40 Years of Computer Graphics in Darmstadt
Computer Graphics “Made in Germany”

Darmstadt, the leading “Computer Graphics and Visual Computing Hub” in Europe: The way from 1975 to 2014

J. L. Encarnação, D. Fellner and Ch. Hornung

Interactive Graphics System Group (TUD-GRIS) Technische Universität Darmstadt, Germany http://www.gris.tu-darmstadt.de

Abstract

The paper reports on the 40 years of development of Computer Graphics and, more recently, Visual Computing at the Technische Universität Darmstadt in Germany, from its beginning in 1975 to the leading “Computer Graphics and Visual Computing Hub” in Europe as of 2014. This development is described along three axes. First, the institutional development and its rational to establish Computer Graphics as a discipline of Computer Science and as an enabling technology for developing our Knowledge Society, are described. Second, the scientific and technological impact based on the teaching activities and the large number of theses submitted in Darmstadt for the area during these 40 years are addressed. Finally, the research road maps of the Computer Graphics and Visual Computing Hub in Darmstadt are presented relatively to the different stages of CG and VC research, relatively to a scientific view to the large number of projects implemented over these 40 years and finally, also relatively to the project results as seen from the media. In order to manage the quantity as well as the complexity of the information available the description of these road maps is divided in four time periods: 1975–1984, 1985–1994, 1995–2004 and 2004–2015. The paper also gives the view of the authors on how they see the future of Computer Graphics and Visual Computing. At the end, the paper includes an extensive list of references for the reported content.

Keywords: ”Computer Graphics Hub” in Darmstadt, Computer Graphics in Germany, Computer Graphics in Europe, Trends in Visual Computing, Trends in Computer Graphics and Visual Computing

1. Introduction

Computer Graphics activities started in Germany around 1965, based on the development of display systems by the companies AEG-Telefunken and by Siemens and also based on the work by some university groups that wanted to do computer-aided circuit design and automotive design, and by others that were working on medical visualization. This work was quite similar to what was, those days, being developed in USA at MIT by I. Sutherland with the Sketchpad Project and also at the University of Utah [1]. Another development at that time was the evolution of displays from vector display to storage tube displays and finally to raster display technology [2]. This work was also being undertaken in Berlin since 1967 at the Heinrich-Hertz-Institute under the leadership of Wolfgang Giloi [3]. Two of his Ph.D. students working in these early Computer Graphics projects were J. Encarnação (one of the authors of this paper) and W. Straßer. These were some of the early activities in Computer Graphics in Berlin; they somehow represent the “infancy“ of this technology in Germany (Figure 1). Computer Graphics was in the sixties and early seventies still far from being widely and well accepted as a core discipline of the emerging Computer Science. In 1968, the German Federal Government started a large program to establish Computer Science as a department in German universities. The program was called ÜRF (Überregionales Forschungsprogramm Informatik) [4]. The program was offering federal funds to start Computer Science departments based on a choice of chairs out of a core of fourteen chairs, representing the emerging main disciplines of Computer Science. Examples of these disciplines were automata theory and formal languages, programming languages and compilers, computer architectures, operating systems, data bases and others.

But Computer Graphics was not explicitly one of them. Nevertheless, in order to be open for special local interests, in the list of disciplines to be established there was a “slot number 9” in the program for “computer-aided applications”. The universities had to develop their own priorities and to make a choice for the disciplines they wanted to bootstrap and get funded based on the ÜRF-Program. Three professors decided to use the “slot no. 9” to establish Computer Graphics in their universities ; these professors were W. Giloi (Berlin), G. Hotz (Saarbrücken) and R. Piloty (Darmstadt). This opened the opportunity to develop Computer Graphics to a discipline of Computer Science in German universities. But at first Computer Graphics had

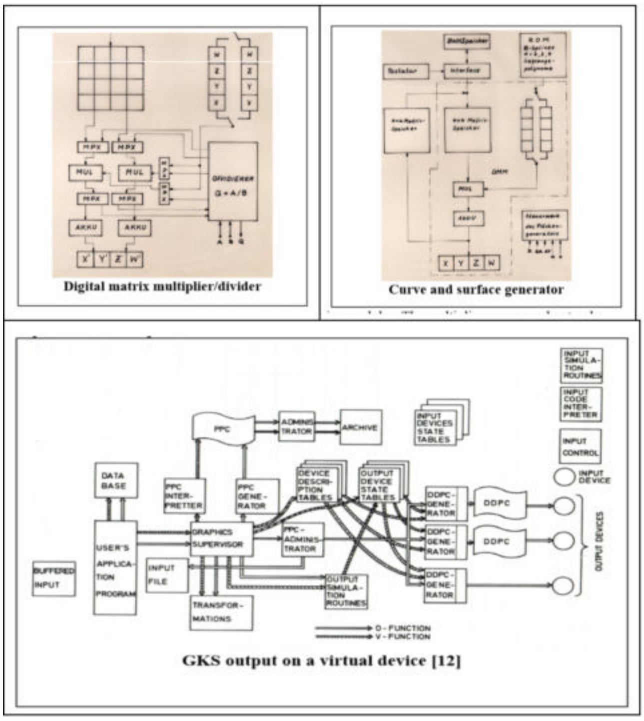

Figure 1: Examples of CG Research in Berlin (ca. 1965)

to be established and accepted by the universities and by the academic community as one of the core disciplines of Computer Science. This was the big challenge at this stage. In this paper the authors describe how this process was successfully implemented in Darmstadt at the Technische Universität Darmstadt (TUD) after J. Encarnação assumed the position as professor for Computer Graphics in 1975 and started the group on "Graphisch- Interaktive Systeme" (Interactive Graphics Systems Group, abbreviated as TUD-GRIS). D. Fellner joined the TUD and the TUD-GRIS group as professor for graphical interactive systems in 2006. The authors share their "contemporary witnesses" for this process. This is the base for this paper. The paper describes the roadmap and the development of Computer Graphics in Darmstadt to the leading "Computer Graphics Hub" in Europe under the leadership of the authors: J. Encarnação (1975–2006) and D. Fellner (2006–2014). D. Fellner describes in the last chapter of this paper also his views and his forecast for the future of Darmstadt as the "Computer Graphics and Visual Computing Hub" in Europe (2014++).

2. Computer Graphics in Darmstadt (1975–1984)

The first task was to establish Computer Graphics in the teaching and research of the newly established Computer Science department by giving classes, by attracting students and by starting first research projects. The first classes addressed the following topics:

- Computer Graphics I (systems, hardware, peripherals)
- Computer Graphics II (math, algorithms, data structures)
- Computer Graphics III (interaction and dialogue programming)
- CAD (engineering applications)
- Technical communication
- Image processing and image analysis
- CG peripherals

These classes followed a German text book first written by Encarnação [5-7] and the standard text book of those days by Foley and van Dam [8]. Wolfgang Straßer joined the group as full professor in 1978 and from then on shared the class delivery with Encarnação. The teaching concept and the offer of classes arose from the understanding that Computer Graphics was based on basic knowledge specific to the area (hardware, software, algorithms, data structures, etc.) but also on its interface to the systems being used (technical communication) and to the images being shown on the display (image processing and image analysis; this would be called today "Visual Computing"). The CG peripherals (for input, for output and for interaction) were the topic of a special class. After two cycles, the classes had a large number of under-graduate students participating, from 150–200 students in CG I to 15–20 students in CG peripherals. This was a good starting basis. On top of that, after few years, about 20 Students were working on their B.Sc. or M.Sc. thesis. This was additionally a good start for doing local research. As stated above, the TUD-GRIS group [9] was reinforced in April 1978 by a second professor position, which was assumed by Wolfgang Straßer. He moved in September 1986 to Tübingen to assume the position as full professor there and start at the University of Tübingen his own new group in Computer Graphics. This group is an important pillar of the development of Computer Graphics in Germany and in Europe.

2.1. Standardization Activities

The most important scientific activities where in the area of standardization of graphical systems, leading to the Graphical Kernel System GKS. At the time when a SIGGRAPH group undertook first activities towards the CORE standard, European researchers, members of the Eurographics, and Industry representatives defined the first ISO-standard for device-independent graphics programming. GRIS had a leading position in this standardization activities. The results of the research at GRIS have led to the founding of GTS/GRAL, providing the first commercially available GKS-implementation. Moreover, a first version of a graphics hardware "GKS on chip" has been developed at GRIS.

2.2. Infrastructure

Since 1975, GRIS was the leading institute for Computer Graphics combining the most innovative infrastructure available on the market (Figure 2). First to mention here is the VARIAN/IDIIOM system, the first commercial available CAD-system. With ICAL-PERQ, the first raster workstation was available, where first research activities in the area of raster

Table 1: The development of TUD-GRIS from 1975–1984

	1975	1981	1984
Professors	1	2	2
Permant	3	5	7
Projects	0	9	16
Scholarships	0	3	4
Visiting Researchers	0	5	8
Infrastructure	2	4	5
Total staff	6	28	42

graphics for GKS were undertaken. Research activities in the area of optical videodisc technology (the predecessor of CD-ROM and DVD) were undertaken based on the Telefunken 1005 device. Research in the area of high-performance 3D visualization was undertaken based on an Evans & Sutherland ESV/50, the leading edge 3D-graphics workstation at that time.

The development of the Group TUD-GRIS (1975–1984) [9] is described best by the following figures (Table 1).

Based on these numbers and on the fact that, at that time, some of the research in Darmstadt was already strongly application and market oriented, there was a need to have an effective link to industry. Such a link was needed to guarantee industrial matching funds for research projects funded by the German research ministry (BMBF and BMWI) and by the European Union (EU), or to open opportunities for doing projects directly linked and funded by industry. Therefore in 1984 an industrial association was founded and associated to TUD-GRIS as a non-profit organization. The founding members were TUD-GRIS and the companies ARISTO, GTS/GRAL, ISSCO, SEL, Siemens and Tektronix. It was the mission of this organization, called ZGDV (Zentrum für Graphische Datenverarbeitung e. V.) [10], to support and lobby Computer Graphics, specially in Germany, as a discipline and as an enabling technology. In 2014, the ZGDV celebrated 30 years of existence; today, the focus of its activities is to be a platform for different types of forums in the domains of Computer Graphics (users, applications and technologies). These forums operate in close co-operation with TUD-GRIS and with Fraunhofer IGD.

With the research group (TUD-GRIS) being well established in the Technische Universität Darmstadt, with the link to the industry based on ZGDV, and with the figures reported above (Table 1), enough creditability and strength had been developed to be able to get the acceptance and enforcement of Computer Graphics as an area of priority for funding in research agendas of the German ministries (BMBF and BMWI) and of the EU, and also of the German Science Foundation (DFG). By 1984, this was well established and a solid foundation for Computer Graphics not only in Darmstadt but also all over Germany. The resulting impact was the proliferation of Computer Graphics based on a strongly increasing number of chairs in German universities, working in Computer Graphics or in some aspect of it. At national level, Germany, as a long-term result of this, has most probably the largest number of professors in Europe specialized, teaching and doing research in Computer Graphics [11] in the widest sense.

But to establish and assure the future of Computer Graphics as a discipline requires more than just having infrastructures for teaching, research and funding. You need to additionally establish platforms for your experts to publish, to present and communicate their research results and to network with other experts working in the area. You need to develop and customize a review- and peer-infrastructure specific to the discipline, so that careers for its constituency can be developed, promoted, and established. The market for this was existing: the number of university chairs was increasing, more and more companies were offering CG career opportunities in the industry. In order to develop solutions for this purpose, three streams of activities were started.

German Computer Society (GI). In 1983, the Computer Graphics Special Interest Group (Fachausschuss 4.1 "Graphische Datenverarbeitung") was established. J. Encarnação was its Chairman from 1983 to 1992. In 2003, this working group was promoted to a department within the GI [11] with D. Fellner as the founding Chairman (from 2003 to 2014).

EUROGRAPHICS (EG). In 1980, the European Association for Computer Graphics (EUROGRAPHICS) was established. Its mission, scope and purpose were very similar to those of ACM- SIGGRAPH in USA. Both associations have a very close and constructive cooperation from the beginning, yet EUROGRAPHICS stronger aligns its focus, emphasis and priorities with the European Computer Graphics constituency, their interests and activities. J. Encarnação was one of the founding member (he is EG member No. 1) and its chairman from 1980 to 1984 and chairman of the EG Professional Board from 1985 to 1991 [12].

International Federation for Information Processing (IFIP). From a global point of view, this Federation was very important in those days because it organized events (conferences, workshops) bringing together experts from the all over world (West- and East- Europe, Asia, USA, Canada, etc.).

At that time, this was quite a difficult task but also a very interesting and important one because of the strong need for international, global networking in Computer Science and in Information Technologies. J. Encarnação was the German representative to the IFIP TC on "Computers & Industry" and the chairman of the IFIP WG 5.10 (Computer Graphics) from 1987 to 1994 [13]. With these activities a large, high-quality and peer-reviewed program of conferences, workshops and seminars for Computer Graphics was developed at the national (GI FA 4.1), European (EUROGRAPHICS) and the international level (ACM SIGGRAPH and IFIP WG 5.10) where experts could publish and present their research and also network with other researchers working in the same discipline, namely Computer Graphics. One piece still missing in this puzzle to support, lobby and build the discipline of Computer Graphics was to have a well established, peer-reviewed European journal dedicated exclusively to Computer Graphics. Therefore, in 1983 J. Encarnação assumed the position of an Editor-in-Chief for the

Figure 2: Infrastructure of GRIS (1975–2004)

Journal "Computers & Graphics", then published by Pergamon Press, today by Elseviers Publ. Co., and held this position until 2006. Today, the Editor-in-Chief of this journal is Joaquim Jorge from the Technical University of Lisbon (IST) [14]. To establish a discipline it is also needed that the basic knowledge and the main results of the research are documented, structured and digested in such a way that they can be used by the next generations of teachers and researchers in the area. This is usually done by publishing books. Following this strategy, there was a need to start some book series that could also be used as "text books" for the new discipline. Therefore, a contract was negotiated for this purpose with an international prestigious and well established publisher in the area of science and technology, the Springer Verlag (Berlin, Heidelberg, New York). Two lines for the publication of science books in Computer Graphics were developed and established

- Two in German under the responsibility of the ZGDV:
  - Beiträge zur Graphischen Datenverarbeitung (1989 – 1998)
  - ZGDV – Computer Graphik Edition (published by the Fraunhofer in-house publisher "Fraunhofer IRB Verlag"; 1999–2005) [15], and
- A third one in English (Editor: J. Encarnação):
  - Computer Graphics: Systems and Applications (1984 – 1998) [16].

Altogether, more than 50 science books in Computer Graphics were published within these three book series. At this stage, all important "ingredients" to establish the "discipline" Computer Graphics (proliferation of chairs for professors in Computer Graphics, networks based on national and international associations and working groups, peer reviewed journals and publication of a series of books in Computer Graphics) were in place and successfully implemented. By the end of 1984, Computer Graphics was well established and accepted by academia and industry as an important discipline of Computer Science, not only in Darmstadt, but also throughout Germany and in Europe. The results of this period of activities seen from the point of view of TUD-GRIS in Darmstadt are shown in Figure 3.

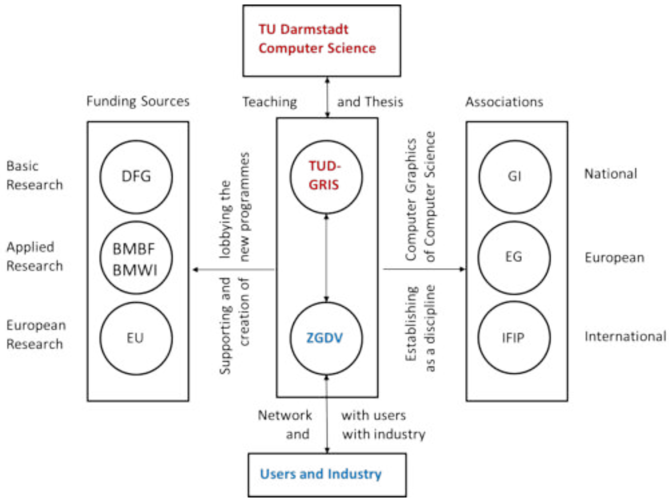

Figure 3: Partnerships and liaisons in the development of Computer Graphics in Darmstadt (from 1975 to 1984)

3. Building Darmstadt as a "Computer Graphics Hub" (1985–1994)

The Fraunhofer-Gesellschaft (FhG) is the largest association for applied, market- and applications-driven research in Germany and in Europe. The FhG has (figures as of 2013) 67 research institutes covering all important areas of science and engineering relevant to the socio-economic development in Europe, specially in Germany. FhG is also active at a global, international scale with different types of research representations (in some other European countries, in USA, in Asia, etc.). In total it has a staff of 23.000 employees and is running on an annual budget well above 2 Billion EUR. The characteristic of FhG is that only 30 % of the budget are publicly funded by the federal government and by the local states (the "Länder"). The remaining 70% are funded by industry and by public research programs in open competition; around 30% of the total budget are funded by contracts directly with the industry [17]. Therefore, it was a major breakthrough for Computer Graphics in Germany and also in Europe, when FhG, attracted by the success of Computer Graphics in Darmstadt (TUD-GRIS + ZGDV), decided

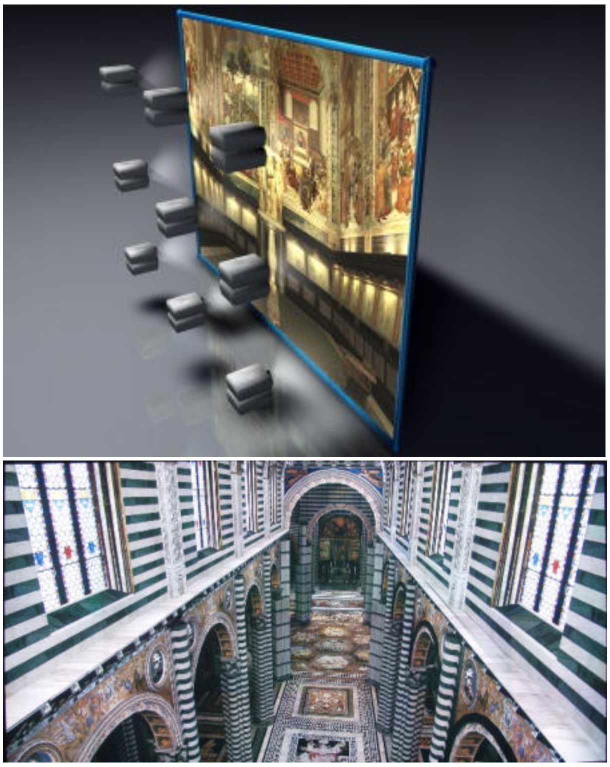

Figure 4: The Darmstadt HEyeWall

Table 2: The growth of IGD (1987-1994)

	1987	1990	1994
Staff	20	60	95
Budget (Mio €)	2.2	4.7	9.0

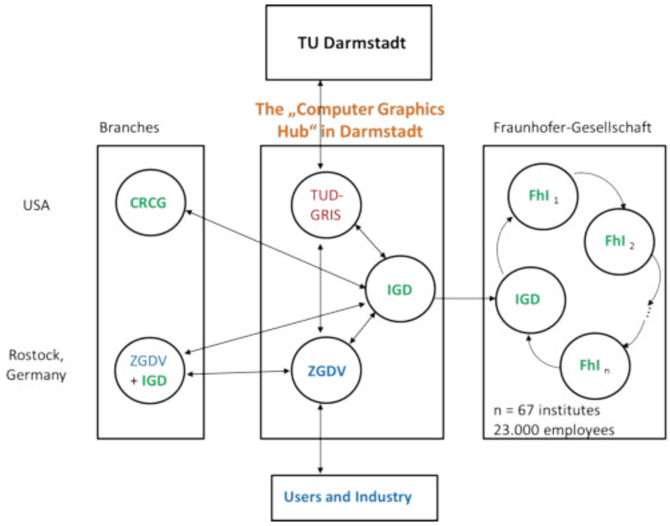

Figure 5: Darmstadt as the "Computer Graphics and Visual Computing Hub" in 1994

to extend its research portfolio to include Computer Graphics. It started negotiations with the State of Hesse, with the TUD and with J. Encarnação on the foundation of a new Fraunhofer institute in Darmstadt with Computer Graphics as its mission, scope and purpose. This institute called "Fraunhofer-Institut für Graphische Datenverarbeitung" (Fraunhofer Institute for Computer Graphics Research, abbreviated "IGD" [18]) started operation in 1987. J. Encarnação was the founding director and remained in this position until he retired from FhG in 2006. D. Fellner assumed the position as his successor in fall 2006.

The Fraunhofer IGD started in 1987 by developing initial activities and research projects in the areas of

- graphics systems
- data structures for graphics and modeling
- raster technologies and processors
- simulation and animation
- graphics in documents
- industrial applications

Examples of these research activities are the first VR lab in Germany as well as the development of different virtual reality technologies, the first 5-sided cave and the HEyeWall, a large projector wall consisting of 8x6 projectors, a resolution of 6.000x3.000 Pixel and a size of 4,8x2,4 meters (Figure 4).

From 1987 to 1994, IGD had a very strong and rapid evolution. This development is shown in Table 2 giving the figures for staff (not including a large number of part-time students working as research assistants and also many visiting researchers including senior researchers and visiting professors coming from all over the world) and budget. The staff consists of about 80 % permanent research employees and about 20 % employees for the infrastructure (secretarial assistants, technicians, programmers).

Encouraged by the successful development of both ZGDV and IGD, it seemed obvious to contribute in a constructive and future-oriented manner to the re-structuring and new formation process of CG activities in the former German Democratic Republic (DDR) after the reunification in 1989. The University of Rostock met all conditions needed to make this possible. In late 1990 the Rostock branch of ZGDV and in January 1992 the Rostock branch of Fraunhofer IGD were founded. In 1991, a small US branch of IGD was started in Providence, Rhode Island, in cooperation with Professor A. van Dam from the Brown University, called Center for Research in Computer Graphics (CRCG). The intention was to come closer to the R&D activities in academia and in industry on the US market [19]. In 1994, the Fraunhofer IGD was very well established and represented the "Computer Graphics Power House" in Germany and at least in Europe (Figure 5). This is not only backed by the figures of staff, students, publications and budget but also by the outstanding research results achieved. This will be described in more detail in Chapter 6 of this paper.

4. The "Computer Graphics and Visual Computing Hub " consolidates and goes global (1995–2004)

The positive and very successful development and growth of the CG institutions in Darmstadt was very motivating, but it is well known that institutional growth is not as difficult to achieve as a stable institutional consolidation. This was the goal for this period (1995–2004). To achieve this at this scale, there is a need to be an important player and stakeholder in the process of defining and implementing research agendas and the related research funding at both national and international level, in order to be able to lobby, to back up and to guarantee the consolidation of the "Computer Graphics Hub" in Darmstadt. This was achieved by assuming certain roles and functions in bodies and committees, such as being the chairman of the Advisory Board for Research and Technology of the State of Hesse (1990–1991), by acting as an elected senior technical reviewer and advisor to the German Science Foundation (DFG) (1995–2004), by assuming the role of a chairman (2002–2004) and vice-chairman (2005–2007) of ISTAG (the Advisory Group of the EU for the 6th and 7th Framework Program), by being a member of the board of the Business Academy of Deutsche Telekom (2000–2007) and by contributing to the Fraunhofer Gesellschaft as a member of its "Executive Board" (Präsidium) from (2002–2006); these are just a few examples for many other important activities and memberships assumed with this purpose in mind. The result was a stable growth and consolidation of the "Computer Graphics Hub" in Darmstadt as shown in Figure 3. The Hub was very well established, consolidated and the leading "motor" for Computer Graphics in Germany and in Europe with a strong impact and influence world-wide [20]. The head count in Table 3 does not take into consideration that a large number of additional part-time students (student research assistants) were on the pay-roll of the institutions to be involved and contribute to the research work in the "Computer Graphics Hub" in Darmstadt. Usually they have a 40, 60, or 80 hours/month contract. In 2004, the total number of these students amounted to about 350. Thus, the "Computer Graphics Hub" in Darmstadt comprised around 535 employees (185 full-time plus 350 part-time) in 2004.

Table 3: Full-time employees working in the "Computer Graphics and Visual Computing Hub" in Darmstadt (without student research assistants)

	1997	2000	2004
TUD-GRIS	40	35	35
ZGDV	65	43	30
Fh-IGD	107	110	120
Total in Da	212	188	185

As already described in Chapter 3, the "Computer Graphics Hub" started expanding out of Darmstadt as early as 1990. The first steps were:

- ZGDV founded a branch in Rostock in 1990.
- IGD founded CRCG in USA in 1991 (this center successfully completed its mission and operation in 2003).
- IGD founded a branch in Rostock in 1992.
- CCG (ZGDV) founded a branch in Coimbra, Portugal, in 1993.

The need for further strategic expansion was obvious and imperative for at least the following reasons:

1. The research itself was becoming more and more international, so that the Hub also had to act more and more at a global scale.
2. The research customers from industry were going global themselves, so that the Hub had to follow them.
3. The size (critical mass based on: staff + budget + infrastructure) and the resulting R&D "power" forced to look for other research markets and additional co-operation and project acquisition opportunities.

Based on this, a strategy to "go global" was developed. As of 2004, the following external branches were additionally started and joint research with the institutions of the "Computer Graphics Hub" in Darmstadt was developed and very successfully implemented:

- 1998: CAMTech with the Nanyang Technological University (NTU) in Singapore.
- 1999: INI-GraphicsNet Foundation: This foundation was founded to act as a holding to initiate, develop and network international branches of the "Computer Graphics Hub" in Darmstadt. The vision and goal of this foundation was to be an instrument to develop co-operations and synergies among the partners at a global level.

After 1999 INI-GraphicsNet started branches in Guimarães, Portugal (CCG in 2001), San Sebastian, Spain (VicomTech in 2000), Trento, Italy (GraphiTech in 2002), Omaha, USA (OGM in 2004), Seoul, Korea (IGI in 2005) and in Panama (MIVTech in 2007). The INI-GraphicsNet stopped its operation in 2009. In 2010 a new legal entity – called GraphicsMedia.net with a new vision, new structure, new officers and new form of operation was established in Kaiserslautern, Germany, to take over the mission and goal of developing co-operations and synergies in Computer Graphics at a global level. New members have since then joined the GraphicsMedia.net (so far DFKI in Kaiserslautern, Fraunhofer Heinrich Hertz Institute in Berlin and Hasso Plattner Institute in Potsdam, all in Germany; other international applications for membership are being processed) [21].

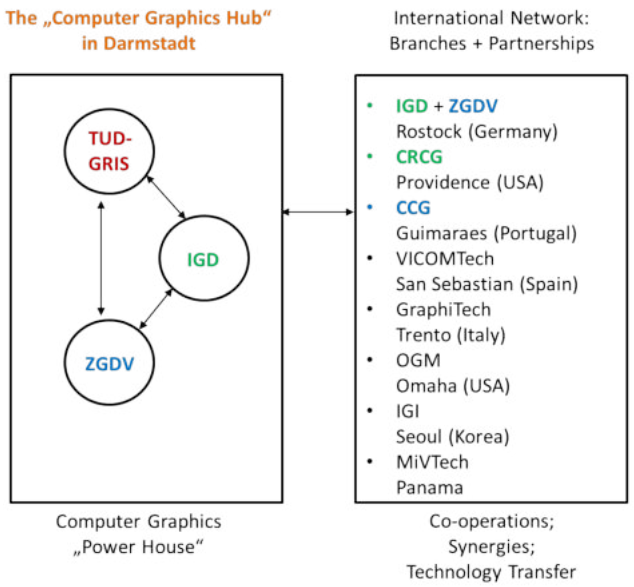

Figure 6: The "Computer Graphics and Visual Computing Hub" and its international network and branches for world-wide co-operations, synergies and technology transfer

By the end of 2004, the "Computer Graphics Hub" in Darmstadt, which, as described in this paper, developed out of TUD-GRIS since 1975, was consolidated, well established in Germany and in Europe and performing very well as an important and strong stakeholder for Computer Graphics R&D at a global, world-wide scale (Figure 6)[20, 21].

5. The Change of Leadership in the "Computer Graphics and Visual Computing Hub" (2005–2014)

In 2006, Prof. Encarnaco handed over his positions as Chair of "Graphische Datenverarbeitung" at the TUD and Director of the Fraunhofer Institute IGD to Prof. Fellner (Figure 7).

Figure 7: Prof. Encarnacao handing over the " Computer Graphics and Visual Computing " Hub to Prof. Fellner

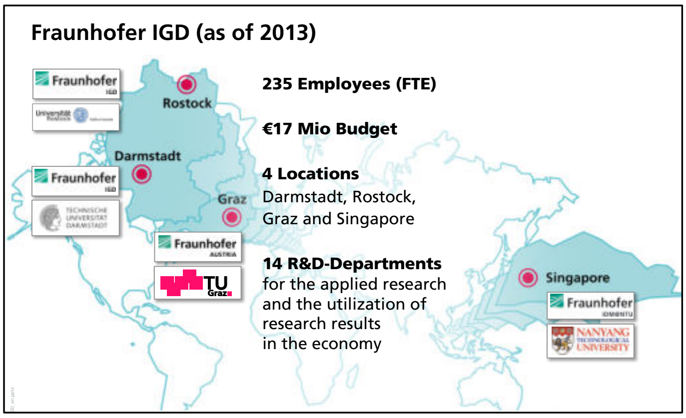

Figure 8: The " Computer Graphics and Visual Computing Hub" in 2013

In the subsequent years, the " Computer Graphics and Visual Computing Hub" in Darmstadt has further expanded as described in the following.

5.1. *Fraunhofer IGD*

The project office of Fraunhofer IGD founded at the Technical University of Graz in 2007 has been transferred to the "Visual Computing" business unit of Fraunhofer Austria Research GmbH in 2008. Thus, the Fraunhofer Graz location is now a fellow subsidiary of Fraunhofer IGD. Researchers from Fraunhofer Austria work very closely together with the staff of the Visual Computing excellence cluster established at TU Graz. The Centre for Advanced Media Technology (CAMTech), as founded at the university's campus in Singapore 1998 by Fraunhofer IGD and the Nanyang Technological University (NTU), has been transformed in May 2010 to the Fraunhofer Project Centre for IDM@NTU (Fraunhofer IDM@NTU) as the new Fraunhofer Research Center in Singapore. This project center is now a fellow subsidiary of Fraunhofer IGD. The Fraunhofer IGD consists of the following branches in 2013 (Figure 8):

5.2. *GRIS*

The research areas of GRIS have been widely expanded by the appointment of two professors: Professor Michael Goesele chairs the "Capturing Reality" group, focusing on digitization methods for all aspects of the real world. This includes capturing geometry, surface color and several other attributes, e.g. reflectance properties of objects. Beyond that, research is undertaken in massively parallel computing to exploit the full potential of nowadays graphics hardware to solve computationally expensive problems. Professor Stefan Roth chairs the research group "Visual Inference". The work of this group lies on the intersection of computer vision and machine learning and focuses on analyzing and interpreting visual data, such as digital images and videos, with a particular emphasis on probabilistic modeling and inference.

As in 2014, the GRIS-Team is organized as follows (Table 4).

Table 4: The GRIS Team 2014

	2014
Professors and Managing Directors	3
Professors	1
Adjunct Professors	4
Assistant Professors	4
Research and Teaching Staff	20
Office	4
Technical Support	2
Total Staff	38

6. Scientific and technological impact of the "Visual Computing Hub"

The strong impact and success of the TUD-GRIS and its sister institutions in the "Visual Computing Hub" in Darmstadt (ZGDV and IGD) in these 40 years (1975–2014) was based on three pillars:

1) The professors responsible for Visual Computing teaching and research in Darmstadt have been over the time:

- Professor José Luis Encarnação (1975–2009)
- Professor Wolfgang Straßer (1978–1986)
- Professor Reinhard Klein (1999–2000)
- Professor Marc Alexa (2003–2004)
- Professor Bernt Schiele (2004–2010)
- Professor Konrad Schindler (2009–2010)
- Professor Dieter Fellner (starting 2006)
- Professor Michael Goesele (starting 2010)
- Professor Stefan Roth (starting 2013)

Additionally, a very large number of visiting professors and lecturers came from all over the world to Darmstadt for a limited period of time (from single months to 1 – 2 years) and contributed substantially to the local teaching and research. The names of these visiting scholars can be taken from the respective annual reports [9].

2) Education of several generations of experts in Visual Computing, which then went to work for universities, research institutes, industry and users. This generated a large constituency with expertise in VC and strongly helped in establishing the technology and the market for Visual Computing in Europe, especially in Germany.

3) Generation of a wide spectrum of advanced knowledge in Computer Graphics and applications based on the R&D and projects in Visual Computing performed in Darmstadt. This encouraged the publishing of more than 200 doctoral theses. Around 40 of these graduates assumed leading professorships or executive research director positions world-wide, but specially in Germany and in Europe. This helped to establish Visual Computing as a core discipline in Computer Science and as an enabling technology on the market of ICT technologies and applications. Prominent examples for such careers are among others Markus Gross (now professor at the ETH and Director of Disney Research, both in Zürich, Switzerland), Reinhard Klein (now professor at Univ. Bonn), Marc Alexa (now professor at TU Berlin), Bernt Schiele (now director at the Max Planck Institute and professor at Univ. Saarbrücken), and Konrad Schindler (now professor at ETH Zürich). Additionally, the scientific impact can also be measured by the number of theses (Studien- und Diplom-Arbeiten, respectively bachelor and master theses, and Doctoral Theses) developed, supervised and submitted to the Technische Universität in Darmstadt by employees and students working in one of the institutions of the "Visual Computing Hub" in Darmstadt. These quite impressive numbers are shown in Table 5.

Table 5: Number of Theses in Computer Graphics in Darmstadt

Theses	1975–2014
Doctoral Theses	210
DA/Master-Theses	1050
SA/Bachelor-Theses	450

Another important indicator for impact is the number and quality of the publications coming out of the institutions in Darmstadt (TUD-GRIS, ZGDV and Fraunhofer IGD). These publications are listed with their references in the annual reports of the respective institution [8]. But, starting in 1990, also a local book series called "Selected Readings" is published in Darmstadt (by Fraunhofer-Verlag IRB, Stuttgart [22]) for the dissemination of these publications to a large constituency of readers. The institutions of the "Computer Graphics and Visual Computing Hub" and their institutional partners produce annually around 400 publications world-wide, including around 200 scientific publications. Each annual volume of "Selected Readings in Computer Graphics" consists of 40 articles selected from a total of these 200 scientific publications. All articles previously appeared in various scientific books, journals, conferences and workshops, and are reprinted with permission of the respective copyright holder. The selection is done by the department heads and by the senior researchers of the institutions involved following certain quality criteria. In a second review process performed by internationally leading experts and established technical societies, a Best Paper Award is granted in the categories impact on business, impact on society, and impact on science. The content of each annual volume of the "Selected Readings" is therefore based on the best papers (10%) selected from among the huge amount published in the respective year. Of course, we cannot go into details of what was published in 40 years (probably around 5.000 to 10.000 publications!), but we recommend to the reader of this paper to have a look at the "Selected Readings" for more detailed information on these publications. Another indicator of the impact is the contribution to conferences and fairs. Contributions of the Visual Computing Hub are honored at international conferences like SIGGRAPH, Eurographics, or IEEE VIS; R&D results are presented at international fairs such as CeBIT, Hannover Fair, Euromold in co-operation with international industry partners.

7. Research road map (1975–2014)

40 Years of Computer Graphics and Visual Computing Research in Darmstadt also resulted in a huge number of projects (somewhere around 2000 projects; some short, others long-term projects, some with a small budget, others with a big budget) and doctoral theses (around 200 implying a research of 3–5 years each). Trying to describe all this research in detail is just a "mission impossible". The research work done in Darmstadt has been documented in the annual reports of TUD-GRIS [8], ZGDV [9] and FhG-IGD [17], in the issues of the house-magazine "CG Topics", in many media publications, in a book edited by P. Blachetta, "Entwicklung der Graphischen Datenverarbeitung 1975–2002" [23] (in German, in a book series published by the Europäischer Wirtschaftsverlag in Darmstadt [22] and in all the doctoral theses submitted to the Technische Universität Darmstadt. To make it short and to base it on some structure, we will try here to access and describe the substance and the highlights of this research in three ways

1) Describing the main axes (systems, applications and users) and the development periods for global VC research, to which Darmstadt contributed as an important player. They very much influenced the decision on what project proposals in a given time period were developed and submitted for public funding or, due to their importance and relevance to industry, directly for industrial funding [24].

2) Presenting a small selection of research topics based on the number and quality of the resulting publications in peer-reviewed international conferences and journals. These publications are not only documenting the projects were they were originated, but also serving as a qualifier for the technical and scientific results achieved by the projects. [23]

3) Presenting a second, different selection of projects based on how the media reacted and informed the public about the project results. This selection relates to the interest and the impact in the public opinion, based on the correspondent media reporting [22]. Based on these three views the reader of this paper should be able to get a quite fair and comprehensive view and understanding of the wide spectrum of research, of output, of achievements and of progress in Visual Computing obtained by 40 years of R&D projects implemented by the institutions of the "Visual Computing Research Hub" in Darmstadt (TUD-GRIS, ZGDV and IGD). These three different views will be discussed and mapped on to the four time periods used in this paper to describe the development of research and teaching in Computer Graphics and Visual Computing in Darmstadt since 1975: 1975–1984, 1985–1994, 1995–2004 and 2005–2014. In each period only a few topics and highlights will be presented as examples. This classification in time periods is used in order to be able to structure and cluster the immense volume of information describing all the work done in the huge number of projects and, by doing so, to simplify its presentation.

7.1. The different stages of CG research

The early phase of Computer Graphics research (1975–1984) worked along the following axes:

- Development of hardware and I/O devices (from displays to workstations).
- Object representation and object output (from vector, to storage, to raster display technologies).
- Interaction technologies (from plotting, to interactive technologies and to dialog systems).
- Object motion (from static, to dynamic, to real-time).
- Object dimension (from 2D, to 3D, to immersion).
- Quality of the object representation (from hidden line / hidden surface removal algorithms, to rendering, to lighting, to high-quality "realistic" representations).

The next period of research (1985–2004) was mainly characterized by the following axes:

- Computer-generated realities (from virtual reality (VR), to augmented reality (AR), to simulated realities (SR)).
- Computer-based simulations and animations.
- CG Software Engineering (from scene graph programming, to immersion programming, to digital storytelling, to integration of agent and avatar technologies, to programming of games).
- Intelligent products (from embedded visual functionality to wearable systems, to mobile graphics technologies).
- Intelligent environments (from presence technologies, to awareness technologies based on CG).

A third period of research (2005–2014) covers work in the following areas:

- Integrated computer vision (Integration of VR/AR technologies and computer vision / markerless tracking. Herewith providing integrated environments for capturing reality.)
- Computational anatomy (Applications of visual computing in medical applications like operation planning.)
- 3D Internet (Bringing 3D to the internet: smooth integration of 3D into the web without plug-ins. Support of streaming and cloud-based graphics.)
- GPU-based graphics and simulation (Usage of high performance GPU clusters for both, graphical and numerical applications supporting integrated real-time simulation applications.)
- Visual big data (Visual interaction with big data, consisting of data with high volume, different structure and time dependency, analysis of different types of graphical data (like twitter, metadata, semantics, . . .), visualization of large-scale data.)
- Visual decision support (Integration of graphics, vision and simulation in integrated environments to support participation of different groups of people e.g. in areas like policy modeling.)

The projects implemented by the institutions of the "Computer Graphics and Visual Computing Hub" in Darmstadt followed round about these research roadmaps. The topics and goals of the projects in a given time period were strongly dependent on the respective state of VC research and of the availability and usability of other enabling technologies, like Micro-Electronics, Micro-Systems, Embedded Systems, Graphics Hardware, Peripherals and End-User Devices, ICT Technologies and Infrastructures. The reader of this paper has to take this development into consideration to appreciate the relevance, importance and value of the research projects at the time of their implementation. (Some of the relevant references for these projects are: [25-36])

7.2. The scientific view to the projects

At the beginning in Darmstadt (1975–1984), the main research done by TUD-GRIS was oriented towards topics such as:

- Graphics algorithms (Hidden line / hidden surface removal algorithms; rendering techniques; analytical visibility methods for displaying parametrically defined surfaces.)
- Graphics programming and graphics standards (GKS (Graphisches Kernsystem); CGM, CGI, PHIGS, . . . ; workstation concept, interfaces and implementation; driver architecture for raster workstations; conformance and certifying GKS; VLSI implementation of GKS; GKS interfaces and libraries for CAD applications; device drivers.)
- Graphics dialogue programming (constructing user-interfaces based on logical input devices; semantics of graphical user-interfaces.)
- CAD systems (architectures, components and interfaces; pilots and application trials; developments of business cases for CAD.)
- Graphics in networks (Load-sensitive software distribution in satellite graphics systems; graphics in computer networks; communication interfaces.)
- Interfacing optical memory discs to graphics systems
- High-speed multiprocessor systems for digital signal processing

In the period of 1985–1994, with a larger number of researchers due to the foundation of ZGDV and Fraunhofer IGD, the list of research topics increased to include the following among others:

- Advanced graphics algorithms (Morphing spaces, shapes and scattered features; mesh morphing; point set surfaces; geometric algebra for CG; point-based animation of elastic, plastic and melting objects.)
- Advanced rendering techniques (Ray tracing; ray tracing of point set surfaces; interactive rendering.)
- Computer vision (Components, systems and applications: interfaces and integration in computer graphics systems.)
- Virtual reality (VR environments, CAVEs, large-screen displays; VR simulators for several application domains; force feed-back, acoustic and light in VR environments; mobile virtual reality; flow simulators; virtual product design; pilots and use cases for VR in industry; business cases for VR.)
- ICT environments (Location-aware computing; time and location independent tele-cooperation; tele-medicine.)
- WWW access (Use of device and user profiles resource adaptive WWW access; Web-Graphics.)
- Multimedia systems (MM-integration in graphics systems; MM authoring and synchronization; video technologies; content-based video editing.)
- Innovative user interfaces (Conversational user interfaces and interface agents for home appliances; Face animation engines for user-interface agents and avatars.)
- Learning and training (Modular, Web-based eLearning systems; GUIs; graphics-based content; authoring systems.)

In the period of 1995–2004 the research done in Darmstadt was following topics like:

- Underlying system architectures and algorithms (Reconstruction and modeling; algorithms and technologies for tracking; integration of imaging (visual computing); knowledge management and visual data mining.)
- Tele-cooperation and collaborative engineering (User interaction and authoring; visualization, simulation and animation.)
- Computer-generated realities (development of augmented reality (AR); integration of VR and AR; digital storytelling and edutainment; ambient intelligence.)
- Mobile computing (Mobile applications of VR and AR in science, engineering and edutainment.)
- Integrating IT-Security in computer graphics systems and applications (Coding schemas; algorithms; technologies; strategies; environments.)
- Web-based applications of Computer Graphics
- Visualization and Simulation (Developing techniques and algorithms and optimizing applications pilots and use cases in medical visualization and simulation, geographical information systems, electronic publishing and multimedia, and teaching and training systems.)

Since, 2005, the scientific work is based on an Extended Model of Visual Computing (Figure 9).

This model consists of the following so-called Research Areas (Figure 10).

Computer Vision. Computer Vision describes the process of analyzing and interpreting real images, converting them into abstract, digital information. It performs the mapping from reality to virtuality and is based on digitization technologies such as tracking, capturing or scanning. Computer Vision encompasses new and improved technologies for augmented reality, material acquisition and 3D reconstruction as well as the combination of computer vision technologies with a great number of sensors.

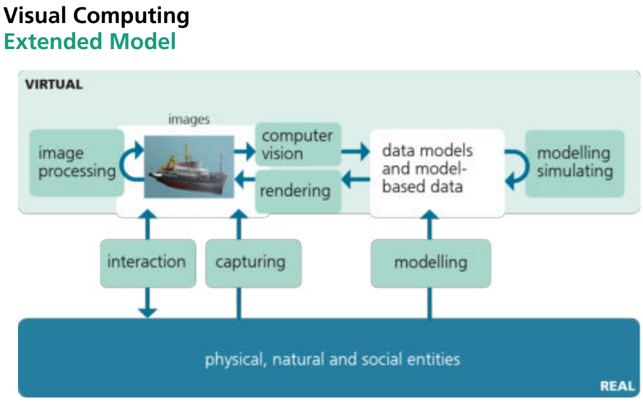

Figure 9: The Extended Model of Visual Computing

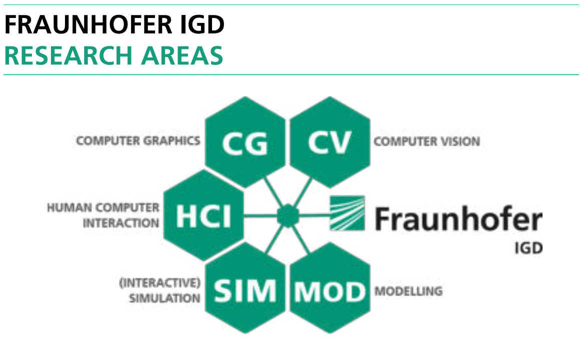

Figure 10: The IGD Research Areas

Modeling. Models are an integral part of visual computing. They may be of different dimensions, 2D (maps), 3D (buildings), 4D (time-varying models), and even higher-dimensional and provide an abstract view of selected aspects of reality. Models may be born-digital, originating in digital form, or digitally reformatted, whereby analog materials become digital as the result applying Computer Vision technologies. Both types of models form integrated, fused digital worlds.

Image Synthesis / Rendering. Image synthesis encompasses technologies and processes to generating images from information, the generation of virtual worlds and augment reality for many different applications and trends such as the shared use of resources, real time and mobility. Interactive Simulation Digital worlds offer many opportunities. Physical objects or physical phenomena can be digitized and visualized quickly and without any risk. Our researchers are developing methods in order to accelerate and directly influence simulation processes.

Interactive Simulation. encompasses technologies like the reproduction and visualization of the behavior of physical objects and physical phenomenon, the support of back-end simulation engines, or the acceleration of simulation using GPU-clusters. Moreover, users can directly influence the simulation and instantly represent simulation results.

Human Computer Interaction. Vital aspects of Visual Computing are single human computer interaction and computer-supported group collaboration. Human computer interaction supports all the technologies and processes describes above. Main research areas are the development of adaptive and effective interaction metaphors, the support of visual interaction in cloud-based environments across heterogeneous mobile devices, interaction techniques in AR-environments (like AR-glasses), context-based and adaptive user interfaces and interaction techniques for managing of scientific big data. Detailed references about the research work auf IGD in the different research lines of Visual Computing can be found in [38-65].

The following are examples of scientific work in these areas:

Cultural heritage digitization and 3D-print technologies. Defining an integrated loop from acquiring information by scanning real 3D-objects and production of 3D-objects, both technologies taking geometry, surface characteristics and optical material properties into account (Figure 11).

Figure 11: Cultural Heritage digitization and 3D-print technologies

3D-Internet. Research on the smooth integration of 3D-technologies in browsers without plugins. Active participation in standardization committees (Web3D).

Underwater image processing. Development of technologies with focus on monitoring marine habitats (Figure 12).

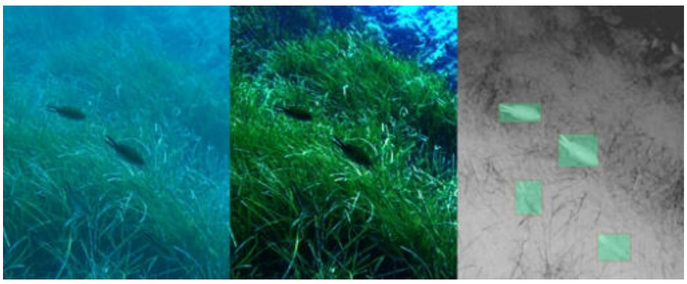

Figure 12: Underwater Image Processing

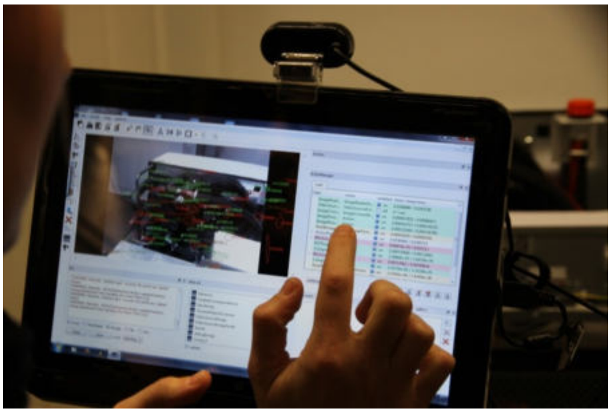

Figure 13: Computer Vision-Based Tracking

Applied computer vision-based tracking and mobile AR for smartphones and tablets. Development of frameworks supporting the integration and configuration of different algorithms for markerless tracking in mobile environments and diverse application scenarios in production, maintenance, or tourism (Figure 13).

7.3. The projects as seen from the media

Some of the most reported projects in the national and international media [24] in the period 1975–1984 were the following:

- GKS (Development of graphics standards (GKS, GKS-3D, PHIGS, CGM, CGI))
- HoMuK (Development of graphic-processors and co-processors (HoMuK – a homogeneous multiprocessor kernel))
- DaScript (A system to integrate graphics in a SGML document)
- AUDIUS (A field workers support system (integration of communication and mobility))
- RKS (The core system for roboter programming)
- PEBSY (Programmable system for real-time image processing in medical applications)
- DEDICATED (A new dimension in computer-aided teaching and education.)

A few highlights of projects strongly reported in the media in 1985–1994 are:

- THESEUS (The software engineering user interface (UNIX based software production environment))
- The Raibach project (3D modeling and visualization of the church of Raibach)
- The Rhinoscopy Training Simulator
- INVIVO (System for volume rendering of 3D ultrasound data)
- ISVAS (Interactive system for the visual analysis of damages in mechanical supplies)
- VR-Demo Center (A center for VR and cyberspace design)
- CASUS (A logistic simulator)

As examples from 1995–2004 the following projects enjoyed a strong interest from the media:

- MAP (Base system for future mobile, multimedia workplaces)
- CIPRESS (Cryptographic intellectual property rights enforcement system)
- SYSCOP (System for copyright protection)
- Dome of Siena (An immersive reality model of the Dome of Siena)
- Virtual Oceanarium (VR of the Oceanarium at World Expo in Lisbon)
- Telebuddy (A mobile webcamera system)
- GEIST (A mobile AR information system)
- “Augmented Man” (A virtual, time-delayed AR-mirror)

To get more media information and reporting on the projects in Darmstadt during these three periods (1975 – 2004) the reader should consult the book by P. Blachetta [23].

In the time-frame 2005–2014 the media reported heavily on the following projects:

CultLab-3D. This BMWI-funded project is aiming at the development of a world leading-edge ”3D scan pipeline” supporting the acquisition of geometry, surface characteristics and optical material properties (see also Figure 11)

3D City models. This project is based on the CityServer3D for managing and interlinking two- and three-dimensional geographic Data, and 3D-Vis, an information visualization tool supporting parties in decision making e.g. in the planning phase of wind parks.

Instantreality. A framework providing features for the smooth integration of augmented reality and virtual reality. Based on web-standards, it sets a new standard.

3D-Coform. An integrated EU-project aiming at the digitization of cultural heritage artifacts. Additionally, artifacts are classified with meta-data and large-scale digital libraries of 3D-objects are implemented (Figure 14)

Figure 14: 3D-Coform

CapFloor. Started as an internal research project, CapFloor is a smart floor for localization and fall detection that is currently being piloted in more than 20 apartments of a technologically advanced retirement home. Its application scenarios include control of intelligent lights, the detection of burglaries, or alerting help when a fall is detected (Figure 15)

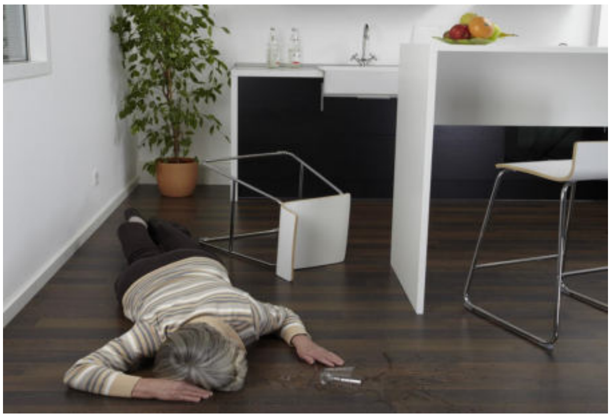

Figure 15: CapFloor

CHESS (Cultural heritage experiences). A system providing an integrated interactive cultural heritage experience, integrating augmented and reality technologies in mobile environments, extended by story-telling: the artifact explains itself (Figure 16)

Figure 16: CHESS

Green Regional Aircraft (GRA). In the EU-project JTI Clean Sky, IGD contributes to the integrated technology demonstrator "Green regional Aircraft" by modeling and simulation of aerodynamics conditions to reduce pollution (Figure 17)

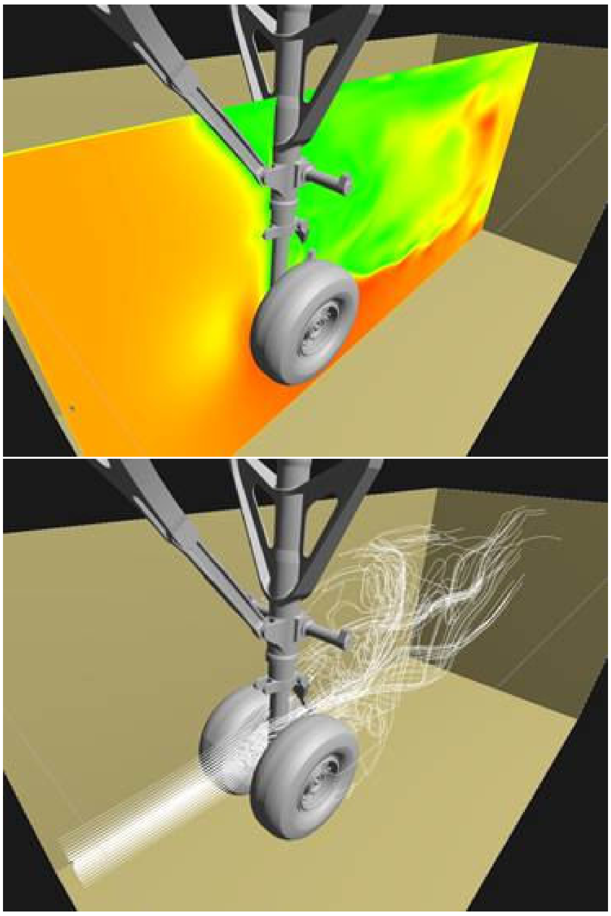

Figure 17: Green regional Aircraft (GRA)

More information about Fraunhofer IGD publications can be found at [65].

8. A forecast for 2014 ++ as seen by the "Computer Graphics and Visual Computing Hub" in Darmstadt

We can forecast the following trends for the next five years from the perspective of the "Computer Graphics and Visual Computing Hub" in Darmstadt.

8.1. Technical perspective

Form a technical perspective, research will be undertaken in the following areas of Visual Computing:

- Visual Big Data
- 3D-Replica
- Autonomous Visual Systems

Visual Big Data. Nowadays, "Big Data" is a buzzword used in many different contexts and with often quite vague and ambiguous meanings. Big Data encompasses a new quality of data with respect to volume, variety, and velocity, and in addition, "veracity", the quality of data. Often, Big Data is reduced to high volume data, but the crucial aspect of Big Data is the management of different forms of data, e.g. the integrated management of very high volumes of unstructured data like tweets, of semi-structured data like documents, structured annotations based on meta data and formally defined semantics. Main application scenarios are enhanced decision making, insight discovery and prediction, and process optimization. Big data will pose different challenges to Visual Computing: data visualization does not yet profit from all the possibilities of computer graphics: the visualization of large-scale data is still a challenge, especially in the field of layout. How to visualize graph structures with millions of nodes and a factor of 10 of relations are open research question. Another challenge is the development of appropriate user interface metaphors. In the field of rendering, concepts like level-of-detail, lighting and shading etc. are already well understood to produce images of high quality. In contrast, big data visualization often uses schematic, abstract 2D-metaphors like dashboards, consisting of graphs, matrices, time-dependent data are often presented as traditional 2D-time lines. The development of natural metaphors for graphical and semantic level of detail, static and time-dependent data is still open and necessary to support non-experts in exploring Big Data. In the next five years, we expect natural renderings of scientific data so that everyone can perceive abstract information in form of natural images.

3D-Replica. 3D-Scan and 3D-Print are well established technologies in the Graphics Hub. In the near future, research will be undertaken towards the design and implementation of an integrated 3D-Replica Pipeline. In the scanning component, research will be undertaken towards the integration of new devices such as smart phones. Besides scanning geometry and textures, all visual surface properties will be captured in form of the complete BRDF. Moreover, techniques will be developed in order to capture additional material properties such as temperature-dependent stiffness or elasticity. The area of processing will be extended by reconstruction of 3D-objects by the analysis of large sets of 2D-images. Methods will be developed to support informal tagging, semi-formal annotations and formal indexing and cataloguing. An important research area is the understanding of scanned objects, e.g. the recognition of the properties of marble by machine learning technologies. Concerning 3D-printing, the focus of future work is on the development of methods supporting the creation of realistic objects, taking all the scanned and recognized information into consideration. The mid-term goal is the development of a "universal 3D-printer driver", allowing the best-fit printing of ideal objects dependent of the device capabilities. In order to establish these algorithms as an international standard, active participation in the corresponding committees will be established. Visual Computing as a Service Today, the Darmstadt Visual Computing Hub offers leading edge technologies in the areas of computer vision and rendering. Future work will be undertaken towards the provision of an integrated vision and rendering framework "as a service". Additionally, real-time simulation methods will be provided by this Cloud-based solution. Marker-less tracking and visual presentation of target/actual comparison are research topics in that area. Streaming technologies for the support of different device categories will be developed.

Autonomous Visual System. Technologies In the area of computer vision with a special focus on tracking techniques, further research will be undertaken in the areas of motion and gesture capturing and the recognition of the underlying semantics. The mid-term goal is to "understand" real-world situations and to derive recommendations of actions. The focus of research is the development of high-level processing algorithms to support experience-based analysis and recommendation. Blended Reality Technologies and Sensor Fusion In the near future, new generations of interaction devices will appear on the market. The fields of Augmented Reality and Virtual Reality will converge towards a continuum, Blended Reality, which also incorporates sensor fusion. Research in Darmstadt will be undertaken towards the development of methodologies for a unifying Blended Reality framework, hereby overcoming the disadvantages of today's proprietary solutions. The focus of this work will be its openness for future products on the market as well as its ability to serve as common basis for the research in specific areas in the Darmstadt Graphics Hub.

8.2. Application Areas

Amongst others, the following application areas will be addressed by the Computer Graphics and Visual Computing Hub in the next five years:

- Humans in Digital Production (Industry 4.0)
- Individualized Health Care
- Opinion Making in Urban Processes

Humans in Digital Production (Industry 4.0). Smart factories (Industry 4.0) consist of ensembles of self-organizing intelligent production units collaborating over the Internet and communicating with the environment via actors and sensors. From the perspective of Visual Computing, the main challenge is in the provision of an integrated environment, encompassing the capturing of a real production/¬manufacturing environment including sensor information, the construction of multi-aspect models taking product- and process-information into account, the real-time visual simulation of optimization and control alternatives, and the design, test and on-line supervision of the factory based on these results. The human is visually supported in all his interactions with the system and the collaboration with colleagues. He has access to best-practice databases and can consult remote experts.

Individualized Health Care. Smart environments like smart hospitals have both, a physical and a virtual representation, and consist of intelligent autonomous components. Real-world data can be blended into virtual models (like real-time webcam video with captured movement data in patient monitoring) as well as abstract information can be blended into real environments (like access to electronic health records during ward round). Based on interactive simulation, decisions for the optimal treatment of patients in hospitals can be supported. The main challenge for Visual Computing in this area is the integration of both worlds into an intuitive user experience. Decisive for the success of such applications will be the provision of optimal user experiences for domain experts (here doctors or hospital nurses).

Opinion Making in Urban Processes. A challenge for Visual Computing in the near future is to support discussion, opinion finding and integration of different parties in processes like policy making in urban processes. Here, many and completely different points of view and interests have to be harmonized to find an optimal solution. One of the main problems of today's participation possibilities is the lack in taking all different aspects into consideration. Research will be undertaken in order to integrate smoothly natural scenes, virtual models and interactive simulations in mobile environments.

8.3. Blended Reality Computing – the Future of Visual Computing

In the near future, we will live in a digital culture, a networked world blending the digital world and the real world we live in. We will interact in a world consisting of indistinguishable virtual and real components. The Computer Graphics and Visual Computing Hub in Darmstadt undertaking applied research in the areas capturing, modeling, simulation, rendering, and human computer inteaction is very well positioned to face these challenges.

9. Conclusions

This paper reports on the development of Computer Graphics and Visual Computing as discipline in Computer Science and as an enabling technology for science and engineering specially in Darmstadt, but also in Europe since 1975. The starting point for this development was the foundation of the TUD-GRIS (Computer Graphics Research Group) at the Technische Universität Darmstadt in Germany in 1975. We report on a 40-years development (1975 to 2014). The authors were the "contemporary witnesses" and leaders of this process, and are therefore in a good position to describe in detail the "inside and rational" of this successful development. An extensive bibliography at the end of the paper opens the opportunity for the reader to access further references, additional information and more details of his / her interest in the context of this 40-year development of Visual Computing and its applications.

Acknowledgments. The authors acknowledge and thank all persons involved in teaching and in doing research in one of the institutions of the "Computer Graphics and Visual Computing Hub" in Darmstadt during some period of these 40 years (1975–2014). Their work and their contributions were fundamental and the bases for this very successful development and for all related achievements. Very special and personal thanks of the authors go to Dr. Christoph Hornung from Fraunhofer IGD, who prepared the material for the period 2005–2014. His contribution was also substantial in structuring and proofreading the content. It was a major effort and is very much appreciated by the authors.

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