Mobile Graphics

Marco Agus [1,3], Enrico Gobbetti [1], Fabio Marton [1], Giovanni Pintore [1], and Pere-Pau Vázquez [2]

[1] Visual Computing, CRS4, Italy
[2] Computer Science Department, Universitat Politècnica de Catalunya, Spain
[3] Visual Computing Center, King Abdullah University of Science and Technology, Saudi Arabia

Abstract

The increased availability and performance of mobile graphics terminals, including smartphones and tablets with high resolution screens and powerful GPUs, combined with the increased availability of high-speed mobile data connections, is opening the door to a variety of networked graphics applications. In this world, native apps or mobile sites coexist to reach the goal of providing us access to a wealth of multimedia information while we are on the move. This half-day tutorial provides a technical introduction to the mobile graphics world spanning the hardware-software spectrum, and explores the state of the art and key advances in specific application domains, including capture and acquisition, real-time high-quality 3D rendering and interactive exploration.

Keywords. *Mobile Rendering, Massive Models, Ambient Occlusion, Global Illumination, Rendering Pipeline, Indoor Scene Reconstruction, Omnidirectional Images, Mobile mapping, Camera Control, Volume Rendering*

1. Tutorial details

1.1. Format and prerequisites

Format Half day (2x90min).

Necessary background The tutorial is at the beginner-intermediate level. Basic programming and interactive graphics background is a pre-requisite.

Intended audience The tutorial targets researchers and practitioners with an interest in developing visual computing applications on mobile devices.

1.2. Detailed tutorial outline

In last decades, worldwide mobile phone subscriptions grew to over seven billion, penetrating 100% of the global population and reaching even the bottom of the economic pyramid. Of these subscriptions, about 3.5 billions have internet access, and the ability to exchange information is continuing to grow exponentially, with multimedia data taking a large share. Hence, it is expected that the future of computing in general, and visual computing in particular, will be dramatically affected by this scenario.

The tutorial will present an overview of the evolution and state-of-the-art of mobile graphics platforms, discuss current graphics APIs and development tools for developing mobile applications, and illustrate current trends in exploiting capture, networking, and display hardware. Detailed examples will be provided in two visual computing domains: exploiting data fusion techniques for metric capture and reconstruction, and exploiting networking and display hardware to visualize and interact with massive models. The tutorial concludes with a view of future challenges.

The outline of the individual sessions is detailed in the following sections.

SESSION 1: Evolution of the mobile graphics world

In the last +15 years, mobiles have changed to being just an useful tool for emergencies, to be with us through most of our daily tasks. We use them for guiding us while driving, to account how many steps or miles we have covered, to answer our mails, and, of course, to spend some time by playing or watching TV shows.

Many companies rely on the ubiquity of mobile devices (and Internet connections through them) to provide their services. We ask for a taxi while listening to cloud-stored music, and get continuous notifications on the transit, weather, shopping offers...

Ericsson Mobility Report [Eri16] predicts that global smartphone subscriptions will grow from 7.3B to 9B by 2021, with a notable growth in smartphones, that will double. Moreover, it also predicts the mobile traffic will grow from 1.4GB/month to 8.9GB/month by 2021.

Early on, with the advent of mobile devices, games arrived with them. In 1997, the Nokia 6610 sported the Snake game. It become so popular that this year, a new version of the Nokia 3310 was announced with all bells and whistles, with the game Snake as one of its selling points. So throughout the history of smartphones, gaming [FGBAR12] (especially casual gaming [Kul09]) has become one of its desired features, and with gaming, the needs of increasing the graphics power come all along.

In this session, we will analyze the evolution of the mobile world from the point of view of the graphics, but also with all the elements that make it possible, such as the GPU, the operative system, and so on...

The main areas that will be covered are:

- Overview of mobile world, and its capillary diffusion;
- Description of the main characteristics of mobile graphics terminals, with respect to network; capabilities, graphics and displays, sensors and CPUs;
- Discussion of current issues and future opportunities.

This section ends with a discussion that will lead to a further analysis of the mobile application trends.

SESSION 2: Mobile graphics application trends

Since the release of the iPhone, smartphones have become mainstream. Most of us own at least one of those, and it is not uncommon to see people sporting two of those. However, despite that, according to the GSM organization, two-thirds of the population own a device ([A*17]) there is a lack of variety in vendors, and operative systems. Most of the devices sold either have iOS or Android, accounting for a 95% of the market. Thus, the evolution of applications and graphics in general is tightly linked to the evolution of those two operative systems ([GR11, Tra12]).

The session will cover different aspects of mobile graphics, such as:

- General overview of rendering pipeline for interactive 3D mobile applications.
- Evolution of 3D graphics applications, from remote rendering solutions to hybrid mobile/remote solutions, exploiting image-based or model-based methods.
- Overview of current trends in hardware acceleration employing parallel pipelines, real-time ray tracing and multi-rate approaches;
- Overview of other visual mobile applications like 3D acquisition and processing, physical simulations, and visual aberration correction.

After this session, the talk will concentrate on the actual development of applications and the technical aspects involved.

SESSION 3: Graphics development for mobile systems

As commented above, only two operative systems dominate the market, with above 95% of the market share: iOS and Android.

Apple was first in creating a closed way to install new apps on a mobile, through the Apple Store. The device owners can only install applications from the official store. Moreover, Apple uses a strict approval-first policy that is lengthy and sometimes arbitrary. Although there are other means to install applications in an iPhone or iPad, they are forbidden by Apple and are by no means accessible to most of the population, due to its technical complications. This has permitted Apple to have a fine grain control on which applications appear in the store, and, though it has its own shortcomings, especially for developers, it has some advantages for the users, such as the relative safety of the content.

Following the path marked by Apple, Google also provides a store, although the users can easily install applications from other sources, even from other vendors such as Amazon or Samsung, that compete with Google both in selling devices, and in selling apps.

Both operative system owners (Apple and Google) have created the tools that facilitate the development of aplications. In the case of iOS, Apple provides an SDK for the development using Objective C. More recently, Apple is shifting to a new language called Swift, and moving the graphics development to a new language, called Metal ([CP15], both developed by Apple.

Google chosed Java instead, for its popularity. Android SDK also provides a set of tools for application development, that is continuously evolving. The graphics language implemented in Android is OpenGL, although new versions of Android are now supporting the evolution of OpenGL: Vulkan.

The outline of the discussed points will be the following one:

- Overview of main operating systems employed in mobile platforms;
- Description of currently used programming languages and tools and deployment environments;
- Introduction to currently available 3D APIs.
- Q&A

SESSION 4: Mobile metric capture and reconstruction

Mobile devices have become increasingly attractive for solving environment sensing problems given their multi-modal acquisition capabilities and their growing processing power, enabling fast digital acquisition and effective information extraction [DL15]. In this tutorial session, we will cover the following subjects:

- Overview of the mobile device sensor and sensor-fusion capabilities available on mobile devices, ranging from commodity smartphones and tablets to new generation spherical panoramic cameras (SPC).
- Introduction to image-based 3D reconstruction methods running on mobile devices;
- Mobile metric reconstruction methods using a combination of images and inertial acceleration data with an example implementation of a full acquisition and SfM reconstruction pipeline working in a limited bounding volume;
- Real-world cases: mobile mapping and reconstruction of indoor scenes, from the limits of the perspective views to the advantages of the wide-FOV panoramic images;
- Example of application: mobile reconstruction and exploration of indoor structures exploiting omnidirectional images;
- Motion estimation and dense depth maps generation from small motion with mobile SPC;
- Future trends: automatic mapping and reconstruction of indoor structures from 360 video sequences.
- Q&A

SESSION 5: Scalable mobile visualization

Since the first version on Snakes back in 1997, the GPUs have evolved, but also gaming and gamers. Nowadays, many hardcore gamers demand for incredibly large, realistic environments, together with multi-user collaboration and interaction. Mobile gaming has also evolved similarly. Nowadays, many applications try to mimic the console quality.

In this session we will analyze some of the developments in mobile graphics that make this possible. From the rendering of massive models, to the implementation of realistic rendering techniques or the use of volume data.

Despite being claimed the contrary, mobile GPUs are still not on par with consoles and/or desktop GPUs. This makes the use of large scenes or datasets, quite difficult. As a result there is a need in the implementation of algorithms that are able to deal with large models. Despite mobile GPUs are equipped with powerful hardware, that implements a large portion of the OpenGL pipeline (e.g. tessellation, 3D textures...), the horsepower is not enough in many cases, to deal with (what in desktop would be considered) medium to large scenes in realtime.

There are several main challenges when developing graphics applications for mobile devices:

- Memory limitations: The model might not fit inside the mobile device.
- GPU capabilities: The algorithm we intend to use either requires non available GPU features (e.g. not all GPUs support tessellation).
- GPU horsepower: Even if the GPU has the capabilities, and the memory to store the data, the algorithm required (e.g. a GPU-based raycasting) is unable to render, because it is so costly that the operative system kills the application because it has become non responsive.
- Performance: We can avoid the previous limitations but still have not enough performance for the implementation run smoothly.

Throughout the last years, there have been many developments tailored to improve the quality of renderings for large datasets, both in terms of quality and in performance.

The initial trend was the creation of client-server architectures, where the mobile simply renders an image generated by a high end device [PGGB12]. This architecture has been used both for meshes [BAMG14a], point clouds [BGM*12], and volume datasets [LS07].

The arrival of more powerful GPUs, just recently, has allowed the possibility of rendering large models with them, although always performing some sort of simplification. This is due to the fact that, even if claimed the contrary, mobile GPUs still are 10 to 40 times slower than a desktop GPU, as can be seen in benchmarks that compare both GPUs (such as GFXBench).

For high quality illumination, we only find papers that address some parts of the rendering equation, being it shadows [BLM16], or some physically-based rendering effects [LKC14]. In many cases, when implemented in mobile, global illumination approximations rely on a high number of precalculations [KUK15], usually in the form of light maps [SE16]. There are just a few techniques that calculate a certain approximation to the rendering equation on realtime, e.g. ambient occlusion [SV16a].

In the case of volumetric models, it was not until 2011-2012 that rendering them directly on the smartphone was possible, using a standard GPU-based raycasting [BV12]. But even the framerates that one can achieve with the latest device are still low for volumetric datasets [SAK15].

- Characteristics of mobile devices with respect to massive models and need for scalable technique with low CPU overhead;
- Converting complex environments to image-based solutions;
- Scaling in terms of geometry: comparison of general chunked triangulation/point-cloud methods with constrained techniques exploiting pre-defined compressed image formats and graphics primitives;
- Improving visual quality with real-time screen-space based global illumination methods for mobile applications.
- Approaches to support interactive volumetric exploration.
- Q&A

SESSION 6: Wrap-up and Conclusions

- Summary and view of future challenges
- Final Q&A session

2. Relevant references

The tutorial will provide a general introduction and summary to the domain of mobile graphics. Some particular works will be presented in more details to illustrate case studies of significant methods and applications. Relevant references are the following:

- capture and reconstruction [PGGS16b, GPG*16, PGG*16, PAG14, PG14]; metric reconstruction with mobile devices [GPG*16];
- presentation of enhanced image representations [AJPG16], image-based exploration of environments [PGGS16a, DGB*14], and real-time interactive exploration of massive surfaces [BAMG14b, BGMT13, BGMT13, GMB*12] and volumes [VB12, DGBN*16]
- real-time global illumination [SV16b]

3. Presenters

Marco Agus is currently research engineer in the Visual Computing Center (VCC) at King Abdullah University of Science and Technology. He holds a Laurea (M.Sc.) degree in Electronics Engineering (1999) and a Ph.D. degree in Mechanical Engineering (2004) from the University of Cagliari, Italy. His research interests span a variety of visual computing topics, including massive model rendering and 3D spatial interaction on various displays, ranging from mobile platforms to light field displays, volume visualization, haptics and surgical simulations, and 3D digital heritage applications. His research is published in book chapters, journal and conference papers in the area of computer graphics. He served as program committee member and reviewer and presented tutorials at international conferences.

Enrico Gobbetti is the director of Visual Computing (ViC) at the Center for Advanced Studies, Research, and Development in Sardinia (CRS4), Italy. He holds an Engineering degree (1989) and a Ph.D. degree (1993) in Computer Science from the Swiss Federal Institute of Technology in Lausanne (EPFL), as well as Full Professor Habilitations in Computer Science and Information Processing from the Italian Ministry of University and Research. Prior to joining CRS4, he held research and teaching positions at EPFL, UMBC, and NASA. Enrico's research spans many areas of visual computing and is widely published in major journals and conferences. Many of the technologies developed by his group have been used in as diverse real-world applications as internet geoviewing, scientific data analysis, surgical training, and cultural heritage study and valorization. Enrico regularly contributes to the community as reviewer, commitee member, and tutorial speaker. He participated to the Editorial Board of Computer Graphics Forum (2008-2011), and is currently Associate Editor of The Visual Computer (2010-now), Frontiers in Virtual Environments (2014-now), and IEEE Transactions on Visualization and Computer Graphics (2015-now). He is key member of IEEE Technical Committes on Multimedia Communication (2010-now) and Human Perception and Multimedia Computing (2012-now). He also served as Program Chair of ACM Web3D 2013 and EGPGV 2016, as well as general co-chair e Eurographics 2012 and EuroVis 2015.

Fabio Marton is a researcher in the Visual Computing (ViC) group at the Center for Advanced Studies, Research, and Development in Sardinia (CRS4). He holds a Laurea (M. Sc.) degree (1999) in Computer Engineering from the University of Padova, as well as an Associate Professor Habilitation in Computer Science from the Italian Ministry of University and Research. His current research interests include out-of-core data processing, compression multiresolution modeling and time-critical rendering. He has participated as a key developer in industrial and research projects that have led to the development of state-of-the-art tools for large scale model rendering. He has co-authored papers in major international refereed journals and conferences, co-chaired EGPGV 2012 (general) and 2013 (papers), and given tutorials at IEEE Visualization, SIGGRAPH, and Eurographics. Before joining CRS4, he worked on 3D scanning at LMTT Padova and Optonet Brescia.

Giovanni Pintore is a researcher in the Visual Computing (ViC) group at the Center for Advanced Studies, Research, and Development in Sardinia (CRS4). He holds a Laurea (M. Sc.) degree (2002) in Electronics Engineering from the University of Cagliari. His research interests include multiresolution representations of large and complex 3D models, lightfield displays, reconstruction and rendering of architectural scenes exploting mobile devices and the new generation mobile spherical cameras. His research is published in major journals and conferences of computer graphics and computer vision. He served as program committee member and reviewer at international conferences and recently as Program Chair of the last Eurographics Italian Chapter conference. He is currently EU project manager in the field of security, where he is developing and applying novel mobile graphics techniques for indoor capture, mapping, and exploration.

Pere Pau Vázquez. is an associate professor at the MOVING Group in Universitat Politècnica de Catalunya. He holds a Degree in Computer Engineering, and a PhD in Computer Science by the Universitat Politècnica de Catalunya. His research interests include the visualization of molecular models, GPU-accelerated rendering, and mobile-based graphics. He has published a number of papers in major journals and conferences of computer graphics and visualization. He has served numerous times as program committee member at different international conferences and he is currently the co-chair of EuroVis 2017.

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