

Powers Live: A Global Interactive Opera Simulcast

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ABSTRACT

The live global interactive simulcast of the final February 2014 performance of *Death and the Powers* in Dallas, Texas made innovative use of satellite broadcast and Internet technologies to expand the boundaries of second-screen experiences and interactivity during a live remote performance. In the opera, the character of Simon Powers uploads his mind, memories, and emotions into The System, represented onstage through reactive robotic, visual, and sonic elements. Remote audiences, via simulcast, were treated as part of The System alongside Powers and the robots. Audiences had an omniscient view of the action of the opera, as presented through surround sound and augmented, multi-camera video. Multimedia content delivered to mobile devices, through the Powers Live app, privileged remote audiences with perspectives from within The System. Mobile devices also allowed audiences to influence The System by affecting the illumination of the Winspear Opera House's Moody Foundation Chandelier.

Author Keywords

Opera; theater; simulcast; second screen; mobile device applications

ACM Classification Keywords

J.5 Performing arts

INTRODUCTION

While seeking to remount the opera *Death and the Powers*, there was considerable interest by several locations in producing it. However, given the costs of touring a production—even one designed to be tourable, as is *Powers*—as well the challenge of finding a suitable venue in some cities, the producers and creative team behind the production considered a simulcast as an innovative platform for extending the reach of the live performance. Simulcasts are typically cinematic in nature, such as the HD broadcasts

to movie theaters offered by the British National Theatre or the Metropolitan Opera [5]. One might question whether these broadcasted performances need actually be live when a pre-recorded version of the performance would provide the same experience at remote locations.

In contrast, the *Powers* simulcast sought to extend the remote audience viewing experience with special perspectives and additional responsive features available on viewers' mobile devices throughout the performance. With the addition of a second screen and interactive components that could influence the broadcast performance, the experience would not be considered a lesser or limited version of the production, but rather a distinct offering with a different point of view from what audiences attending the production in person would find. The addition of screens throughout the audience transformed the viewing experience from two dimensions to three, with capability of visual effects to 'spill' off the broadcast screen onto users' devices throughout remote venues; each screen functioning essentially as an extension of the original production systems. In addition to the creative advantages of mounting this special version of the production from a completely different perspective, the simulcast provided several logistical benefits as well. Venues appropriate for the staged production are traditionally scheduled years in advance. This simulcast could be agile, outside of the advanced scheduling of opera companies' seasons, and flexible in venue requirements. In this way the production was able to reach a much larger audience while exploring what was ultimately a new medium for live performance.

The Second-Screen

The orchestrated second screen is slowly becoming more commonplace in entertainment viewing. In television, services such as Miso, offer related content or textual commentary to pre-recorded programming [7]. Some theatrical organizations have experimented with just-in-time program notes and commentary on mobile devices [1]. The recent production of *The Crackle* by the Royal Opera House in Covent Garden, London relied on the mobile application Chirp by Animal Systems to transmit images to audiences mobile devices using sounds embedded in the performance [8].

Death and the Powers

Death and the Powers is an opera that was commissioned for its 2010 world premiere in Monte Carlo, Monaco. It has

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since been presented in Boston, Massachusetts (2011); Chicago, Illinois (2011); and Dallas, Texas (2014). Developed at the MIT Media Lab in the Opera of the Future research group, under the creative direction of composer Tod Machover, *Powers* is the result of the efforts of an interdisciplinary team of professionals, graduate students, and undergraduates. The opera was conceived of as an innovative work that would revitalize opera audiences and explore new approaches to music-driven storytelling.

The story, created by Machover with librettist Robert Pinsky and dramaturg Randy Weiner and directed by Diane Paulus, opens with a prologue set in the distant future. A troupe of robots awakens and prepares to enact an ancient, ritual pageant play about the Powers family that forms the inner narrative of the oeuvre [9]. Four of the robots come forward and are transformed into the principal human characters in a cinematic sequence of images representing the characters' backstory. The action begins with Simon Powers, an ailing, wealthy entrepreneur and inventor, preparing to enter The System, a technological infrastructure he has created with his adopted son and research assistant Nicholas. The System promises to keep Powers's essence and consciousness alive beyond the moment of his death, which occurs at the culmination of the first scene. Powers is then seen transforming into his non-corporeal and omnipresent form. The drama continues on to explore the reactions of Nicholas, Simon's third wife Evvy, and Simon's daughter Miranda, as well as the outside world at large, to Simon Powers's new, technologically-immortal form. Nicholas and Evvy ultimately choose to join Powers in The System, though Miranda is hesitant to leave behind those suffering in the world. A simulacrum of Powers emerges from The System to implore her to join him and her loved ones in the realm beyond, but Miranda chooses to favor humanity and remain in the corporeal world as Simon disappears and The System sublimates. The robots appear again as the opera closes and comment on their failure to understand the themes, notably death, treated in their pageant play.

The technique of Disembodied Performance was developed for *Death and the Powers* to make Simon in The System come alive throughout the theatrical environment [10]. The opera singer and actor portraying Simon Powers leaves the stage as the character is transformed into The System. The singer then performs from a booth within the orchestra pit, where he dons gestural and physiological sensors. While the singer is still performing as if he were onstage, data from the sensors about the qualities of his movements and breathing is combined with analysis of his voice and used to generate expressive parameters describing his performance. This information is then sent to a collection of interconnected, networked control systems in order to shape onstage visuals, transformations and effects processing of spatialized sound, and the movement of the robotic scenic elements [6].

Remote Theatrical Immersion

Previous Opera of the Future projects have sought to connect remote audiences to live musical and theatrical productions in meaningful and experiential ways. An early example can be found in the *Brain Opera* (1996), a musical work that invited contributions from audience members through novel musical interfaces in an interactive installation at the performance venue and through an online web application. In the *Brain Opera*, online users could contribute to live performances at Lincoln Center through a Java Applet called The Palette. In this applet, users manipulated a visual representation of descriptive musical dimensions, which could then be transmitted over the Internet to the computers generating sonic material during the live performance.

A more recent project took the form of a collaboration between the Media Lab and the British theater group Punchdrunk as part of a NESTA Digital R&D Fund for the Arts grant [2]. During a one-week pilot period in 2012, Punchdrunk's ongoing production of *Sleep No More* in New York City was augmented to allow up to five audience members per performance to be connected individually to online audience members. The online experience featured a predominantly text-based interactive version of the performance augmented by an immersive soundscape. Occasionally, online audience members would trigger pre-rendered video content or live video glimpses into the physical performance. Onsite audience members wore masks augmented with environmental and physiological sensors, data from which could be communicated through the story interface to their online partners. Online participants could communicate with onsite participants by triggering voices produced using bone conduction transducers in the masks or through physical portals embedded throughout the show, such as an actuated typewriter or Ouija board.



Figure 1: Simon Powers (James Maddalena) and Nicholas (Hal Czalet) with robots, ©Jonathan Williams

THE SIMULCAST

The primary component of the Death and the Powers simulcast was an audiovisual broadcast to nine remote venues in the United States and Europe. The placement of cameras and the overall design of the simulcast experience positioned the remote audiences as being inside The System. As the story unfolds, they discover that, unlike the audiences in the opera house, they are not just watching the action from the outside, but are seeing events transpire as if they are in the same realm as Simon Powers. Ten television cameras were situated both in the opera house and on stage. The onstage cameras were embedded in set elements, such as the display walls, the chandelier, and on robots to provide point-of-view shots for robotic cameras and Simon in The System.

Satellite was chosen over Internet-based delivery of the audiovisual content for reliability, quality, and in order to make latency guarantees necessary for synchronizing the second-screen content, described in the next section. Video was transmitted and projected in 1080i. A second broadcast audio engineer created 5.1 and stereo mixes of the performance using a direct split of all stage inputs. Surround sound for the stage production consisted of 150 channels of Wave Field Synthesis and 3rd Order Ambisonics. Sources to the WFS array were positioned appropriately in the broadcast mixes, while 3rd Order Ambisonic effects were first decoded for 5.1 and stereo and then added to the broadcast mixes separately. Remote

venues were encouraged to reproduce the 5.1 surround mix in order to more closely match the immersive sonic quality of the live production.

Video Processing

The broadcast video image was augmented to create specific narrative perspectives through real time processing and compositing of three live camera feeds and specific pre-authored content. The processing was accomplished using Apple's Quartz Composer software, taking advantage of GPU accelerated real-time processing. Kineme plugins allowed the video capture directly from four HD-SDI connections. Three of these video inputs were sub-switched from the simulcast's broadcast switcher, routing a selection of three of the eleven available cameras for processing at a given time. The fourth input was a version of the graphics rendered in response to Disembodied Performance data for display onset. These graphics could then be composited with live camera images from on set to create the impression of a point of view shot of the action onstage from within The System. The video output from Quartz Composer was then returned to the broadcast switcher via HD-SDI so it could be considered an additional camera feed available during the live switch.

SECOND-SCREEN EXPERIENCE

In addition to the satellite audiovisual broadcast to remote venues, audience members at these sites were invited to use their mobile devices in order to experience a coordinated

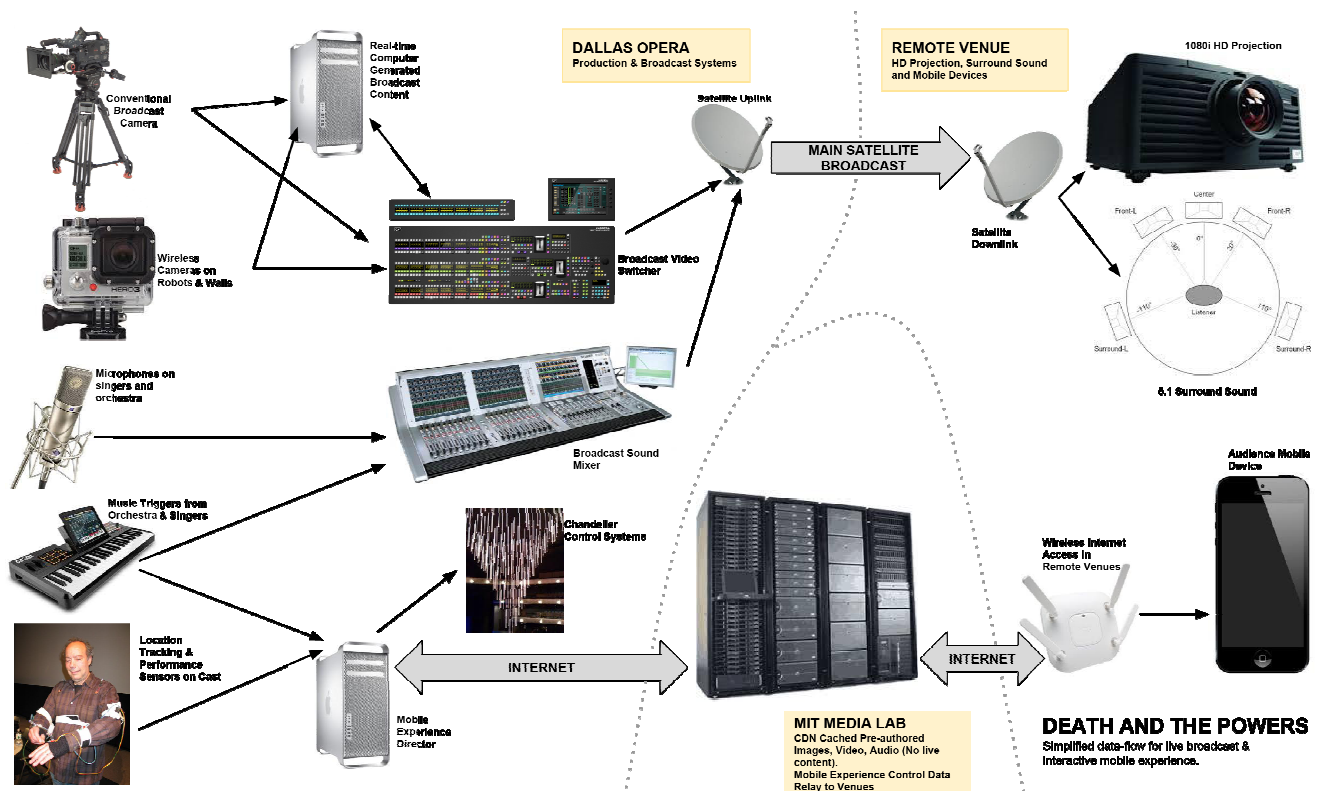


Figure 2: Simulcast systems overview



Figure 3: Example mobile device visual cues

second-screen augmentation of the performance. The second-screen experience contributed to the goal of connecting remote audiences to the live production. Simply watching the main broadcast screen does not necessitate that the audiovisual content shown there is happening live. Extending the experience off of the screen onto remote audience members' own mobile devices and affording them the opportunity to interact with content and shape visual content happening in the opera house in Dallas reinforced the fact that audience members in nine cities were a part of the production as it was happening.

Mobile Application

The experience was made accessible through an application called Powers Live available for Android 4.2 and later through the Google Play store and for iOS 6 and later through the Apple iTunes store. The native application serves as a host for a web view and manages the connections to the server and caching of assets such as video, audio, and images. When the native application loads, it establishes a connection with a server. The server reports a content version number to the mobile application. If the version is later than the version cached with the application, an updated cue list is retrieved. The cue list is parsed for assets that need to be cached and any new or modified assets are downloaded. The server may also push an updated content version while the application is running. This architecture allows the content of the second-screen experience to be revised and modified after the application has been deployed to users through the app stores. Pre-caching content mitigates bandwidth requirements during an actual performance, as users can download the media when they install and launch the application prior to the performance.

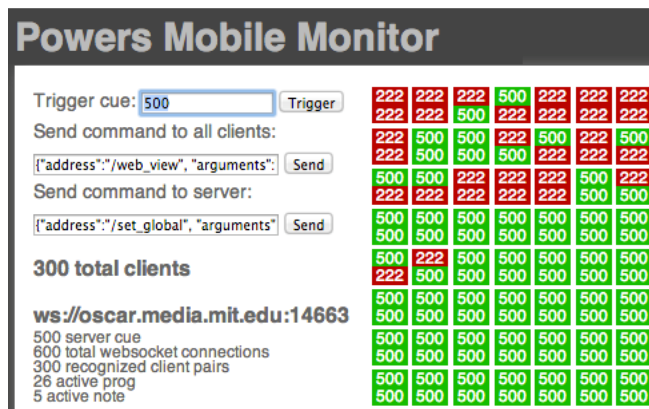
Prior to the performance time, the default cue for the application presents a static website through the embedded web view that provides additional information and program notes about the performance. During the performance, triggers are sent to all connected mobile devices that execute a particular cue. In the existing production of *Death and the Powers*, show systems for audio, visuals, and Disembodied Performance analysis are triggered by a

second keyboardist performing a part notated in the opera's orchestral score specifically to cue these systems. For the mobile experience, these same triggers are routed to the mobile devices, so no additional cuing was required.

Generative Rendering and Cuing Playback

After the initial setup, the web view within the native mobile application is the primary graphical display and user interface. On iOS, the web view component uses the native Safari implementation. For Android 4.4, the default Chrome implementation was used. For earlier versions of Android, a build of Chromium was distributed with the Powers Live application, since the default browser does not implement the WebSocket protocol API. A cross-platform web application was written to respond to the triggered cue list, featuring a set of interactive renderers that produce generative graphics for each cue. These renderers are implemented using CSS and the HTML5 2D Canvas API. WebGL was not used, as it is not supported by the Safari web client on iOS at the time of this writing, though CSS transforms were used for cross-platform hardware accelerated 3D rendering. Content in the web view was arranged in layers so that transitions could be created between layers using CSS.

The cue list file for the mobile experience specifies cues in a dictionary. Thus they are recalled via random access and identified by their trigger number, which is computed from the MIDI note number and a "mode" number corresponding to the triggers as notated in the orchestral score. The cue list file also contains show metadata, certain configuration options for the host application, and a list of assets required by the cues for pre-caching. Each cue may specify an HTML class name for invoking CSS rules and the name of a JavaScript module for canvas rendering, as well as parameters and colors that may be used to configure the behavior of the renderer. Assets or actions that are performed by the native host application, described below, are also indicated. Cue entries optionally specify a transition time and an auto-follow time, a duration after which a target cue is executed. This can be used to create sequences. A cue may also be given a probability of occurring, specified as a float [0.0, 1.0]. If a pseudo-random



value is greater than the probability value, the cue is not executed, but an optional target cue may be taken instead. This enables different content to be served to different devices, so not all devices display the same visuals at the same time, where desired. An audience member may notice that their neighbor is having a somewhat different experience or that content first appears on a few devices, progressively spreading throughout the entire audience.

The mobile application was designed to function much like the existing networked show systems developed for *Death and the Powers*. In addition to cue triggers, live performance data may be sent to the mobile application web view for cues in which it is desired. These performance data streams may be derived from audio analysis of the orchestra or Disembodied Performance parameters originating with the singer portraying Simon Powers. The data is then used to shape the generative graphics displayed on the mobile devices in real time. Cues within the web view can also collect touch and device motion data from devices and transmit these data back to the server to allow remote audiences to influence the live performance in Dallas, as described in the next section.

Playing video and audio content within the mobile experience is handled by the native application, instead of the web view. This ensures responsive performance of media playback as well as circumvents restrictions on non-user-initiated playback within mobile web browsers. In order to trigger playback, the native application needs to process the cue list and handle triggers in parallel with the web view. Video playback appears in an interface component on top of the web view. An implication of this, however, is that video content cannot be transitioned into or out of the content displayed in the web view and cannot be composited with generative imagery in the canvas. The native application also handles additional cue instructions to vibrate the device and to dim the device's display backlight or set it to full brightness. The latter feature was used both to selectively shift focus away from the mobile device and conserve device battery power when the second

screen was not a focal point. The host application registers a custom protocol handler with the web view to enable CSS and JavaScript access to assets cached on the device by the host application.

The design of the second-screen experience was intended to complement the primary screen of the main broadcast. The content displayed was an extension of the visual language already in use throughout the production. In contrast to many second-screen experiences, the use of text was generally avoided in *Powers Live*, instead relying on evocative and abstract imagery that coordinated with the action in color, quality, and movement. Example images can be seen in Figure 3.

Nearly all of the cues featuring visuals created through CSS or the Canvas API afforded some degree of responsiveness to touch or device motion events. Users could discover that the content responded to their interactions, which primed audiences for moments when data about their interaction was fed back to the live performance. Overall, this gave the impression of a unique and individualized experience. Additionally, when first launching the Powers Live application, users were prompted to optionally log into Facebook. If the user agreed, images from Facebook in which they were tagged were downloaded by the application and cached. Following the climax of the opera, a Memory Upload sequence was rendered on the mobile devices to parallel the cinematic Memory Download displayed on stage as the robots took human form. Each user's Facebook images (or images of the opera's cast, if the user did not consent) were composited into this visual sequence, thereby creating a truly personal moment.

Server Infrastructure

The server infrastructure is based on NodeJS, HAProxy and Nginx. WebSocket communication in NodeJS is mature and performs efficiently, and the asynchronous architecture of NodeJS provides good scalability. The server application infrastructure is hosted on an Intel i7 machine running Ubuntu Server 12.04 LTS and VMWare Server. Two VMs function as NodeJS application servers, each running four processes using the Node Cluster module. This provides in-built load-balancing between the processes, which all listen on a single TCP port. On the primary VM, HA Proxy is configured to balance the WebSocket connections between the two VM machines. This configuration allows the backend application servers to be switched, modified, scaled up or down or moved to different hardware without reconfiguration of the application. The secondary VM runs a Redis server to keep track of device registrations and specific distribution lists for testing. The function of the database server will be discussed later on.

Stateless Architecture

The server system was designed with the notion that all processes remain stateless. This provides the benefit that clients can connect, disconnect and reconnect to any of the

8 main processes, perhaps running on different machines. Since no data is stored in the process, it is possible to start and stop processes fairly flexibly. Clients are automatically load-balanced to another process if the process they are connected to dies.

In addition to listening on a single port for incoming client connections, each process listens on its own administration port, which provides analytics about the clients connected to the process and also receives control commands from an administration console. The administration console connects to all running server processes, aggregates client data to a centralized display, allows the manual triggering of cues on all processes, sets server configuration switches, and can use the servers to relay raw messages to clients on the system.

Server Switches

The server processes use a variety of operating modes to facilitate a smooth production even given unexpected circumstances.

- The server can instruct clients to bypass detection of Wi-Fi.
- The server can instruct clients to require users to select a location and Wi-Fi network but not require a specific SSID for operation of the application.
- The server can instruct clients to skip the registration process all together and go directly into the performance.
- The server can instruct clients to wait on a holding screen instead of transitioning into the performance.
- The server can instruct clients to download a specific version of the cue list from a specific server.
- The server can broadcast all messages only to a small subset of clients used for testing while ordinary users were connected to the system.

In practice, all of these configuration modes were utilized to ensure a smooth experience for all of the remote audiences from application download, configuration, and leading up to the start of the performance.

Identifying Clients and Client Connections

The client application generates a UUID upon first launch. This ID is stored in the application configuration and serves as a fingerprint for the device. Each client establishes two WebSocket connections to the server: one for the native app to handle device behaviors such as audio, video and vibration; and one for the web view which handles all generative imagery, touch and motion events. The UUID generated by the native app is passed to the web view, and both the native app and web view send that UUID to the server. The admin console uses the UUID to associate the web view and native sockets even if they are on separate processes or machines.

Since the native app does not render generative imagery, by default the server does not broadcast continuous data over the WebSocket connections. The web view socket sends a message to request this data for its connection.

Database

The server uses a Redis database to keep track of device registrations in each venue. The database also stores distribution lists of UUIDs and has a special mode where triggers and live data are sent only to specific lists. For testing, we maintained a list of devices which would be sent cues during rehearsals and non-simulcast performances. This allowed a small group of users to test content without sending the show to all users who had already installed the app.

Interaction Host

All server processes, in addition to listening on a single port for clients and a separate port for administration, open up a third socket connection as clients to an *interaction host*. This single server is responsible for communicating all aspects of the production to the app server infrastructure. In return, the server processes aggregate all data returned from touch and motion events on devices to this host, which is connected to the production systems via internal show networks to control the Moody Foundation Chandelier. This host served as a single control point for the system. An instance of the cue-based mapping system used in Disembodied Performance runs on the interaction host to analyze and map performance and audience data being sent to the chandelier and other show systems. Analytics and client information were not provided to the interaction host to save bandwidth, since this dedicated connection carried production control data and was dependent on the physical link from the performance venue to the Media Lab.

Assets and Content Distribution

Assets are stored on a secondary VM with a 5Gb internet connection. This system serves static assets using Nginx. Assets are versioned such that no files are ever modified; when a new asset or version was required, a new file with a new name is posted. This allows the most aggressive

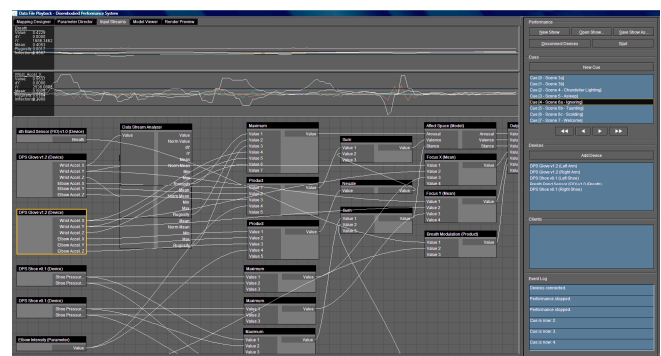


Figure 5: The mapping system on the interaction host analyzes performance and audience data

caching mechanisms to be employed. In addition to setting maximum caching for HTTP clients, the CloudFlare CDN is used to provide local copies of assets.

In the client application, all assets are downloaded over HTTP. Each asset is stored locally and referenced by file name. An asset filename name existing in local storage indicates the asset should not be downloaded again. Media assets are played by the native application or made available to the web view through the installed custom protocol handler.

System Performance

The system was only run at full capacity during the final performance, so special care had to be taken to ensure it would perform adequately under load. Secondary NodeJS instances were created with the express function of simulating several thousand devices connected to the application servers. Each of these scripts simulated exactly the interactions that real devices would have with the server and responded to real-time data in response. This allowed the optimization of kernel parameters for allowable open sockets, HAProxy parameters and NodeJS testing.

With two virtual machines running 8 NodeJS threads, four HAProxy threads and a single Redis instance, the system was able to sustain 7500 simulated devices that consisted of 15,000 concurrent WebSocket connections.

During the simulcast performance, approximately 1000 devices were seen connected to the system simultaneously. The system was able to handle that number of devices quite easily.

CHANDELIER

The centerpiece of the Winspear Opera House in Dallas, Texas is the Moody Foundation Chandelier. The chandelier is comprised of 318 acrylic rods, each with independent LED illumination at one end. The rods are arranged into 44 groups that can be positioned independently from fully retracted within the opera house ceiling to descended 48 feet below the ceiling. The chandelier is typically used as illumination and retracts at the start of performances in the venue. For the performances of *Death and the Powers* in Dallas, it was decided to integrate the chandelier into the performance in two ways.

Like other visual components in the production, it could represent Simon in The System. It could also serve as a primary way of allowing remote audiences interactions to feel present in the opera house, visually represented floating among the actual Dallas audience. To accomplish this, a second instance of the visual rendering software originally designed for the production's LED walls was adapted to output image data using the Art-Net IP-based lighting protocol. The system had triggers similar to those for the walls and responded to Disembodied Performance data from the singer portraying Powers. The Art-Net was routed to two ETC Unison Mosaic controllers for DMX output to

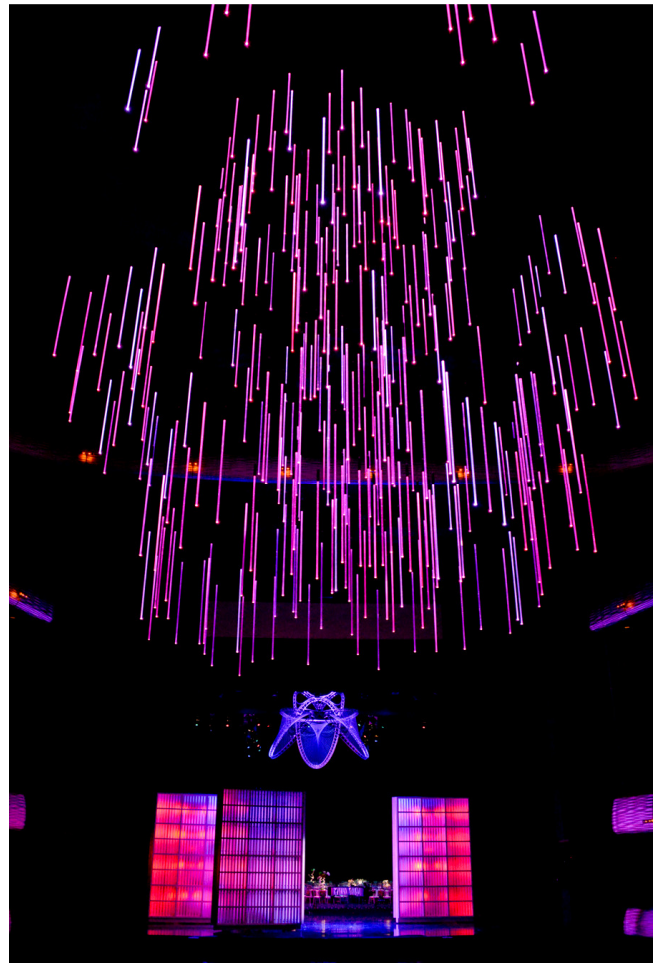


Figure 6: Moody Foundation Chandelier incorporated into *Death and the Powers*, ©Karen Almond

the chandelier's LEDs. Motion and the physical configurations of the acrylic rods were pre-programmed and manually cued in response to show events.

Since the remote audiences were conceived of as being in The System with Simon, at appropriate moments the chandelier assumed a configuration and color palette representing The System during the simulcast performance. At these times, incoming data from mobile devices were aggregated and processed by the interaction host and mapped to the chandelier rendering system. The number of degrees of freedom of the chandelier was too low to give each remote participant direct control over some aspect of it in a meaningful way. Thus, the forms of interaction and data aggregation had to be designed such that each participant felt like they could produce a response, seeing the results of their contributions in the video transmission of the chandelier back to the simulcast venues. This generally took the form of an average that weighted sudden changes and sharp deviations from the median by individual audience members more heavily, so as to feel responsive while still encouraging *en masse* behaviors. Such mappings were included and tuned on a per-cue basis in the mapping

system. The renderers on the mobile devices would visually encourage specific types of interaction, such as tracing a point moving in a circular manner on the screen or shaking the device in time with the beat of the musical climax. The rendering indicated not only the target, but a representation of how close the user was to the target. The image became more intense or more cohesive as the individual got closer to moving in time with the image. The data returned from each device was the percentage accuracy. Thus, the overall accuracy of all participants could be computed and reflected in the graphical content of the chandelier in a similar visual on the second screen devices. If an audience member chose to depart from the encouraged behavior, this could be seen in the behavior of the aggregate visuals. Effectively, these activities served to synchronize the movements of participating audience members across all nine simulcast sites.

CONCLUSION

For the February simulcast of *Death and the Powers*, over 1000 audience members in the nine remote venues worldwide participated using the Powers Live mobile application. Anecdotal audience responses were generally favorable; often citing the novelty of using their mobile devices in what is typically a staid theatrical or cinematic viewing context. Audiences appreciated the responsiveness of the abstract quality of the visual content. Critical reviews of the simulcast laude the innovative attempt to rethink opera distribution and access. However, a review by Gavin Dixon in the magazine *Opera* notes that the mobile device content was not always successful, being at times unnecessarily distracting or, at other moments, uninteresting relative to the action taking place onstage in the main broadcast [3].

Awareness of these two extremes speaks to the great challenge of designing second-screen experiences: directing attention. In the design of the Powers Live experience, the authors, together with the opera's directorial team, tried to balance the desire for the audience to focus on the onstage action with providing unique and additional perspectives on mobile devices in ways that fit the dramaturgy of the existing opera.

An iterative process was put into place to evaluate the technical robustness of the systems and application as well as the development of the content. Periods of cue and software development concluded with various test audiences of increasing size, from directorial staff and a few unaffiliated individuals trying out prototypes of the web view cues for key scenes to a screening of a prior recording of the full opera for an audience of 60 persons, each with a variety of mobile devices. The latter screenings also featured real-time video processing on the recorded performance and a visualization of the chandelier lighting. Feedback at each stage contributed to our understanding of how audiences shifted their attention and what their expectations were for interacting with the mobile device



Figure 7: Remote simulcast at the Hammer Museum, Los Angeles

looks, prior to the presentation of the final version from Dallas. Due to logistics and concerns about human subjects research during the actual broadcast performance, data about the remote audience's experiences was not preserved.

The additional elements of video processing, mobile application, and chandelier were scripted out to fit the arc of the opera itself, becoming more elaborate at times when there was less onstage action. Initial versions of the mobile experience featured content only at significant moments where it would directly contribute to the storytelling and the conceit that the remote audiences were inside The System, leaving the mobile device screens black much of the time so as not to distract from the main presentation. However, test audiences reacted to the black screen with uncertainty about whether the application was functioning correctly or whether their device had shut off. Thus, the decision was made to display content throughout the entirety of the performance and use visual detail, intensity, and screen brightness to focus the audience's attention on the second screen or to let the mobile content recede into the ambience of the screening venue. Another lesson was that, once a participant discovered some form of responsiveness in the visual content, the ability to interact became expected throughout. Thus, wherever possible, content was made to respond to user behavior.

Future Applications

Future research projects will leverage the infrastructure developed for Powers Live for additional performance scenarios and modes of audience interaction. Whereas the second-screen experience was amended to the existing production of *Death and the Powers*, the authors would like to develop new works with the second-screen experience in mind, so it becomes an essential and integrated part of the overall experience and does not compete for attention with a pre-designed presentation. It is also interesting to consider longer-timescale experiences that begin on the mobile device and can, at various points in time, coincide with live, synchronous events.

Extensions to the cue list syntax and functionality could allow for persistent user state and thus greater individual variation and branching content structures. Currently, variability in cue execution is determined probabilistically on pseudo-random values. In subsequent versions, cues could set state based on user interactions or metadata (e.g. user location), and other cues could be executed conditionally based on stored state.

In order to easily apply the Powers Live technologies and approaches to other productions, a more general native mobile application would be desirable. Since the cue list and assets can be retrieved and updated once the mobile application is in the field, all show-specific branding for the application could be defined in the cue list, as well. Thus, a single install of the app could host multiple experiences for a variety of productions. Convenience tools for generating and editing cue list files would also facilitate the process of designing second-screen content and behavior.

On-Demand Second-Screen Experiences

The existing implementation has already been employed in an originally-unintended use case so that the second-screen experience could be made available outside of the live performance context. With minor modifications to the server program, Powers Live can now support synchronous on-demand second-screen experiences. Any web-based media player, such as HTML5 audio or video elements, YouTube, or Vimeo players can now be linked to a second-screen experience on the mobile device. The web page hosting the media player needs to present a numerical code. A new static web cue presented in Powers Live prompts the user to enter the code displayed on the player. Once entered, the mobile device is now connected to that instance of the player and triggers from the media player are sent to the server via the WebSocket protocol and relayed to one or more instances of Powers Live paired with that player's numeric code.

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