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DEPARTMENT: GRAPHICALLY SPEAKING

Computer Graphics: From Research to Commodity to New Highs

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Dear readers, I have been heading the Department Graphically Speaking for seven years now, and, this month, for the first time since starting this position, I would like to take the opportunity to write a "column" myself.

Some eight years ago, my Ph.D. father, Jose Luis Encarnação (see Figure 1), who is about to turn 80 at the time of writing this article, approached me whether I would like to take over the responsibility for one of the departments of IEEE CG&A. Of course, I felt honored and accepted the possibility offered by IEEE CG&A.

I first met Prof. Encarnação as a student in 1990. As you can guess, I belong to that generation playing with Atari and Commodore computers in the 1980s and enjoying movies like *Tron* as a teenager. Thus, I have had the "computer graphics virus" from that time ever since. Today, besides trying to take care of interesting articles in this department, I am heading the Competence Center for Interactive Engineering Technologies at Fraunhofer Institute for Computer Graphics Research (IGD), Darmstadt, Germany, and have an honorary professorship at Technical University Darmstadt. From the title of the competence center, you can probably infer that our research is more directed toward industrial applications of computer graphics than toward games and movies—I will touch on this later.

Once IEEE CG&A accepted the proposal to handover the GS department to me, I started to arrange things for a Special Issue on Computer Graphics and Industry 4.0 because of the proximity of this topic to my background and research interests. Since then, 30 articles (see Figure 2) have been published in Graphically Speaking ranging from Cultural Heritage to new display technology to VR for better health and environment to information visualization technology for journalists—not to forget parts of the series on Beautiful Math. In many cases, these articles have been collaborative efforts between the authors—them doing the major part of the work—and the editor/coeditor (Rahul Basole joined forces with me as a coeditor of this department a few years ago) guiding the authors to shape their articles and ideas to best fit with the goals of Graphically Speaking.

Graphically Speaking seeks articles that communicate the possibilities and importance of computer graphics techniques to help create and gain insights into processes and phenomena otherwise hard/much harder to grasp. We, the editors, are interpreting this goal pretty flexibly not binding it to "just" visualization. We also like to open the research community to certain trends and developments and try to find papers that underpin the need for new research in certain directions; for example, we had articles trying to push synergies between InfoVis and 3-D SciVIs and a contribution pushing for more research into homogenized representation schemes for geometric modeling and physics-based simulation.

Anyway, after roughly seven years, I thought it may be a good point in time to reflect on where I think computer graphics is coming from and where it is heading. Most of the readership knows where it is coming from and where we are today with computer graphics, so I do not strive to summarize this in an exhaustive manner, but rather I would like to share an anecdote with you. As a young professional—it must have been in the first half of the 1990s—I was asked where I thought CG would go, since I worked at "that" institute. Well, I answered "3-D will become ubiquitous." Remember at that time most CAD workplaces and systems still rendered 3-D models as line drawings—at the same time, "we" were developing VR systems and had 3-D face scanners in our labs. It probably did not take much imagination to envisage that this type of 3-D would become more usual for desktop workstations than the dominant line

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FIGURE 1. Jose Luis Encarnação, my Ph.D. father, and me at my Ph.D. celebration, September 2000.

drawing mode. But was I imaginative enough to think that 25 years later we would carry around our 3-D face scanner with our smartphones? Well, no, certainly not.

So, has computer graphics become a commodity? To a certain extent, it surely has. But has it matured to an extent where research in computer graphics is becoming increasingly irrelevant? No, definitively not.

Today, images that are hardly distinguishable from photographs—if at all—can be generated and AI is further enhancing this realism. However, it takes considerable amounts of time to collect and prepare the needed information and models to render realistic images. Today, photo-realistic rendering still approximates the physics of light matter interaction—increasing the frame rates usually implies compromises with respect to approximation accuracy. However, computer graphics has come so far in terms of visually believable results that new research fields have developed exploring ways for detecting fake imagery.

So, undoubtedly, computer-generated imagery surrounds us and can be found almost everywhere: in movies, games, advertisements (also in their printed form), at work, at home when using our coffee machines and touching their interactive displays, etc. Display technology and affordability is another large contributor to computer graphics becoming a commodity. After all, never before has a new display technology for TVs become so affordable in such a short time as when OLED was introduced. We now have displays almost everywhere in many form factors, and it is safe to assume that we will have more and more of them. We have small e-paper displays in grocery stores that show the prices of goods, their contents being centrally controlled and changeable at will; we have displays in our smartphones, lately flappable and soon bendable and extendable; we have displays in our laptops, recently even more than one, and so on and so forth, and we have larger and larger screens, e.g., in stadiums. Cars are an obvious example for how fast the display sizes grew over the past few years, lately spanning the whole dashboard and soon to be found almost everywhere in the interior. As soon as cars will drive fully autonomously, we will have in-car entertainment for all passengers, not just on small displays in the back of the headrest of the front seats but maybe even the windows can turn into displays when desired as well. Display technology influenced and will further influence lighting systems of cars since it helps achieve better illumination, projection of hints onto street surfaces, etc.—might this become unnecessary by fully autonomous driving cars? Anyway, criticism has been voiced concerning touch displays in cars particularly and with respect to compromising haptic feedback and operation in general while the driver's eyes (are supposed to) stay focused on traffic. Displays incorporating haptic feedback and/or form-changing displays may overcome this in the future, a future in which cars may even change their outer color at will, applying display technology or metamaterials.

Talking about displays and real 3-D rendering, 3-D printing can also be considered a display device, displaying/rendering an object physically. Computer graphics heavily contributed and will continue to contribute to the advance of 3-D printing technology, especially when multicolor becomes important. The research of a colleague of mine at Fraunhofer IGD allows him to 3-D print irises for eye implants visually indistinguishable from the healthy eye much more efficiently than today's manual artistic painting process (see Figure 3). Multimaterial and multiproperty 3-D printing will pose the next challenge to the entire digital pipeline from designing to simulating to actually 3-D printing an object with locally varying functions in a reliable, robust, and repetitive manner. For this end, cross-discipline research is needed spanning computer graphics, material sciences, numerical computation, mechanical, and production engineering to render the new dimension of flexibility manageable for human beings and allow them to master it—the dimension that not only allows for almost arbitrary shapes, such as single-material 3-D printing, but for locally varying shapes and material choices. The process of mastering this flexibility and, thus, complexity may also benefit from incorporating AI as some of the research in this field already indicates.

These additional degrees of freedom require a lot of computational power, probably new data structures/representations schemes and algorithms as well. While high-performance computing is becoming more and more accessible via cloud providers,

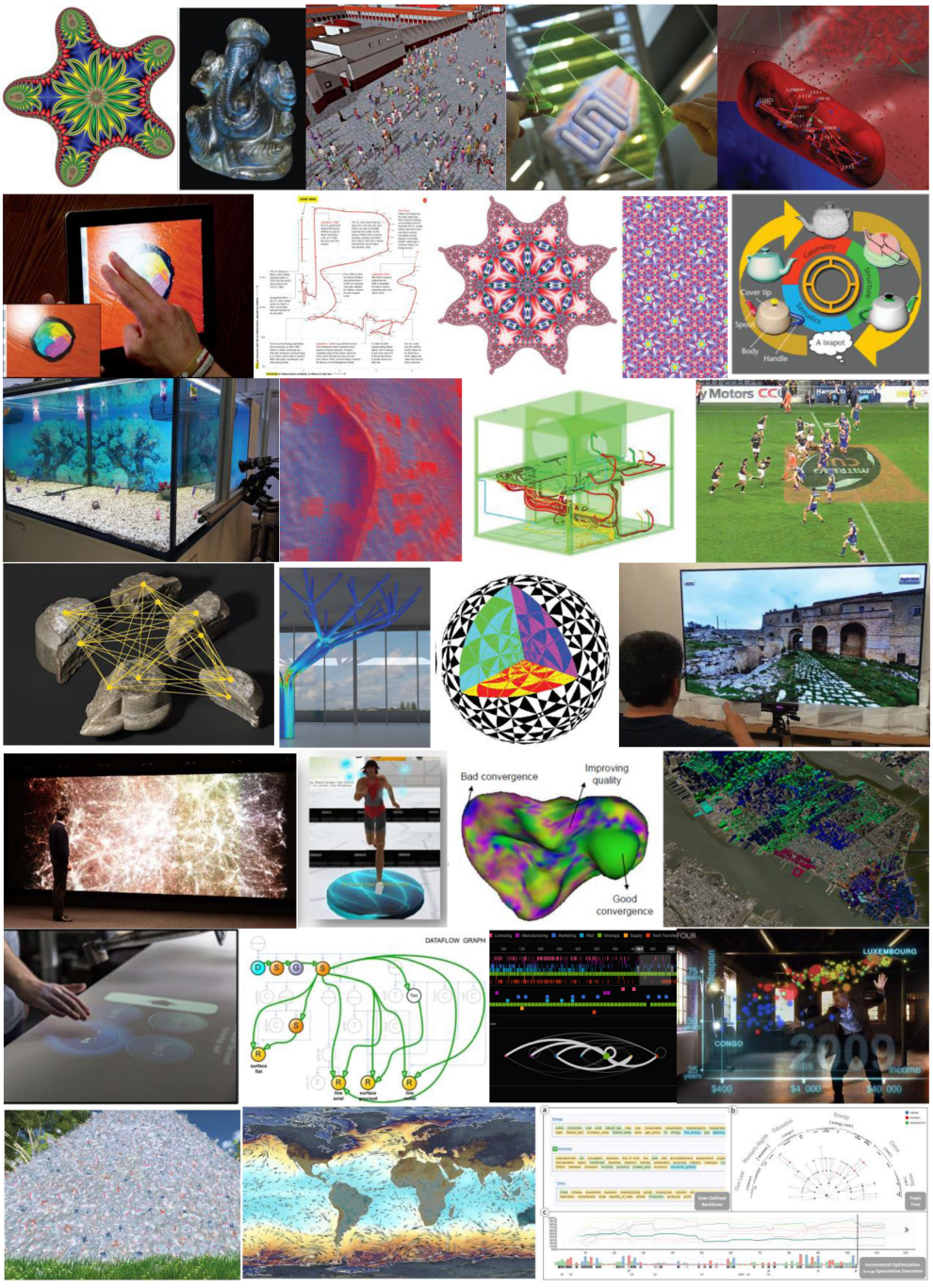

FIGURE 2. Collage of pictures from the GS articles since March 2014.

quantum computing promises to be the next big thing for certain types of problems that go beyond what we can—economically or not—calculate today. Quantum computing poses new challenges on how to formulate algorithms—to some extent, GPUs posed challenges on how to form an algorithm so as to best exploit their parallelism—and, currently, quantum computers are only understood by a very limited set of researchers in this filed. Computer graphics and visualization research can not only help to better understand QC but also allow developers of algorithms for quantum computers to gain insight into and further improve exploiting the capabilities and promises of QC.

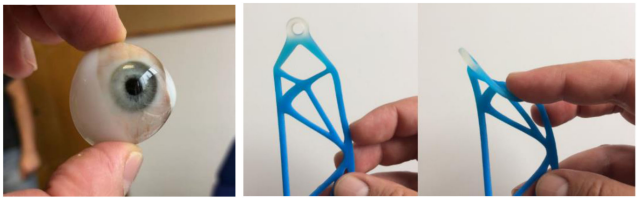

FIGURE 3. Left: 3-D printed iris. Right. 3-D printed multiproperty parts (copyright Fraunhofer IGD).

Dear readers, let me now try to start to conclude. I have touched on some of the developments computer graphics has seen as well as current and future applications—I have, of course, not touched on all that would be beyond the limitations of this article. I have also tried to convey and confirm what the editors of Graphically Speaking want articles in this department to communicate: computer graphics as a tool to help humans better understand and adapt to phenomena—first and foremost in interactive settings. I spanned research and applications from 3-D capture over modeling, simulation, and 3-D printing to opportunities for computer graphics to help better understand quantum computing.

FIGURE 4. Single-plastic bottles consumption in a week versus 1000 people consumption in one year. Source: GS article in issue no. 5 from 2020 (Giulia Wally Scurati and Francesco Ferrise, "Looking Into a Future Which Hopefully Will Not Become Reality: How Computer Graphics Can Impact Our Behavior—A Study of the Potential of VR," Politecnico di Milano.).

Probably the biggest challenge we have at our hands is to evolve computer graphics and interactive techniques so that they "speak" to us in a comprehensive and convincing way, with the hope that in so doing we can influence and change human behavior in a positive manner. I started this article by referring to Jose Luis Encarnação who was also engaged in narrowing down the digital divide. As computer graphics is a digital technology, it does not mean that it automatically contributes to the digital divide; actually, it can be shaped in a way to contribute to the opposite, i.e., to minimize the divide. It can do so by showing what the consequences of our current habits are and it can possibly trigger change in our behavior.

Lately, we have seen a few articles on research that does not just want to gain insight into some subject by applying computer graphics, but which strives to trigger change in human behavior, such as change for better health and for greater sustainability (see Figure 4). To this end, graphics have to speak to us, speak in a visually obvious way, and speak to us in a convincing way.

While we do not want to limit Graphically Speaking to articles of this kind (as should have become clear from this article, there are plenty of areas relevant to Graphically Speaking), we would like to encourage the CG community to explore the latter direction more actively.

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