Future Generation Computer Systems 27 (2011) 935–943

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

# A collaborative computing model for audio post-production

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ARTICLE INFO

*Article history:*
Received 9 March 2010
Received in revised form
21 December 2010
Accepted 3 February 2011
Available online 18 February 2011

*Keywords:*
Post-production
Audio
Virtual organization
Collaborative computing
OptIPuter
CineGrid

ABSTRACT

Networked systems for audio post-production provide solutions to several persistent problems in the cinema industry. By enabling remote collaboration between media professionals, networked computing increases efficiency and reduces costs. This practice creates a virtual organization in which media and media editing devices are tightly synchronized between remote locations. An experimental system meeting these needs is described. Two successful demonstrations of this system have taken place, in which media assets and control information were streamed between several locations using a secure managed network. The practicality and decreasing expense of this system have led many to predict its widespread adoption in the near future.

Published by Elsevier B.V.

## 1. Introduction

Contemporary practices in cinema post-production are dependent on long-distance travel between studio installations, location shoots, and media review facilities. Audio and video assets are physically transported, often via airplane, from one site to another. Beyond the monetary and environmental costs of this practice, it discourages collaboration between remote media professionals, introduces security risks, and adds delays to projects that are frequently behind schedule. The problems associated with a geographically fragmented film industry make a networked post-production environment, in which media is streamed in real time between remote facilities, very appealing.

In this paper, we present a networked system, a "virtual studio", for post-production of audio for film. The primary purpose of such a system is to enable real-time collaboration between members of creative teams who are not collocated. There are two primary areas in which this type of collaboration would be valuable to the film industry. The first is review and feedback. Media projects tend to be dominated by a single individual, or a small group of individuals, who exert primary creative and quality control over the project. In current practice, this individual, whether director, producer, or composer, regularly reviews work-in-progress from each division working on the project. Without a robust networked post-production system, the work-in-progress must be physically delivered to the director, moving among many locations usually via encrypted portable hard drive. As an alternative to physically moving works in progress, sometimes low-quality compressed proxies are used. The director reviews the work, comments on it, and communicates those comments back to the division in question. However, even if this communication is in real time (e.g. via telephone or video conferencing) the changes cannot be immediately made and observed. The creative team has to make the changes offline and deliver a revised version of the work-in-progress for approval and further comments. By introducing a system through which the director can see and hear the changes being made in the remote studio in real time, the efficiency of the review and feedback process is greatly improved. The work-in-progress is streamed live to the director, the director comments using a video conferencing system, the remote creative team makes the suggested changes immediately, and the director can approve or suggest other options without delay.

The second area in which real-time remote collaboration would be valuable is cross-modal collaboration. In the post-production industry, current practice is to divide the required tasks between several different groups, many of which are physically remote from one another. For instance, one group will work on film editing, another on color correction, a third on dialog, a fourth on visual effects, etc. These groups usually have minimal interaction with one another before their work is integrated at a later stage in the production cycle, and interaction between video and audio-related teams is particularly uncommon. However, fruitful collaborative relationships can emerge when interaction between

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0167-739X/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.future.2011.02.005

remote creative teams is enabled, while maintaining access to their familiar human and computing resources and environments. An example is collaboration between film editing and sound effects editing teams. In film editing, the many takes and camera angles captured on set are combined into a single version of the scene. Among other things, the film editor is responsible for organizing the time elements of the movie, including the lengths of particular shots. The sound effects editor selects the sounds meant to represent action in the scene, and aligns those sounds with the visual elements to which they are linked. However, the sound effects editor is restricted by the choices the film editor has made with regard to timing. With remote collaboration, the sound effects engineer and the film editor can work together, each in his or her own studio, and balance the sound effects options with the timing and rhythmic ideas of the film editor. Since sound and picture studios are traditionally housed separately, this level of collaboration has not usually been possible.

Several problems have hampered previous efforts to achieve similar remote collaborations. Historically, remote collaboration for audio post-production has been dominated by Integrated Services Digital Network (ISDN) connections [1]. The robustness, low jitter, and low data loss resulting from point-to-point connections via ISDN have made it appealing, but its low bandwidth, forcing the use of compressed audio, and high cost mean that ISDN is not a practical replacement for physical transportation of assets and cannot enable fully effective remote collaboration. In particular, the use of audio compression often introduces audible artifacts, meaning that decisions made via such a system could only be considered tentative, to be confirmed by offline review of the original assets. The encoding and decoding of compressed audio also adds latency to the system, making real-time remote collaboration more difficult; current industry standards recommend less than 150 ms one-way latency between nodes to allow near-transparent interactivity [2].

With the widespread availability of low-cost high-speed Internet connections to businesses, IP-based media streaming becomes a possible alternative to ISDN for long-distance streaming. Lack of sufficient bandwidth and guaranteed quality of service over the traditional Internet means that, as with ISDN, streaming uncompressed audio is typically not practical. However, with the increasing availability of dedicated 10 Gbps optical connections, it is possible to guarantee greater quality of service and higher bandwidth availability, making IP-based audio streaming systems a viable alternative to ISDN. Previous work in IP-based audio streaming has focused on uncompressed audio for live interactive musical performance [3,4], compressed audio for broadcasting applications [5], or remote audio-only recording environments [6]. However, none of these systems has focused specifically on the needs of the audio post-production community. Also, they typically have not addressed the problem of the precise audio–video synchronization required for reliable playback. For example, a sound effect that corresponds to a particular action on screen must be properly time-aligned even after remote streaming, or the scene cannot be reviewed accurately. Nor do these systems allow remote control of computing resources, an important function which would allow audio engineers to work on the same material from multiple different locations, depending on the current needs of the project.

As described below, our system leverages the post-production industry's increasing access to high bandwidth managed networks to overcome many of these obstacles. Our work builds on advancements in long-distance media streaming of uncompressed multi-channel audio and 4K video [7] by applying collaborative computing models to media post-production. These advancements enable integration of uncompressed streaming audio, remote control of computing resources, and extremely tight synchronization between audio and video. Real-time communication is achieved using video conferencing side-channels. Although most of the technology used in our system is not new, we are deploying it in novel ways; ours is the first use of many of these individual pieces of technology over wide area networks, including our streaming audio unit and our method for remote synchronization of audio and video editing devices. We have also developed an original approach to remote control of mixing resources for audio.

Beyond allowing collaboration between studios on a project basis, a collaborative model for cinema post-production must reflect real-world needs and therefore hold the potential to encompass many simultaneous projects involving competing studios in order to be economically viable and universally adopted. With that in mind, we have worked to ensure flexibility in system topography, and have begun investigating decentralized management tools to guarantee security and equitable access for eventual industry-wide adoption.

## 2. A collaborative computing system for post-production

As described above, the primary requirement for a remote audio post-production system is to enable remote collaboration between media professionals. This means that high-quality, low-latency audio must be streamed between locations, in some cases along with production-quality video; audio must be closely synchronized with video originating either locally or remotely to allow correct alignment; low-latency, robust video conferencing equipment must allow near-transparent side-channel communication between nodes; and keyboard, video, and mouse (KVM) control over remote computing resources should be available.

Besides enabling remote collaboration, a networked post-production system has a few other requirements. First, it should enable active collaboration between three or more nodes. Although most use cases involve simple point-to-point connectivity, scenarios exist [8] in which assets from several different locations must be combined. In many cases, connections should be fully duplex, allowing users on any node to control computing resources and media assets on any other node. The industry-wide adoption of such a system would also require a given node to be able to simultaneously connect with multiple remote nodes to accommodate several concurrent post-production projects, allowing projects between many different production and post-production studios to exist in parallel.

The deadline-driven nature of media work and the expense of delays mean that a networked post-production system must be robust. A system with high packet-loss rates and frequent dropped connections would be unusable, particularly since traditional ways of recovering from packet loss, such as the use of TCP rather than UDP as part of a streaming protocol, are not conducive to uninterrupted real-time media streaming. Therefore, collaborative media work requires a well-managed network providing very low packet-loss and redundant systems to guard against failure.

Also, given the flexible, project-oriented nature of the post-production industry, all connections should be considered temporary. When a post-production studio is contracted to work on a movie, they enter into a relationship with a group of other entities, including the main production studio and other post-production facilities. This particular grouping will not be permanent, and may coexist with other media projects that have contracted with the post-production studio. The body of connections that are in use at a given point in time is dynamic; as projects begin and end, the collaborative needs of the facility will change.

### 2.1. The post-production industry as a virtual organization

Given that a networked post-production system requires the seamless integration of computing assets and resources at many