

Sound objects: exploring embedded computing for procedural audio in theatre

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Sound Objects: Towards Procedural Audio for and as Theatre

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ABSTRACT

Procedural audio has been the subject of significant contemporary interest, but prior examples in relation to theatre sound are limited. After providing background to theatre sound and procedural audio, we introduce two artefacts, RayGun and INTERIOR, that explore issues around theatre sound. RayGun is an augmented prop prototype that uses sensor driven, procedurally generated and locally diffused sound to address prior deficiencies. INTERIOR reimagines Maurice Maeterlinck's 1895 play Interior as an embedded, generative and largely procedurally generated audio play housed in a shortwave radio-like artefact. Intended to provide an accessible experience, the listener uses a single knob interface to scan through a soundscape of simulated radio stations and 'find' the play. We present some initial findings and conclude with suggestions for future work.

1. INTRODUCTION

This paper explores two practical projects that explore the nature and possibilities of sound in theatre and generative audio in particular. The first of these projects, RayGun, is an augmented prop prototype that has the potential advantages related to responsiveness to user interaction and sound localisation. The second project, INTERIOR, consists of a generative audio play embedded in a tangible, radio-like artefact intended to offer an accessible, bi-modal (audio and haptic) experience in a self-contained and portable package. There are potential applications where existing attempts to make theatre accessible are unsuitable, for instance where travel to an audio-described performance is difficult or impossible.

Our approach is informed two bodies of theory: discourse around sound in theatre and related areas such as film and video game sound; and research in procedural generation and procedural audio specifically. As crossover between the two areas has been limited, these are introduced separately. We then move on to discuss a variety of design issues, describe implementational choices, and consider our experiences and initial findings.

1.1. SOUND FOR/IN THEATRE

The use of sound in theatre is likely as old as theatre itself: there is at least some evidence that ancient Greek and Roman amphitheatres exploited a range of acoustic characteristics (Rindel, 2011) and that ancient Greek theatre masks were intended to transform the acoustic properties of actors' voices (Vovolis *et al.*, 2013). From these origins, Max Culver (1981) notes that sound effects in particular "increased in number and sophistication throughout all theatre periods." For both Culver (1981) and Susan Bennett (2019, p.93), these technological advances are closely related to developments in theatre architecture. Bennett (2019, p.93) offers the development of a mechanical 'thunder run' for the newly opened Globe theatre in 1599 as a specific example.

The role of sound in theatre is also seen to fundamentally change over time. If use of sound in theatre was initially 'realistic', playwrights eventually moved away from realism (Culver, 1981). This in turn enabled sound to operate more freely. It could: create mood; operate symbolically; fulfil character roles; or enhance spectacle (Culver, 1981).

Nevertheless, sound in theatre has typically been neglected and the "nucleus of theatre is usually the dramatic text, the actor's body or the visual spectacle" (Sahai, 2009). This is reinforced by Bennett (2019, pp. 117-118) who, in relation to the 19th century, states that the "theatre created its most spectacular effects from new advances in lighting technology with sound and music relegated to little more than a backdrop to a visually compelling scene." Similarly, Ross Brown (2009) adds that, in reference to more recent developments, "sound, unlike lighting, was not generally considered to be a base-level technical requirement of theatre other than in musicals."

Theatre today exists as part of crowded cultural and entertainment industries, but the national advisory body Theatres Trust (2019) estimates that more than 1300 theatres remain active in the UK and 15.5 million people attended theatre in the West End last year (SOLT 2018). Nevertheless, despite the size and importance of the industry, MacDonald (2016) emphasises that theatre sound and its practitioners continue to be misunderstood.

1.2. PROCEDURAL GENERATION

Procedural Generation relates to any content or structures created by a formal process (Smith, 2015), but is usually assumed to be computerised and is therefore often contrasted with manual creation (Hendriks *et al.*, 2013). For Farnell (2007) however, a more useful contrast is between the fluid processes of PG and the relative 'fixedness' of non-PG content. The use of PG dates back to early video games (Brewer, 2017), but there has been renewed interest over the last decade. In some instances, PG is seen to enable the real-time creation of entire universes unique to each player (Freiknecht and Effelsberg, 2017). In others, PG is seen to liberate artists from laborious or repetitive content creation. Nevertheless, if PG may have other advantages such as reduced file size compared to pre-rendered content (Hell *et al.*, 2017), Green (2016) notes that it is not a universal panacea.

Coined or popularised by Farnell (2007), procedural audio relates to "non-linear, often synthetic sound, created in real-time according to a set of programmatic rules and live input." In contrast to the inherent fixedness of recorded sound ('sound qua product'), procedural audio ('sound qua process') is able to be continuously reshaped (Farnell, 2007). This notion of malleability is also articulated by Verron and Drettakis (2012):

Compared to pre-recorded sounds, it [procedural audio] allows interactive manipulations that would be difficult (if not impossible) otherwise. In particular, procedural audio parameters can be linked to motion parameters of graphics objects to enhance the sound/graphics interactions.

(Verron and Drettakis, 2012)

Like PG generally, the last decade has seen revived interest in procedural audio and procedurally-generated audio features prominently in titles such as *Grand Theft Auto V* (2013) and *No Man's Sky* (2016). Procedural audio has also been used in commercially released music (Collins and Brown, 2009) and sound design for animation (Farnell, 2007) and electric vehicles (Fitzgerald, 2015). Given these diverse applications it is surprising that, bar a few tentative links, the theatre context remains unexplored. For instance, Fry (2019) discusses synthesis in relation to sound design for theatre but makes no explicit connection to procedural audio.

2. TOWARDS A CATEGORISATION OF SOUNDS IN THEATRE

If the importance of sound in theatre has (musical theatre excepted) tended to be underplayed, there has also been limited discourse (Curtin and Roesner, 2015; Brown, 2009, p. 13). If it is obvious that sound in theatre consists of disparate elements and many are “fully deserving of a theoretical study of their own” (Bennett, 2019, p. 47), how to dissect sound in theatre?

In contrast to the limited material around sound in theatre, there is significant discourse around film and video game sound. Particularly prescient are the ideas of Michel Chion. Starting broadly, he (Chion, 1994, p. 216) argues that sound and image are an innately artificial construction, but their fusion enables a suspension of audience disbelief so that sound and image can be perceived as one. Beyond these foundations, Chion (1994, pp. 71-72) introduces notions of acousmatic and visualised sound to refer (respectively) to “sounds one hears without seeing their originating cause” and “accompanied by the sight of its source of cause.” Particularly prescient is that Chion (1994, p. 73) distinguishes three further sound types: ‘onscreen sound’ relates to a sound source that is on-screen; ‘offscreen sound’ relates to a sound source that is not present on-screen; ‘non-diegetic’ sound is acousmatic and its source is not only unseen, but also “external to the story” (Chion, 1994, p. 73).

More than a decade after Chion (1994) and accepting nonlinearity and interactivity as crucial differences, Karen Collins (2008, p. 5) outlines dialogue, ambience and music as the three basic types of video game sound. Similar sound types are suggested by Mats Liljedahl (in Grimshaw, 2010, p.31), but he notes that “in reality, the possible borders between them are floating”, and considers ambient sounds to be a distinct subcategory of sound effects.

A provisional classification of types of sound in theatre maps quite readily to those suggested by Collins (2008, p. 5) and Liljedahl (in Grimshaw, 2010, p. 31). Theatre also increasingly crosses over into multimedia (Salihbegovic, 2013). However, it is useful to make explicit a distinction between sound effects related to props and more environmentally orientated ambient sounds. This implies four possible categories of sounds in theatre:

- dialogue
- sound effects (prop sounds)
- ambience
- music

To aid subsequent discussion, a synthesized outline of each category is presented below.

2.1. DIALOGUE

Dialogue relates to “human language brought to sound, the sounding counterpart to the visual text” (Liljedahl, in Grimshaw, 2010, p. 31) and, more specifically, to the voice. Chion argues that while discussions about the soundtrack have tended to overlook the voice (Chion, 1999, i-ii), the soundtrack “almost always privileges the voice” (Chion, 1994, p. 5) to the extent that “the other sounds (music and noise) are merely the accompaniment” (Chion, 1994, p. 6).

While Chion (1999, i-ii) emphasises that vococentrism almost always means that language and its meaning are privileged, he also discusses how the non-semantic properties of the voice (i.e. those not primarily perceived as message) have a certain “elusive” power. Smith (in Nudds and O’Callaghan, 2009, pp. 204-205) goes further, arguing that even if a listener cannot hear

what is being said, the non-semantic properties of the voice might identify the speaker, or something about the speaker.

2.2. SOUND EFFECTS (PROP SOUNDS)

There are substantial histories of performative, materials-based sound design – most notably Foley sound (Keenan and Pauletta, 2017) – but the theatre context has been comparatively neglected. Unlike environmental sounds or ambience, sound effects are typically linked to physical objects (props). Props are stage artefacts used to enhance a performance and are usually inert, although there are limited examples of interactive or augmented props (Zhang *et al.*, 2017). Sounds are sometimes produced acoustically (i.e. entirely by the prop-object), but this inertness means that external sound is often added; in turn raising issues of synchronicity, localisation, responsiveness and repetition.

Current approaches to prop sound typically involve recorded sounds (samples) being played back (i.e. triggered), either humanly or automatically, sufficiently precisely that they synchronise to performer-prop interactions. This requirement for coordination creates the potential for significant temporal discrepancy. Sample-based approaches also have the potential for repetition; and as Collins (2008, p. 93) notes, any sound that displays repetition quickly becomes noticed. Additionally, if acoustic sound generation can produce subtle, near-endless variations (Hunt, 1999), the pre-fixed nature of sampled sounds means that they are limited in their ability to respond to interaction nuances:

Although, we have access to techniques such as pitch and speed manipulation for a while now (which allows us to manipulate the source material even during application run-time) it still doesn't change the linear-in-time nature of the prerecorded audio material. Which is essentially, frozen in time.

(Nil, 2019)

Lastly, the use of standard house sound systems for sound diffusion instigates a separation of sound from sound source that emphatically limits sound localisation. Rather than emanate from an object located in a specific position on or off-stage, sounds are 'lost' in an 'outside in' stereo or multichannel field. Related issues are described by Smallwood and colleagues (2009) in the context of the Princeton Laptop Orchestra (PLOrk).

2.3. AMBIENCE

In contrast to the spatial specificity of sound effects (prop sounds), Chion (1994, p. 76) describes ambient sound as amorphous and immersive; it “envelops a scene and inhabits its space, without raising the question of the identification or visual embodiment of its source.” However, Chion (1994, p. 76) also posits that ambient sounds are inherently related to site, to the extent that “[w]e might also call them territory sounds, because they serve to identify a particular locale through their pervasive and continuous presence.” If Chattopadhyay (2017) notes that this meaning has become standardised, Brian Eno's (1978) less restrictive definition of ambience “as an atmosphere, or a surrounding influence: a tint” implies more creative possibilities.

2.4. MUSIC

Chion (1994, pp. 8-9) outlines two models of music for image: ‘empathetic’ and ‘anempathetic’. Empathetic music follows the rhythms, tone, and emotion of the image with which it is presented. By contrast, anempathetic music proceeds steadily and with indifference to the image. He concedes that there “also exist cases of music that is neither empathetic nor anempathetic”, but these are downplayed as having “an abstract meaning, or a simple function of presence, a value as a signpost.”

3. THEORY INTO PRACTICE: RAYGUN

Our interests in sound in theatre and procedural audio were first manifest in RayGun; a prop prototype focussed on embedded, procedurally generated audio and sound effects (prop sounds) specifically.

RayGun is inspired by the iconic ray-guns of mid-century science fiction. Here, the appeal of the ray-gun subject lies in its abstract and relatively simple but immediately recognisable sound. Developed over a two-month period, RayGun has twin focus:

- improved responsiveness relative to sample-based approaches
- highly localised, object-like sound diffusion

To address the responsiveness issue (Verron and Drettakis, 2012), the audio output of RayGun is entirely procedurally generated. This ‘audio engine’ is implemented in the open source Pure Data (Pd) programming environment and runs on the Bela (2019) embedded computer platform. The Pd patch can be seen below (Figure 1).

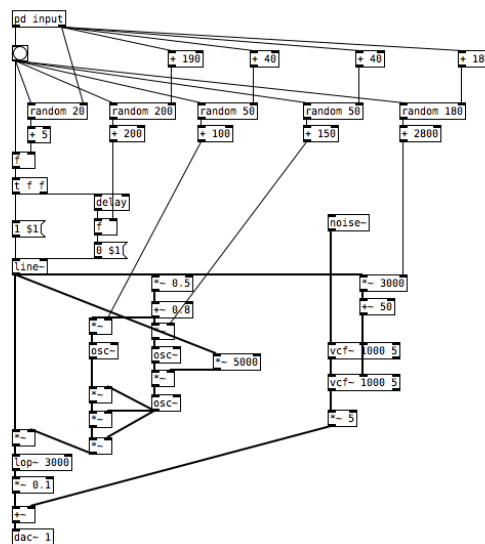


Figure 1. The RayGun audio engine as implemented in Pd.

Synthetic gun sounds are not new and the RayGun audio engine extends earlier work by Brooker (1963, pp. 15-17) and Farnell (u.d.). It combines two techniques:

- white noise progressively filtered by two bandpass filters in series
- three-operator Frequency Modulation (FM) synthesis

The two elements share an Attack-Decay envelope generator that jointly modulates the cut-off frequency of the bandpass filters (and effectively the amplitude of the noise), the pitch of the FM modulators and the FM index. Key parameters are randomised to avoid repetition; the bounds determined by the output of a 3-D accelerometer. Two control inputs – trigger and accelerometer – enable the audio engine to be precisely activated but also be influenced by nuances in user interaction (Figure 2).

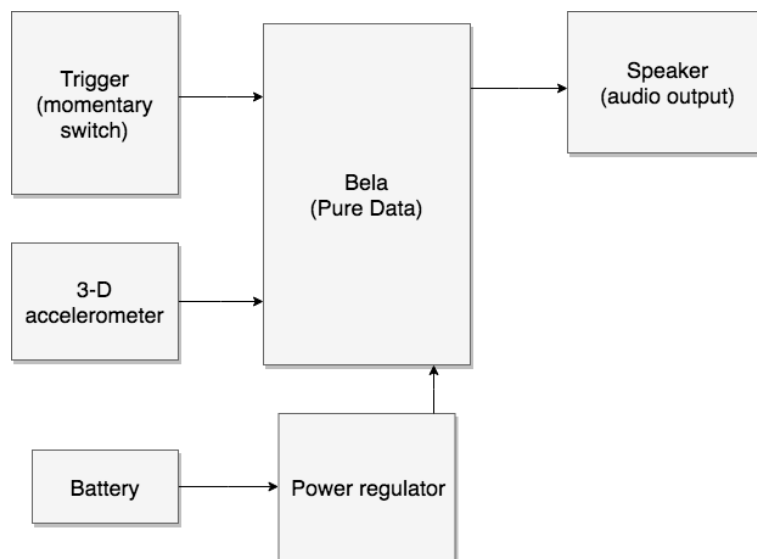


Figure 2. RayGun system diagram.

With little prior work relating to the localisation of object-based sounds in theatre, RayGun draws instead on the localisation solution developed by Smallwood *et al.* (2009) for PLOrk. This uses a hemispherical loudspeaker near each performer to diffuse sound out in all directions from a single point (Smallwood *et al.*, 2009). Informed by this ‘inside-out’ model, RayGun embeds a single 3" loudspeaker into the prop body (Figure 3) so that sound is perceived to emanate from ‘inside’ the artefact (rather than a house sound system) and come from its location on stage.



Figure 3. The RayGun prop prototype.

The physical coupling between prop and loudspeaker means that vibrations are also passed through the prop body to the hands of the performer as haptic feedback.

4. INTERIOR

Theatre's reliance on visual information can be a significant barrier for blind and visually impaired audience members. Blindness and visual impairment encompass a wide variety of conditions and some 360,000 people in the UK are registered as blind and 2,000,000 are estimated to have a visual impairment (RNIB, 2019). Attempts to make theatre accessible to these populations have focussed on audio description (AD); a service that translates the visual aspects of a performance into a succinct spoken commentary (Holland, in Diaz and Andermann, 2009, p.170). While 40% of theatres offered at least one audio-described performance between 2013 and 2016 (Cock, 2016), AD for theatre can be problematised in terms of:

- cost of specialist staff and equipment
- setup time and the complexity and/or reliability of equipment
- 'othering' of service users
- attention/distraction issues
- limited opportunities for creativity by describers
- few opportunities for imaginative interpretation by audiences

Court *et al.* (2014) note that a significant number of people with a visual impairment have at least one comorbid impairment; most commonly a mobility impairment, auditory impairment or learning disabilities, and it is likely that AD for theatre is not suitable for all. Additionally, independent travel – for instance to a theatre – is a source of anxiety for many blind people, and is sometimes avoided completely (Johnson and Petrie, 1998).

Against this backdrop, INTERIOR explores alternative modes of accessibility. More specifically, it recasts Maurice Maeterlinck's *Interior* – an 1895 play intended for marionettes –

as a generative and largely procedurally generated audio play embedded in a radio-inspired tangible artefact. While RayGun focussed on sound effects (prop sounds), INTERIOR incorporates all four sound types. It provides a multi-layered, bi-sensory experience that can be accessed in a number of different ways. Additionally, rather than require users to travel to a specialised venue, it is self-contained and portable so that it can go to users 'in-the-wild'.

4.1. INTERIOR (INTERIEUR): THE CONTEXT

Belgian playwright Maurice Maeterlinck (b.1862 - d.1949), was a writer and playwright who cared little for the demands of the stage and far more for ephemeral nature of theatrical performance as a site for exploration in his creative practice. His 1895 play *Interior* was first performed at the Théâtre de l'Œuvre (where Alfred Jarry's *Ubu Roi* would be performed only a year later), and along Maeterlinck's other early plays, is considered an "ancestor of absurdist theatre" (Knapp, 1975, p. 174). This play was specifically written to be performed by marionettes, which Maeterlinck preferred at that stage to actors. He felt that the wooden dolls had the potential for different kinds of meaning, particularly given that the puppeteer would also be visible to the audience. The dolls were for Maeterlinck, as Bettina Knapp (1975, p. 76) argues, able to "[be] inhabitants of two worlds, the real and the unreal, they could be transformed into anything at any time: god or man, saint or sinner." In this play, almost nothing takes place, we simply wait for terrible news to be communicated - when the action is completed, we remain outside of 'the interior' in which the climax is reached.

The play begins with a house, inside of which we can see a living room and a family at peace; outside in the gardens of the property, we see and hear the conversation between an Old Man and a Stranger. The two men consider how to break the terrible news to the family that their daughter has drowned down in the village, and her body has been found (it is never made clear whether this is an accident or something she done on purpose). The men resist telling the family, but they must, since the villagers are bringing her body back to the house. Pressured by the arrival of his granddaughter, the old man does venture inside, only for the Mother to realise what his arrival heralds. We are never able to hear what goes on inside the house, all of the dialogue happens in the garden. Bettina Knapp notes that *Interior* is important because of the way in which it carries out a "dissociation of speech and action [which] breaks to a certain extent the conventional empathy usually existing between actor and audience" (1975, p. 82) Even performed by puppets, she notes, "the inevitability of death is so powerful at times as to become unbearable" (Knapp, 1975, p.84).

Maeterlinck went on to win the Nobel Prize (2019) in Literature in 1911 and his complex body of work comprised novels, plays, theoretical essays and explorations of mysticism; often with a recurring theme of the ways in which ordinary life unfolds. Maeterlinck's skill as a writer was "to impose a dreamlike strangeness on the most homely and everyday scenes" (Worth, 1979, p. 164). *Interior* was originally in rhyming couplets, which we have not preserved. In INTERIOR, we have carried out a close adaptation of the 1899 translation to ensure that the rhythm and meaning of the now dated text does not jolt the listener out of the experience of hearing the unfolding drama. Changes have been made where needed for understanding and for phrasing, keeping close to the intention of the original where possible, but with the goal of allowing the inevitable to unfold over the duration.

While he would work with actors again, Maeterlinck remained suspicious of their involvement in theatre. In one later essay, 'The Tragical in Daily Life', he writes:

The mysterious chant of the Infinite, the ominous silence of the soul and of God, the murmur of Eternity on the horizon [...] do not all these underlie King Lear, Macbeth,

Hamlet? And would it not be possible, by some interchanging of the rôles, to bring them nearer to us, and send the actors farther off?

(Maeterlinck, 1905, pp. 98-99)

He is particularly focused on the relationship between the “situation of deep seriousness” and the way in which it has to be “unravelling by means of words” (Maeterlinck, 1905, p. 113).

4.2. DESIGN CONCEPT

The INTERIOR artefact (Figure 8) draws heavily on the portable radio. From the motor car to the theremin, there are many examples of how, to increase acceptability, designers choose to imitate familiar designs (Hunt, 1999). In relation to the radio specifically, Nilsson *et al.* (2003) created a radio-like media player for older users (an often-neglected user group). The authors reported that their device had “gained acceptance among the elderly and that they were deeply touched by their use of it.” Beyond increased acceptance, familiar design language is often incorporated to improve ease of use or leverage existing skills. For instance, early digital audio workstations such as Pro Tools incorporated extensive skeuomorphic design elements in an attempt to aid the transition from earlier analogue equipment (Bell *et al.*, 2015).

A distinctive feature of the radio interface is its persistence. As Ullmer (2002) describes, the radio has been superseded by a combination of online services and multi-purpose devices. However, the radio interface has seemingly endured the loss of the technology itself. For instance, Brazil and Fernström (2004), creators of a radio-like museum exhibit, note that “visitors had no problems in determining how to use the device, or in ‘tuning’ to hear different recordings” (Brazil and Fernström, 2004).

That this intuitiveness endures beyond the lifespan of the technology perhaps relates to the incorporation of its interaction language into more recent technologies. For instance, the radio interface is a clearly identifiable influence in the user interfaces of digital radios and smartphone applications (Figure 4 and Figure 5).



Figure 4. A Roberts Revival DAB/DAB+ radio.

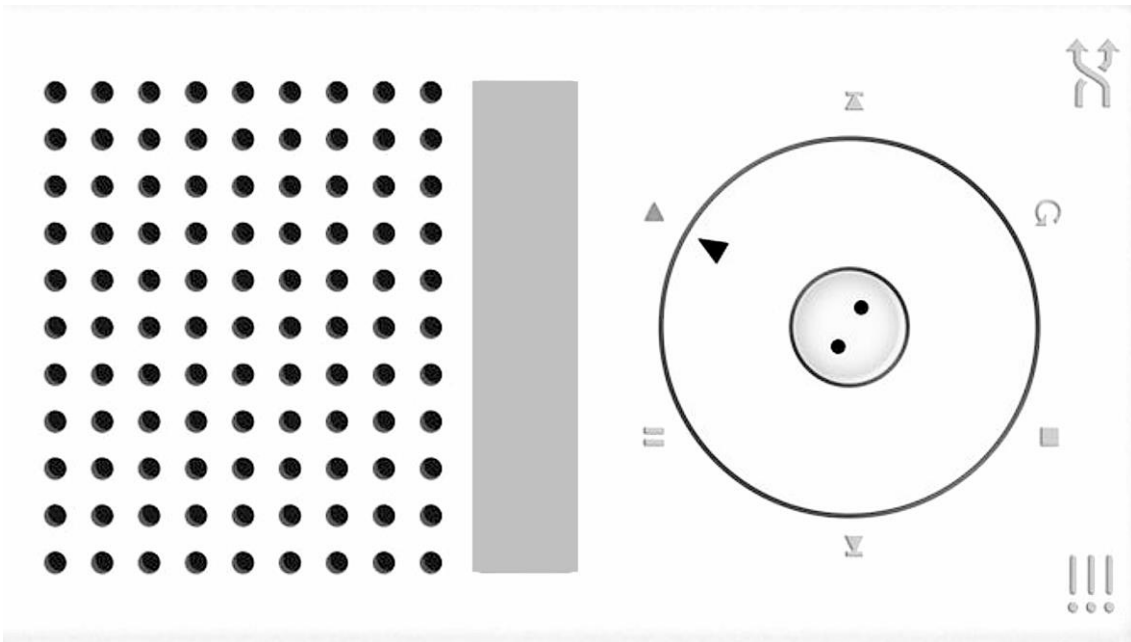


Figure 5. The T3 Player for iOS by Motion Pixels.

INTERIOR reduces the radio interface to a single rotary knob that is used to ‘tune into’ and ‘find’ the audio play amongst a radio-like soundscape. This single knob interface is intended to be intuitively operated, but also accessible to a wide variety of users: it offers a persistent, bi-modal representation of the system state, little penalty for recovery from interaction errors, and can be operated one-handed.

The hiss, hum, static and crackle that characterises the shortwave bands is reproduced throughout. These artefacts are primarily intended to offer additional interaction clues, but, in the post-radio era, may also be of aesthetic interest in their own right (Eno, 1996, p.283).

4.3. IMPLEMENTATION

Like RayGun, the INTERIOR prototype utilises the Bela platform (Figure 6) and is capable of self-contained operation: external connectivity for power and headphones is provided, but an internal battery and inbuilt loudspeaker are also present.

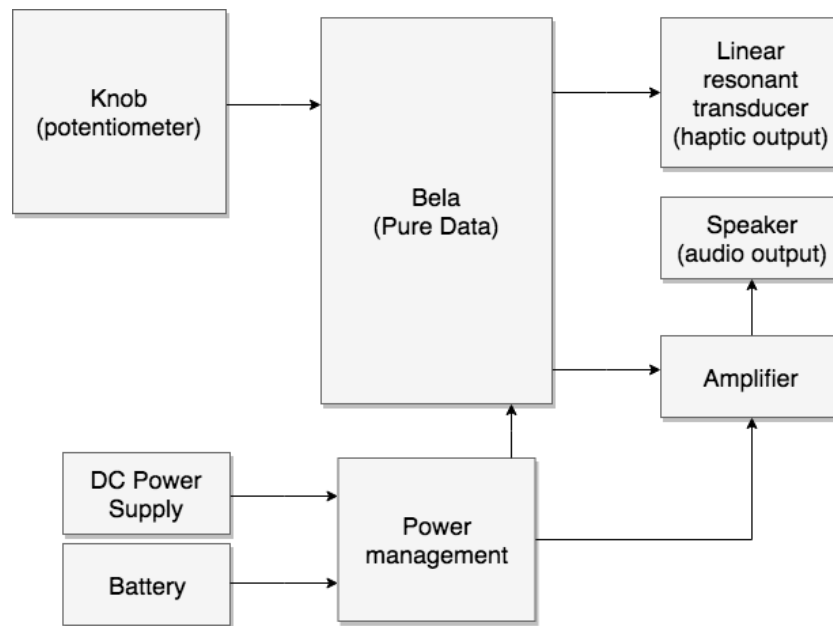


Figure 6. INTERIOR system diagram.

The software component is again implemented in Pd. The implementation has six layers:

- Input (tuner) layer
- Airwaves layer
- Radio Play layer
- Mix layer
- Artefacts and Distortion layer
- Output layer

Their structure and topology can be seen below (Figure 7).

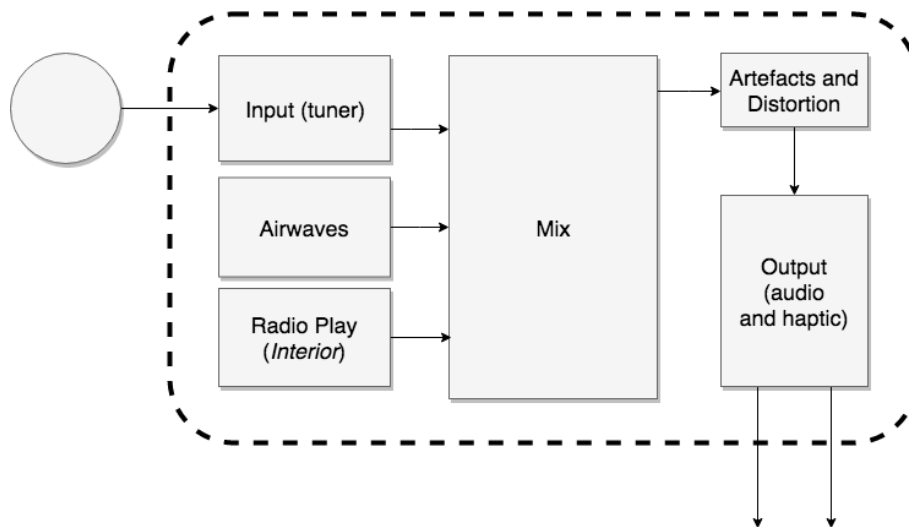


Figure 7. The software topology of INTERIOR.

The Input (tuner) layer consists of a single knob interface that enables the user to ‘tune’ the INTERIOR artefact and thereby choose what is heard. The knob is knurled to improve grip and the output of its underlying potentiometer is received inside Pd on the Bela’s third input.

The Airwaves layer is informed by the in-game radio stations of *Grand Theft Auto V* (Rockstar Games, 2013) and ‘Easter eggs’ more generally. It features seven pseudo-radio stations that are encountered as the user ‘tunes in’ to the audio play. The effect is of reaching in and grasping the audio play through a richly textured gauze. Nine stations are currently implemented:

- five music stations
- three ‘numbers’ stations
- one news station

All three numbers stations and one music station are realised procedurally; their sounds entirely synthesized in real-time. The other four music stations and news station (currently) rely on recorded audio but utilise generative playlists to reduce repetition.

The Radio Play layer is intended to be the main user experience and presents a generative version of Maeterlinck’s Interior that is unique each time it is played. The play consists of a mixture of dialogue, sound effects, ambience and music, and most sounds are procedurally generated. More specifically, all dialogue uses concatenative text-to-speech synthesis to produce ‘spoken’ sequences on-the-fly from a database of pre-recorded fragments. This dialogue is then extensively processed and combined with additional synthesized sounds to produce a backdrop of ambience and ambient music. More focused sound effects are also present. They include a fire based on a design by Farnell (2010, pp. 409-418) and footsteps (individual and group).

The Mix layer manages the balance between the Airwaves and Radio Play layers. This balance is largely determined by the Input (tuner) layer, but some random movement is also added.

The Mix layer output passes into the Artefacts and Distortion layer where it is split into wet and dry signals. The dry signal is sent directly to the Output layer. Shortwave-like artefacts are added to the wet signal, and three distortion processes applied:

- hard clipping
- 8-bit transfer functions
- tanh distortion

To add subtle motion, all distortion parameters and the wet/dry balance are slowly modulated by one-dimensional random processes.

The Output layer is bi-modal (auditory and haptic) and has two channels. The first channel carries the audio output to a MAX98306-based 3.7W Class D amplifier that drives a 3" loudspeaker. The second channel carries low-frequency information to a linear resonant (haptic) actuator fixed to the artefact baseplate.



Figure 8. The prototype INTERIOR artefact.

These elements are housed in a recycled wooden box (Figure 8) with removable lid to enable modification and maintenance.

5. DISCUSSION

This paper has introduced RayGun and INTERIOR, in the context of a mixed background in sound in theatre and procedural audio. Further details and documentation of the projects are available online (Dalglish, 2019). RayGun represented an initial attempt to bring together two previously largely unconnected areas and our own practices. Although relatively simple, it provided useful experience of a new (to us) technological platform and served as a discussion

point. Although only tested briefly, its immediacy appears to create interest and encourage actors (who by their own admission would not usually think about technology) to start to consider the creative possibilities of interactive artefacts.

If RayGun instilled confidence in the basic technological platform, its sounds are relatively simple by design. It is in the more complex INTERIOR that some of the current limitations of procedural audio become evident. For example, if a degree of artificiality suits the Interior source material, it is evident that convincingly naturalistic dialogue generated in real-time using solely procedural techniques remains some way off. As such, it may be useful to consider procedural techniques as part of a broader palette of techniques for synthetic audio that also includes sample playback and hybrid techniques such as granular synthesis. The latter are seen to offer some of the stated advantages of PG around fluidity and reduced file size, but also avoid some of the current limitations of ‘pure’ PG related to sonic detail.

One area in which procedural audio appears more successful is the production of background or other quiet sounds. These sounds are not usually an attentional focus, but their presence is important and more conventional recorded implementations would (given the need for multiple variations) result in unmanageably large file sizes. Our experiences are that, as Farnell (2007) suggests, PG is also well-suited to sound types that emphasise movement over static detail, but most interesting is the ability to create sounds that move between different types. For instance, numerous sounds in INTERIOR seamlessly crossover between ambience and music. This instability problematises the rigid categories proposed Chion (1994) and Collins (2008), amongst others: it is likely that the further development and adoption of PG techniques will require new, more flexible theorisation around sound types.

6. FUTURE WORK

The next design iteration of INTERIOR will add an LED-based display. This is intended to provide visual feedback as the artefact is ‘tuned’ and, more generally, supplement the current auditory and haptic modalities. Once implemented, a user study will be carried out to test the efficacy of INTERIOR in-the-wild. Having donated it to the 14/48 Wolverhampton speed theatre festival, we will also receive detailed user feedback on the RayGun prototype in June 2020.

More speculatively, exploration of soft haptics could enable a subsequent INTERIOR iteration to change its shape and mechanical properties. This could in turn facilitate new paradigms of interaction; for example, interaction properties tailored to individual user needs. To similar ends, we are also interested in how virtual reality (VR) might offer users individualised visual stimuli. Soft haptics could also enable the physical form of the artefact to convey information that evolves as part of a narrative journey.

Considered as a platform, INTERIOR has the potential to present works by others, for instance, as additional ‘stations’ in its soundscape.

7. REFERENCES

- Bela (2019). Bela: beautifully interactive sensors and sound, *Bela* (website), available online at <https://bela.io/> [accessed November 2019]
- Bell, A., Hein, E. and Ratcliffe, J. (2015). Beyond Skeuomorphism: The Evolution of Music Production Software User Interface Metaphors, *Journal of the Art of Record Production*, Vol 9, available online at <https://www.arjournal.com/asarpwp/beyond-skeuomorphism-the->

- evolution-of-music-production-software-user-interface-metaphors-2/ [accessed October 2019]
- Bennett, S. (2019). *Theory for Theatre Studies: Sound*, London, Bloomsbury.
- Brazil, E. and Fernström, M. (2004). Interactive Radio: Exploring Visitor Stories Using a Radio Interface, *Proceedings of the Tenth Meeting of the International Conference on Auditory Display (ICAD 04)*, Sydney, Australia.
- Brewer, N. (2017). Computerized Dungeons and Randomly Generated Worlds: From Rogue to Minecraft (Scanning Our Past), *Proceedings of the IEEE*, Vol. 105, No. 5, pp. 970-977.
- Brooker, F.C. (1963). *Radiophonics in the BBC (monograph number 51)*, London, BBC Engineering Division.
- Brown, R. (2009). *Sound: A Reader in Theatre Practice*, New York, Macmillan.
- Chattopadhyay, B. (2017). Reconstructing Atmospheres: Ambient Sound in Film and Media Production, *Communication and the Public*, Vol. 2, No. 4, pp. 352-364.
- Chion, M. (1994). *Audio-vision Sound on Screen*, New York, Columbia University Press.
- Chion, M. (1999). *The Voice in Cinema*, New York, Columbia University Press.
- Cock, M. (2016). Dark Performances, *Arts Professional* (website), available online at <https://www.artsprofessional.co.uk/magazine/article/dark-performances> [accessed October 2019]
- Collins, K. (2008). *Game Sound: An Introduction to the History, Theory, and Practice of Video Game Music and Sound Design*, Cambridge, MA, MIT Press.
- Collins, N. and Brown, A.R. (2009). Generative Music Editorial, *Contemporary Music Review*, Vol. 28, No. 1, pp. 1-4.
- Court, H., McLean, G., Guthrie, B., Mercer, S.W. and Smith, D.J. (2014). Visual impairment is associated with physical and mental comorbidities in older adults: a cross-sectional study, *BMC medicine*, Vol. 12, No. 181.
- Culver, M.K. (1981). *A History of Theatre Sound Effect Devices to 1927*. Doctoral thesis, University of Illinois at Urbana-Champaign.
- Curtin, A. and Roesner, D. (2015). Sounding out ‘the scenographic turn’: eight position statements, *Theatre and Performance Design*, Vol. 1, No. 1-2, pp. 107-125.
- Dagleish, M. (2019). *Sound Objects documentation* (website), available online at <https://github.com/matdwlv/soundobjects> [accessed November 2019]
- Diaz, J. and Andermann, G. (eds.) (2009). *Audiovisual Translation: Language Transfer on Screen*, Basingstoke, Palgrave Macmillan.
- Eno, B. (1978). *Music for Airports liner notes* (website), available online at http://music.hyperreal.org/artists/brian_eno/MFA-txt.html [accessed November 2019]
- Eno, B. (1996). *A Year with Swollen Appendices*, London, Faber and Faber.
- Farnell, A. (2007). An Introduction to Procedural Audio and its Application in Computer Games, *Proceedings of the Audio Mostly Conference*, Röntgenbau, pp. 27-28.
- Farnell, A. (2010). *Designing Sound*, Cambridge, MA, MIT Press.
- Farnell, A. (u.d.) *Red laser beam* (website), available online at https://www.moz.ac.at/sem/lehre/lib/pd-sounddesign/tutorial_laserbeam.html [accessed November 2019]
- Freiknecht, J. and Effelsberg, W. (2017). A Survey on the Procedural Generation of Virtual Worlds, *Multimodal Technologies Interact*, Vol. 1, No. 4, pp. 27.
- Fitzgerald, R.J. (2015). Sound Design for Electric Vehicles, *Physics Today*, Vol. 68, No. 1, p. 17.
- Grand Theft Auto V (standard edition). PlayStation 4 [Game]. New York: Rockstar Games.

- Green, D. (2016). *Procedural Content Generation for C++ Game Development*, Birmingham, Packt Publishing.
- Grimshaw, M. (ed.) (2010). *Game Sound Technology and Player Interaction: Concepts and Development*, Hershey, IGI Global.
- Hell, J., Clay, M. and Elaarag, H. (2017). Hierarchical dungeon procedural generation and optimal path finding based on user input, *Journal of Computing Sciences in Colleges*, Vol. 33, No. 1, pp. 175-183.
- Hendriks, M., Meijer, S., Van Der Velden, J. and Iosup, A. (2013). Procedural Content Generation for Games, *ACM Transactions on Multimedia Computing, Communications, and Applications*, Vol. 9, No. 1, pp. 1-22.
- Hunt, A. (1999). *Radical User Interfaces for Real-time Musical Control*, doctoral thesis, University of York.
- Johnson, V. and Petrie, H. (1998). Travelling safely: the problems and concerns of blind pedestrians, *British Journal of Visual Impairment*, Vol. 16, No. 1, pp. 27-31.
- Keenan, F. and Pauletto, S. (2017). Listening back: exploring the sonic interactions at the heart of historical sound effects performance, *The New Soundtrack*, Vol. 7, No. 1, pp. 15-30.
- Knapp, B. (1975). *Maurice Maeterlinck*, Boston, Twayne Publishers.
- MacDonald, P. (2016). Gareth Owen: Theatre Sound Designer, *Sound on Sound* (website), available online at <https://www.soundonsound.com/people/gareth-owen-theatre-sound-designer> [accessed November 2019].
- Maeterlinck, M. (1899). *Alladine And Palomides: Interior, And The Death of Tintagiles: Three Little Dramas for Marionettes* (trans by William Archer and Alfred Sutro), Chicago, Charles H. Sergel Co.
- Maeterlinck, M. (1905). *The Treasure of the Humble* (trans. by Alfred Sutro), London, Ballantyne, Hanson and Co.
- Nil, B. (2019). Procedural Audio on the Web: Part One, *Medium* (website), available online at <https://medium.com/@berraknil/procedural-audio-on-the-web-part-one-166462e7be1e> [accessed November 2019]
- Nilsson, M., Johansson, S. and Håkansson, M. (2003). Nostalgia: An Evocative Tangible Interface for Elderly Users, *Proceedings of CHI '03 Extended Abstracts on Human Factors in Computing Systems*, Fort Lauderdale, pp. 964-965.
- No Man's Sky (standard edition). 2016. PlayStation 4 [Game]. Guildford: Hello Games.
- Nobel Prize (2019). *Nobel Prize in Literature 1911* (website), available online at <https://www.nobelprize.org/prizes/literature/1911/summary/> [accessed November 2019]
- Rindel, J.H. (2011). The ERATO Project and its Contribution to our Understanding of the Acoustics of Ancient Theatres, *Proceedings of the Acoustics of Ancient Theatres Conference*, Patras, Greece.
- RNIB (2019). Key information and statistics on sight loss in the UK, *Royal National Institute for the Blind* (website), available online at <https://www.rnib.org.uk/professionals/knowledge-and-research-hub/key-information-and-statistics> [accessed November 2019]
- Sahai, S. (2009). Exploring a Theatre of Sounds, *Proceedings of Sound, Sight, Space and Play 2009: Postgraduate Symposium for the Creative Sonic Arts*, Leicester, UK.
- Salihbegovic, F. (2013). Multimedia Theatre Before the Digital Age. *Scene*, Vol. 1, No. 3, pp. 389-403.
- Smallwood, S., Cook, P.R., Trueman, D. and McIntyre, L. (2009). Don't Forget the Loudspeaker: A History of Hemispherical Speakers at Princeton, Plus a DIY Guide,

- Proceedings of 9th International Conference on New Interfaces for Musical Expression (NIME '09)*, pp. 110-115.
- Smith, G. (2015). An Analog History of Procedural Content Generation, *Proceedings of the 10th International Conference on the Foundations of Digital Games (FDG 2015)*, Pacific Grove, CA, USA.
- SOLT (2018). *2018 Box Office Figures Released by Society of London Theatre and UK Theatre* (website), available online at <https://solt.co.uk/about-london-theatre/press-office/2018-box-office-figures-released-by-society-of-london-theatre-and-uk-theatre/> [Accessed October 2019]
- Theatres Trust (2019). Theatres Database, *Theatres Trust* (website), available online at: <https://database.theatrust.org.uk/> [accessed 09/11/2019]
- Ullmer, B.A. (2002). *Tangible Interfaces for Manipulating Aggregates of Digital Information*, Doctoral thesis, Massachusetts Institute of Technology.
- Verron, C. and Drettakis, G. (2012). Procedural audio modelling for particle-based environmental effects, *Proceedings of the 133rd AES Convention*, San Francisco, USA.
- Vovolis, T., Tsilfidis, A., Georganti, E. and Mouriopoulos, J. (2013). Function and Acoustic Properties of Ancient Greek Theatre Masks vol 2, *Acta Acustica united with Acustica*, Vol. 99, No. 1, pp. 82-90.
- Worth, K. (1979). Evolution of European “Drama of the Interior”: Maeterlinck, Wilde and Yeats, *Maske und Kothurn*, Vol. 25, No. 1-2, pp. 161-170.
- Zhang, Y.X., Ma, P.F. and Zhu, Z.Q. (2017). Magic Props: A Multi-sensory System Fusing Virtual Effects in Live Drama Performance Spatially, *Proceedings of the International Conference on Culture and Computing (Culture and Computing 2017)*, Kyoto, Japan.