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Pre-thesis & Free Option Planning

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Theme: interactive Computer Generated Holography
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1 Thesis context, theme & objectives

1.1 The problem

Despite the proliferation, in recent years, of 3D display technology in the consumer market [PT1], the current approaches still suffer from insufficient realism, hindering both scientific, precise applications, and entertainment ones. The main problem resides in the inability to provide all natural depth cues available with natural vision, especially motion parallax and synchronization of internal ocular motions (focusing and stereo convergence). While motion parallax can be achieved with head tracking, and to some degree with autostereoscopic displays, the effect is hard to adapt to multiple users, and does not convey a convincing 3D representation of the observed scene in the case of autostereoscopic displays. Focusing-convergence matching, on the other hand, is impossible with these techniques.

Holography has the potential to overcome these limitations, since it consists in a faithful reproduction of the wavefront that irradiates from the scene. However, due to the complex setup needed for their recording, and especially due to the static nature of the holographic plates, analog holography isn't suited for consumer-level, interactive applications. Computer generated holography (CGH), on the other hand, has the potential to produce true 3D representations of both real and virtual objects, as well as holographic video through updatable displays, and even interactive applications, for multiple, moving users, without requiring any headgear. But all this potential remains confined to academic and research laboratories, due to the huge amount of data that needs to be generated, transmitted and reproduced in very high-resolution displays, in order to reconstruct the whole radiant wavefront with sufficient detail, in enough directions, to produce this effect. Techniques for optimizing CGH generation and reproduction are thus fundamental to allow their introduction into the consumer and industrial market.

1.2 The theme

Computer Generated Holography (CGH) entails rendering the digital scene's light field by densely sampling both the camera and the focal planes, which results in high computational requirements.

Interactive CGH, specifically, aims to generate digital holograms in real time, which is mandatory to enable most of the applications in scientific visualization, professional design, entertainment, medical imaging, among others. This consists in two computationally very demanding stages: densely sampling the virtual scene, by rendering it at high resolution for a huge number of camera positions, and numerically simulating light interference to produce the holographic fringe pattern [PT2,PT3,PT4].

Optimizations have been proposed to the latter stage, including horizontal-parallax only CGH [PT2], precomputation of elemental fringe patterns [PT2] and point source holograms inspired on ray tracing [PT3]. [PT8] attempted a reduced viewing zone sub-hologram, coupled with an eye-tracking system, while [PT16] proposes detail-driven holograms by selectively reducing spatial resolution such that perceived image quality remains constant.

The rendering stage, which is referred to as Massive Multi-View Rendering (MMVR), entails calculating the radiance scattered by the virtual objects for a large number of camera positions, each with high resolution, leading to the 4D light field function [PT6,PT7], and hasn't been targeted by optimization attempts. The typical approach consists in using regular and uniform sampling patterns to capture the light field [PT17]. This seems inappropriate for interactive settings due to the high loads involved [PT8,PT4]. However, light transport is locally low-dimensional [PT9,PT10], meaning that neighboring pixels exhibit some form of spatial coherence, which can be exploited to reduce the number of evaluated samples, thus reducing rendering times. Spatial coherence is often exploited in rendering algorithms [PT5,PT11], but we have no knowledge of it having been exploited in the context of CGH and over the 4D light field space.

1.3 Objectives

The goal of this PhD is to:

- propose innovative sampling strategies that allow sparse irregular sampling of the 4-dimensional space, together with the corresponding reconstruction filters to allow artifact free holographic fringes computation from the undersampled data [PT12];
- exploit temporal coherence, which has often been exploited in the context of rendering [PT5,PT11,PT13,PT18] but not over the light field space;
- implement parallel CGH computation on both CPUs and GPUs, which has been proposed to speedup both rendering and hologram generation [PT14,PT15,PT19,PT20], but is made a much less trivial problem due to coherence exploitation techniques that reduce the regularity and independence of workload components.

With good results on these contributions, real time high fidelity CGH of dynamic scenes should be possible.

2 External member of the thesis committee

Prof. **Pedro Moreira**, PhD in Electrical and Computer Engineering by the Porto University, Adjunct Professor and Coordinator of the Computer Graphics and Multimedia Engineering course at the Polytechnic Institute of Viana do Castelo (IPVC).

3 Pre-thesis Planning

3.1 Aims

1. To refine the problem statement, research directions and goals initially stated in the thesis proposal;
2. To acquire a solid understanding of the current problems and proposed solutions in CGH, and produce an extensive state of the art report;
3. To propose a detailed thesis plan and schedule of research activities.

3.2 Outcomes

State of the art review. This includes understanding the principles behind CGH, assessing current limitations of interactive CGH and possible approaches to solve them, including:

- techniques specifically developed to speed up CGH generation and reproduction: HPO, sub-holograms, and similar approaches;
- optimization techniques that may be adapted to the optimization of the light-field reconstruction: spatial and temporal coherence exploitation in rendering contexts, parallel processing in optimized workloads,

Deliverable: part of the pre-thesis report (off which the state of the art review in the thesis will be based)

Library for CGH basic functionality. After the acquisition of theoretical knowledge about CGH generation, a set of algorithms will be collected to provide the base functionality that will afterwards be optimized as described above. Among these tools are transforms such as Fourier, Fresnel, sampling strategies and patterns of camera geometry and placement, and similar building blocks necessary for CGH production.

Deliverable: CGH library and respective manual

4 Free Option Planning

4.1 Aims

1. To become proficient in parallel processing and programming principles and techniques, a fundamental topic for the proposed plan of doctoral studies.
2. To become acquainted with sampling and reconstruction theory and with its applications to Computer Graphics

4.2 Outcomes

Parallel Processing and Programming. Study of parallel processing paradigms and metrics [FO1]. Theory and practice of parallel programming for two main architectures: distributed memory message-passing systems and multi-threaded multi-core shared memory systems [FO2]. The former will be illustrated by using MPI [FO3], whereas the latter will use two different technologies: Intel TBB for multi-core Central Processing Units [FO4] and NVIDIA CUDA for many-core Graphics Processing Units [FO5].

Deliverable: report and exercises on parallel programming;

Sampling and Reconstruction Theory. Acquaintance with signal processing, sampling, reconstruction, the Fourier Transform and its derivatives [FO6]. Applications to Computer Graphics [FO7, FO8 (Chapter 7)] and quasi random sampling [FO9].

Deliverable: report on sampling theory;

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Declaração de Aceitação

Para os devidos efeitos declaro aceitar a responsabilidade da orientação dos trabalhos conducentes ao grau de Doutor do **Waldir Spencer Pimenta Lima**, no âmbito do Programa Doutoral em Informática conjunto das Universidades do Minho, Aveiro e Porto.

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