Figure 1: Ethnographic study at the OB truck of Wembley Stadium (top) and Kingsmeadow Stadium (bottom), Uk

From the Lab to the OB Truck: Object-Based Broadcasting at the FA Cup in Wembley Stadium

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ABSTRACT

While traditional live-broadcasting is typically comprised of a handful of well-defined workflows, these become insufficient when targeting at multiple screens and interactive companion devices on the viewer side. In this case study, we describe the development of an end-to-end system enabling immersive and interactive experiences using an object-based broadcasting approach. We detail the deployment of this system during the live broadcast of the FA Cup final at Wembley Stadium in London in May 2018. We also describe the trials and interviews we ran, the infrastructure we used, the final software developed for controlling and rendering on-screen graphics and the system for generating and configuring the live broadcast-objects. During this process, we learned about the workflows inside an OB truck during live productions through an ethnographic study and the challenges involved in running an object-based broadcast over the Internet which we discuss alongside other gained insights.

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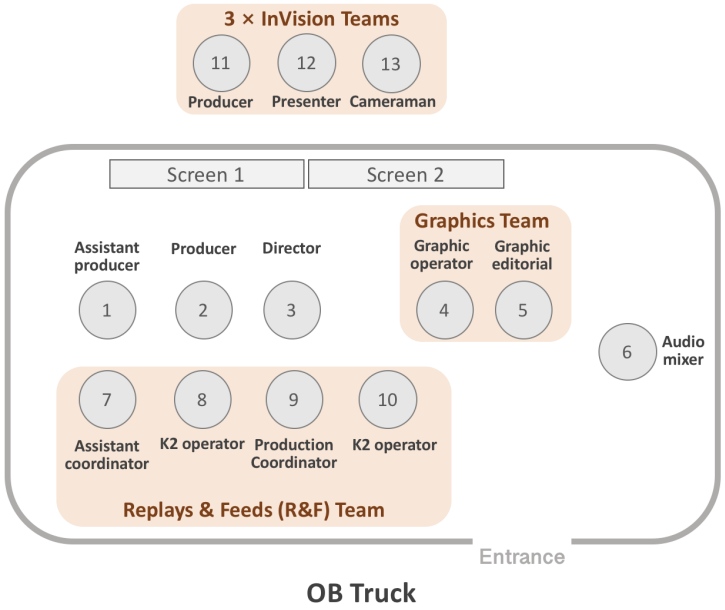

Figure 2: Layout of a typical OB truck used at a live sporting event

CCS CONCEPTS

• **Human-centered computing** → **Field studies**; Graphical user interfaces; Empirical studies in HCI;

KEYWORDS

Field study; user interface design; networking; object-based broadcasting; second screens; immersive experiences

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INTRODUCTION

Live sport events are at the core of the television industry, since it brings the viewers close to the experience and enables them to enjoy the excitement of the event. The liveness is essential and irreplaceable by time-shifted on-demand viewing such as on Netflix [9]. However, due to the unpredictable characteristics of a live sport event, this is challenging for the production team, also because the event does not take place in a studio. Live outside broadcasts are a world of well-defined workflows to deal with time-critical tasks. The roles inside an outside broadcast (OB) truck at a live sport event are divided by task, to capture the event while minimizing delays and mistakes (Figure 1). Therefore, it is important that any software designed to supplement the workflow in an OB truck should be easy to operate, facilitate the collaboration within the production team and guarantee timely delivery of the live broadcast.

This case study presents the development and successful deployment of an end-to-end platform for interactive, immersive broadcast at a live sports event. In particular, we detail the requirement gathering phase, the aspects of the system used during the broadcast, including *a graphics compositing application*, a so-called *Live Triggering* tool for inserting broadcast objects into live streams, the camera setup, real-time encoding of video feeds and content distribution over the Internet. We show the path from a rough first prototype to a complete multi-user platform with hardware integration. Finally, we also present a series of trials and experiments that were completed along the way, culminating the final deployment of the system at the FA Cup final at Wembley stadium in London in May 2018. There, the platform was used to support a test-broadcast of the football match, delivering the experience to a number of viewers at their homes.

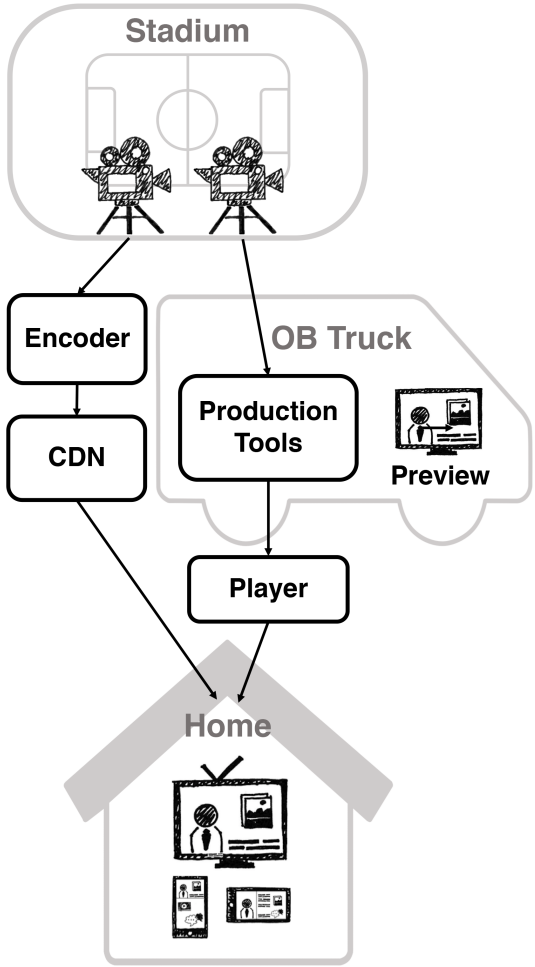

Figure 3: Production process for a live broadcast with our production platform

At a big sports event such as this, an Outside Broadcasting (OB) truck is the most common unit for live broadcasting. With its mobility, OB trucks can access any location and work as a drive-in temporary production control center during live transmission, providing complete video and audio facilities (Figure 2). An OB truck typically has a wall of monitors shared by all the staff in the truck. A video production switcher controlled by the director, audio mixer, a team in charge of recording and playback decks, and a team responsible for live graphics and so on. It enables the production team to bring the TV audience an authentic visual representation of an event as it is happening [10]. OB trucks vary in sizes depending on the scale of coverage and the nature of the event. For a sport event, the coverage includes dozens of stationary cameras, a couple of handheld cameras, cameras on motorcycles to capture the main athletes and one or two helicopters with cameras to shoot the *long-shot* of the scene [7, 10]. Today, the production team on OB trucks orchestrate smoothly to deliver the same linear live program to all kinds TV screens. The team typically follows a pre-scripted *running order document* that defines in detail where graphics, visual sources and sound come from and when they should be *on-air* [7].

As companion screens (e.g. smartphones and tablets) continue to be integrated into standard television, a challenge the production team facing is to tailor the content of the TV program so that it works for companion screens as though it had been uniquely created for them. Content on companion screens is customizable to provide audience access to additional information next to the TV screen, thus enabling interactive and immersive TV viewing experiences [2, 4]. However, given the current workload of the live broadcasting on OB trucks, it is difficult to deliver additional versions of the program to companion screens. New technologies are required for this purpose [1, 7]. One such technology is *object-based broadcasting* (OBB). It allows the content of a TV program to adapt to the requirements of different viewers on multiple companion screens, without requiring the production team to separately produce different versions of the program. The *object*, here, refers to different media assets or content objects that are used to make a TV program [1]. The OBB approach involves breaking down a program into separate objects, typically graphics, audio, video, background music, dialogues, subtitles, sound/visual effects, etc., and including metadata to describe how these objects can be assembled on multiple screens. It enables the creation of a flexible, personalized, and responsive program without increasing the production workload [1, 6]. A rough layout of the production process using our OBB system can be seen in Figure 3.

PREPARATION

Previously, we have reported successful groundwork for the design and development of a novel object-based broadcasting platform [6–8]. Our next objective was its deployment during a live event like the FA Cup Final 2018 in Wembley. To better understand the challenges of delivering such a trial at a live football match broadcast, the authors negotiated (via BT Sport) to allow observation for

Figure 4: Timeline of the deployment of our end-to-end platform

better understanding of the current workflow involved at an OB truck. In particular, the following events were observed:

- FA Community Shield match at Wembley Stadium on Sunday 6^{th} August 2017, where access was granted only to one match truck. This event provided us with an overview of the director's role in creating the broadcast mix of video, graphics and commentary narrative for the match;
- Women's Super League match at Kingsmeadow Stadium on Thursday 1^{st} February 2018, where access was granted to observe and record inside the OB truck. A number of GoPro cameras were used to capture the pre-broadcast preparation and live broadcast activity within the main gallery of the truck. These videos were composited into a synchronized quad view video along with the broadcast output.

The capacity afforded by Wembley Stadium in terms of connectivity, as well as physical gantry and production space, made it the preferred option as an event venue. In addition to the more ethnographic observations detailed above, the research team, working closely with the Chief Engineer and production team at BT Sport, was allowed to run live tests during two matches at Wembley on 22^{nd} April 2018 (FA Cup Semi-Final) and on 12^{th} May 2018 (National League Play-Off Final).

Such observations and tests resulted in a number of requirements, anticipating operational and technological risks. Such requirements included, for example, the creation of a number of documents such as the call sheet and the team sheet (for pre-populating the graphics with the correct player names one hour before the beginning of the match). The requirements covered as well technological aspects, such as the pre-production of the assets, the development of the infrastructure to be deployed at the venue and in the cloud and the access to various data channels such as the clean video data feeds. Finally, there were other operational guidelines for, for example, granting access to the researchers or colocating our mini OB truck in the OB Compound with the other broadcasters. The following subsections will detail the different preparation steps before the official match day.

Graphics

Object-Based broadcasting provides user-level personalization and it thus requires all broadcast graphics (non-video visualizations overlaid on top of the video) to be directly composited on the client device. This is a major shift from traditional broadcasts, where all graphics are overlaid at the OB Truck, making the creation process for such graphics quite cumbersome and time consuming. The design of these graphic elements and animations is thoroughly defined and specified down to pixel perfection. We tried to adopt a workflow common in traditional TV stations and networks, which meant that a new purpose-built WYSIWYG design tool was needed. Since there was no time and resources to create one, the short-term solution was to adapt an existing one from ChyronHego's

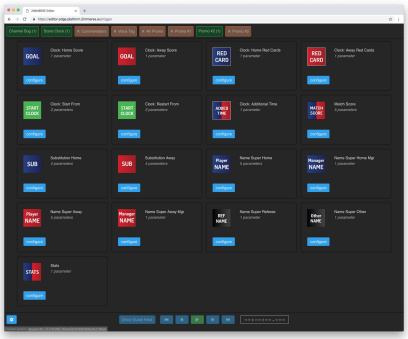

Figure 5: Triggering tool in operation inside a web browser

Figure 6: Trigger launcher (top) and hardware device *StreamDeck* (bottom) for operating it more conveniently

product range. The researchers extended the existing broadcast graphics authoring tool *ChyronHego Prime* with a compatible renderer, making it usable within our object-based broadcast infrastructure.

Production Tool

Previous work of the research team resulted in a novel model and workflow for production tools that allow for object-based broadcasting [5, 7]. The tools were intended for covering MotoGP races, but we had the intuition that they could be adapted for football, and other sports as well. We thus arranged a number of conversations with professionals working on TV sports broadcast and carefully observed the recordings from the OB truck at the FA Women's Super League football game. Drawing on the focus groups and the observations, we concluded that our previous work was a good starting point, but required some modifications. First, all controls should be easy to manipulate and to target. Second, the person preparing the content for, for example, replay clips is not the same one as the person who decides when and if the content is inserted into the broadcast. The former task is shared by several people, whereas the latter is usually performed by either the director or a vision mixer. Finally, we learned that in the truck there are a lot of special-purpose hardware devices with big buttons and dials, providing quick access to specific functions.

Based on the new requirements, we designed a new version of our live triggering tool, diving it into two sub-tasks, each one targeted at a different professional (Figure 5). The first tool, called *Triggering Tool* allows to prepare media related to the events, such as replay clips or inserting on-screen labels and queueing them for the director to launch. The second one, called *Trigger Launcher*, intended for the director, can be used for launching the events when ready, i.e. inserting them into the broadcast. For the second one, we were able to integrate support for *StreamDeck*, a hardware device intended for video-game streamers. The device is equipped with 15 hardware buttons, where each button is backed by a 72x72 pixel LCD screen, plugged into the computer via USB (Figure 6). This enabled us to map the events rendered in the trigger launcher application onto the buttons, allowing the user to conveniently launch and modify events quickly from this console instead of having to use the mouse and click the corresponding button on the computer screen.

OBJECT-BASED BROADCASTING DURING FA CUP FINAL

After the preparation work described in the previous section, the research team was (almost) ready to bring a unique football experience during the FA Cup Final at Wembley Stadium to people's homes. The football experience was to be a unique, object-based broadcast, since a multitude of media objects could be assembled in a personalized manner and rendered on different screens at home: a single primary shared screen (main TV) coupled with a companion device such as a tablet (Figure 7).

The deployment at Wembley Stadium was centered around our very own OB vehicle, a Mercedes Sprinter van fitted with two small work areas and basic services such as power, cable routing, air

Figure 7: Experience at home as viewed by an end user: television screen (top), tablet (middle) and user-customizable screen configurations for companion screen (bottom)

conditioning and lighting. This vehicle was essential as a space to safely host and operate the additional components required for object-based broadcasting. The vehicle was provided by BT Sport supplier Telegenic, who also provided personnel to support the research team. The Telegenic team provided essential assistance for gaining access to the necessary infrastructure and live feeds and provided a listen-only feed of the Match Director's talkback channel within the vehicle. This enabled the team to hear and follow the majority of vision and graphics cues given by the director throughout each match and thus test the object-based production tools in a representative way. The following paragraphs detail the different components deployed during the day of the match.

Live Camera Feeds. The project team requested access to a range of live camera feeds. We had access to the clean and dirty (Match Director's output) broadcast feeds, the main camera-wide shot, the manager cameras, the team benches, the LH and RH High behind, and the Spider cam. Each camera feed was provided in HD-SDI format in a separate coaxial cable routed from the BT Sport production truck to the vehicle.

Live Encoding. Two live streaming encoders were loaned for the duration of the tests by BT supplier AWS Elemental, who also provided technical assistance with configuring them and resolving issues. Each encoder was capable of live encoding a multi-layer DASH representation of 8 HD-SDI input streams. Once encoded, the DASH segments were uploaded to the CDN Origin Server, from where they could be consumed by the client applications. Given that the FA Cup Final match was simultaneously broadcast free-to-air in the UK, it was agreed that stream encryption need not be used, but instead access control was applied to the Origin Server so that client apps were required to authenticate before they could download the stream.

Internet Uplink. Using additional live encoders also necessitated providing Internet uplink capacity dedicated to the OB vehicle. This proved to be the most challenging dependency. To upload the 3-layer MPEG-DASH representation for 8 distinct live streams, while providing headroom for audio streams and signaling, at least 100Mbps upstream was required. Finally, we used a dedicated BT uplink.

Triggering Interface. One half of the OB vehicle was dedicated to live triggering of object-based production graphics using the production tools described above. The tools ran on a laptop PC with the addition of an Elgato Streamdeck programmable keypad. the production tools communicate with our platform services, which were hosted off-site within an Amazon Web Services environment. The production tools were modified as well to enable the preview client to display the live feed from the capture device within the primary video player component, rather than opening the delayed MPEG-DASH stream from the CDN Origin Server.

Virtual Placement. The Virtual Placement system was set up independently of the live production tools in one half of the vehicle during the FA Cup Final event. Its purpose was to enable the ChyronHego

Figure 8: The setup of the system in the OB truck at the stadium

Figure 9: Presenting the project at IBC 2018 in Amsterdam

team to test their new workflow, enabling object-based virtual graphics to be rendered in a personalised way on a viewer's client device. This workflow uses ChyronHego's player tracking technology, *Tracab*, based on dedicated networked cameras installed in a stadium to determine the location of players on the pitch at any point in time. Virtual Placement, at the same time, uses calibration parameters derived from a wide-angle camera to enable graphics to be rendered on the live broadcast feed as if they were part of the three-dimensional scene. By synchronizing Tracab player tracking data with Virtual Placement camera tracking data and streaming it to a client device, it should be possible for the client device to render virtual graphics around players as they move across the pitch - for example to provide additional statistics or a comparison between a viewer's favourite players.

Content Distribution Network (CDN). The 2-IMMERSE platform [5, 6] was the most significant off-site components, playing a vital role in the delivery of the end-to-end live tests. As with all 2-IMMERSE Distributed Media Applications, the Layout and Timeline services were responsible for orchestrating the viewer experience on the TV and companion devices. In addition, for these tests it was also necessary to orchestrate the Live Preview Client. Another crucial extension to the platform was the ability for timeline updates which were created by the Live Triggering Tool to be automatically inserted by the Editor service within the active timelines of every client context which was watching the match, while accounting for the fact that off-site viewers' timelines would be delayed by up to a minute due to large buffers resulting from the MPEG-DASH live streaming configuration.

DISCUSSION

New challenges for the industry. Over the course of the project (Figure 4), we successfully bridged the gap between lab research and key players in the production chain (e.g. BT Sports, MoovTV), motivating them to think of developing use cases or tools taking advantage of OBB. As noted by Bentley et.al. [3], the ethnographic-style field study can take new concepts to real users in early stages of development, quickly illuminating potential bottlenecks and challenges. In our trial, the first challenge was to smooth the graphics creation workflow in this time-critical environment. To do so, we used an existing authoring tool (ChyronHego Prime) with a graphical interface but an XML-based storage format, enabling a *designer* to create graphics without needing a *developer*. However, the application was not specifically designed for OBB processes. New production tools to visually create OBB assets are needed. The second challenge addressed is the usability of the live OBB production tool. A new version of this tool was separated into two parts. One part is used to prepare and queue the media assets by an assistant of the director, the other part is for the director to launch the media assets in queues. The new version is expected to reduce the workload for the director and result in a smoother workflow. The third challenge we addressed was the live delivery of the objects triggered in the OB truck to the homes of all viewers in a timely manner.

Impact on the industry. Based on the video assets collected (Figure 8), we developed a more complete and polished as-live multiscreen FA Cup demonstration, showing how production tools can be used to edit and broadcast graphics following an OBB approach. Together with the production tools, it exhibited how viewers can personalize their experiences through companion screens in home contexts. The demonstration was successfully presented at the *Future Zone* of IBC (Figure 9), the most influential media technology exhibition in Europe. It received a wide audience range including key stakeholders from the broadcast industry, academics, and production teams; all who believed "OBB is the future".

FUTURE WORK & CONCLUSION

To help integrate the OBB approach into the existing production workflow, the next step is to develop a pre-production tool with a graphical interface, to allow people without programming skills to author multiscreen TV content. The preproduction tool aims at reducing the workload of the live broadcasting by creating a hierarchical overview of the content and arranging media objects on a storyline ahead of time [7]. The prototype of the pre-production tool is expected to be tested by a group of producers and directors in the end of November, 2018. The live trial at Wembley Stadium for the 2018 FA Cup Final was a milestone to help the OBB approach to make an impact. Through observing two live football matches, the content acquisition and distribution was tested and the live production tools were refined to be able to trigger all match graphics during the match. Our objective of authoring a live end-to-end OBB experience and testing the reach and scalability of our solution was achieved.

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