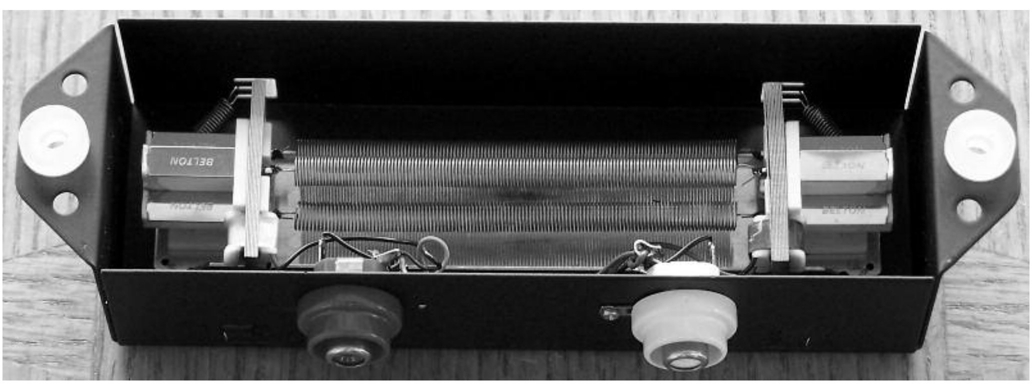
Doepfer. A-199 spring reverb, ca. 2015.



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Space within Space: Artificial Reverb and the Detachable Echo

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In her classic book *The Soundscape of Modernity*, Emily Thompson writes of a "modern sound" characterized by a "lack of reverberation . . . clear and direct," commoditized, private, and separated from physical environments. In Thompson's account, modern architectural acoustics worked hard to eliminate or at least transform the sonic signatures of built spaces—for instance, to eliminate the reverberation in a large hall with high ceilings. According to Thompson, the mere fact that the "same" room can sound different based on the materials used in its construction marks an important historical break:

> When reverberation was conceived as noise, it lost its traditional meaning as the acoustic signature of a space, and the age-old connection between sound and space—a connection as old as architecture itself—was severed. Reverberation connected sound and space through the element of time, and its loss was just one element in a larger cultural matrix of modernity dedicated to the destruction of traditional space-time relationships.[1]

Leaving aside the question of whether "traditional space-time relationships" were indeed stable prior to the twentieth century, Thompson is right to highlight the moment when architects and engineers set up a relation of supplementarity between reverb-free sounds (the essence of a sound) and their physical presence in a space (its supplement). By defining reverb as noise and seeking to eliminate it, they created a more restricted definition of sound and abstracted sounds-in-themselves from the lived experience of hearing subjects.

This new construct, which for convenience I will call the "detachable echo," meant that the two terms—*sound* and *reverberation*—no longer had any necessary, given relationship. A cathedral could sound echoless, even dead; a tiny enclosed space like a car could sound cavernous. This restricted definition of sound, based in the idea that reverberation is supplemental to an essentially spaceless sound, remains a dominant construct to the present day. This logic is at work in many places, from visually grand and surprisingly quiet entrance halls at corporate headquarters to THX-certified movie theaters.[2] Detached and detachable echoes can be found in fields of practice as diverse as architectural acoustics; speech and hearing science; soundtrack mixing for film, television, and videogames; sound art installations; signal processing for telecommunications; and production practices for live and recorded music.

Thompson's narrative has two stages: first, architectural acousticians separated sound and space and privileged a single-best sound; later, in the mid-twentieth century, that dominant aesthetic was shattered. Thompson writes that by the end of the nineteenth century architectural acousticians were working with a fairly defined concept of "the modern sound" that they could apply to built spaces regardless of their physical configuration and regardless of whether those spaces were retrofitted or new construction. By the mid-twentieth century, however, this singular aesthetic gave way to the idea that any given space had a variety of possible sonic signatures and that architectural acoustics ought to be charged with the development of a varied sonic palette.[3] Yet her two-stage story works only if it begins with architecture. If we widen our focus from architectural acoustics to the audio arts in general, we see that as soon as they could produce a detachable echo, engineers, artists, and musicians treated it as aesthetic raw material: sonic space itself became the object of an artistic palette. In this article, I give an account of the detachable echo that traverses the history of sound and the history of space: the detachable echo as at once a phenomenon of engineering, aesthetics, and subjectivity. In so doing, I focus on artificial reverberation because it represents a particularly explicit and conscious attempt both to represent sonic space and to manipulate it—artificial reverb and the practices around it carry forward the proposition of the detachable echo to an even greater extreme than Thompson's architectural acousticians. Thompson's modernity is the moment when reverberation is defined as a supplement; it is also the moment when sonic space gains a new level of plasticity through the control and measurement of physical space.

A clarification of terms is in order here. *Artificial reverberation* is reverberation that is added to sounds—anything recorded, transmitted, or stored that will eventually come out of a speaker (the appellation *loud* has mostly been dropped from the term *loudspeaker*). Sound engineers distinguish *reverb* from *echo* or *delay.* In engineering parlance, *delay* refers to a process whereby separate echoes . . . echoes . . . echoes . . . are each audible, whereas *reverb* refers to the sonic signature of a room or a simulation or reproduction thereof: a series of echoes so dense they meld together into a shared ambiance for listeners. Changes in reverberation transform both the timbre of a sound—

the characteristics of the sound "in itself" (a construct that also demands some scrutiny)—and the range of possible spatial meanings or connotations attributed to the sound. Artificial reverb at once *represents* space and *constructs* it.

Consider the echoes attached to a liturgy in a cathedral or an announcement in a train or subway station, in contradistinction to the FM radio announcer's voice booming from the speakers inside a car. If we consider sound and space as separate things, space is part of the timbre of sounds. Space also provides a great deal of contextual and allusive meaning even though these meanings change over time, with context, and according to the people listening. Jason Stanyek and Benjamin Piekut refer to the "fundamentally fragmented yet proliferative condition of sound reproduction and recording, where sounds and bodies are constantly dislocated, relocated, and co-located in temporary aural configurations."[4] In this article, I extend their argument to spaces. Temporary and ever-shifting dislocations, relocations and co-locations are conditions of modern sound *in general*. Recording, reproduction, and architecture are all simply pieces in a mosaic and cases in a larger story.

In the sections that follow, I offer an account of the theories of space animated by the detachable echo; the mechanics of its separation of sounds into "dry" and "wet" dimensions; and the history of reverb technology as a history of representation and construction of space. The separation of sounds from themselves—the detachable echo—multiplied spatial perspectives for listeners and proliferated possible sonic configurations and modes of representation. The detachable echo presages the kinds of spatial overlays that are now emerging with augmented and mixed reality. In the end, the separation of sound and reverberation did not lead to the discarding of the latter as "noise," as some acousticians may have argued. Instead it has led to an increased mobility, flexibility, and layering of all acoustic space.

Compounding Acoustic Space: From Detachable Echoes to Speaker Culture

Both artificial reverb and modern instantiations of acoustic space depend on a prior separation of sound from space, a separation that should be taken as a construct. If we take the detachable echo as describing the ontology of a sound, it is a fictitious construct; if we take it as an engineering project and working concept, the detachable echo is a tremendously important and efficacious construct. Both built spaces and artificial reverberators depend heavily on representations of space available to the people who make them, as well as to auditors who experience them. And both point to an ever-growing proliferation of sonic spaces inside one another, a phenomenon that characterizes the modern experience of sonic space, a world where treated rooms and speakers are everywhere. When audio engineers talk about space in a recording, they generally mean space as a perceived volume or depth, as well as a set of behaviors—for instance, does the sound move as if reflected by concrete or by drapery? But this is not strictly a discourse of "realism"—artificial reverberation may give a sense of a cathedral by invoking "cathedralness" rather than any particular building material; it may also give a sense of outer space, which is impossible since there is no sound in outer space.[5]

All sound needs a medium. Which is to say that acoustic space can never be empty or neutral. Although generations of acousticians have made claims about Euclidean space, strictly speaking, sonic space cannot be Euclidean space defined by X, Y, and Z axes. Sound cannot move through empty space—this is crucial to recognize for a social and aesthetic theory of sonic space. In *The Production of Space*, Henri Lefebvre proposes that space is both produced by social activity and productive of it. That is, space should not be thought of as an empty container for social activity, its frame, or its backdrop but rather must be granted its own contours, activities, affects, and tendencies.[6] Lefebvre's space offers a perfect frame for thinking sound. In a non-Euclidean sonic space, the mediatic dimensions of space are essential, a point well documented by Stefan Helmreich's ethnography of the submarine *Alvin*: switch out water for air and a completely different sonic ontology obtains.[7] Even air, which looks empty even though it is not, becomes a vibrant, variant, oscillating field when considered acoustically. The speed of sound is directly affected by the density of air, which is in turn affected by air currents and heat. For instance, the typical concert hall has tremendous variations in its density—something like 60 billion little cubes of heated air, each acting differently on the sound waves bouncing around the room. The very idea of a detached echo, a truly pure sound without echo, requires us to imagine an impossible sound that exists outside relations, outside space, a sound that brackets its own historicity and situatedness.

Sonic space is thus complex and multidimensional—it mixes media (in all senses of the term *media*), auditors, and vibrations. Artificial reverberation represents and manipulates sonic space to produce a sense of spatiality, but it is never a perfect model of physical space. At one level, this is unsurprising to anyone familiar with the history of representation; no representation has ever perfectly modeled what it claimed to represent. But the specific challenges presented by sonic space and the specific solutions presented by artificial reverberators can tell us a lot about the history of sonic space (I return to this in the last section of the essay). In her history of ornamentation, Alina Payne writes that as ornamentation fell out of fashion with architects in the early twentieth century, they turned to objects as focal elements of interior space: the "attached" layer of ornament became "detached" and mobile in the form of objects.[8] A similar process appears to have been at work on an even grander scale with acoustic space, which became detached from physical structures first by a conceptual separation of sound and space, second by a set of emerging architectural practices, and third by the proliferation of sound-reproduction technologies. But what occurs as a result is not a proliferation of sonic objects (and we should not overstate the parallel): it is a proliferation of sonic spaces *within* a single space—sonic space becomes ever more plastic.

The history of architectural ornament and the history of sound explicitly intersect in another place. As Robert Bruegmann writes, the turn to new heating technologies in the nineteenth century had profound effects on the way architects understood the insides of buildings. More and more interior space was taken up by equipment—often behind or next to walls—in the form of air columns, radiators, pipes, and insulation.

> To conserve heat, architects became more aware of the value of thick plate glass, double glazing, hollow brick and cavity wall construction, weatherstripping, insulation, double doors, and entrance vestibules. They even recommended the elimination of curtains and draperies, particularly in hospitals, as well as mouldings and applied ornament, because these impeded air flow. They specified rounded corners and the use of hard, bright, impervious substances to allow for easy cleaning.[9]

Around the same time that Thompson's architectural acousticians became aware of the power of dampening materials, architects were pushed for changes to interior spaces that had the (likely unintended) side-effect of making them ever more reverberant. Eliminating doors, barriers, treatments, and impedances to air flow would also eliminate impedances to sound flow. Once separate, acoustic spaces would be more likely to blend into one another.

Audio engineers use the term *space within space* to describe a recording or sound field with multiple spatial signatures. Picture this not as a Russian doll with its neatly nested layers but as a mixed metaphor of overlays and tide pools—multiple spaces that can exist at once on top of one another but also that go in and out of existence. These multiple spaces may occur within recordings themselves; for instance, in a popular music mix where the drums are recorded in one space and the vocals another, or in a film that combines diegetic and nondiegetic sound. In multitrack recording for music, film, television, and games, ensembles are often broken down into their components by instrument. A rock band recording, for instance, will be broken down into separate or even multiple tracks for each vocalist and each instrument, each of which can then be processed individually so that the vocalist sounds close up and intimate in the verse and distant and in a cavernous space for the chorus. A guitar may be recorded with a microphone right up against the amplifier and another microphone across the room so that the engineer can manually blend in the "space" in the recording. Or, the engineer may take the dry guitar sound and use software or hardware to place it in an artificial sonic space that could not physically exist. As a result, most soundtracks and popular music recordings contain an array of spatial perspectives that confront listeners' ears all at once. Meanwhile, many recording and performance spaces make use of acoustical materials to change the sonic signature of a room, by adding various kinds of sound dampening materials and then selectively removing them for different uses, producing another kind of sonic plasticity.[10] And yet, with all these incoherent spatial signatures, listeners hear a coherent sonic text.

Considering the scene of playback and listening highlights another crucial architectonic feature of modern sonic space: the speaker. Since speakers *also* exist in physical space, the reproduced sound exists in the physical space in which they are heard, as well as the reproduction system itself (and the interior space of the speaker). This aspect of modern sound culture deserves an essay in itself, but for now I will simply point to it. For lack of a better term, we live in a *speaker culture*. The contemporary experience of sound is shaped by a landscape populated with, and often dominated by, speakers—and where speakers are absent, their possibility exists.[11] As Kyle Devine argues, loudspeakers were at the center of modern sonic quests for rationality, fidelity, objectivity, and privacy: speakers are central to the design of modern spaces.[12]

In speaker culture, the "space within space" effect multiplies: spaces nest within spaces *within spaces*. The omnipresence of speakers also forms the basis for a host of arguments about modern subjectivities, from the distracted subjects of radio history, who shifted between listening and not-listening to music, to the distributed subjects of ubiquitous music, where affects are available on-call anywhere, anytime.[13] Detachable echoes and speaker culture are constitutive features of one another: recorded and transmitted sounds are made for speakers before they are made for spaces or for ears. That sounds with artificial reverb emanate from speakers in built space guarantees a compound multiplication of spatialities in the instance a recording hits listeners' ears—whether they are attentive or distracted.

Dry and Wet

Audio engineers use the terms *dry* and *wet* to describe the difference between a sound and its detachable echo. The "dry" part is the sound, separate from any echo; the "wet" part can be all echo, all space, or it can refer to the sound with a mix of echoless and reverberated components. Here, I use *dry* and *wet* as opposites even if in common use the semantic separation is not always as clear. Artificial reverb allows *dry* echoless sound to be placed in any of a number of *wet* reverberant spaces. Both are abstractions, but they are also real constructs that inform action: when an engineer mixes the "dry" anechoic sound with a "wet" artificial ambiance, she is performing the arbitrary relationship between sounds and spaces, a relationship that is a hallmark of modern sonic culture. A little reverb added to a dry sound gives it more complexity and depth; a lot of reverb added to a sound *washes it out*. The once clear wave metaphor for sound thus loses its precision. These metaphors are themselves artifactual: as Tara Rodgers argues, the wave metaphor used to organize and manage electronic sound has close ties to late-nineteenth-century colonial and gendered languages of maritime voyage and travel that prevailed as concepts of electronic sound first developed. Both conjured rhetorics of mastery, which is to say that waves were not just waves and wetness was not just wetness but—as with so many other figurations of the feminine in this period—were rather that which men sought to master.[14]

The earliest approach to reverberation as a truly plastic art was in the domain of popular music recording and its use of artificial reverb. Early accounts of makeshift recording studios for Berliner Gramophone records refer to potato sacks and other appropriated sound-dampening materials.[15] Already in the 1920s, a split was developing between recording of classical music and other kinds of "popular" recording: the former pursued a "realist, concert hall" aesthetic, while a variety of popular genres deliberately used artificial reverb to achieve effects. Peter Doyle deftly analyzes the tension between sonic realism and explicit artifice in the 1920s:

> The potential to record either with or without "depth" then presented record makers with a serious technico-aesthetic problem. A split soon arose whereby it become broadly acceptable to record classical orchestral music so as to include room ambience (and thus aural depth), while "popular music" was in the main recorded "dry," with little or no discernable depth and minimal reverberation. The voices and sounds of high art were accorded virtual sonic space, while low art was denied it.[16]

Another set of aesthetic developments emerged in the 1920s, as the echoless recordings of some popular genres gave way to experimental uses of echo to indicate various kinds of place or even otherworldliness in music. Doyle writes of Gene Austin's 1927 recording of "My Blue Heaven" as an early example: the crooner's close-up voice is contrasted with distant, reverberant piano and cello. In subsequent decades, reverb was also important for genres like *hapa haole* Hawaiian music and cowboy songs. As a result, reverb became the main means through which recording engineers could place music spatially, at least before the advent of stereo. With the former, engineers could give a sense of depth and distance; with the latter, a sense of relative placement. Today, engineers generally discuss stereo as left-to-right placement and reverb as front-to-back, but the history and range of aesthetic practices in recording is considerably more complex.[17] Doyle writes, "echo and reverberation made it seem as though the music was coming from a somewhere—from inside an enclosed space or 'out of' a specific geographic location—and this 'somewhere' was often semiotically highly volatile."[18]

Doyle's point about volatility is absolutely crucial to understanding the possibility of a detachable echo. In his account, engineers did not separate sounds from sources, as is often erroneously said of recording. They separated aspects of sounds from sounds themselves. A detachable echo reconceives sound, a fundamentally spatial phenomenon, as something that can exist outside and across space. But to make this claim does not mean that a sound separated from itself diminishes a previously whole reality or that it fractures a previously coherent set of relations among space and time. Detachable echoes proliferate possible realities, experiences, and perspectives on them.

Barry Blesser and Linda-Ruth Salter write that artificial reverb "destroys the internal temporal fine structure of a sound."[19] As their choice of words illustrates, all artificial reverb is based on the founding construct of detachable echoes: that sounds have an essential *dry* interior structure separate from the spaces in which they emanate. But this dry, echoless condition can exist only if it is carefully manufactured. The dry interior condition of a sound "in itself" is thus an aftereffect of manipulation and not the sound's true essence. And yet, to engineer sound in this way it is useful to describe sound *as if* it could exist outside of space, as Blesser and Salter imply. In this formulation, echoes do more than fill up the empty space inside that structure. Like water entering a sponge, they expand it, even beyond its original size and capacity. In her study of the Hagia Sofia, Bissera Pentcheva notes that the cathedral's long reverb times would have effectively destroyed intelligible speech—listeners in that space were "no longer focused on intelligible words but on their sensual perception."[20] If we accept the detachable echo, that founding fiction of artificial reverb, then the power of all these watery metaphors flows through, for they describe first the erosion and then the total reorganization of an idealized, "dry" sonic structure. In the extreme, artificial reverb may produce a kind of sensory disorientation or psychedelic effect because it mixes the *inside* and *outside* of an echoless, "in-itself" sound. Artificial reverberation thus presupposes echolessness as a prior feat of engineering.

Of course, plenty of sounds lack much in the way of an echoic dimension.[21] Consider the (landline) telephone. As Thompson points out, the person on the other end of the line is literally speaking into the receiver's ear; the acoustic space in which their speech emanates is inaudible at the other end of the line.[22] A kind of mediated sonic proximity becomes possible through the use of microphones and speakers. The intimacy of voices heard in telephones was a concern for Victorians and today remains a fetish tied to nostalgia for landlines: "your phone voice was distinctive; your phone manner was distinctive. You thought a great deal about people who rhythmically and mysteriously inhaled and exhaled cigarette smoke while they talked or left long silences or didn't hang up immediately after saying goodbye."[23] From Roosevelt's famous fireside chats to crooners' intimate singing styles, recording and radio performers who spoke softly into microphones also performed a kind of intimacy. Drawing on anthropologist Edward Hall's notion of proxemics, British music scholars Allan Moore, Patricia Schmidt, and Ruth Dockway argue that sounds that feel close to the listener are construed as particularly intimate, portending physical and emotional intimacy, connections between two peoples and the possibility of touch.[24] Following their line of reasoning, echolessness is not simply a pure condition but carries with it an affect, one that closes in on the listener. The current popularity of ASMR ("Autonomous Sensory Meridian Response") videos on YouTube also follows this pattern. These videos use whispering, scratching, and other quiet-but-tactile noises to induce physical responses (like goose bumps) in viewers. As Joshua Hudelson argues, such videos "traverse the gap between the sonic and the haptic" through the technique of the sonic close-up.[25]

Space within space also carries with it a range of affects, especially because hearing multiple acoustic spaces at once is now such a banal experience. Recordings that bear a mix of sonic signatures that would be impossible to hear in a live performance resound out of speakers in a room. The audio then becomes part of the sonic space of the room alongside other noises—hums of electrical appliances or computer fans, street noise that filters in through the windows, voices of people speaking, and so on. This sonic scenario is an almost textbook case of the effect that visual augmented- and mixed-reality practitioners are attempting to accomplish: nonimmersive media that allow for some kind of interaction and that coexist with physical objects in an environment. In augmented reality (AR), "the real environment is not completely suppressed; instead it plays a dominant role. Rather than immersing a person into a completely synthetic world, AR attempts to embed synthetic [virtual] supplements into the real environment (or into a live video of the real environment)."[26] Lev Manovich uses the term *augmented* to describe a new digital spatial condition. For him, "augmented space is the physical space overlaid with dynamically changing information. This information is likely to be in multimedia form and is often localized for each user."[27]

But this condition outlined by Manovich has existed since architects started to hang rock wool to dampen sound; since recordists started using echo chambers, springs, and plates to add artificial ambiance; and since such recordings were played back before the ears of modern listeners in mixed spaces. The overlay of physical and mediatic space in digital media *has already happened* in the sonic domain. The fractured perspective implied in the overcoding of physical space with information is an accomplished fact in speaker culture; it is a basis for the coherence of a modern hearing subject, not its dissolution or supersession.[28] Like augmented and mixed reality, detachable echoes combine multiple sonic spatialities within a single space (and subject sounds to one another such that they are both "actual" in the same register). By their nature, the sounds are interactive, as our hearing of them changes each time we move around the room. In their apprehension of multiple spaces within a single space, with their multiperspectival perceptions, the subjects of augmented and mixed reality will not be radically different from the media subjects we already know, such as the audiences who have attended to radio and popular music for close to a century.

Modeling Space: Constructing Reverb Effects

The extreme variance of physical space makes exact reproduction of its reverberant performance impossible. Consider the typical concert hall, with its 60 billion cubes of differentially heated, moving air. Even now, no computer could calculate 60 billion undulating cubes in real time. So for most of the twentieth century, reverb designers followed the tack of other sound technologists: they aimed to reproduce the *effect* of reverberation, rather than the cause or *process* of reverberation. In the process, they did not just represent space but produced it, reproduced it, and overlaid it. As Blesser and Salter write, the goal of artificial reverberation is "perceptual equivalence," not precise mimicry. This is a common technological practice in sound reproduction: rather than modeling the cause of a sound in the world, engineers model its effect on the ear. This work-around was important both to the development of early sound-reproduction technologies like telephones and phonographs and more recent developments like mp3s. Today this approach is widely used in audio signal processing—the goal is to produce specific effects for listeners' ears, not to produce accurate three-dimensional models.[29]

Artificial-reverb devices must therefore take a sound and multiply it, creating echoes so fast and in such multitude and variety (through filtering, stereo effects, and other techniques) that they blur together and convey a sense of ambiance. They produce, proliferate, and manipulate sound; the process of modeling acoustic space is thus inseparable from the process of making acoustic space. Artificial reverbs selectively annihilate "the temporal fine structure of a sound," if, like Thompson's moderns, we conceive of sounds as separable from their environmental ambiances. The earliest artificial reverberators, which are still in use, were mechanical and used plates or springs: the relatively random behavior of the spring or plate mimicked the relatively random compound of echoes that creates the experience of reverberation in a room. A spring reverb used the vibration of springs to introduce artificial ambiance into a sound. Once transduced into electricity, the sound was run through the springs, which could be more or less dampened to produce different effects. Plate reverbs worked according to a similar logic: here, an electrical signal was sent into the plate through a "driver" and received in

Elektromesstecknik.
EMT-140 plate reverb, ca. 1957.

its diffused form through two “pickups.” Engineers had a limited palette: they could control the relative tone of mechanical reverbs (more treble, more bass) and the balance of original signal to the effected one.

The first kinds of digital reverb modeled physical spaces through algorithms that attempted to mimic the behavior of the space in some way. Now called algorithmic reverbs, they are complex devices involving multiple stages and two kinds of mathematical operations: statistical (for early echoes, sometimes called “early reflections”) and random (for later echoes called the “tail”). Both operations work to filter sounds, adjust their stereo positions, multiply them, and add time delays to them, all of which happen to sounds in rooms once sound and its space, as separate things, can be treated as, and treat the room as, a signal-processing device applied to the constructed “dry” sound. Statistical procedures work for early echoes because fewer variables affect how those echoes confront listeners’ ears. But things like air density and heat become bigger problems as engineers try to model the larger echoes that give a sense of a larger space. Because of the complexity of these spaces, the easier approach is to use various techniques of random value generation rather than calculate what actually happens as sound bounces around a large space like a concert hall. What will happen in a physical space from one moment to the next is hard to predict exactly and mathematically, but the variance that happens in a physical space gives a liveliness to the sound. Randomization in a reverb algorithm attempts to mimic this behavior without actually having to model it.

At one level, the turn to randomization is akin to surrendering in the face of overdetermination: so many things are happening in so many different ways that they cannot be calculated or captured by any modern computing device. But here, the human dimension is crucial: artificial reverb uses time delays and filters to simulate sounds’ movements through space, but their ultimate goal is to produce a particular kind of perceptual effect, not to map a space. Reverberation orients a subject, gives the feel of a space without tracing it directly. Through different kinds of statistical behaviors and degrees of randomness, digital reverbs simulate the reverberation of a variety of physical spaces and devices, but they do so by mimicking effects, sharing an aesthetic heritage with their mechanical predecessors, even if their operational protocols are entirely different. A digital reverb has presets like “drum room,” “vocal room,” “hall,” “cathedral,” and even mechanical reverbs like “spring” or “plate” (which have become signature sounds in various kinds of music and audio production for film, television, and video games).

These operations do not have any direct or corresponding relationship to echoes in the rooms they seek to imitate. Algorithmic reverb programmers seek to produce specific sonic effects, not actual places. These effects are judged according to the nebulous aesthetic of satisfactory impressions rather than accuracy. Programmers tweak the math until they achieve their desired effect—not the other way around. The "cathedral" setting on a reverb device, for example, bears that name because it sounds like a cathedral to the designer, not because it has any actual relation to any particular cathedral. In Charles Sanders Peirce's terms, algorithmic reverb is not iconic, as one might imagine; it is symbolic.[30] Blesser and Salter explain the algorithmic model as a social and ultimately conventional process:

> to appreciate the role of art in the design process, consider how Manfred Schroeder, one of the most famous acoustic and mathematical scientists of the twentieth century, selected the delay values in the world's first electronic reverberator. . . . He explained that "we just picked numbers and subjectively listened to the results until we were *happy*."[31]

That the reverb does not sound like the actual room does not really matter. More radically, whether a reverb sounds like a room at all *also* does not matter.

As signal processing becomes part and parcel of musical history, some new algorithmic reverbs, like Sean Costello's Valhalla DSP programs, now seek to emulate specific musical effects or devices. Costello's ValhallaShimmer reproduces the "shimmer effect" in the productions of Brian Eno and Daniel Lanois.[32] His "Valhalla VintageVerb" is "inspired by" different generations of now canonical digital reverbs produced by the companies Lexicon and EMT, again pursuing a specific set of aesthetic effects—often more surreal than realist—rather than the ambiance of a physical space.[33] Reverb devices achieve canonical status not because of their realism or their particular operational characteristics but because of sonic signatures that they impart to notable passages in notable recordings.

Whether in software or hardware, an artificial reverberator is more aesthetically akin to a musical instrument than a building: "once a spatial parameter is connected to a knob, button, or key, a reverberator becomes effectively indistinguishable from a musical instrument, played in real time by a musician."[34] Those knobs and buttons, or pictures thereof, represent artificial reverb as something fundamentally different from a building. Even though, from an experiential standpoint, artificial reverberation and room reverberation combine inextricably in listeners' experiences, we should not confuse that fact with the discourse of realism that populates the interfaces and sales literature for each new reverb device to come along.

One class of digital reverbs called "convolution reverbs" is interesting for our purposes because they begin from a different set of premises than analog and algorithmic reverbs, which treat reverberation as a perceptual effect. Convolution reverbs use physical models of actual rooms *derived from recordings of echoes in those rooms* in order to achieve their reverberation effects. If a traditional algorithmic reverb can be said to operate on principles analogous to impressionism, convolution reverbs operate on principles analogous to photography.[35] Their claims to realism are based on indexicality, which, according to Peirce, indicates a causal relation, as in the weathervane that points to the wind's prevailing direction: a convolution reverb's claim to realism is based in a causal chain between a physical space and the echo applied to a dry sound.

In digital signal processing, a convolution multiplies the spectra of two recorded signals to combine them, expressing the domain within which they overlap. Just as light has a range of wavelengths that make up a spectrum, so, too, do sounds contain a range of wavelengths that make up their spectra. In theory, *any* two signals can be convolved to create a third signal, though the most common practice is to combine a relatively reverb-free or dry signal with the reverberant signature of a room. This second recording, called an "impulse response" (or IR), is created by introducing a short burst of sound in a room and recording the echo. Recordists usually use a starter gunshot, a burst of broadband noise, or a sine sweep, though interesting effects can be achieved with other sources, such as balloon pops or cymbals. This is essentially the electronic equivalent of testing the echo of a room by walking into it and clapping. By combining the impulse response with a dry recording, convolution software effectively places the dry recording in the "room" that was recorded with the IR. Even though it is completely contrived, the relationship between the impulse response and the physical space it seeks to model is causal, though an impulse response can be edited, like any other sound recording.

Convolution reverbs, available commercially since 1999 with the Sony DRE-777 convolution processor, exist today as software that can be used within most digital recording and mixing programs (software add-ons are called "plugins").[36] In their interfaces (and their advertising copy, for that matter), convolution reverbs often assert that a sonic sample of an actual physical space will produce a more realistic-sounding artificial reverb. The conceit of a program like Audio Ease's Altiverb, one of the oldest and most common software convolution processors, is that the user can place any recorded sound in a variety of rooms famous for their sound. In fact, a selling point of the program is that it comes with samples of interesting rooms and equipment from around the world.

Audio Ease. Altiverb 7, 2011–2015. Main interface window. Once users select a preset (pictured), they can manipulate it through the set of skeuomorphic controls on the screen.

But grafting the sounds of rooms onto dry tracks is not the only option. Convolution is a kind of universal translator device. An impulse response can be taken of electronic equipment just as easily as of a physical room, and so a convolution reverb can also reproduce the setting of any other artificial reverberator or any other device. Users are also not limited to lifelike choices: a drum set could be placed “inside” a washing machine, a piano, or a garbage can, and nothing prevents users from simply convolving two signals, neither of which is an impulse response. Nevertheless, most convolution processing is used for reverberation, because most of the presets in convolution programs are reverb presets, and convolution reverb is sold on the basis of its claims to realism and predictability.[37]

We should not make too much of this aesthetic of realism. For convolution processing is still significantly different from the sound one hears when sitting in a concert hall, even though it is no more artificial than concert hall sound.[38] Even with the increased power of contemporary computers, convolution processors still do not have enough computing power to account for every variable in the impulse response of a concert hall. Further, the same space will reverberate differently from moment to moment because of the circulation of heat waves. A single impulse response no more captures the motion of sound in a room over time than a photograph of a person walking captures his or her route. More recent versions of the software have introduced randomization of late echoes to compensate for this difference, thus moving more toward the impressionistic style of algorithmic reverbs.

As a wave phenomenon, the heat issue also points to the distinctive temporality of convolution. Convolution operates according to the logic of the sample. While an algorithmic reverb introduces randomness into a signal to simulate changes that 60 billion cubes might have on a sound, a convolved signal is not exactly random. The impulse sound causes a response in the room, and this causal relationship is what makes it an index. We can think of the sound waves as going out and exploring the space, reaching its outer walls and returning to the center of the space, tracing the territory. That response is then grafted onto the dry signal as if it were in the space. In a recording, a sound can be heard as if it were in Gol Gumbaz without being in Gol Gumbaz. Sonically, the difference may be inaudible, but if we understand technological action as a form of social relation, then this indexical

effect is very different from a generic "tomb" setting on an algorithmic device, which is really nothing more than an engineer's impression of what a tomb should sound like.

By its very nature, the impulse's tracing is a reduction of the space it traces. Perhaps in some future age of quantum computing, a convolution processor will be able to calculate the response for 60 billion cubes of undulating heat, and Jorge Luis Borges's story about the map that was coextensive with the territory will no longer be fiction. Except that the map still would not *be* the territory: "coextensive with" is not "the same as." Both auditions would involve representations of space, but of completely different orders. Our listener standing in a reverberant hall is completely different from a computer programmer's imagination of those undulating cubes. The sonic similarities actually occlude the different materialities. While this may sound like an aural illusion, tricking the ears, it is not a trick. Rather, space is being constructed, shaped, and represented. Artificial reverberators, their makers, and their users treat space as a function of time, just as ears do, but it is more a matter of constructing representations and aesthetics *for* ears than tricking them. Realism is nothing more and nothing less than an aesthetic effect.

Convolution achieves at the level of processing what artificial reverb achieved at the aesthetic level all along. To call convolution a reduction of reality and leave it at that would be to miss the bigger innovation. The impulse signal's reduction of the space is less important than its openness to the space it seeks to model. Like augmented and mixed reality technologies, convolution processing overcodes the space that it samples with a set of calculations so as to make it portable and transposable and in the process makes possible the partial coexistence of two acoustic spaces inside a single physical space. Convolution traces space in order to actualize it at a distance from itself and in relation to other spaces. In the convolution equation, different sonic spaces gel together within one sonic environment. The practice of artificial reverberation, while realistic, is a realism of multiple, compounding acoustic perspectives and spaces. In a world defined by detachable echoes and speaker culture, to hear things at once from multiple perspectives and in multiple spaces is a banal experience. In this way, the history of artificial reverb points to one possible future for the increasingly overcoded spaces of everyday life as augmented and mixed-reality technologies become ever more common. Perhaps the proliferating layers of "there" in lived space will simply be folded back into how subjects place themselves. This is what has happened in the domain of acoustic space, and no immediately compelling evidence suggests that the history of haptic or visual spaces *must* be different. If we follow reverb's lead, then perhaps complex, contradictory, overlapping multiple architectonics are not the undoing of modern subjectivities but one of their baselines. If we follow reverb's tail, then times and spaces are not compressed or annihilated through modern technology and aesthetics. Time and space are endlessly recombined, choreographed, pinpointed, and diffused.

Notes

1. Emily Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America 1900–1930* (Cambridge: MIT Press, 2002), 171–72. For a contrasting account, see George C. Izenour, Vern Oliver Knudsen, and Robert B. Newman, *Theater Design* (New Haven: Yale University Press, 1996).

2. On THX, see Michel Chion, *Audio-Vision*, trans. Claudia Gorbman (New York: Columbia University Press, 1994), 99–101.

3. Thompson, 317–24.

4. Jason Stanyek and Benjamin Piekut, "Deadness: Technologies of the Intermundane," *Drama Review* 54, no. 1 (2010): 19. Stanyek and Piekut describe that condition as "rhizophonic," which they offer as a replacement for Murray Schafer's notion of "schizophonia," which uses the stigmas attached to schizophrenia to argue that the fundamental characteristic of sound recording is to separate a sound from its source and that it is a diminishment of the real. I have critiqued Schafer elsewhere, but the point here is that the split between mediated/nonmediated is precisely not what is at issue, since sonic space is already set up according to the same logic as its mediatic form. I am not arguing that artificial reverberation diminishes the real; I am arguing that artificial reverberation is possible because of a cutting up of the real.

5. Or, as the tagline to the 1979 release of the movie *Alien* says, "In space, no one can hear you scream."

6. Henri Lefebvre, *The Production of Space* (Cambridge, UK: Blackwell, 1991).

7. Stefan Helmreich, "An Anthropologist Underwater: Immersive Soundscapes, Submarine Cyborgs and Transductive Ethnography," *American Ethnologist* 34, no. 4 (2007): 621–41.

8. Alina Payne, *From Ornament to Object: Genealogies of Architectural Modernism* (New Haven: Yale University Press, 2012), 8–9.

9. Robert Bruegmann, "Central Heating and Forced Ventilation: Origins and Effects on Architectural Design," *Journal of the Society of Architectural Historians* 37, no. 3 (October 1978): 157–58. See also Reyner Banham, *Architecture of the Well-Tempered Environment* (1969; Chicago: University of Chicago Press, 1984).

10. For broader discussions of reverb and mixing as aesthetic practices, see, for example, Albin J. Zak, *The Poetics of Rock: Cutting Tracks, Making Records* (Berkeley and Los Angeles: University of California Press, 2001).

11. As Ian Reyes argues, "despite the deep transformation of audio effected by the digital turn, one fact remains: recorded music is made for speakers." Ian Reyes, "To Know Beyond Listening: Monitoring Digital Music," *Senses and Society* 5, no. 3 (2010): 324.

12. Kyle Devine, "Imperfect Sound Forever" (Ph.D. diss., Carleton University, 2012). Writers in visual studies have argued that a proliferation of screens has brought together a host of visual modes and rhetorics, making them more portable and ubiquitous. Something similar has happened with sound, and one could argue that it happened considerably earlier. I cannot find a precise genealogy for the term *screen culture*, though it is now in widespread use. My guess is the line of thinking goes back to work such as Margaret Morse, "An Ontology of Everyday Distraction: The Freeway, the Mall, and Television," in *Logics of Television*, ed. Patricia Mellencamp (Bloomington: Indiana University Press, 1990); and Anne Friedberg, *Window Shopping: Cinema and the Postmodern* (Berkeley and Los Angeles: University of California Press, 1993). Speakers are not only essential features of architectural installations

and media technologies; they are also essential components of arguably the most important musical instruments invented in the twentieth century: electric guitars and synthesizers. Steve Waksman, "California Noise: Tinkering with Hardcore and Heavy Metal in Southern California," *Social Studies of Science* 34, no. 5 (2004): 675–702; Trevor Pinch and Frank Trocco, *Analog Days: The Invention and Impact of the Moog Synthesizer* (Cambridge: Harvard University Press, 2002); Paul Théberge, *Any Sound You Can Imagine: Making Music/Consuming Technology* (Hanover, NH: Wesleyan University Press and the University Press of New England, 1997); and Georgina Born, *Rationalizing Culture: IRCAM, Boulez and the Institutionalization of the Musical Avant-Garde* (Berkeley and Los Angeles: University of California Press, 1995).

13. See, for example, David Goodman, "Distracted Listening: On Not Making Sound Choices in the 1930s," in *Sound in the Age of Mechanical Reproduction*, ed. David Suisman and Susan Strasser (Philadelphia: University of Pennsylvania Press, 2009); and Anahid Kassabian, *Ubiquitous Listening* (Berkeley and Los Angeles: University of California Press, 2013). For recent iterations of the concept, see, for example, Anna McCarthy, *Ambient Television: Visual Culture and Public Space* (Durham, NC: Duke University Press, 2001); and Haidee Wasson and Charles Acland, "Introduction: Utility and Cinema," in *Useful Cinema*, ed. Charles Acland and Haidee Wasson (Durham, NC: Duke University Press, 2011).

14. Tara Rodgers, "Synthesizing Sound: Metaphor in Audio-Technical Discourse and Synthesis History" (Ph.D. diss., McGill University, 2011), 55–90.

15. Fred Gaisberg, *The Music Goes Round* (New York: Macmillan, 1942).

16. Peter Doyle, *Echo and Reverb: Fabricating Space in Popular Music Recording, 1900–1960* (Middletown, CT: Wesleyan University Press, 2005), 57.

17. On the history and culture of stereo, see Paul Théberge, Kyle Devine, and Tom Everrett, eds., *Living Stereo: Histories and Cultures of Multichannel Sound* (New York: Bloomsbury, 2015).

18. Doyle, 5.

19. Barry Blesser and Linda-Ruth Salter, *Spaces Speak, Are You Listening? Experiencing Aural Architecture* (Cambridge: MIT Press, 2007), 246.

20. Bissera Pentcheva, "Hagia Sofia and Multisensory Aesthetics," *Gesta* 50, no. 2 (2013): 105.

21. A truly anechoic space can be claustrophobic for the listener. When I first visited an anechoic chamber—a room designed to absorb all echoes—I immediately noticed that my voice and breath seemed to stop in front of my face. On the history of anechoic chambers, see Henning Schmidgen, "Camera Silenta: Time Experiments, Media Networks, and the Experience of Organlessness," *Osiris* 28, no. 1 (January 2013): 162–88.

22. Thompson, 235 (but see also her subsequent discussion of tone tests and radio listening). The argument that modernity is defined by a plasticity of time and space is a well-worn position in both cultural history and media studies. See, for example, Menachem Blondheim, *News over the Wires: The Telegraph and the Flow of Public Information in America, 1844–1897* (Cambridge: Harvard University Press, 1994); James Carey, *Communication as Culture* (Boston: Unwin Hyman, 1988); Stephen Kern, *The Culture of Time and Space 1880–1918* (Cambridge: Harvard University Press, 1983); Donald M. Lowe, *History of Bourgeois Perception* (Chicago: University of Chicago Press, 1982); and Wolfgang Schivelbusch, *The Railway Journey: The Industrialization of Time and Space in the 19th Century* (Berkeley and Los Angeles: University of California Press, 1986).

23. Virginia Heffernan, "Funeral for a Friend," *New York Times*, 31 October 2010, 22. See also Carolyn Marvin, *When Old Technologies Were New: Thinking about Electrical Communication in the Nineteenth Century* (New York: Oxford University Press, 1988); Jason Loviglio, *Radio's Intimate Public: Network Broadcasting and Mass-Mediated Democracy* (Minneapolis: University of Minnesota Press, 2005); Michael Chanan, *Repeated Takes: A Short History of Recording and Its Effects on Music* (New York: Verso, 1995); and Vincent Stephens, "Theorizing Jazz and Pop Vocal Signing Discourse in the Rock Era, 1955–1978," *American Music* 26, no. 2 (2008), 156–195.

24. Allan F. Moore, Patricia Schmidt, and Ruth Dockwray, "A Hermeneutics of Spatialization for Recorded Song," *Twentieth-Century Music* 6, no. 1 (2011): 98–102.

25. Joshua Hudelson, "Listening to Whisperers: Performance, ASMR Community and Fetish on YouTube," *Sounding Out! The Sound Studies Blog*, 10 December 2012, http://soundstudiesblog.com/2012/12/10/whisper-community/.

26. Oliver Bimber and Ramesh Raskar, *Spatial Augmented Reality: Merging Real and Virtual Worlds* (Wellesley, MA: A.K. Peters, 2005), 2.

27. Lev Manovich, "The Poetics of Augmented Space," *Visual Communication* 5, no. 2 (2006): 220.

28. Steve Jones made this point over two decades ago in an essay arguing that many of the promises of virtual reality had already happened in the sonic domain. See Steve Jones, "A Sense of Space: Virtual Reality, Authenticity and the Aural," *Critical Studies in Mass Communication* 10 (1993): 246.

29. Blesser and Salter, 261. For the longer history, see Jonathan Sterne, *The Audible Past: Cultural Origins of Sound Reproduction* (Durham, NC: Duke University Press, 2003); and Jonathan Sterne, *MP3: The Meaning of a Format* (Durham, NC: Duke University Press, 2012).

30. Charles S. Peirce, *Philosophical Writings of Peirce* (New York: Dover Publications, 1955), 98–119; and Thomas Turino, "Signs of Imagination, Identity and Experience: A Peircean Semiotics Theory for Music," *Ethnomusicology* 43, no. 2 (1999): 221–55.

31. Blesser and Salter, 265–66 (emphasis in original).

32. Costello documents the ideas behind his design work on his blog. See especially, Sean Costello, "Introducing ValhallaShimmer," *Halls of Valhalla*, 30 August 2010, http://valhalladsp.wordpress.com/2010/08/30/introducing-valhallashimmer/; and Sean Costello, "Eno/Lanois Shimmer Effect: Early Examples," *Halls of Valhalla*, 10 May 2010, http://valhalladsp.wordpress.com/2010/05/10/enolanois-shimmer-effect-early-examples/.

33. Sean Costello, "Valhalla DSP State of the Union, June 2013," *Halls of Valhalla*, 18 June 2013, http://valhalladsp.wordpress.com/2013/06/18/valhalla-dsp-in-june-2013/.

34. Blesser and Salter, 213.

35. Convolution reverbs are also algorithmic in their operations, but the nomenclature is meant to distinguish reverbs that model space through an algorithmic process based on a set of assumptions about spaces and parameters, and reverbs that model space through a convolution process.

36. The idea has been around even longer. Jones wrote in 1993 of the Quantec Room Simulator, a digital reverb that worked by basing its calculations on room measurements, though it was not strictly a convolution device. Jones, 243.

37. As Paul Théberge notes, users of digital devices often purchase them for the presets, and a large proportion of users never edit the presets. Théberge, 75. Nevertheless, programs

like Nebula use convolution more widely, and digital software that models analog hardware such as guitar amplifiers often uses convolution as part of the modeling process. (For an explanation of Nebula's functions, see the Acustica company website, http://www.acustica-audio.com/.) Audio Ease also makes a product called Speakerphone that is used in sound design to model not only spaces but situations (e.g., a speaker in a train station). Convolution is also useful in film postproduction for applying the ambiance of a soundstage to dubbed dialogue. I discuss the modeling process in another, in-progress paper, "Hearing with Ears, Eyes, and Hands: Comparing Music Technologies and Their Models."

38. Blesser and Salter may be right that "any designer of an artificial reverberator or a spatial simulator who claims to have successfully incorporated the acoustic details of a real concert hall by using measured impulse response is naïve, dishonest, or a marketing zealot" (242), but we must also be careful of the rhetoric of realism applied to other forms of reverberation.