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DEPARTMENT: APPLICATIONS

Thirty Years of Applications

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***Abstract*—IEEE Computer Graphics and Applications began publishing "Applications" as a regular department under its present editor 30 years ago in November 1994, with the goal of featuring interesting examples of using computer graphics to solve real-world problems. The Applications department has appeared in every issue since, making the present article the 181st such article to appear. To mark this occasion, the Applications department takes a look back by revisiting the most cited articles that have appeared since the department's inception.**

The Applications department began its run as a regular *CG&A* department in November 1994 with the article "Comet Explodes on Jupiter – and the Web" by IEEE staff writer Karen Whitehouse [1]. Prior to that time, "Applications Briefs" had appeared in these pages as far back as *CG&A* vol. 1, no. 1 in January 1981. But usually these were staff-edited rewrites of industry-provided "application notes" common at that time, not authored papers. In 1994, *CG&A* Managing Editor Nancy Hayes asked me to help edit a formal department that would solicit and review regular articles for inclusion in these pages. This appealed to me given my background developing computer graphics for scientific applications and so I signed up for the task. Somehow, I forgot to specify an expiration date and have been doing it ever since.

In November of 2004, to commemorate 10 years of editing the department, I wrote an article "A Decade of Applications" [2] about the aims of the department that had emerged and how it was run. By then it had become a mix of author-submitted papers, articles I invited from authors whose work I had come across, and articles written by freelance science writers we had engaged on topics I felt would interest our readers.

I remember thinking 10 years seemed like a nice span and never envisioned doing it 20 years, but in November of 2014 the department was still going strong. By then the department had become entirely submitted or invited papers. In the November 2014 issue, I co-authored an article with then Associate Editor-in-Chief (now Interim Editor-in-Chief) Pak Chung Wong entitled "Visualizing 20 Years of Applications" [3] featuring a dive into metrics for the department, looking at page and word counts, author affiliations and countries of origin, and topic areas.

Now here we are at 30 years and it appears I'm still at it, so it would seem that a 30 year

commemoration article is called for. I thought this time I'd take a look back and reflect on the most successful papers that have appeared in these pages to see what that might reveal.

METHODOLOGY

I began this article wanting to feature the "top 10" all-time articles by some measure, like the most downloaded or most viewed. IEEE Xplore Analytics provides detailed data for PDF downloads and HTML views, but only those occurring in 2015 or later. To the extent articles get many of their downloads and views when new, I worried this would lead to an undercount for older articles. Also, downloads and views are impacted by whether and how long articles are featured outside the IEEE digital library paywalls, as happens selectively when issues first appear. So, downloads and views were problematic.

Xplore also has data for citations, which would seem to have fewer of these problems, especially for producing a "most cited" ranking. While total citations arguably gives weight to older articles, that seems in keeping with a retrospective article such as this. In addition, Google Scholar also provides citation data, and reassuringly, Google Scholar and Xplore Analytics produced very similar top citation lists: the exact same top 3, the same next 6 with some reordering, and disagreeing only on number 10. Calling those last two a tie resulted in the 11-member "top 10" list featured in this article. Since the lists disagree on the exact order, I'll present them instead in order of publication but will note the top 3 given the agreement on those.

CLOTHING DESIGN (1996)

The article "3D Scanning in Apparel Design and Human Engineering" [4] by Steven Paquette from 1996 is the earliest article on our "most cited" list. It is also one of the first author-submitted articles in the Applications department, as opposed to articles invited or topics selected by me.

Steve was an anthropologist working for the US Army R&D Center in Natick, MA, where he and his group engaged in the design, development, and testing of military clothing and equipment. Acquiring useful body size data is a challenge given the great variation in body sizes and types. There is also a wide disparity in the types of clothing and equipment needed for carrying out different responsibilities. Steve's paper described work they were doing using whole-body 3D scanners to measure and analyze soldiers and different designs and styles of wearable equipment, such as protective body armor shown in Fig. 1.

Figure 1. 3D scanner used to record the surface of a mannequin wearing body armor. From [4].

As of 2022 Steve Paquette and his team were still at the U.S. Army Natick Soldier System Center[a] and actively engaged in research using increasingly sophisticated 3D scanning systems and anthropomorphic modeling to better outfit soldiers and facilitate their missions.

FOXTRAX (1997)

"The FoxTrax Hockey Puck Tracking System" [5] by Rick Cavallaro presents one of the first widely seen commercial applications of augmented reality. Rick and his team at New Corporation's Fox Sports division used specially designed IR beacons embedded in hockey pucks, a grid of sensors over the playing area, and instrumented cameras to track and enhance images of fast-moving, hard-to-see pucks in real-time during hockey game telecasts; see Fig. 2.

I was intrigued by the technology when I first saw it broadcast, then spotted a notice that Rick was giving a talk on their work here in Silicon Valley. I contacted Rick and invited him to write a paper, and he produced this excellent description of their system.

The FoxTrax system was introduced with great fanfare by Fox but was not without its controversies. While viewed as a breakthrough by viewers struggling to follow the puck on their low-def TVs of that era, many hockey purists (a key viewing demographic) viewed it as a distraction and gimmick.[b]

After a couple years Fox stopping using the system, but Rick and his team persevered. The group eventually left to form a separate company, Sportvision. Their next attempt was the virtual first down line for televised football, which became an immediate hit. Versions of this technology have become an integral part of just about every professional and college football broadcast today, and Sportvision went on to become a leader in producing enhanced augmented reality graphics for many other sports.

Figure 2. The FoxTrax system adds a glowing highlight in real-time to a moving hockey puck and "comet tail" to indicate the speed of a shot, also displayed in an inset (lower right). From [5].

[a] usarmygvsc.com/wp-content/uploads/2022/06/Highly-Reclined-Seat-CAD-Accommodation-Model-Verification-Plan-28Apr22v1.0-DISTA.pdf

[b] wikipedia.org/wiki/FoxTrax

DANCE (2005)

The article "Applications of Computers to Dance" [6] by Tom Calvert and colleagues described their work enabling visualization of dance movements transcribed into Labanotation, a system for analyzing and recording human movement developed by Rudolf von Laban in the 1920's. The paper includes a summary of Labanotation itself and an overview of multiple tools for using it to enter and edit single and multiple dancer choreography.

The paper featured the group's development of "LabanDancer" (Fig. 3), an application that generates animated dance sequences from dance scores captured in Labanotation. The LabanDancer application facilitated control over deformable polygon mesh models and underlying hierarchical skeletons driven by a Labanotation score. Multiple dancers can be viewed simultaneously and from multiple angles. Users can view the dance animations in real-time, slow-motion, or backwards and forwards to examine nuances in the motion sequences. LabanDancer helped address the needs of the many dancers and choreographers who were not fluent in Labanotation itself.

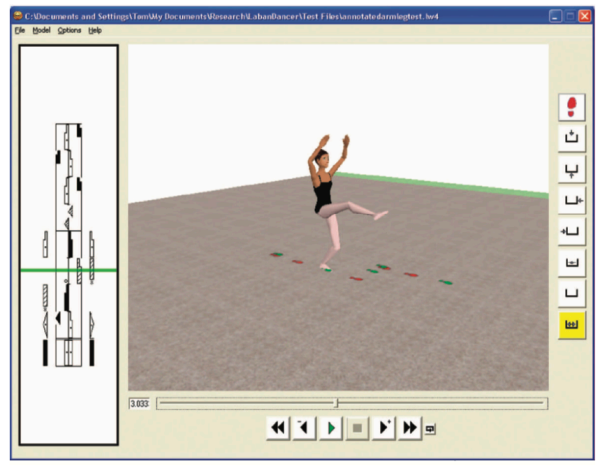

Figure 3. LabanDancer permits interactive viewing of dance animations generated from choreography captured in a Labaonotation score. From [6].

Tom Calvert enjoyed a 45-year career at Simon Fraser University where he made significant contributions to the study of human figure animation, multimedia, and human computer interaction, eventually becoming a Professor Emeritus. Sadly, Tom passed away in 2021[c] but his contributions to the study of human motion live on.

HUMPBACK WHALES (2006)

"Visualizing the Underwater Behavior of Humpback Whales" [7] was an article by Colin Ware and colleagues at the University of New Hampshire and the Stellwagen Bank National Marine Sanctuary. Their paper described their use of acoustic tags for tracking and digitally recording humpback whale movements.

Each tag device included a 3D accelerometer, a 3D magnetometer, a pressure sensor, and an acoustic hydrophone for listening to the whales.

[c] sfu.ca/siat/news-events/news/2021/10/in-memoriam--tom-calvert.html

The tags used suction cups to attach to the whale which released after some number of hours of recording, floating to the surface for retrieval. The tags captured elaborate multi-track recordings of whale behavior, most notably the complex and varied foraging and surfacing patterns employed by the whales as part of hunting and feeding; see Fig. 4.

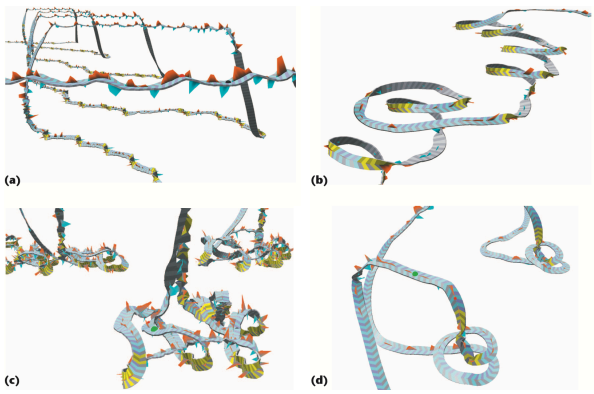

Figure 4. Visualizations showing humpback whale foraging behavior including multiple swimming patterns of both individuals and groups. From [7].

To explore this data, the team developed an interactive visualization application "GeoZui4D" for navigating through the time-varying, multi-track, geospatial data, synchronously displaying patterns of motion of the whales as well as ships in the area.

Colin Ware is still at the University of New Hampshire as a Professor Emeritus[d] where he continues his involvement with the Data Visualization Research Lab in the UNH Center for Coastal and Ocean Mapping.

MUSEUMS & GALLERIES (2006)

The article "Interactive Tabletop Exhibits in Museums and Galleries" [8] was written by Tom Geller, a freelance technology writer located in San Francisco. In its earlier days, the Applications department was envisioned as also including directed articles such as this one to cover developing areas and timely topics.

Figure 5. Interactive tabletop museum display system tracks visitors with IR cameras to control projected works from the museum collection. From [8]. (Courtesy Indianapolis Museum of Art, Pervasive Technology Labs at Indiana University).

In this case, I had been contacted by Sheelagh Carpendale at the University of Calgary who was a Guest Editor for the September 2006 *CG&A* special issue "Interacting with Digital Tabletops". Computer-based museum and art exhibits were in active development around the world, and Sheelagh felt their theme issue should have an article on the emerging use of interactive "horizontal" displays at such venues. She knew of multiple installations in places like the Museum of Modern Art in New York and the Indianapolis Museum of Art (Fig. 5), but they hadn't received any submissions specific to this use case and asked if I could help. Given the short deadline, I contacted Tom Geller, with whom I had previously kicked around ideas for possible articles, and he agreed to take it on.

[d] ccom.unh.edu/vislab/people/colin_ware/

Tom did a fine job chasing down content from Sheelagh's many leads and finding more. Over the next few years, he wrote other articles for the Applications department (see below). Tom is still very active, having relocated to the Netherlands where he has developed a series of LinkedIn Learning courses on technical writing and communications skills[e].

GEOWALL (2006)

"GeoWall: Stereoscopic Visualization for Geoscience Research and Education" [9] was a paper by Andy Johnson at the University of Illinois Chicago (UIC) with colleagues at the University of Minnesota and University of Michigan. It was originally submitted to the special July 2006 *CG&A* theme issue "Exploring Geovisualization." That theme issue had a wealth of submissions, so Guest Editor Theresa-Marie Rhyne (also our long-time Department Editor for "Visualization Viewpoints") recommended this paper to me. Andy was happy to revise his paper for the Applications department and it appeared a couple issues later.

The paper featured the GeoWall project originally developed at UIC, then replicated at multiple other institutions under the umbrella of the GeoWall Consortium. It was available in two variants: a stereo projection GeoWall and a non-stereo large-scale GeoWall-2 (Fig. 6). Andy's 3 coauthors reflected on the GeoWall installations at their different institutions, representative of over 500 GeoWall installations that had by then been installed for both education and research purposes.

Figure 6. GeoWall 2 uses an array of LCD panels driven by PCs as a high-resolution interactive environment for large format geovisualization. From [9]. (© 2005, used with permission of the Electronic Visualization Lab, Univ. of Illinois Chicago and the GeoWall Consortium.)

Andy Johnson has had a long, distinguished career as the Director of UIC's Electronic Visualization Laboratory and just retired this summer. He tells me that at the high-water mark, about one third of all undergraduate earth science students in the US were using a GeoWall in their coursework.

EVACUTION PLANNING (2008)

"Using a Game Engine for VR Simulations in Evacuation Planning" [10] by Antônio Carlos A. Mól and colleagues at the Comissão Nacional de Energia Nuclear, Brazil described their use of an Unreal game engine for virtual simulations of emergency building evacuations. Their system took unique advantage of extending Unreal engine classes to model people, building areas, movement, collisions, sounds and alarms, status displays, and controls; see Fig. 7.

[e] linkedin.com/in/tgeller

Antônio and co-author Carlos Alexandre Jorge had originally submitted an earlier draft of this paper to our former "Projects in VR" department, run by current *CG&A* Advisory Council member Larry Rosenblum. Larry thought its application aspect held a lot of promise and suggested that the authors flesh out that aspect of the work and resubmit to me.

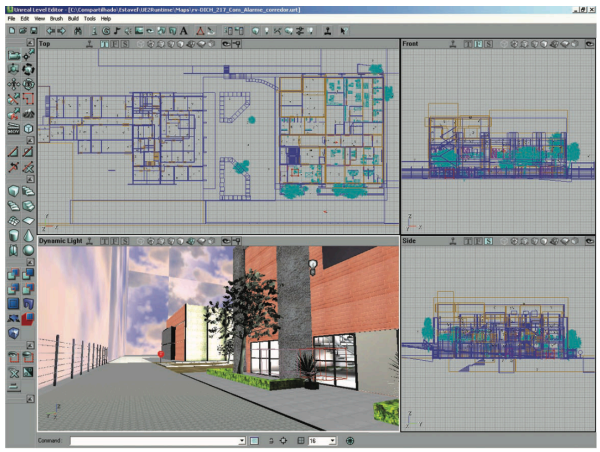

Figure 7. Building models representing complex floorplans are extracted from architectural data then fed into an Unreal game engine. From [10].

The authors demonstrated that it is possible for a game engine to model evacuation scenarios sufficiently well to gain insight to proposed building and office layouts, including key factors such as door and stair locations and dimensions and planning of alternative exit routes. The paper has been cited by facilities designers both for its usefulness as a tool for physical environment engineering as well as for its proof that game engines had evolved sufficiently to be effective modeling tools for addressing real-world problems.

UNCANNY VALLEY (2008)

Next up is "Overcoming the Uncanny Valley" [11] by Tom Geller. After his first successful engagement on the tabletop museum displays article (above), Tom subsequently developed Applications department articles on emerging trends in on-line map sites such as Google, Yahoo, and MapQuest (March 2007) and on-line weather sites such as Weather Underground (September 2007).

Then, in 2008 Tom was floating ideas to me about motion capture and digital actors. I mentioned the controversies at that time about the "uncanny valley", the idea that as digital representations of humans get increasingly close to (but not quite) indistinguishable from reality, their appearance becomes off-putting. That idea intrigued Tom, and he agreed to take on the question of whether it was possible to overcome the uncanny valley problem and indeed how valid it is in the first place.

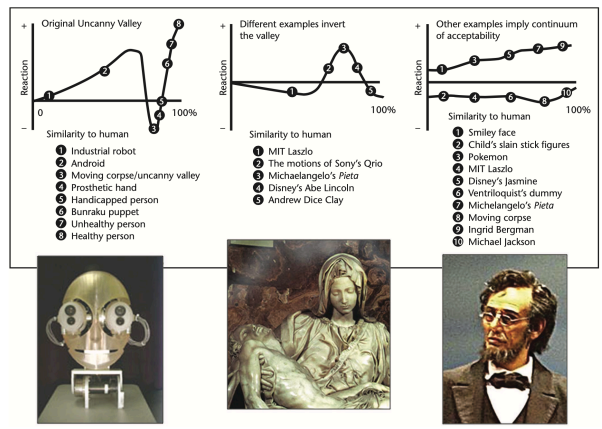

Figure 8. The classic "uncanny valley" concept (left) and two models with seemingly contradictory examples. From [11]. (Originally published in [12], used by permission)

The resulting paper made the case that while there is support for the uncanny valley idea and it does capture a concept that appears helpful in understanding the challenges inherent in photorealism, the concept may well be an oversimplification and has limits; see Fig. 8.

Perhaps because the article was timely and addressed a topic of popular interest and debate, it became the second-most cited article in the 30 years of the Applications department.

MEDICAL IMAGING (2009)

The paper "Voreen: A Rapid-Prototyping Environment for Ray-Casting-Based Volume Visualizations" [13] by Jennis Meyer-Spradow and colleagues at the University of Münster, Germany, presented a volume visualization toolkit for prototyping visualization approaches to understanding 3D medical imaging data. CT and MRI volume images data sets are notoriously difficult to dissect appropriately for different medical diagnostic tasks. The Voreen system was built around an interactive environment in which modular data flow networks allow configuration of volume ray casting techniques tailored for different diagnostic visualization needs.

This paper arose from Jennis's Ph.D. work on an architecture for volume rendering software, and an early version had been submitted for consideration as a regular paper to *CG&A*. The initial reviewer feedback suggested there were really two different directions represented in the initial submission and advised separating those out. Associate Editor-in-Chief for general submissions (and later EIC) Miguel Encarnação thought a paper focused on the design elements of the system useful to practitioners would fit especially well as an Applications paper and encouraged Jennis to contact me.

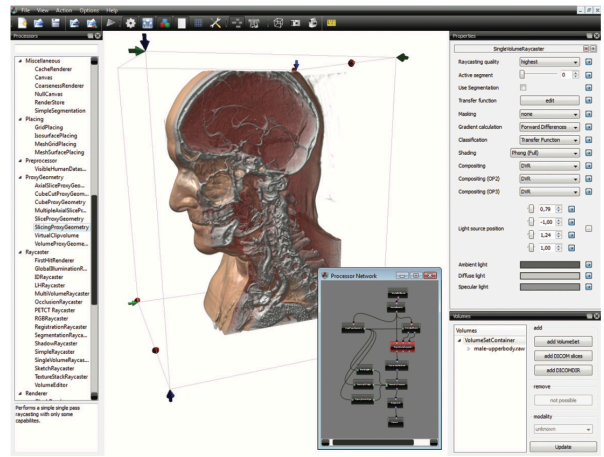

Figure 9. The Voreen volume-rendering engine is a modular rapid-prototyping environment for designing ray-casting data-flow networks tailored to different medical diagnostic objectives. From [13].

Jennis and colleagues did a fine job deriving a paper built around the application examples from their original work, illustrating the flexibility of their system to compose different volume rendering processing steps adapted for diverse specialized diagnostic problems; see Fig. 9. The result became the third most-cited paper in the Application department's 30-year history.

AIRCRAFT MAINTENANCE (2011)

The paper "Augmented Reality for Aircraft Maintenance Training and Operations Support" [14] by Francesca De Crescenzio and colleagues at the University of Bologna, Italy, was also referred to me by Miguel Encarnação who encouraged the authors to submit their work to the Applications department. Their study presented a real-time augmented reality system that could map and label live images of aircraft systems such as engines, fuselage, and cockpit matched with information extracted from manufacturer flight and maintenance manuals.

A key feature of the system was that it supported markerless camera pose estimation and worked with ordinary manufacturer manuals, hence could readily be used in everyday civilian and commercial aircraft maintenance provider applications; see Fig. 10. An easy-to-use graphics authoring system facilitated entry of aircraft details and maintenance procedures. The paper included a validation study of their prototype and assessed efficiency and usability when working on different aircraft under varied lighting conditions performing a variety of tasks.

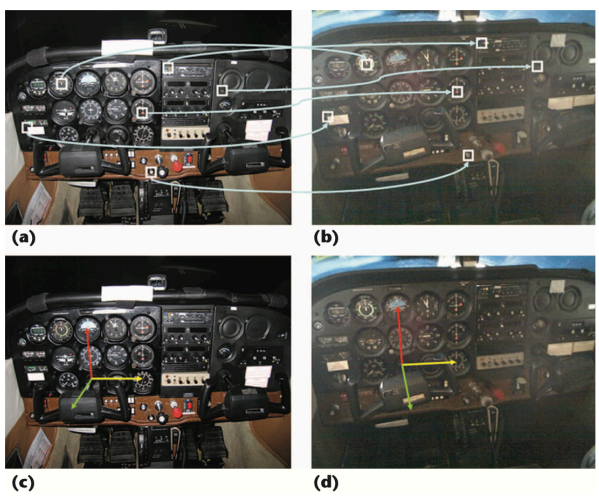

Figure 10. AR system matches features (top row) and camera pose coordinate systems (bottom row) between a cockpit reference images (left) and real-time camera images (right). From [14].

The authors expressed hope that demonstrating the effectiveness of their system would help overcome the skepticism at that time about AR in the real-world aircraft maintenance community. They have validation in the fact that this article became the top cited paper over the 30-year history of the Applications department.

REHABILITATION (2019)

"Using Virtual Reality to Increase Motivation in Poststroke Rehabilitation" [15] was an article by Paulo Dias and colleagues including co-Department Editor of *CG&A*'s Education department Beatriz Sousa Santos at the University of Aveiro and the Hospital Rovisco Pais in Portugal.

Paulo and Beatriz had published previous articles in the Applications department on visualizing landfill contamination in 2014 and another on 3D craniometric skull modeling in 2015, so I was happy to receive this submission describing their latest project.

The premise of this article is that VR has multiple characteristics well-suited to neural rehabilitation applications including intensity, task-oriented training, biofeedback, and motivation. The authors built their system around a series of mini-games mirroring real-life situations that would help patients reacquire basic motor and cognitive capacities; see Fig. 11.

Figure 11. Virtual reality workstation used for poststroke rehabilitation with computer, monitor, speaker, Oculus Rift HMD, and Leap Motion Controller. From [15].

The paper presented both their detailed system design and results from a study with patients, confirming many of the anticipated benefits but also identifying areas where the technology and implementations could be further developed. This paper is notable for the number of citations it has received in just a handful of years, indicative

of the interest in VR as an engaging application technology.

METRICS

It is interesting to look at how the Applications department has evolved over the thirty years, as represented in the following tables.

Table 1. Per article metrics over each decade of the Applications department.

Per article	1st decade	2nd decade	3rd decade
Words	3695	3715	4565
Pages	5.4	6.6	8.6
Figures+Tables	8.4	13.0	14.9
References	0.8	4.2	12.0
Citations	21	40	13
Downloads+Views (since 2015)	239	525	610

Article size. Applications department articles have grown in size over the three decades from about 3500 to about 4500 (total) words each and from 5-6 pages to 8-9 pages each, on average. This is consistent with *CG&A*'s intent to keep departments more compact and easier to digest. The typical number of figures and tables have almost doubled over that time to meet a desire for more visual content. References were somewhat discouraged in the early days to keep articles more accessible, and often incorporated instead into sidebars (not counted here), but have since grown to about a dozen per article.

Citations. The number of citations per article (here based on Google Scholar data) is of course a widely recognized way to measure the impact of technical and scientific papers. There is much debate as to how many total citations is significant for published papers, but there is data that says 10 or more citations places a paper in the top 24%, and 100 or more citations gets to the top 1.8%[f]. By this standard, the Applications department papers stack up well, averaging about 25 citations per paper over all 181 papers published. Moreover, each of the 11 papers featured in this retrospective have received over 100 citations, with the top cited article over 300 times.

The lower citation value for the last decade appears to reflect that citations are a lagging indicator, given the time it takes for articles to be published, assimilated, and eventually cited in subsequent work, especially in applied science and engineering disciplines.

Downloads+Views. IEEE Xplore Analytics makes available a metric it calls "Usage", capturing the number of times a published article is accessed either by downloading the PDF or reading the article on-line in HTML. In contrast to citations, this number shows no lag at all in the department's third decade. Recall also that Xplore only reports downloads and views that have occurred since 2015, so we see that even the articles published in the first decade ending 2004 continue to get ample downloads and views.

Authors and Countries. Table 2 shows the collective number of (unique) authors for all the articles in each decade in addition to how many different countries they are from. In the first decade, 45 different authors accounted for the 61 papers, about 40 of which were written by a

[f] lucbeaulieu.com/2015/11/19/how-many-citations-are-actually-a-lot-of-citations/

dozen individual freelance writers or IEEE staff. In the subsequent two decades, with almost all papers written by submitting authors, the papers have come to average 3-4 authors per article.

As to countries represented, the first decade featured articles from only 7 different countries, with half of them articles by authors in the US. This imbalance has changed substantially, indeed in the last decade the 60 papers were written by authors based in no less than 26 different countries.

Table 2. Authors and countries over each decade of the Applications department.

Total	1st decade	2nd decade	3rd decade
Authors	45	180	243
Countries	7	21	26

How Big is Big? We can take some measure of the whole 30 years of 181 Applications department papers by comparing to a large well-known written work, Tolstoy's *War and Peace*, see Table 3.

Table 3. Comparison of Applications department to Tolstoy's *War and Peace*.

Total	Applications department	*War and Peace*
Words	722,212	587,287
Pages	1239	1225
Authors	458	1
Countries	30	1
Downloads+Views vs. Sales	82,668 (since 2015)	36,000,000 (since 1868) in Russia alone[g]

During its 30 years, the Applications department has amazingly enough published 14 more pages than *War and Peace* and about 135,000 more words. Of course, that is the work of 458 different authors from 30 different countries, versus one very prolific Russian author. And the Applications department's tally of downloads and views is impressive until it is compared with the 36 million print copies of *War and Peace* sold in Russia alone since 1868, so we have a way to go.

CONCLUSION

I often say the Applications department is the easiest *CG&A* department to source, given that it basically covers using any computer graphics technology to address any real-world problem. It also helps that "Applications" is right there in the *CG&A* name. But what I know for sure is that it would not have been successful without all of the authors and the readers who have found their way to these pages over the years. Let's hope for many more.

ACKNOWLEDGMENTS

My thanks to Cathy Frantz for her assistance in developing the statistics and reviewing content for this article. The Applications department would not be possible without the efforts of IEEE staff, fellow *CG&A* editors, and the many authors who have shared their work with us, I thank them all.

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