DREAMSPACE: A PLATFORM AND TOOLS FOR COLLABORATIVE VIRTUAL PRODUCTION

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ABSTRACT

This paper describes the concepts and results implemented by the European FP7 Dreamspace project. Dreamspace is developing a new platform and tools for collaborative virtual production of visual effects in film and TV and new immersive experiences. The aim of the project is to enable creative professionals to combine live performances, video and computer-generated imagery in real-time. In particular the project has developed tools allowing on-set manipulation of 3D assets, live integration of video feeds from tracked cameras and live-compositing of either CGI content or background plates from panoramic video, captured by Omnidirectional video rigs. The CGI content is lit by automatically captured studio lighting using a new real-time global illumination rendering system. Furthermore, Dreamspace is investigating the use of omnidirectional video and 3D assets in new immersive user experiences.

INTRODUCTION

The film and TV industry is seeking ways of producing audio-visual media that combines the real world, CGI and 3D animation in ever increasing quality but at lower cost. The use of CGI in movie and TV productions has reached a degree that makes it hard to identify what parts of a production are real and which are virtual. However, the traditional two-phase approach of on-set filming and integration of visual effects later in a post-production phase has proven to be a major bottleneck in terms of creativity and cost-effectiveness.

The European FP7 Dreamspace project (1) has developed new techniques and workflows to provide full creative control over the virtual (computer-generated) components in production with real-time visualisation, and continuity of the data and creative decisions through to post-production. This includes: intuitive on-set manipulation of 3D assets; live camera tracking and compositing with depth for visualisation; and capture of on-set lighting and real-time global illumination rendering to harmonise real and virtual elements. All this is done with panoramic video to provide low-cost photo-real environments. The project has also explored the impact on film production and the cross-over to create new immersive experiences for live performance and installation art using emerging head-mounted displays and head-tracked projection screens.

This paper introduces the concepts that have been developed in Dreamspace. It combines leading research and commercial organizations in imaging, visual production and creative experiences, having a total of seven partners. The text provides an overview, followed by a more detailed description of the data capture and processing, the collaborative virtual production environment and an overview of some of the creative virtual productions carried out in the project.

OVERVIEW

Dreamspace has created an end-to-end pipeline for data capture, processing and rendering with control of virtual elements to produce a visualisation environment for use on set in both film and TV. It can also be part of an immersive space for installation or performance art.

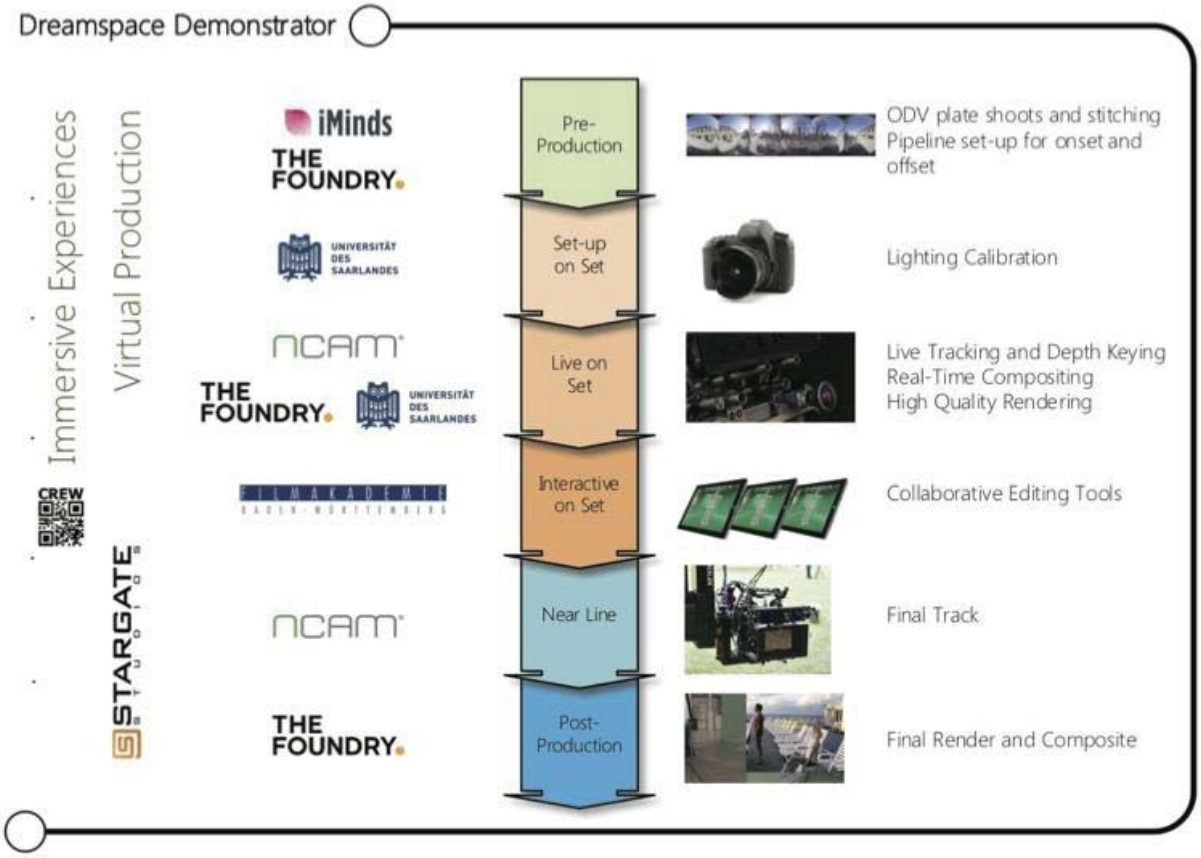

Figure 1 shows how the technologies fit a conventional production pipeline with capture of video back-plates using: omni-directional video camera rigs; on-set capture of light models to harmonise real and virtual lights in rendering; real-time integration of real and virtual elements through live camera tracking with depth capture; high-performance global illumination rendering and real-time compositing for live visualization; collaborative editing tools to control digital content; and finally, data continuity through to post-production to deliver the final camera track and final composite.

The technologies and prototypes focus on providing greater control, streamlining the workflow and pipeline, connecting the different phases of production and delivering high

quality content at a lower cost. These targets span virtual production and the performance arts, where the challenge is the same - how to enhance creativity and experimentation through real-time visualization and interaction with accessible tools and workflows.

DATA CAPTURE AND LIVE VISUALISATION

Real-time camera tracking and depth capture

In virtual production today, live-action foreground elements are visualised in real-time with a CGI background to allow the director and director of photography to make creative decisions on shot framing, lighting and timing. Live visualisation systems require a specialist studio with a chroma-key background to separate the foreground elements and camera tracking to render the CGI background. The preview is usually restricted to a simple live-action overlay. In Dreamspace, a real-time camera tracking system with live depth capture has been developed to allow integration of live-action content inside a virtual set with dynamic occlusions between real and virtual elements. The system works in natural scenes, potentially removing the need for a dedicated studio and green screens, to make virtual production techniques accessible to a range of productions.

Figure 2 – Live depth capture

Two approaches to live depth capture have been developed using the *ncam* camera bar as the only hardware. The first prototype focuses on regular blue or green screen studios. It uses the known background to separate the live action elements and compute the corresponding depth information. This supports dynamic occlusions in existing virtual production studios. The second prototype has been designed for uncontrolled backgrounds. It iteratively computes a 3D model of the static scene geometry. As the camera is tracked, the live action elements are separated to provide depth measurements for moving elements together with the static background. This supports live depth capture in natural scenes.

The real-time system on set needs to be robust, reliable, accurate, easy-to-use and with minimal latency to fit within existing film pipelines. A post-processing technique has been developed to deliver a final match-move camera ready for post-production using the data recorded from set. This removes the need for dedicated match-moving in post production.

Live on-set compositing

On-set visualisation provides a live preview to assess shot composition. Final visual effects are then typically created in post-production using separate offline tools that allow artists complete control over the look and integration of real and virtual elements. In Dreamspace, a live visualisation system has been developed that allows the virtual set and the live composite to be prepared using conventional post-production tools, with exactly the same pipeline and results available both on-set and in post production.

The live compositing system supports an arbitrary graph of user-defined image processing operations created in Nuke[1]. A heterogeneous scheduling system has been created to make optimal use of hardware in the on-set system. The scheduler distributes data processing to CPU and GPU devices to maximise the frame-rate. The system provides the flexibility to switch and modify the composite live on set. This is then passed to an offline pipeline that is designed to deliver the final integration of real and virtual elements based on the RGB + depth data recorded from set. An image-based matting technique has been developed to automatically estimate the opacity at the boundary between depth layers in the scene. This allows virtual elements to be integrated seamlessly without the need for manual rotoscoping or green screen keying.

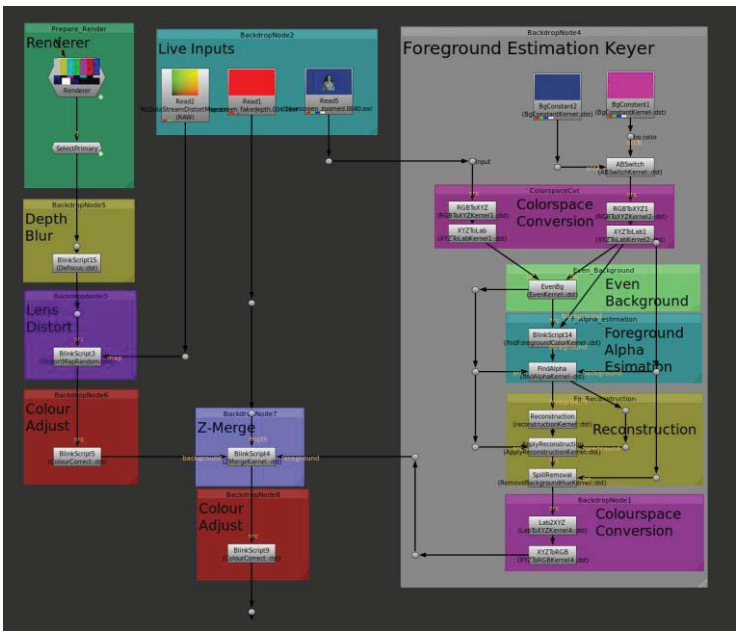

Figure 3 - Live compositing supports an arbitrary graph of user-defined operations

Real-time rendering with global illumination

Live visualisation requires real-time rendering which typically restricts the quality that can be achieved on-set. In post-production, global illumination is used to create highly realistic virtual scenes but at the cost of many hours to render a single frame. In Dreamspace, a framework for high-performance global illumination rendering has been developed with a scalable distributed architecture, to achieve final quality rendering in real-time on-set.

Figure 4 – The San Miguel scene rendered with global illumination in *LiveView*

Ray-tracing routines have been developed using AnyDSL (4), a compiler framework for domain-specific libraries (DSLs). Current state-of-the-art frameworks for rendering provide low-level routines that are optimized and tied to a single platform such as Embree from Intel or OptiX from NVIDIA. AnyDSL allows mapping of ray tracing routines to different hardware platforms using code refinement and partial evaluation (4), making best use of the available hardware resources. We achieve the

[1] http://www.thefoundry.co.uk/products/nuke/

same performance – in some cases even slightly faster - than the highly hand-optimized implementations from Intel and NVIDIA on a single node. Rendering is distributed over multiple nodes in a cluster with load balancing to account for varying scene complexity to achieve real-time performance. We have implemented three algorithms for light simulation on top of the low-level ray tracing routines. Figure 4 shows the scene 'San Miguel' rendered in *LiveView* using Path Tracing. As an alternative, the renderer can also use Bidirectional Path Tracing and Vertex Connection and Merging as rendering algorithm. Additionally, it supports live scene updates coming from *LiveView*.

COLLABORATIVE VIRTUAL PRODUCTION ENVIRONMENT

Virtual Production Editing Tools (VPET[2])

Virtual studio systems require highly technical and dedicated tools to control the on-set environment. In Dreamspace, we have developed a holistic approach for collaborative tools that allow on-set light, asset and animation editing via an intuitive interface. The Virtual Production Editing Tool (VPET) is a tablet-based on-set editing application that works within a real-time virtual production environment. It is designed to run on mobile and head-mounted devices (HMD) allowing easy access to edit parameters of virtual objects (set, lights, animation) without dedicated training. VPET provides live editing of assets in the film pipeline synchronized across all VPET clients and Digital Content Creation (DCC) applications through a network interface.

Figure 5 – (upper) VPET during live production at Filmakademie and (lower) early prototype using HMD and gesture recognition sensor

The client application is realized using the Unity framework. Figure 5 (bottom) shows early versions with HMD and gesture approaches, evaluation (2) of those have led to using tablets in the current versions. Working with VPET does not require a dedicated export procedure. The scene only needs to hold a medium resolution representation of the geometry for playback on mobile devices. VPET connects to the central production system which streams the scene automatically to the clients. Authoring of content is realized through the established Katana[3] software for appearance (look) development and lighting. Using Katana maintains an established film production pipeline for real-time, collaborative use in virtual production. VPET is not restricted to one central production system. The scene distribution can be easily adapted to any DCC application. VPET clients can communicate to other hardware

[2] http://vpet.research.animationsinstitut.de/

[3] http://www.thefoundry.co.uk/products/katana/

used in virtual production such as the *ncam* tracking system for display of the primary camera view directly on the VPET client. Latest hardware like Google Tango enables users to explore the scene interactively. VPET is released as Open-Source software and is seeking active participation from interested individuals, research groups and companies.

Light capture and control

Creative control and understanding of the virtual environment requires the connection and harmonisation of real and virtual elements with easy-to-use interfaces and controls. Dreamspace has addressed the harmonisation of real and virtual lights, to assess the impact of physical lights in the virtual environment and also to control the physical lighting to match a virtual configuration.

Real light sources are captured with a high-dynamic range (HDR) light-probing device. We use a tracked camera equipped with a fisheye lens (Figure 6 left) to capture lights from a number of positions, typically taken on a sampling grid (e.g. one probe every 1m). From these samples our method can automatically compute the position and intensity of point lights and direction and fall-off characteristics of spot light sources (3). The computed light parameters are communicated to the Dreamspace renderer so that the virtual scene can be rendered with the same lighting as the real studio lamps (Figure 6, right). These estimated light sources can be edited in the virtual scene using the VPET editing tools, and the changes are then sent back to the real lamps via a DMX controller interface to update the studio lighting. This gives creative professionals direct control and feedback of the combined real and virtual lighting, and the possibility to try out and edit the lights and make creative decisions directly on-set.

Figure 6 - Light probing device (left), image of reference object (middle) and rendered image of the object with estimated lighting (right)

Filmed immersive spaces

The construction of virtual environments is a high-cost process requiring teams of artists to create highly realistic digital assets. Dreamspace has addressed the low-cost capture of real environments as virtual sets, using an omni-directional camera rig and free-viewpoint rendering to support novel viewpoints. Dreamspace has also developed techniques to capture the geometry of a physical space to act as a display surface for multiple projectors. This allows the projection of filmed environments in novel spaces to create a true holographic display, without the need for a head mounted display.

A high-resolution modular camera system has been constructed to support either 360° capture of real environments, or panoramic capture for a 180° view in a defined direction. New techniques have been developed based on reconstructed scene depth to create a single seamless video back-plate from multiple views, and also to synthesise novel viewpoints to support free-viewpoint visualisation (5). The calibration of a physical space as a display surface is based on the projection and 360° capture of a calibration pattern in a target space. The calibration step defines the warping required for a multi-projector system to produce a seamless view of a film environment for a spectator at different positions in the space.

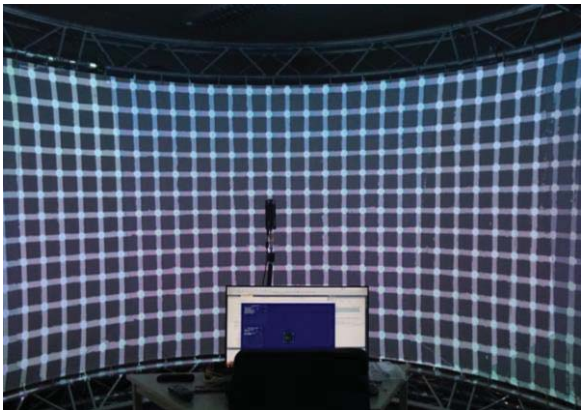

Figure 7 – Calibration of a multi-projector system to create a seamless immersive 360 view

CREATIVE VIRTUAL PRODUCTIONS

The Dreamspace project focuses on making the creation and manipulation of virtual content simpler and easier, so that it becomes a more creative process. A *LiveView* visualisation system has been developed that connects to the conventional film pipeline, with real-time tracking, live compositing with depth, real-time global illumination rendering, view-dependent video and intuitive tools for on-set control. These technologies have been tested and validated in real contexts through a series of creative productions that explore the application in film as well as installation and performance arts. This section describes a few of the productions explored in Dreamspace.

Skywriters Production

Skywriters is a documentary film of a family business for sky advertisement. The project was a collaboration with the Institute of Animation at Filmakademie Baden-Württemberg, and made use of the *LiveView* system for shot planning, visualisation and interactive manipulation of animation. The director had no previous experience with virtual production technology. After a short introduction he was able to direct digital assets and animation using a VPET tablet in agreement with the director of photography to design the shots. Figure 8 shows the *LiveView* display as part of the interactive shot planning session. The biggest bottleneck that was found was the scene preparation for the film

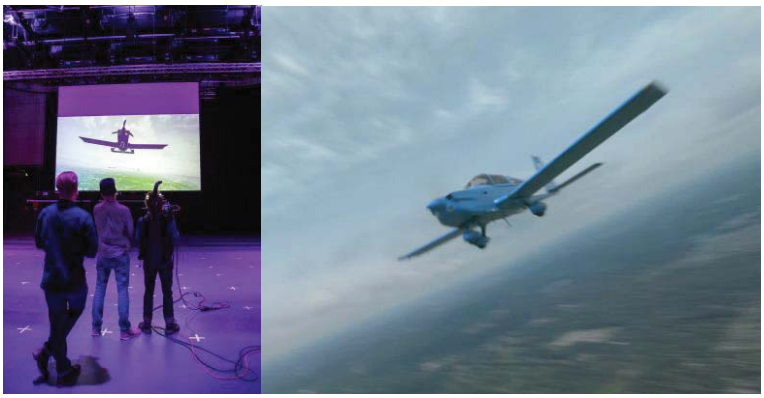

Figure 8 – Virtual Production *Skywriters*, CGI final shot

pipeline. The setup was evaluated as 'very intuitive' and with a high potential to increase creativity.

Immersive Display

One of the ambitions in Dreamspace is to immerse the viewer inside a space, without the need for a head-mounted display. This was first demonstrated at CVMP 2015. The *LiveView* system provided a virtual window (Figure 9) onto a captured environment for a tracked viewer, with virtual elements that could be controlled using the VPET tools. The environment was captured using the modular camera array, with offline rendering of novel views for real-time playback. The concept worked well to interactively adjust shot framing for film production, but additional cues are needed to create the illusion of immersion such as a zero latency stereoscopic display.

Figure 9 - Viewer's perspective.

Absence Performance

Another Dreamspace ambition is to research the possibilities of applying Virtual Production technologies in live performances, to tell stories in new ways, create new experiences and even to allow audiences to become part of the story. In *Absence*, a virtual environment was brought on stage using the Dreamspace multi-projector system to manipulate reality. A blend of real and virtual objects was created by projecting virtual content onto both the physical set and the performers, who were tracked using a motion capture system. The concept worked well since the illusion of 'reality' was supported by the use of real-world objects and an accompanying narration.

Figure 10 - 'Absence' with set reconstruction, virtual texturing, lighting, augmented transparency and augmented performers tracked using real-time motion capture suits

CONCLUSIONS

Virtual Production today is utilizing more and more rapidly emerging technologies and new workflows for greater creativity and efficiency. There are two constant pressures, the

financial demand for more cost-effective productions, and creative demand for greater flexibility and assessment on-set. In addition is the demand from audiences for more advanced story telling. In the creative arts, the demand again is for tools and technologies that enhance creativity and experimentation but at a cost that makes these techniques accessible in a wide range of contexts.

The Dreamspace project has developed key innovations that advance the state-of-the-art in conventional virtual production: real-time depth capture for natural environments, heterogeneous computing for real-time compositing, distributed real-time global illumination for high quality rendering, capture of physical lights to harmonize real and virtual elements, capture of physical spaces to create projected immersive environments, and intuitive tools to control digital assets connected to conventional film pipelines. These innovations have focused on making these techniques more accessible to a range of budgets, removing the need for a dedicated studio or a green screen shoot, automatically delivering final quality tracking, compositing and rendering and integrating with live performance environments. The hope is that these tools will artistically, practically and financially open up virtual production techniques to a range of productions and immersive experiences.

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