the pool of candidates. Conference and symposium chairs could specifically ask their leaders to be on the look-out for scientists and practitioners who can bring diverse perspectives to our program and organizing committees. Even small honors can have a big impact, such as asking someone to chair a session or serve on a committee. That first invitation can lead to many new opportunities for individuals, and bring cascading insights into the organization.

1.7 CONCLUSION

This chapter looked at the IEEE Visualization community through an ecological lens. Diversity is critical for maintaining the health of an ecosystem, and to do so, all members need the opportunity to thrive. We examined diversity statistics for women authors, program committee members, and award recipients, and studied several exogenous factors that affect the diversity of our community, such as the disciplines and home countries of our population. We also explored the role of multidisciplinary applications and symposia in broadening our population demographics, widening the opportunity for inclusion. We have seen a healthy increase in the topics and disciplines in our current mix, and see exciting opportunities for growth. We are happy to show a steady increase in the geographic distribution of our program committee members. But we have work to do. Although the proportion female authors and program committee members has grown over the years, the numbers still hover around 20%, and the number of women who have won recognition for their academic achievements is embarrassingly small. The representation of African American and Hispanic scientists is almost uncountably low. In the VIS 2017 Panel on Diversity in Visualization, two young women scientists shared their lived experience in our community, showing how much further we need to come in simply treating members who have different backgrounds with respect. Visualization as a field has thrived on cross-pollination from diverse disciplines and perspectives, increasing the demographic and geographic diversity of our community. We hope the explicit links we have drawn between diversity and ecosystem health will help guide our vision for the future.

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