A Process for the Restoration of Performances from Musical Errors on Live Progressive Rock Albums

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Abstract

In the course of my practice of producing live progressive rock albums, a significant challenge has emerged: how to repair performance errors while retaining the intended expressive performance. Using a practice as research methodology, I develop a novel process, Error Analysis and Performance Restoration (EAPR), to restore a performer's intention where an error was assessed to have been made. In developing this process, within the context of my practice, I investigate: the nature of live albums and the groups to which I am accountable, a definition of performance errors, an examination of their causes, and the existing literature on these topics. In presenting EAPR, I demonstrate, drawing from existing research, a mechanism by which originally intended performances can be extracted from recorded errors. The EAPR process exists as a conceptual model; each album has a specific implementation to address the needs of that album, and the currently available technology. Restoration techniques are developed as part of this implementation. EAPR is developed and demonstrated through my work restoring performances on a front-line commercial live release, the Creative Submission Album. The specific EAPR implementation I design for it is laid out, and detailed examples of its techniques demonstrated.

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A thesis has one author, representing the knowledge and support of many. I began this journey at Glasgow University, where Dr Nick Bailey adopted me as one of his own and gave me a space in his lab equal to that of his own students. He taught me what music technology really was, and how to make a proper cup of tea. Professor Graham Hair taught me the deep, sharp, and pointy bits about music, and showed me the demeanour fitting of a distinguished gentleman.

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My greatest thanks to Jason Wooley for stepping in and providing outstanding guidance. Ben Challis for his time and understanding. And to acknowledge the support, patience and wisdom of my first MMU advisor, Carola Böhm. Even when I had no idea what I was doing (which was not uncommon) she believed in me, keeping me inspired and frequently well-caffeinated.

Statement of Originality

I hereby certify that all the work described within this thesis is the original work of the author. Any published (or unpublished) ideas and/or techniques from the work of others are fully acknowledged in accordance with the standard referencing practices.

William Evans

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List of Abbreviations & Acronyms

Text	Translation/Meaning
A&R	Artist and Repertoire
AP	Album Producer
ARMI	Audio Representation, Modification, and Interaction
DAW	Digital Audio Workstation
EP	Executive Producer
FOH	Front of House
FOHE	Front of House Engineer
HPAR	Harmonic Phrase Analysis & Restoration
ICTT	In the Context of This Thesis
IS	Intended Score
ITT	Introduced in This Thesis
IRP	Intended Recorded Performance
ME	Mix Engineer
MIDI	Musical Instrument Digital Interface

PaR†	Practice as Research
PAS	Primary Audio Source
PE	Post-Production Engineer
PS	Performed Score
RDI	Rear Direct Illumination
RRP	*Restored Recorded Performance*
RE	Recording Engineer
SAE	Stand-alone Audio Editor
TMA	Too Many Acronyms
UDAW	Universal Digital Audio Workstation
VAW	Virtual Audio Workstation

† The lowercase 'a' is standard formatting for the Practice as Research acronym.

Definitions

The terms below are either neologisms for my investigation [Ⓝ], compounds [Ⓒ], established academic [Ⓐ] terms, music industry jargon [Ⓙ], or existing terms defined specifically within the context of my practice [Ⓟ]. The need for context-sensitive definitions arises from a term having multiple definitions (e.g. *executive producer*), being vague (e.g. *performance error*), or that the definition's full complexity is irrelevant to the discussion (e.g. early reflections).

Term	Type	Definition
Album	Ⓟ	Any media configuration of a music release (e.g. CD, Blu-Ray, iTunes download, mixed media).
Album Co-Producer	Ⓟ	Helps implement the project's creative vision, in tandem with the artist and Executive Producer.
Creative Submission Album	Ⓟ	A combination audio-only and concert video (4K, Blu-ray, DVD) as the artistic submission with this thesis. Also abbreviated as simply, "The Album" (proper noun).
Ambience	Ⓟ	ICTT: All of the spatial audio decay for a space; i.e. early reflections together with reverb.
Audience Groups	Ⓟ	The different audiences that judge the error content of live progressive rock albums, and who decide the success of these albums according to the goals of my practice.
Audio Signal	Ⓟ	An electrical signal with a voltage wave that corresponds to an audio wave. The audio signal is abstract; it does not exist within the context of a source or destination for routing.
Audio Stream	Ⓟ	An electrical signal with a voltage wave that corresponds to an audio wave. It exists within the context of a specific routing (from a microphone to a mixer).
Authenticity	Ⓟ	Within the context of my investigation, an authentic recording is perceived by the audience groups (that I am accountable to) as representative of the artist's repertoire, and a specific instance of an unaltered recording.
Blob	Ⓙ	The representation of a musical event, analogous to a note, in the software application, Melodyn.
Difference-Artefacts	Ⓒ	Sonic artefacts that are manifested when, through the process of repairing performance errors, audio tracks with modified (repaired) audio interferes with tracks containing the original audio.
Digital Audio Workstation	Ⓙ	A comprehensive software or software/hardware system for music and sound production.

Direct Signal	J	Electrical signals emitted directly from an instrument which contain a transduction of an audio wave, ready to be amplified or converted to digital information for recording.
Early Reflection	P	The first reflection of a Sound Pressure Wave; it is typically very fast, and the loudest portion of ambience because the amplitude of pressure waves falls in proportion to the square of the distance travelled.
Error Analysis & Performance Restoration	P	The process developed in this investigation to restore performances where errors exist on a live concert recording.
Envelope	A	The rate and duration at which some aspect of an audio signal (e.g. amplitude) changes.
Forensic Assembly	C	A method within the EAPR Process to assemble audio representing restored performances, based on the concept that recorded performance errors often contain significant elements that are correct; these aspects can be combined with information from similar (correct) performances in lieu of replacing entire notes.
Front-Line	J	The highest profile release category for a record label. Others are Mid-Line and Back-Line.
Flexture Editing	C	A type of audio modification where pivot points can be set within an audio region, and then moved forward or backwards in time, compressing or stretching the audio without changing its pitch. This technique is usually known by brand names unique to different DAWs; e.g. "Flex Time" in Logic Pro X (Apple, 2013) or "Liquid Audio" in Pro Tools (Avid Technology, 2014) . There is no universally accepted term; I formed this compound term based on Bryan's paper on the topic (Bryan et al., 2012).
Front of House	P	Refers to the audio signal of the band's performance, and the large speakers that produce the corresponding sound pressure waves for the audience to hear. In smaller venues, the speakers are at the front of the stage (hence the name); in larger venues, additional speaker arrays will be positioned throughout the venue.
Executive Producer	P	Develops the concept for a project, oversees it until complete, creates the marketing plan, secures funding.
Gridding	N	A philosophy in audio engineering of repairing errors in recorded performances that emphasizes an aesthetic of perfection.
Incident Signal	P	The sound pressure waves directly emitted by a speaker on stage; the resulting ambience is not part of the incident signal.
Mix Incoherence	C	A lack of clarity and fidelity in a mix.
Intended Recorded Performance (IRP)	C	The audio that corresponds to what a performer intended to record, as judged by the performer. When using HPAR, the practitioner should be able to determine this well enough to restore performances.
Monitors	P	Monitors are speakers that produce sound only for the band, so that they may hear themselves. These speakers are usually in front of the artists, facing away from the audience and toward the artists; additionally, they may be positioned on either side of the stage, facing inward (i.e. *side fills*).

Musical Event Editing	P	A process by which software applications employ heuristics to extract information from an audio file to create musical representations which can be edited as such.
Non-Program Audio	P	The audio (recorded onto a track) that was *not* intended to be captured (i.e. via a Direct Signal or microphone). Examples include EMI interference, distortion from levels being overdriven, and 50Hz/60Hz hum.
Patch	N	The term I use (as a verb) for the current audio engineering and production practices of addressing performance errors in live progressive rock recordings.
Performance Error	C	Within the context of live performances, an error refers to the perception by audience members (including the artist, listening after the fact) of an error in the performance. This can apply directly to the performer's execution of the score, or external phenomena such as radio interference.
Performance Forensics	C	A term within EAPR describing the heuristic estimation of intended performances (in the context of recorded performance errors).
Phantom Fundamental	A	The perception of a fundamental pitch that does not have a corresponding frequency emitted by a vibration source.
PBE Taxonomy	P	The practice-based error taxonomy defined as part of my investigation.
Post-Production Engineer	P	As part of my practice, the person who performs all of the audio engineering on raw audio recorded from a concert in order to create a project ready for mixing.
Practice as Research	A	A research methodology, frequently with a creative arts component, employing an investigative model where significant discovery takes place in the context of the investigator's practice.
Praxis	A	An iterative, self-reflective methodology for discovering knowledge about a process through an internal dialogue by the practitioner between the process and the results.
Pressure waves	P	The physical manifestation of sound—a series of compressions travelling through a medium, produced by the vibration of an object.
Primary Audio Source	C	The specific acoustic vibration source (e.g. the top of a snare drum) that an engineer wishes to capture with a specific microphone.
Program Audio	P	The audio that was intended to be captured (i.e. via a Direct Signal or microphone). It is comprised of the Primary Audio Source and any leakage from other Primary Audio Sources.
Project	P	The set of all Tracks for a live concert recording.
Recording	P	The measurement and storage of information about pressure waves over a fixed period of time.
Raw Recording	C	All of the audio recordings from a specific concert, without any modification.
Reverb	P	The spatial audio decay of sound pressure waves due to repeated reflections of a vibrating source within a 3D space.

Restored Recorded Performance (RRP)	C	In the context of my practice, the ideal performance of a specific concert, according to the best-determined intentions of the performers and the median ability of their creative improvisation.
Reverb Suppression	A	The perception that there is less reverb when listening to a live event than a scientific measurement shows there to be.
Sound	P	I employ this term to refer to the perceptual experience of sound—informed by travelling pressure waves in the listener's environment
Spectral Editing	J	A process by which audio is broken down into separate frequency and amplitude components, to be viewed and edited as such.
Studio	C	The top-level conceptual level of Belexes.
Stand-Alone Audio Application (SAAA)	C	A computer application devoted to editing audio files. It differs from digital audio workstations, which provide more comprehensive music production including MIDI. Stand-alone editors often have audio editing features beyond the typically more general abilities of DAWs.
Technical Mistake	C	An instance where the recorded audio does not correspond to the performer's intention.
Track	P	A data file on a computer which is a recording of a specific Audio Stream from the live concert (e.g. Lead Vocal).
Transient	A	A rapid change in amplitude.
Transient Design	J	The process is undertaken by a mixing engineer to control the rate at which a sound changes amplitude (also known as a sound's *envelope*).
Virtuoso Performance	C	The skilful technical execution of complex and challenging material according to the performer's intention, without regard to improvisational creativity.
Universal Digital Audio Workstation	C	Any DAW that supports the standard set of DAW features, given that there is widespread adoption of such features (i.e. DAW Functional Equivalency).

1 : Introduction

1.1 Background, Context and Motivation

My creative practice focuses on the production of commercial, live progressive rock albums and accompanying concert films. In the context of this thesis, my practice focuses on my role as executive producer and audio engineer for the progressive rock/pop band, Flying Colors.

I conceived the band to explore the musical interaction of progress rock and mainstream rock, enlisting four musicians from popular progressive rock bands, and a lead singer from Disney's Hollywood Records.

The modest commercial success[3] of this band brought with it significant challenges for me regarding our live release, technically and artistically. My experience in responding to these challenges creates the basis for my research enquiry.

Progressive (prog) rock adopts complex musical attributes from other genres, combining sophisticated compositional structures from the symphonic repertoire with the adept improvisational tradition from jazz. Prog-rock performers are expected to have similar virtuoso performance ability in both disciplines.

During my enquiry, I will develop a process that addresses the primary problem emerging from my production of live, prog-rock albums: managing performer errors. This is a common issue in the production of live music albums (Lukather, 2018). However, the available tools and standard industry practice do not optimally serve the needs of my practice; while the standard practice manages them by obscuring them according to standards of perfection (Blier-Carruthers, 2013). I seek to restore the originally intended performances.

My investigation will explore the technical and artistic factors within the commercial context of my practice to develop a process that addresses this research problem. I will then apply and refine that process as part of producing a creative artefact, which I will refer to as the Creative Submission Album. This album is the live Flying Colors record and concert film, *Second Flight: Live at the Z7* (Flying Colors, 2015).

[3] 100,000 albums sold from 2012 - 2015.

Following my self-assessment during this process, I will perform a final assessment of my work within the context of my practice. I will also apply my process to an album outside the live progressive rock genre, and self-assess the result.

This investigation is grounded in the interdisciplinary realm of music technology (Boehm, 2005). My methodology for this investigation is practice as research (PaR). I will pursue a dialogic cycle of developing my error repair processes—and reflecting on the results—driving knowledge acquisition iteratively. This inquiry will yield new knowledge residing in myself as the practitioner, and documented in this thesis.

While I offer a more complete examination of my application of practice as research in Section 1.4.1, a useful introduction is provided by Linden, drawn from PALATINE's submission to the HEAV[4] indexer:

> *Practice as Research = research activity in which disciplinary practice—normally arts/media/performance practice—is an integral part of the research method and outcome (in the form of documented processes and/or products) of an articulated and positioned research inquiry.*[5] *(Linden, 2012)*

Given that the motivations in pursuing the research are the personal, professional, artistic, and other components that drive practice—the questions, results, and outcomes are evaluated within the context of that practice. Barret comments:

> *Because creative arts research is often motivated by emotional, personal and subjective concerns, it operates not only on the basis of explicit and exact knowledge, but also on that of tacit knowledge. An innovative dimension of this subjective approach to research lies in its capacity to bring into view, particularities of lived experience that reflect alternative realities that are either marginalised or not yet recognised in established theory and practice.* (Barrett and Bolt, 2014)

[4] HEAV is the United Kingdom's Higher Education Academy. In 2007, they called for submissions for a short definition of Practice as Research; Linden's offering is the submission from the PALATINE group of researchers. There is more to the story, including the adventures of a capricious but lovable unicorn who saves a kingdom from a marauding band of pedagogical acronyms.

[5] The grammatical formatting of this quote matches the original.

It is my hope that the process and techniques that emerge from my investigation will not only inform my future practice, but that other practitioners may benefit within their own practices by observing, adapting and integrating aspects of my research.

1.2 Motivation

As discussed in Section 1.1, my research questions first emerged in my creative practice from my experience with the progressive rock/pop group, Flying Colors. In this section of Chapter 1, I will provide an informal overview of my previous engagement with the issues that arose from working on this album. This early foundation will provide context for my research question of investigating improved methods for repairing performance errors.

1.2.1 Flying Colors

In 2009, I wrote a proposal for progressive rock/pop band, Flying Colors. I brought the proposal to four leading progressive rock and jazz/fusion artists, a pop singer from Disney's Hollywood Records label, two guest artists, and an album producer. The concept was to create an all-star band that combined the musical complexity and virtuoso performances of each artist's genres with a mainstream pop sensibility. After soliciting offers from record labels, we signed with Mascot Label Group in 2011, with myself as executive producer and (eventually) post-production audio engineer. Our first album, the eponymous *Flying Colors* (Flying Colors, 2012), was considered by Mascot Label Group to be a modest commercial and critical success. They agreed to renew our contract.

Our next release was the concert film and accompanying live album, *Live in Europe* (Flying Colors, 2013). While a commercial and critical success[6], I was unsatisfied with the result. My main issue was how performance errors were managed. Before mixing, I undertook the task of repairing performance errors. In conjunction with re-recording by the band, we addressed the relatively small number of mistakes made during the performance. I had hoped to improve on the industry's standard practice of "patching" such errors to better capture the performer's abilities, but the final result felt as compromised as the other live albums I'd worked on, and the others I had experienced as a consumer.

Our next studio album was Second Nature (Flying Colors, 2014), followed by another concert film and live album, *Second Flight: Live at the Z7* (Flying Colors, 2015). Due to a

[6] *Live in Europe* debuted with #1 chart position in France, briefly displacing the distinguished popular music auteurs, One Direction.

confluence of factors, a significant number of performance errors were manifested on this release.

1.2.2 Second Flight: Live at the Z7

The performance issues during this concert stemmed from several causes. There were monitoring problems, preventing the musicians from hearing themselves and each other. Lighting was another; the venue insisted on running the lights without knowing the cues. As a result, bright lights appeared at random times on the musicians; other times, they would suddenly find themselves playing in the dark. One of the band members was also seriously ill the night of the taping. Additionally, it was a very short tour, and the concert needed to be recorded after the band had played the songs only seven times (including tour rehearsal).

After the concert, the band and I discussed the recording. They expressed scepticism that the performances could be repaired, given their seriousness—even with re-recording. Given that there were only three shows left on the tour, there was no time to schedule another professional shoot. It appeared we might not have a live concert album to release.

As executive producer, this became my problem. I needed to transform the audio on the album, so it could be released according to the artistic and technical standards of all the audiences in my practice: the band, the record label, progressive rock fans, and the media. And the audio would need to work both with and without the accompanying video.

I realised that, regardless of the techniques employed, the album would pose technical challenges to repair some of the errors that occurred. Additionally, I wanted to find a process to repair errors that did not result in albums I felt were artistically compromised.

Meeting these two goals would require a formal academic investigation, and I chose *Second Flight: Live at the Z7* as my Creative Submission to develop and demonstrate my research. With the band's permission, I embarked upon this journey. This thesis, and the accompanying albums[7] represent the results of this enquiry.

[7] After completing the Creation Submission Album, I produced a second album to further develop and demonstrate my error management process.

1.3 Objectives

In this section, I discuss the objectives of my research.

1.3.1 Provide Context for My Investigation

Within the context of my practice, I explore the origin, meaning and implications of my primary research problem. I integrate this problem with the goals of my practice, ensuring that my ensuing investigation will serve my needs.

1.3.2 Define Performance Errors

Within my practice of live progressive rock, I investigate and define the nature of performance errors. This investigation is informed by the rich body of existing research on performance errors within other genres and related fields.

1.3.3 Review Previous and Existing Techniques

I review previous research in fields including performance error research, conceptual error models, the capabilities of available audio tools, and current techniques for error management in live progressive rock.

1.3.4 Establish a Theoretical Foundation

Building on my performance error definition, I establish a theoretical and philosophical foundation for a comprehensive system to repair performance errors in my practice. This includes such elements as a taxonomy of performance errors, and an exploration of methods to deduce aspects of intended performances from incomplete recordings.

1.3.5 Conceive a Performance Restoration Process

I develop a novel post-production process to address my research problem of repairing performance errors. It meets the goals of my practice, supports my definition of performance errors and the theoretical foundation I establish around it. The process includes an abstract set of operations that is realised with an implementation created specifically for the challenges of each album project.

Given the relative lack of research on the required audio modification techniques, I implement the process with new techniques, and adapt existing techniques from other contexts. They are carried out using existing software tools.

This process meets the needs of my practice by incorporating such goals as eliminating the need for re-recording, preserving the performer's musical intention based on available data about the performance and its context, retaining more of the original audio than other processes, and improving video synchronization with concert films.

1.3.6 Develop and Apply the Processes

My creative practice is governed by the requirements and constraints of the commercial audio market, especially with respect to progressive rock. The results of my investigation are therefore be presented in that context.

The Creative Album Submission serves my practice in several ways: as a front-line commercial release from Flying Colors' record label, a praxical research development vehicle, and a demonstration of my error repair process. A significant portion of the release's audio was affected/altered by my process. Every altered section is documented[8].

I further demonstrate the process, as a post-investigative exercise, with a non-progressive rock album.

1.3.7 Demonstrate the Process

I provide detailed examples of my process applied to a section of the Creative Submission Album. These examples include a description of the issues to be addressed, relevant information from my investigation to classify and analyse these issues, sheet music

[8] See Appendix B and Appendix E.

transcriptions, spectrographs, and the specific audio involved. Intermediate steps and improvements are documented.

1.4 Methodology

> *"Whilst a PhD is a very specific undertaking requiring a clear framework, and not an extended, and ongoing, contemplation of mutating ideas, the value of 'practice' within this framework may be best determined through a mixed-mode revealing that demonstrates rather than dictates how new ideas can arise out of imaginative consideration of the perceived relationships between existing ones.* — Jane Linden (Linden, 2012)

This thesis is an interdisciplinary investigation in the research area of music technology, employing a practice-as-research (PaR) methodology. In this section, I offer: a definition of how I will use this methodology in my research, the reasons it best informs my topic, and how I will use it to discover new knowledge.

1.4.1 Practice as Research

> *Knowledge exists on a spectrum. At one extreme, it is almost completely tacit; that is semiconscious and unconscious knowledge held in peoples' heads and bodies. At the other end of the spectrum, knowledge is almost completely explicit or codified, structured and accessible to people other than the individuals originating it. Most knowledge of course exists between the extremes. Explicit elements are objective, rational and created in the 'then and there', while the tacit elements are subjective experiential and created in the 'here and now'.* — Leonard and Sensiper (Leonard and Sensiper, 1998)

Although the last ten years have shown rapid growth in the examination and adaption of PaR, it remains a relatively nascent development compared with more traditional epistemological methodology (Doğantan-Dack, 2016). While the terminology is not agreed on at this point (Regan et al., n.d.), the methodology is expanding into new fields (McIntyre, 2001). Winter and Brabazon offer:

> *First, there is no universally agreed-upon definition of Practice-based Research. That discussion continues. To further confuse matters, there are other terms for this*

methodology, perhaps because the methodology has not yet formalized, rather than due to major differences in methods. (Winter and Brabazon, 2010)

Given the spectrum of concepts and schools of thought in the literature about PaR (McCormack and Titchen, 2006), I will clarify my usage of the term and how my PaR methodology will inform my investigation.

1.4.1.1 The Emergence of My Research Question

> *A recognition that objectivity can only be partial, calls for re-admitting embodied vision and positioning in research. Embodied vision involves seeing something from somewhere. It links experience, practice and theory to produce situated knowledge, knowledge that operates in relation to established knowledge and thus has the capacity to extend or alter what is known.* — Estelle Barret, Practice as Research: Approaches to Creative Arts Enquiry (Barrett, 2014)

My research questions emerge from my practice—any possible resolutions, and metrics to evaluate them can exist only within the context of that practice. In order to address performance issues, subjective questions present themselves:

- "What does it mean for a performer to make a mistake?"
- "What does it mean to fix a mistake?"
- "Can mistakes be fixed at all?"
- "Under what circumstances?"
- "How do we know if a mistake has been fixed?"
- "Is there even such a thing as a mistake by a performer?"

These questions have both quantitative and qualitative components. It is unlikely that objective answers, and even subjective ones that apply universally, would be of academic merit. Such questions are inherently hermeneutical; when defined within the context of a practice, however, sufficient constraints are introduced, and the questions can be answered within an established framework.

1.4.1.2 Usage of PaR in My Investigation

My investigation employs *praxis*, which Nelson defines as "theory imbricated within practice". (Nelson, 2013). With a feedback loop between my process and my evaluation of the results, knowledge can emerge as a dialogue between developing my process and examining the tools I use to achieve my results (Smith, 2016).

Higgs and Titchen characterise the ability of a practitioner to evaluate her work as part of *practice wisdom*:

> *"Practice wisdom" is the possession of practice experience and knowledge together with the ability to use them critically, intuitively and practically. Including characteristics of clarity, discernment and caring deeply from an objective stance, practice wisdom is a component of professional artistry.* (Higgs and Titchen, 2008)

There are several areas within my investigation requiring assessment, such as the repair of individual performance errors, the reception of the Creative Submission Album within the context of my error repair process, and the cumulative result of my investigation. (These interpretations are all presented in Chapter 8, the thesis' conclusion.

In keeping with my methodology, my evaluations will be self-reviews within the context of my practice. They are not formal, scientific findings. This is a critical distinction in my appraisals, and the claims I make (and do not make).

1.4.1.3 The Locality of Knowledge

Some characterisations of PaR consider the epistemological role and/or locale of the creative artefact[9] (Niedderer and Roworth-Stokes, 2007). In referencing a PaR PhD investigation, Winter and Brabazon present several possible roles for the artefact:

> *In content, it can be entirely stand-alone, in that no artifact is needed to convey, or help convey, the information in the document. In this case, the artifact is more of an appendage, an interesting example of the conclusions reached in the written document. It can also be partially stand-alone, in that the artifact makes it much*

[9] In my investigation, this is the album, *Second Flight: Live at the Z7*.

> *easier for the reader of the document to understand information in the document that can be fully understood only through some sort of experience other than text on a dissertation page. And, it can be totally dependent on the artifact, in which case the artifact not only illuminates, but completely and solely expresses the research and its conclusions.* (Winter and Brabazon, 2010)

Generally, the two proposed locations of new knowledge are: the practitioner/ practice or the artefact, itself (Mäkelä, 2007). A common set of terminologies for these designations is (practitioner/practice) *Practice-led Research* and (artefact) *Practice-based Research* (Candy, 2011). Skains states:

> *Practice-led research focuses on the nature of creative practice, leading to new knowledge of operational significance for that practice, in order to advance knowledge about or within practice. The results of practice-led research may be communicated in a critical exegesis without inclusion of the creative artifact, though the creative practice is an integral part of the research. In practice-based research, the creative artifact is the basis of the contribution to knowledge.* (Skains, 2017)

Given the commonality of performance errors on albums in my practice, the end result of my investigation will be new knowledge I can carry forth to new album productions, and that may be useful in the practice of others. This new knowledge from this practice-led research resides in me as the practitioner.

The creative artefact's (i.e. Creative Submission Album) role in my investigation serves as an object I interact with while creating it, to develop new knowledge. The artefact then also serves as a demonstration of this knowledge that can be observed and referenced by other practitioners. Additionally, it is experienced by the groups[10] relevant to my creative practice—the audiences for the album—outside the context of an investigative enquiry.

[10] See Section 2.3.2.4.

1.5 Scope of Thesis

The nature of my practice is interdisciplinary; it draws from audio technology, performance studies, music production, psychology, music theory, cognition, and musicology.

The context of my research question is within my practice: the production of live progressive rock albums. My practice is commercial, and the answers to my research question are informed by and adhere to commercial goals and constraints. My overall goals are dictated specifically by my roles as executive producer and post-production engineer; while there are many other roles and possible goals for musical recordings, I address only those relevant to my practice.

The research methodology I employ is practice as research; the locality of knowledge is myself as the practitioner, not the creative artefact. My results are not intended to be directly applicable outside of my practice—it is my hope that the new knowledge garnered from my investigation can inform the practice of others.

My solution is a theoretical foundation and practical process, comprised of related techniques. It is novel and addresses only the primary research problem that emerges from the audio post-production process that I have identified: performance errors. It is be solved within the context of my practice.

My error management process is implemented using commercially available tools. When implementing the process, I evaluate the applicability of candidate tools to implement it. This includes not only a technical evaluation, but also issues such as workflow and time requirements, as these are all relevant criteria to the needs of my practice.

I undertake the production of a creative artefact, termed the Creative Album Submission, to praxically develop and demonstrate and implement my process. It is a live progressive rock album containing significant performance errors (relative to the genre's standard).

Additionally, I undertake production of a non-progressive (blues) rock studio album, the Supplementary Submission Album, to provide additional information about the results of my process outside of progressive rock.

Given the integration with my practice, the albums must meet certain commercial standards. This is necessary because it provides context for my internal evaluation: that my error management process is valid at a high level of professional standards and evaluation.

This not to suggest that commercial performance was a result of my research, but that the presence of its results, which is significant on both albums (as a percentage of running time[11]), did not prevent the albums from meeting these commercial criteria. This position is not presented from a scientific perspective; within my own evaluation, I recognise that correlation does not imply causality.

The commercial criteria met by both the Creative Albums Submission, and Supplemental Album Submission: release by a record company with major-label distribution, and the band being signed directly to a major label in at least one territory. The label assigned the releases front-line[12] status.

In keeping with my research methodology, the results of my process are evaluated only by myself, within the praxical context of my practice, informed by my past experience working on similar commercial progressive albums, with similar labels and artists. My research question arises from my work on these releases, and is therefore evaluated within that domain.

To aid in my praxical evaluation, one of the professional criteria I employ on my albums is an informal interpretation of reactions by the groups to which I am professionally accountable[13]. This examination does not provide scientific data on the results of my investigation, and is a standard component of my practice; it is not an empirical exercise.

[11] On the Creative Album Submission, this is 22%. On the Supplementary Submission Album, this is 100%.
[12] These albums are considered the highest priority by the label.
[13] See Section 2.3.2.4.

1.6 Creative Submission Album

The album selected is a Flying Colors release, *Second Flight: Live at the Z7*. The record labels are Mascot Label Group and Warner Music Group. It is a good candidate for my research question because the artists felt the performance errors were such that the album could not be repaired using conventional error management techniques. The artists themselves are amongst the most respected virtuoso performers in progressive rock and jazz-fusion, each with 30+ year careers, ensuring detail and nuance in their performances—both recorded, and to be restored.

The errors were caused by a confluence of factors: health issues with band members, limited rehearsal time, and the recording of the show after only seven performances. These issues were combined—non-functional monitoring (rendering the artists unable to hear themselves and each other) and disruptive lighting that randomly illuminated parts of the stage instead of following pre-defined cues.

Only if I am able to develop a set of new processes to repair the album, and execute them to the standards established within my practice, and to the those of the artists, could *Second Flight: Live at the Z7* be commercially released.

The technical details of the Creative Submission Album are covered in Appendix F.

1.7 Chapters and Appendices Summary

Chapter 1: Introduction

The chapter begins with the background and motivation of my investigation. A list of my research objectives is then be established, followed by a thorough discussion of my research methodology. Next, I present the scope of this thesis, followed by an introduction to the Creative Submission album. The chapter concludes with a chapter summary of the thesis, beginning with the introductory chapter, which you are reading right now. (You are here.)

Chapter 2: Research Problem

This chapter begins with an overview of progressive rock. Next, I explore the roles I perform in my practice. Following this, I discuss the nature of the albums I undertake, and present the four domains which inform my ideology. The four groups to which I am accountable are then presented. Finally, I reveal how performance errors emerge as a challenge in my practice.

Chapter 3: The Ontology of Performance Errors

This chapter investigates the nature of performance errors within my practice of live progressive rock, and establishes the formal definition to be used throughout this investigation. Previous research defining errors is considered and used to inform this definition. Additionally, a review of performance error taxonomies is undertaken; the chapter concludes with the introduction of a new performance error taxonomy for my practice.

Chapter 4: A Process to Identify and Repair Performance Errors

Building on the error taxonomy established in Chapter 3, Chapter 4 presents the goals in my practice for repairing performance errors in terms of this taxonomy, and a process for achieving them. Existing research is examined to inform the development of this process. I determine the knowledge domains required to both inform my estimation of intended performances, and for me (as practitioner) to evaluate the restorations I attempt. The process itself is then presented, comprised of analytical and restoration phases: Error Analysis and Performance Restoration. Following this, I introduce strategies to apply this process to the specific errors of the error taxonomy.

Chapter 5: Performance Error Management in Other Practices

This chapter focuses on how error management is addressed in other practices. I present this investigation within the context of my own practice, as an objective survey is both outside the scope of my thesis, and not relevant to my investigation. Given the limited publications on these practices, I undertake informal correspondence with 18 other practitioners. The knowledge is presented ethnographically and is limited to inform me only within the framework of my investigation and personal practice.

Chapter 6: Implementation of the EAPR Process for the Creative Submission Album

The practical implementation and praxical development of the specific techniques used to implement my error repair process are discussed in this chapter. Beginning with the operational needs for my process, I identify the software tools best-suited to implement them. Next, I explore the specific issues with these tools in implementing EAPR. Closing the chapter, I discuss the challenges of keeping a score-based praxical diary of my work.

Chapter 7: Example Restoration from the Creative Submission Album

This chapter provides detailed examples of my process being applied to specific audio sections on the Creative Album Submission. Quantitative data will accompany my qualitative reporting, including spectrographs, music notation, overlays, and screenshots from specific audio production tools. Additionally, audio samples will be available for each example on the FTP download that accompanies this thesis submission.

Chapter 8: Conclusion and Suggested Future Work

The thesis concludes by first reviewing the new knowledge presented in this thesis, by chapter. The Creative Album Submission Project is then presented, along with the research challenges I experienced while undertaking it are discussed Then, I consider my internal evaluation of the album's commercial and critical reception by my accountability groups. Following this, I review my work on the Supplementary Submission Album. I conclude the chapter with an examination of the commercial implications of my investigation, and an exploration of future research.

Appendix A: Accompanying Media

The media accompanying this thesis, available via FTP download, are listed.

Appendix B: EAPR Log

A log of the 245 Audio Segments repaired on the Creative Submission Album is presented. The start and end points, text-based error description, tool(s) used, repair operations performed, error class, error type, error domain, and ID of each Segment are specified.

Appendix C: Practitioner Correspondence Data

This appendix presents information regarding my correspondence with practitioners in Chapter 5. It includes details of the correspondence, and industry biographies for each participant.

Appendix D: Live Recording Primer

A primer on the concepts and terms of live recording, in terms of their context within this thesis, is presented here.

Appendix E: Additional EAPR Restoration Techniques

Additional restoration techniques for EAPR are presented in this appendix. Unlike those demonstrated in Chapter 7, these examples are described textually (i.e. without graphics).

Appendix F: Creative Submission Album Specifications

This appendix details the technical and commercial specifications of the Creative Submission Album.

2 : Research Problem

This chapter serves to present and contextualise the issues in my practice. The genre of progressive rock is introduced; this provides musical context for my investigation. This is followed by a discussion of the professional roles I undertake in my practice within this genre follow, exploring the relationship between them. From there, the nature of live albums in my practice is established within the context of these roles, defining the creative objects I produce.

Next, the four professional domains that I am accountable to are introduced. They are important to my investigation because my work is oriented to serve them, and I interpret and appraise their responses to inform the internal evaluation of my albums.

Concluding the chapter, the issue of performance errors is introduced within the context of my practice.

2.1 Progressive Rock

My creative practice is within the genre of progressive rock (abbreviated as “prog”). Progressive rock adopts musical attributes from other genres, combining sophisticated compositional structures from the symphonic repertoire with skilled improvisation from the jazz tradition. Performers are expected to possess virtuoso ability to the same technical standards as classical and jazz musicians. Sheinbaum’s (Sheinbaum, 2002) distilment of the genre’s characteristics from Macan (Macan, 1997) include:

- Soundscape: Reaching “beyond" conventional rock instrumentation; explorations of sound; focus on keyboards; acoustic versus electric sections.
- Thematic material: Use of riffs (short repeating ideas); potential for "development" reminiscent of classical music.
- Rhythm & Meter: Syncopations, tricky rhythms; less reliance on 4/4 time signature.
- Harmonic progression: Less reliance on "three-chord" songs, and the simplest chords.
- Influences: Use of blues, jazz, classical, folk, the Anglican Church, “exotic" musics.
- Length: Longer songs; toward whole album (concept album) structures.
- Deployment of band: Long instrumental sections; less focus on singer (tenor); virtuoso playing; 'choral" vocal arrangement.
- Form: Embellishment of traditional shapes (AABA, verse-chorus); less reliance on traditional shapes; unconventional forms.

(Sheinbaum, 2002)

Prog’s specific elements play a major role in my research enquiry by serving as constraints and impetuses within my creative practice.

2.2 Roles in My Practice

I operate within several roles in my practice, which together, carry responsibilities that affect and inform each other; my research enquiry emerges from challenges posed by their intersection. I regard the managing of any creative enterprise as inherently multidisciplinary (Townley et al., 2009) because goals must be met across multiple criteria. My roles are as Executive Producer (EP) and Post-Production Audio Engineer (PE[13]).

- *Executive Producer*: Primarily a business enterprise, the EP generally develops a project's concept, assembles the personnel, creates a marketing plan, and secures funding.
- *Audio Engineer (Post-Production)*: Mostly a technical undertaking; a post-production audio engineer fixes any problems with the raw audio (in the case of my investigation, the live audio tracks from the Creative Album Project, Second Flight: Live at the Z7) before mixing by the Mix Engineer.

2.2.1 Executive Producer

As Executive Producer, I bear overall responsibility for the success of a project. I do not directly engage in any creative activity in this role. Rather, I define the project (if not already defined), confirm that all requirements are met, and ensure that all necessary work is performed according to the standards required by the project definition. My work in this role, in turn, can inform my work in project-specific roles such as Post-Production engineer by providing guidance and context (Leijenaar, 2018).

2.2.2 Post-Production Engineer

PEs are relatively uncommon in live album production. Textbooks on recording and live audio engineering rarely cover this as a role for studio or live albums, including *Modern Recording Techniques* (Huber and Runstein, 2013), *The Handbook for Sound Engineers* (Ballou, 2008), *Mixing Live Sound: An Application Guide for the Audio Technician* (Boonstra, 2016), *The Sound Reinforcement Handbook* (Davis and Jones, 1989), *The Mixing Engineer's Handbook* (Owsinski, 2006), and *The Recording Engineer's Handbook* (Owsinksi,

[13] "Post" is short for "Post-Production", so the acronym I use is simply "PE".

2005) . The term is employed in the film/TV industry, and my practice is perhaps best described as transferring the PE aesthetic to live music.

Post-Production Engineers, in film, are responsible for gathering the production's sonic elements (e.g. sound effects, dialogue, final score mix), performing any necessary modifications, and mixing the final amalgamated soundtrack. In *Audio Post Production for Television and Film: An Introduction to Technology and Techniques*, Hilary Wyatt defines the post-production as:

> The term audio post-production refers to that part of the production process which deals with the tracklaying, mixing and mastering of a soundtrack. Whilst the complexity of the finished soundtrack will vary, depending on the type of production, the aims of the audio post-production process are:
>
> - To enhance the storyline or narrative flow by establishing mood, time, location or period through the use of dialogue, music and sound effects.
> - To add pace, excitement and impact using the full dynamic range available within the viewing medium.
> - To complete the illusion of reality and perspective through the use of sound effects and the recreation of natural acoustics in the mix, using equalization and artificial reverbs.
> - To complete the illusion of unreality and fantasy through the use of sound design and effects processing.
> - To complete the illusion of continuity through scenes which have been shot discontinuously.
> - To create an illusion of spatial depth and width by placing sound elements across the stereo/surround sound field.
> - To fix any problems which [sic] the location sound by editing, or replacing dialogue in post-production, and by using processors in the mix to maximize clarity and reduce unwanted noise.
> - To deliver the final soundtrack in the appropriate broadcast/film specifications and mastered onto the correct format.

(Wyatt and Amyes, 2004)

Of these descriptions, the following is most applicable to my practice:

> *To fix any problems which [sic] the location sound by editing, or replacing dialogue in post-production, and by using processors in the mix to maximize clarity and reduce unwanted noise.*

In contemporary live progressive rock album production, any post-production is usually carried out by the mix engineer. It consists mostly of repairing performer errors and removing non-program audio. Prior to my research investigation, I had become significantly dissatisfied with the industry's standard practice in repairing errors, because I felt that (within the context of my practice), it did not preserve the artists' original performances. The result is my own post-production process, the topic of this thesis. As this process requires specialised techniques, I became the post-production engineer on *Second Flight: Live at the Z7*, engaging in an increasingly complex and time-consuming endeavour. (This evolution is documented in Section 1.2.)

2.3 Nature of Live Albums

> *The technological sophistication of the recording process with its easy correction of errors results in the 'perfect' construct. The recording takes place in an ideal acoustic, but one that is artificially enhanced. The skilfully placed microphones, not simply a stereo pair but close-miked with ambient ones farther away, create a depth and richness of balanced parts and voices, a clarity of foreground and background, left and right stereo spread, with the outcome most certainly not a document of a concert performance but something else – an idealised, irreproducible entity, the recording as art object in its own right.* — Roger Heaton (Heaton, 2011)

In this section, I explore my ontology of live albums in my practice. This doctrine is one of the ideological building blocks that informs my outlook on performance errors.
I begin by describing this ontology. Then, I discuss the four domains that informed this definition, providing additional context with commentary from other researchers.

2.3.1 Ontology

While each project is unique, my overarching principle is to produce live albums that are intentional creative artefacts, and not an attempt to accurately document an historical event. Although I approach the performances with the utmost respect, my albums are decidedly constructivist.

Commenting on live recording, Francombe, et al. write:

> *There is often debate as to whether reproduced audio should mimic a real life listening experience as closely as possible, or whether it should simply provide the most enjoyable listening experience—potentially even improving on a live performance or "real" situation…there are some (but not all) situations where replication of a real listening experience is desirable, but it is currently felt to be impossible to exactly recreate such an experience (due to limitations in audio technology and cross-modal interactions)."* (Francombe et al., 2015)

Blier-Carruthers offers:

> *It is obvious that a recording is not simply a live performance captured.* (Blier-Carruthers, 2013)

As executive producer, I operate under the onus that any musical object I aim to deliver must be precisely defined. Once in place, I can formulate a plan for its execution, evaluate its development, and guide its production.

2.3.2 Ontological Domains

My constructivist (intentional) ideology for live albums is informed by philosophical, practical, cultural, and commercial domains of thinking. The shaping of my conclusions is influenced by the body of research on this question, viewed from the perspective of my practice as a profession.

2.3.2.1 Philosophical

> *The recording studio and its machines were always integrated with the creative aspects of a production. Even at their most primitive, the recording environment, technology, and process influenced the result, and producers actively manipulated all three. This was true even in Edison's day. He was aware of the potential for recordings to improve upon the experience of a live performance, stating: "I shall yet put before the world a phonograph that will render whole operas better than the singers themselves could sing them in a theatre…I shall do this by virtue of the fact that with a phonograph I can record the voices better than any person in a theatre can hear them."* — Richard James Burgess, The History of Music Production (Burgess, 2014)

Even from the dawn of recording, the idea of documenting a performance intersected with the idea of creating the best recording. This dichotomy begs the fundamental question; even before looking at specific technology: "Is it (logically) possible to document the sound of an event?" This question then emerges: "What would the metrics be for having done it?" While intriguing questions, their objective analysis is outside the scope of this thesis. Within my practice, though, a relevant question is, "Can I document the sound of a live progressive rock concert?"

An early recording device was created by Jean-Marie Constant Duhmael, first published about in 1843; it recorded the vibrations of a tuning fork by drawing the resulting pressure waves on smoke-coated paper (Burgess, 2014). The device's existence introduced questions such as the point at which vibration becomes sound, and what to call the phenomena (in this case) that were recorded (especially given that it could not reproduce its recordings, acoustically).

All that is required for a person to experience sound is a medium through which pressure waves can travel—air is one, but so is water—a tuning fork vibrating at a specific frequency will sound different in each. There is an audible difference between sound in dry and humid air. Recordings are therefore context sensitive; there is no objective sound that a tuning fork makes—there is what we hear only under specific circumstances.

Simply the fact that a performer knows she is being recorded expands the dialogue between audience and performer to a trifecta of performer, audience and microphone. This raises a question about to whom the performer is playing—and has the audience now become a much deeper part of the conversation? By measuring the event, is it being altered? An early commenter on this entanglement, from a practical perspective, was recording engineer Raymond Sooy. In 1903, he noted:

> *We have used as many as twelve recording horns at one time with good results. This made it very difficult because the more horns used, the less volume you would get in the records, consequently a very sensitive diaphragm had to be used for this purpose; then again, we were forced to use Stroh violins. These violins were made with a horn attached to them so that they could throw the music in one direction, but the tone quality was not so good. It was also necessary to place the musicians playing the 'cello, oboe, clarinet, cornet, trombones and some of the other instruments on high chairs or stools, so that they could concentrate their tone directly toward the recording horns. They had to be placed so close together that it was almost impossible for them to play—the violinists, while playing, would oftentimes run their bows up the bell of the clarinets which were being played directly above them, or in one of the other musician's eyes, which would cause a heated argument.* (Fischer, 2012)

Burgess comments on this phenomenon:

> *Photographs and accounts of the acoustic recording process toward the end of the nineteenth century indicate that recorders or directors of recording were doing everything in their power to optimize the quality of the recording. They positioned the singer inches from the collecting horn giving a perspective to the recording that was better than the "best seats in the house" for a live performance. They actively manipulated the position of the singer, moving him or her into and away from the collecting horn, to control dynamics and to allow the instrumental parts to come through clearly and so on.* (Burgess, 2014)

Returning to my own practice, to literally record a live progressive rock concert, there would need to exist at least a specific recording (Salomon, 2007) of any concert, that when played back, would reproduce the sound of the original performance, accurately. But what does it mean to be accurate? In the studio, the recording process can be largely based on finely controlling the sound that is captured from acoustic sources; the selection of equipment and technique captures and colours aspects of a source. Even with the goal of documenting a performance, numerous decisions must be made about *what* sound will be captured.

Cook offers:

> *As Thomas Porcello has put it, because microphones "…do not 'hear' in the same way as ears, the sound engineer must…mediate between the interpretive and performance habits of the conductor and the musicians on the one hand, and the acoustic properties of microphones and the (psycho)acoustics of the ear on the other." Add to this formulation the acoustic properties of the architectural spaces and a picture emerges of a complex set of elements ever in motion. Indeed, the 'original' version of an acoustic event changes its form depending on what sort of microphone is used and where it is placed.*
>
> *The question, then, is more properly framed in terms not of transparency or realism but of suitability. What will suit the aesthetic stance and aim of the project at hand? Making such decisions regarding the colour, shape and texture of the sonic rendering (elements, ultimately, of a recording's affective impact) fall to the recording team, of*

which there may be many members. But turning the concept into actual recorded sound is the job of the project's engineer. (Cook, 2011)

Burgess concurs:

> *These choices, such as which microphone, what placement, the EQ, compression, expansion, effects, and so on, optimize the recorded quality and make the production interestingly varied, introducing clarity, depth, and dimension or whatever qualities the work needs.* (Burgess, 2013)

Another barrier to capturing the sound of a live event is that our experience is only partially informed by sound. Our other senses are in play as well. Live events have distinct smells, and this sense has particularly powerful links to memory. The subharmonic frequencies of the kick drum are experienced as vibrations, not sounds—but these pressure waves cannot be recorded (nor reproduced)[14]. They can affect our brain chemistry; for example, one of the effects of the body's exposure to low frequencies is drowsiness (Anund et al., 2015).

As audience members, our attention is visual in addition to being aural: the artists, lights, large-screen displays, and the rest of the audience. In the presence of sound, sight often takes precedence (Styles, 2005). As a result, we may not perceive significant aspects of the event, such as mistakes made by the musicians. Another example explored later in more in Section 2.3.2.2, is that we perceive less ambience at a live event than an objective measure of the pressure waves indicates; when a recording is played back, though, we hear the additional reverberation. As with many recording-related psychoacoustic phenomena, the reaction is often, "I don't remember it sounding like that." And of course, it didn't.

Human working memory has a small capacity for processing information—and all our senses are competing for that space (Miller, 1956). Yet we are not fully in control of what we consciously hear. Emotion also plays a significant part in how we experience any event, including a live a concert. Of course, there is no way to record or reproduce these feelings. While technology has produced transducers that garner more precise information about pressure waves travelling through the air, what is recorded remains a property of the transducer. Likewise, what we then experience as sound is a property of our ourselves.

[14] Few sound reproduction systems have a flat response down to 20 Hz, and generally none reproduce below that frequency.

For these reasons, I don't believe that, philosophically, it is literally possible for me to *record* concerts. There is no accepted practice for "authentically" recording an instrument—or how that would even be evaluated. Therefore, I take a constructive approach based on my professional goals and the groups I am accountable to.

2.3.2.2 Practical Considerations

In a live setting, practicality and logistics take centre stage, introducing additional barriers for capturing precise recordings. The result is that compared to studio recordings, live recordings are significantly compromised in many ways, making them even less suitable as historical documents than studio productions.

Microphone choice is constrained by audio issues such as leakage[15], feedback[16], and phase interference (Waller et al., 2007). The type of microphones that more precisely capture sound (condenser) are generally substituted for ones that are inexpensive (dynamic) and are resistant to being damaged. In lieu of choosing amongst different microphone techniques in the studio, depending on the desired sound—the predominant technique in live recording is to simply put a dynamic microphone directly in front of acoustic wave sources, pointed directly at them

While recording studio practice allows instruments to be isolated and recorded separately, all live instruments need to be recorded simultaneously in the same space. Recording studios are also painstakingly designed for their acoustic recording properties; live rock venues have poor acoustic properties due to factors such as ambience and standing waves[17]. It's not even possible to know how a live recording will sound until after it's made, because the venue's acoustics will be dependent on factors such as the size of the audience, and even the temperature of the air. From a practical perspective, if it were conceptually possible to capture a realistic live recording, practical requirements would render such a goal unlikely to be realised.

[15] *Leakage* refers the phenomena of pressure waves from other audio sources being recorded by a microphone intended to only record one specific source.
[16] *Feedback* is a cycle of pressure waves that is unintentionally continuously amplified through a microphone and sound system until a high-pitched sound is emitted—usually with vocal microphones.
[17] Frequencies that are unintentionally amplified because of a venue's shape and other acoustic properties.

Just as the live recording captured is informed by technical choices made by the recording engineer, another choice must be made: if we cling to the concept of an *accurate* live recording, a choice must be made as to the location where it is being captured—in any concert venue, especially rock venues, the listener's location can have significant effects on the sound she perceives, and other aspects of the experience.

Therefore, any live recording made with the goal of documenting a performance must exist in the context of a specific listening location—but everyone except the recording engineer will have heard it from somewhere else. Likewise, most of the ~36 microphones employed to record a progressive rock show are placed directly in front of the vibration sources, so there is no actual (specific) place from which the concert was recorded[18].

So far, we have examined only the recording that is made at an event. Another practical consideration is that differences in playback system will result in (often radically) different aural experiences for listeners. Each playback system and environment will alter the recording based on transformations to frequency response, colouration of the signal, acoustic ambience, and stereo field. Examples range from laptop speakers to headphones, and from monophonic tablets to home cinema systems.

The most precise method to record the spatial information (of which ambience is an element of) at a live event is with the use of binaural microphones (Rumsey and McCormick, 2014). A binaural system is designed to accurately capture human transduction by recording events using a model human head with microphones placed inside each ear. But even when listening to the playback made using this system, though, listeners can experience more reverb than at the live event, itself.

Francombe, et al. state:

> *In summary, there are some (but not all) situations where replication of a real listening experience is desirable, but it is currently felt to be impossible to exactly recreate such an experience (due to limitations in audio technology and cross-modal interactions).* (Francombe et al., 2015)

[18] In Second Flight: Live at the Z7, I produced two mixes, to simulate two different positions to listen to the concert from: the front of the stage (center), and the FOH mixing desk. These were completely artificial constructions, however, based on how I felt listeners would *think* it should sound, and would would sound *good*.

Given the practical challenges to documenting a concert with a precise recording, and that the recording process necessarily requires choices that adversely affect the resulting sound quality, I capture the signals so the resulting audio can best serve the professional requirements of my specific practice: with maximum source separation. This approach maximises my flexibility during post-production.

2.3.2.3 Cultural

> *Recording has influenced the public's expectations to such an extent that perfection of execution is now seen as not just the ideal but the norm. It seems that bit by bit audiences and musicians have come to expect increasingly technically accurate performances, unthinkingly, even in the concert hall, a perfection which musicians are at constant pains to deliver. We could invoke [Phillip] Auslander's argument here that although live performances hold a higher cultural valence than recordings, ironically live performance now seeks to emulate its mediatised other.* — Bliers-Carruthers (Blier-Carruthers, 2013)
>
> *Who wants to hear a mistake repeated endlessly?* — Paul Stanley, KISS (Stanley, 2014)

Any commercial albums I (executive) produce will be judged by listeners within contemporary cultural contexts. There are two cultural factors that particularly inform how I define the live album. The first is an expectation of performance perfection. The second is the artificial enhancement of the raw audio common on commercial recordings.

In progressive rock, performances are generally expected to be flawless—and so are the live albums that purport to document them. While more mainstream rock genres have a lower threshold for error (Rustvold, 2018), progressive rock albums could best be described with the cultural aesthetic of a live, classical symphonic album. But regardless of genre, the issue of impeccable performances has been a significant factor throughout the history of recording.

> *"Ordinary musicians are of little use...I have known musicians to play for three consecutive hours [to get a satisfactory take]."* – T. J. Theobald Noble, "The Experiences of a Recorder" (Noble, 1912)

For most of commercial recording's history, the line between studio and live albums wasn't as clear as it is today. Every recording was performed live. The difference in a studio recording was that it could be rerecorded. The world's first recording, in 1860, began with the words, "Au clair de la lune" (Burgess, 2014); the second may have been, "Attends, je peux faire mieux que ça!"

The ability to significantly alter recordings (after the fact) began in the mid-1970s (Watson, 2015) with the mainstream commercial adoption of 24-track[19] (Mullin, 1977) recording. It was now possible to record each sound source (instrument and vocal) on a separate track. Therefore, if someone made a mistake, just that track could be re-recorded (and not all the other instruments).

With live recordings, the process was more challenging because many of the microphones on stage would pick up (at some volume) everything else, so each track didn't contain the only instance of each instrument. This could be remedied by re-recording all the tracks with leakage. In fact, the entire album could simply be rerecorded, with crowd noises overdubbed.

The most common reason for rerecording was to correct errors. Another rationale was the enhancement of sound; as previously discussed, the practical considerations of recording shows limited the fidelity of sounds, in comparison to those recorded in the studio (Waller et al., 2007). Additional tracks were sometimes added to those recorded at the concert, such as additional harmonies. Crowd noises might be added, layered and mixed at high levels to evoke massive audience response.

During this period, many of the best-selling and highest-acclaimed live albums of all time were created. Looking at one market—the United States—the sales figures are particularly noteworthy because there were ~1/3 (104 million) fewer people in the country than today (US Census Bureau, n.d.). In some instances, these albums launched careers. Many of these albums were not only corrected in the studio—they were heavily edited or almost entirely rerecorded—sometimes by studio musicians, instead of the band. But it was sometimes difficult to confirm such re-recording because the practice was rarely admitted. The opinion

[19] Less than 24 tracks required some instruments/vocals to be mixed together, and therefore could not individually be rerecorded.

was that consumers would reject these practices as dishonest, and sales would suffer as a result.

Let's examine three of rock's most iconic (Invisible Oranges Staff, 2015) live albums, in terms of sales and critical acclaim (Rolling Stone, 2015). All a product of this time, they launched the careers of the respective artists: KISS, Peter Frampton, and Thin Lizzy. Giles comments:

> *The '70s were the decade of the live rock album, with a few concert sets, such as* KISS Alive! *and Peter Frampton's* Frampton Comes Alive!, *helping trigger massive mainstream breakthroughs.* — Jeff Giles, Ultimate Classic Rock (Giles, 2016)

Producer Tony Visconti noted that his production of Thin Lizzy's double-LP *Live and Dangerous* contained significant re-recordings (Visconti, 2016). Peter Frampton's *Frampton Comes Alive*, produced by Eddie Kramer, remains the highest-selling live album of all time at 16x Multi-Platinum[20] (RIAA, 2016); it was heavily rumoured to be a product of studio as much as of stage. (One impetus for the rumours was that the crowd erupts into applause at the first few notes of the album's singles—songs that had not been released yet.)

Frampton denied these allegations, but himself levelled the same allegations (Maletsky, 2011) at another Kramer production, KISS's Gold-certified[21] *KISS Alive*, which likewise brought that band to mainstream attention. These were followed by Kramer's 2x Multi-Platinum *KISS Alive II*, and Gold *KISS Alive III*. Years after its release, Kramer shared that, aside from the drums, the entire album was recorded in the studio (Blabbermouth.net, n.d.). KISS's Peter Criss noted:

> Alive *was crafted to sound like it was recorded in one night at Cobo Hall in Detroit, but we actually recorded a bunch of shows. Then (Eddie) Kramer went back to New York and began culling the best performances. Picking out the best drum tracks was the first step. Once you had the drum track, then you could sweeten everything else. If you had to throw on a new lead, you could. Throw on some bass, add some rhythm guitar, all possible. In the end, we wound up keeping only my drum tracks, my vocals,*

[20] Platinum is the Recording Industry Association of America's (RIAA) award for domestic (USA) sales of 1,000,000 units.
[21] Gold is the Recording Industry Association of America's (RIAA) award for domestic (USA) sales of 500,000 units.

and Paul's between-song raps. Everything else was re-created in the studio. — Peter Criss, Makeup to Breakup (Criss, 2012)

Criss' mention of sweetening—the process of enhancing sound—points to another cultural factor in my decision to approach live albums as constructions: listeners of commercial live recordings are informed, culturally, by industry practices in studio recordings. Andrew Gwilliam comments on this issue, with an eye toward its ramifications:

As the vast majority of most people's musical experience is via the recorded medium rather than through live performance, and recording is now much easier to manipulate into artificial constructs of performance, there needs to be an investigation of how this experience is changing the audiences' and performers' view of musical performance." — Andrew Gwilliam, "Production and the Listener: The 'Perfect' Performance." (Gwilliam, 2009)

From the dawn of the recording industry, even before electrical recordings, engineers sought to change how pressure waves were produced by instruments and vocalists to yield what they felt were superior sounds (Noble, 1912). Tape's development in the 1940s allowed for an intermediary stage in the recording process whereby audio could be almost endlessly altered—after the recording was over, and before the vinyl master was recorded. Burgess comments on the paradigm shift enabled by this and related technologies:

Looked at from the perspective of capturing a performance, these technologies introduced a distinct shift in the degree of "fragmentation and control" or "disaggregation and intermediation" by the producer. Even when the objective is to record purely for documentation, there is a degree of artificiality, adaptation, and deconstruction of the performance in response to the technological limitations and possibilities of the medium. This began with the first phonograph recording. Since a production is a composition in sound on a specific medium, for playback on various other media, through diverse systems, the primary consideration is not the process of performance but the sonic end result heard by the listener. (Burgess, 2014)

Zak offers:

> *The increased blurring of lines between engineering and producing in pop music over the last twenty-five years is the by-product of a process that began in the late 1940s, most notably (based on record sales) with the work of Mitch Miller. The practice of making records whose sounds distinguished them from real-world music-making fostered a gradual change in the nature of sonic representation. Contemporary pop records are most often made not simply to represent a performance, a performer, or a performing tradition, but to evince in themselves a distinctive reality.* (Zak, 2011)

The recording studio, not the performance, could now be the canvas. Brian Wilson's *Pet Sounds* was a landmark achievement in this new medium. While the Beach Boys were on tour, Wilson entered the studio with a large group of studio musicians at his disposal, employing sounds never before used on a popular music album—and some sounds that had never been heard at all. Paul McCartney comments:

> *… kind of instruments he's got on there; a sort of an oscillator, a harpsichord, you know he's got some crazy stuff in there. It's the instruments he uses and the way he places them against each other. It's very cleverly done. It's a really clever album. So we were inspired…* (Bragg, 1992)

George Martin and the Beatles, upon hearing *Pet Sounds*, embarked on *Sgt. Pepper's Lonely Hearts Club Band* as a response (Clydesdale, 2006). These two albums were the most acclaimed of all time (Rolling Stone, 2012) yet they had no live performance counterpart—they were created in the studio, to be experienced by audiences only via playback (Julien, 2009).

As audio technology progressed, it afforded new ways to create higher fidelity sounds. Where the producer wanted, acoustic instruments could assume sonic signatures not possible in real life.

> *The gated reverb applied to snare drums on pop records of all sorts, which presented listeners with an insistent artifice a large space, but as the anticipated long decay (a sort of ambient shadow) is truncated artificially, or 'gated', the impression is formed of repeated interruption. Because a short decay time is associated with a small space, the cavernous sonic explosion followed by an abrupt decay presents listeners with a paradoxical ambient architecture. The repeated morphing of space gives the ambience*

> *a dynamic temporality, that is, an essentially musical character. Such a space could only exist electronically, and its architect was the recording engineer.* (Zak, 2011)

Sounds were often pushed to extremes, as Izhaki notes:

> *Some inexperienced engineers are scared to process since they take the raw recording as a natural touchstone. Even gentle processing they apply appears to them as harmful. Listening to a commercial track that was mixed with an artificial approach can reveal how extreme mixing treatments can be. Taking vocals for example, their body might be removed, they might be compressed to show no dynamic variations, they might even be distorted quite explicitly. We have to remember that mixing radicalism is unperceived by common listeners.* (Izhaki, 2008)

In combination with increased fidelity for playback media, instruments on studio albums could bear little auditory resemblance to the original pressure waves they produced. A corollary can be drawn to the evolution of special effects in movies, where accuracy is no longer the objective—impact is. Burgess comments:

> *An exciting mix may use a combination of static and dynamic balance, equalization, compression, limiting, expansion, gating, reverbs, delays, and other effects to optimize the sounds, increase their impact, and ensure they occupy their own space in the audio spectrum.* (Burgess, 2013)

Izhaki elaborates:

> *Popular music nowadays tends to be all but natural – heavy compression, distortions, aggressive filtering, artificial reverbs, delays, distorted spatial images and the likes are all very common. These, in essence, are used as a form of enhancement that despite not sounding natural can have a profound impact. Mixes are sonic illusions. On the same basis that color enhancement improves visuals, our mixing tools let us craft an illusion that simply sounds better than life*. (Izhaki, 2008)

Drums, for example, sound more clear and powerful on contemporary (popular music) commercial albums than on recordings made with unprocessed stereo or binaural microphones[22]. These contemporary drum sounds may be created with over a dozen microphones, two dozen channels of audio streams, and three dozen separate audio processing units that alter sonic characteristics such as frequency, dynamics, and ambience. Often, even that is judged insufficient by engineers, and artificial drum sounds are added (Mynett, 2012).

The expectations of audiences for live albums are informed by the results of these techniques on studio albums. And the techniques are used consistently on live albums, as well. Due to practical and logistical issues, as discussed in Section 2.3.2.2, live recordings cannot generally have the same fidelity of studio recordings—yet they will still be compared to studio recordings. The resulting transformation may be much more drastic than in the studio. Inglis offers:

> *When we record and mix a band, we are creating an illusion. In the studio, that might mean replicating the impression of having the band straightforwardly perform to the listener; but it frequently does not, and we all have an arsenal of mixing tricks that can make sources sound 'big' rather than necessarily 'real'. With a live recording, by contrast, the aim is usually to capture the experience of being there in front of the band. As anyone who's ever recorded a gig using a handheld recorder will know, there can be a huge difference between a convincing live multitrack mix of a gig, and a faithful capture of what it actually sounded like in the audience.* (Inglis, 2016)

A specific manifestation of audio enhancement that is relevant to live recordings is mix clarity. Due to leakage, many of the audio enhancement techniques and tools are not as effective as on studio recordings (and increased clarity is often one of the changes).

Another result of leakage is *ambience*. If we define an *incident signal* the direct pressure waves emanating from a (vibrating) acoustic source, then ambience is comprised of the pressure waves that are reflected when the incident signal hits a reflective surface. The ambience that leaks into stage microphones is not the controlled ambience of the studio, but the chaotic ambience of the venue; it would be desirable to remove all of it, but technical limitations often prevent this. See Appendix F for a review of this issue.

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[22] These are the two microphone techniques that most accurately capture sound pressure waves at a given physical location.

Ambience from the venue is also introduced into the mix on purpose via the audience mics. This is done because the sound of the audience is an integral part of a live event, even though it clouds the mix.

New technology, as well as re-recording parts in the studio, have pushed the envelope to where an album can be viewed as sound as "live" as the producer wants it to be. Without employing significant production techniques, which process and create sounds far removed from their pressure wave origins.

For these cultural and their accompanying technical issues, I view all contemporary commercial live albums as constructs—not just my own.

2.3.2.4 Commercial

> *The producer's singular responsibility is to make a successful record in terms demanded by the stakeholders. The stakeholders might include one, some, or all of the artist, the label, the management company, and the producer. Depending upon genre, the label, and the career stage of the artist, success may not be defined by Multi-Platinum sales and a number-one chart position. It is the producer's first responsibility to determine who the stakeholders are and what the measures of success will be. Then it is his or her job to orient every aspect of the project in order to achieve those goals.* — Richard Burgess, *The Art of Record Production* (Burgess, 2013)

After deciding the specific nature of an album I undertake, I must recognise who I will be accountable to, and establish my criteria for its success. My practice is based in industry, and commercial considerations dictate that I employ a constructivist approach to producing albums in order to satisfy commercial requirements.

2.3.2.4.1 Accountability Groups

Burgess identifies four groups that an album producer is accountable to: artist, project, record label, and yourself. As an executive and co-producer, Burgess' parties overlap with mine, though in some cases my responsibilities to them are more business-oriented; additional groups also come into play: fans and the press. The cumulative list of groups, and my requirement to serve them, inform all aspects of my research enquiry, because they set the goals of my practice. My ensuing discussion of these groups takes places under the aegis of my practice; I am not generalising outside of it unless specifically noted.

2.3.2.4.1.1 Artist

Artists usually have multiple metrics. Personal income could be considered the most important in my practice. As with most popular music genres, album compensation comes primarily[23] from the distributor (e.g. label) as an advance against future[24] sales. The artists generally want the album to be profitable for the label, and this depends on factors that overlap—but they are not the same as the ones resulting in artist income. Artists also place importance on reaction to the album from their fans and peers. Although interest in album reviews varies considerably, generally their importance is substantially less than fans' opinions.

2.3.2.4.1.2 Fans

In my planning and evaluations, I divide fans into two groups: existing fans, and potential (new) fans. In an era when albums can be experienced for free (or close to it), artists have become more dependent on existing fans (especially the core base). Their collective response to an album influences artist income beyond (á la carte[25]) album sales, and across the entire financial ecosystem (e.g. concert attendance, merchandise, Patreon-type activity). The response further drives social media engagement, which in turn, feeds back into the ecosystem—and by extension, auxiliary income streams such as synch and sponsorship opportunities.

Fan bases have attrition, however; for an artist to grow, new fans must usually be garnered. While secondary to satisfying the existing base, garnering new fans is critical in my responsibilities, even with well-known artists. Unlike existing fans, potential new fans don't

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[23] An additional (often significant) source of income for artists who re also songwriters on an album is mechanical royalties: payments based (mostly) on a la carte music sales. However, many artists (or band members) are not credited as songwriters.
[24] The cashflow of master sales royalties (artist income resulting from commercial exploitation of the master recording) is complex. In practice, even with all parties acting in good faith, and regardless of the commercial success of an album, artists rarely receive actual sales royalties.
[25] Á la carte sales are music purchases, in contrast to directed and undirected streams. Purchases are the most important income vector related to album income for artists in my practice.

compare new artists to their previous repertoire—they compare them to other artists they've heard (including performances and performance errors).

2.3.2.4.1.3 Media / Critics

Critics' reactions can encourage or discourage existing and potential fans from engaging with an album. These reactions are most important to garnering new fans, as existing fans will likely audition the album on their own volition via streaming (commercially or DCMA-enabled[26]). Some journalists are particularly influential because they serve as gatekeepers for decisions about running editorial features on the band, which appeal to both new and potential fans alike. A similar group is social media taste-makers.

2.3.2.4.1.4 Distributor / Record Label

A label will usually retain an artist based on two criteria: profitability (short and/or long-term), and public cachet (i.e. a critically-acclaimed artist). Likewise, a label may drop an artist based on these issues, or refuse to work with their (previous) album or executive producer. It is important for me to identify how label personnel approach these criteria, and to identify alternate metrics, such as the label president simply enjoying the album.

Even as music purchases continue to decrease across the industry, prog labels' most important revenue source remains á la carte sales. They remain critical for profitability even with artist agreements that include ancillary revenue streams, such as publishing, synch[27], touring, and merchandise.

Critical acclaim, however, can weather an artist through unprofitable albums. But the albums themselves must be *highly*-lauded by critics—especially those judged prominent or influential by the label. Fans' reactions are of little importance for this criterion; an artist whose only notoriety is amongst enthusiastic fans who don't engage commercially is generally of little interest to a label.

[26] The DCMA (Digital Millennium Copyright Act) is a set of American laws regarding legal liability for copyright infringement by streaming sources (e.g. YouTube).
[27] "Synch" refers to income from placement of music in (synchronization with) other media (e.g. video games, films). Sometimes this is considered part of publishing.

2.3.2.4.1.5 Personal

As production is my vocation, I view personal fulfilment as a luxury, and not a party I am responsible to; rather, it is a result of the others. Burgess suggests framing this responsibility in terms of career advancement (Burgess, 2013), and ultimately, this is the responsibility I have to myself—one that can only be satisfied by satisfying the other groups. I also trust the process. If an album is well-promoted and rejected by all these groups, then I have probably made a poor album.

2.3.2.4.2 Self-Evaluation

In my practice, after finishing a project, I perform a self-evaluation. While not providing me with formal quantitative or qualitative data, it informs me within the context of my own experience, in terms of the accountability groups. My engagement with the groups is shown in Table 1:

Table 1: Self-Evaluation Group Engagement in My Practice

Group	Explanation
Artist	I discuss the results with the artist(s), usually in person. We'll discuss what we felt worked about the album, and what we didn't. The topics will usually gravitate to whatever specific issues were at the forefront when the album was undertaken.
Fans	On social media, I follow the response threads to major posts about the album.
Critics	While I avoid print reviews because they require me to have the physical media, I read professional online reviews. My level of concern about possible criticisms of the album dictates how many reviews I read.
Publisher/Label	When I deliver an album, I speak to the label heads about their artistic perception and personal enjoyment of the album. After the release, we discuss the economic results.

2.3.2.4.3 Cultures of Perfection

Any practice-specific consideration about performance errors first takes place within the larger cultural expectations of perfection in commercial musical objects. Heaton comments:

> *Today's CD buyer/internet downloader demands, and mostly gets, a 'perfect' soundworld: sonic sumptuousness is as important as compositional content, and the*

> *performer's prowess goes without saying. If, in so-and-so's new Chopin recording, the piano is too distant, or too tinny, or in an acoustic so reverberant as to blur detail and condense the dynamic range, then it will simply collect dust on the shelf. Recordings with performer errors are similarly undesirable.* (Heaton, 2011)

In live progressive rock, performances are evaluated under the rubric of expectation for artists to be virtuoso musicians. In addition to the wider cultural expectations of commercial perfection, prog audiences, therefore, view error-free performances as intrinsic to the musical genre, *itself*.

Virtuosity, however, is not just about not making mistakes while performing challenging technical material; it is also the ability to be (highly) musical while doing so. This expectation transforms the notion of perfection to one of artistic *and* technical perfection. Therefore, audiences in my practice evaluate albums on the calibre of the performances; being error-free is assumed.

Perfection is so intrinsic to live progressive rock that, as discussed, the standard practice for progressive rock producers to achieve their aesthetic definition of a live album can be described as adjusting the level of performance perfection. (As described in Chapter 5, they make this adjustment by modulating the number of errors they repair.) And even the lower levels of error repair correspond to a high level of technical performance excellence.

The need for my process arises from, and exists within, the standard practice in progressive rock for error management, and the larger cultural context of popular music's perfection aesthetic. My research problem is the restoration of the intended performances where a musician makes an error—while still producing albums that are successful within the aforementioned prog and cultural models.

2.4 The Emergence of Performance Errors

Performance perfection is especially important in progressive rock—but this expectation is difficult for artists to fulfil not only within the aforementioned cultural contexts, but also because of the circumstances surrounding the recording of prog albums and concert films. In this section, I will explore the causes of such errors in live prog to better inform the development of my own process for performance error management.

Kruse-Weber and Parncutt identify both external (social, organisational and material) and internal (psychological) error factors for classical musicians, and stress the importance of adequate preparation. Social and organisational issues include miscommunication with other performers and cultural practices. Examples of material factors are problems with the performance space (e.g. lighting or temperature) or instrument malfunction (e.g. stuck MIDI note).

Internally, psychological factors (e.g. state of mind) can influences errors. The authors also list insufficient practice and physiological concerns (e.g. injury, lack of sleep) as internal factors. All of this takes place with audiences "…accustomed to perfection." (Kruse-Weber and Parncutt, 2014)

Give the influence of the classical repertoire on progressive rock, it is not surprising that performance threats to the former also affect the latter. Within prog's context, they combine with the added dangers inherited from jazz's potential for improvisational errors (Sawyer, 1992). Former Dream Theater manager Jim Pitulski recounts:

> *I remember being out on the road with this one particular [progressive rock] band who were known for their musical skill. Now, one of the things I like to do is to walk around at these shows to observe the reactions of the audience. On this particular night, the singer was struggling - he was giving in to a bit to road fatigue because the band had just done a string of dates without a day off and the singer…well, the singer was only human. Anyway, there was a very challenging vocal passage in this one particular song and that night the singer just couldn't hit it - he cracked a note. If you*

> *could have seen the reactions of some of the fans. Their jaws dropped and they stood there, arms akimbo, as they looked at each other for an explanation. They were clearly very upset - in short, they took it personally.* — Jim Pitulski (Pitulski, 2016)

Cook notes that unlike jazz (historically rooted in live performance), popular music's engagement with errors varies by genre, using as Rush (a progressive rock group), and Pet Shop Boys (a pop group):

> *But within popular music the situation is different and more complicated. There are bands like Rush, whose concerts sound like their records because their records sound like their concerts…there are bands like the Pet Shop Boys, whose vocalist, Neil Tennant, said of their lip-synching at the American Music Awards, "I quite like proving we can't cut it live."* (Cook, 2014)

As discussed, prog performances are comprised of challenging instrumental parts that also require improvisation, similar to symphonic and jazz repertoires, respectively. However, sheet music is generally eschewed; in popular music, a performer is expected to engage the audience. As illustrated by Figure 1, in the context of a rock concert, the optics of a featured performer consulting sheet music may appear out of place.

Figure 1: Keyboardist Neal Morse of Flying Colors (Second Flight: Live at the Z7, 2015)

The expectation to entertain the audience visually, as well as aurally, provides additional challenges to precise performances. Sitting down and concentrating on your instrument is anathema. While a performer focusses on engaging the audience, projecting an emotional experience, and body movement—she is also playing a technically demanding musical piece. For example, the prog-rock band Kansas had a singer/keyboardist who performed headstands while continuing to sing and play keyboard parts, as illustrated in Figure 2:

Figure 2: Steve Walsh of Kansas (Walsh, 1978)

For most of popular music's history, tours were mounted as promotion (Coplan, 2014) for artists' main income stream: music sales. With global music industry income in continued decline since 2005 (Crutchley, 2016), prog artists and labels are pressured to make cuts to tour and album budgets. Two cuts that affect recorded performances in my practice are: reduced rehearsal time, and the recording of only one show.

Deep Purple guitarist Steve Morse recounts:

> *It's very hard for people to know how much pressure there is to make the show. For instance, when my wife was going in for emergency surgery, I inquired how much it would cost me to go home to be with her. Ironically, most people with jobs would be able to leave, and even get paid in some circumstances for the time they were gone.* (Morse, 2016)

Reduced rehearsal time can significantly affect prog artists due to the length and complexity of the repertoire, especially without sheet music. The challenge is compounded because the artists are often members of several bands, and begin tours with one act immediately after finishing with another. In the past, lost rehearsal time could be partially offset by recording the live album toward the end of the tour. Reduced tour budgets can limit an international tour to three weeks, with each show in a different country. The concert may be recorded after only a dozen performances—including rehearsal, which may be only one or two days.

In my correspondence with Deep Purple guitarist Steve Morse, he recounted:

> *I was told that there was the liability of the entire proceeds of the concerts, since being a key player would mean the shows would be cancelled. Next, the costs of the advertising, costs of administering refunds, the legal costs, and at least 15% in liquidated damages on top of that. So, several million dollars that I didn't have, plus the cost of a last-minute ticket.* (Morse, 2016)

Such a schedule, traversing multiple time zones over a short time, often leaves an artist in sub-optimal condition to perform. Insomnia and moderate to serious illness[28] are commonplace. However, regardless of physical state, emotional distress, or simply having a bad night—the show goes on, and the audio/video recording takes place.

> *They said that if she died, then there might be a way that I could go without any liability other than the fact that 40 people in our crew would need to get paid. So, I didn't go; she will never understand or forgive that. When my Dad was on his deathbed, I went home, and had to write a check for the tour that I had played, and planned on as income.* (Morse, 2016)

The pressure to perform is heightened because budget constraints often dictate that only one show is recorded. And during that show, a song cannot be stopped and started again. Whatever happened that one night, in real-time, is the basis for what is released worldwide, 6-8 months later.

> *Everybody I know (seasoned pros) has, at some time, collapsed onstage from fever or dehydration (from dysentery or food poisoning), and we all carry medicines including antibiotics, and act as our own witch doctors. Some countries, such as*

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[28] Artists often shake the hands of many fans—sometimes over 100 each night, and their immune system is often compromised on tour from stress and lack of sleep. Even running a high fever, or in extreme pain, artists still perform; cancellations are very rare.

> *Australia, won't let us in until we prove that we have medical insurance, which does little good if you have no time to get any medical help because you're travelling, or getting sprayed with insecticide on their flights.* (Morse, 2016)

Given these factors, it is challenging for prog artists to record the exacting concerts that are expected of them. Yet the stakes could be considered more serious than in other genres. Progressive rock artists are held to virtuoso standards by the fans, their label and the press; a series of errors can damage an artist's reputation and career. With social media's milieu of sharing and commentary, combined with instant and widespread dissemination of audio and video, prog artists have little room for mistakes to be forgotten.

> *Live performance has mutated from a special bond between the people that took the effort to come to the show…to a YouTube event recorded on a smartphone that rarely looks or sounds very special. Artists go to great lengths to get that extra few percents of improvement, so they will spend an entire album budget trying to make a live recording that's better than the free, unauthorized, YouTube ones. Then, after it's released, it's available within minutes on free file sharing somewhere on the internet. But, the elusive, great sounding gig recording is always something that musicians want to have*. (Morse, 2016)

The mainstream popular music albums discussed in Section 2.3.2.3 were recorded under much more forgiving circumstances: rehearsals ran for weeks, tours for months, simpler material, and multiple recorded shows—yet their producers *still* felt compelled to rerecord the performances. Today, in a different economic climate, within progressive rock constraints, there is a higher level of performance expectation. Within the standard industry practice, re-recording remains the primary technique for error management. (See Section 5.3.2.1 for additional discussion.)

The first step in me developing a new error-repair process is to develop a consistent foundation by establishing the elements that comprise my practice: my roles in it, how they inform my goals, the way these goals define the musical objects I produce, and how the issue of performance errors emerges. I continue this investigation by exploring the nature of performance errors, and building the conceptual foundation for a new process to manage them, in Chapter 3.

3 : The Ontology of Performance Errors

In this chapter, I investigate the nature of performance errors in my practice. I begin by building on the nature of live albums introduced in 2.3, and develop this into a formal definition. Next, I explore previous research on performance errors, and build a foundation for examining errors within the context of my practice. Then, I formally define performance errors within the context of my practice, and conclude by introducing a performance-based error taxonomy. These knowledge constructs establish the initial framework for building my error management process on, which is formally introduced in Chapter 4.

3.1 Defining Live Albums

Before I can define performance errors, I must define the musical object in which such errors occur.

3.1.1 Score

> *Since complete compliance with the score is the only requirement for a genuine instance of a work, the most miserable performance without actual mistakes does count as such an instance, while the most brilliant performance with a single wrong note does not. Could we not bring our theoretical vocabulary into better agreement with common practice and common sense by allowing some limited degree of deviation in performances admitted as instances of a work?* — Nelson Goodman, Languages of Art (Goodman, 1968)

Goodman's theory of notation (Goodman, 1968) and authenticity is influential as applied to music. Composer Ben Boretz describes it as an "imposing benefice" (Boretz, 1970)[29]. It is likewise controversial, with Goehr offering that Goodman's "account has struck most theorists as counterintuitive." (Goehr, 1994). A formal examination of Goodman's concepts, along with their social and historical contexts within the larger discipline of musical aesthetics, are outside the scope of this thesis. His theories will be considered as he applied them to classical[30] music, and used to inform our discussions of scores in the context of the live progressive rock recordings comprising my practice. His analysis is particularly applicable to my investigation because it includes an ontology of error.

One of the bases for Goodman's theory of notation is his delineation of works into allographic and autographic:

> *Let us speak of a work of art as autographic if and only if the distinction between original and forgery of it is significant; or better, if and only if even the most exact duplication of it does not thereby count as genuine. If a work of art is autographic, we*

[29] Boretz also stated, "Goodman's contribution to the meta-languages of art had seemed a considerable one, long before the publication of his most recent book." A former advisor of mine at Bard College, Boretz also once stated, "Bill writes too many footnotes."
[30] "Classical" meaning the Baroque, Classical, and Romantic periods.

may also call that art autographic. Thus painting is autographic, music nonautographic, or allographic. These terms are introduced purely for convenience; nothing is implied concerning the relative individuality of expression demanded by or attainable in these arts. Now the problem before us is to account for the fact that some arts but not others are autographic. (Boretz, 1970)

Goodman argues that musical works are entirely allographic, meaning that a work's performance was only authentic if corresponding perfectly to its written score. Any aberration, no matter how minute, regardless of whether it was intended (artistic) or not (mechanical), is a mistake. While this position has found support (Repp, 1996), it is not without controversy. Alperson states that Goodman was "clearly at odds with the common sense understanding of music with his notorious insistence that the most miserable performance without actual mistakes does count as such an instance, while the most brilliant performance with a single wrong note does not." (Alperson, 1984) Taruskin pronounced, "The score is not meant to define the work, only to make its performance possible." (Taruskin, 1995)

This idea is predicated on music existing in terms of (immutable) works, with the score being the primary musical object. Contemporary classical music performances generally adhere to the schema, but it is a relatively modern construction (Saving, 2011). Goehr writes:

…it has become extraordinarily difficult for us nowadays to think about music—especially so-called classical music—in terms other than those associated with the work-concept. Yet for most of its history the tradition of 'serious' music was not thought about in these terms. (Goehr, 1994)

Sherman notes that performances until the nineteenth century focused on new compositions. Changes were brought on by factors such as economic progress, allowing diverse groups access to music—with a growing social, historical awareness of previous composers (Sherman, 1998). He describes Goehr's position as:

Lydia Goehr argues that the century brought a related shift: musical practice began to be governed to an unprecedented extent by the concept of the musical "work." Earlier eras, she argues, were more likely to conceive of a piece of music as an act of performance, a carrier of a text, or a functional part of some other event such as an

> *aristocratic wedding or a church service (although musicians had anticipated the "work concept" to varying degrees since the Renaissance). The work concept, by contrast, elevates a piece of music to the status of an autonomous, enduring, integral work of art.* (Sherman, 1998)

What then, is the primary musical object of a live progressive rock album? In the case of popular music, it has been proposed that the studio recording is the primary object (Chanan, 1995; Middleton, 2000). Gwilliam, regarding Gracyk, notes:

> *Gracyk argued that you should consider the recordings not the score as the primary musical work, this applies to modern popular music where compositions tend not to be formally written down but are more often than not a synthesis of artists, producers, engineers and programmers working together to produce the finished result from a very basic idea instead of them being performed from a written score.* (Gwilliam, 2009)

Gracyk's position is that a score, alone, may not encompass a work. He goes on to make the case that recordings in popular music can define an authoritative version, and that this recording is (partly) autographic.

> *Against Goodman, and mainstream musicology, I think precise details of timbre and articulation can be essential properties of a musical work. … The Born to Run album is a musical work, but it is autographic, because notional determination is entirely irrelevant to the genuine of its instantiations…if Springsteen or anyone else re-records the songs on Born to Run, notational fidelity may occur (we may genuinely have the same eight songs in the same order), and it may resemble Born to Run as closely as two performances might. But it won't be Born to Run, the work that got Springsteen onto the covers of Time and Newsweek in 1975. Notational accuracy is insufficient for access to the relevant piece of rock history.* (Gracyk, 1996)

The authenticity of performance, based on a score, can be described by the term, Werktreue (Cook, 2014). Because progressive rock is only partially informed by rock; while Gracyk's position applies, prog's classical elements render the score relevant, as well—especially in live performances.

Continuing with Gracyk's example of Springsteen's "Born to Run" (Springsteen, 1975), the score for the first verse of the studio recording is reproduced in Figure 3. Precise adherence to this score is likely to be less of a factor for audiences, in terms of perceived legitimacy, than if Springsteen sings it.

Progressive rock audiences, in contrast, expect most instrumental parts to be performed exactly as on the studio album. One reason is that audiences expect to see the same virtuosity live, as presented on the studio album (Pitulski, 2016). Another is that part of the genre is informed by classical music, where a piece is a complex composition with potentially numerous parts that are informed by Goodman's espousal of "exact" score compliance for legitimacy.

Returning to Gracyk's example, Springsteen's fans may consider a guitar-accompanied performance of the *song* "Born to Run" as requiring only the basic chords, regardless of the specific arrangement performed by (E-Street Band guitarist) Steve Van Zandt. But in progressive rock culture, a performer can only play Steve Morse's guitar *part* in (for example) Flying Colors' "Infinite Fire" (McPherson et al., 2012) on guitar—and only that if she plays Morse's exact score. In this sense, it would be no different from playing the first violin part of Mozart's String Quartet Number 14—and claiming it was a performance of Number 14.

In performing Morse's part, one would also be expected to reproduce Gracyk's "details" on the original studio recording, which are not part of a traditional score. In this sense, a progressive rock performance could be compared to Lacasse's definition of a performance copy for recordings:

> *In the context of popular music, I will therefore define a copy as a performance that aims at being the closest possible imitation of a pre-existent, usually recorded, performance. The aesthetic value here resides in the ability of a particular artist to reperform as faithfully as possible what has been already performed. So it is possible to regard copying (in the sense of 'copying a performance') as a hypertextual practice in popular music, although such a practice applies more frequently to live performance, which lies beyond the scope of this essay.* (Lacasse, 2000)

Below are the scores (defined by the studio album performance) for the verse rhythm guitars from “Born to Run” and “Infinite Fire”. These are presented not to contrast the performance difficulty of the two parts, but to demonstrate that Springsteen’s part can be regarded as accompaniment (to the lead vocals), while Morse’s part is a specific part in a “scored” arrangement. (By contrast, the lead vocal is generally of less importance in prog, with the vocal awarded similar weight to an instrumental part.)

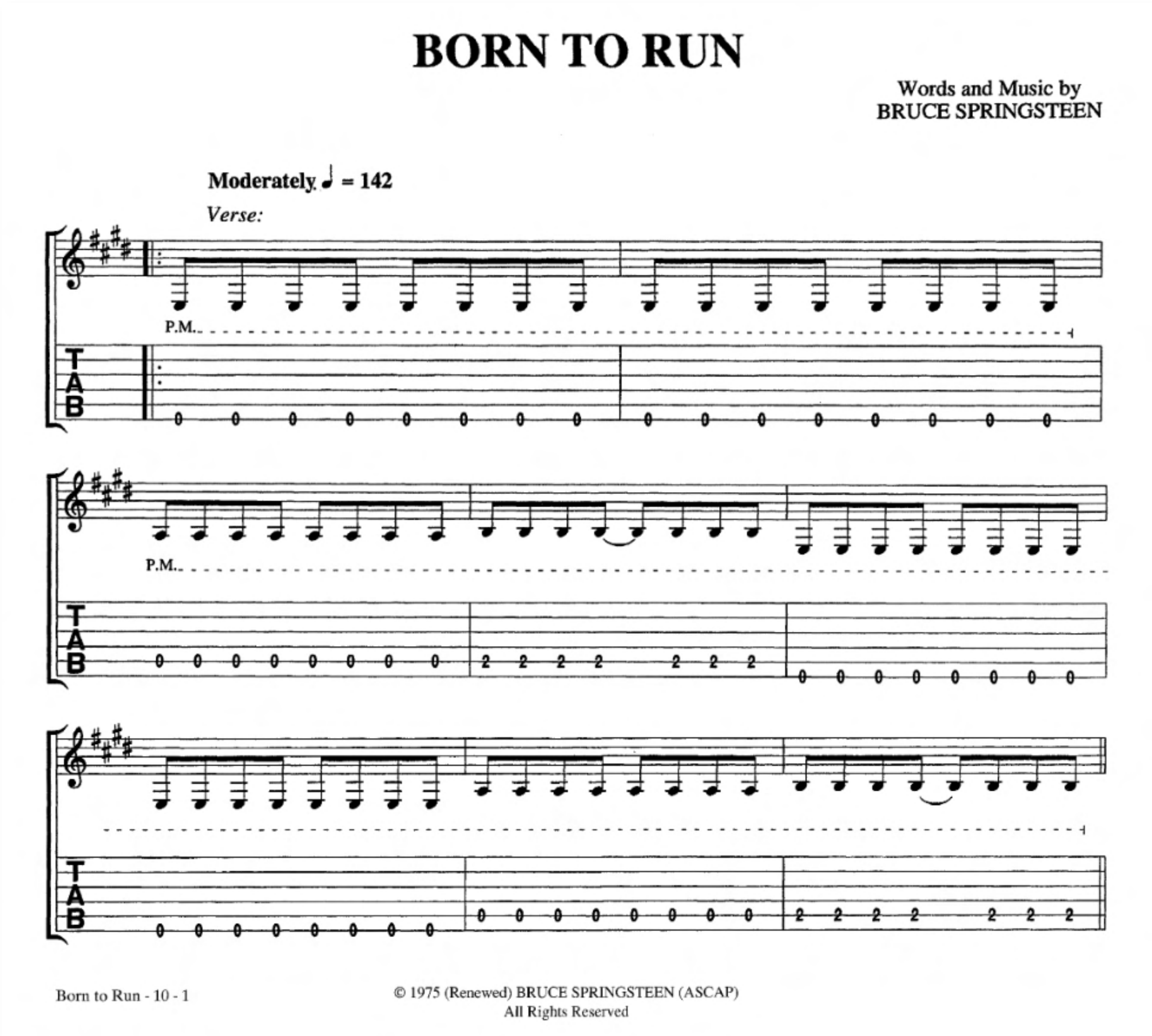

Figure 3: "Born to Run" Main Rhythm Guitar – Verse (Springsteen, 1975)

Figure 4: "Infinite Fire" Main Rhythm Guitar – Verse (McPherson et al., 2012)

Despite the importance of live progressive rock adhering to a score (written or unwritten), scores are rarely used in live performances, as detailed in Section 2.4. Though the musicians are required to memorise up to three hours of complex music, the demands are less than for classical musicians. While progressive rock musicians have a relatively small repertoire that they perform repeatedly, often written by themselves—classical musicians must perform from a large repertoire, written by others, often performed only once.

Returning to Goodman's assertion about mistakes, it can now be applied to live progressive rock albums. Therefore, would any deviation from the score constitute a mistake? Given our previous discussion, the answer could be yes—if the musician did not intend to play what she did (e.g. technical error, forgetting a part). However, progressive rock also embraces improvisation of the score; and in that case, the result would not necessarily be a mistake; at that point, it would be a value judgement on the creative worth of the resulting performance.

The strong influences of classical music and jazz in progressive rock create a compound musical object with competing interests, each noted by Kruse-Weber and Parncutt:

> *The classical music world increasingly identified with a perfectionist, error-free aesthetic that contrasted with, and increasingly diverged from, the more unconventional improvisatory aesthetic of jazz (Hamilton, 2003). In the words of Martin (1996–2007)[31], "Jazz is an art form that must strive for greatness on all levels; (...) if the artists are not encouraged to take risks, how can greatness ever be achieved? There are no sure things in life or art."* (Kruse-Weber and Parncutt, 2014)

There is likewise a duality in the recorded musical object that prog inherits from mainstream rock, and prog's performance aspect that it inherits from jazz. Hamilton describes the two aesthetics, which could be perceived as mutually exclusive:

> *It has been argued that rock music and tape composition are recording-centred, while jazz is performance-centred and Western art music is work-centred. But jazz is in different ways recording-centred too.* (Hamilton, 2003)

[31] Martin was not known for rushing his prose.

These competing, and perhaps mutually exclusive, aspects create a unique musical object for live progressive rock albums, and the meaning of errors within them.

3.1.2 Improvisation

Improvisation in live prog is informed mostly from jazz (R. Sawyer, 2006), though also from classical traditions. Such extemporizations serve similar purposes in live progressive rock as its inspirations, such as additional entertainment for the audience, a forum for performers to showcase their virtuoso abilities, and an added creative outlet for performers.

3.1.2.1 Jazz Influences

Progressive rock soloing is strongly influenced by the improvisational tradition of jazz. As in the latter genre, a progressive rock band is a small group playing instruments similar to those in jazz. Improvised solos are often lengthy, and contain sophisticated elements of formal musical structures (Sawyer, 1992; McPherson and Gabrielsson, 2002). They're often performed by all members of the band when the rest of the group accompanies the soloist.

Bill Evans[32] discusses the nature of improvisation in jazz:

> *There is a Japanese visual art in which the artist is forced to be spontaneous. He must paint on a thin stretched parchment with a special brush and black water paint in such a way that an unnatural or interrupted stroke will destroy the line or break through the parchment. Erasures or changes are impossible. These artists must practice a particular discipline, that of allowing the idea to express itself in communication with their hands in such a direct way that deliberation cannot interfere. The resulting pictures lack the complex composition and textures of ordinary painting, but it is said that those who see well find something captured that escapes explanation. This conviction that direct deed is the most meaningful reflections, I believe, has prompted the evolution of the extremely severe and unique disciplines of the jazz or improvising musician.* (Evans, 1959)

[32] Bill Evans as in the pianist, writing the liner notes for *Kind of Blue*; not Bill Evans as in the academic, writing the footnotes for *A Process for Repairing Musical Performances in Live Progressive Rock Recordings and Implementation with a Commercial Album*.

Evans implies that jazz is imbued with musical depth and complexity through improvisation, rather than score.

3.1.2.2 Classical Influences

Improvisation may not be a common aspect of contemporary mainstream classical performance culture, but as previously noted, this was not always case. The change in culture surrounding improvisation didn't occur at any specific time (Sherman, 1998a), but solidified in the 20^{th} Century, as noted by Hamilton: "Our current standard recital is, in terms of programming, performance style, and etiquette, very much a product of the twentieth century." (Hamilton, 2008) The transition can be expressed in the previously-discussed context of classical works moving from performance to works, and echoes back to Goodman.

It was not uncommon for composers, themselves, to improvise when performing their own compositions. Examples from the Baroque, Classical and Romantic periods include Mendelssohn, Chopin, Brahms, Paganini, Schubert, Bach, Mozart, Beethoven and Liszt (Moore, 1992; Dolan et al., 2013). Not all composers shared this view, though, with some believing that the score should be "unambiguously" manifested; composers such as Stravinsky and Ravel articulated a "profound mistrust of the performing artist" (Korman, 1996).

Generally, improvisatory practice extended to non-composer performers of the periods, as well, as noted by Clive:

> *For much of the period examined here, performers' freedom to impress their own personality on the music, often through minor, and sometimes major modifications of the strict meaning of the notation, was regarded as a right which only a few composers seriously disputed.* (Brown and Norrington, 1999)

Some improvisation occurred in scored or structured locations, such as cadenzas and preludes. During a Classical-era cadenza, the orchestra might stop playing (or play minimally), and the featured performer would then improvise in free time, often showing off virtuoso skills. The cadenzas could be considered analogous to the planned solo sections of progressive rock songs.

Preludes, beginning in the 17^{th} century, began taking the form of either partially or completely improvised prefaces to orchestral works. For live renditions of particularly long songs, progressive rock artists often add a semi-improvised prelude. Bands such as Deep Purple embrace Liszt's (arguably western music's first rock star) practice of improvising on the themes of other pieces (Horowitz, 2010), usually choosing one at random each night.

Extemporaneous elements included embellishments, ornamentation (e.g. during a recapitulation), and alteration (Moore, 1992; Dobbins, 2010). It is likewise common for prog artists, during the live versions of songs, to add such elements to all songs that were played, throughout their performances.

3.1.2.3 Conclusion

Improvisation in progressive rock is a hybrid of multiple traditions and repertoires. A complex score must be generally followed, but there are allowances for periodic ornamentation and embellishment by all band members. The alterations, musically, are similar to those of the improvisatory classical tradition, but available to all band members as in jazz. Soloing in progressive rock usually occurs at designated areas as in classical, but with the rest of the band providing full accompaniment, and designated ("scored") sections for every band member to solo.

3.2 Defining Performance Errors

With the definition of live progressive rock's primary musical object having been established, the definition of performance errors on live prog albums can be investigated. Following this characterisation, a taxonomy of performance errors can be developed. Once that is in place, techniques to identify and repair these errors will be explored in Chapter 4.

The nature of empirical musical performance errors is a complex topic with relatively nascent branches across several of its domains (Repp, 1992; Flossmann and Widmer, 2011). The operational definition of performance errors within the context of my practice enables the establishment of metrics for error detection. As defined by the APA[33]:

> *[An] operational definition is a description of something in terms of the operations (procedures, actions, or processes) by which it could be observed and measured. For example, the operational definition of anxiety could be in terms of a test score, withdrawal from a situation, or activation of the sympathetic nervous system.* (Vandenbos, 2007)

3.2.1 Previous Research

Several theories defining musical performance errors will be examined, with the intent of informing a definition for my practice.

3.2.1.1 Deviation from the Score (Strict)

Goodman's controversial definition will not aid in our investigation. While an argument can be made that some expressive playing (e.g. rubato) can, by itself, meet Goodman's definition of an error, the validity of incorporating improvisation into any part of a progressive rock performance renders his definition an unsuitable foundation for defining progressive rock errors.

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[33] American Psychological Association.

3.2.1.2 Faithfulness to the Score (Loose)

Repp argues, “Faithfulness to the score is the generally accepted criterion for deciding what constitutes an error in performance.” (Repp, 1996) This definition is applicable to progressive rock because, as previously discussed, audiences expect performances “faithful” to the studio album. Improvisation is not accounted for by Repp, but an argument could be made that improvisation is permitted in these performances if the non-improvised parts generally adhere to the score.

However, Repp’s definition is inductive, based on general acceptance. The definition of performance errors, within my practice, must be defined to enable errors to be repaired within the context of the practice’s goals—to be effective, it therefore needs to be defined deductively, beginning with the practice.

3.2.1.3 Deviation from Performer’s Intention

Oore establishes his own definition of a performance error thusly: “By ‘mistake’, I here refer to the occasions when the actual output was different from the intended output (assuming the performer had an intention in the first place).” (Oore, 2005)

Skilled performers in classical music can cover up mistakes such that the audience is unaware of a problem. Within the context of progressive rock, even if the audience noticed a deviation from the score, if handled skilfully enough by the artist, it might simply appear to be an improvisation—and thus not a mistake. Sloboda recalls:

> *Experienced performers soon come to realize just how much they can 'get away with' in live performance. I have often been amazed, when listening to a recording of my own performance, just how unnoticeable were errors which, at the time of performance, struck me as catastrophic. Indeed, part of the art of sight reading is knowing which parts of the music will not be salient for a listener. One learns how to create an impression of accuracy in a performance that is actually far from faithful to the score.* (Sloboda, 1986)

Covering for mistakes is an established part of improvisation, even for the most skilled improvisers. McPherson and Gabrielsson offer: “As a creative endeavour that occurs in real time, improvisation often involves the necessary disguising and making musical sense of mistakes." (McPherson and Gabrielsson, 2002)

Skilled improvisers are able to hide mistakes, even when the results do not match the performer's intention. And unlike the classical performer who must obscure an error, the improviser's result may be considered positive by both the performer and audience. Indeed, the creative benefit in improvisation can be tied as much to error recovery as it is to a perfectly executed extemporization (Sawyer, 1992). Oyan adds:

> *Creativity means being able to work with what exists in the moment of performance and to "bring something new into being." This kind of creativity suggests a willingness to struggle with whatever happens during the performance—be it mistakes in the playing, the physical and mental symptoms of anxiety, or whatever else may arise.* (Oyan, 2006)

While cogent, Oore's definition doesn't meet the criteria as the basis for error definition in my practice. He overcomes Goodman's and Repp's exclusion of improvisation, but doesn't account for error recovery. Additionally, as with Goodman and Repp, his definition of error is objective, rather than being defined contextually within a specific practice.

3.2.1.4 Perception-Based

A perceptual approach to performance errors does not necessitate a specific definition; it deals with the perception of errors rather than (though not necessarily rejecting) an objective ontology about errors, themselves. Repp offers:

> *The definition of pitch errors in piano performance thus depends on the level that is at the focus of attention. Listeners operate mainly on the perceptual level; pianists focus both on the kinematic and perceptual levels, perhaps giving emphasis to one or the other in different situations; but psychologists who investigate music performance tend to focus on the mechanical level, because of the objectivity it affords and also because of its accessibility through the Musical Instrument Digital Interface (MIDI) systems that are now widely available. However, it is at the perceptual level that it is decided whether an error really counts.* (Repp, 1996)

A consideration of perception in examining errors invokes the investigation of the contexts within which perception occurs (Flossmann and Widmer, 2011). Kruse-Weber states, "In general, the perception of errors is context-, listener-, and situation-dependent." (Kruse-Weber and Parncutt, 2014) Fyans et al. add, "…understanding error (and assessing skill) depends on a rich set of personal and environmental factors." (Fyans et al., 2009)

Vila proposes the pedagogical precept that errors are entirely defined by the perceptions of the concerned parties:

> *Traditionally in the field of music education, the criteria related to the definition of how correct had been a performance of a musical piece is based on subjective appreciations and aspects of the perception of the personal criteria of the people evaluating the performance.* (Vila et al., 2013)

Fyans adds:

> *It was proposed that it was useful to examine the understanding of interaction in terms of the spectators [sic] mental model. Furthermore, the spectators mental model, understanding of intention and understanding of error in performance were presumed to be primary factors in assessments of skill and success.* (Fyans et al., 2010)

A perceptual approach to defining errors meets the criteria necessary to build the definition of errors in my practice. It embraces the specific attitudes of prog culture toward faithfulness to score, as well as improvisation, and the masking of errors.

3.2.2 Who Decides What is an Error?

The most common context of error perception study is the dichotomy between audience and performer, as "…performers and audiences often perceive errors quite differently." (Kruse-Weber and Parncutt, 2014) Repp adds:

> *Performers, who monitor their own movements as well as the resulting sounds, may notice errors that listeners do not hear. MIDI registration in addition detects errors that performers may not notice. Thus, errors can be defined and counted at different levels in the process of musical communication.* (Repp, 1996)

In the case of live prog albums, the context of performer and audience are different from that of the literature. While the performer will have had opinions about her performance during the concert, her opinion about the resulting album will be in the context of an audience (when listening to it). Likewise, error perception by the live audience (during the concert) is unlikely to significantly affect the audience listening to the album.

Revisiting the audience groups I am accountable to in my practice[34], due to them being the audiences for the album, it can be established that they are also the evaluators of performance errors on them. Therefore, we can now define performance errors within the context of my practice.

Table 2: Album Perception by Audience Group

	GROUPS			
Aspect	**Artist**	**Label**	**Press**	**Fans**
Release Access Order	First	Second	Third	Fourth
Listening Frequency	Minimal	Varies	Once	Many
Perceptual Dispersion	None	None	One-way (publishing)	Two-way (social media)
Evaluation Context	Existing repertoire Peer releases	Label catalogue	Top genre releases	Artist's catalogue
Error Focus Level	Varies	Varies	Macro	Micro

This table presents the error perception groups (the artist, music press, and "fans") for performance errors within my practice, and the salient aspects relevant for evaluating how these perceptions inform the selection and seriousness of these errors. The information is drawn from my practical experience.

- **Access Order to Release**: The order in which each group hears the album. The artist and press hear the album before its commercial release.
- **Listening Frequency**: How many times a group listens to the album. Repeated listens make listeners more sensitive to consciously perceived errors.
- **Perceptual Dispersion**: With whom groups potentially discuss their error perceptions with, which in turn, can influence others. One-way means that the group cannot discuss errors amongst themselves, and influence each other—they can only communicate with

[34] Artist, label, press and fans.

other groups. Two-way indicates the group can communicate with other groups and amongst themselves, creating feedback loops.

- **Evaluation Context**: The repertoire used for comparison when evaluating performance errors.
- **Error Focus Level**: The level of conscious focus on performance errors. Macro indicates that judgements about errors will be made based on overall impressions of the album. Micro refers to conscious attention to errors, themselves, apart from the album.

Artists have the opportunity to hear a live album before any engineering is performed. They will often evaluate their performances in the context of past performances and those of other artists. They communicate only with other band members, the producer (if there is one), and the mix engineer (to specify which parts she will re-record to address errors).

The press receives the album and completes their reviews before the album is released. They don't have a medium to communicate with each other about the release, nor usually the interest. With smaller media, the reviewer may be a fan of the band; with larger (and more significant for my practice) media, the review is simply assigned. Given the limited payment for reviews, and the professional nature of the work, the album will be listened to probably just once; over-arching reactions will be the focus. In lieu of mistakes, the reviewer will focus on the quality of the performances (which are informed partially by mistakes).

Fans have varying levels of interest in a progressive artist, but as part of the genre's culture, rarely have only a casual interest. Live releases may be poured over in detail, with an artist's previous live releases—as well as the studio versions of the live tracks—as context. Fans often listen to a new release many times, sharing their impressions over social media. Hamilton comments:

> *The possibilities of 'perfect' recording have had an undeniable effect on audiences. Listening many times to a single performance of a work means that errors as well as felicities become prominent; as a result [sic] there is now less tolerance, both by performers and listeners, of note-imperfection and similar flaws.* (Hamilton, 2003)

Labels, for their part, look to press and fans to inform their own assessment of an album's quality. As a label's interest in an artist is primarily sales and cachet, an album noted for mediocre performances, and high sales, would not be considered a complete success.

3.2.3 Practice-Based Discussion

By defining errors in terms of perception, an investigation into repairing them moves from identifying errors made at the performer's end—to how performer's actions will be perceived and interpreted by audiences. A definition of performance errors, in my practice, can now be developed. As a matter of terminology, instances where the performer's output does not equal her intention will be *technical mistakes* (or *mistakes* for short). If the end result is perceived as a mistake, it will be referred to as a *performance error* (or *error* for short).

If errors are defined by their perception—created by their observation in an almost quantum fashion—then any causal relationship between a technical (physical) error on the part of the performer—where output does not equal intention—requires consideration. There is potential for the audience to make a mistake in error perception. Fyans et al. propose a model of "a spectator's understanding of error by a performer" for non-traditional digital musical instruments; while the potential is ostensibly much greater there for such mistakes[35], the model raises useful ideas:

> *The spectator's understanding of the performer's intention, their [sic] knowledge and expectation of actions, and perception of the result contribute to the spectator's understanding of error.* (Fyans et al., 2009)

If an audio event is perceived by audiences as not being the performer's intention, it may be perceived as an error. Based on cognitive research, Fyans *et al.* argue that performers have an objective intention, and that listeners' can misidentify performances as errors in three ways:

1. *Error in Perception of Intention*: Misinterpreting the performer's intention; didn't understand what the performer wanted to do.
2. *Error in Performance*: Misunderstanding the result of the performer's intention; understood what the performer wanted to do, but not what it would sound like.
3. *Error in Perception of Result*: Misidentifying the actual result of the performer's action/sound; unable to correlate the sound produced with the performer's intention.

(Fyans et al., 2009)

[35] The study by Fyans *et al.* concerned digital instruments that audiences had no experience in hearing. Likewise, it did not mandate skill on the part of the performer with the instruments.

Such errors in perception, however, are not ontological aspects of errors in live progressive rock albums. In my practice, I view the existence of performance errors as: whether or not the error perception of an error's existence is *correct*, the perception of one occurring creates a performance error. This notion incorporates both conscious and unconscious perception, comparing the audience's enjoyment of the recording versus their reaction to having heard the originally intended performance.

In assessing the potential for error perception, the program material must be examined in two contexts: audio-only, and with video. With the addition of visual information, an obvious mistake by the performer which has a skilful recovery may be a highlight of the show. If the drummer, for example, in the midst of a drum fill accidentally throws a stick and misses a few 16^{th} notes, but performs the rest of them with one hand without interrupting the rhythm, the result may be a roar of applause from the crowd—and a positive reaction on viewing of the video release. However, the audio-only listener will simply hear part of the drum performance drop out, and then applause.

Likewise, the guitarist may break a string but recover by instantly transposing to other strings. The sound of the string snapping would be a non-program audio event for the audio-only listener, but a necessary audio event for the video watcher.

A further example concerns the leader singer forgetting the lyrics; she can turn this into a humorous (and positive) event—but to fully perceive the context, facial expressions, and the reaction of the band, may be necessary.

Some technical mistakes by the performers will be more likely to be perceived as errors than others. Mistakes that maintain the rhythmic context are one example. Another example is the mistakes that maintain the melodic context (e.g. in the same key or mode as surrounding notes). Especially given progressive rock's allowance for improvisation in both rhythm/accompaniment and solo parts, such mistakes are less likely to be perceived as errors.

3.2.4 A Practice-Based Error Definition

I will define an error within my practice of producing live progressive rock albums, comprised of both audio-only and audio/video configurations, within the context of my practice's goals, as:

Any conscious or unconscious perceptual occurrence experienced by a significant portion of any audience group in my practice, or that has the potential to be communicated and then experienced by a significant portion of a group, which creates the impression of a performance that is inferior to the one intended by the performer(s).

3.3 A Review of Performance Error Taxonomies

This section begins with an investigation of previous research in performance error taxonomies. That knowledge will be analysed, then used to inform the creation of an error taxonomy specifically for my practice.

3.3.1 Taxonomies

Most research involving performance error taxonomies is empirical; it is a relatively nascent field. Of the investigations, most are reductive and undertaken in controlled environments—in lieu of live ones (Gudmundsdottir, 2010; Flossmann and Widmer, 2011; Kruse-Weber and Parncutt, 2014). The taxonomies created are usually for classical music performed on solo piano[36], based on reading sheet music (Repp, 1996; Flossmann and Widmer, 2011). The errors examined are pitch-errors, only—meaning an error where the incorrect pitch was played, in reference to the score. Even within such a narrow domain, these taxonomies can inform my investigation.

Error taxonomies are sometimes created for real-time score-following applications, such as automatic page-turning and real-time accompaniment (Baird et al., 1993; Arzt and Widmer, 2008). As in performance error research, the domain is usually solo classical piano. Both require, at some level, a taxonomy of errors. There are significant differences, however between these taxonomies and those for human performers.

Score-following taxonomies are generally less applicable to *understanding* errors because the causes are often not relevant. They are also generally simpler because the error processing is built into the pattern-patching algorithm where the internal states are unknown, often a hidden Markov model (Rabiner and Juang, 1986; Simon et al., 2008; Nakamura and Nakamura, 2014). Therefore, these taxonomies will not be examined in this investigation.

[36] The default setting is “Chopin”.

3.3.1.1 Palmer and Van de Sande

In their influential (Arzt and Widmer et al., 2008) 1993 paper, "Units of Knowledge in Music Performance", Palmer and Van de Sande argue that empirical analysis of classical piano playing reveals specific cognitive planning of music performances. In their analysis, they target pitch errors, only:

> *Deviations from the musical notation are expected in Western tonal music as part of a performer's artistic license, and it is often difficult to distinguish these artistic deviations from actual errors. For example, the variability of timing and velocity measures in keyboard performances often increases with playing speed (MacKenzie & Van Eerd, 1990). Therefore, most references to musical errors refer to pitch events, because pitch is relatively fixed by the compositional notation of Western tonal music.* (Palmer and de Sande, 1993)

Pitches (notes) are categorized as one of three entities: *the target* (indicated by the score), *intended event* (cognitively planned by the performer), or *intruder* (an unintended event that substitutes for *the target*). Their findings, based on errors manifested as single notes, compare performances with scores using a taxonomy they presented:

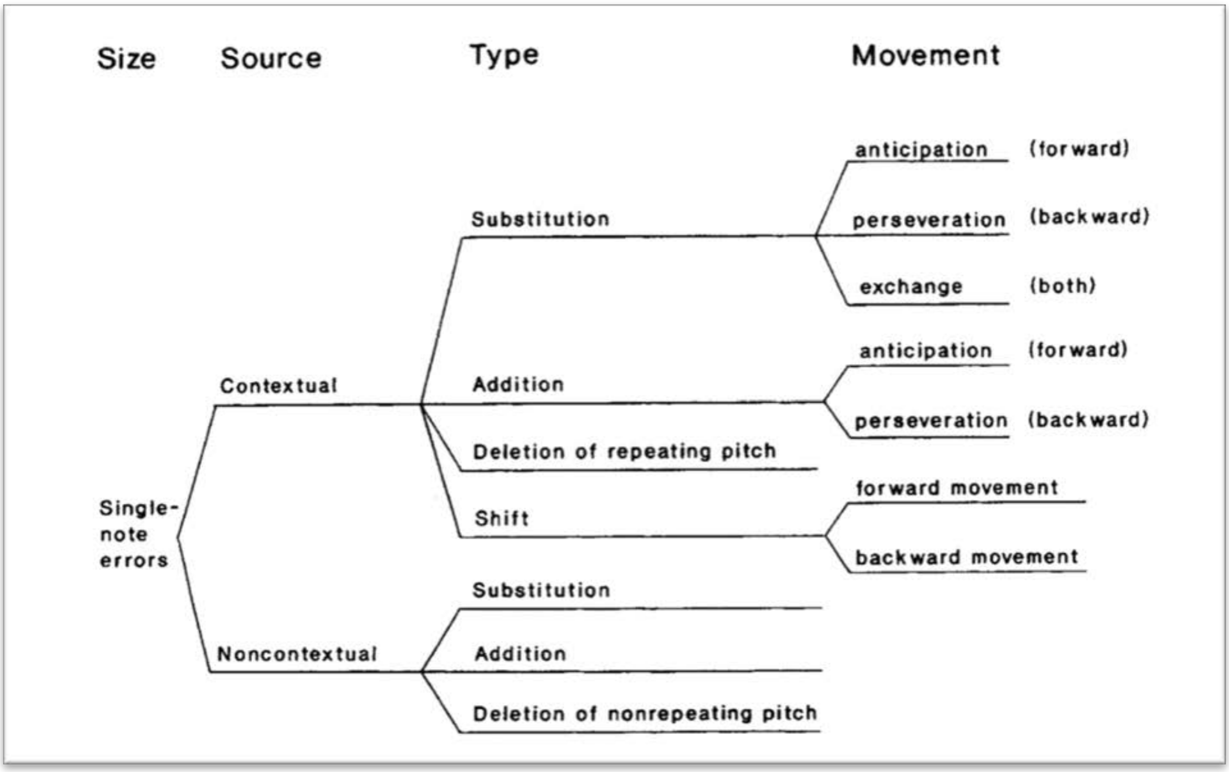

Figure 5: 2.3.1.1 Palmer and Van de Sande's Error Taxonomy (Palmer, 1993)

In their taxonomy, the four dimensions are *size*, *source*, *type*, and *movement*. *Size* refers to single-note, chord, or note-chord combination contexts. (All the errors, themselves, are single notes.) *Source* indicates if the error appeared to be musically-related to the passage that contains it, reflecting a misordering of the score. The concept that errors can be categorised in this manner is intrinsic to Palmer and Van de Sande's theory of cognitive performance modelling.

There are four types of errors. Deletion of a repeating pitch describes a note that is sustained instead of being repeated. The other three are described by Palmer et al. as:

> *A* substitution *involves an* intruder *replacing a* target*; an* addition *involves an* intruder *being added (without replacing a target); a* deletion *involves a* target *being deleted; and a* shift *involves the movement of a* target *to a neighboring location*[37]. (Palmer and de Sande, 1993)

With contextual errors, events are further characterized in relation to their corresponding target notes in the score, and in the deduced cognitive plan(s) of the performer. *Anticipation* occurs if a duplicate note is performed early (before one or more notes it was supposed to follow). *Preservation* occurs when a duplicate note is performed afterwards. In the case of an *exchange*, there is no duplicate; the intruder and the note it refers to in the score (earlier or later) are switched. With a shift, the intruder remains in the correct ordering of targets; it can be *forward* or *backwards*, but not categorized as anticipation or preservation.

Palmer and Van de Sande provided these examples (graphics added for clarity):

[37] Emphasis added for clarity and consistency.

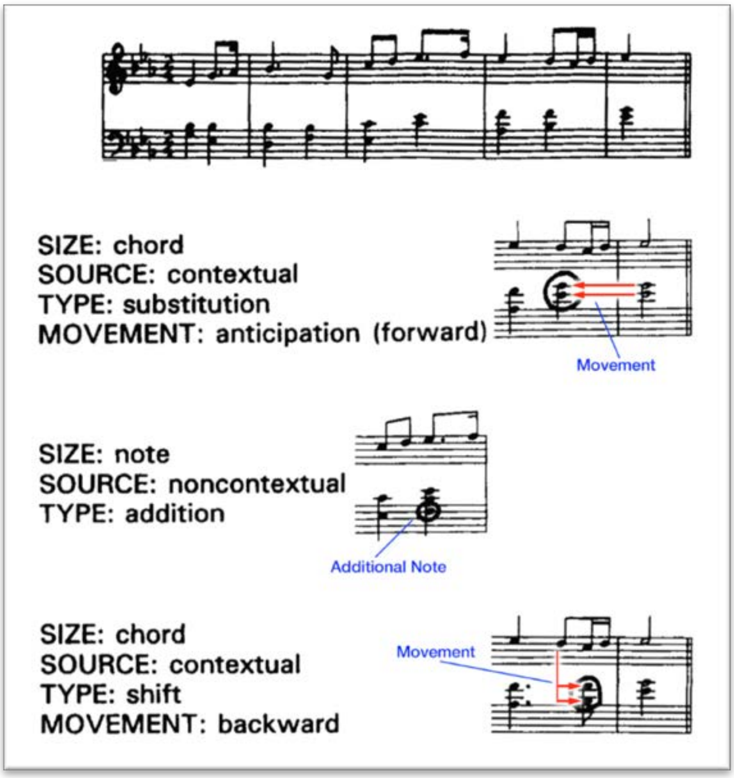

Figure 6: Examples of Pitch Errors (Palmer and de Sande, 1993); graphics added for clarity

3.3.1.2 Repp

As with Palmer and Van de Sande's research, Repp's 1996 investigation with performance errors is an empirical experiment based on classical piano performances from a score. Rather than cognitive planning, Repp focuses on how likely audiences were to perceive errors. His hypothesis, which he confirms, is that many errors in his experimental domain—as he defines them—are not noticeable by a live concert audience.

Repp's error taxonomy is defined as part of the experiment, and is markedly simpler than Palmer and Van de Sande's:

> *This study deals only with a limited class of errors, pitch errors in piano performance of tonal "classical" music, whose definition is straightforward—or so it seems. There are three types of such errors: substitutions, omissions, and intrusions. A substitution is the playing of a note with the wrong pitch, such as E4 instead of C4. The underlying assumption (which seems justified in most instances) is that the pianist either misread C4 as E4 or intended to play C4 but hit E4 instead. Occasionally, however, such an*

error may arise from the simultaneous but independent occurrence of an omission and an intrusion in the same chord. An omission is the failure to play a note that is in the score, whereas an intrusion is the playing of a note that is not in the score. A special kind of intrusion is the "untied note," which does appear in the score but is tied to a previous note of the same pitch and thus is not intended to be sounded again. (Repp, 1996)

Error Frequencies and Percentages

Piece	No. of Notes	Substitutions	Omissions	Intrusions	"Untied" notes
(a) Error frequencies, separately for the three performances of each piece[a]					
Schumann	4,570	2 2 4	30 38 37	23 22 30	56 46 43
Debussy	5,830	27 27 20	102 103 90	32 29 20	16 14 14
Chopin	15,180	34 32 28	262 214 200	156 135 154	[b]
Grieg	6,580	27 18 24	190 164 165	156 154 153	[b]
(b) Error percentages, for the three performances combined[c]					
Schumann	13,253	0.06	0.77	0.55	9.86
Debussy	16,907	0.42	1.69	0.46	2.07
Chopin	44,022	0.21	1.48	0.98	[b]
Grieg	19,082	0.35	2.63	2.35	[b]

[a]The error counts from P4's second performance are included in the totals for both the second and third performances, but are included only once in the error percentages.
[b]Untied notes were too infrequent to be listed separately; they are included among the intrusions.
[c]Intrusions are expressed as percentages of all notes played, untied notes as percentages of tied notes.

Figure 7: Example Usage of Repp's Error Taxonomy (Repp, 1996)

Repp posits his error definitions objectively, based on mathematical analysis of MIDI data gathered during the piano performances, compared with the corresponding score. He then measured audiences' perception of those errors via self-reporting. He found a range of thresholds for error perception, based on multiple contextual variables:

The listener's musical experience, knowledge of the music, availability of the score, level of attention, and other factors determine a perceptual criterion or threshold that admits only a certain proportion of errors to consciousness. (Repp, 1996)

3.3.1.3 Flossmann and Widmer

As with their predecessors, the domain of Flossmann and Widmer's 2011 investigation was solo classical piano pieces read from a score (Flossmann and Widmer, 2011). Also in keeping with their predecessors, errors were defined objectively in terms of the performer's physical actions. And errors, except for one category, were all pitch-errors. They accepted Palmer and

Van de Sande's position that errors reveal cognitive planning by the performer, and that these plans could be used to reveal information about the errors.

Unlike the previous two investigations, the primary goal in Flossman and Widmer's research is to establish a taxonomy of errors, and to ascertain their causes. They seek to expand on previous research, which they consider focused on single note errors, including Palmer and Van de Sande. Specifically: "The goal of the present study was to build and analyze groups of errors, the context in which they occur, the patterns they form, and what conclusions can be drawn as to the potential causes." (Flossmann and Widmer, 2011) Their taxonomy employs elements belonging to both Repp's, and Palmer and Van de Sande's, research:

Category	*Insertions*	*Omissions*	*Substitutions*
Omitted inner voice	-	630	-
Forward-related errors	59	9	40
Backward-related errors	75	8	53
Unharmonic errors	694	-	88
Harmonic errors	104	-	69
Tied notes	91	294	-
Repeated notes	123	-	-
Systematic errors	228	555	110
Note order errors	-	-	261
Total	*1385*	*1496*	*635*

Figure 8: Data from Flossman and Widmer Using Their Taxonomy

Insertions, *omissions* and *substitutions* correspond to Repp's taxonomy, with *insertions* having the same general meaning as *intruders*. Most of the categories terms can be approximately correlated with Palmer's:

Table 3: Flossman et al. and Palmer et al. Terms Comparison

Flossman et al. Term(s)	Cause(s)	Note	Palmer et al. Term(s)
Forward, Backward	Memorisation	Palmer's term is oriented toward cognitive models.	Anticipation, Preservation
Harmonic	Memorisation[38]	Whether the intruder disturbs the current harmonic context.	n/a[39]
Unharmonic	Technical	(As opposed to the above.)	n/a
Tied	Technical	A tied note is played twice, or two successive notes are played once.	Deletion of Repeating Pitch[40]
Repeated Notes	Technical	A single target is accidentally struck twice.	Insertion (specific case)
Systematic	Dependent on other categories	Meta-category; any error that frequently occurs within the same context.	n/a
Omitted Inner Voice	Memorisation or technical	Throughout a sequence, an inner voice is partially or completely omitted (e.g. two hands moving across parallel octaves).	Deletion (specific case)
Note Order	n/a	Exchange within successive notes.	Exchange (specific case)

3.3.2 Analysis

The taxonomies accompanying research in performance are useful in my investigation in terms of informing the development of a practice-based taxonomy. However, none of them can be the basis for a taxonomy serving my practice because of differences in the contexts and constraints of most performance research. As such, I will analyse the existing taxonomies, demonstrating the need for a new taxonomy within the context of my practice.

Although one of the taxonomies is part of research that examined performance errors within the context of perception, all of them define errors as objective occurrences; none of them incorporates perception into the taxonomies, themselves. In "The Art of Inaccuracy: Why Pianists' Errors Are Difficult to Hear", Repp writes "…pitch errors (really: key-depression errors) can be defined objectively and unambiguously."

[38] The authors point to this error also possibly being attributed to a deliberate decision on the performer's part, though this would seem to be potentially an error of judgment, which is in a different context from the errors considered in the investigation.
[39] While *harmonic* and *contextual* may appear similar to *unharmonic* and *non-contextual* errors, they differ in several significant ways. One is the perception of the audience: an harmonic error may not be detected by the audience because it may sound like part of the composition; a contextual (re-ordering) of notes could result in significant harmonic dissonance.
[40] Specifically, the second case of Flossman's criteria: two successive notes played once.

Within the context of my practice, an error does not exist in the first place if it cannot be perceived. The error is not that the score or cognitive improvisational model was not followed—it is that an event that occurred causing the audience to perceive the performer as playing to less than the expectations of her ability—or not as intended.

As noted, most performance error literature occurs under laboratory conditions; the remainder happen under live ones. None of them occurs with the audience judging errors from a recording of that performance after the fact. As demonstrated in Section 2.3.2.1, it is relevant to note that audiences are less sensitive to errors during performances than when listening to recordings of them.

The literature focuses on solo instrumental performances; progressive rock bands are group performances with vocals. Groups are subject to errors that solo performers are not. An example is the so-called "train wreck" where a cascade of error-laden performance dialogues occurs among players to the point where the group cannot continue. While trained performers are able to employ error-obscuring techniques (Kruse-Weber and Parncutt, 2014) without such inter-musician feedback loops, ensemble performers use collaborative strategies to obscure an error by a single performer (Baird et al., 1993) (Sawyer, 2006).

Rhythm becomes a significant domain for errors in a group context because rhythmic cohesiveness must be maintained among all instruments, including during tempo-altering expressive playing. Error taxonomies rarely refer to rhythm, however. Palmer and Van de Sande's *shift* category describes a note moved forward or backwards in time, but represented as an exact crotchet-multiple. Repp describes note order as his only category that incorporates rhythm as an element, though it refers only to a re-ordering of notes (Repp, 1996).

Performance error taxonomies are predominantly drawn from the solo classical piano repertoire; Chopin is common (Arzt and Widmer, 2008; Flossmann and Widmer, 2011). While progressive rock is informed by classical music, there are obviously significant differences in the genres, such as a lack of solo piano works. Piano, when used in progressive rock, is not used to perform entire pieces—the rhythm and bass, for example, are usually provided by other instruments. Likewise, the melody is often carried by the singer.

Polyphony is limited to allow room for other instruments, both harmonically and rhythmically.

When referring to solo classical piano, Repp notes: "Errors will be less noticeable (and will occur more frequently) in subsidiary voices, especially inner voices, than in the principal melody (which is most often the highest voice)." (Repp, 1996)Flossman and Widmore explain:

> *We call an error systematic if it occurs in more than 60% of instances of the same or an analogous context. This covers a variety of situations. Figure 2 shows a systematic insertion from Ballade Op. 38: in almost all instances in which the right-hand starts with a downward run, accompanied by a rising sequence of octaves in the left hand.* (Flossmann and Widmer, 2011)

Palmer and Van de Sand write:

> *We examined the influence of compositional structure on the size of units planned in music performance by presenting pianists with two types of musical compositions: homophonic and polyphonic, each containing three simultaneous voices or parts. The homophonic compositions contained one melody and two accompanying voices of secondary importance. Thus, homophonic structure emphasized across-voice associations, and errors should reflect associations among simultaneous voices (chords). The polyphonic compositions contained two melodies and a third (less important) voice. Thus, polyphonic structure emphasized within-voice associations, and errors should reflect associations among elements within the voices (single notes).* (Palmer and de Sande, 1993)

The instruments of progressive rock, even within a solo context, cannot be represented by these existing taxonomies. Acoustic guitar, electric guitar, electric bass, organ, synthesizer, drums, and vocals can present unique error categories not represented in piano-based taxonomies.

For stringed instruments such as guitar and bass, error categories such as *omitted inner voice* (Flossmann and Widmer, 2011) do not necessarily apply—to either strumming or finger picking. The inception and end of pitches, themselves, are not straight-forward as on a piano—both instruments support portamento and string bending. In comparison, the limited articulation control and remote hammer mechanism leave little potential for such errors on piano, and are not reflected in those taxonomies.

Direct contact with the vibrating sound source facilitates numerous articulations—setting the stage for errors in executing them. Possible errors include occlusion of the note attack, obscuring a note's pitch and the smearing of surrounding notes such they cannot be perceived as individual events. It's possible to miss the string altogether and make no sound at all. In lieu of classical piano's left and right parts, guitars and bass often play a singular part—both hands are usually required. Synchronization issues between them create the potential for a spectrum of specialised errors.

Drums in popular music, of course, generally cannot have pitch errors. While the analogous mistake on drums is playing the wrong drum, this is rare. Most drum errors in progressive rock are related to performing the wrong part, missed cues from other musicians, and unintended tempo changes.

While not a direct focus of my investigation, vocal errors have significant differences in error taxonomy from those described in the literature for piano. As with stringed instruments, the beginning and ending of notes can sometimes be a matter of interpretation. In progressive rock, lead vocals are generally expected to carry the melody, and performances are evaluated largely based on their expressiveness, which is often tied to unique performance contexts that constantly change during a performance—the same performance as the recording (representing the score) is not expected. In this context, the lack of a convincing, authentic and expressive performance can be viewed as an error—even if it is otherwise technically perfect.

There are no performer-induced tuning errors for concert piano during a performance. There are such issues for stringed instruments, however; their tuning often changes throughout performances. Likewise, pitch errors can occur when bending up or down to a note. It is vocals, though, that have the most potential for pitch errors are manifested—both in lead and composite harmony vocals.

Improvisation introduces additional considerations for error taxonomies. Score-based taxonomies have a correct (target) note for each pitch, and that is the metric for errors to be evaluated. Within a genre where improvisation is a significant element, the perception of an extemporaneous performance not being representative of a performer's repertoire has the potential to produce negative audience reactions—which in the context of my practice, could be considered a performance error. Even we take Oore's definition of error—unfulfilled intention (Oore, 2005)—then anything less than a perfect creative (as opposed to technical) component to improvisation can be considered erroneous.

⁂

Despite their differences with my investigation, these empirical studies and their taxonomies are certainly useful in informing both my own taxonomy and model for repairing errors. In many cases, progressive rock performers do adhere to a score. Evidence of cognitive planning may be used in predicting performer's intentions—and this could be applicable to determining the intention of improvisation when mistakes are made.

Each model considered—Palmer and Can de Sande, Repp, and Flossman and Widmer—provide significant relevant research to inform and develop my investigation. This is due not only to theoretical concepts behind the taxonomies, but the empirical evidence to support them.

In summation, a new error taxonomy is required for my practice for two reasons. First, current research was undertaken in different genres, instruments, and performance contexts. Second, a practice-based error taxonomy must relate to the goals of my practice, according to the audiences groups I am accountable to.

3.4 A Practice-Based Error Taxonomy

In this section, I develop a practice-based error taxonomy (hereafter, PBE taxonomy) of errors for live progressive rock albums in my practice. Based on the error-perception behaviour of my audience groups (shown below), I will identify the phenomena most likely to be observed by them as errors.

	GROUPS			
Aspect	Artist	Label	Press	Fans
Release Access Order	First	Second	Third	Fourth
Listening Frequency	Minimal	Varies	Once	Many
Perceptual Dispersion	None	None	One-way (publishing)	Two-way (social media)
Evaluation Context	Existing repertoire Peer releases	Label catalogue	Top genre releases	Artist's catalogue
Error Focus Level	Varies	Varies	Macro	Micro

Figure 9: Review of Table 2, "Album Perception by Audience Group"

With 36 recorded tracks and five musicians, there is the potential for thousands of errors on the Creative Submission Album. The error analysis must be performed manually, as with Repp's perceptual investigation (Repp, 1996). My taxonomy is, therefore, be reduced to its minimum complexity while maintaining sufficient information to inform the repair process. In commercial practice, a process that is too time-consuming is not effective. To allow for additional information that is not expressed by the taxonomy, annotation field is included.

One suggestion might be to employ an existing taxonomy, and research method, to empirically catalogue the errors on a previous live album in my practice—and then measure the perception of audiences in regard to those errors, according to my album error perception groups. Such an undertaking, however, is neither practical nor effective within my investigative context.

Within a commercial practice, it would be untenable for a producer to survey the listening groups (e.g. fans, music critiques) of her album about issues such as perceived errors and quality of improvisation. It would only be possible to consider the responses of audience groups to an album corrected/restored using a new process, with the intention of inferring feedback—and that is an element of this investigation. The considerations of what audiences ultimately respond to, within a commercial practice, is part of the practice itself, and therefore can only be drawn from there.

There are two *classes* of errors in my taxonomy: *event* and *rhythm*. Within each class are several types. A given section of music for one instrument can have multiple (overlapping) classes and types of performances errors. For example, an instrument can be out of tune for a section, and also contain intruder notes. From types, two hierarchical classifications descend: domains (which are not mutually exclusive) and categories (which are). For each error catalogued, an annotation field provides details, so the taxonomy is not required to be descriptively exhaustive.

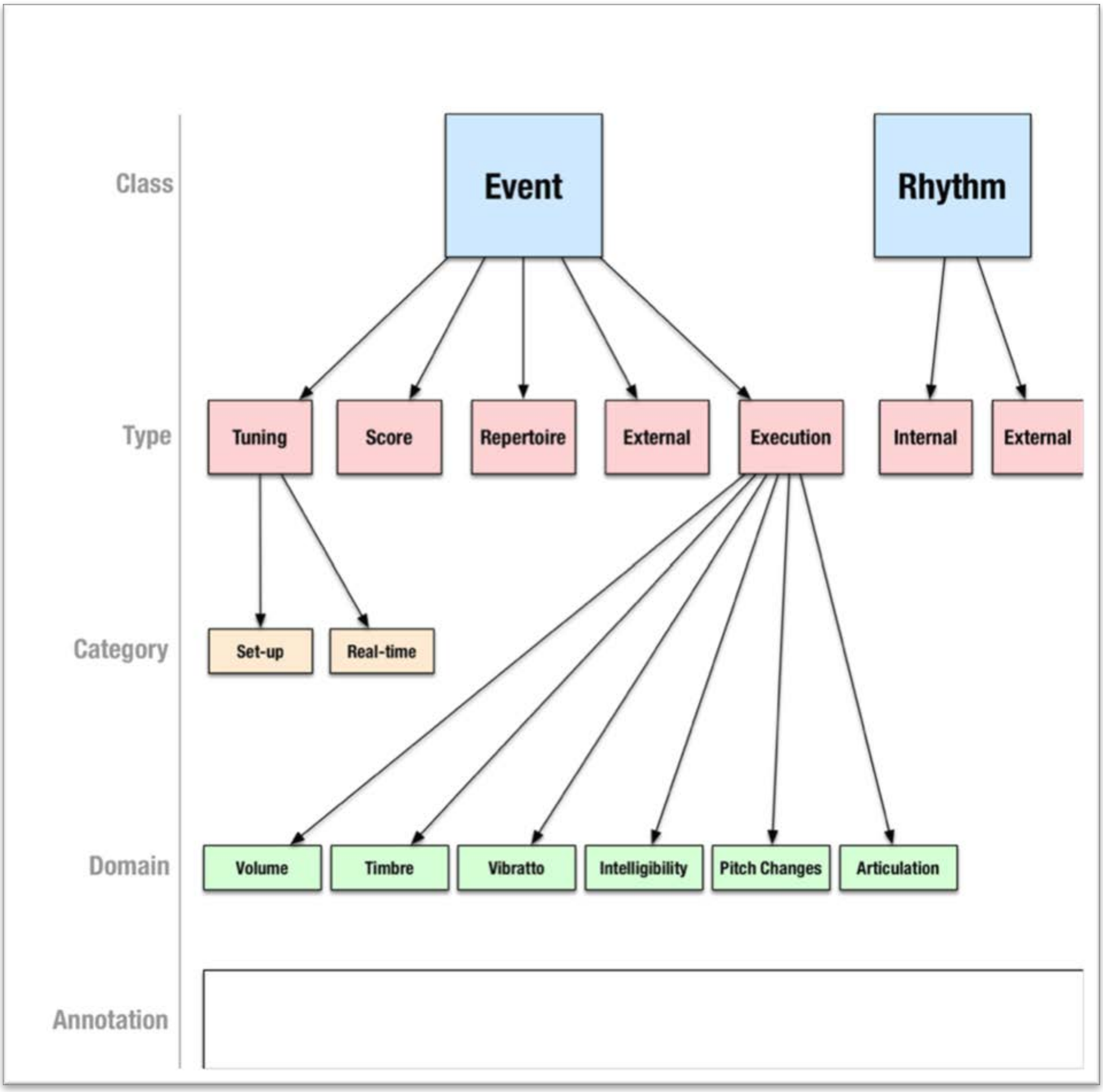

Figure 10: The PBE Taxonomy

3.4.1 Event Errors

Events are the smallest unit of audio in the PBE taxonomy. In the piano-based error taxonomies discussed in Section 3.3.1, the error-object is usually a note, representing a single pitch (thus construed as *pitch errors*). This is the case in the PBE taxonomy for piano; no other instruments on the progressive rock stage have only a single note onset, pitch and release.

Some instruments (including the human voice) are capable of pitch changes without additional note onsets (e.g. portamento, bends, vibrato). In this case, the resulting audio event may be a sequence of uninterrupted pitches. Likewise, these instruments can sustain notes, and have greater control over dynamics, such that the onset and release of notes are ambiguous.

There are five *event* error types: *score compliance*, *execution, tuning, creativity* and *external*. A single event can have multiple error types.

3.4.1.1 Score Compliance

As noted in Section 3.1.1, the score for a live progressive rock album is derived from the set of corresponding studio recordings. Any deviation from the score that is not perceived as intentional (i.e. improvisation) may be considered an error. A Score error indicates (my prediction that) audience groups (will) perceive a performer as intending to play the score, but unintentionally playing different musical events.

3.4.1.2 Execution

This error type measures audience perception of how well an audio event was executed by the performer. It is informed by the success of the performer's technique. Because there are numerous possible issues with technical execution (and the perception thereof), compounded by multiple instruments, there is no attempt within the PBE taxonomy to enumerate them completely. Instead, the most common ones are assigned to *domains*. They are: *dynamics* (volume changes), *vibrato*, *pitch-change*, *articulation*, *timbre*, and *intelligibility*. Multiple domains may be assigned to a single execution error.

Because domains are assigned based on perception, an error that sounds like the fault of the performer, but isn't—is still attributed to the performer in the taxonomy. For example, when a microphone malfunctions, and the bass player's notes become difficult to hear, there may appear to be a problem with either the performer's execution or the ability to operate her signal processing chain. If such an error is obviously out of the performer's control, though, the error is characterised as an *external* event error.

3.4.1.2.1 Volume/Dynamics

In the case of simple events, volume[41] may simply be soft or loud—either in relation to other notes, or by itself (e.g. cannot be heard). Complex events may include volume changes (e.g. crescendos, swells) and elaborate amplitude envelopes.

3.4.1.2.2 Vibrato

Possible issues include inconsistency, improper depth, or incorrect timing before onset.

3.4.1.2.3 Pitch Changes

Complex events can contain changes in pitch(es)[42]. Potential cases include pitch-bends, portamento, and vocal slurs. A piano crush note (acciaccatura) would also qualify as a pitch change, as that is the intended perception—this is the only complex event for piano in the PBE taxonomy.

3.4.1.2.4 Articulation

Articulation errors concern whether the correct articulation was perceived as being used, and how well it was executed. This error can overlap with other domains such as intelligibility and timbre. An error pertaining to the amplitude envelope, however, would only be a *volume* error if the articulation was perceived as executed correctly.

[41] The term *volume* is used in lieu of *amplitude*, as volume is a perceptual phenomenon.
[42] The rate of a pitch envelope is often important, and is sometimes intended to be synchronized with the song's rhythm; because this represents timing *within* an event, this error is not in the *rhythm* class.

Different instruments, of course, have unique ranges of articulations. Pianos cannot have an articulation error in the PBE taxonomy because the only variable (other than onset/duration) is how quickly a key is struck (Goebl et al., 2005). Synthesizers can have articulation errors, though, because they can sustain notes and employ additional controllers (e.g. aftertouch, modulation wheels) to affect aspects of their sound. While it is possible for drums to have articulation errors, this is rare due to highly skilled performers.

The instruments which most often incur articulation errors are guitar, bass, drums and voice. They have the greatest range of articulations, and there is direct contact with the vibrating element producing the sound. Guitarists in progressive rock switch between multiple articulations, including: apagados (palm muting), tapped harmonics, pinched harmonics, traditional fingerpicking, chicken-picking, sweeping, finger tapping (single and double-handed), alternate/economy[43] picking, slapping/popping, legato fingerings, hammer-ons, slides, and volume swells. Within each of these articulations, there is the possibility for a range of other articulations (e.g. staccato). Bass players employ many of the same articulations.

The human voice can be argued as possessing an even greater range of articulations. They cannot, however, be easily classified with the objective cardinality of physical instruments. In the PBE taxonomy, voice articulation errors are specified in the *annotation* field.

3.4.1.2.5 Timbre

As with articulation, although pianos allow some control over timbre, most other instruments in progressive rock provide a far greater range. Guitar, bass, synthesizer, and voice also allow for harmonic envelopes, whereby the timbre changes during an event can be controlled.

Most timbre errors occur in combination with articulation errors. The difference is that timbre errors can occur at any point during an event; articulation errors occur only at the beginning or ending, or during a transition within.

Some examples by instrument:

[43] Both techniques result in every note being picked, so they create the same articulation for the listener.

Keyboard

- An organ's Leslie breaks instead of accelerating.
- The modulation wheel controlling a high-pass filter is swept in the wrong direction, or at the wrong time. Or, the modulation wheel was supposed to affect a different parameter.
- A brass patch is set to become brighter with aftertouch, but not enough pressure is employed to create the brightness expected by the audience.

Guitar/Bass

- The pickup is accidentally changed, globally altering the timbre of the guitar's tone.
- The strings are excited in the wrong position relative to the pick-ups, producing the wrong tone.
- A tapped harmonic isn't precise enough, and fewer high harmonics are produced than expected. This would also be an articulation error. If the sound produced was also not at the volume expected, that would be an additional domain for the error.

Voice

- A timbre error with vocals is often a technical error. Examples include the voice breaking during a belting tone, losing power during a sustained note causing higher harmonics to fade out faster than lower ones, and switching to falsetto because of a temporary inability to use full voice.
- A vocal timbre error can also appear to be the result of a creative decision. This follows from every audio event in a prog (or popular music, in general) vocal performance being viewable as having some degree of improvisation (because the exact same performance is rarely desired across concerts). Examples of such potential errors include pulling back when the audience expects a louder delivery, and delivering events with more of a spoken than sung quality (where not expected).

3.4.1.2.6 Intelligibility

Intelligibility is the perception of an audio event's clarity. Examples of errors include difficulty perceiving the onset or release of an event, or its pitch(es). Common causes are improper articulation, and the accidental sounding of notes in addition to the intended one(s).

Artificial distortion, as an intended audio effect, is a common contributor to Intelligibility errors. Artificial distortion creates new overtones; some are unharmonic—and others occur at frequencies, ratios and amplitudes not associated with physical objects. Therefore, the human ear may have difficulty identifying and resolving the intended fundamental pitches.

Vocal intelligibility issues include the decipherability of lyrics and volume. These issues may be a result of technical problems outside the singer's control; unless the cause is obviously so, then it may still be perceived as a performer error, and must be considered as such.

In the case of an improvised solo, there is no score to reference to guide the restoration of the intended notes. In this case, the practitioner employs Regeneration to fill in the missing part of the solo's score, and render the corresponding audio for the performance. See Section 4.4.2.3 for more information.

3.4.1.3 Tuning

Tuning problems during a piano performance would not be attributed by audiences to the performer. This is not the case with the other instruments in live progressive rock; drums, guitars, basses, synthesizers and vocals are all expected to be under the performer's control. The PBE taxonomy has two categories for tuning: *set-up* (tuned before the performance) and *real-time* (tuned during).

Drums and synthesizers (except vintage analogue ones) employ set-up tuning. Drums, however, can still be tuned to pitches that conflict with the band or specific songs. Synthesizers may be tuned to a different standard than the rest of the band.

Guitars and basses employ real-time tuning because the tension on the strings can change for a variety of reasons during a performance. Performers often re-tune between songs, but even with polyphonic tuners, experienced guitarists may tune incorrectly because of time constraints. They may also employ techniques which accidentally produce differing intonations. For example, the pitch of a guitar generally rises the harder a note is struck. Another tuning issue for guitars and basses is a physical limitation in the instruments' design: tuning changes depending on a song's key, and where notes are played on the neck[44].

[44] Guitarists such as Steve Morse address this issue by approaching intonation more like a string player, adjusting the tuning of each note manually during the performance. In doing so, he strikes a balance between internal tuning for his instrument,

3.4.1.4 Repertoire

A Repertoire error is a musical passage that is not an accurate portrayal of artists' overall intention and ability. It's not typical of their repertoire, and not an accurate reflection of their performance—and therefore considered a performance error in EAPR.

For example, if there are many performances of a song during a tour, a seasoned virtuoso performer should have consistent performance in her improvised solos. But if she has an "off" night, and that happens to the show recorded to represent the tour, then using it on the album could be viewed as not being an "authentic" representation of the solo (Guidoz, 2018).

Establishing the score to replace a performance within the context of a Repertoire error is termed *Regeneration*, and as is discussed more in Section 4.4.

3.4.1.5 External

External errors are perceived as coming from outside performers' control. They are often non-program audio. Examples include microphone feedback, and audible radio transmissions picked up by unshielded cables. Regardless of the cause of these sounds, an audience may perceive their source to be the performer, and the sounds become a performer error. Even if the sound is clearly not the fault of a performer, the event can still be considered a performance error—because there is also a perception that the artists should possess sufficient professionalism to prevent external sounds. This topic is further explored, within the context of EAPR and other practices, in Chapter 5.

3.4.2 Rhythm Errors

Rhythm errors are specified by either a list of specific events, or a specific length of time. In the latter case, the length of time extends before and beyond the errant events to establish the correct rhythmic context. When specific events are specified, they are usually small in

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and the pitch environment of the band. During a song, depending on musical context, he may also switch between tunings such as just, equal-tempered, and expressive (e.g. during a solo). This is an important issue when correcting the tuning of other instruments during post-production, because it can disrupt the delicate intonation of a player like Morse.

number, and their correct rhythmic positions are evident. The division among these selection criteria is fluid; both can be employed simultaneously, across overlapping areas, to represent different rhythmic errors.

The two variations of rhythm errors are *internal* and *external*. *Internal* errors apply when the rhythm of a track's performance is incorrect in reference to the rest of the band. This is the most common type of error. *External* errors manifest themselves when the band's meter or beat is unclear. It usually occurs when multiple tracks contain rhythmic errors, and indicates serious technical performance issues. In these cases, attempting to improve the rhythmic coherence of one track, by referencing the momentary tempo of another track, may exacerbate timing inconsistencies between other (simultaneous) tracks.

3.5 Conclusion

The PBE taxonomy provides a framework to identify and catalogue audience group perceptions of performance errors within the context of my practice. This is done as a key part of a process to analyse musical errors and restore intended performances.

4 : A Process to Analyse Musical Errors and Restore Performances

This chapter begins with definitions of terms related to my process for restoring performances. The relative lack of research on performance error repair is reviewed, followed by the suggestion of exploring tangential domains that could inform repair. Compositional and performance hierarchies are examined for evidence of performers' intentional emotional cues. Improvisation is investigated in terms of both group error handling and the uses of motifs to help identify and predict extemporaneous performances.

The chapter continues by introducing a process for identifying and repairing performance errors in live progressive rock music, with the goal of restoring the original (intended) performance. Concluding the chapter is a conceptual guide to the application of the aforementioned process to the error taxonomy introduced in Section 3.4.

4.1 Introduction

As discussed thus far in my investigation, I wish to develop a new process for restoring the originally intended performances where musicians have made mistakes during a live recording. Within the context of my practice, I believe this approach will result in recorded performances that are more authentic than those resulting from the industry standard practice for error management. Before I define this process, I must define the term “authentic” within the context of my investigation:

> A recorded performance is considered *authentic* if it is perceived by my audience accountability groups as representative of the artist’s repertoire, and as an unaltered recording. I make this evaluation solely based on experience in my practice with these groups.

What would such a recording be, if not an historical record of an acoustic event? My aim is to restore performances, instead of using the industry standard error management process, because (based on my experience with my accountability groups) such a process would produce more authentic performances within the context of my practice. (See Chapter 5 for an examination of the industry standard approach.)

In the context of my practice, I will define a *restored album*:

> A *restored album*, in the context of my investigation, is defined as a recording of a specific concert with the originally intended performances (as can be best determined) restored solely from the audio that was recorded. Elements of the performance which require interpretation or regeneration will be restored according to the performers’ median ability based on existing repertoire, not a level of perfection.

Instead of focussing on identifying and solving errors in the performance (as in the performance literature) the focus in my practice is on defining and solving errors on the recording. In other words, I am not producing a recording of what could have been, in the traditional sense of an idealised performance free from error. My goal is to restore what would have been, by predicting the intended performance based on fulfilment of intention.

Therefore, from this point forward, when referring to my practice, “repairing performances” will be replaced with “restoring performances”. The complete restoration process will be termed Error Analysis & Performance Restoration (EAPR). The process can initially be defined as:

> *EAPR Process*: First, technical errors in the recording will be identified based on perceived importance to the album’s audience groups. Flagged errors are categorised according to the PBE taxonomy. Next, the performer’s intention for each of these events (or series of events in the case of rhythm errors) is investigated using a procedure termed *Performance Forensics*. Once specific determinations are made, the audio that corresponds to the intended sound of events is created.

4.2 Existing Research to Inform Performance Restoration

Determining (or predicting) the expressive intention of a performer is a non-trivial problem. For example: Pitch events errors could be accidental deviations from the score—or accidental deviations from an intended improvisatory embellishment. How is rhythm properly evaluated for intended expressive devices such as rubato? If complex pitch events (e.g. pitch bends or portamento) are erratic, how would the performer have wanted to play them? The literature and contemporary industry practices do not provide significant information necessary to address this problem, unless the part is re-recorded by the original performer—as discussed in Section 5.3.2.1, this technique is not compatible with the goals of my practice.

4.2.1 From Performance Errors to Restoring Expressive Performances

A recording of an ideal performance would contain all the expressive elements of that performance—these elements are especially important given the importance of virtuoso performances to progressive rock's audience groups. However, the performance error literature cited in Chapter 3 cannot fully inform about issues of expressive performances.

While informative to my investigation, this literature focuses mostly on pitch errors—deviations from the score (and the assumption of a written one existing). Expressive performance characteristics are largely not considered. The literature also does not largely consider improvisation, which is also an important part of progressive rock performances and errors.

Another departure from the literature appears in the methods of dealing with errors; errors in a live performance (as opposed to a recorded one) can only be addressed only in real-time using specific recovery techniques (Kruse-Weber and Parncutt, 2014). On a recording, a process will be undertaken by an audio engineer, using ontologically different techniques, and external tools. By analysing real-time recovery, though, it may be possible to garner information about the intended performance.

As has been discussed, the needs of EAPR also depart from contemporary industry practice for repairing errors. I am not producing a recording of what could have been, in the traditional sense of an idealised (industry standard) performance free from consciously-perceptible error. My goal is to restore what would have been, by predicting the intended performance, creatively and technically.

4.2.2 Investigating Related Research

An investigation of expressive performance research, and of issues in expressive error correction in contemporary industry practice, are likely to inform my investigation. Several topics will now be investigated toward that end, with analysis of their applicability to informing EAPR.

4.2.2.1 The Cognitive Elements of Expressive Errors

More information about what an improviser was intending to play—or perhaps simply thinking about—can be discovered by examining the mistakes she made, and their musical context. It is perhaps most useful when determining if pitch error events were intended as minor improvisations (e.g. embellishments), but can also shed light on soloing. This begs the question: are mistakes random? Palmer provides some insight:

> *Probably the most widespread structural characteristic of Western music is its hierarchical nature; both pitch and rhythm structures are represented in a series of levels, between which relationships of reduction or elaboration operate (Clarke 1988, Lerdahl & Jackendoff 1983, Schenker 1969). For instance, Schenker's (1969) music theory views the melodic and harmonic organization of a musical piece as a series of progressively more complex elaborations of a simple foundation, the background, from which the surface level or foreground (the note-to-note aspects of the musical score) is generated. These hierarchical levels not only embody music-theoretic principles but also have implications for perceptual and cognitive processes, such as the prediction that more important events are processed at deeper levels and thus memory should be facilitated for those events.* (Palmer, 1997)

The idea that tonal music has an underlying hierarchical structure, while not without controversy, enjoys considerable acceptance. The most influential theory was proposed by Schenker in the first half of the 20th century. Schenker asserted that musical works contain a stratified series of elaborative layers composed of shapes, patterns, and other musical elements. To reveal this information in traditional scores, he introduced an hierarchic notation indicating the underlying structural data and importance thereof. Schenker demonstrated the notation through a series of sketches in *Fünf Urlinie-Tafeln* or *Five Graphic Music Analyses* (Schenker, 1932, 1969)

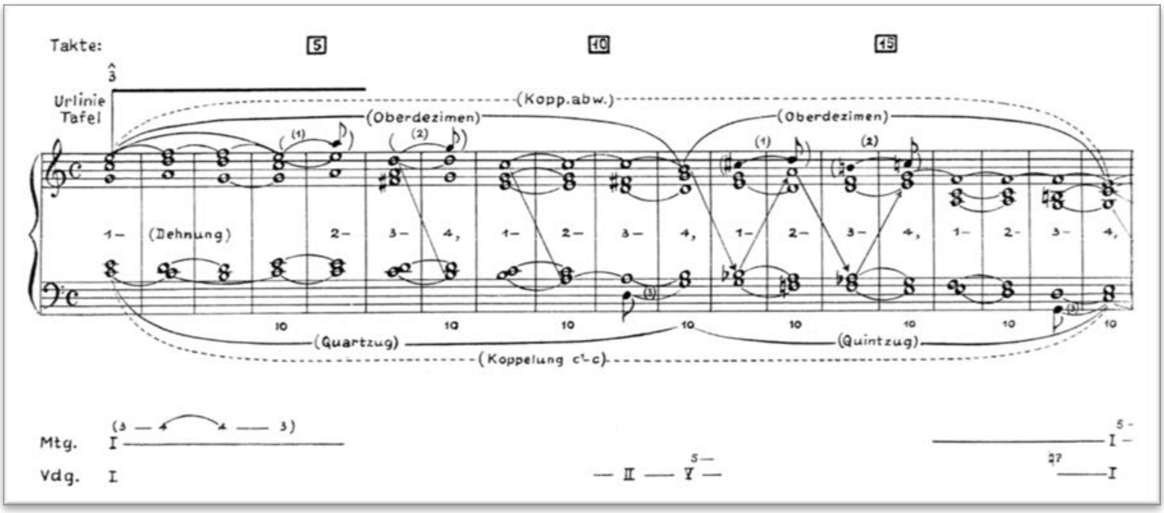

Figure 11: Detail from Bach's Prelude №1 in C Major, Fünf Urlinie-Tafeln*, p.36*

In 1983, Lerdahl & Jackendoff introduced their theory of Generative Theory of Tonal Music (GTTM) in their eponymous book. While not as influential as Schenker's work, GTTM has similarities, including a hierarchical representation of musical structure.

Schenker established this hierarchy in the score, and GTTM asserts that a similar topological structure exists in the cognitive processes experienced by the listener. Lerdahl & Jackendoff begin their book by describing it in these terms: "We take the goal of a theory of music to be a formal description of the musical intuitions of a listener who is experienced in a musical idiom[45]." (Lerdahl and Jackendoff, 1996) Their model is informed by generative linguistic grammars, most notably of Noam Chomsky.

[45] By "musical idiom", they mean (for example) Western tonal music, not a specific genre of music.

The authors describe GTTM's hierarchical commonality with Schenker's theory (and credit him thereof):

> *In all these cases, the listener or performer has an intuitive understanding of the relative structural importance of pitches. If a pitch is heard as ornamenting another pitch, it is felt as structurally less important than the other pitch; it is subordinate to the other pitch. In short, the pitch relations involved in these intuitions are hierarchical.* (Lerdahl and Jackendoff, 1996)

An example of an analytical sketch from Lerdahl and Jackendoff:

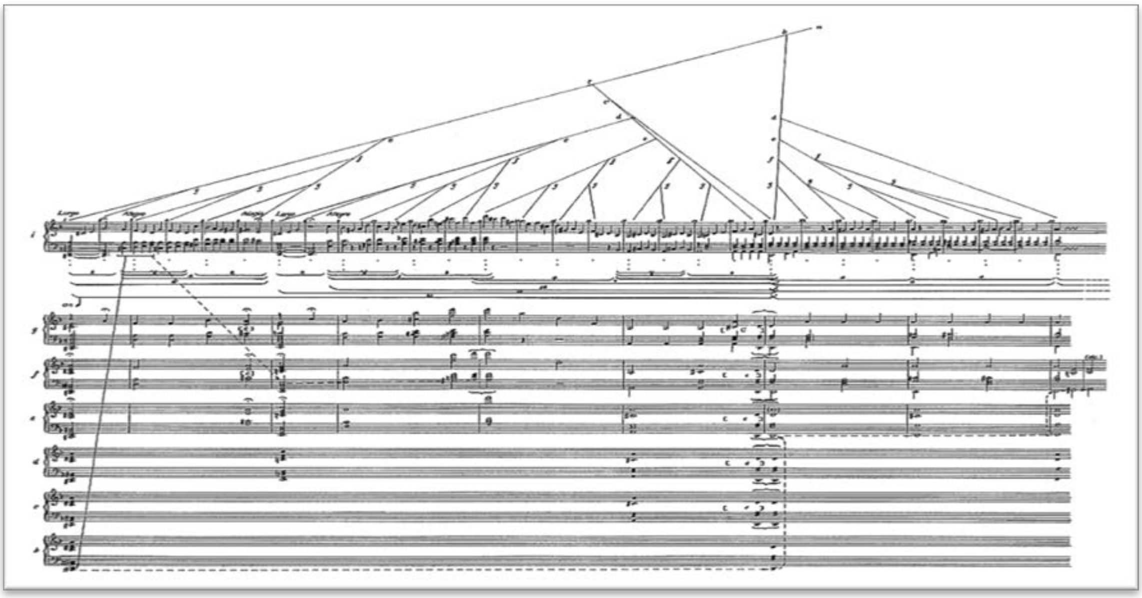

Figure 12: Beethoven's "Tempest" Sonata op. 31 № 2, A Generative Theory of Tonal Music, p. 256

Clarke is one of several researchers who expanded Lerdahl & Jackendoff's work to the realm of performance. Given the applicability of his research to Error Analysis & Performance Restoration, his definition of expression is noted:

> *Pieces of music are invariably open to a number of different structural interpretations, and the primary role of expression is to limit the extent of this ambiguity by emphasizing certain structural interpretations at the expense of others.* (Clarke, 2001)

Palmer contends, "…the mapping of musical thought to musical action is rule-governed, and the same rules produce different interpretations…expressive timing in music performance appears to carry information conveying a performer's interpretation of structural content." (Palmer, 1989) Clark's research asserts that the performer's hierarchical model of the score is transformed, through a set of generative rules for expression, into a hierarchy for expressive performance. This hierarchy is then used to create the motor program[46] (which is executed through the effector[47] system).

Clark writes:

> *One level concerns the representation of musical structure in a form that gives a coherent and intelligent input into a motor system. The word generative is understood here in the same descriptive and analytic sense as in Chomsky (1957), and in the more recent music theory of Lerdahl and Jackendoff (1983). The second level at which generative principles are identifiable is in the production and control of the expressive aspects of performance, which function so as to convey a particular interpretation of a musical structure.* (Clarke, 2001)

Clark asserts that performers who have memorised a musical work have a hierarchical representation (though not necessarily a complete one) of it in memory that shares commonalities with Lerdahl and Jackendoff's (and by extension, Schenker.) Given that progressive rock performers work entirely from memory, Clarke's claim could be argued to apply to performers of this genre:

> *All of these studies make use of tree diagrams as representations for a generative structure, although it is not a requirement that a generative structure be represented in this way. Since a tree diagram is a useful shorthand that conveys generative relationships, I will make use of it for illustrative purposes in the following discussion. In considering the generative structures of musical knowledge, my aim is to examine their more global characteristics, rather than the precise nature of the generative principles themselves. It is the topology of generative relationships that is*

[46] Motor program theory proposes a control process that organises and executes intended (in the case of performance, complex sets of) muscle movements via the central nervous system.

[47] Effectors, in this context, are muscles that can respond to a nerve impulse to contract, such as the extensor and flexor muscle groups that help provide movement for fingers during performance.

of interest, or put another way, the pattern of hierarchical structures that constitutes musical knowledge. (Clarke, 2001)

A strategy in Error Analysis & Performance Restoration (EAPR) for determining information about the intent of an expressive performance, in the context of an error, will be to employ the type of tree-based topology described by Clarke. This method of organisation could be applied to musical and expressive phrases to provide clues as to not only what notes (Pitch Events) were specified, but also the specific intentions in relation to the specific errors in the MBE error taxonomy. Clark writes:

> *At a detailed level, however, each expressive act operates so as to project a particular functional meaning for a given musical structure…examples of this are the establishment of boundaries in the grouping structure of the music by means of changes in dynamic, articulation, or timing; the imposition or emphasis of a sense of direction towards a structural focal point by means of dynamic, articulation, or timing gradients; or the modification of the accentual status of events (that is, changes in figure/ground relations) by means of dynamic or agogic emphasis.* (Clarke, 2001)

If intention, in the context of musical performance, is "the formation of a conscious plan for future behaviour" (Fyans et al., 2009), then expressive performances have a specific intention—correctly restoring them may be an attainable goal.

Earlier in this section, the question was posed, "Are mistakes random?" Palmer demonstrates that "…compositional structures should influence performers' conceptual representations of the music, which in turn should be revealed in distinctive error patterns."

4.2.2.2 Emotional Intentions and Performance Cues

Research has demonstrated that highly skilled performers often have specific emotional intentions they wish to convey to audiences during live performance (Juslin, 1996). Audiences usually correctly identify these intentions (Gabrielsson and Juslin, 1996). The veracity of these perceptions is unaffected by whether or not the audience members are musicians (Juslin, 1997). The cues for expressive communication may therefore be gleaned from recording with performances, and used to inform the restoration of the original performances.

Juslin identifies these performance cues: tempo, timing, intonation, articulation and timbre (Juslin, 1997). Bresin & Friberg note “tempo, sound level, articulation (staccato, legato), tone onsets and decays, timbre, deviations of IOI (Inter-Onset Interval), vibrato, [and] final ritardando.” (Bresin and Friberg, 1999)

Kamenetsky found that tempo and dynamics, when removed from performances, significantly decreased emotional expressiveness rating from audiences. Experimentally tested articulation, loudness and timing—finding all of them significant conveyors of specific emotional expression (Kamenetsky et al., 1997).

These cues are represented in the PBE taxonomy, which is used to analyse recorded performances for both expressive performance and improvisational errors in Error Analysis & Performance Restoration (EAPR). Restoring the expressive elements occurs within the context of restoring technical performance elements, as technique can be considered the means through which emotional cues are imparted.

The practitioner can iterate through the PBE error taxonomy with respect to each audio event on a recorded performance, searching for errors. Elements of expressive performances can be restored as each PBE error is addressed because the taxonomy incorporates many of performance characteristics that comprise expressive playing.

4.2.2.3 Perfection in Correcting Expressive Performances in Popular Music

The popular music industry’s practice for managing performance errors can be viewed in terms of an expectation for perfection (Dannenberg, 2007), which often creates performances that exceed the ability of the performer (Hamilton, 2003; Dannenberg, 2007).

In line with the goal of perfection is an approach to managing them by *correcting* them according to objective metrics (i.e. perfect pitch, exact timing). I will refer to audio engineering techniques employed to achieve this as *gridding*. Both manual and automated gridding techniques often don't preserve the expressiveness of performances (Gwilliam, 2009).

In gridding, errant notes are aligned and shortened/lengthened to a strict rhythmic grid, in lieu of preserving expressive timing. If existing notes cannot be repaired, then notes are copied from elsewhere in the performance, often without regard to the originally intended execution of the replaced note. Pitch is "corrected" to "perfect" values, even if the surrounding notes are not. The result can be perceived as having a mechanical aesthetic lacking the "feel" of the original performance (Dannenberg, 2007). The goal is "perfection" over authenticity.

> *A perfectionist aesthetic of recording aims to screen out allegedly contingent imperfections of live performance. For imperfectionists, in contrast, live performance is privileged, and recording has at best documentary status—when one aspires to the illusion of spontaneous creation, there is the risk of failure and minor imperfection, and so, imperfectionists believe, improvisation and interpretation are not well-served by recording.* (Hamilton, 2003)

In a *Sound on Sound* article on mixing live rock albums, Paul White comments on the dangers of gridding:

> *Timing correction is a case in point: on the one hand, you don't want there to be obvious mistakes, but on the other, you don't want to introduce a robotic, artificial feel, and correcting sources with lots of spill can be problematic from a technical point of view.* (White, 2016)

However, White is referring to the practice of removing all tempo fluctuations from the performance, which were not characterised as mistakes per se, but are part of the perfectionist aesthetic. White suggests a different form of gridding. This method, while not as extreme as the one he eschewed, likely does not preserve or restore the performance (except for the caveat, "…and then checking with my ears"):

> *With Clive's recordings, it wasn't practical, or even desirable, in my view, to address the general tempo fluctuations, but I did tighten up a couple of individual hits, just to keep the kick and bass together during exposed sections. This was done using the simple method of slicing the track into regions and then lining up the bass-guitar*

notes with the kick drum, using the waveforms in the main Logic Arrange page (and then checking with my ears!). (White, 2010, 2016)

Formal research in performance error management for recordings is nascent. A relevant study by Gwilliam compared the perceptions of musicians and non-musicians to errors that had been repaired according to gridding techniques, on a blues song:

> *The basic methodology for the study was to record an experienced band in free time then edit that performance into a strict tempo grid. Both performances were then played to audiences and a questionnaire completed which included details about themselves and their musical experience. They were then asked which of the two versions of the recording was preferred, and what differences they noted about them. These results were then entered into a database, and the results analysed.* (Gwilliam, 2009)

The results indicated that non-musicians preferred the gridded version; musicians (closer to the audience of progressive rock) preferred the non-gridded version. Neither group, however, could articulate why they consciously preferred one version or the other—the differences between the two performances could not be consciously delineated. Gwilliam attributed the difference to musicians' heightened perception of expressive performance:

> *The split in the preference between musicians and non-musicians was marked as well, with the non-musicians again preferring the edited version; maybe this is a sign that the musicians are more tolerant or aware of feel in performance.* (Gwilliam, 2009)

While the performance restoration process for my practice, in terms of the technical performance aspects, aims to restore the musician's intention of not playing with a mistake, the results will be imperfect in terms of the gridding philosophy. A performer will never play perfectly on the grid (Sloboda, 1982).

Instead, it is the goal of the EAPR process to determine what/where/how the performer intended to play—and based on her style, musical context and other factors—what audio would have resulted. As progressive rock performers are expected to be highly skilled performers, the "flawlessness" of the virtuoso performances, after performance restoration, is a result of the performer's median abilities—not an embracing of a perfectionist philosophy.

From this review, it has been demonstrated that industry standard gridding techniques, both technically and philosophically, are not likely to preserve expressive performances within my practice. Quantisation of any kind should be avoided. Restorations must be made within the context of the expressive phrasing (e.g. rubato, articulations).

4.2.2.3.1 Within Progressive Rock

During the course of my investigation, a common practice for error management emerged, which I termed the Standard [progressive rock] Industry Approach (SIA). Within the context of the SIA, error management can be characterised as the "correction" of "mistakes". This approach reflects the broader popular music industry's aesthetic regarding perfection.

As discussed, with popular music (overall), in the SIA, error management is performed by "obscuring" (e.g. preventing the perception of, by the audience) of the errors (Mouser, 2016). Progressive rock producers and engineers choose the amount of what can be considered realism in live albums by choosing how many of the "mistakes" they "fix", creating the live aesthetic they wish (Leijenaar, 2018). Degrees of perfection, not the preservation of "authenticity" (Hamilton, 2003), is the aesthetic.

4.2.2.4 Dealing with Improvisation

Progressive rock audiences expect skilful improvisation. As previously noted, improvisation in live progressive rock can be divided into two categories: relatively minor changes to the score (e.g. embellishments to rhythm parts) and solos. Both occur in a context similar to that of jazz ensembles, with some influence from the classical tradition.

There are two improvisational problems to be solved in EAPR. The first is determining when there are errant pitch events, if a minor improvisation was taking place that was not executed as intended, or if there was an unintentional deviation from the score. The second is generating the audio for extended solo sections where the performer's intention cannot be determined—either because the pitch of the events cannot be deciphered (intelligibility errors), or the performance does not appear to represent the performer's improvisational repertoire accurately.

4.2.2.4.1 Group Improvisation

Researchers describe improvisation as best occurring under a heightened conscious state (McPherson and Gabrielsson, 2002). *Flow*, popularised by Csikszentmihalyi, is an example of such a state (though it was only applied to individuals):

> *In our studies, we found that every flow activity, whether it involved competition, chance, or any other dimension of experience, had this in common: It provided a sense of discovery, a creative feeling of transporting the person into a new reality. It pushed the person to higher levels of performance, and led to previously undreamed-of states of consciousness. In short, it transformed the self by making it more complex. In this growth of the self lies the key to flow activities.* (Csikszentmihalyi, 1991)

Sawyer examines group creativity in improvisation in terms of what he calls *group flow* (Sawyer, 2014). His approach is based on most improvisational studies being focussed on individuals:

> *Group flow is an emergent property of the group. Group flow can inspire musicians to play things that they would not have been able to play alone, or that they would not have thought of without the inspiration of the group…in musical ensembles, group flow requires a type of parallel processing; the musicians are playing non-stop, yet while they are playing they must simultaneously listen to their band members, hearing and immediately responding to what they are playing.* (Sawyer, 2006)

Sawyer also notes error correction by the group, citing Weeks:

> *Improvisational coordination becomes salient when one of the performers makes a mistake, playing a wrong note or losing the tempo of the piece. Musicians refer to this as 'covering up' a mistake. Weeks (1990) analyzed the interactional processes that occurred during the rehearsal of a chamber group of seven musicians that had no conductor. He documented how a cellist and pianist executed a series of 'collaborative maneuvers' (p. 211) to recover from several mistakes made by the cellist, so that the performance could continue in such a way that the average listener would not notice the variation. The covering-up action involved a retrospective contextualization of the mistake, redefining it by modifying the scored performance*

that immediately followed so that it retroactively seemed to have been the correct note or tempo to have played (p. 216). (Sawyer, 2006)

Weeks notes that when performed successfully, it can be difficult for audiences to perceive an error:

In these cases, the restoration of synchrony and the routine performance of the piece thereafter are accomplished successfully in the sense that those listening to the tape of it generally fail to notice any problem! (Weeks, 1996)

Based on Sawyer and Week's work, it can be established that clues to what an improvising performer was intending to play—or based on her performance style, where she may be drawing from—can be garnered by examining not only what she is performing, but also what the other musicians are expecting based on their musical dialogue. Information about errors can also be gleaned by examining how the groups react when a member makes mistakes.

4.2.2.4.2 The Use of Motifs

But how can this knowledge be used to inform the regeneration of authentic-sounding improvisation by the practitioner? A performer's style and repertoire can yield further information. On example is that improvisers often employ draw from a catalogue of musical phrases, unique to the performer, called "motifs":

In musical improvisation, scholars have identified parallels with formulaic speech. These are usually known as 'motifs'; some improvisational traditions are referred to as 'motivic improvisation', meaning that the performer's creativity rests in choosing which one of a set of conventional musical phrases will be played next. Some jazz performers improvise in a partially motivic style; for example, Charlie Parker had a repertoire of over 100 personal licks that he used repeatedly, in many different solos (Owens, 1995). These correspond to scripted bits of conversation like 'How are you?' except that they are idiosyncratic, associated specifically with Parker. (Sawyer, 2006)

Owens adds:

> *Parker, like all important improvisers, developed a personal repertory of melodic formulas that he used in the course of improvising. He found many ways to reshape, combine, and phrase these formulas, so that no two choruses were just alike.* (Owens, 1996)

By using information about the non-randomness of mistakes, it may be possible to determine when a known motif of a performer was intended to be used, even if the pitch events are not all correct. This requires expertise in the performer's repertoire. Such knowledge could also be used to predict if a specific motif might be used where improvisation needs to be regenerated.

In summary, despite a relative lack of literature on expressive performance error repair, a variety of research areas can inform the heuristics of Error Analysis & Performance Restoration (EAPR). The hierarchical structure of performance planning, combined with shared generative expressive cues, provide the possibility of learning about the performer's intention based on the errors made. Emotional cues can indicate definitive intention in performers, and provide criteria to compare with the error taxonomy in EAPR to help establish the possibility of restoring expression in errors. A review of the literature on gridding provides insight into how expressive performances can be lost in error repair. Finally, the literature on improvisation demonstrates the possibility of learning about performer intention during an extemporaneous performance by examining a player's use of motifs in her repertoire, and reactions of groups to a specific member's errors.

4.3 Knowledge Domains to Aid Error Analysis & Performance Restoration

Given that EAPR employs analysis and prediction, there are specific domains of knowledge which can improve its results.

4.3.1 Performer's Style

The practitioner should be familiar with the performer's complete recorded repertoire. This will inform the prediction for intended expressive performance characteristics, and what they would sound like on a recording. The repertoire can help provide the benefits of a *groove reference* that events are similar events can be compared to in terms of articulation, dynamics and rhythm.

Similarly, one of the contexts in which errors can be identified is the performer's style. An informed fan may note, "Those may be the right notes, but she would never play it that way." Or, "That's not a mistake—that's just how she does that."

A singer may often go flat the first few times going for a note, and then hit it on the final repetition; this may be an artistic way of building and releasing tension, and should be preserved. A guitarist may regularly use pinched harmonics to accent certain types of notes. A bassist may move her fingers close to the bridge for quick runs to produce a more staccato tone that cuts through the mix better. A drummer may always come out of certain fills a little bit late and rush the first hit of the next measure. During EAPR, some of these traits may be reduced if they sound like errors, but they should never be removed if they are part of a virtuoso performer's style.

Additionally, the repertoire can provide context for how songs were performed in the past. The repertoire may likewise help in the construction of improvised performances, with attention to the use of motifs and other devices. Past repertoire can also point to how a performer will react when they make mistakes, and how they react when others do.

4.3.2 Western Music Theory

As discussed, a working knowledge of western[48] music theory can inform the identification of errors. (See Sections 3.1.1, 3.4.1.1 and 4.2.2.1.) Likewise, it can help a practitioner in predicting an intended performance. (See Sections 4.2 and 3.1.2.) The identification of structural hierarchies based on both the score, and the actual performance, may be required to understand the context within which errors occur, and can be resolved. Concepts such as passing and escape notes, meter, key signatures, counterpoint, harmony, syncopation—can be essential for error identification and resolution. With such expertise, the cognitive hierarchy of a performance (informed, in turn, by the hierarchy of the score) can be used with known contextual error characteristics to provide a heuristic for determining pitch intentions when evaluating score errors, or even improvisation. (See Section 4.2.2.1.)

4.3.3 Expertise in the Instruments

A practitioner of EAPR should have a working knowledge of the instruments she is working on; some level of performance ability is helpful, as well. A corollary is the notion that conductors should have a working knowledge of all the instruments of the orchestra (Bowen, 2003).

For example, all the articulations of the electric guitar should be understood[49], the challenges in employing them, and how they should sound when executed correctly (and the common sounds when they are not). It may even be helpful to learn a specific part of a performance to discover how and why certain sounds are being produced, and to garner clues as to the performer's intention. (See Section 7.2.3.1.3 for an example.)

4.3.4 Audio Science and Psychoacoustics

Psychoacoustics can be helpful in understanding the nature and timbre of sound and how it's perceived by listeners. This perspective can help to identify the parts of an audio signal that may be problematic. It can also help to create the sound of an audio event that existed only in a performer's mind. For example, an understanding of how overtones comprise (what is

[48] Progressive rock music is rooted in western music theory.
[49] Another corollary here, to conducting, is the importance of understanding string instruments, and the helpfulness of being of being able to play at least one.

perceived as) a single tone can inform the understanding of timbre and spectral envelopes. The nature of even and odd harmonics can reveal clues to audio events, especially with distorted guitar signals.

Understanding the correlation between the digital representation of audio—and what is perceived—can be essential for understanding how errors are perceived, and what changes are required to alter their perception. An example is the determination of note onsets when reconstructing a performance—a challenge whether using automated or manual techniques (Dannenberg, 2007).

Individual voices can be separated not only by volume, but by rhythm; in this way, expressive performance can change the emphasis of certain voices by slight rhythmic changes (Vernon, 1937). Palmer measured a common characteristic in piano performances where the melody leads the rhythm by 20-50ms (Palmer, 1989). Altering the timing (spacing) of pitch events during reconstruction in EAPR, can also be risky—depending on the sonic context, temporal spacing of just several milliseconds[50] can be perceived by audiences as originating from two *sequential* (not simultaneous as with Palmer's example) events, depending on contextual factors (Hirsh, 1959).

4.3.5 Video Playback

EAPR is focussed entirely on audio recordings, and performance errors in EAPR exist only in the audio recordings of them. When there is a visual component to an album (e.g. concert movie), there are wide-ranging implications for EAPR. The audio programme is evaluated in context with optical data, to consider additional errors, as discussed in Section 3.2.3. Even in these cases, though, EAPR errors still exist solely in the audio domain.

Video of a performance can be helpful in providing additional information to aid in identifying intended performances, and restoring them. In these cases, the video represents an additional knowledge base.[51]

[50] A minimum range of 15-20ms is required for listeners to identify which sound preceded the other.
[51] All video captures in this section are from my creative submission, *Flying Colors' Second Flight: Live at the Z7* (Flying Colors, 2015).

With up to 24 cameras recording simultaneously, a wide variety of visual information can be gathered about performances. For the commercial release, a single video edit is assembled. First, though, a draft edit is produced for EAPR use. This edit is based on the director's view of the performance's best visual representation—it does not take into account performance issues. Although as the EAPR practitioner I have offline access to each camera recording, I perform EAPR from only this draft edit. There are two reasons:

First, no DAW, including post-centred Steinberg's Nuendo supports multiple video streams (Steinberg, 2012). Therefore, I would need to run a separate video editor, on a separate computer, which was not synched to the DAW timeline, to view multiple camera angles.

The second reason is applicable if video is part of a final configuration for the consumer (e.g. a Blu-ray): synchronisation. In this case, I must ensure there are no inconsistencies between the video and (altered) audio. In reviewing how consumers will experience the concert video against the audio track, I may either remove or add close-ups, depending on whether EAPR decreases or increases perceived synchronisation. It's more time efficient for me to do this during EAPR because I can change either the audio or video at the same time, and not have to go back if either is problematic[52].

The efficacy of video to inform EAPR is heavily dependent on the quality of the video (e.g. lighting, contrast, resolution) and the specific shot. In my productions, I employ two types of cameras: flexible *main* units, and *detail* units for dedicated close-ups.

[52] If I determine that a close-up shot needs to be removed, I must determine what type of shot to replace it with. If the synchronization problem is minor, I may request a wide-shot of the whole band. If the inconsistency would still be apparent, I will ask for a close-up of another player. Experience with the process dictates what will be effective, without having the audition the new shot.

Figure 13: The performance viewed from a main camera

Figure 14: Simultaneously, the same performance from a different main camera

Figure 15: A drum detail camera view of the same moment

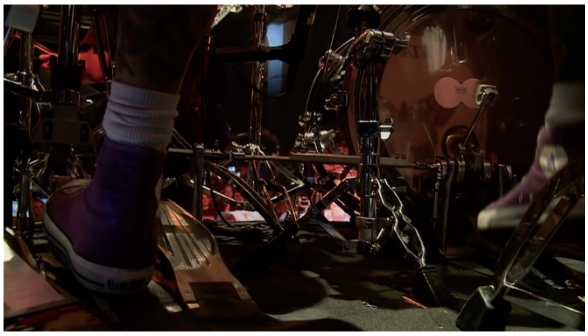

Figure 16: Another drum detail camera of the same moment

The main cameras are large, and mounted on stationary tripods, cranes, or dolly tracks. They require a camera operator, who continually alters the pan, zoom, and (if crane or dolly) position of the camera.

Figure 17: A camera dolly tracks sideways during a bass solo

Despite their superior fidelity, main cameras are not reliable for EAPR because the framing and subjects change rapidly; if there is a shot that's useful for EAPR, it won't last. The exception is solos because progressive rock audiences want to see how a solo is executed—particularly guitar and bass solos. Therefore, during solos, the soloist is usually in the frame, and there are often close-ups of the soloist's fingers.

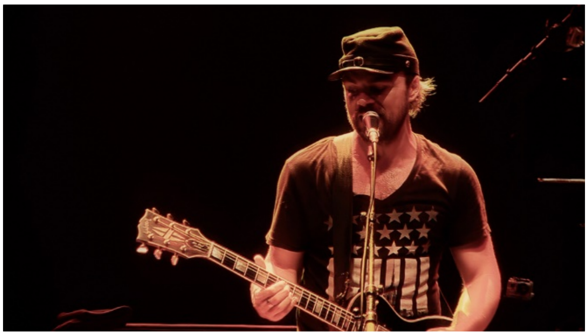

Figure 18: A main camera on rhythm guitar and vocals during a draft video edit

Figure 19: Switching to a different main camera, moments later in the edit

The editing is focused on maximising entertainment, of course, and not on musical instruction; there are constant cuts between multiple cameras and framings. As a result, though during a solo I am more likely to see a performer's hands (and more likely to see them closer) I often can't see what I'm looking for. There may be a close-up of a soloist's left hand when for EAPR, the right hand is needed. We may see reaction shots of other band members or the audience. Or the framing may be blurry due to motion (based on shutter speed and other factors).

Figure 20: A main camera zoom on a guitar solo during the draft video edit

Figure 21: Switching to a different main camera for a medium shot, moments later in the edit

The detail units are small GoPro (GoPro, 2017) cameras. Multiple units are embedded in each of the musician's instrument rigs. As progressive rock audiences like to see close-ups of performances, most of these units are aimed and focussed on performer's hands, and don't move. Despite reduced fidelity compared to main cameras, the detail cameras are ideal for EAPR.

Performance footage constitutes a knowledge base for EAPR by potentially providing clues about the intended performance when an error occurs. It can also help identify the source of an error; this can include non-instrumental sounds such as a microphone dropping, or an amplifier being accidentally kicked.

For example, a guitarist may be heard to be playing a major scale; a minor is produced in the middle of the apparent scale, at a different interval. The video may reveal a finger placement on the wrong string, but the correct fret, for the expected major note (if a scale was intended). This indicates that the intended note was the major candidate.

Figure 22: A main camera zoom on a guitar solo during the draft video edit

Figure 23: Switching to a different main camera at a similar zoom, moments later in the edit

Another example would be a guitarist playing a rapid sequence of notes, on distorted guitar. The sequence is marred by a sustaining note that is clearly not intentioned; due to the distortion, the practitioner cannot identify the intended notes. The video, however, can reveal the performer's pick accidentally hitting the low E-string, and the intended notes that were otherwise performed correctly.

A final example is a keyboard player performing a series of triad chords. One of the chords sounds only with two notes, however. The video may reveal the performer's pinky reaching for the expected third note, but not quite making it. The practitioner would then have additional information to add that third note.

Figure 24: A keyboard detail camera during the draft video edit

Figure 25: A different keyboard detail camera, moments later in the edit

While video can be a useful knowledge base for performing EPAR, it is not required. EAPR, as a process, is effective (and must be) without video[53].

[53] In my work on the creative submission, video did not play a significant factor in providing information about the intended performances.

4.4 : The EAPR Process

There are two objectives in EAPR: Determining the intended performance, and creating the audio that corresponds to it. The first objective is addressed through what I will term *Performance Forensics*. It designed to reveal information about a performance by examining the available information about the performance (e.g. audio of the recording, video), and correlating it with the knowledge domains presented in Section 4.3. The second objective is addressed through *Performance Rendering*.

The EAPR *process* is comprised of two phases, to achieve these objectives: Analysis and Restoration. The first phase determines if performance errors are present, and if the intended performances should be restored; the second phase restores them.

EAPR is defined as an *abstract process*, and implemented as a *concrete process* . By separating its theory from the techniques used to actualise it (Buscemi and Melgratti, 2009), the EAPR process can solve problems requiring a theoretical domain. The components of the EAPR framework are necessarily conceptual (e.g. the definition of a performance error); likewise, so is its result: a restored performance.

The EAPR process is therefore isolated from its implementation, unbound by the limitations of an error-treatment process that specifies particular techniques, software features or audio programs. As technology evolves, new techniques can be developed within the context of EAPR, while the process itself remains unchanged.

When applying the process to a specific Project, EAPR is thus implemented with the most appropriate software and features available at that time. As new technology makes new functionality available for analysing and transforming audio, practitioners can integrate it as appropriate, and develop new techniques to more effectively and efficiently implement the phases and stages of the EAPR Process. An instance of an EAPR Process implementation can be found in Chapter 6; an overview of updated techniques, based on newly available tools, is available in the conclusion of this thesis, Chapter 8.

4.4.1 Analytical Phase

There are three stages in the Analytical Phase of the EAPR Process: *Screening*, *Triage* and *Authentication*. Screening identifies potential errors, and groups them into *Audio Segments*. Authentication identifies the track(s) responsible for the audio containing the potential error(s). Triage determines which potential errors are important enough to have their performances restored. These stages are summarised in Table 4, below:

Table 4: Stages in EAPR's Analysis Phase

Stage	Explanation
Screening	Scan the audio recording for possible performance errors.
Authentication	Determine the location and immediate (physical) cause of an error.
Triage	Determine if the error should be addressed or not.

4.4.1.1 Screening

The Analytical Phase begins with the practitioner auditioning the concert's multi-track project file in a DAW. Production occurs linearly, from beginning to end. Screening occurs in small sections; there is no defined delineation—an example is song units such as verses, choruses and bridges.

For each section, there are two listening stages: First, the section is auditioned as a stereo mix; then with individual instruments in the same section. Even if the practitioner did not notice a potential error in the stereo mix, the individual tracks might reveal additional information.

Individual tracks are auditioned in either three or four ways, depending on how the instrument was recorded:

1) Within the context of the full mix, focussing on one instrument. This simulates the audience's listening experience.
2) Auditioning the instrument by itself (solo). At this level, the practitioner can locate problems within the instrument which may cause problems in the full mix, but not be specifically or sufficiently identifiable in that context.

3) If the instrument is comprised of several tracks (e.g. snare drum top, snare drum bottom), these will be auditioned both separately, and in combination with each other.
4) With groups of other instruments (e.g. guitar with just the drums). This auditioning can particularly help identify the cause of rhythmic problems. Additionally, the cause of complex harmonic phenomena that is neither detectable within the individual track, nor the full mix (and is a result of a combination of tracks) can be revealed.

Chapter 3 introduced the definition of, and criteria for the identification of, performance errors in EAPR. To summarise, an error is any deviation from the performer's intention; I evaluate such errors based on my experience with the audience groups in my practice. This includes errors that were not caused by the performer, or directly involved the performer in any way. Some examples of the latter are EMI (e.g. radio) interference, amplifier hum, signal distortion, and drop-outs.

4.4.1.1.1 Defining Audio Segments

When errors are identified, the practitioner defines the relevant section of in the project's timeline as an Audio Segment, for analysis. The Segment applies to all the tracks in the project, on the global timeline. This is because there was no DAW, at the time of my work on the Album Project, that supported markers for individual and groups of tracks[54]. With a DAW that supported these types of markers, the definition of Audio Segments would be part of the Authentication Phase.

Audio Error Segments usually range from 5-30 seconds. Depending on the nature of the error (for example, one continuous error), they may be much longer. Given that a recorded performance may contain thousands of performance errors, and that those in close proximity are often related, a Segment often contains multiple errors.

An Audio Segment will usually contain error-free sections before and after the performance error(s), to provide context and other information to aid in the restoration. The Segment should contain enough audio to provide all the information needed to restore any errors within it. Segments should generally not overlap, but in some cases not doing so would

[54] Based on this experience with the Creative Submission Album, I worked with Steinberg to add these capabilities to Cubase 9.5. I cover this topic in Section 8.4.1.1.

obfuscate organisation (e.g. a single error of one type, within a long section of a single other type, might be best delineated as two overlapping Segments).

4.4.1.2 Authentication

Before a performance error can be evaluated or restored, the location and cause of that error must be authenticated. This process is often carried out in parallel with, or as an extension of, the individual track auditioning from the Screening stage. Errors that may appear to originate from one instrument may actually be caused by another. Or, they may only be the result of multiple tracks of different instruments heard simultaneously.

When instruments are recorded with multiple microphones, such as the Dry and Wet channels of a guitar, an error may be confined to only one channel. Some errors that sound like they originate with a performer may actually be the result of other audio phenomena, such as cumulative harmonics that manifest themselves as a sound source that doesn't exist physically.

Other errors can only be authenticated with detailed investigation. Tools such as spectral editors may be required, and a physical understanding of the performer's actions (and other factors) may be required to evaluate a performance error candidate. In these cases, the practitioner will make an initial judgement during the Authentication stage, and return to it during stages of the Restoration phase.

4.4.1.3 Triage

If an audio Segment appears to contain an error, the practitioner will then assess its importance during the Triage stage. The metrics and threshold for both assessments are established by the practitioner's experience in her practice. For my practice, in Section 2.3.2.4, I identified a set of audience groups whose response determined the success of my practice: the artist(s), critics, fans and label. In Section 3.2.2, I showed the same groups to be the judges of performance errors in my practice. During the Screening and Triage stages, I employ my practical experience with these audience groups, within the context of previous albums, to predict how their response to the current album would be affected by a specific performance error.

This prediction may be a conscious (audience) reaction to the error after hearing it, or an unconscious reaction that contributes to their overall experience with, and opinion of, the album. The threshold is also mitigated by the specific goals of the project, resources available and limitations in play—my practice is a commercial one, and commercial factors ultimately dictate what must be altered, and what is acceptable.

At the end of the Analytical phase, three things have been accomplished: An Audio Segment has been defined; the performance errors (and any other audio problems) have been triaged to determine which will be restored; and the cause/location of problematic performance elements have been determined.

4.4.2 Restoration Phase

The second and final phase of EAPR is *Restoration*; the goal is to transform the original audio representation (containing the performance errors) to a recording corresponding to the performer's original intention.

The Restoration phase has five stages: *Transcription*, *Conceptualisation*, *Identification*, *Rendering*, and *Evaluation*. The stages are presented in the general order in which they are performed in, and the final two are always Rendering (the modification of audio) and Evaluation (the auditioning of the results). The other three stages may be refined, in parallel, during any of the other stages; in many cases, information about an error at one stage is revealed only while working in another. As my praxis revealed, however, without a formal process to follow, work can quickly become a case of not knowing where to start or continue to— a "chicken and egg" problem.

Phases are also repeated, linearly or recursively, as the practitioner discovers mistakes she made during the process. These may be analytical errors (e.g. incorrectly determining the *Intended Score*) or technical (e.g. rendering an unrealistic-sounding performance).

4.4.2.1 The Three Scores

There are three scores in the EAPR process: *Work*, *Performance* and *Intended*. The Work score is analogous to a traditional music score. While this score is frequently improvised and embellished in live progressive rock, the basis for the Work is the studio recording[55]. The other two scores are created as part of the EAPR process.

The Performance score is created first, and is a record of the musician's performance. The Intended score is created next, representing the performance the musician intended to record. Depending on the needs of a specific restoration, these scores vary in detail and notation type—from mental models to detailed mark-ups. As the EAPR process continues into other stages, these scores are often refined and expanded, depending on the need for specific, additional information to inform the EAPR process.

Figure 26, Figure 27 and Figure 28 illustrate a range of Performance and Intended scores. (Specific scores are demonstrated and explicated in Chapter 7.)

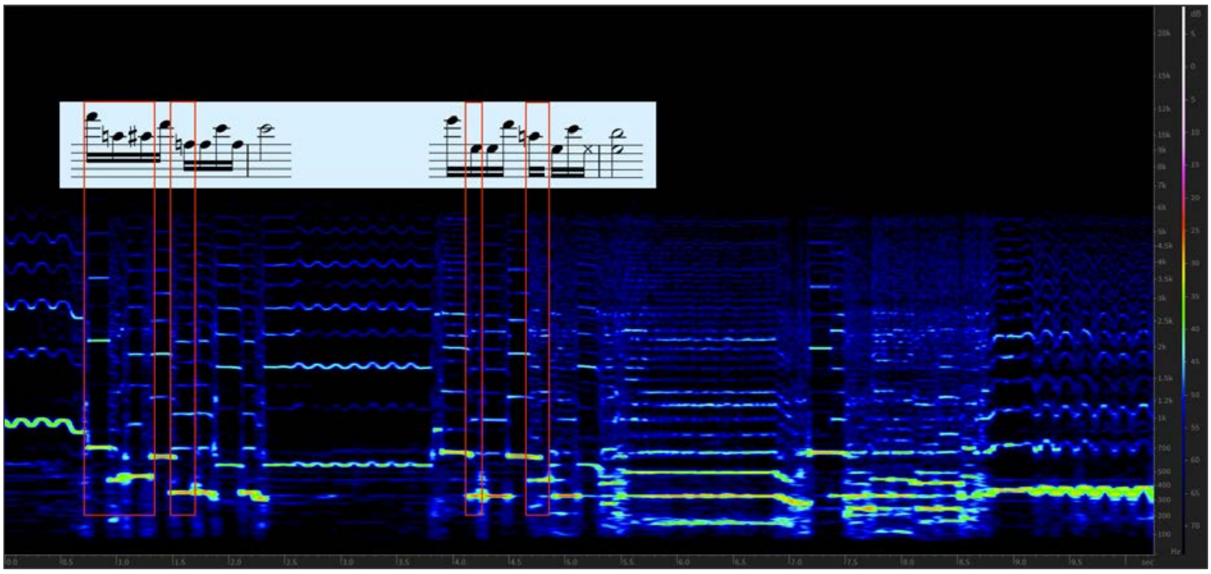

Figure 26: Sample EAPR Score A

[55] As noted, when there is insufficient rehearsal time, progressive rock musicians may be required to read notated music during a performance.

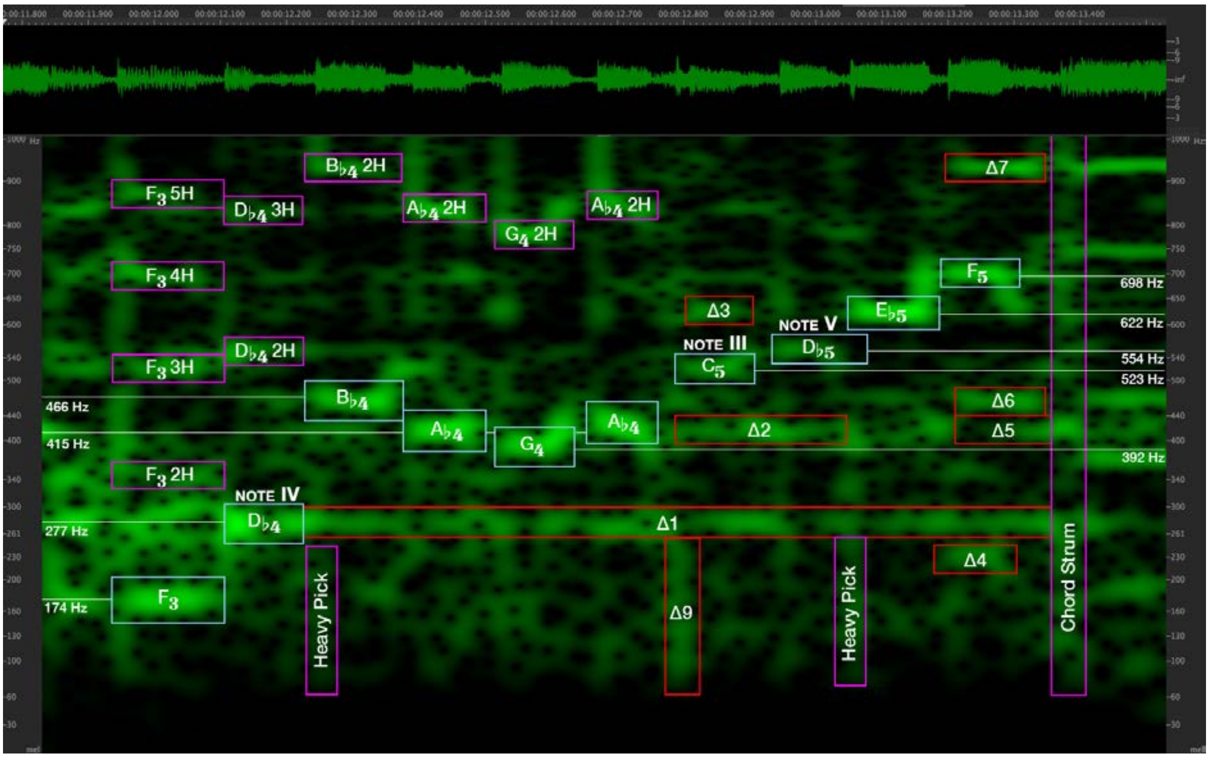

Figure 27: Sample EAPR Score B

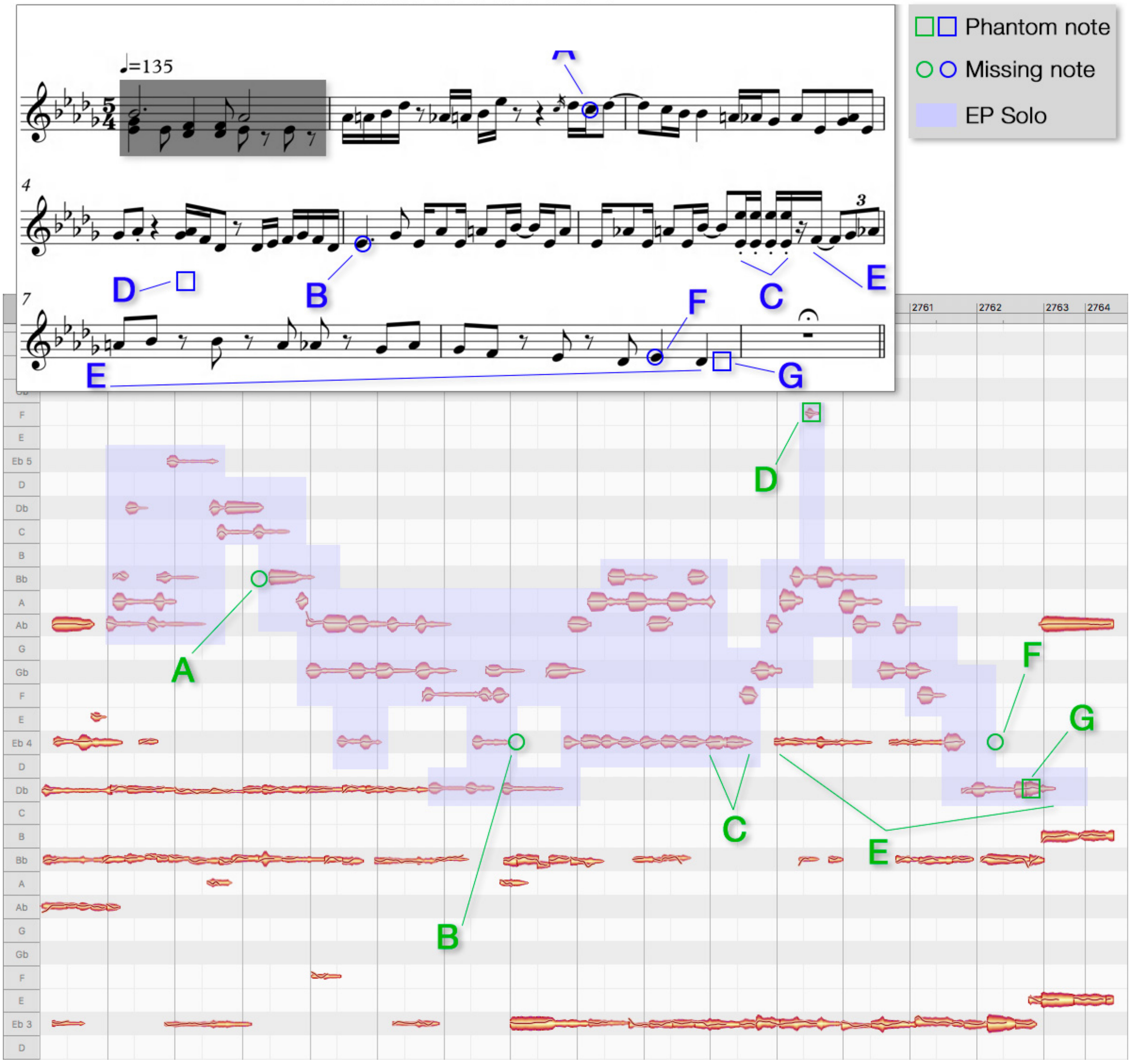

Figure 28: Sample EAPR Score C

4.4.2.2 The Five Stages of EAPR Restoration

Table 5 introduces the five stages of EAPR Restoration:

Table 5: Stages in EAPR's Restoration Phase

Stage	Location[56]	Explanation
Transcription	4.2	Determine the score of the performance represented by the recorded audio file.
Conceptualisation	4.2	Determine the score of the intended performance.
Identification	3.4	Categorise and label the error type(s), class(es), and domain(s) according to the PBE taxonomy defined.
Rendering	Chapter 7	Generate (render) the audio for that performance.
Evaluation	4.4.1	Assess the results, based on the analytical process outlined in the EAPR Analysis Criteria.

4.4.2.2.1 Transcription

Transcription is the creation of the Performance score (PS). It generally serves a different purpose than a traditional compositional manuscript. (In the case of EAPR, that is the Work score). While the latter can be considered the instructions for realising the audio component of a composition, the Performance score is the audio transcription of a specific realisation of that composition.

While some implementation of traditional music notation is often essential for the Performance score, it often cannot express all of the necessary information. One example is the performance characteristics for musical events (e.g. notes). Some of these characteristics are physical, such as starting and ending time, average amplitude, precise pitch-centre, pitch modulation, and envelopes for amplitude and frequency envelope. Others are more interpretive, such as timbre and articulation. As such, alternate notation can be used in the PS, or it can be accompanied by traditional notation, often with added markup by the practitioner.

Even the idea of a note, itself, is more of an interpretation (or implication) of a Performance score, rather than a direct element. Additional audio components of a recorded performance, such as microphone leakage, are challenging to represent within the traditional notation idiom. Beyond the audio and musical components of the PS, physical ones can also be represented. For a guitar, this could be demarking the sound of an accidental brushing of a guitar's pickguard, or of the fingering used in the performance.

[56] Where in the thesis the research providing this information was presented.

In some cases, the musical elements themselves may not be immediately decipherable; reasons include the nature of the performance (e.g. rapid and highly distorted guitar) and severe microphone leakage. In these cases, many or all of the performance aspects may likewise be difficult to determine. Typically, these situations are best informed much later in the EAPR process.

In all cases, the Performance Score ascribes meaning to the recorded audio—a language that can be used to analyse the performance characteristics to determine what happened. This information can then be used to inform the intended performance (and its representative audio), and the approach to creating new audio to realise that performance for listeners.

This process of extracting from audio from, and assigning meaning to, the performance data is often a significant part of restoring errors. In order to create a linear process for Restoration, the creation of the Performance score often begins with a simplified version, to be re-evaluated and expanded as EAPR continues. The initial score will be enough to form a foundation for Restoration to continue, based on the practitioner's intuition about what will be required for the rest of the process. At this point, the PS may be, for example, simply traditional notation of the performance, with limited additional markup.

4.4.2.2.2 Conceptualisation

The converse of the Performance score is the Intended score (IS). While it shares more in common with a traditional (notated) score, there are two important differences. One is that while a Work score can (generally) be used for many (different) performances of a work, the Intended score is the data for creating just one performance. As such, the other difference is that the IS contains more performance-focused information.

The goal of creating this score is to establish the performance (not the work) that the musician intended to record. Because the Intended score is compared and contrasted to the Performance score, the former often shares the same score format(s) as the latter.

Building the Performance score requires analysing what went wrong with the performance; garnering that knowledge requires may require an understanding of what was intended. For example, while an unmuted string may be obvious in terms of the intention, a deviation from intended pitches may not. In this way, the two scores inform each other.

As with the Performance score, the initial IS is often simple, as sufficient information has usually not been ascertained at this point in the EAPR process for a complete score. The exception is that the initial IS must resolve any *musical* ambiguity as to the performer's intention. In this context, "musical" is defined as the set of compositional elements represented in traditional notated scores.

As such, one result of creating the Intended Score is that all [Event: Score] errors are determined at this point. Deciding the rest of the performance intentions may not occur until much later in the EAPR process.

In some cases, determining the intended musical events is non-trivial. While the Work score is accessible, the process of finding the relevant audio is often too time-consuming due to the (currently-available) tools available to the practitioner. There may also be improvised embellishments that are challenging to resolve because the performer may use relatively sophisticated musical techniques.

A challenging case is where the practitioner has determined that the artist's improvisation has been poorly conceived in relation to the artist's existing repertoire. In this case, the practitioner heuristically attempts to determine a more representative improvisation. (See Sections 3.1.2 and 3.2.1.3.)

Later in the Intended score development, the intended performance (e.g. precise articulation) of these musical elements must also be determined. In progressive rock, performers may employ numerous performance techniques, and often precise intentions regarding the execution of individual notes.

Resolving these questions often requires an understanding of the performance on a musical level. The two general questions are: *What* was played (e.g. a C-major triad), and why (it resolved a suspended F-major). This information, combined with knowledge of the performer's repertoire, and other knowledge domains, can inform the practitioner in producing the finished Intended score. It is a heuristic process, and the aim is authenticity, not perfection across any specific variable.

4.4.2.2.3 Identification

In this phase, the performance errors in a segment are formally identified and categorised according to the PBE error Taxonomy introduced in Section 3.4. While this process usually begins with the creation of the initial Performance score, and continues throughout all the Restoration stages, the most significant work often occurs between completion of the initial Performance and Intended scores, and the start of the final Restoration phase: Rendering. Identification can also be considered as a formal description of the difference between the Performance and the Identification scores.

In Identification, problematic audio is examined from a musical performance perspective (if relevant) to determine which physical actions caused the problem(s). These determinations are made using the practitioner's experience, as well as specific software visualisation and audition tools: audio waveform, pitch tracking, and spectrogram. Likewise, experimental manipulation of the audio can help uncover the required information.

It is important to have visual evidence of the error, and for this evidence to be understood in terms of precisely which aspects of the audio caused it to exhibit the sonic elements identified as problematic. Without this information, the performance cannot be restored, because the physical location and construction of the relevant audio data are not sufficiently understood. Likewise, this information will sometimes be necessary to ascertain the cause of the error, especially from a physical performance perspective (e.g. learning that the guitarist accidentally picked an open string).

Once this information been determined, each error can be identified and labelled according to the PBE taxonomy. This information is frequently added as part of both Performance and Intended scores. As with other aspects of EAPR, depending on the situation, this information may be stored mentally, or recorded in an Error Identification Table, such as in Table 6.

Table 6: A Sample Error Identification Table

ID	Class	Category	Type	Start	Description
I	Event	Execution	Articulation		The note's sustain ends early, accidentally.
II	Event	Execution	Intelligibility		It's not clear if this is a note or an unintentional sound.
III	Event	External			An audience member can be heard yelling; the sound could be confused with keyboard sound playing at that point.
IV	Event	Score			The first three notes of the chorus are actually those of the bridge.
V	Event	External			A string breaks, but there is no sound to alert the listener. As a result, the resulting gap in playback (which is not an error) is unexplained and may be perceived as an error.
VI	Event	Tuning			The tuning difference between the two guitars is especially audible here, causing unintentional phasing.

The final stage of Identification, after the results have been auditioned and approved, is the updating of the Identification Table.

4.4.2.2.4 Rendering

The Rendering phase involves the modification of the existing audio, and/or the creation of new audio, to realise the audio associated with the intended performance. The general audio tools for carrying this out include spectral editors, waveform editors, musical event editors (e.g. Melodyn and AutoTune offline mode), Flexture Editing, audio synthesis and sound design, and automated algorithms (e.g. Reverb removal).

Rendering requires a process termed *Envisioning* in EAPR. While the Intended score instructs what the performance should be, Envisioning determines what that performance should sound like. It is usually a mental model created by the practitioner during Rendering. Once envisioned, the practitioner uses the aforementioned audio tools to *render* the sound of the audio intended by the performer.

Rendering requires the application of an heuristic set to predict the audio's components (e.g. timbre, rhythmic structure). These sets are informed through procedures such as analysing the erroneous notes within the context of their phrases, and comparing them with similar phrases elsewhere in the performance—and against the performer's existing repertoire. Such sets can be comprised of erroneous notes' problematic characteristics (e.g. articulation); these

characteristics can then be derived from similar, error-free notes. Example technical methods employed in the Restoration stage are demonstrated
in Chapter 7.

An important goal in Restoration is to identify and preserve the physical and musical aspects of the audio associated with the performance error—those that, despite the error, *did* correspond to the performer's intention. For example, a note may have been performed perfectly—but the pitch was wrong. Depending on the result, this error might be resolved by simply pitch-shifting the note. However, a shifted note won't sound correct if, for example, it was played on a different guitar string.

In this case, the practitioner may employ an EAPR concept termed *Forensic Assembly*. It is used when there is not enough information in the error's recording for the practitioner to render the new audio corresponding to the intended performance. While the error might be *obscured* by replacing the audio with a similar section from elsewhere in the performance, the intended performance is essentially being replaced with a different one. The replacement may have the correct score (or be "close enough"), but its performance is from a different musical context.

Using Forensic Assembly, once *envisioning* has been completed for a performance error, the practitioner can identify which aspects of the original audio can be preserved—and search the rest of the performance for components similar to those that cannot. These components are isolated and then transformed to those of the restored performance. The final rendering of the restored performance is then assembled from these components. There are several examples of Forensic Assembly in Chapter 7.

Returning to the example above, the practitioner might identify a different note (elsewhere in the performance) of the correct pitch, on the same string—and extract the harmonic spectrum from it. Then, she might copy only the attack (non-pitched) portion of the errant note to this spectrum, and then adjust the timing and average volume of the spectrum to match that of the errant note (as those aspects were performed as intended).

Rendering is usually the most time-intensive part of EAPR. In some cases, the practitioner may have developed a set of techniques to address common errors. In many cases, though, each restoration presents unique challenges that require the use of multiple tools, and many iterations of different attempts to arrive at an acceptable restoration.

4.4.2.2.5 Evaluation

Evaluation is the final step, where the results of the EAPR process are auditioned both within the context of a larger performance and by themselves. As with the initial Screening phase of Analysis, the audio is evaluated by the practitioner to determine if the new audio reflects the practitioner's conclusion regarding the artist's intended performance.

An important goal is for the restored audio to sound *authentic*. One part of pursuing this aim is to audition the new sounds within the context of the (unaltered) surrounding notes: "Do they sound like there were *played*?" The other part is asking, "Do they sound like they were played by *this* performer?"

Rarely is a restoration acceptable on the first attempt. When the results are not satisfactory, the practitioner returns to other stages of Restoration, or even Analysis.

The complete EAPR conceptual process is presented in Table 7:

Table 7: The EAPR Performance Restoration Process

Phase	Stage	Explanation
Analysis	Screening	Scan the audio recording for possible performance errors.
Analysis	Authentication	Determine the location and immediate (physical) cause of an error.
Analysis	Triage	Determine if the error should be addressed or not.
Restoration	Transcription	Determine the score of the performance represented by the recorded audio file.
Restoration	Conceptualisation	Determine the score of the intended performance.
Restoration	Identification	Categorise and label the error type(s), class(es), and domain(s) according to the PBE taxonomy defined.
Restoration	Rendering	Generate (render) the audio for that performance.
Restoration	Evaluation	Assess the results, based on the analytical process outlined in the EAPR Analysis Criteria.

4.4.2.3 Regeneration

In the process of restoring repertoire and intelligibility errors, it may be particularly challenging to determine aspects of the musician's intention, leading to gaps in the Intended score. This occurs most often with Intelligibility and Repertoire errors, during improvisation. In both cases, the missing parts of the Intended score must be *Regenerated*; this sometimes requires the practitioner to make choices about the composition of the performer's intended score. Several knowledge bases and other epistemological tools, explored in this thesis, can be synergised to inform the Regeneration process.

Unlike other aspects of EAPR, Regeneration does not necessarily assume a specific performance to be restored if there is significant improvisation. In these cases, the aim is for the practitioner's accountability groups (especially the artist) to be comfortable that the finished recording is something she *could* have played. As such, the artist would be comfortable with the performance being attributed to her, and the audience would perceive it as (within the context of the EAPR's definition of) authentic.

Table 8 details the knowledge bases, relevant thesis section, and summary:

Table 8: Knowledge Basis to Inform Regeneration

Knowledge Base	Section	Summary
Performer's Style	4.3.1	Past repertoire is likely to be most applicable in a related musical context to that of the error. Significant, related repertoire could possibly be used to provide macro-level clues for Regeneration.
Motifs	4.2.2.4.2	Skilled improvisers draw from a lexicon of previously-used motifs (K. R. Sawyer, 2006). An analysis of them can inform Regeneration at the micro level.
Emotional Intention	4.2.2.2	Artists often have a specific emotional intention they wish to convey, which can often be correctly identified by an audience (Gabrielsson and Juslin, 1996).
Hierarchical Musical Structure	4.2.2.1	Solos can have a sophisticated, hierarchical musical structure (Palmer, 1997) By analysing parts of an extemporaneous performance that are not problematic, it may be possible to extrapolate meaningful structures for the content of erroneous branches and leaves.

5 : Performance Error Management in Other Practices

5.1 Introduction

The first four chapters of this thesis introduced a new model for addressing performance errors within my practice, *Error Analysis and Performance Restoration* (EAPR). Its components are the EAPR Process and Error Taxonomy, supported by a theoretical foundation and objective definitions drawn from the goals of my practice.

The second half of the thesis examines the implementation of EAPR for producing the Creative Submission Album. This implementation is comprised of specific software tools and an unlimited set of techniques used with them. It begins with this Chapter, which informs my investigation by surveying other practices for their approach to performance error management within the context of live progressive rock albums.

A survey of these practices reveals a standard industry approach (hereafter "SIA") with a common goal. As demonstrated in this chapter, the SIA's goal differs from mine in handling performance errors, precluding a direct comparison of approaches. New knowledge can emerge, however, by contextualising our examination of the SIA within my framework of my practice.

I will investigate the SIA in two ways. First, I will examine it conceptually, regarding its internal model. Then, I will present a concrete taxonomy of its techniques and tools. Ambiguity in this discussion is reduced by creating a related set of common, operational definitions, listed in Table 9.

Table 9: Hierarchical Operational Definitions for Chapter 5

Term	Definition	Examples
Practice	Area of vocational work and professional expertise.	"My practice is in live progressive rock albums."
Approach	Informal term for the sum of all terms below.	"My approach to managing performance errors is to restore the intended performances."
Goal	One of a *practice*'s formal aims.	"One of the goals in my practice is to satisfy our record label's financial benchmarks."
Objective	A specific outcome informed by a *goal*.	"The objective for managing performance errors, in my practice, is to restore the intended performance."
Philosophy	The practitioner's ontological philosophy about live albums.	"I define live albums as artificial constructions informed by an historical event."
Method	A way to meet an *objective.*	"The EAPR system allows me to restore performances through heuristic determination of the intended performance, and then rendering of the results based on the existing recording."
Process	A sequential set of activities to accomplish an *objective* using a specific *method* within the context of a *practice*.	"EAPR is a process to meet the objective of restoring performances by using a novel method.
Operation	Abstract technical function performed on digital audio, used as part of, or implementing a, *process*.	"Flexture Editing can be a useful operation in the EAPR Process."
Feature	Implementation of an *operation* in a specific software application.	"Cubase's support for Flexture Editing is called *Warp Markers*."
Technique	The use of one or more software programme *features* to perform a specific digital audio transformation.	"Re-recording is not a technique used with Warp Markers."

Another term I will use throughout the discussion is *repair*, to refer to a practice's approach to addressing a performance error, be it *correcting* it or *restoring the intended performance*.

In this discussion, there is no implied or explicit judgement regarding the efficacy of a specific practice's approach to error management. Within the context of my investigation, the individual practitioner evaluates and establishes the metrics for her own success. As a practice as research investigation, it is my aim that other practitioners find my approach helpful to inform new constructs in their own practices.

5.1.1 Knowledge Sources

Researching the topic of error management for live albums, based on existing literature, is challenging. Published work is limited on the topics of both live progressive rock album production practice, and on addressing performance errors on recordings in live (or studio) recordings. This limitation applies to textbooks[57], academic literature (Burgess, 2018), and professional audio engineering publications (Oppenheimer, 2016). Steve Oppenheimer, former editor-in-chief of several recording industry magazines, offers this explanation about the scarcity of articles on error repair methods:

> *Although countless articles and instructional videos teach mixing and editing for studio recordings, it's rare to find detailed technical explanations of how to fix the types of issues that are commonly found in live recordings.* — Steve Oppenheimer *(Oppenheimer, 2016)*

To provide a larger knowledge base to inform my investigation, I engaged 16 other industry practitioners through personal correspondence to survey their thoughts on performance error management. I selected two types of subjects: producers/engineers and musicians. Their practices were in three genre categories: predominantly in progressive rock, multiple genres (including prog), or outside prog.

This enquiry occurred within, and was integrated into, the epistemological context of my research methodology; it was not a formal study. Where practical, I employed controls, such as the random ordering of multiple-choice answers. I did not, however, aim to (nor need to) establish knowledge directly generalisable outside the framework of my own research. Details of my correspondence, along with biographies of the respondents, appear in Appendix D. All of the quotes and references in this section, from these practitioners, are specifically in reference to live progressive rock practice.

[57] These textbooks include: *Handbook for Sound Engineers, Fourth Edition* (Ballou, 2008), *Sound and Recording: Applications and Theory* (Rumsey and McCormick, 2014), *Sound for Film and Television, Third Edition* (Holman, 2010), *The Mixing Engineer's Handbook, Second Edition* (Owsinski, 2006), *The Recording Engineer's Handbook* (Owsinksi, 2005), *Audio Post Production for Television and Film* (Wyatt and Amyes, 2004), *Mixing Audio: Concepts, Practices and Tools* (Izhaki, 2008), *Modern Recording Techniques* (Huber and Runstein, 2013), *Recording Music on Location* (Bartlett, 2014), *The Cambridge Companion to Recorded Music* (Cook, 2011a)

5.2 An Examination of Practice-based Error Management Approaches

Performance errors are a significant issue for practitioners in live popular music albums, including progressive rock. In this section, I will explore the industry-standard approach (SIA) for addressing performance errors that emerged from my review of the available literature, correspondence with industry practitioners, and my own professional experience. Rather than an objective exercise, my methodology for contextualising with my own approach will be ethnographic. In this discussion, there is no implication that any approach to error management is objectively superior; within the context of my practice and research methodology (Practice as Research), efficacy is measured within the framework of a specific practice, according to the goals set by its practitioner.

5.2.1 Live Album Ontologies

Within the context of error management, the SIA and EAPR's methods are informed by the practitioners' philosophical definition of live albums. SIA practitioners often define such ontologies informally, in terms of how albums should *feel* to them (or the producer). Practitioners comment:

> *The goal is to make it 'perfect' or fix any wart at all…* — Steve Lukather (Lukather, 2018)
>
> There was a time when I and whatever band I was in - or the 'client' wanted a totally polished mix that was as close to a studio recording as possible. However, over the years, I have come to look for letting the recorded show be as close to 'non-fixed' as possible. — Roine Stolt (Stolt, 2018)
>
> *I don't overdo the fixing. It's never perfect, and should not be perfect… you can fix it all, but you tend to lose the magic.* — Collin Leijenaar (Leijenaar, 2018)
>
> *Mistakes by artists and musicians in live recordings, should be fixed only when deemed by the producer to be distracting from enjoyment of performance.* — Peter Collins (Collins, 2016)

> …[performance error management] is a critical - and difficult - process because interfering with the live recording too much can fix the bumps but also iron the life out of the performance. — Bob Ezrin (Ezrin, 2016)

Three aesthetics can represent a range of ontologies, which I will term: *perfect*, *convincing* or *raw*. In this context, *convincing* refers to some degree of artificiality due to (often "perfect") error correction, but with some percentage of errors left intact. Inglis writes in *Sound on Sound*:

> *As anyone who's ever recorded a gig using a handheld recorder will know, there can be a huge difference between a convincing live multitrack mix of a gig, and a faithful capture of what it actually sounded like in the audience.* (Inglis, 2016)

Table 10 presents this taxonomy, along with related factors that emerge from this enquiry:

Table 10: Live Album Aesthetics of the Standing Industry Approach to Error Management

Aesthetic	Live Album Ontology	Description	Style
Perfect	Artificial construct	The album feels flawless as a result of *all* performance errors being fixed.	Full grid
Convincing	Creative construct informed by historical event	The album feels convincing as a result of *some* errors being fixed.	Ranges from partial to full grid
Raw	Historical artefact	The album feels real, as a result of having *no* performance errors fixed.	No grid

5.2.2 Objectives

One of these aesthetics is similar to EAPR's: A live album is a construction informed by an historical event. SIA and EAPR diverge in their *objective* and *method*. These elements are shared by SIA practitioners, regardless of aesthetic: the most common *objective* is to control the perception of errors; the *method* is to mask or obscure[58] them. (Lukather, 2018; Mouser, 2018)

[58] In this context, *obscuring* includes re-recording over a performance error, as the error was obscured by replacing it with something else.

From this perspective, SIA error management is binary: something is *fixed*, or *not* (Gilligan, 2016). In this sense, the objective results in a deterministic error correction process. The *performance* is not the focus, because that's not what is fixed— it's the *perception* thereof. For these reasons, I use the terms *fixed* and *corrected* to refer to successfully addressed errors in the SIA.

In contrast, EAPR's objective is to restore performances. The method is to reconstruct the performer's intention and then create the audio corresponding to that performance. These elements are derived from EAPR's live album ontology: the *historical* aspect refers to the artist's intentions, and the *constructive* one refers to the restored performance audio being created.

While it is beyond my investigation's scope to offer a formal rationale for the SIA objective (as opposed to an alternative such as restoration), some possibilities emerged within the context of my enquiry:

- Obscuring errors is generally less complex and faster than repairing them—and the results may fit the underlying goals of the practice. (As an analogy, taping a broken vase may be easier than mending it—and if houseguests don't notice, does it need to be mended?)
- The tools required to repair performance errors have only recently emerged, and the dominant error management approach has evolved slowly throughout the course of recording's history. Even with contemporary tools, the technical challenges are often seen by many as too great. {Oppenheimer:2016wr}
- As established, there is little published literature on the subject, in either academic or industrial realms.

EAPR formally defines when EAPR is applied: performances should be restored regardless of whether an error is judged to be consciously perceivable in the mix. In contrast, the SIA practitioner will rarely fix errors she does not hear. (Collins, 2016)

SIA practitioners use terms such as "fix" and "correct" to describe their error management (Darken, 2018; Stolt, 2018). It is one of the indicators that emerged regarding the SIA tradition to correct errors according to a metric of perfection. This is not always possible within the SIA, though, for technical (e.g. microphone bleed), artistic (e.g. can't determine the exact score), or time-management reasons. In these cases, the "perfection" of the correction may be judged "good enough" (Gilligan, 2016), or re-recording can be employed (Guidoz, 2018).

The standard of precision in EAPR is that of the intended performance; in all cases, the precision should be maximised. This never results, though, in a (physically) perfect performance; the restored performance reflects what the performer intended, and executed according to her physical (and where applicable, musical) ability.

For example, in EAPR, if a guitarist's repertoire establishes consistently clean-picked 32nd note runs, then the restored performance should reflect that. However, if the guitarist struggles with those runs, and executes one resulting in an error, EAPR would direct the practitioner to reconstruct in accordance with other runs (even though she was struggling). Within the tradition of progressive rock, performers being viewed as virtuosos; she would be aware of her limitations when performing such a riff—in turn, this reflects intention, and preserves EAPR's own context of authenticity, overcorrection.

However, if the "flawed" run violates any of my practice's goals (e.g. the performance error alters the musician's reputation), there is still a performance error. In such a case, the practitioner would audition examples from the artist's repertoire similarly "flawed" runs, but (in the practitioner's estimation of the audience, including the artist's) were received positively. This enquiry would then inform the restoration of the current performance error. The goal would be transforming the audience's perception, but not EAPR's contextual performance authenticity.

From a purely theoretical perspective, a specific album processed by different SIA practitioners will likely yield different results; the same album, processed by different EAPR practitioners, should produce similar results.

5.2.3 Process Architectures

I defined error management processes as the set of instructions the practitioner follows to meet her approach's objective using her method. The SIA and EAPR can be viewed as having significant differences in their error management processes, as a result of their differing objectives and methods. EAPR is constructive: It aims to determine the precise elements of an intended performance, and then create the audio corresponding to it.

5.2.3.1 Theoretical Foundations

As such, the EAPR process requires a theoretical foundation to create the macro epistemological structures representing the musical elements being constructed. These structures inform the heuristics employed by the practitioner, assigning meaning to the underlying performance data so that disparate audio can be combined into music elements and reassembled into a performance. The artist is not involved in the process, and Audio is not to be replaced. (See Section 4.4.2.2.4.)

The SIA does not require such a foundation; from an information perspective, its process can be viewed as destructive. If errors cannot be obscured using audio manipulation, then the audio may be replaced. From the perspective of my practice, more information is usually lost about the original performance with the SIA than with EAPR; preserving it is not an SIA objective.

5.2.3.2 Abstraction

Another difference in the architecture of the two processes is how they are realised. The EAPR process requires complex analytical and technical operations for performance forensics and audio reconstruction. The operations are non-trivial, and there is a constant possibility that any given restoration may fail[59]. (In this case, EAPR would fall back to the SIA.)

As introduced in Section 4.4, to best address these challenges, EAPR is defined conceptually, as an abstract process. There are no tools or techniques defined as part of the process. When a project is undertaken, EAPR is implemented by choosing specific tools and developing individual techniques to solve specific performance errors, based on the needs of the project and the available technology. This delineation is not intrinsic to EAPR; it is a result of the

[59] On the Creative Album Submission, re-recording only required twice. Some restorations were time-consuming, with one eight-second performance error requiring two weeks to restore.

nascent technology available for the process; sufficiently advanced technical capability would allow implementation to be defined as part of EAPR.

Within this context, the SIA concrete process that includes implementation; there is no conceptual component. In terms of the EAPR Error Taxonomy, the SIA is concerned primarily with score and tuning errors—and then, only if it is perceptible according to the practitioner's aesthetic. If an error is flagged for correction, but there are problems with analysis or transformation, a similar part might replace it with different performance elements—even a different score—provided it isn't perceived as problematic. Or, the part can simply be re-recorded.

5.2.3.3 Phases

EAPR process has two phases: Analysis and Restoration. This can be considered true of the SIA, as well. For this discussion, I will collectively term the phases for both processes, *Analysis* and *Repair*.

5.2.3.3.1 The Analysis Phase

Two EAPR Analysis stages, *Screening* and *Triage*, have similar analogues in both the SIA and EAPR. During Screening, potential errors are flagged for possible repair; in triage, the practitioner determines if an error will be repaired. EAPR adds a third stage, between the two, where additional information about the error is gathered. Examples include identifying other tracks that may inform about the intended performance on the primary error track, or helping attenuate microphone bleed.

5.2.3.3.2 The Repair Phase

The SIA's Repair phrase, within the context of EAPR, can be considered to be comprised of three stages: *Interpretation*, *Correction* and *Evaluation*. Although the EAPR stages are generally more complex, the IAP stages could be viewed as contained within the five stages in EAPR's Repair phase, as defined in Section 4.4: Transcription, Conceptualisation, Identification, Rendering and Evaluation. To aid in our discussion, I will create terms describing approximate intersections in functionality.

5.2.3.3.2.1 Resolution

Our term for the first phase(s) in the two approaches is *Resolution*, as in "resolving" the conceptual problem posed in addressing the performance error (according to each approach's respective goals and methods).

Resolution in the SIA (i.e. Interpretation) provides an interpretation of the error, and may include a determination of the parameters for a relevant substitution. (For example, a monophonic musical event is flat, and needs to be tuned up to the next semitone.) Establishing the recorded (i.e. performed) or intended scores is not necessarily required by the practitioner, especially if the determination is made to replace or re-record it.

In EAPR, Resolution is contained within the first three EAPR Restoration phases: Transcription, Conceptualisation and Identification. These phases are generally more detailed than the SIA's interpretation phase, and include other tasks. For example, EAPR requires three scores to be constructed, encompassing heuristic determinations of notation, performance variables, and the performer's intention.

5.2.3.3.2.2 Alteration

Correction in the SIA can be considered as fulfilling a similar function (in terms of the approaches' objectives) as *rendering* in EAPR; I will call both, *alteration*. In this stage, audio engineering techniques are employed by the practitioner to transform old audio, and/or create or record the new audio, to repair the performance error.

5.2.3.3.2.3 Audio Alteration Techniques

Building on our previous discussion, the SIA employs a small set of common, categorizable audio engineering correction techniques during *alteration*. They are largely independent of software or hardware tools. These techniques are relatively intransient, and new ones are rarely introduced (Burgess, 2018).

In contrast, EAPR requires a theoretically unlimited number of engineering techniques. Many are tied to specific tools, based on those tools' unique capabilities. Creating these techniques is part of EAPR's *rendering* phase (in addition to the actual audio modification). As such, the techniques are often developed for, or customized to, specifically-occurring performance errors.

5.2.3.3.2.4 EAPR Analytical Techniques

EAPR has a second type of audio engineering technique used in its Analysis phase. Like EAPR's alteration techniques, the analysis techniques are developed for specific problems encountered during album production, rely on specific tools, and are often customised and combined to address future errors.

SIA does not require significant audio or musical analysis, however; performance forensics are minimal, and re-recording is a common alteration technique. (Analysis is not required because the new recording is presumably performed by the artist.)

5.2.3.3.3 Evaluation

Evaluation is the final stage for both processes: the practitioner (or artist, if re-recording was employed) evaluates the results of the *alteration* stage. In the SIA, contextualised within my practice, the metric for success is: if *an* error (not necessarily *the* error) is no longer perceivable; and, if the new audio conforms to (i.e. is authentic within the *philosophy* of) the practitioner's live album aesthetic (Elefante, 2016)

EAPR employs different metrics for *evaluation*, based on its differing *objective* for error management. The metric for success is (if the practitioner predicts) the audience groups will experience the artist's intended performance. Authenticity, in the context of this investigation, is framed by the practitioner in terms of the audience's response to the restored performance, and if they (including the artist) identify it as belonging to that artist.

5.3 Alteration Techniques of the SIA

As discussed in Section 5.2.3.3.2.3, the SIA has a specific set of common techniques. I will now present a taxonomy of these techniques, contextualised with those of EAPR. The taxonomy is informed by my correspondence with practitioners, and the available published literature.

Two top-level categories emerge from SIA techniques: *replacement* and *modification*. *Replacement* refers to the substitution of the erroneous audio with a different performance. *Modification* refers to the alteration of existing audio.

A logical dichotomy of two types exists in replacement techniques: *re-recording* and *copy-and-paste*. Both occur primarily inside the host DAW. In *re-recording*, a musician (usually the original artist) records a new performance, in the studio, over an erroneous section of the live recording. *Copy-and-paste* replaces the erroneous audio with a similar section from elsewhere in the existing recorded performance. Ideally (and usually), the external section has the same score as the one it's replacing. If not, there are sometimes modification techniques that can be applied.

Modification can be divided into *Region Alignment*, *Pitch/Duration Adjustment*, and *Automatic Spectral Replacement*. Time-alignment and pitch/time have several sub-categories and modes. Modification differs from replacement techniques, and can occur: inside the DAW, within third-party plugins, and in stand-alone applications. Also unique to modification is that multiple techniques may be used on the same error. If combined with copy-and-paste, the latter is performed first.

The SIA alteration techniques are mostly adaptations of studio techniques. Almost all of them, including the sub-categories, are common in studio practice. The exception is re-recording, which by context, is unique to live-album practice. Yet even this technique is often viewed within a studio context. Burgess describes it as "punch-in/punch-out". Lukather writes: "No one is perfect if it is really live. In the studio, you do take after take till its right correct?" (Lukather, 2018)

5.3.1 Modification

Modification transforms existing audio within the erroneous error section to correct the error(s). Usually, it is applied directly on the originally recorded audio. If the original audio has been replaced via copy-and-paste, though, Modification can sometimes be used to transform the external audio to better fit the score and timing of the erroneous section it replaces.

As discussed in Section 5.2, error correction in the SIA is primarily score- and tuning-based. Modification techniques inform and reflect this point, consisting primarily of two categories: *time-adjustment* and *pitch-adjustment*.

Depending on what audio programmes are used, SIA and EAPR techniques operate on either time-defined audio sections (i.e. audio regions and Flexture Edit sections) or musically-defined audio sections (e.g. *musical events*, as in Melodyn and AutoTune Graph Mode). For the purposes of this discussion, I will refer to both as *Audio Events*.

5.3.1.1 General Limitations

The range of transformations available in the SIA, using modification, is limited due to three general factors: *design*, *identification*, and *availability*. The first can be attributed to the recording studio heritage of SIA techniques, which were not designed for audio with bleed from other sound sources. When these techniques are used with audio sources containing bleed, difference-artefacts often result. While there are some techniques in the SIA for mitigating these artefacts, it is not uncommon for them to be insufficiently effective.

Another issue is that, in order for the practitioner to modify music events, she usually must know the performed and intended scores, and be able to identify pertinent musical events in the relevant audio file(s). For example, if a note is to be transposed, then the audio corresponding to that note must be selected. Likewise, if a is shifted to begin at a different time, then the position of this time must be located. The use of distortion on guitars, and rapid playing, are two particular factors that can make the identification of musical data challenging for practice within the SIA. Broadly, there are no techniques for addressing these issues; re-recording is primarily used in the case for these issues (when an error can't be fixed).

The third issue is that the tools employed in the SIA have limited operations available to make the changes sometimes necessary, even if the scores are known, and the note-audio identified. The software employed has particular problems with distorted instruments (e.g. guitar) and polyphonic audio.

5.3.1.1.1 EAPR Context

EAPR's techniques are specifically designed for use with live audio. Within the EAPR Process, there are conceptual tools to help with the *identification* issues inherent in the SIA. These tools are realised in EAPR's Analysis and Alteration techniques, enabling Performance Forensics; the SIA only supports Alteration. Additionally, EAPR employs spectral editing for both Analysis and Alteration. This mechanism enables novel techniques on its own; it also expands the capability of tools shared with the SIA, such as Melodyn, chaining techniques together. (See Chapter 7 for examples of all aforementioned functionality using EAPR techniques.)

5.3.1.2 Timing Adjustment

Timing adjustment is used to change the starting-time and/or duration of Audio Events. By itself, the technique is most often employed to alter single musical events (e.g. notes). When used with Copy-and-Paste, it is usually employed to align the entire audio section. The primary differences in techniques are based on how the sonic data is represented and edited: as *audio sections*, or *musical events*. The procedure is completely manual with audio-based selections (e.g. regions and Flexture Edits), and semi-automated (due to heuristic software estimation) with musically-based selections (e.g. musical event editors such as Melodyn).

5.3.1.2.1 Region-Based

With Region-Based Time Adjustment, the practitioner creates or selects an existing DAW region corresponding to the audio she wishes to modify. The starting point of the region can then be modified, non-destructively; the region's length (indicating duration) remains constant (Mouser, 2016; Burgess, 2018).

Most DAWs also support a separate, non-destructive operation to change the region's duration. Any changes to the region affect all of the audio inside; specific musical events (i.e. notes) can only have different values assigned to them if regions are defined for each such event. This operation is rarely used in the SIA, though.

5.3.1.2.1.1 Limitations

This is a manual operation; it is time-consuming and can be challenging—waveforms do not discriminate between the perceptual and physical (e.g. note onset and note start), and it is sometimes difficult to tell where any division among musical events occurs. For these reasons, region-based editing is a good choice for transformations to multiple musical events not requiring precision, except for the starting point and overall duration—not any musical events within.

A common problem with the Region-based technique is that regions moved apart from each other create a silent gap between them. This silence disturbs not only the programme material, but any audio bleed, as well. Patterson writes:

> *When slicing, percussive material tends to offer the perception of a 'gap' between the relatively short transients with the exception of naturally sustaining sounds such as cymbals, and distant mic'ed recordings such as room mics on a drum kit that typically contain continuous ambience between notes. Pitched material will more often sustain between notes, and so the slicing will tend to create more artifacts.* (Paterson, 2009)

One technique to mitigate this problem is to insert a fade at the end of each region. Another is to use time-stretching of the first region to reach the second; however, this changes the timing of all the audio within the first region, and also introduces the potential for additional difference-artefacts.

5.3.1.2.1.2 Within EAPR

Region-based editing is generally not employed in EAPR because it lacks sufficient detail in both visualisation and exactness.

5.3.1.2.2 Flexture Editing

Flexture Editing is functionally equivalent to Region-Based editing. The difference is the user interface and workflow, making it is generally more efficient if there are many timing edits required to fix an error. The start and end points of audio sections are automatically linked together; changes to start times incur a corresponding change in the section's duration, along with an automatic crossfade between the sections. This eliminates the gaps created between repositioned audio regions, automatically.

Most significantly, Flexture Editing includes an heuristic function to estimate the starting points (not onsets) of musical events. Another advantage over region-based editing is that the interface better supports a significant number of edit points. Together, the two features can facilitate a timing-only musical event editor (*temporal event editor*).

As with the time-stretching feature of audio regions, Flexture Editing does not appear to be common in live progressive rock error management. Possible reasons include the limitations listed below, within the context that re-recording is usually an option.

5.3.1.2.2.1 Limitations

While potentially efficient, practitioners may find the automated start points are less accurate with melodic instruments than percussive ones. The fall-back is creating the divisions manually, as when creating audio regions. The standard Modification problems are also manifested: the heuristic parsing of distorted guitar is unreliable, and Flexture Editing applies only at a macro-level to audio—it is a monophonic operation.

Another potential issue concerns the requirement that the duration of audio change whenever a starting point is moved. While this avoids the silent gap that can occur with region-based techniques, it can also introduce more prominent difference-artefacts due to the additional duration-based audio transformation.

Perhaps due to these limitations, Flexture Editing techniques are not common in live progressive rock. None of the practitioners I corresponded with employed it; nor was it used in any of the available published papers, except for one specifically on methods of altering the timing of audio events.

EAPR sometimes employ Flexture Editing, if the sophistication of full Musical Event editors is not required. The advantage of Flexture Editing is that it is native to the DAW. (See Chapter 6.)

5.3.1.2.3 Musical Event Editing

Building on the interface and functionality of Flexture Editing, pitch and time event editing uses similar note-start estimation to divide audio into musical events. This representation is combined with monophonic pitch estimation to attempt the representation of audio as musical events similar to noted music. In this form, both time and pitch alterations are supported. In terms of time-based operations, the capabilities and limitations of this technique are similar to those of Flexture Editing.

EAPR heavily employs Pitch and Time Event Editing. For additional information, see Section 6.1.1.

5.3.1.3 Pitch Adjustment

There are three primary techniques to adjust pitch in the SIA. One is for *transposing*, and two are for *tuning*. Within *tuning*, there is one technique for *real-time* operation, and one for *off-line* usage.

5.3.1.3.1 Limitations

Pitch operations, more so than time-based ones, are susceptible to generating difference-artefacts (White, 2016). A common technique in the SIA is to automate the attenuation of conflicting audio tracks when the artefacts are most audible (Guidoz, 2018). In some cases, this will have a noticeable effect on the mix; re-recording can be used in these cases. It may not eliminate the artefacts, but in some cases, will reduce it.

As discussed in Section 5.3.1.1, SIA's techniques only support polyphonic editing using Melodyn. The limitations for pitch are the same as for time, discussed in Section 5.3.1.2.2.1. As with time-based editing techniques, the fall-back for Pitch Adjustment is Re-recording.

5.3.1.3.2 Within EAPR

In EAPR, difference-artefacts are not as prevalent because spectral editing allows localised editing within the frequency spectrum, resulting in potentially less audio to conflict with other tracks. Additionally, microphone bleed can be directly attenuated (though rarely eliminated) using spectral editing.

EAPR Polyphonic pitch editing is more effective in EAPR than in the SIA due to EAPR's additional usage of spectral editing. This tool can be used in conjunction with Melodyn or on its own to perform polyphonic editing. See Chapter 7 for examples of spectral polyphonic editing techniques with EAPR; see Section 6.2.1 for more information on the use of this tool with EAPR.

5.3.1.3.3 Tuning

There are two techniques for tuning in the SIA: real-time and offline. Polyphonic operation is only effectively possible using the offline technique with Melodyn (Mitchell, 2014). As discussed, however, Melodyn's polyphonic editor is limited in its applicability to live audio (Celemony, 2010).

5.3.1.3.3.1 Real-Time

Real-time tuning is implemented as a plugin (either Third Party, or native to the DAW), employing heuristic pitch analysis to tune monophonic audio in real-time. It is common in the SIA (Mouser, 2016; Guidoz, 2018; Sherwood, 2018). Some practitioners leave the plugin active throughout the mix; others use automation to activate it only when they have flagged an error for correction.

The primary advantage of the real-time technique for practitioners is that, potentially, it requires less setup than the offline technique. In practice, the result depends on how often the practitioner wishes to apply correction, and/or in instances where the original pitch is off by more than 100 cents, the plugin must be adjusted. If these variables change throughout a song, automation is the only solution.

This technique is not employed in EAPR because it cannot be controlled with as much precision as with the offline technique, and the offline audio rendering is rendered with more realism.

5.3.1.3.3.2 Offline (Musical Event)

The offline tuning technique offers higher precision in exchange for a more complex and time-consuming setup. For example, Individual words and syllables can be targeted (Stolt, 2018). Melodyn requires all of the target audio to be analysed before pitch modifications can be made. After set-up is complete, the practitioner must review all of the musical event heuristics performed by the offline editor: the separation of audio into musical events (i.e. notes) and the pitch of each event .

In practice, especially with live audio that includes bleed, the practitioner must consistently make corrections to the editor's estimations. Some of these corrections, particularly event/note separation, can be challenging—especially with distorted audio instruments. (See Section 6.1.1.5.)

Once corrections are complete, each musical event can be tuned precisely by the practitioner. The realism of the results depends partially on the practitioner's accuracy in identifying mistakes in the editor's heuristics, and making corrections with high precision.

For the use of offline tuning in EAPR, see Section 6.1.1

5.3.1.3.4 Transposing

Transposing is largely limited to an offline technique[60]. It is realised using the same methods as offline tuning, but is used for a different purpose. When a practitioner uses Copy-and-Paste, replacing erroneous audio with a similar external performance, transposing can be used to modify notes in the external audio to better match the score of what it is replacing.

[60]Although it is possible to transpose audio in real-time, the timing requirements make this problematic in practice. Additionally, real-time pitch algorithms are generally not as high quality as offline ones; tuning is often within one semitone, but transposing can be across much larger pitch ranges.

This technique appears to be uncommon in the SIA. It can be considered that this is due to the technical limitations of this technique, such as the pitch-shifting failing in a polyphonic context (Graydon, 2018), or difference-artefacts from microphone bleed. If the required score is not present in the copied audio section, replacement is commonly employed (Rustvold, 2018).

The use of Transposing is common within EAPR, though in a different context than the SIA. In EAPR, Transposing is most used as part of Forensic Assembly to adapt information from other sections of the performance to the current, erroneous audio—rather than entirely replace that audio, as with the SIA.

More information on transposing in EAPR with offline musical event editing can be found in Section 6.1.1. Examples of it used as part of Forensic Assembly are in Chapter 7.

5.3.2 Replacement

Although re-recording and copy-and-paste both substitute a new performance for the original, there are significant differences between them. The variables are: who evaluates the correction, who interprets the performance, and if any of the original can be preserved. Common to both is the bypassing of Modification's technical limitations, and the waiving of two requirements for the practitioner: understanding the error's cause, and knowing the score of the intended performance. Replacement can be comprehensive enough in the SIA as to be all that is required for error management techniques (Doss, 2018).

A significant practical difference between the SIA and EAPR techniques is that EAPR does not employ replacement—all EAPR techniques would fall under the SIA category of modification[61].

Replacement is not compatible with EAPR's goal of restoring performances because the original performance is erased. Frost states: "It is a highly efficient way of re-creating the score, but almost totally ineffective at revealing the music within it." (Frost, 2007)

[61] Even though forensic assembly incorporates an element of cut-and-paste, and therefore replacement, the operation has a different usage and purpose from the SIA. In EAPR, only the aspects of musical events that cannot be preserved are copied; they are integrated within the context of restoring what has been determined to be audio corresponding to the original performance.

Re-recording retains none of the original audio, and usually none of the original performance parameters. These results do not conflict the SIA, however; as previously discussed, the new performance is generally not specifically intended to restore the original performance (Mouser, 2018).

5.3.2.1 Re-recording

Re-recording is a complete replacement of an erroneous performance. It is usually performed by the artist who performed the corresponding part in the original performance. Within the SIA, it one of the most common alteration techniques (Leijenaar, 2018; Lukather, 2018).

5.3.2.1.1 Usage

There are three cases in which re-recording is invoked. The first two relate to the SIA practitioner: either *modification* isn't technically possible (Guidoz, 2018), or the practitioner cannot determine the intended score. The third is when the artist requests to re-record her own part; this is the only alteration technique generally invoked—and evaluated—by a performer.

5.3.2.1.2 Limitations

Within the SIA, re-recording's primary limitation is that the tone of the new recording will often not match the existing material. This is commonly addressed by cross-fading (Stolt, 2018). A secondary issue is that correct and erroneous notes, alike, may be replaced—this may require more re-editing of the video if the album is also a concert film. Conceptually, re-recording retains none of the original performance, (primarily) only its score (Davies, 1991).

5.3.2.1.3 Within EAPR

Re-recording is only used in EAPR if the EAPR process has failed. (On both the Creative Album Submission and Supplementary Album Submission, this occurred only twice.)

5.3.2.2 Copy and Paste

Copy-and-Paste is a procedure whereby the erroneous performance audio is replaced with another performance from elsewhere in the recording (Graydon, 2018). The primary replacement criterion is an equivalency of, or sufficient similarity in, the scores of the two sections. A second criterion is a similarity[62] in tempo.

It is preferable if the scores match, though there are two cases where similarity is sufficient. In the first, the part may be of sufficient harmonic similarity that it does not conflict with the other instruments, or otherwise draw attention as an error. For example, a guitarist may have played an Eb major 7^{th} in the erroneous part, but that passage might be replaceable (within the ISA) with an Eb major played elsewhere in the song.

Rhythmically, it is unlikely that Copy-and-Pasted sections will match tempos. If the section is relatively short, though, it may be sufficient to avoid the perception of error according to the SIA practitioner's aesthetic. A workaround technique is to split the copied section into multiple sections, and then adjust those positions using either region-based or Flexture Edit techniques. In these cases, it is also common to re-record the part.

As previously mentioned, Transposition and positioning can be applied to musical events in the copied section, though this is rare in the SIA.

5.3.3 Restoration

Some practitioners of the SIA describe audio restoration as part of their performance error management:

> *I often get files that have audio glitches/pops, perhaps due to overlooked bad crossfades…* — Billy Sherwood (Sherwood, 2018)
>
> *The fourth basic step is to get rid of noise, hum, and artifacts that are unwanted.* — Jay Graydon (Graydon, 2018)

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[62] It is unlikely the tempos will be identical because drummers rarely perform live to click tracks when performing live.

As discussed in this thesis, within the context of EAPR, these audio elements are termed *non-program audio*. It falls under the category of performance errors only if its presence negatively affects the audience's perception of the performer.

Outside the context of a performance error, I will use industry-standard techniques for audio restoration. These techniques are outside the scope of my investigation. If problematic audio is part of a performance error, then my most common technique is to use manual spectral editing with SpectraLayers.

This is a similar use case to the automated spectral replacement technique found in the SIA; the difference is that the automated technique is not always successful because it is heuristic, not manual (Gilligan, 2016). While manual editing is not consistently successful, it is applicable to a larger class of audio restoration problems. Additional information regarding restoration in EAPR is found in Section 6.3.

5.4 A Sample SIA Error Management Process

The following error management process[63] is from producer/engineer/artist Jay Graydon. His full description is presented to provide sufficient detail to contextually compare and contrast with the EAPR Process established in 4.4, and implementation for the Creative Submission Album in Chapter 6, and examples techniques in 7 and Appendix E.

The first step is to fix any musical issue such as vocal tuning, guitar tuning, and time alignment. It is most difficult to do in most cases, as every microphone is hearing leakage from other instruments. If there are serious musical mistakes such as an incorrect guitar chord, since that chord will show up in a similar section in the song, I would copy from the source track, paste into a blank track, and then time-align the newly-pasted track (sample accurate) to match the exact starting point of the guitar track that has the mistake.

I would then draw a volume ramp down and up around the original incorrect chord, and do the opposite with the newly-pasted track, doing my best to make the transition sound natural. Again, on account of leakage, this may not be possible. I would then try a pitch correction tool to correct the wrong note(s) in the chord. So much more but let's move on for now.

The second basic step is to address is the phase (polarity), starting with the drums, so all attack waveforms start in a positive, uprising direction. The next move is to nudge the drum-overhead tracks to match (in phase) with the snare drum. Then, I perform the same with the toms, etc.

After the drums are phase aligned, the bass is next, to match the phase of the kick drum. This is very time consuming, and it is very important to have [all] the speaker's woofers moving forward at the same time. Note: All nudging is no more than 1/2 of the length of one complete waveform cycle.

The third basic step is to EQ all instruments and vocals to taste. We may revisit EQ as needed during any stage of the process. Note that negative EQ settings are your best friend, especially when leakage (bleed) is in play. (More on leakage as you read on.)

The fourth basic step is to get rid of unwanted noise, hum, and artefacts. Let's say the guitar player has his/her amp settings for extreme distortion, which creates noise and possible 60-cycle hum. Plugins such as Spectral Layers and RX, enable the user to draw out hum, noise, and artefacts such as a chair falling over during the performance. More on these tools in the following section.

[63] The process description has been reformatted for clarity; the information has not been altered.

The 5th basic step is to bring down leakage caused by instruments such as a loud guitar amp being picked up by other microphones (such as the vocal mic, drum mikes, etc.). Instead of using gates on such tracks receiving the leakage (bleed), so as to make such level changes sound musical, I draw in level rides on all tracks to bring down the leakage as much as possible when such tracks are not in use. For example, when the drum toms are not being played, I pull down the level as much as possible without it sounding unnatural (in regard the complete drum set sound) and then draw a volume ramp up just before the tom(s) will be hit—and then a smooth quick musical fade out as soon as the tom(s) level begins to fade out naturally.

Let's assume the leakage into the vocalist(s) mic(s) is loud; we have stand-alone applications such as Spectral Layers and RX, which enable the user to draw out some of the leakage. Such tools offer unique functionality, but may also be time-consuming to work with. Let's say a drummer hits the snare drum mic when playing. Using such tools is an easy fix to get rid of such a sound[64].

The 6th basic step is to set the individual track levels to taste, starting from the beginning of the song. All of the recording systems in use have automation for level riding and plug-in parameters. So, after setting the starting levels, we automate the individual track levels. We may revisit EQ during the process and may need to automate the EQ parameters.

— Jay Graydon (Graydon, 2018)

[64] The context within which states this is in terms of it being *possible* for there to be an easy fix with those tools.

5.5 A Taxonomy of the SIA Alteration Techniques

The SIA taxonomy for alteration techniques is presented in Figure 29.

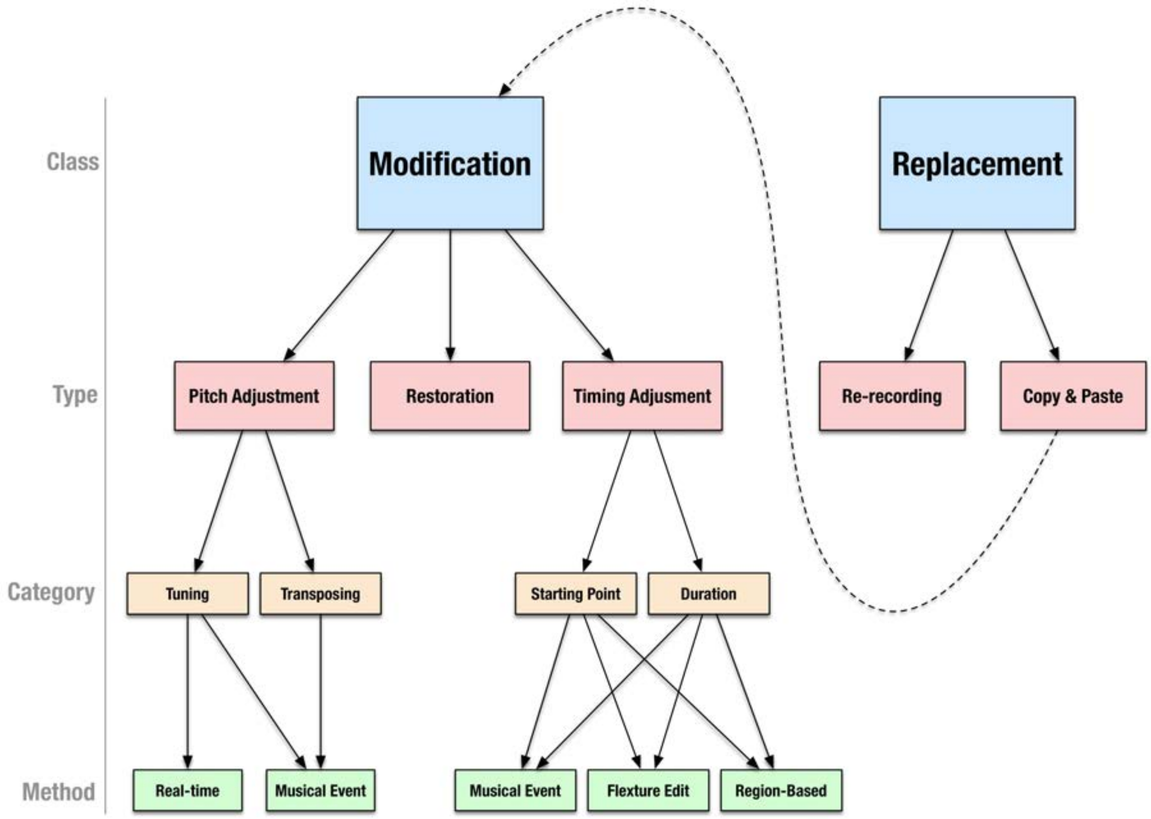

Figure 29: The SIA Taxonomy for Alteration Techniques

6 : Implementation of the EAPR Process for the Creative Submission Album

In chapters 3 and 4, I developed an abstract process for addressing performance errors on live albums in my practice: EAPR (i.e. Performance Forensics), which has two functions: to estimate the performer's original intentions, and also create the new audio corresponding to those performances. In developing this model, I contextualised my practice with research by other investigators across a range of related topics and music industry conventions.

As discussed in Chapter 4, EAPR is an abstract process that precludes a specific implementation. The implementation has two parts: the software tools used, and the techniques developed using those tools. In this chapter, I discuss the tools I selected to restore the performances on the Creative Submission Album, and refine EAPR through praxis during its production.

The first step in my selection process was to create a taxonomy of tool classes that would most effectively facilitate the analysis and audio transformations required by the EAPR Process. These classes would not necessarily reflect existing taxonomies, but would be tailored specifically for EAPR realisation. From this investigation, five divisions emerged: Project Management, Musical Event Editors, Raw Audio Editors, and Audio Restoration.

For some of these classes, subclasses emerged. Two types of Musical Event Editors were revealed: Offline Pitch and Flexture. Raw Audio Editors were split into Waveform and Spectral. This resulted in a total of six tools. Each type of editor was limited to one software tool; multiple editors of the same type would increase the workflow complexity, which already was challenging to manage. By analysing the needs of each division, and comparing the candidates' capabilities, it was revealed that one tool would meet the necessary criteria. Therefore, the designation of one tool per class represented an increase in efficiency and efficacy.

In this chapter, for each class, I provide several points of investigation. Each class is introduced by explaining its relevance to the EAPR Process. The needs for that class are defined, and a detailed survey of available software tools is undertaken. Each tool selection is specifically justified. The usage of each tool is explored; the depth of this examination is determined by the complexity of EAPR-specific issues. As part of this discussion, the challenges and limitations of each tool are documented in the context of EAPR, along with the methods I use to apply these tools to the Process.

The tools selected in this chapter, combined with the analysis and audio transformation techniques I developed in using them, comprise my implementation of the EAPR process for producing the Creative Submission Album. The techniques will not be discussed in this chapter; as discussed in Section 4.4, there are no specific techniques that result from implementing EAPR—they are developed during restoration to solve specific problems. Elements of them developed early in production are reused in later, sometimes combined with other techniques, and often with improvements. Detailed examples of the techniques used on the Creative Submission Album, with the tools presented in this chapter, are presented in Chapter 7. The discussion of tool usage in this chapter also provides a technical and operational primer for reading this appendix, allowing the discussion there to focus solely on techniques.

6.1 Musical Event Editing

I will define Musical Event Editing (MEE) as a paradigm employing music information retrieval to imbue raw audio data with musical information, allowing such data to be edited in a musical, (rather than sonic) context. Working within this model provides two advantages for EAPR over raw audio tools (e.g. waveform editor): musical representation and musical modification.

The raw audio files that comprise a recording represent only amplitude changes over time. Waveform editors present this data directly; spectral editors add the additional variable of frequency, at the cost of some precision. However, many elements of the EAPR process exist in musical contexts. Visualising musical information (such as a notated score) from raw audio data is often significantly challenging and inefficient.

Using a combination of complex measurements and sophisticated heuristics, MEEs extract multiple types of data from the raw audio, synergistically combining and encapsulating them into higher-level entities. These entities correspond (depending on the specific software) to a range of equivalent concepts in the EAPR theoretical framework and process. For MEEs such as pitch editors, these concepts include notes and pitches, providing significant benefits over raw audio when evaluating score compliance.

Once the audio data has been transformed to one imbued with musical meaning, some MEEs allow similarly musical transformations of the data. For example, an MEE audio object corresponding to a musical note can be dragged upward or downward to change its pitch, or dragged left or right to change its starting point.

Such transformations not only support changes in a musical context; they also often represent significant savings in time over the manual methods required to achieve the same result. Additionally, because the actual audio transformations are automatic, the modifications (involving numerous complex calculations) can be more reliable. And because there are fewer steps in MEE transformations, it is much easier for the practitioner to experiment and backtrack to previous states.

There are disadvantages to using MEEs, as well. The primary one, in the context of EAPR, is that the heuristic estimations of the audio data may be incorrect. In much of the programme material in live progressive rock, such errors are not uncommon. These mistakes will not only result in providing the practitioner with incorrect information she may not be aware of, but also result in transformations that are inaccurate. Most of these errors can be manually corrected, doing so correctly, with sufficient precision for EAPR, is often non-trivial, given live prog's programme material (e.g. rapidly played distorted guitar).

Within the context of my practice, I identified two types of Musical Event Editing tools: Flexture Editors and Offline Pitch Editors. Of the two, I used Offline Pitch Editing almost exclusively. (My reasoning is discussed in Section 6.1.2, which focuses on Flexture Editing.)

6.1.1 Offline Pitch Editor: Melodyn

Melodyn was regarded at the time {Mitchell:2014wu} of my investigation as the industry standard for high-end work. However, this didn't necessarily mean it was the best choice for implementing EAPR. There were seven offline pitch editors available during my investigation. All, except for Melodyn, had similar workflow: Operating on monophonic audio, they would present a piano-roll notation of what it judged to be the musical events corresponding to musical notes; these events could then be edited.

Likewise, except for Melodyn, their basic feature sets were similar (Albano, 2015)[65]. However, the implementation and flexibility of those features varied. Table 11, below, summaries this range.

Table 11: Summary of Available Offline Pitch Editors

Name	Company	Version	Level
Auto-Tune	AntaresTech	8 (Graph Mode)	High-end {Walden:2015uy}
Flex-Pitch	Apple	Logic Pro X (Built-in)	Mid-level {Macdonald:2013vl}
Melodyn	Celemony	3.2	High-end {Discoll:2015wf} {Mitchell:2014wu}
Nectar	iZotope	2	Mid-level {White:2014te}
Tune	Waves	9	Mid-level {Cooper:2018tt}
VariAudio	Steinberg	Cubase 5[66] (Built-in)	Mid-level {Walden:2009wa}

[65] The reference here also notes SynchroArts Revoice as also having unique features; however, that version of Revoice (3) wasn't released until August, 2015—too late for use in my Creative Album Project.
[66] Cubase 8 was the current version during my investigation; VariAudio's features had not changed since Cubase 5.

As part of my pre-implementation research, I auditioned all but one of the above editors (omitting Waves Tune, which I did not have). My conclusion was that Melodyn was the best fit. Unlike the other editors, which had basically the same features at different levels of sophistication, Melodyn had two features that were different: ARA and polyphonic editing.

ARA improved workflow by removing the requirement to transfer audio into the plugin manually. However, only the PreSonus Studio One Pro DAW (at the time) supported this functionality. The other, and more important feature was the ability to process and edit polyphonic audio, under certain conditions. And given that performers often play chords on the instruments in progressive rock, this was an essential capability.

A lesser but still important reason was the increased level of flexibility offered by Melodyne in the types of edits that could be performed on blobs. A parameter relevant to EAPR, and unique to Melodyn, is having two parameters (instead of one) defining the start of a note: one marks the *physical* beginning of the note; the other marks the *perceptual* onset of the note. Being able to adjust these parameters independently provided additional realism when I modified other aspects of a note. However, as discussed in Section 6.1.1.4.3, it also meant that I often needed to correct these start points manually.

The other high-end offline pitch editor, the Graph Editor in Auto-Tune, while similarly sophisticated as Melodyn (Albano, 2015), lacked a separate note onset parameter. It offered the advantage of more precise amplitude information, but Melodyn was the best solution: Note onset was more important in EAPR for achieving realistic transformations, and the polyphonic capability significantly increased my transformative options.

6.1.1.1 Introduction to Melodyn with EAPR

Melodyn contains algorithms to estimate and represent recorded audio as musical events termed *blobs* (Celemony, 2010). Blobs share some similarity with notes in a score; they express less musical data, but more performance data. One reason for their use: an automatic, direct translation from audio events to a notated score is generally not possible, nor is it necessary for audio modification functionality. Blobs present a simplified way to represent performance data that is challenging to express in a traditional score.

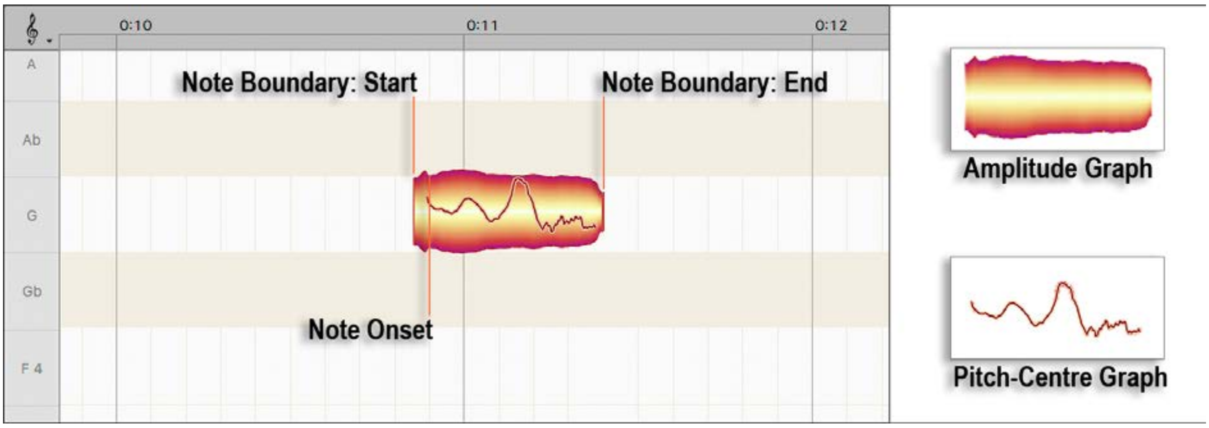

Figure 30: Basic Parameters of a Melodyn Note Blob

Integrated into a blob's visual depiction is a representation of raw audio data that can be interpreted as performance data: parameters such as pitch envelope, note onset, note boundaries (begin/end), pitch modulation, pitch centre and amplitude envelope. This representation is more applicable to the visualisation of performance data for EAPR because it captures performance nuances that are challenging to express with traditional music notation (e.g. precise timing and pitch). It is also more applicable to making specific audio modifications related to musical performance.

6.1.1.2 Sequence in EAPR Toolchain

The tools I use are dependent on the types of performance errors, the cause of the error (both musically and technically), and what is required technically to render a restored performance. For some errors, I used a combination.

In many cases, I began a restoration with Melodyn, for several reasons. One is that Melodyn is part of my process for generating EAPR scores, which are required at the beginning of the Restoration phase. Another is that Melodyn's representation and editing occur at the macro level; it also represents audio as musical (not waveform) data. As such, any reconstruction I can perform at this level is generally more efficient than if done at a lower, audio-based level. Therefore, I generally perform this work first.

In contrast, *spectral editing*, which generally follows Melodyn editing in EAPR, provides consistently accurate automatic recognition of audio and frequency data—and permits any imagined change to that information. However, there is no musical structure present in the visualisation, or the use of the editor's available tools. Many changes imagined by the practitioner are non-trivial, and many more (if not most) are for all practical purposes impossible. This is due to the difficulty of recognising all the elements of the spectrum that correspond to a specific audio event—and the difficulty of understanding all the required changes to such elements to reach the desired sound.

6.1.1.3 Roles

Melodyn served multiple roles across early stages of the Restoration phase: performance visualisation, audio modification, what-if auditioning, and partially-automated scoring.

6.1.1.3.1 Performance Visualisation

Melodyn's blobs comprise one of the four systems I used to visualise performance data on the Album Project: score, waveform, Melodyn blobs, and spectral content. Unlike the other algorithmically-generated representations (spectral data and waveforms), however, significant amounts of Melodyn's data representations are incorrect when used with my data set[67]. Some mistakes can be manually corrected, but there is often no feedback other than the practitioner's ears to judge the veracity of these changes. Some information simply cannot be recognized or represented by Melodyn as blobs. When information is incorrect or not available about an audio event (blob), correct transformations are usually impossible.

6.1.1.3.2 Audio Manipulation

Another capability of Melodyn is audio manipulation, used primarily in the Rendering stage of Reconstruction. It is one of the five major tools/paradigms I employed on the Album Project for altering audio data: Waveform Editing and Flexture Editing[68] in Logic Pro (Apple, 2013), Musical Event Editing in Melodyn, Spectral Editing in SpectraLayers (Lobel, 2015), and Algorithmic Transformations in RX (iZotope, Inc., 2015).

Many of a blob's data members can be altered in Melodyn using a visual interface. As data is organised in Melodyn according to musical events, the ability of Melodyn to allow (or attempt) editing of audio data as musical entities can provide substantial efficiency and

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[67] This is a result of current research in pitch recognition and related issues, not a failure within Melodyn.
[68] Flexture Editing has brand-specific names in different DAWs, e.g. Elastic Audio in ProTools (Avid Technology, 2014), and Warp Markers in Cubase (Steinberg, 2017).

accuracy, compared with waveform and spectral-editing paradigms—provided such an edit can be accomplished in Melodyn.

There are two classes of algorithms in Melodyn relevant for EAPR Rendering: monophonic and polyphonic. Melodyn's scoring estimation is most effective with monophonic music. Some support for polyphonic analysis and modification is provided by Melodyn; it is the only such application to do so. Polyphonic analysis is a non-trivial problem, and an ongoing area of research in the literature (Byrd and Crawford, 2002).

The accuracy of Melodyn's audio modification is directly dependent on the accuracy of its blob parameters. If the structured blob representation in Melodyn can be considered a performance score, then the accuracy (and usefulness for EAPR) is dependent on that accuracy. It is the responsibility of the user to evaluate and correct Melodyn's estimations manually.

6.1.1.3.3 What-If Auditioning

During Restoration, Melodyn is also useful to perform what-if scenarios. After I have corrected Melodyn's heuristic recognition errors, I can often quickly audition changes to parameters such as pitch and duration. Such capabilities allow me to explore and experiment with quick, rough ideas for performance restorations.

6.1.1.3.4 Scoring Assistance

Every performance restoration on the Album Project, as in all EAPR restorations, required some form of an Intended and Performance Scores. Time and efficiency were the most significant factors in determining the level of detail, depth, accuracy, and form the scores took.

For most Audio Segments, there was neither enough time, nor did I estimate the need for, the scores to be written. Instead, I created and used mental representations. In some cases, however, a more detailed score (of some form) would have prevented problems either during the initial restoration, or when revisiting it for refinement at a later date. The time required was simply too much; instead, I would take the chance that what I undertook would be sufficient. After my experience with the Creative Submission Album, I was able to judge the need for written scores better.

The most common form of written score was created in Melodyn if it was to be used for audio modifications in the Rendering stage. Any use of Melodyn requires it to parse the imported Audio Segment for pitch and duration. Sections intended for audio modification within Melodyn required explicit blob-based score representations of the Intended and Performance scores.

First, the initial pitch/duration blob representation was manually corrected. These operations included assigning the intended pitch centre, and dividing note-blobs into notation-based notes. The finished representation in Melodyn was the Performance Score for those notes.

As mentioned in Section 3.1.1, there is no predetermined intended score for live progressive rock performance, due to the improvisational elements and solos. The practitioner creates it by heuristically aggregating multiple knowledge sources. Once the intended score for errant notes is determined, the new blobs are then altered in Melodyn to achieve the desired changes to the score.

These changes, in turn, instruct Melodyn to perform the necessary corresponding audio modifications to those blobs. Under ideal circumstances, the resulting representation would (visually) constitute the intended score for these specific notes.

However, it was sometimes impossible to alter the blobs in Melodyn to correspond to their correlated pitch and duration, due to detection mistakes by Melodyn; often, these errors were related to issues such as background noise, non-pitched instrumental sounds (intended or accidental), and intended distortion. Electric guitars were particularly problematic, especially when high distortion was applied.

This issue was particularly frequent when using Melodyn's polyphonic pitch recognition and modification mode. In this case, Melodyn could have problems assigning overtones to their psychoacoustic fundamental frequency. While Melodyn provided significant features to resolve this problem, the required functionality was not available for most cases on the Album Project.

In these cases, neither the Performance nor Intended score representations for these notes were correct. Usually, this meant the audio modifications I desired could not be performed either—although in some cases, by using a variety of techniques, I was able to achieve usable results. These techniques included pre-processing with spectral editing to remove specific frequencies/overtones, post-processing with spectral editing to remove artefacts and/or restore frequencies/overtones removed in pre-processing, and "reading" the errant Melodyn blob score to predict the effect of alternative audio modifications.

When I wished to create complete blob scores for an Audio Segment, I began by correcting (to the extent possible) Melodyn's pitch/recognition errors for all notes in the Segment—not just the ones I targeted for audio modification. A screenshot was then taken. However, often there was additional audio modification after my initial work in other audio applications. All such changes had to be incorporated (manually) using a drawing program. Likewise, graphical changes were required to correct blob representation errors in Melodyn.

If I wished to generate a traditional notated score, I first performed the above process, and then used a notation program to begin from scratch. Although Melodyn was able to estimate tempo (and thus assign partial meaning to note durations), this process also required manual correction in the cases of errors, a frequent occurrence given the complex and continually evolving drum patterns in live progressive rock.

Additionally, Melodyn was unable to estimate time-signatures (another ongoing area of academic research); given the multiple time signatures that often occur in progressive rock, the duration information provided even with correct mapping of the tempo would therefore not be meaningful in music notation. Likewise, Melodyn was unable to determine key signatures[69]. Therefore, exporting MIDI from Melodyn was not an effective basis to begin the (traditional) notated score.

Another type of score I created was a *restoration* score, as detailed in Section 8.3.1.2; these scores contain a record of a Segment's restoration. I began by creating a set of scores representing different points in the restoration process. These are usually based on manually-corrected screenshots from the audio programs in which I performed the restorations. The scores are then marked up to add additional information about the processes I performed, and

[69] Melodyn Version 4 (Neubäcker, 2016), released after my completion of the Album Project, provides algorithms to estimate key signatures.

other data. However, for multiple reasons, these scores are often impractical as records, and erroneous in veracity.

6.1.1.4 Representation and Manual Correction

As mentioned in Section 6.1.1.4.1, extreme precision in Melodyn's representation of blobs is essential for accurate audio manipulation results. While Melodyn's pitch and duration estimation is highly effective compared to other solutions (and is the only one offering any polyphonic capability), the live progressive rock repertoire requires extensive and challenging corrections in Melodyn.

6.1.1.4.1 Factors in Heuristic Accuracy

Melodyn's algorithms are most accurate under specific conditions, few of which are present in live progressive rock. Relevant limiting factors include *background noise*, *polyphony*, *instrumental effects*, and *distortion*.

6.1.1.4.1.1 Background Noise

Melodyn's pitch recognition relies on measuring the amplitude of specific sinusoids in relation to each other. Background noise, such as produced from microphone leakage in live music, can often be loud enough to obfuscate the sound spectrum. Likewise, when audio is transformed, the background noise is transformed as well; this can make the resulting audio unusable, as the transformation is realistic only if applied to the foreground—not the background noise.

6.1.1.4.1.2 Polyphony

Melodyn is significantly more accurate in recognising monophonic audio than polyphonic. Aside from the bass guitar, however, most instruments in progressive rock are polyphonic. Even under pristine conditions, effective polyphonic analysis can be elusive for Melodyn; numerous mitigating factors render it unusable. Unlike with monophonic audio data, polyphonic, recognition errors often cannot be corrected in Melodyn—especially with live music.

6.1.1.4.1.3 Instrumental Effects

In progressive rock, keyboard players and guitarists (almost invariably) apply time-delay audio effects on them (e.g. echo, delay, reverberation). This results in monophonic music becoming effectively polyphonic because the effected[70] audio tails continue to sound during the notes that follow.

If the effected (i.e. *wet*) level is relatively soft, Melodyn can often successfully parse the audio with monophonic algorithms. If it's loud, one approach I employed was to attenuate the audio tails using spectral editing manually. It is challenging to remove these sinusoids without damaging the dry signal on the same track; my results were mixed. With polyphonic material, audio tails often confuse Melodyn's algorithms.

6.1.1.4.1.4 Distortion

Acoustic instruments generally have a recognizable mathematical relationship among overtones, in the form of harmonics—for both frequency and amplitude. This relationship allows fundamental (or perceived fundamental) pitches to be determined; the related sinusoids can then be grouped into a musical unit for further representation, transformation, and further analysis. Distortion, as is common on electric guitars and organs in progressive rock, introduces inharmonic overtones; identifying every overtone that comprises a note, as well as analysis of this note, is problematic for Melodyn. One result is that Melodyn's polyphonic capabilities are usually not functionally available for distorted instruments. These issues are discussed more thoroughly in Section 6.1.1.5.

6.1.1.4.2 Visualisation

Detailed visualisation is required for the Melodyn practitioner to make precise, manual corrections. However, the display of blob parameters, especially amplitude, is coarse. Unlike a waveform display, only a rough approximation of a blob's envelope is portrayed. If note boundaries have not been *correctly* assigned by Melodyn, the lack of amplitude detail is especially problematic, because this information is critical for determining note boundaries (by the practitioner) in the first place.

[70] As in an audio effect.

Pitch-centre information is detailed in Melodyn. However, when Melodyn is unable to determine the pitch of note blob, it simply displays no information. There is no way, in Melodyn, to know anything about the frequency content. Combined with low amplitude resolution, this phenomenon can produce "black holes" of information in note blobs, rendering the evaluation and assignment of blob data problematic. This is especially the case when evaluating whether rapid, unpitched transients—and whether they belong to the end of one blob, or the beginning of another.

A detailed waveform would help. But the best solution, and one required for effectively evaluating note onset, is a spectral display for each blob. For this reason, sometimes my only way to properly align the timing of notes was to export Audio Segments to a spectral editor.

6.1.1.4.3 Essential Offline Pitch Parameters for EAPR

Melodyn's information retrieval algorithms are mostly heuristic, providing a large and complex set of data, across many parameters. Likewise, there are numerous ways to correct this data, and perform specific audio transformations. All of this material is intrinsic to performing EAPR. With an application of such complexity, my discussion here will be limited to parameters for note blobs, and a focus on those essential for EAPR. While I did make use of additional parameters and capabilities in Melodyn, they were not the core functionality I employed.

Table 12: Essential Blob Parameters for EAPR in Melodyn

Aspect	Description
Boundaries	Where (when) does the audio for a note begin and end, physically? This also indicates the note's duration.
Onset	Where (when) does a note begin, perceptually?
Amplitude	Can the amplitude of the note be detected and represented for its entire duration?
Pitch Centre	What is the perceived pitch of the note?
Noise	How are sounds (e.g. a pick scrape) without a strong pitched component classified?

Some of these parameters are perceptual, and others are physical. *Boundaries* is a physical phenomenon—when amplitude increases to reach (or decreases to escape) the threshold of human perception[71]. *Onset* is a perceptual (psychoacoustical) phenomena: when a sound is *perceived* to begin. The onset time may be different from a note's boundary start time (which may coincide with an amplitude transient). For example, an acoustic guitar note's starting boundary may be when the finger first contacts a string; but the onset may begin when that string is released, and harmonics become audible.

Pitch Centre is a perceptual phenomenon because most sounds are comprised of multiple overtones; frequency is in the physical domain. A note may have multiple, overlapping frequencies that form the perceptual basis of the fundamental; therefore Melodyn terms the fundamental the *pitch centre* of the note (and not just the *pitch*). Amplitude is a physical phenomena; volume is perceptual.

Given Melodyn's focus on pitch, there is not a developed representation of, or tools for dealing specifically with, noise. In Melodyn, all audio is represented as note blobs at specific frequencies; when Melodyn cannot recognise the pitch in a blob, the internal pitch line is not displayed—but the blob remains assigned to a specific pitch-centre.

Under ideal conditions, for notes that have both pitched and (often very short) unpitched segments (e.g. picked guitar), Melodyn recognizes the unpitched part; it displays the blob at the pitch centre of the melodic part, and leaves the unpitched section blank. However, it is also common to encounter a blob with this appearance, but where the noise component is simply pitched information that Melodyn cannot recognise; in these cases, the delineation of the blob's noise portion(s) has no meaningful value. For sounds with quick attacks (i.e. most sounds in progressive rock), it is not possible to tell if Melodyn has made this mistake—or not.

Because these recognition errors represent non-trivial problems (and active areas of academic research), a significant portion of Melodyn's user interface is devoted to allowing the manual adjustment of a note blob's parameters. There are two types: properties that affect the meaning of audio (assignment), and ones that physically alter the audio directly when changed (modification). Many note-blob parameters are both.

[71] This threshold is determined by the audio software. In digital audio software, the underlying parameters vary by sample rate and bit depth; a common standard is: 20-20kHz, 0-120db. Human sensitivity to amplitude is influenced by multiple factors (e.g. frequency). The figure given here is common in audio applications; specifically, the dynamic range of 16-bit integer recording, less considerations such as noise filters.

As another example, note onset is purely an assignment parameter. However, note boundaries can be both. Assignment occurs by separating or joining note blobs; it is altered by changing their duration (via length). Pitch centre has two parameters: the first designates a note's pitch *assigned* (intended) value; the other *modifies* that value, allowing a blob's pitch to be shifted (altering its actual frequency components).

As previously discussed, the EAPR practitioner must assign/modify these parameters *precisely* for blobs. This is critical for accurate (and usable) results when (later) making audio modifications to them in Melodyn. (This level of precision is not required for many other uses of Melodyn.) An example of this requirement concerns the restoration of a misplayed note's original timing. Both the *note boundaries* and *note onset* must be assigned perfectly; otherwise, the visual adjustments that I make will not correspond to what is heard. For virtuoso performers, even minute timing inaccuracies are not acceptable. Likewise, when the relationship between *note onset* and *note boundary start* is not correct, then changing the duration of a note will not preserve the attack of the note.

An additional consideration is that the boundaries between notes are often legato, and only a precisely defined point will yield the most accurate modifications. The notes, themselves, especially on guitar, also contain sounds such as pick-noise and pitch-bends that can blur the delineation between note blobs. Ensuring the most effective boundaries and note onsets can be the difference between (traditionally) "fixing" a performance and restoring it.

Likewise, if I incorrectly (manually) assign the pitch-centre of a note (which is possible when the performed pitch is unclear), then the pitch modifications I make won't sound realistic. Melodyn's pitch-shifting algorithm, to produce the most natural-sounding pitch transformations, moves each blob's overtones independently, based on the fundamental frequency. Therefore, my assignments must be correct—I can't simply specify the shift value.

6.1.1.5 Special Considerations for Distorted Guitar

Based on my work with electric guitar on Flying Colors' *Live in Europe* (Flying Colors, 2013), I learned that working with distorted electric guitars, in Melodyn, was significantly more challenging than with other instruments—and that much of my EAPR work would be on this programme material (given that there are two guitarists in Flying Colors).

Distortion, as a performer-introduced effect, creates problems for automatic recognition of note parameters, reducing its accuracy or even making recognition impossible. One problem is that the amplitude and frequency relationships of the overtones are not predictable—indeed, it is this property that creates our auditory perception of distortion. Tasks such as determining the fundamental of a note can, therefore, be considerably more difficult. Likewise, note onset may be difficult to determine, as it can be influenced by when a note's pitched portion is identified as beginning.

Another problem results from the high gain levels. Under these conditions, more nonharmonic overtones are produced, compression increases, and transients will change shape. All these variables can complicate evaluating both note boundaries and onset.

Gain can also obfuscate the pitch of currently sustaining notes even in monophonic performances, because non-played strings will sometimes resonate—either on their own or because they were not perfectly muted. (This creates a polyphonic performance.)

Another gain-related problem is that (originally) soft, non-musical sounds (e.g. pick noise, unintentional note ringing, sympatric vibrations, finger noise) are amplified, competing with the programme material. Detection may be affected, for example. Melodyn may mistakenly conclude that these non-performance sounds are actually musical notes.

If Melodyn determines that these are distinct sounds, Melodyn cannot recognize whether these are intentional (part of the score) or not. If they are part of the score, they might not be intended to be pitched elements at all (e.g. pick slides). They could also be accidental noise. Or, they might be intended as pitched notes, but where the pitch is obscured by distortion. In all three cases, Melodyn has no way to represent this data to the user; it deals only with pitched notes.

As introduced in Section 6.1.1.4.1, the use of audio effects (e.g. reverberation) can significantly reduce the accuracy of Melodyn's recognition and the usability of its transformations. On the Album Project, the two guitarists were recorded differently. The rhythm guitarist was recorded on one track; it combined both the guitar's Dry and Wet (effected) signals. The lead guitarist's tracks were recorded separately for the Dry and Wet components of his guitar. This was accomplished by using different guitar cabinets for each signal, and with separate microphones. However, the Dry track was contaminated by significant leakage from the Wet signal's cabinet.

6.1.2 Flexture Editor

Flexture editing is native to Logic, as with all commercial DAWs except Ardour. As it is a well-known audio transformation tool in DAWs, a discussion of their usage is not required. In implementing the EAPR process for the Creative Submission Album, I used Flexture editing less frequently than Offline Pitch. Melodyn offers time-stretching abilities that are similar to Flexture editing, but with more flexibility, and significantly more musical data.

Flexture Markers support a single, crude musical data variable: the boundary between musical events. While there is one variable for this, Melodyn has three (*start* and *end boundaries*, and *note onset*). Like Melodyn, the identification and assignment of these notes can be performed heuristically; however, the process is generally less accurate than with Melodyn's algorithms, especially with distorted musical instruments.

When I did use Flexture editing, I assigned the boundaries manually. Given that there is only a waveform display to work with when doing so, the visual identification of average transient changes was the only way to gauge the position of event divisions. There is no support in Flexture editing for note onset, and events cannot be separately muted and modified to test the division points.

As I often began my EAPR process with musical event editing, using Melodyn, much of my time-stretching was performed with it. If time-stretching was required during spectral editing, I would perform it directly within SpectraLayers.

There were sometimes advantages to using Flexture editing, however. One advantage was that my workflow could be more efficient and flexible. Flexture editing integrated my timing changes directly into their respective audio regions; therefore, I could then perform additional operations on those regions (including transferring into Melodyn for further modification, though not SpectraLayers). Additionally, Flexture edits became part of the DAW's undo history (unlike Melodyn or SpectraLayers), and audio did not need to be transferred in.

Flexture editing also allowed me to quickly compare average transient changes between tracks, which was especially useful when evaluating the rhythm of instruments in relation to each other. This led to a meta-technique where I might restore each track's timing using Melodyn, render the tracks, and then use Flexture edits to restore the timing between instruments.[72]

[72] This technique was supplemented with my use of ARA, and the release Melodyn 4, which allowed simultaneous pitch, amplitude and timing visualization within Melodyn across all tracks assigned to Melodyn. I used this technique on the Supplementary Submission Album, summarised in Chapter 0.

6.2 Raw Audio Transformation

While musical event editing was of significant use in both the analysis and modification of audio, it was limited to the specific musical data and transformation endemic to it. The editing of raw audio, theoretically, allows *any* type of audio modification. There are two significant challenges, however, within EAPR. First, it is often challenging to recognize what, in the audio display, corresponds to the sonic item of interest. Second, it is likewise challenging to imagine and perform the specific modification required to create the desired sonic alteration.

There are two major types of editors that operate on raw audio: Waveform editors, and Spectral editors. All digital audio is stored as a series of amplitude levels corresponding to specific points in time. Waveform editors display and facilitate editing of this information verbatim. Spectral editors sacrifice a degree of precision to allow a third variable to be extracted: frequency.

6.2.1 Spectral Editing

Spectral editing occurs on a graph with three dimensions: time, frequency and amplitude. As such, visualisations and edits that (for all practical purposes) would be impossible using waveforms. But they can be facilitated through spectral editing.

A spectral display is created by analysing the audio, using either a Fast Fourier Transform or wavelet analysis. (Because FFTs are used almost exclusively[73] in spectral editors, I will assume FFT usage for spectral editing in this discussion.) Unlike waveforms, which have a one-to-one representation to the underlying audio data, spectral displays can never display all of the underlying audio data; this is a mathematical limitation, not a programming one.

Spectral displays use an FFT to analyse audio in user-defined blocks of time (the *sample window size*), so every spectral display is constructed with specific time and frequency resolutions. The relationship is reciprocal: as the resolution of one increases, the other decreases. Therefore, even at a granular level, the practitioner can visualise and modify only averages of time and frequency.

[73] Wavelets may be used in spectral editors, but are generally too slow for more than visualization.

There are three variables in a spectral display, but only two dimensions are available on a visual display. Spectral editors typically assign the x-axis to time, and the y-axis to frequency. Amplitude is represented as the colour and/brightness of frequency data.

There were two workflows available for me to use spectral editors: DAWs with native spectral editors, and SAAs. Of the two options, a native DAW implementation was preferable, due to the workflow advantages. The question was whether the more feature-rich SAAs provided significantly superior capabilities for EAPR. First, I would identify the common features to most spectral editors relevant to EAPR. Then, I identified any relevant EAPR features unique to specific editors.

The DAWs supporting spectral editing were Cockos' REAPER and two MAGIX DAWs: Samplitude and Sequoia. The SAAs were iZotope RX 4, MAGIX's SpectraLayers 4, Cedar Retouch 5, Steinberg's Wavelab 8, and Adobe's Audition CC.

The common, relevant spectral editing features were basic: An offline-adjustable FFT display, manual tools to select a specific part of the spectrum for editing, heuristic tools to automatically select related sinusoids, numeric amplitude adjustment of selections, and copy and paste of selections.

Spectral editing features relevant to EAPR are listed and defined in Table 13, below.

Table 13: Relevant EAPR Spectral Editing Features

Product	Unique EAPR Features
Amplitude Hue	Instead of a monochromatic spectrogram with brightness to indicate amplitude, a colour map of hues is also used. This increases the visible dynamic range for amplitude.
Heuristic Repair	Attempts to remove small audio events by replacing them with an estimation of the background noise. While useful in some contexts, it is unreliable for live audio due to constantly changing background audio (i.e. the PAS instrument itself and bleed).
Real-time FFT	Allows the user to alter the spectrogram's parameters in real-time while editing. Important for precision editing because FFTS contain detail in either frequency or time, but not both.
Layers	Akin to layers in Photoshop. Permits experimentation by providing places to extract sounds, and a permanent (though manual) undo buffer to be created.
3D Visualisation	Instead of using brightness (or that and hue) to indicate amplitude, the z-axis is employed. Helpful because visualising detail is important, and this provides an additional perspective.
Burn/Dodge Tool	Similar to Photoshop: Allows precise amplification or attenuation without requiring selection. This is much faster than using selections and numerical adjustments.
Stamp Tool	Similar to Photoshop: Enables the user to set a copy point, and then paste into a near area wherever the tool is applied. In addition to being much faster than using selections, it creates smoother edits.
Tool Size	Similar to Photoshop: Allows the user to set the size of tools (e.g. Burn/Dodge, Stamp). This permits more precise control over an operation's area than with selections.
Tool Opacity	Similar to Photoshop: Sets the strength of the tool. This is the most important of all the spectral editing features for EAPR. It enables faster workflow, and ultimately much more realistic editing than with selections.

Support for these features is shown in Table 14, below.

Table 14: Relevant EAPR Spectral Editing Support

Editor	Publisher	Vers	Unique EAPR Features	Reference	OS's
Audition	Adobe	CS6	Amplitude Colours, Heuristic Repair	(Adobe Systems, 2012)	mac OS, Windows
REAPER	Cockos	4.5	Amplitude Colours	(Francis, 2013)	Windows
RX	iZotope	4	Amplitude Colours, Heuristic Repair	(iZotope, 2014)	mac OS, Windows
Retouch	Cedar Audio	5	Amplitude Colours, Heuristic Repair, Stamp Tool	(Cedar Audio, 2012)	Windows
Samplitude	MAGIX	X1	Amplitude Colours	(Richter, 2011)	Windows
Sequoia	MAGIX	12	Amplitude Colours, Heuristic Repair	(Richter, 2012)	Windows
SpectraLayers	MAGIX	4	Real-time Adjustable FFT, Layers, 3D Visualisation, Brush Tool, Stamp Tool, Tool Size, Tool Opacity	(Lobel, 2015a)	mac OS, Windows
Wavelab	Steinberg	8	Amplitude Colours, Heuristic Repair	(Steinberg, 2013)	mac OS, Windows

The spectral editor survey revealed SpectraLayers as the most effective tool for EAPR. While Heuristic Repair was a useful feature, it was largely ineffective with my programme material. Amplitude Colours were useful but did not offset all the other features unique to SpectraLayers, especially the availability of resizable tools with adjustable opacity. These abilities not only represented substantial savings in efficiency, but also enabled more precise and realistic edits. Likewise, the workflow savings with DAW integration did not offset these features.

6.2.1.1 The SpectraLayers Application

There is only one advanced spectral editor: SpectraLayers (Lobel, 2015a); I used Version 4 on the Album Project. It is a completely manual editing program; all operations are performed directly on the spectral display. (Later versions include heuristic, automated functions.) I used two basic abilities that could be applied to arbitrary sections of the audio spectrum: amplitude modification, and copy/paste/move.

For amplitude changes, I employed a resizable, round brush that either amplifies or attenuates the audio spectrum beneath it. Two key variables are transformation strength, and cross-fade geometry (around the brush). I employed two different tools for copy/paste/move; one employed a crossfade region, the other did not.

Theoretically, simply being able to change the amplitude of any region of an audio spectrum allows a practitioner to make any imagined change to the audio, and create every sound that is possible. In practice, it is non-trivial to determine the correlation between what is seen on a spectral display and to impart imagined changes to it.

6.2.1.2 Challenges in Spectral Editing

Unlike with a musical event editor (e.g. Melodyn), none of the visual data in a spectral display is imbued with musical meaning; as with a waveform display, such meaning must be inferred and constructed by the practitioner. More information is available, however, as frequency data is not visible in an audio waveform. This is a complex topic, and only a partial overview, relevant to the audio examples later in this chapter, will be discussed.

A significant challenge with spectral displays is the lack of resolution. It is not possible to observe or alter individual sinusoids (though it can appear so). If the display is imagined to be comprised of pixels, each pixel is an average of both time and frequency, with the resolution of each controlled by the FFT window size. One way I addressed this issue was by continually altering the window size, sweeping through different values. In the end, though, it's possible to make only audio modifications with the window size at one value. When working, I seek a window size that best expresses the information I need for a specific edit.

Even if the resolution issue could be resolved, the most serious issue with spectral editing is the difficulty of locating which parts of the spectral landscape correspond to the audio you are hearing—or where and how the sound you want to hear would exist. Most sounds are comprised of sinusoid groups at different frequencies, each with its own amplitude envelope. To "find" a sound, the practitioner must be able to identify all of those sinusoids. Likewise, to alter or create a sound, she must know the frequency and amplitude envelopes for each sinusoid.

One strategy, if working with tonal sounds (especially acoustic ones), is to look for sinusoid approximations with larger amplitude values than those in the surrounding spectrum—and for frequencies that approximate the harmonic series. This can usually allow a portion—sometimes a significant portion—of a sound to be identified. However, unless all the sinusoids are identified, then any modifications to the (partial) group of sinusoids will exhibit audio artefacts rendering the transformation useless.

There are several factors complicating the identification of all the sinusoids. One is that even acoustic, tonal instruments have inharmonic components (e.g. plucking sounds on stringed instruments, breaths on flutes) that are often required to be included in any modification of a sound. (Also the practitioner must understand why the underlying audio produces that sound). Another reason concerns overlapping sounds, such as with polyphony. In this case, multiple sinusoids are competing for the same frequency space; attenuating a second harmonic for one sound can attenuate the fourth harmonic for another—at different places in each sound's envelope.

The live progressive rock repertoire has elements that introduce and exacerbate many confounding factors in reading the spectral landscape and producing modifications free from audible artefacts. These factors are similar to those discussed in other contexts throughout this thesis, such as Section 6.1.1.4.1: leakage, audio effects, accidental and incidental sounds, and (intended and unintended) distortion. All of these sound sources obscure and create potential editing pitfalls in the spectral landscape. Intentional guitar and organ distortion is particularly misleading, as it creates many new overtones, some which of which are not in the harmonic series.

There are several strategies I developed for spectral edits, though many successful ones were time-consuming, requiring considerable analysis and experimentation. And it was not uncommon for me to be unable to make a successful edit—other approaches were required (i.e. other software tools, or a combination thereof).

The most important skill I developed during my work on the Creative Submission Album was in reading the spectral landscape. Some of this was executed by identifying and performing calculations on apparent overtones to find harmonic correlations. The most effective resource I found, though, was experience. Over the course of the Submission, I began to see patterns emerge in the spectrum, and estimate which non-harmonic sinusoids were relevant to what I was looking for.

The next skill was learning how to perform EAPR Rendering in the spectral landscape. While it is theoretically possible to create any sound in a spectral editor, it is non-trivial to create any *specific* sound. The repertoire I was modifying was comprised of complex sounds that evolved and changed significantly over time. My tasks included determining what changes, to which sinusoids, would produce the sound of a specific picking articulation I was aiming to restore.

With experience, I found myself able to solve many of these problems. With practice, my transformations increased in realism, and eventually, authenticity. Effective transformations sometimes required modifying specific parts of a sound with different modifications. But although realistic in terms of what the listener imagined the performer was doing, sound artefacts were often present that rendered the result unusable.

The presence of sound artefacts after transformations was the most significant problem I encountered, and the most common reason why I needed to abandon either my specific approach or spectral editing altogether (before perhaps returning to it after modifications in a different audio application). As discussed, this was partly a result of failing to identify every sinusoid in the sound I was modifying (which was generally impossible). The other factor was that when reassembled to hear, each of the modified sinusoid regions needed to combine congruently and without phasing—so even if I was able to read the spectral landscape perfectly, I would need to modify it, as well.

The solution that emerged was that often, it was possible to identify a small group of sinusoids that when modified, would carry enough harmonic change to trick the listener into perceiving the whole sound had changed. This wasn't necessarily a function of the overtone's amplitude—it was also a psychoacoustic phenomenon. By minimising the number of sinusoids, I minimised the potential for sonic artefacts.

Artefacts, in turn, could then be further reduced by avoiding drastic amplitude changes during my modifications—instead of erasing existing (and creating new) sinusoids, I only attenuated or amplified them. This combination of transformation techniques, combined with the visualisation and modification techniques I developed, typically allowed me to make the spectral changes I intended to a high degree of realism.

6.2.2 Waveform Editing: DAW Native

Waveform editing is the standard audio editing mechanism in DAWs; as such, it does not require explication here. Given that the specific technical needs of EAPR were best addressed with Musical Event and Spectral editors, I seldom employed waveform editing.

Waveform editors are native to all major DAWs; there were many Stand-Alone Audio editors that provided waveform editors, along with additional capabilities—but none of them enhanced the visualisation or editing capabilities relevant to the needs of EAPR. Therefore, due to the workflow advantages of native editing (i.e. within the DAW), I chose to use my DAW's internal waveform editor. Because DAW waveform editors do not significantly differ between DAWs with respect to EAPR, this decision would not affect my choice of DAW.

One of these workflow advantages was direct support the DAW's undo buffer, allowing for fine adjustments stepping backwards and forward through edits. In contrast, changes I made in TPP (i.e. Melodyn) SAAs (i.e. SpectraLayers, RX) could only be reverted within a separate undo buffer inside those editors. The ability to revert effectively to previous edit states was important for EAPR: My first restoration attempt was rarely successful, and it might be hours later, in a different editor, when the mistake would emerge.

Melodyn's undo buffer was maintained until I needed to perform a different type of transformation; then, the Melodyn transformations were rendered to a new audio file—this process could not be reverted. SpectraLayers and RX were even less flexible: I could only revert changes during a specific edit; after completing one, all changes were permanent. (To enable backtracking, I maintained multiple versions of files, which not all DAWs support in this context, leading to organisational challenges due to their being hundreds of such files.)

The frequency with which I used waveform editors, however, was rare. My external editors were usually more efficient and effective. As discussed, Melodyn often allowed (though sometimes with significant manual preparation) audio to be interacted with in a musical context, and often allowed transformations such as tuning and transposition. And SpectraLayers often provided, effectively, more accuracy than waveform editing due to the additional dimension of frequency (in addition to amplitude and time.)

6.3 Audio Restoration

When I began my investigation of audio tools to implement EAPR for the Album, a logical class of tool to consider was Audio Restoration tools. Indeed, a Spectral Editor could certainly be considered as part of this category. Spectral editors can be used for tasks other than audio restoration, such as source separation (Walden, 2016). SpectraLayers, specifically, was envisioned as a creative tool (Rothwell, 2012), in addition to audio restoration needs (Bookwalter, 2017).

Before continuing, I will establish my usage of "Audio Restoration", and then of Audio Restoration tools. Godsill et al. define Audio Restoration as removing "outliers", sonic artefacts that are not part of (or intended to be part of) the recording, itself (Godsill and Rayner, 1996). Within the context of EAPR, I refer to these outliers as Non-Program Audio, and will define audio restoration as *the transparent removal of audio that is not produced by the instrument as part of the performance.*

Therefore, for example, removing the sound of a performer hitting the pickup accidentally on a bass would not be considered audio restoration in EAPR; it would be part of Performance Restoration. Removing hum, introduced into a track during recording due to EMI interference, would be considered audio restoration in EAPR.

Apart from spectral editors, most audio restoration tools operate as user-adjustable automated algorithms. According to Paul White, the most common audio restoration tools that remove clicks, buzzes and noise (White, 2010). CEDAR Studio, considered amongst the most capable restoration tools (Robjohns, 2015), was at version 5 during my investigation; it provided three restoration modules: Dialogue noise suppression, Debuzz and Declip. {Morton:2013us}.

In the Encyclopedia of Information Science (Khosrow-Pour, 2015), Maue and Kush use iZotope RX to describe the state of the art in audio restoration, claiming it is the industry standard (Maue and Kush, 2015). They suggest these RX modules as being for audio restoration: Declip, Declick, Decrackle, Remove Hum, Denoise, and Spectral Repair.

Spectral Repair, iZotope's name for the automatic removal of sounds through heuristic estimation of the remaining background noise (iZotope, 2014), is worthy of special consideration in implementing EAPR. This functionality is included in several audio restoration packages, including CEDAR Studio, and is used by other practitioners, such as Michael Brauer and Ryan Gilligan, in live progressive rock in post-production (Gilligan, 2016).

After analysis, I determined this was not an important tool for implementing EAPR. One reason, Gilligan reveals, is that the tool is not reliable in its effectiveness (Gilligan, 2016). Additionally, he states that it is only useful for removing short sounds, a description echoed by iZotope itself. During my investigation, I found it more effective to learn to remove unwanted sounds (that were in a performance restoration context) manually using SpectraLayers, than by relying on RX's Spectral Repair. This was only possible in SpectraLayers, though, and not other spectral editors, due to features such as the resizable brush with variable opacity. Manual editing also granted me more flexibility; instead of simply removing sounds, I could also modify them, as that was sometimes the requirement for restoring the performance.

Turning to the more standard automated algorithms, most of them did not apply to the Creative Submission Album. There was no clipping, crackling or hum. There was, however, a significant problem with audio clicks; these were not part of the recorded performance, but were introduced as an artefact of the audio transformation process. I chose iZotope RX 4 for this task. I discuss this issue, in more depth, in the next section.

6.3.1 Heuristic Click Removal: RX

Audio clicks, as accidental artefacts, are caused by (unintended) rapid changes in waveform amplitude. In my workflow, it was an artefact of using Melodyn, as a result of *hard separations*. This operation splits a blob into two blobs. While the user has general control over where the division occurs, Melodyn does not offer the precision of waveform editor to control exactly where the cut takes place; nor does it offer a crossfade option.

After a cut, I would reposition, remove, or modify one or both of the two resulting blobs. If, as a result, there was a large amplitude difference between one of the cut points and the new audio following or proceeding that transition, an audio "click" was often manifested (Discoll, 2015).

There are several ways to remove audio clicks without damaging the surrounding audio. One way is to redraw the audio waveform around manually, and include the transition point (White, 2012). This can be done with a waveform editor, and is significantly challenging. Another is to remove the click, manually, in a spectral editor; this approach is less challenging but still time-consuming.

As discussed, most audio restoration programmes provide automated heuristic algorithms to remove such artefacts. Most such tools were implemented as real-time plugins; some were offline, and others still offered real-time and offline versions. In testing of different tools on my programme material, the offline versions were preferable for two reasons. The first was that they offered superior transparency. The other was that offline processing offered another advantage for my workflow, as click removal was more useful as a permanent change to audio files.

The Sequoia DAW included audio restoration in feature set, including spectral editing and audio restoration algorithms. As discussed in Section 6.2.1, Sequoia's spectral editor was not as effective for EAPR as SpectraLayers. Its audio restoration tools were also not a good match for EAPR, because they were not part of the program itself; they were implemented as plugins. As such, they offered neither the workflow advantages of native editing nor the specific offline click-removal advantage for EAPR.

Based on my analysis of audio restoration within the context of EAPR, and the results of my testing, I chose iZotope RX 4 for audio restoration tasks for the Album. With my spectral editor set to be SpectraLayers, the only audio restoration need was click removal. Several offline click removal tools would have sufficed. RX was relatively inexpensive[74], and its De-Click module (iZotope, 2018) was consistently transparent, effective in every instance for removing clicks during my production, with minimal adjustment of parameters.

74 CEDAR Studio, at the time of my investigation, was $14,203. {Morton:2013us}

6.4 Summary

In summary, the tool categories, and specific selections for these them, are summarised in Table 15:

Table 15: Tools Taxonomy of, and Selections for, the Creative Album

Tool Category	Selection	Version
Project Management	Logic Pro X	10.1
Flexture Editor	Logic Pro X	10.1
Offline Pitch Editor	Melodyn Studio	3.2
Spectral Editing	MAGIX SpectraLayers	4.0
Waveform Editing	Logic Pro X	10.1
Audio Restoration	iZotope RX	4

6.5 Project Management: Logic Pro X DAW

The logical choice for management of the audio project was a Digital Audio Workstation. DAWs are a monolithic application framework which support many aspects of audio and MIDI production on a single project: organising, composing, recording, editing, mixing and mastering. As such, they provide significant functionality for both of the project management needs I required: organising project elements, and controlling how audio data could be edited. After careful evaluation, I selected Apple's Logic Pro X (Apple, 2013b) DAW. In this section, I discuss my criteria for this choice, and how I used this software for the Creative Submission Album. Given that DAWs are well established in the industry, and generally share feature parity (Korff, 2015), our discussion here will be narrowly focussed on considerations unique to my investigation.

6.5.1 Project Management

Most of the project organisation features I required are standardised across DAWs, such as non-destructive audio file regions, visual track-grouping (e.g. folders), and the assignment of names and colours to tracks and regions. An uncommon organisational need emerged, however: multiple sets of timeline markers.

Timeline markers have long been standard in every commercial DAW, providing user-named marking points on the DAW timeline. In EAPR, they are used for two purposes. The first is to define the boundaries of each time-based error repair region of a track, termed an *Audio Segment* in EAPR[75]. The second is store a description of the technique used (or attempted) to restore the performances in that Segment.

This level of specification is necessary for two reasons. One is that audio modification methods in EAPR are relatively complex, sometimes requiring multiple techniques across several audio tools. These methods can also be unique to one specific Audio Segment. The other reason is that over the course of a praxical investigation, I must refer back to work on previous Segments to inform the creation and application of new techniques (as well as

[75] For reference, there are 245 instrumental Segments defined in the Creative Submission Album; see Appendix B for the complete list.

revisions to the EAPR process, itself). The only way to store these notes is in the name of the marker, itself.

Most DAWs, however, only support one global set of track markers. This is a problem for EAPR because two performers may make errors at the same time. (In my practice, this is common.) Even instruments recorded onto multiple tracks may require different techniques to be applied to tracks (e.g. Wet Guitar and Dry Guitar) comprising that instrument. However, there is no way to mark the boundaries of overlapping Audio Segments on one global marker track.

Logic Pro X's Marker Sets (Apple, Inc., 2017) allowed me to assign specific markers to each performer. For each performer, this allowed me to: Define the boundaries of each Audio Segment, and document my restoration procedure in each one. I employed additional Marker Sets data such as video editing, indicating precisely where a close-up on a performer's hands could not be used.

6.5.2 Editors

In the introduction to this chapter, I defined two editing paradigms I wished to use for EAPR, and the two types of editors available for each of them. Cumulatively, these editors are: Offline Pitch, Flexture, Waveform and Spectral. All major DAWs include deployments of at least one of these editors, natively. Part of my DAW selection process was to evaluate every such editor of each DAW, comparing them to each other, and to available external editors.

Native editing offers two primary workflow advantages: elimination of audio export/import requirements, and direct undo/redo support. External third-party editors, however often offered superior functionality. The decision, affecting DAW selection, came down to which approach (including the specific external editor, if applicable) offered the greatest advantage for EAPR. In making these decisions, I balanced technical flexibility against workflow; my practice was commercial, and the time required for performance restorations was a factor.

Waveform and Flexture editors are native to most DAWs. The implementations, relevant to EAPR, are not significantly different. Although there are some SAAs that support these types of editing (especially waveform), these applications' implementations do not offer any additional features relevant to implementing EAPR. For workflow efficiency, I therefore aimed to use DAWs that supported them natively (internally). A detailed discussion of my selection of these editors is in Sections 6.1.2 (Flexture) and 6.2.2 (Waveform) of this chapter.

Offline Pitch Editors were native to several DAWs at the time of my production. Unlike Waveform and Flexture editors, the implementation in supported DAWs varied considerably. However, none of them approached the capabilities or sound quality of high-end external editors. This topic is further explored, along with my editor selection, in Section 6.1.1.

Spectral editing, which I used significantly in the Creative Album Project, is supported natively by a minority of DAWs. After reviewing the features of native editors in each of the DAWs that included them, it emerged that their capabilities were far from those offered by dedicated SAA spectral editors—and that these additional capabilities were applicable to my needs. The DAWs supporting this feature are indicated in Table 16, and a complete discussion of my selection for spectral editor is in Section 6.2.1.

One DAWs worthy of special consideration was Sequoia. It appeared to be a strong contender given its native spectral editing and audio restoration algorithms. However, its spectral editor, while the most sophisticated of all DAWs, did not support the many important EAPR-specific features of SpectraLayers. Its restoration abilities, like RX, were algorithmic. However, RX contained all the algorithm types of Sequoia and many more. The restoration algorithms Sequoia did have were implemented as plugins, not native functions—therefore, they offered no workflow advantage over RX or Cedar Audio.

Celemony's ARA (Audio Random Access) editor protocol, as discussed, provided workflow improvements by eliminating the requirement of transferring audio into Melodyn 3. It was available in Samplitude X1, Studio One 2.6 and Tracktion 5. While still relatively new in 2015 (Korff, 2015), this functionality appeared to hold great promise for improving my EAPR implementations.[76] However, the benefit at that time (a modest workflow improvement) did not offset the benefits of Marker Sets (a pivotal capability for organising, documentation and tracking my investigation).

[76] Melodyn 4 offered significantly more functionality for EAPR. It was released in time for use on the Supplemental Submission Album. Even with the importance of Marker Sets, I switched to Studio One Pro with ARA to implement the EAPR Process for that project. This evolution is discussed in the thesis' conclusion, Chapter 0.

A summary of EAPR-specific DAW editor features identified for deciding my Project Organisation requirement is shown below in Table 16

Table 16: EAPR-Specific DAW Editor Features

Product	Vers	Publisher	EAPR Unique	Refs	OSs
Acid Pro	7	MAGIX		(MAGIX, 2016)[E]	macOS, Windows
Ardour	4	N/A[A]	- Flex Edit	(Holzer, 2014)	macOS, Windows
Digital Performer	8	MOTU		(MOTU, 2012)	macOS, Windows
SONAR	X3	BandLab		(Cakewalk, 2013)	Windows
Cubase	8	Steinberg		(Steinberg, 2014)	macOS, Windows
FL Studio	11	Image-Line		(Image Line Software, 2013)	macOS, Windows
Live	9	Ableton		(DeSantis, 2013)	macOS, Windows
Logic Pro X	10.1	Apple	+ Marker Sets	(Apple, 2013b)	macOS
Mixcraft	7	Acoustica		(Acoustica, 2014)	Windows
Nuendo	6	Steinberg		(Steinberg, 2012)	macOS, Windows
Pro Tools	11.3	Avid		(Avid, 2014)	macOS, Windows
REAPER	4.5	Cockos	+ Spectral Editing	(Francis, 2013)	macOS, Windows
Reason	8	Propellerhead		(Propellerhead, 2014)	macOS, Windows
Samplitude	X1	MAGIX	+ ARA + Spectral Editing	(Richter, 2011)	Windows
Sequoia	12	MAGIX	+ Spectral Editing + Audio Restoration[D]	(Richter, 2012)	Windows
Studio One	2.6	PreSonus	+ ARA	(PreSonus, 2013)	macOS, Windows
Tracktion[C]	5	Tracktion	+ ARA	(Edstrom, 2015)	macOS, Windows

[A] While Ardour is listed under the GPLv2, Paul Davis has claimed ownership and charges a fee for it.
[B] Tracktion doesn't issue manuals; they are written as independent books by Bill Estrom. Edstrom did not write one for Tracktion 5, however—only for Tracktion 6. Tracktion 5 was released on June 16, 2014.
[C] Now called "Waveform".
[D] Implemented as plugins.
[E] This manual was a reprint of the original from 2008.

7 : Example Restoration from the Creative Submission Album

In this chapter, I will present an example EAPR restoration (as defined in Section 4.4) from the Creative Submission Album, using the practical implementation defined in Chapter 5. The example will take the form of a praxical narrative, following the basic timeline and order of operations as they occurred. The knowledge of this restoration, as with all the restorations performed on the Album, fed back into and further informed the development of the theoretical EAPR model.

The example restoration is of two contiguous Audio Segments, numbered 80 and 81. (These Segments are referenced in the album's error catalogue in Appendix B. Combined, the two Segments are 13 seconds long. They occur during the first song of the concert, "Open Up Your Eyes."

I have chosen this example because the errors in these Segments represent a broad selection of the EAPR error taxonomy; a broad array of techniques for analysis and restoration are demonstrated. Annotated screenshot composites from the audio tools I used are presented to document my process and support my conclusions. The steps I took in restoring each performance error, the criteria used for evaluation, and the obstacles encountered, are documented. The relevant audio files will accompany this thesis. Additional examples are presented in Appendix E in a more summarised presentation style.

Over the course of the praxis in engineering the creative submission (album project), I restored 245 Audio Segments, ranging from milliseconds to several minutes, covering thousands of individual error events. For 22.5% of the album's running length, EAPR was implemented and experienced by the listener on at least one track. The complete accounting of this work is presented in Appendix B.

Limitations on word count and other institutional parameters prevent an exhaustive narrative of the restoration diary. The narrative in this appendix focuses on techniques and results most pertinent to informing the reader about my process. Some stages of the restoration will be combined into single discussions to prevent repetition. Where space can be saved, steps will be abbreviated or summarised. Section 8.3.1.2 explores the exigency of recording a praxical account of my progress on the Creative Submission Album while using the specific tools employed to realise EAPR. This discourse also comes into play in my consideration of further research in Chapter 8, the conclusion to my thesis.

The instrument to be restored in Audio Segments 80 and 81 is Lead Guitar. It was recorded from two amplified cabinets[77] on stage. One cabinet carried the guitar's dry signal; the other carried the wet (e.g. reverb, delay) signal. They were recorded onto separate tracks for the album. (See Figure 31.)

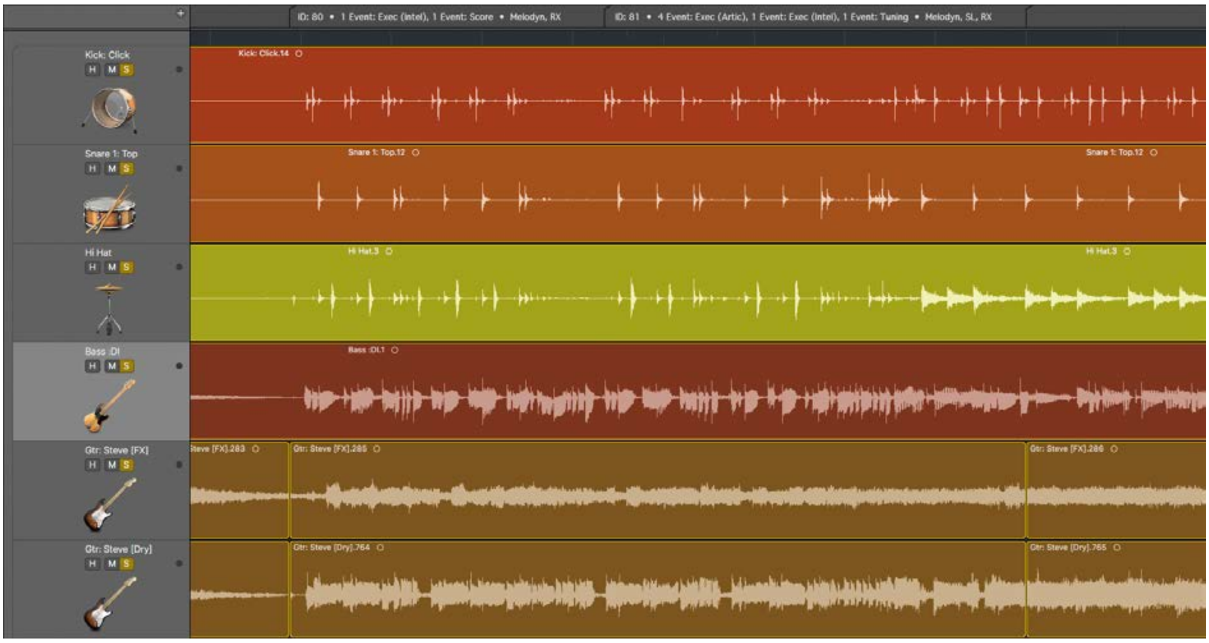

Figure 31: Starting Point in Logic Pro X for the Creative Submission Album Example

As discussed in Section 4.3.1, knowledge of a performer's technique is an important knowledge base to draw from when analysing performance errors. Two important techniques for the band's lead guitarist, in the context of restoring Segments 80 and 81, are *picking* and *muting*.

The lead guitarist for Flying Colors employs a litany of picking techniques. In this example, however, he employs only alternate picking. This is one of the two techniques where every[78] note is struck with the guitar pick (plectrum). It is in lieu of *economy picking*, where the most direct route to pick the next string is always used. In *alternate picking*, every note is picked in alternating directions, even if this means skipping over the desired target-string, and then doubling back to strike it in the opposite direction. When I am listening to the Lead Guitar

[77] A *guitar cabinet* refers to an enclose containing a large speaker, or array of speakers, for reproducing a guitar at significant stage volume.
[78] Legato picking, where typically only the first note of a string is picked (with the remaining notes pressed only with the fretting hand), is generally more widely used in popular music.

tracks in the Creative Submission Album, and he has picked a string, I then have data available regarding the physical process, intention, and sonic analysis.

His muting style likewise informs my process. For muting, he employs a completely unique style which requires him to position his right hand in a non-standard position. His goal is similarly unique, due to its extreme difficulty: He mutes every note on the guitar which should not be resonating, regardless of playing speed.

With his fretting (left) hand, he follows one string behind, muting strings manually. With his picking (right) hand, he creates an arch that mutes all strings except the one currently resonating. This also allows him to control the release velocity of notes by applying differential dampening.

Due to the difficult of muting every string, consistently, some guitarists will not attempt to mute troublesome strings. When I hear a sustaining string on the Creative Submission Album, on the Lead Guitar tracks, which is not in the score—a performance error is implied.

7.1 Analysis Phase

My Analysis phase for the example consisted of Screening, Authentication and Triage. My process for each is summarised below, before moving on to a detailed description of the Restoration phase.

7.1.1 Screening

While auditioning the Lead Guitar tracks in "Open Up Your Eyes", I came upon a 13-second instrumental break that appeared to contain performance errors. It is composed of two repeating melodies; the second is a slight variation on the first. I organized the break into two contiguous Audio Segments (80 and 81 in Appendix B)—one for each of the melodies.

7.1.2 Authentication

An investigation of both Segments confirmed that they contained performance errors, and that the errors originated on the lead guitar track. At this stage, I did not isolate or identify specific errors; rather, I simply noted their presence and determined their origin.

I began by first listening to both guitar tracks in isolation. I then looked for discrepancies between the Wet and Dry tracks that could incorrectly manifest themselves as performance errors. Next, I listened to the tracks simultaneously with different groups of tracks from the full mix. (What appeared to be an error on the lead guitar track might actually be an audio event on the keyboard track—or there might be an audio event that was formed by a combination of multiple tracks.)

7.1.3 Triage

My triage considerations were the audience's expectation of lead guitar perfection in progressive rock, the additional exposure the guitar received in this instrumental section, and its placement early in the concert (thus colouring the audience's expectations). These factors led me to flag Segments 80 and 81for performance restoration.

7.2 Restoration Phase

During the Analysis Phase, I identified Audio Segments 80 and 81. I began Restoration in the Logic DAW by creating markers for the Segments, and creating corresponding audio regions within the Lead Guitar's Dry and Wet tracks. This procedure visually demarked, both on the DAW timeline, and on the tracks themselves, the locations of the two Audio Segments.

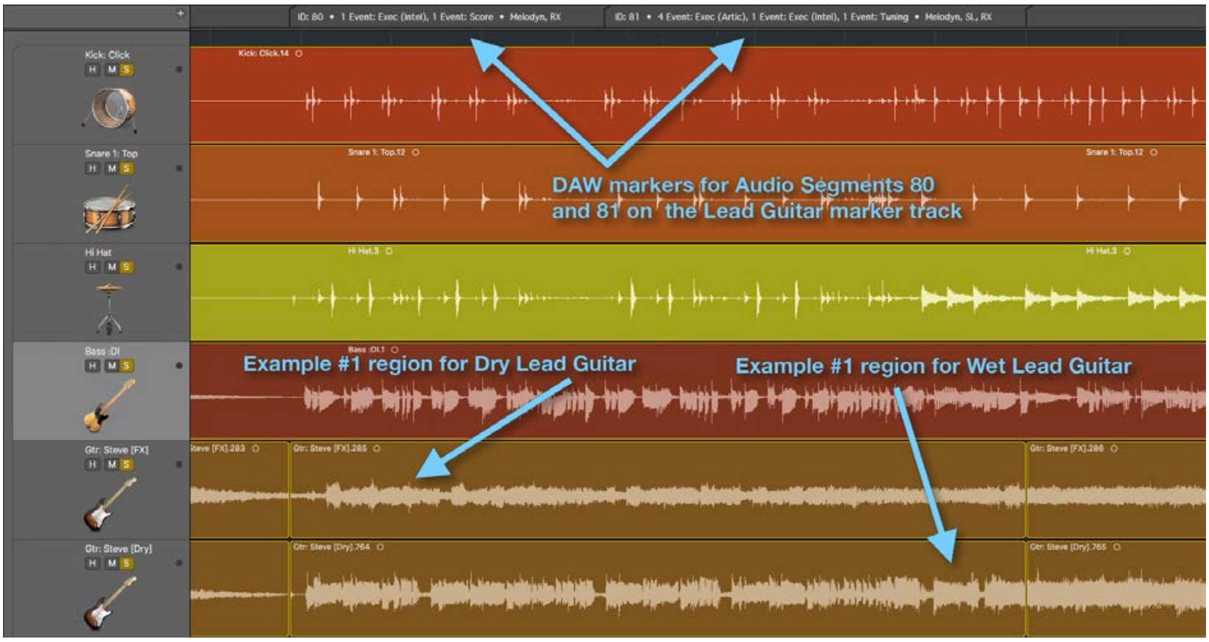

Figure 32: Regions Created on Wet (FX) and Dry Lead Guitar Tracks for Audio Segments 80 & 81

In delineating the restoration work, I decided to work on the two segments simultaneously: they were contiguous and contained the same basic melody (allowing comparison between the two). For each track, one audio file was therefore exported, containing both segments. These audio files would be used for examination and modification in performing the restoration. At the end of the process, two new audio files (containing the restored performances) would replace them.

7.2.1 Conceptualisation

As introduced in Section 4.4.2.2.2, Conceptualisation is the process of determining the two scores required for Restoration: Performance and Intended. The performance score represents the recording of what the performer played. The Intended score represents the performance that the recording musician intended to make.

7.2.1.1 Generating the Performance Score

In this section, I will cover my generation of the Performance Score. Included will be an introduction to general strategy and a spotlight on specific corrections. Along the way, EAPR scores will be used to illustrate specific steps. Concluding the section will be a noted score of the performance score.

7.2.1.1.1 General Strategies

I used the Dry Guitar track to build the performance score, as the Wet track was (mostly) delay and reverbs applied to the Dry track; it was also ~400ms behind. The Dry track was still challenging for Melodyn to parse; guitar distortion was applied to the signal, other instruments from the stage leaked through, and a significant amount of the Wet channel bled onto it.

Once I had corrected Melodyn's initial parsing of the Dry track, I could reference it while constructing the Wet track's score (which Melodyn would have more difficulty correctly parsing). Having separate tracks for guitars can significantly increase the difficulty of EAPR's Rendering stage, because any changes made to the Dry track must be made to the Wet track, with perfect pitch, timing and phase (to avoid audio artefacts). With experimentation, though, I found that certain changes to the dry track did not need to be made to the wet track; I auditioned the relevant sections of restored Dry and Wet tracks, mixed together, to determine when modification of only the Dry track was sufficient.

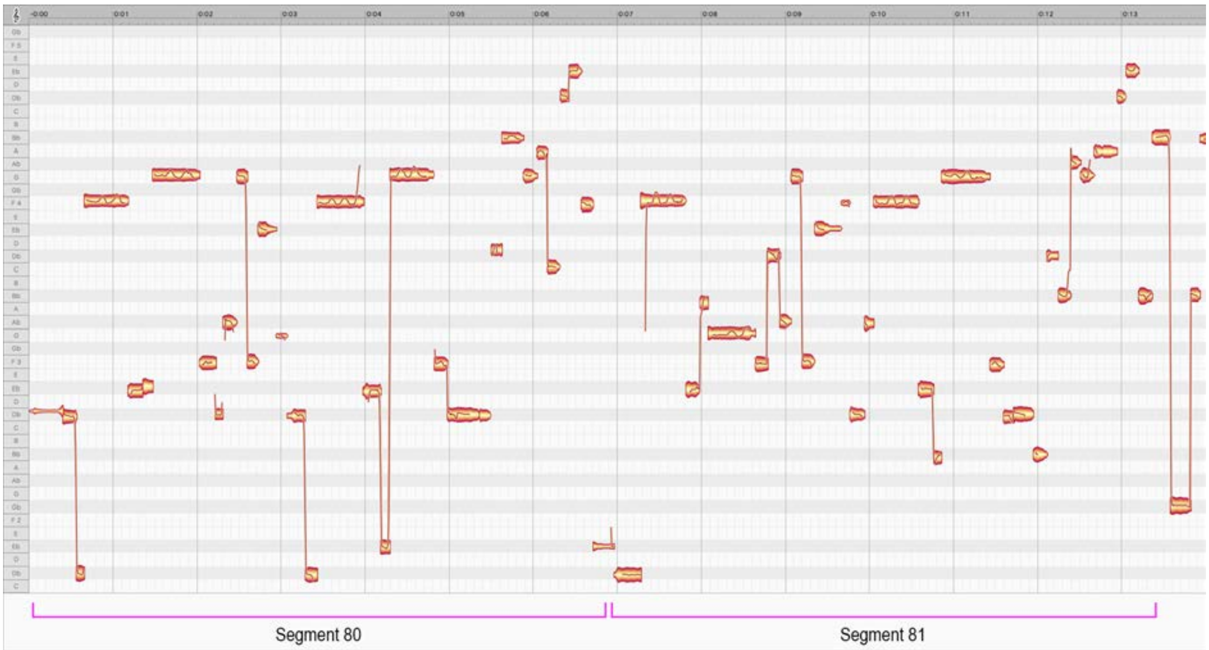

Figure 33: Melodyn's Initial Parsing of the Dry Guitar Track from Segments 80 & 81

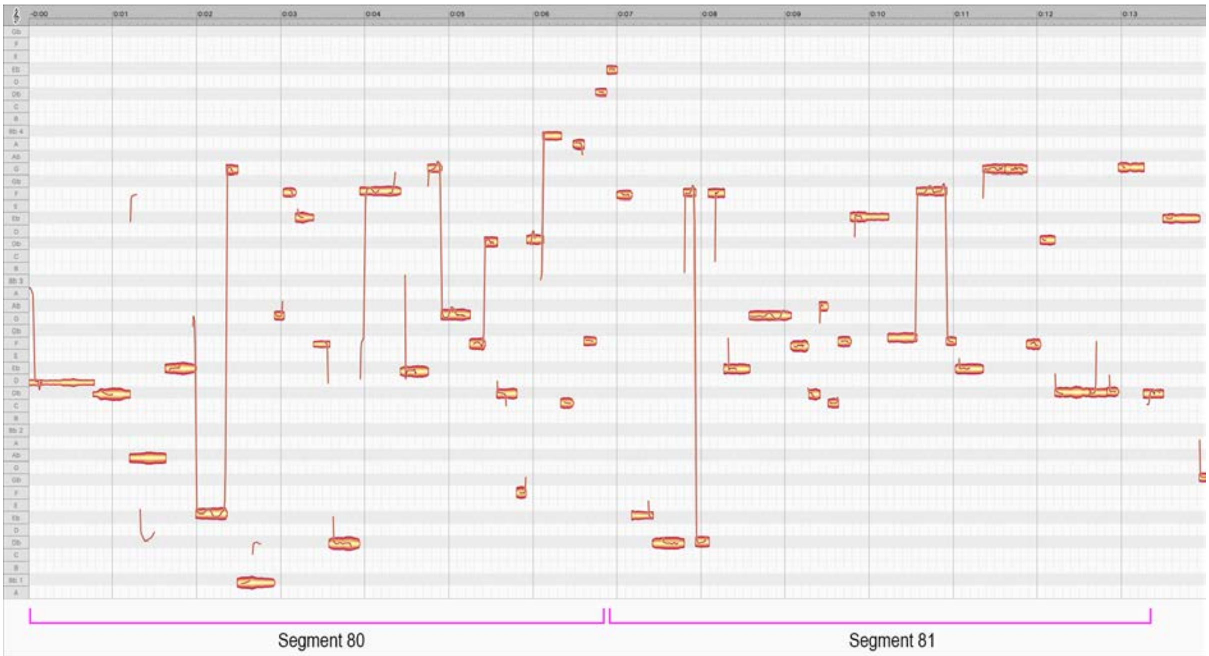

Figure 34: Melodyn's Initial Parsing of the Wet Guitar Track from Segments 80 & 81

Correction of the initial Melodyn parsing is the heart of creating the Performance (blob-based) score. The parameters I assigned were: pitch-centre, note boundaries, and note onset. I made most of my decisions by ear, as this was often the only time-efficient method.

Before I assigned pitch-centres, I needed to have separate note blobs for each note (which could then be assigned to their centres.) The assignments here were note boundaries and note onset. Altering these parameters does not affect the audio, although each blob was reanalysed for internal parameters. At the visual level, note separation delineates the notes; note onset is not displayed in this interface window.

Once all the blobs were separated into notes, I ensured their intended pitch-centres were correct. The actual pitch-centre may be different, which is often caused by a parsing mistake in Melodyn. Literal pitch-shifting of blobs came later in the Restoration Phase when I generated the intended score. Unfortunately, in Melodyn's user interface, there is no difference between the appearance of a blob's assigned pitch-centre, and shifted pitch-centre—this can lead to visual ambiguity.

7.2.1.1.2 Spotlight on Specific Corrections

Melodyn was unable to identify the pitch-centre of many notes due to the music's vivace (fast and lively) tempo, frequent staccato execution, and guitar distortion. One section, which was repeated in both Segments 80 and 81, provided a particular challenge. It was part of a monophonic phrase of arpeggio-like motifs. This section is shown in both Segments in Figure 35, below. (Please note this is a display Melodyn's raw pitch-recognition before I corrected pitches and separations.)

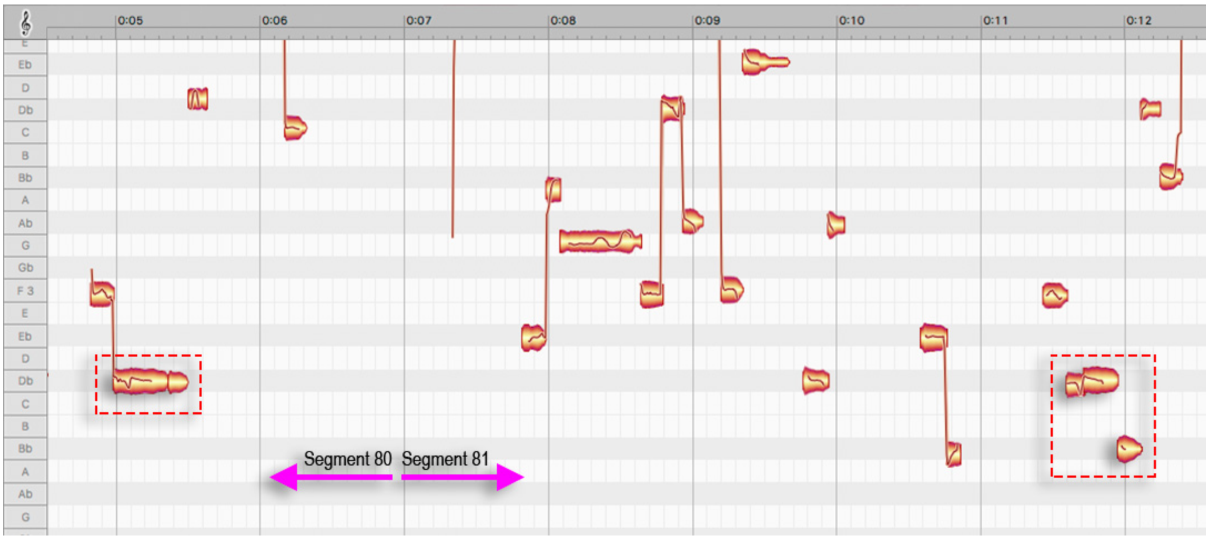

Figure 35: Section for Special Pitch and Separation Work in Segment 80 & 81

My first task was determining the note boundaries and onset times. Melodyn was unable to parse the audio here into separate notes, correctly. I set these parameters manually, though it was challenging because Melodyn's display data was inaccurate, and the notes were played too quickly for me to separate easily by ear. The second task was determining their pitch-centre, which was also hampered by similar problems.

This type of issues, especially with distorted electric guitar, was very common when working on the Creative Submission Album. It was most common with rapid 16th and dotted 32nd notes. In making the separations, I drew from my experience of previous musical situations, mostly from Flying Colors' *Live in Europe* {LiveinEurope:2013vq}. To a large extent, I relied on intuition and trial & error, as I had not yet been able to develop a deterministic process.

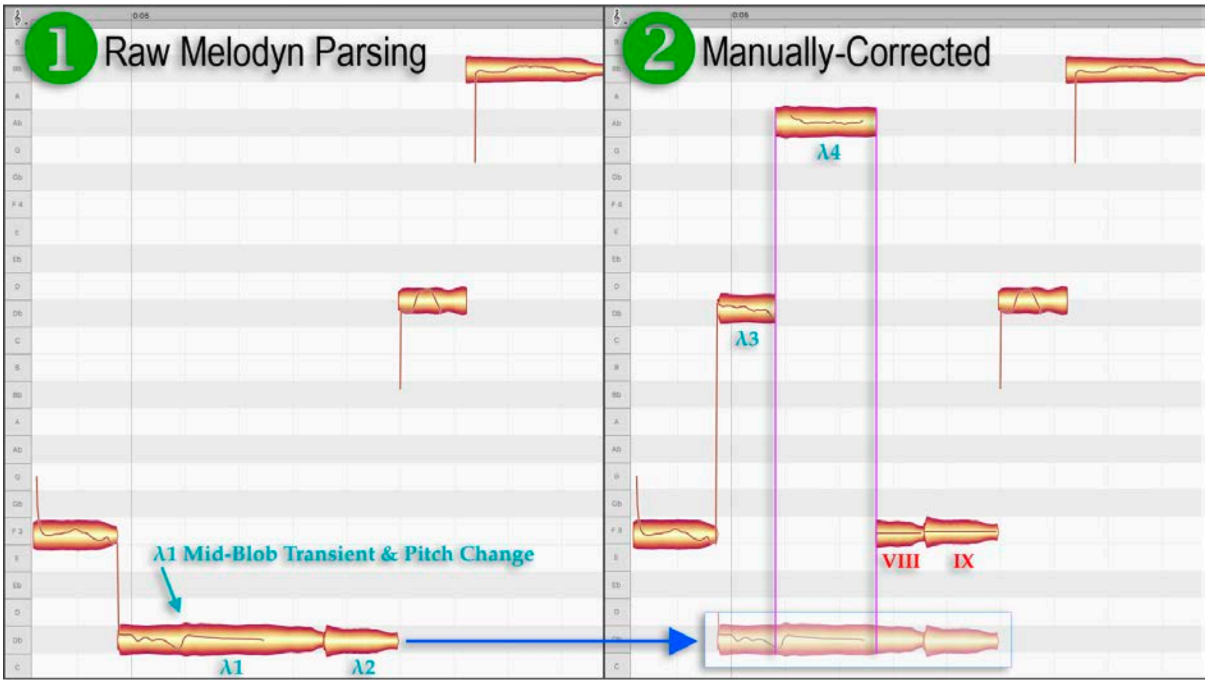

Figure 36: Separation and Assignment of Ambiguous Material in Segment 80

Figure 36 shows my process in Segment 80. Melodyn's original parsing is shown in Part 1 of the figure. First, I identified the correctly separated blobs and corrected their pitch-centre assignments. Then, I turned to two obvious parsing errors by Melodyn, noted as blobs λ1 and λ2.

Melodyn displayed a pitch change and minute amplitude transient 1/3 along the blob, indicating the possible presence of two notes (later to become λ3 and λ4), and a logical point to separate their note boundaries. I tested various separations by repositioning the resulting blobs, and auditioning the realism of their articulations. It was revealed that Melodyn's transient in λ1 (implying a starting boundary) was actually a note onset, allowing me to preserve the resulting attack and release sounds later during Rendering.

Notice that in Part 2 of Figure 36, after I correctly separated note λ4, Melodyn re-analysed the blob, and this time correctly identified the unpitched pick-sound (note boundary start) that begins λ4 but precedes the onset (start of the pitched region). However, the unpitched region after note λ4's sustain was not the guitar pick's sound of the next note, as one might expect—it was still part of λ4 sustain/release envelope; recognising and preserving this would also be key to further Rendering work sounding accurate.

The final 1/3 of λ1 contained a hidden note, which would later be marked as VIII. After correctly determining its correct boundaries and onset, my separation work for blobs λ1 and λ2 was complete. I turned to pitch assignment correction for the same blobs.

The blob created from the first 1/3 of λ1 had an audible pitch of D♭3. However, the next two blobs that were split from λ1 contained two pitches at similar volumes: F3 and D♭3. From their musical context, it was obvious these were intended to be monophonic notes. But there was no single pitch that was *performed*. Not to be helpful, Melodyn re-analysed the new blobs, and this time displayed pitches: however, they were flat lines, which was clearly erroneous[79].

I would attempt to determine the intended pitch, later in Conceptualisation stage. For the Performance Score, I assigned the note's pitches to be ambiguous. Unfortunately, Melodyn requires all blobs to be assigned a pitch, so I needed to assign these blobs to *something* (in this case, F3), which I considered a "working"[80] pitch, making a mental note. Due to their ambiguous pitch, I marked the notes as errors: VIII and IX.

[79] A flat pitch line would indicate zero pitch modulation, which is impossible for an instrument such as a guitar.
[80] Melodyn requires all audio to be represented by blobs, and all blobs to have a pitch-centre (regardless of harmonic content). There is no concept of "working" values because Melodyn is only concerned with the current state of an audio file; there is no analogous Intended Score, or consideration of past or future tenses.

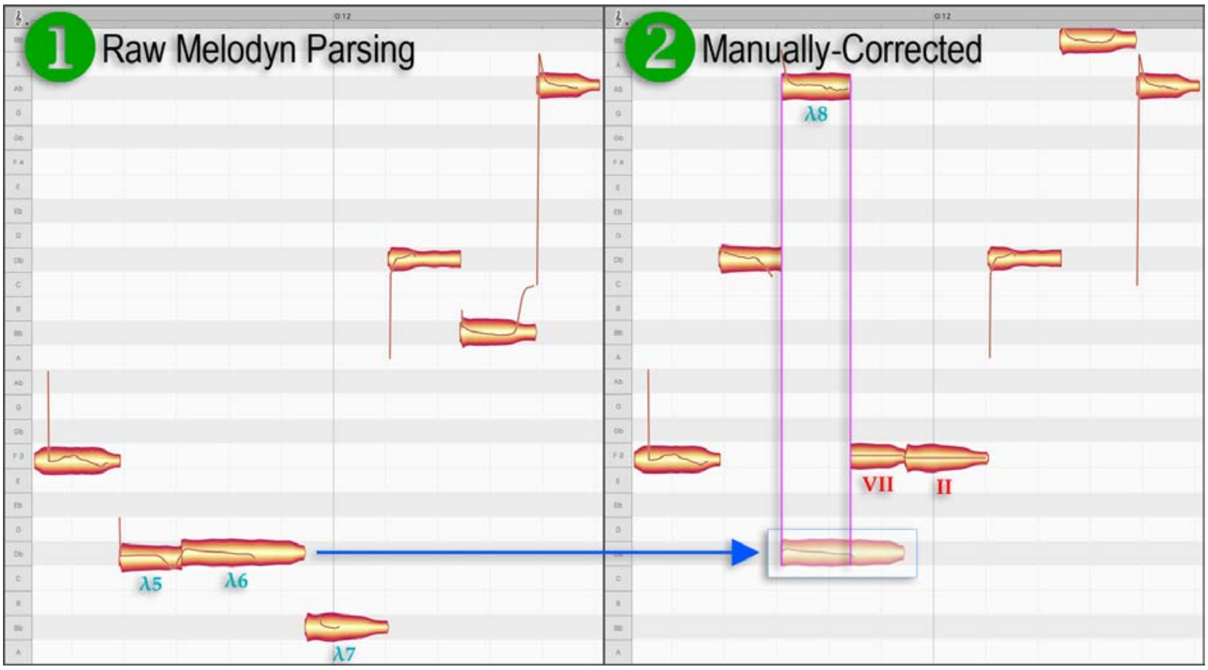

Figure 37: Separation and Assignment of Ambiguous Material in Segment 81

When performing separation and pitch assignment in Segment 81, I came upon a run of blobs that appeared to represent the same (performance and intended) score as λ1 and λ2. In 40, I have labelled them blob λ5, λ6 and λ7. Melodyn parses these blobs slightly better, separating λ5 (analogous to Segment 80's λ3). I separated λ6 into the corresponding λ8 and VII. As with Segment 80's VIII and IX, Segment 81's VII and II contained the F3 and D♭3 at equal volumes (leading to their likewise error designations, and working pitch-centres of F3).

7.2.1.1.3 Completed EAPR Performance Scores

After completing all the remaining separations and pitch-centre corrections, the Dry Guitar track performance score was now complete. Below are comparisons of Melodyn's initial parsing, and the finished EAPR performance score.

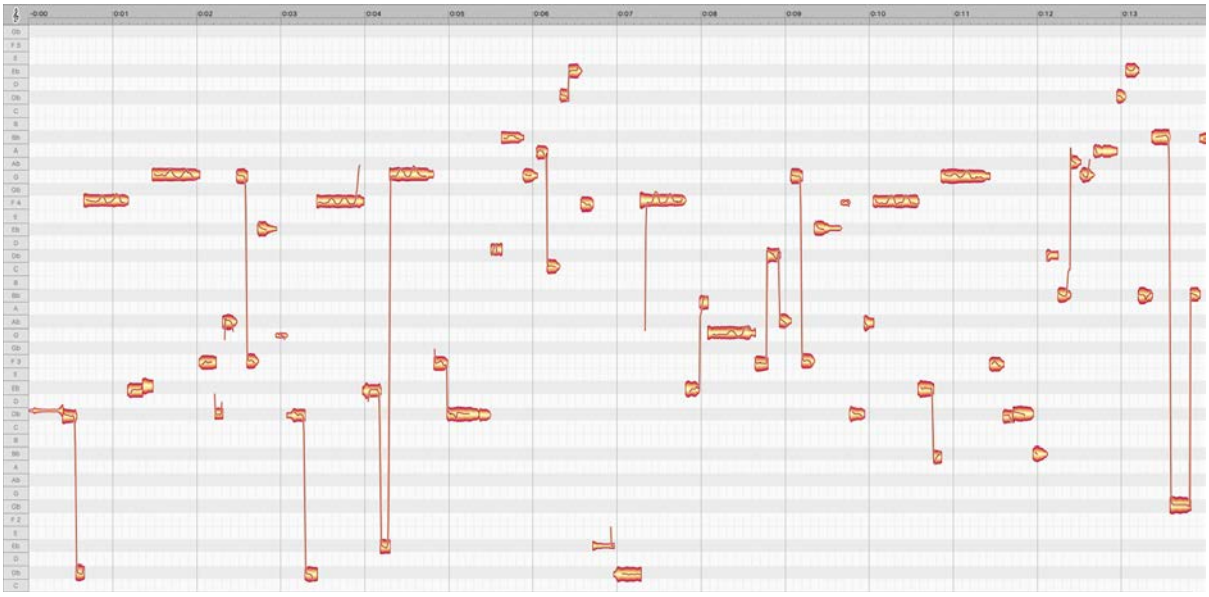

Figure 38: Melodyn's Initial Parsing of the Dry Guitar Track from Audio Segments 80 & 81

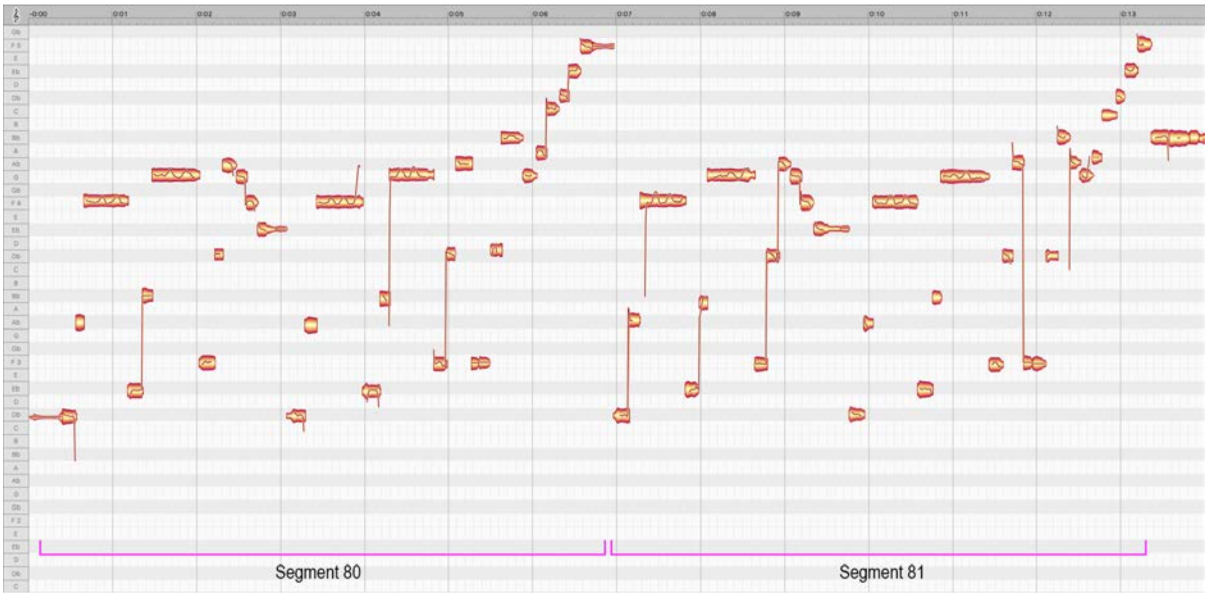

Figure 39: EAPR Performance Score of the Dry Guitar Track from Audio Segments 80 & 81

For the Wet guitar track, I performed an analysis to that used for the Dry track. Because the Wet track contains significant reverb, Melodyn’s pitch analysis was not as accurate as for the Dry track. Having completed the performance score for the Dry track, though, I used it to inform my work on correcting the Wet score.

Below are comparisons of Melodyn's initial parsing of the Wet guitar track, and the finished EAPR performance score for it.

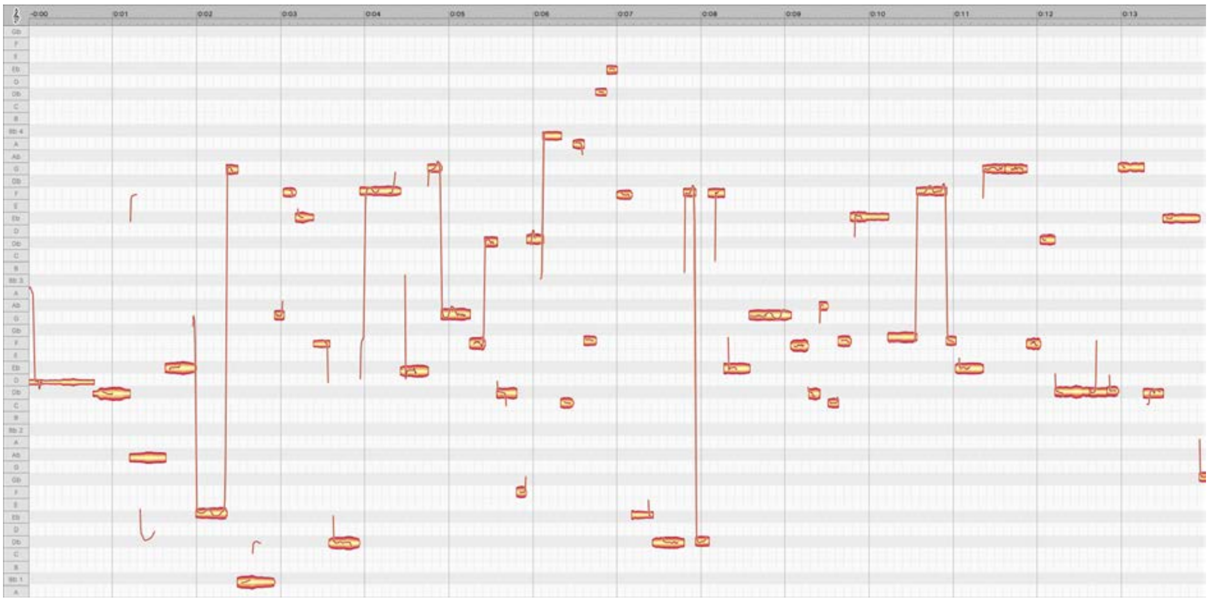

Figure 40: Melodyn's Initial Parsing of the Dry Guitar Track from Audio Segments 80 & 81

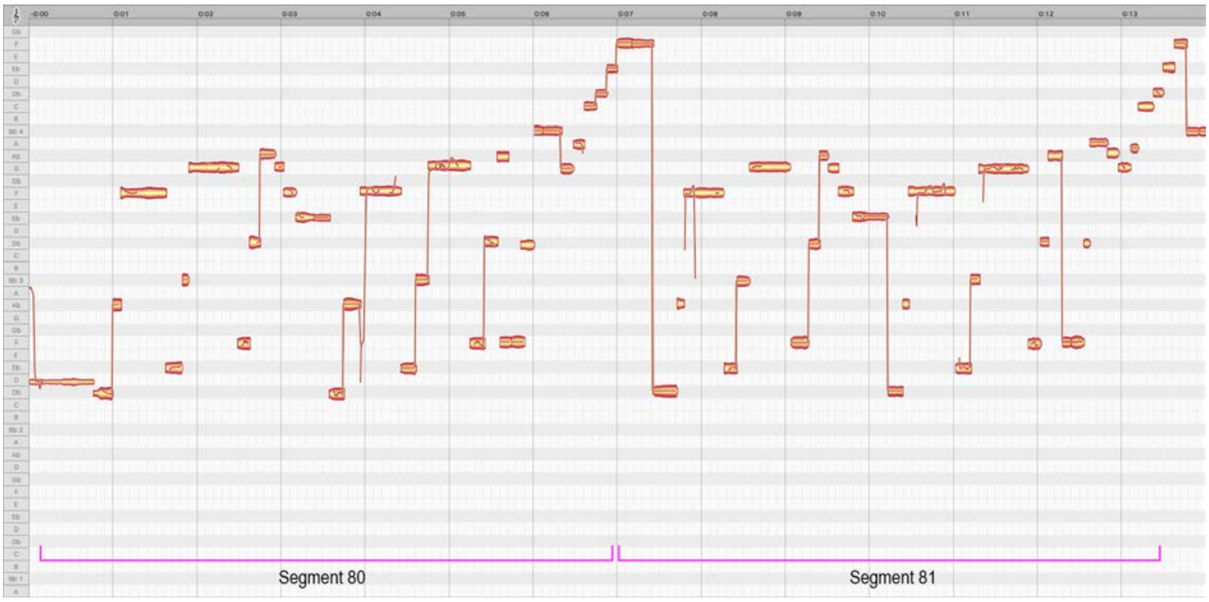

Figure 41: EAPR Performance Score of the Wet Guitar Track from Audio Segments 80 & 81

In summary, below is an EAPR music notation version of the performance score:

Figure 42: EAPR Notated Performance Score for Segments 80 & 81

7.2.1.2 Determining the Intended Score

As discussed in Section 3.1.1, there is no prewritten written *intended* score for an entire live progressive rock performance. Because of the improvisational element, a score denoting the performer's intentions can only be established only after the fact. If the practitioner wishes to create this score, she bases it on several factors; it is not a deterministic process.

After analysing the performance score, I marked five notes as requiring further analysis: VII, II, VIII, IX (with ambiguous pitch-centres), as well as note I (which appeared to be sharp by one semi-tone). They are marked in Figure 43.

Figure 43: Suspected Errors in the Performance Score for the Intended Score

As discussed in Section 7.2.3.1.4, notes VII, II, VIII and IX were intended to be monophonic, but contained multiple pitches. Each of the four notes was comprised of two distinct pitches at approximately equal volume: F3 and D♭3. It was not immediately clear which (if either) was the intended pitch in the score.

Recalling that both notes occurred within identical motifs in their respective Segments, I examined the rest of the score. At this point, I was unable to determine the correct pitch for VII and VIII. Based on similar motifs throughout both Segments, however, it was clear that II and IX were F3.

Turning to notes VII and VIII, I examined how the notes were played to determine their intended pitches. With alternate picking, if a monophonic note has two pitches, then two strings were accidentally struck instead of one. The pitches in VII and VIII both occurred so closely together in time that only one strike is audible: thus, the two strings were adjacent. And on the intended score, the notes on either side of VII and VIII are (likewise) 16th note staccato articulations of A♭4 and D♭3. But the pitches the inside them of were F2 and D♭3. There was no need to examine the fingering or identify which strings were involved. The note played after VII and VIII was F3; the note before it was A♭4. So, the only way VII and VIII could contain a D♭3 is if there was a D♭3 played between the A♭4 and F3, and the only place it could physically be is VII/VIII. This pitch also matched the common musical form implied by these arpeggios.

The intended note for I was also not simple to determine. While there was a mirror note in the other Segment to compare it to, I couldn't be positive which was correct; the scale the guitarist was playing was (in terms of standard music theory) not a formal scale.

The simplest method for identifying the intended notes would have been to access the same song section on the Lead Dry Guitar track in multi-tracks of the song's studio version DAW project. However, this process carried with it an unacceptable time penalty, due to the available tools at my disposal. None the less, to be certain of the score, I auditioned the studio version's Lead Dry Guitar track. My conclusions had been correct.

The Intended Score, shown in Figure 44, now appeared to be complete.

Figure 44: Completed EAPR Intended Score for Audio Segments 80 & 81

7.2.2 Identification

As discussed in Section 4.4.2.2.3, the Identification stage is the process of identifying performance errors in Audio Segments. Specific errors are assigned either to notes, passages of audio, or both. Like Envisioning, Identification doesn't occur at a specific point in a linear EAPR timeline; it occurs throughout all stages of EAPR. After the Conceptualisation stage, however, the Identification stage is mostly complete, and I will provide an accounting of my Identification progress at this point.

Table 17: Performance Errors for Segments 80 & 81 After Conceptualisation

ID	Class	Category	Type	Description
I	Event	Score	n/a	The note is one semitone low.
	Event	Execution	Articulation	Muted?
II	Event	Execution	Intelligibility	An intended monophonic note containing two pitches at equal volume.
III	Event	Tuning	n/a	The note is sharp by an unknown amount.
IV	Event	Execution	Articulation	A sustaining tone begins after this note, indicating it may not have been muted as intended.
V	Event	Execution	Articulation	Two strings appear to have been hit instead of one, with both sustaining for the intended note's duration.
VI	Event	Execution	Articulation	Two strings appear to have been hit instead of one, with one sustaining for the intended note's duration.
VII	Event	Execution	Intelligibility	An intended monophonic note containing two pitches at equal volume.
VIII	Event	Execution	Intelligibility	An intended monophonic note containing two pitches at equal volume.
IX	Event	Execution	Intelligibility	An intended monophonic note containing two pitches at equal volume.
X	Event	Execution	Intelligibility	An intended monophonic note containing two pitches at different, but still audible, volumes.

I labelled and identified the performance errors on the Dry Guitar blob score (Figure 45) and Wet score (Figure 46). Note that this is Performance score, not the Intended score; as the Wet Guitar track is delayed, the Dry track score is used for the primary Performance score.

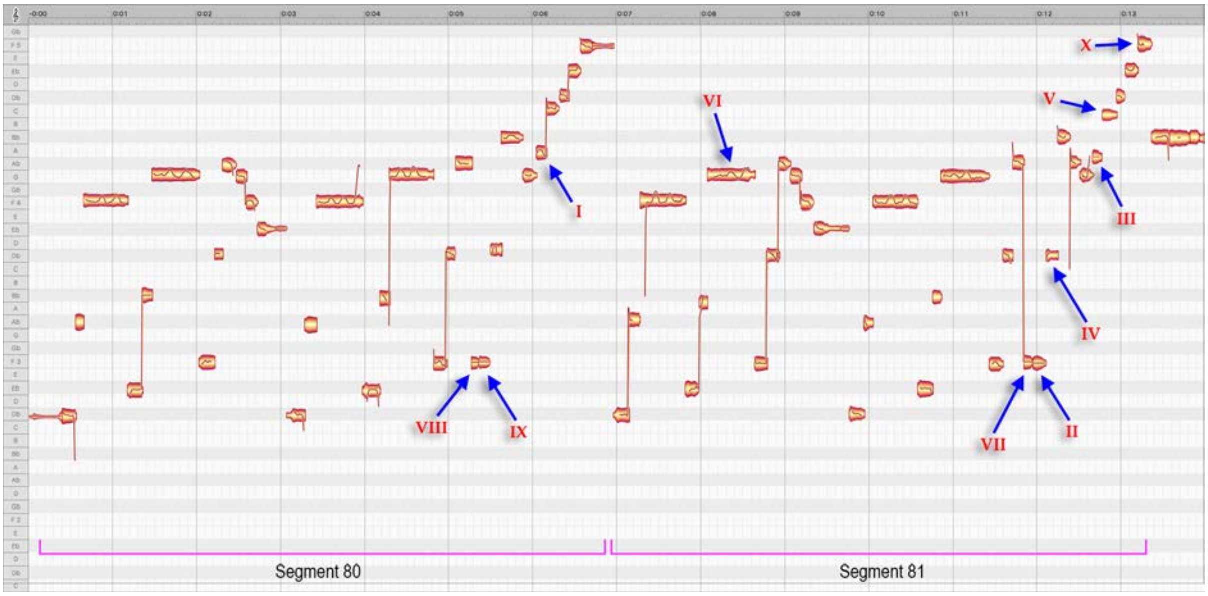

Figure 45: Identification of Performance Errors on the Dry Blob Score

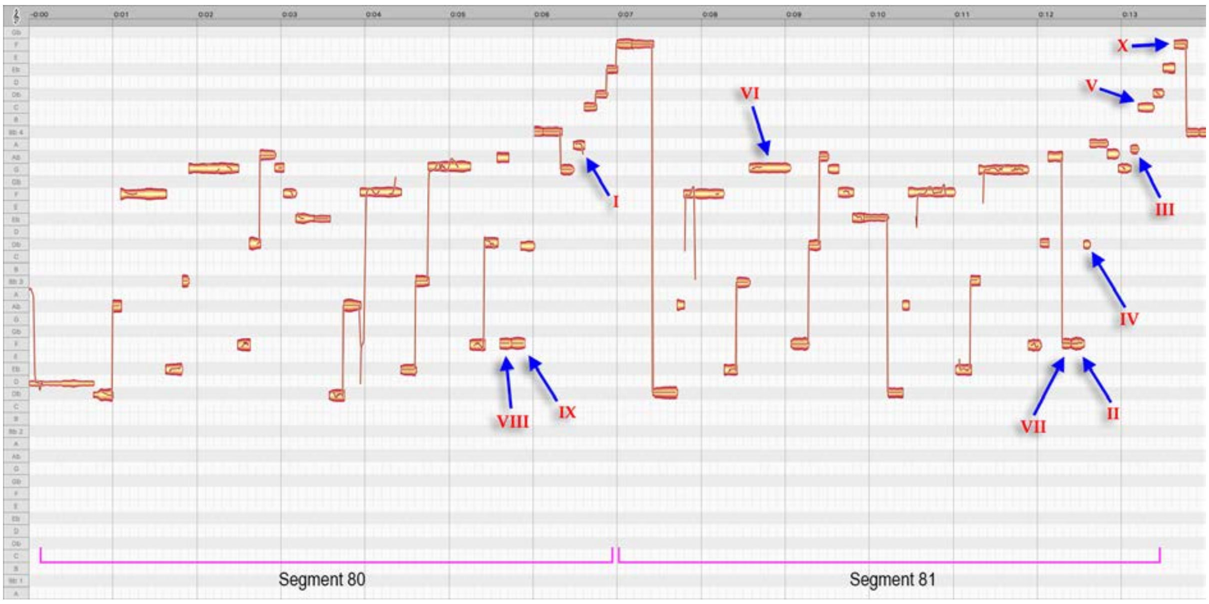

Figure 46: Identification of Performance Errors on the Wet Blob Score

There are two errors in Segment 80. The first (VIII) is a 16th note where the intended pitch is unclear, constituting an Intelligibility error. The second (I) is a Score error, where another 16th note deviates from the score by one semitone. This note is also poorly articulated, constituting an Articulation error.

Segment 81 has several problematic passages: An early note (VI) has an Articulation error, followed by two pitch-based Intelligibility errors (VII and II). During the final motif, there is a Tuning error (III), followed by an Articulation error (V). During most of this motif, an unmuted note (IV) appears to be sustaining, constituting an articulation error.

Figure 47 shows a notated version of the Dry Guitar error-identified score at this point in the EAPR process.

Figure 47: Noted EAPR Score of Identified Performance Errors

7.2.3 Rendering

In this stage, I will modify the audio corresponding to the performance errors, creating new audio that creates the sounds that the performer intended to record there. Identification and Envisioning inform the rendering process. I will ask, "What *performance* mistake did the guitarist make, and by what physical mechanism?" As discussed in Section 4.4, the current practice in live progressive rock is to address an artist's mistakes is to *hide* the error—with the goal that the audience simply doesn't realise a mistake was made. In EAPR, the goal is to restore the originally intended *performance*. Section 4.4 detailed that one of the critical knowledge bases to draw from in this endeavour is an analysis of what mistake, *physically*, occurred in the recorded performance. (The musical intentions, depending on the error, are also analysed.)

The tools I used are described in Chapter 6: Logic Pro (DAW), Melodyn (musical event editing) and SpectraLayers (spectral editing). I began with Melodyn, as musical event editing is highly efficient, allowing direct editing of the blob score; as such, it is most suited for restoring performances where the error is wholly contained within specific notes. Once blobs are modified, Melodyn performs many of the required audio transformations, automatically (though not always correctly).

The hiding of errors, and the restoring of performances, is not a binary delineation; it is on a linear scale. Some errors that could be dealt with in Melodyn, can be restored more authentically with spectral editing. One of the goals of EAPR is to maximise the use of the originally recorded audio, instead of replacing it with another performance. Spectral editing provides far greater ability to employ the former approach. It also facilitates the restoration of many errors that cannot be addressed by Melodyn (or by any other musical-event-based editor).

7.2.3.1 Melodyn Restoration Rendering

Here, I will show my process for restoring, or partially restoring, notes in Melodyn. I will show supporting EAPR scores and graphical audio data where it is most illuminating.

7.2.3.1.1 Note I

Figure 48: Notes I and Iß in Segments 80 & 81

Note I had two errors: Articulation and Score. The rendering of the restored note is detailed in Figure 49. The specific articulation error was a slight muting of the note. (Melodyn often cannot provide visual indication of this error, and it is not displayed here.) I began with the Dry Guitar track.

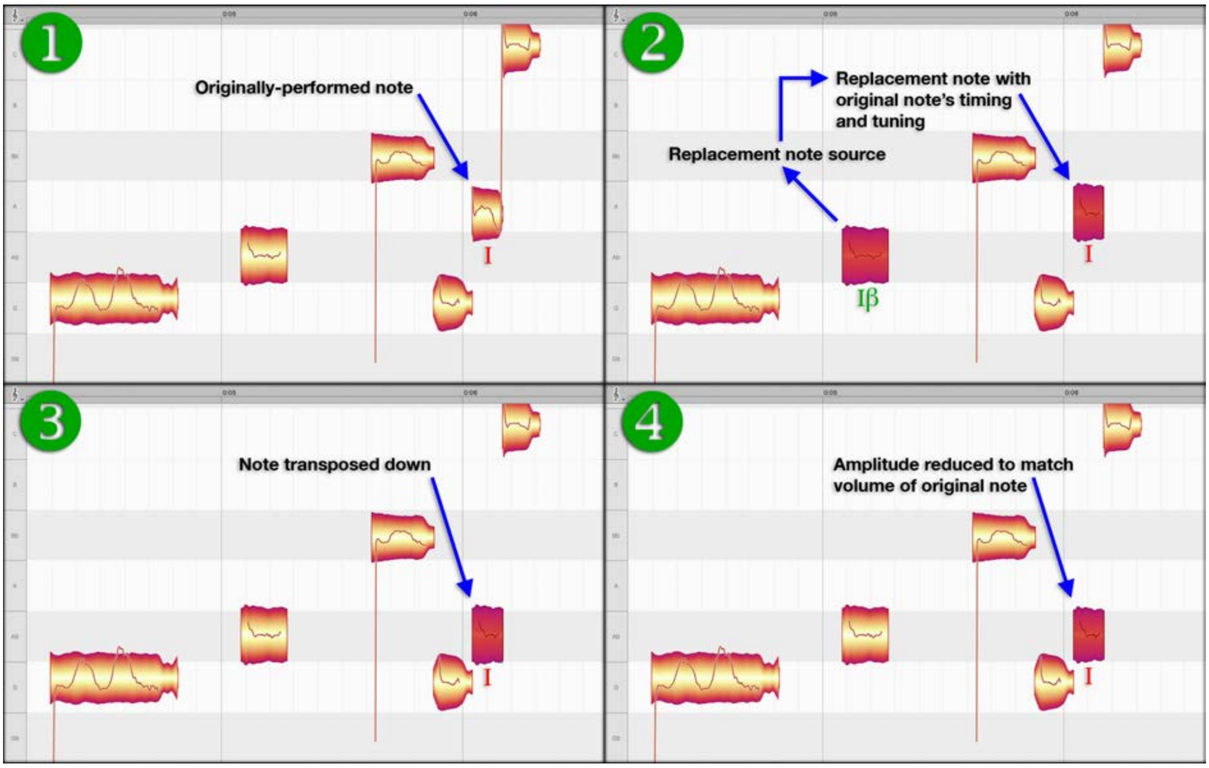

Figure 49: Restoration of Note I on the Dry Guitar Track in Melodyn

Articulation, like many performance parameters, does not have a binary error value. It is a linear metric with a context-dependent threshold. Many articulation problems are not performance errors requiring restoration; the result meets the intention well enough. And by itself, note I was articulated well enough to sound intentional to the audience. However, the guitarist's precise, bright articulation is intrinsic to the melodic intention; when I heard note I, the continuity stumbled. Without even reference to repertoire, it was obvious this was not intended.

Articulation errors are often non-trivial to repair by using the existing audio. However, from the surrounding context, and the audio that is present, it is possible to learn what audio needs to be created to replace it.

The pitch-centre, duration, and amplitude envelope of note I were acceptable, and to be preserved. The frequency content needed to be replaced, however, with one where the pick and sustain portions of the sound were better separated—and simpler, harmonically.

In Step 1, I examined note I's pitch envelope, and found a note with a similar attack and sustain, nearby: note Iβ. In step 2, I replaced the frequency component of note I with note

Iβ's, maintaining note I's duration and pitch-centre. In Step 3, I transposed note I down, leaving it a little sharp, like the others in the motif. I completed the rendering by attenuating note I to its previous volume[81].

Having completed the restoration of note I on the Dry track, I now needed to make equivalent changes to the Wet track. Given that the Wet track was lower in the mix, and mostly provided atmosphere, I did not perform the articulation restoration; I pitch-shifted the pitch-centre by the same number of cents as in the Dry track. The two steps are shown in:

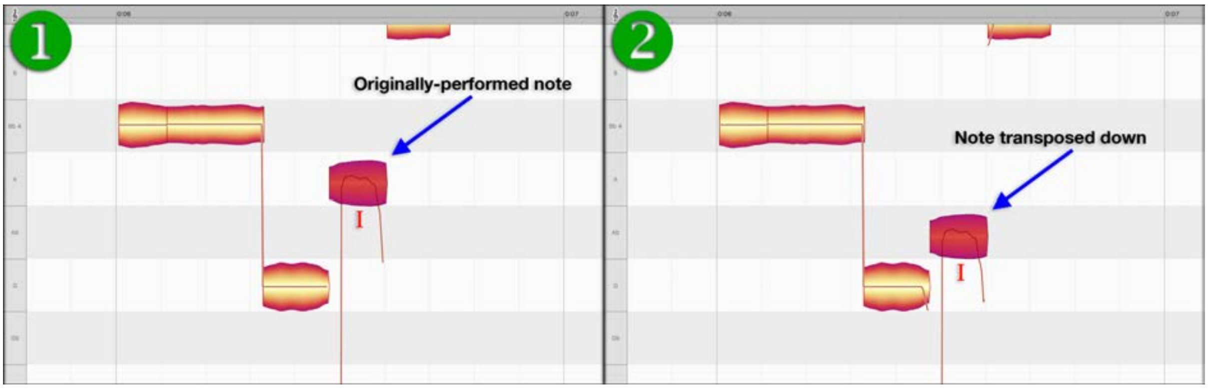

Figure 50: Restoration of Note I on the Wet Guitar Track in Melodyn

After auditioning the results, the performance restoration of note I appeared to be complete.

7.2.3.1.2 Note IV

Figure 51: Note IV in Segments 80 & 81

[81] Volume is perceptual; I listened to the old and new notes to compare volume. I didn't use Melodyn's amplitude envelope display for guidance.

Starting with note IV, a loud (unintended) string sustained throughout the final motif of Segment 81. This type of error can be addressed only in EAPR with spectral editing. It is challenging: the sinusoids (e.g. harmonics) corresponding to the unwanted string must be removed, while leaving all the desired strings' sinusoids untouched (even if they overlapped).

In addition, there were specific note errors within the motif; they would also need repair. Given my time considerations, I abandoned EAPR here and tried an industry-standard approach: Replace the final motif with the same section (repeated) later in the song. The result, however, was not acceptable.

Timing was one problem. The drummer accelerated at the end of Segment 81, and the guitarist matched pace, to meet the downbeat. I tried adjusting the timing of the replaced performance to meet the original one—the downbeat still arrived unexpectedly. It felt like the continuity broke when the replacement performance began. I auditioned the later song section (from which the replacement was copied): The notes leading up to the replacement were articulated with slightly more staccato than in Segment 81.

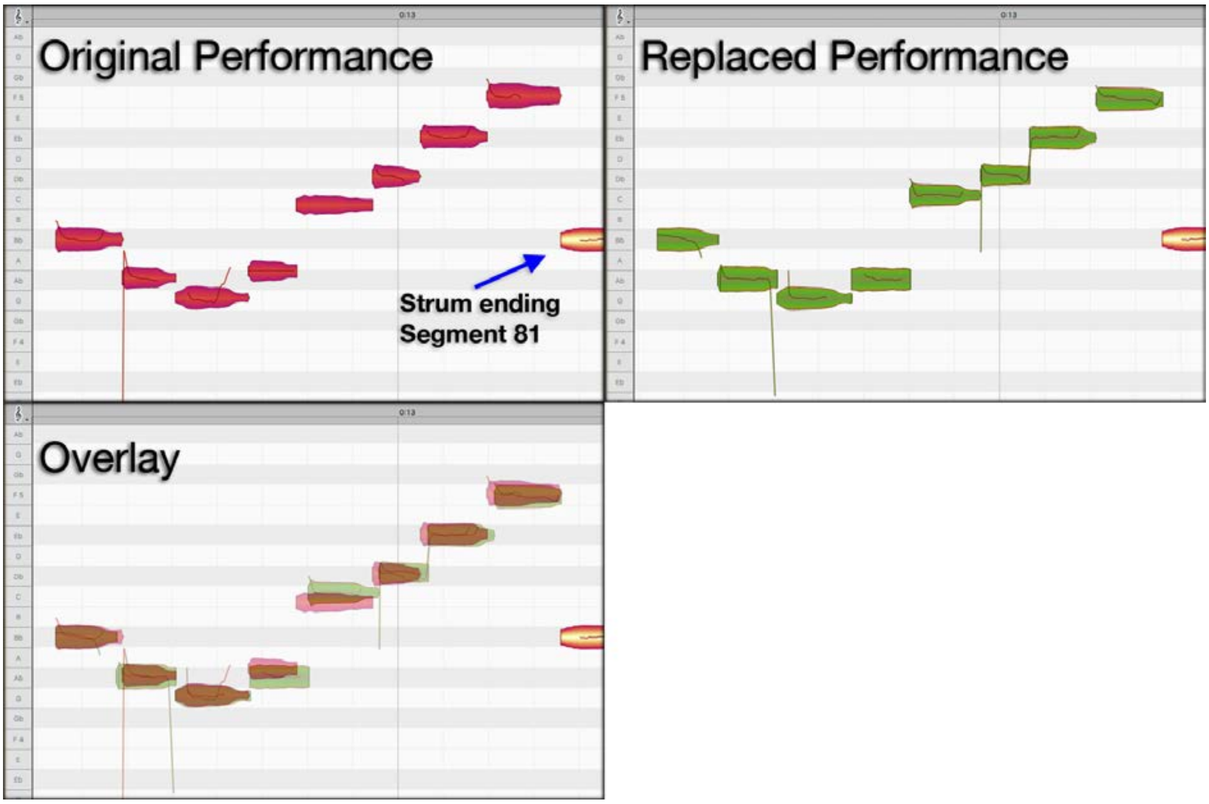

Figure 52: Original and Replacement Candidate Motifs for the End of Segment 81

Therefore, I decided to forgo note IV in Melodyn, and try again during spectral editing, after completing my first round of Melodyn renderings.

7.2.3.1.3 Note III

Figure 53: Note III in Segments 80 & 81

This note was a Tuning error; note III was sharp by about 50 cents. It's not uncommon for notes to be out-of-tune on the guitar, due to the layout of the fretboard, and that (in theory) the same note should have different pitch-centres depending on the current key. Another[82] common reason for tuning errors is that, in the course of playing, finger placement between the frets may not be stable.

In many cases, I don't consider tuning issues on individual guitar notes to be errors—the variations of tuning sound natural to audiences. And to an experienced guitarist, the tuning issues are sometimes part of the performance—for example, deviations in pitch can evoke specific emotional responses (e.g. the tension of "reaching" for a note).

For a note's tuning problem to be elevated to a tuning error, it needs to obstruct an intended musical result. Note III is sufficiently sharp as to cause pitch ambiguity in the listener.

Figure 54 and Figure 55 show the restoration steps of the Dry and Wet Guitar tracks, respectively. It was a simple matter of pitch-shifting the note's pitch-centre down by ~50 cents.

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[82] I'm leaving out the guitar being out of tune; the instruments of virtuoso players are, and this one in particular is, rarely out of tune.

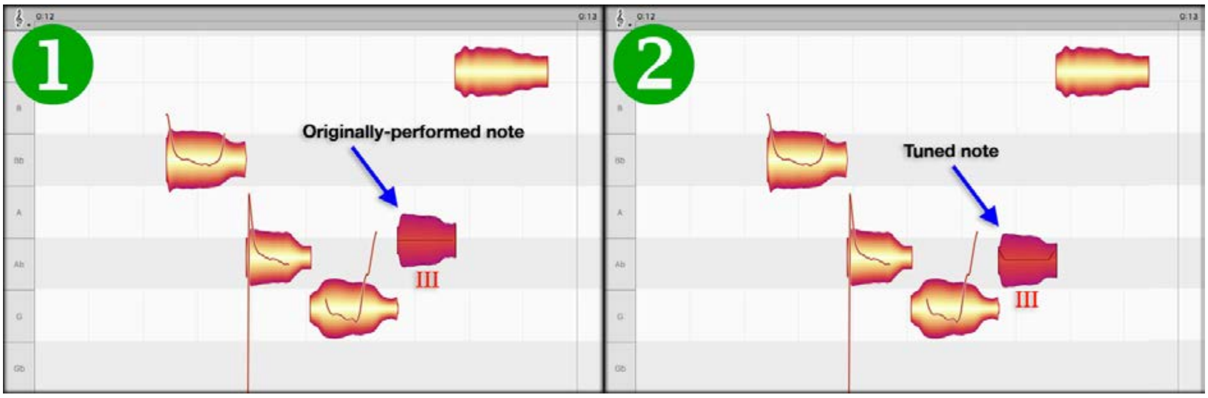

Figure 54: Restoration of Note III on the Dry Guitar Track in Melodyn

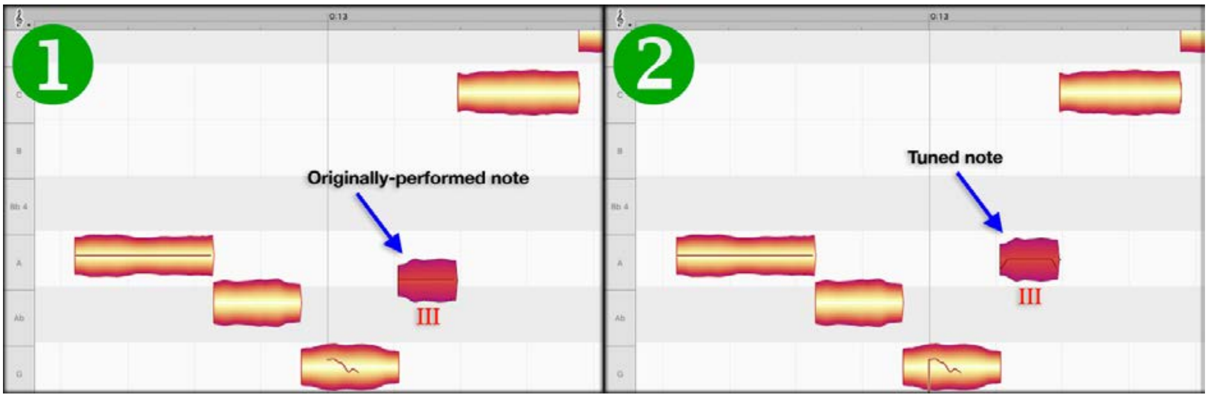

Figure 55: Restoration of Note III on the Wet Guitar Track in Melodyn

After auditioning the results, the performance restoration of note III appeared to be complete.

7.2.3.1.4 Notes VII and II

Figure 56: Notes VII, II, VIIβ and IIβ in Segments 80 & 81

Notes VII and II both had Intelligibility errors relating to pitch: they were comprised of the same two pitches, at equal volume: F3 and D♭. Their articulation was acceptable. As discussed in 7.2.1.1.2, determining the performance score for the notes was problematic, and for the intended score was challenging.

Because the motifs containing VII and II both repeated elsewhere in the Segment, it was clear they were monophonic; therefore, instead of just one string containing note VII being struck with the guitar pick, an adjacent string containing II was also struck. Unlike dual-strike note errors such as note VI, notes VII and II were both struck so quickly—and together—that no audible gap between the strikes is audible. Therefore, there was no ambiguity regarding the intended timing, especially when compared to that of other notes in the motif.

Therefore, spectral editing could be avoided, and I could restore these notes while still in Melodyn. My strategy was to locate two similar notes (VIIβ and IIβ) with the same pitch-centre, articulation, and notation-length (e.g. 8th or 16th note). Additionally, I would look for note transitions in the same harmonic direction (e.g. up or down). I would use these similar notes to replace the harmonic content of notes VII and II. Then, I would restore the average amplitude, pitch-centre, and note boundary (i.e. timing and length) parameters; there was no evidence they were not performed as intended. The aforementioned steps are shown in Figure 57, below.

Figure 57: Restoration of Notes VII and II on the Dry Guitar track in Melodyn

I performed the same process on the Wet Guitar track. The difference between the work on the Dry and Wet tracks was similar to the difference between notes I and III; for brevity, I will not show the same work for notes VII and II.

After auditioning the results, the performance restoration of notes VII and II appeared to be complete.

7.2.3.1.5 Notes VIII & IX

Figure 58: Notes VIII, IX, VIIIβ and IXβ in Segments 80 & 81

Notes VIII and IX, occurring in Segment 80, were the musical equivalent of VII and II in Segment 81. They exhibited the same intelligibility errors: suitable articulation but containing two different pitches at equal volume.

Another similarity to notes VII and II was that the pitch-centre, average amplitude, and note separations were not problematic. Therefore, I used the same restoration process for VIII and IX as with notes VII and II, as illustrated in Figure 59, below.

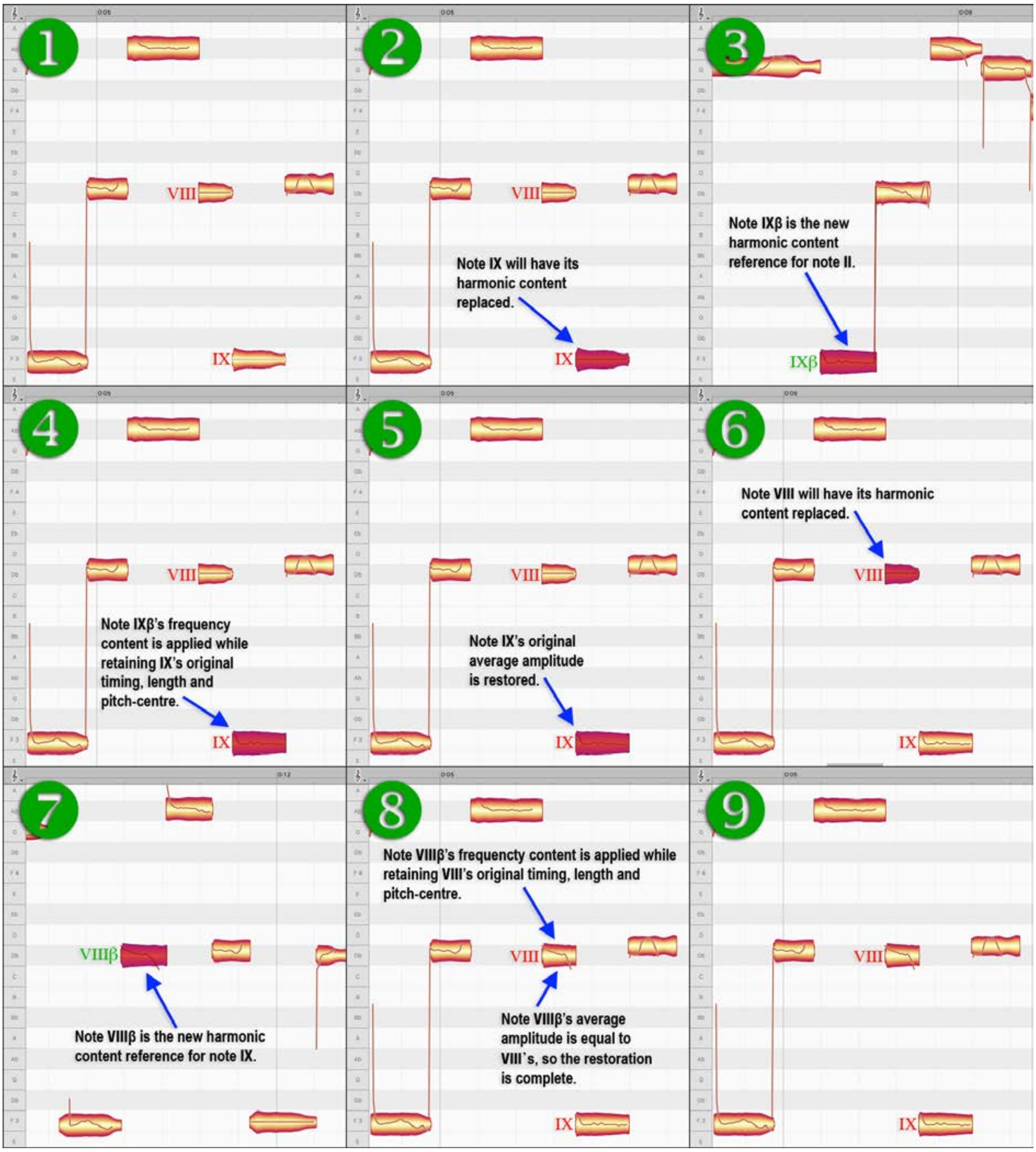

Figure 59: Restoration of Notes VIII and IX on the Dry Guitar track in Melodyn

I performed the same process on the Wet Guitar track. Once again, this work was similar to other notes I restored in Melodyn; for brevity, I will not show the same work for notes VIII and IX.

After auditioning the results, the performance restoration of notes VIII and IX appeared to be complete.

7.2.3.2 Spectral Editing

That concluded the Rendering work in Melodyn. I exported the Dry and Wet Guitar, and imported the Dry track into SpectraLayers. I hoped that I would need only to modify the Dry track; spectral edits are time-consuming, and involve frequent backtracking. Recreating a similar edit in the Wet track (especially one that wouldn't cause audio artefacts when layered with the Dry track), would be challenging.

I began by viewing a spectral display of both audio segments at a bin size of 2048 samples. This can be seen in Figure 60. The waveform display corresponding to the spectrum can be seen in the screen heading. This also illustrates the additional information available in a spectral display—each pixel of the waveform is represented by the entire y-axis line of frequencies below it. While it appears there is little amplitude above ~8kHz, this is simply because mono-colour (green) display can represent only a limited dynamic range of amplitudes.

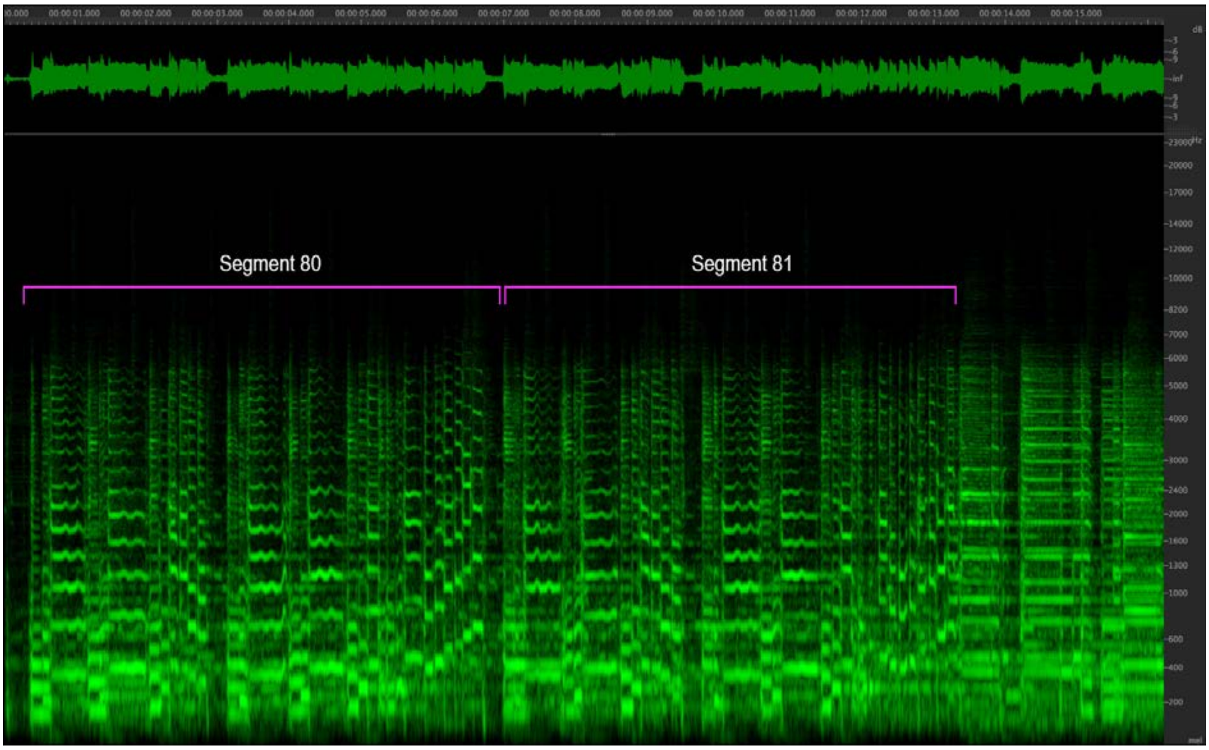

Figure 60: An FFT Spectral Display of Audio Segments 80 and 81 @ 2048 Samples

7.2.3.2.1 Note IV Revisited

Figure 61: Note IV in Segments 80 & 81

Note IV occurs in the final motif of Segment 81. As illustrated in Figure 68, it's a D♭5 that should be a 16th note, but appeared to sustain, in some form, until the end of Segment 81. To restore the performance of note IV, I needed to identify this note first, and then the rest of the notes in the motif (in the spectral display). I began my search in the region of the motif's fundamental frequencies, as shown in Figure 62.

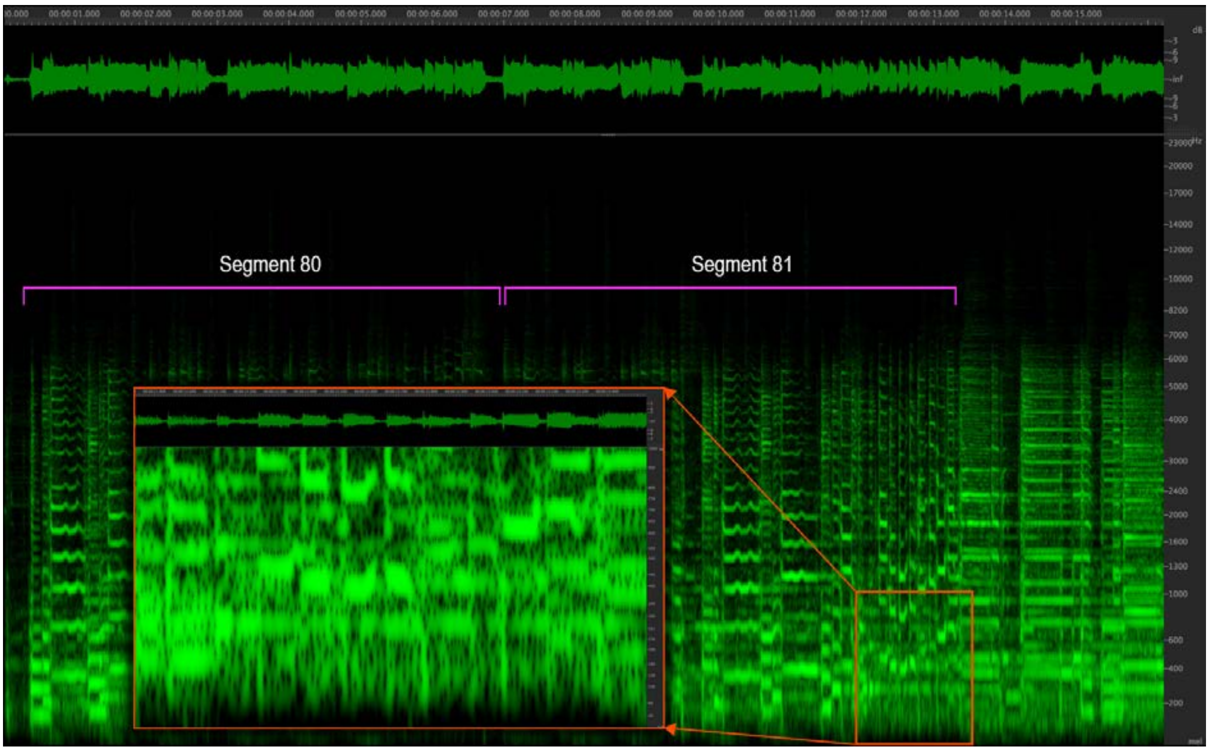

Figure 62: Region of the Spectral Display Associated with the Motif's Fundamental Frequencies

At the industry default FFT window size of 2048 samples, the enlarged region appeared as in Figure 63. My effective frequency resolution was ~23 Hz, with a time resolution of ~43 ms; I required additional frequency resolution. By setting the size to 5120 samples, I increased my frequency resolution to ~9 Hz, but decreased the time resolution to ~107 ms; this provided the display shown in Figure 64, and was an acceptable trade-off, allowing me to proceed.

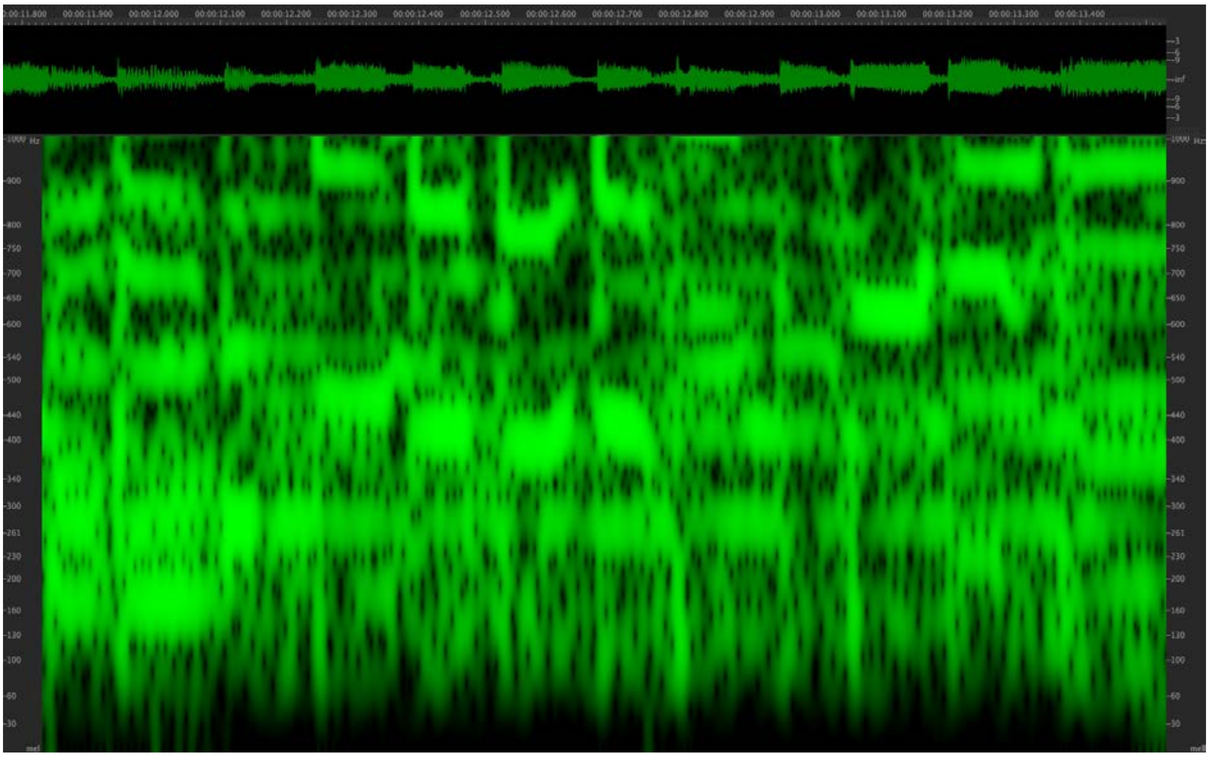

Figure 63: Spectral Region of Note IV @ 2048 Samples

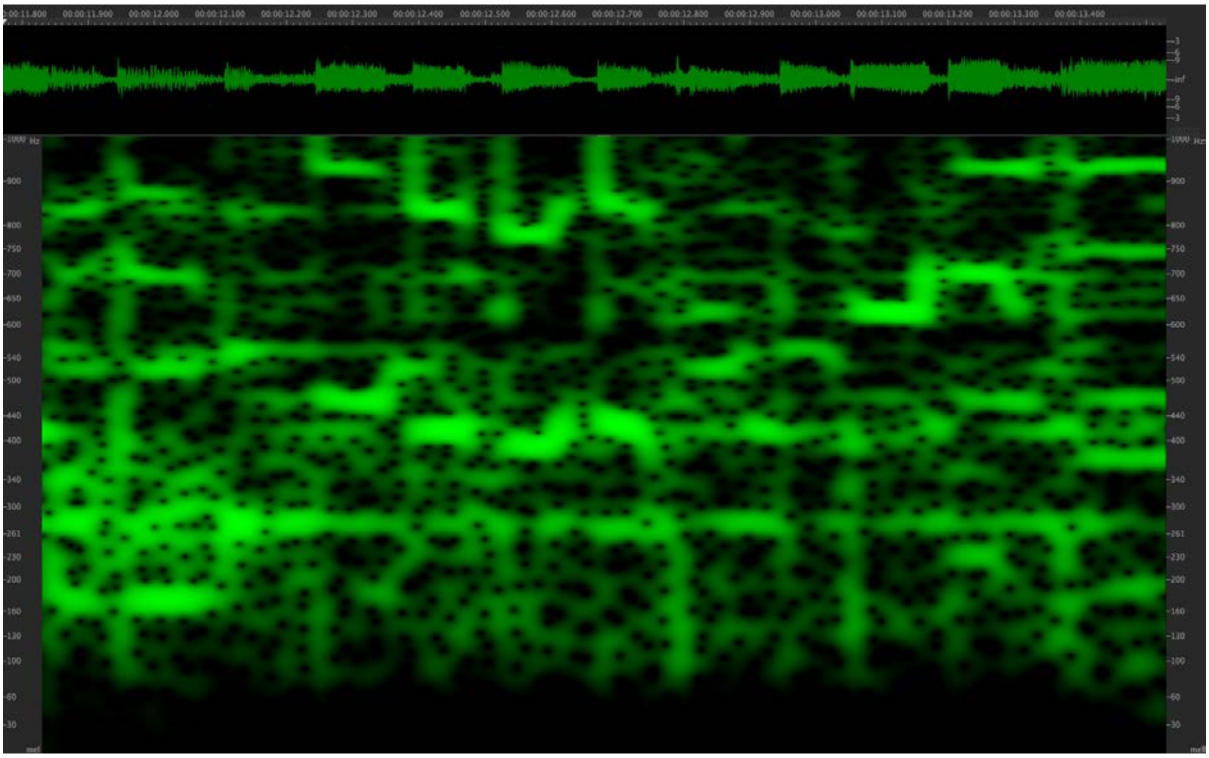

Figure 64: Spectral Region of Note IV @ 5120 Samples

Based on the performance score, I calculated the fundamental frequency of each note in the motif, and looked for matches. Their identification is shown in Figure 65.

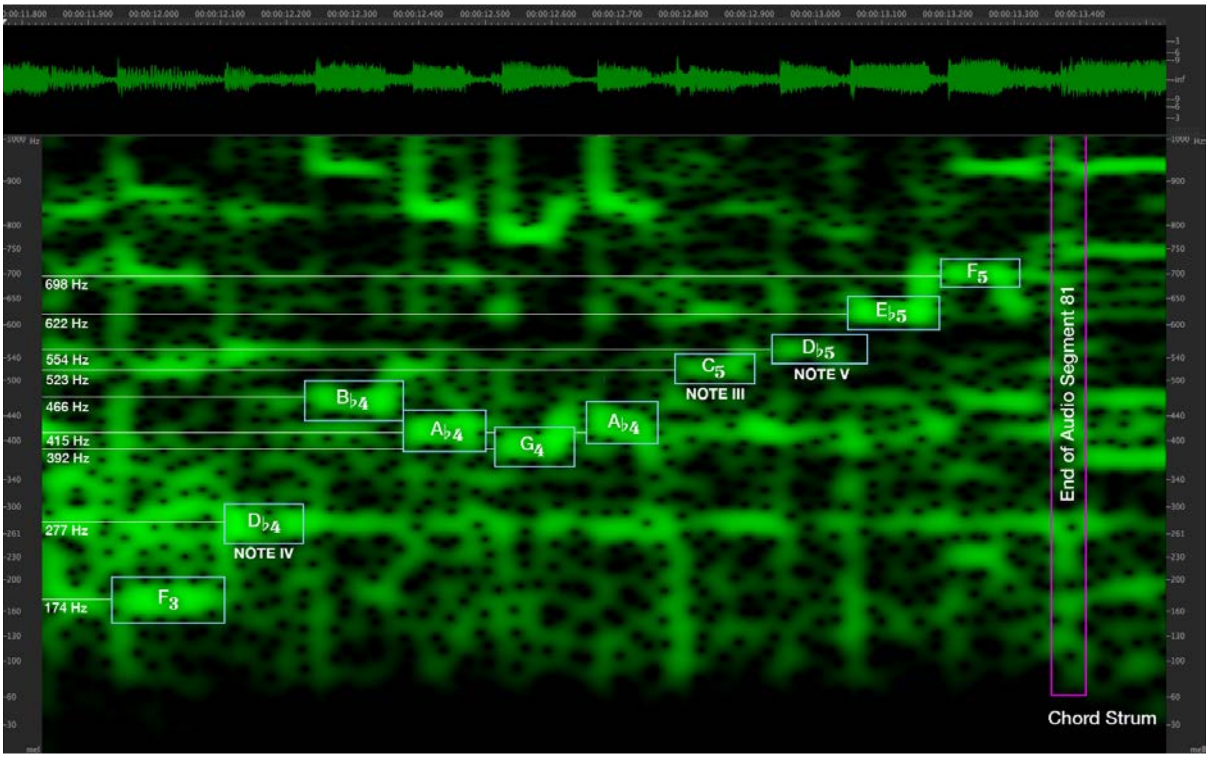

Figure 65: Spectral Region of Note IV with Notes Identified by Fundamental Frequency

To check my work, I sought out the second harmonics that would appear in this view. (The other second harmonics would appear above the display, out of view.) As Figure 66 illustrates, they were all in place.

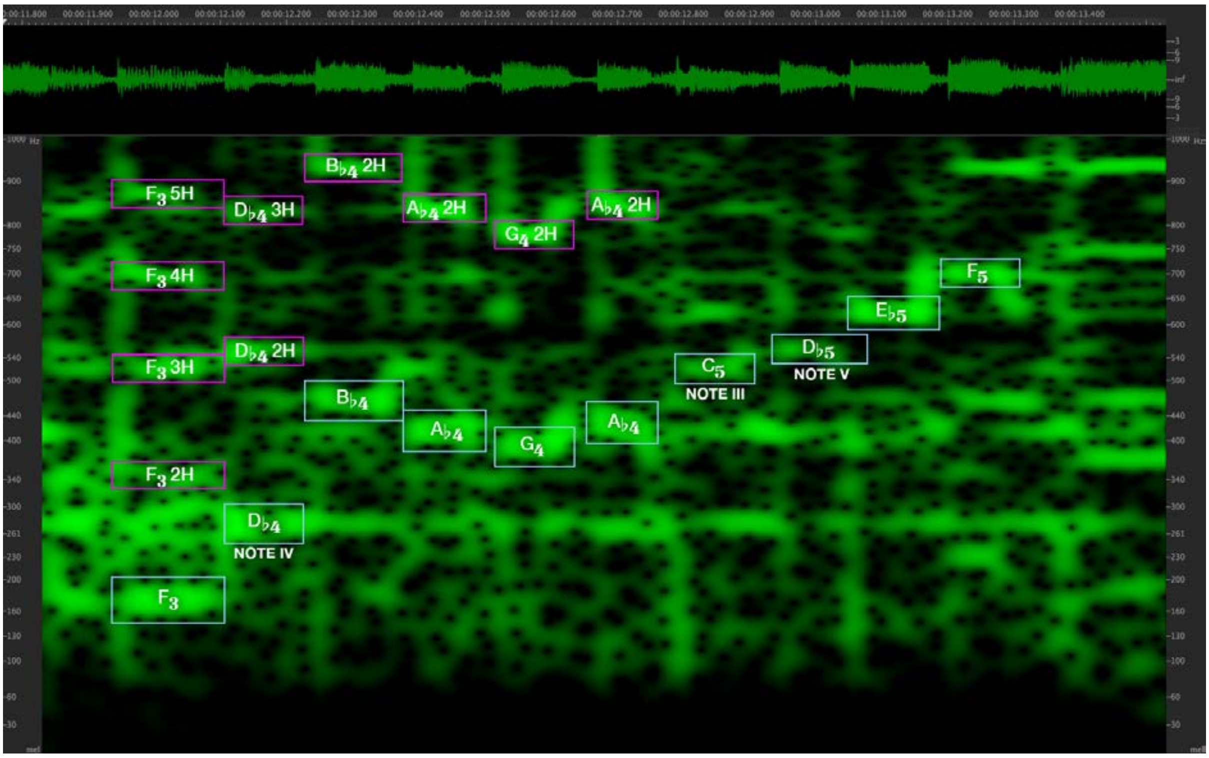

Figure 66: Note IV Spectral Region with Notes Identified by 1st and 2nd Harmonics

Zooming out, I could see a spectral transient at 12.200 secs. I had no explanation for it but took note. (See Figure 67.) I then returned to my previous spectral view, for greater detail on the fundamentals and early harmonics.

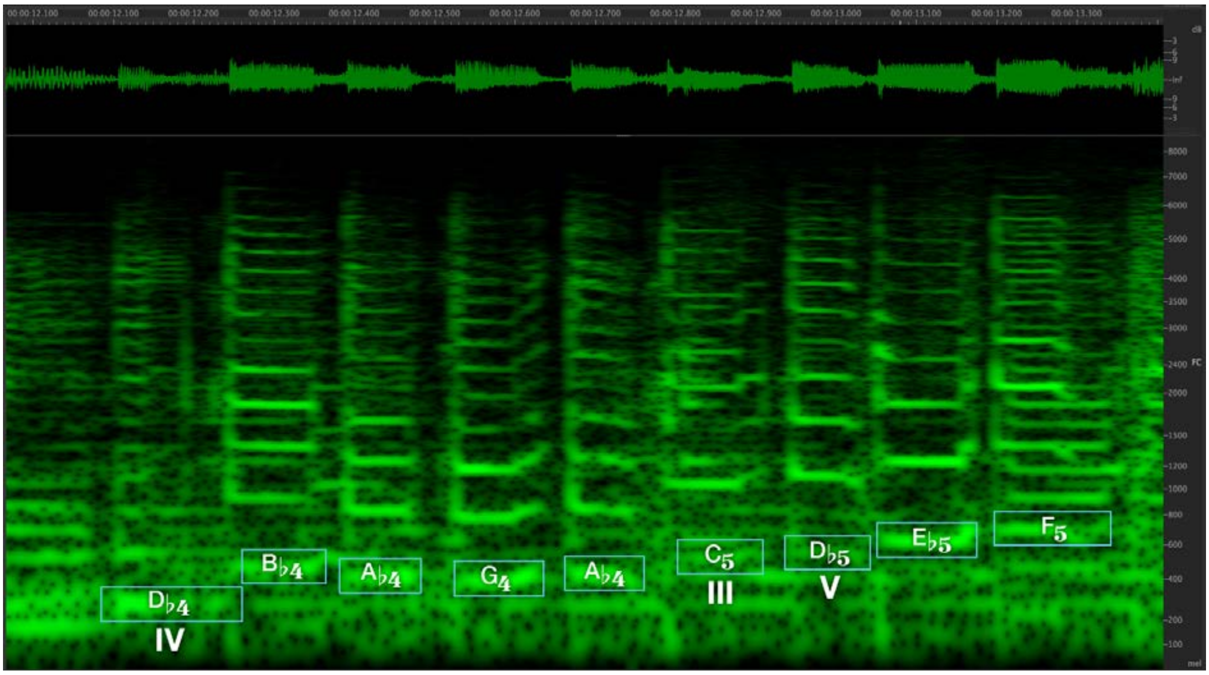

Figure 67: Spectral Overview of Segment 81 End Motif

I then began to analyse the spectrum to find the sustaining tone. (See Figure 68.) A strong sinusoid (Δ1), at IV's fundamental frequency, begins at the end of IV, and continues until the end of Segment 81. (At this point strumming of full chords begins.) I auditioned the isolated frequency region of Δ1, and this tone corresponded to what I heard when identifying this error in the context of hearing the full track.

This preliminary data is indeed indicative of the performer accidentally failing to mute the note, and the note sustaining (in some form) for the rest of Segment 81. This hypothesis will need to be verified, however, by first examining the relevant aspects of the spectrum in detail.

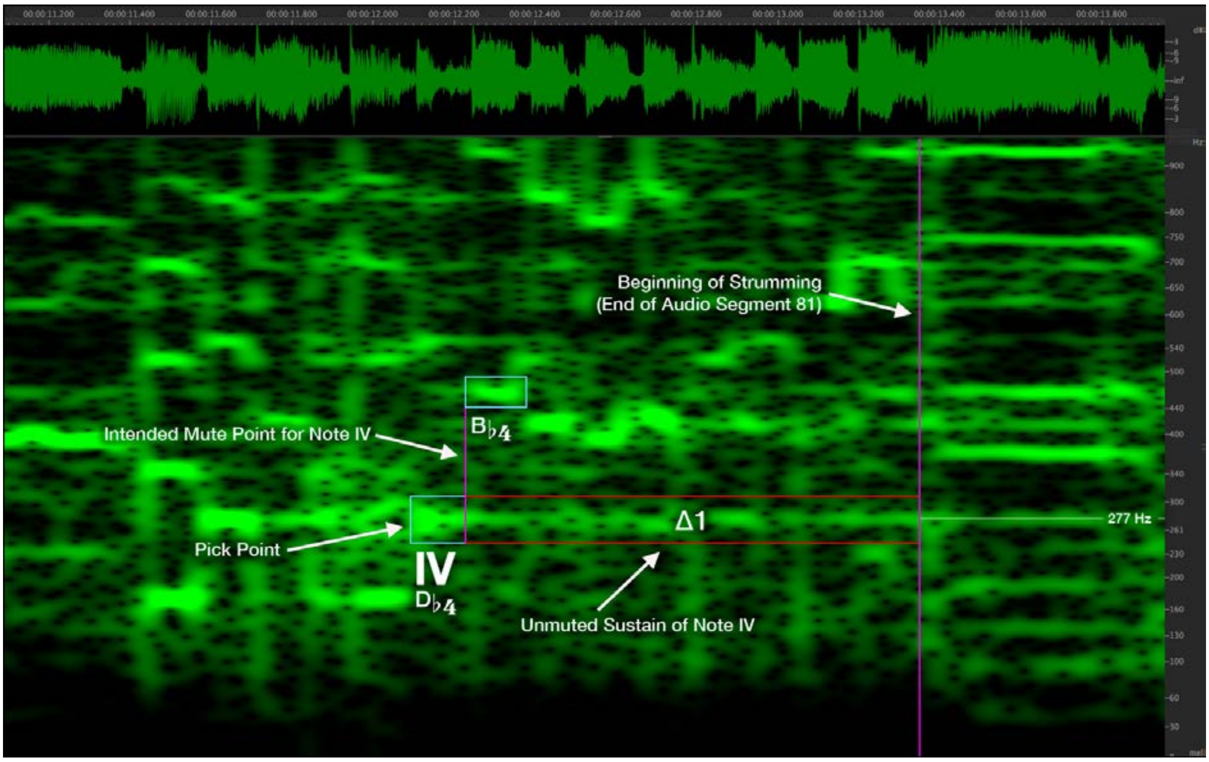

Figure 68: Analysis of Spectral Data Related to the Sustaining Tone Linked to Note IV

A possible conflicting fact is that the sinusoid appears to continue through the six-string chord strumming that marks the end of Segment 80. This could indicate that the sound source was external to the instrument. However, given that the strumming section is in the same key, it is likely that there would be a sinusoid here—possibly as the fundamental of one of the six notes in the chord, but more likely as one of their harmonics. There is also a small region of low amplitude at the strumming point, indicating that there may have been a gap in the sinusoid.

There was more troubling data which contradicted Δ1 occurring as a result of IV being unmuted, however. If the string continued ringing, then the second harmonic should be pronounced in the spectrum, at 554 Hz. But there is no trace of it in the spectrum.

Another issue is the length of sustain. For sustain to continue, at such a high amplitude, throughout the motif, I saw two possibilities: Either Δ1 was the result of an open string, or the finger pressing IV remained fixed throughout the motif (impossible, given the motif).

The open string explanation held more promise because the band played this song transposed down one step—there would indeed have been an open string at D♭4 (139 Hz). However, if this string was resonating, a strong sinusoid at 139 Hz would be expected. But there was no trace of that, either.

At this point, I could not imagine how Δ1 could even have been created on the guitar. Without knowing that fact, I could not restore any of the notes in this section, because I could not know the performer's intention.

I turned my investigation to how the final motif was played. I began with video footage from the solo, frame by frame. Unfortunately, the footage I had at this time was low-resolution; I couldn't see the finger action precisely. But I was able to see where on the neck the fingers were generally positioned. Figure 69 shows one of these frames.

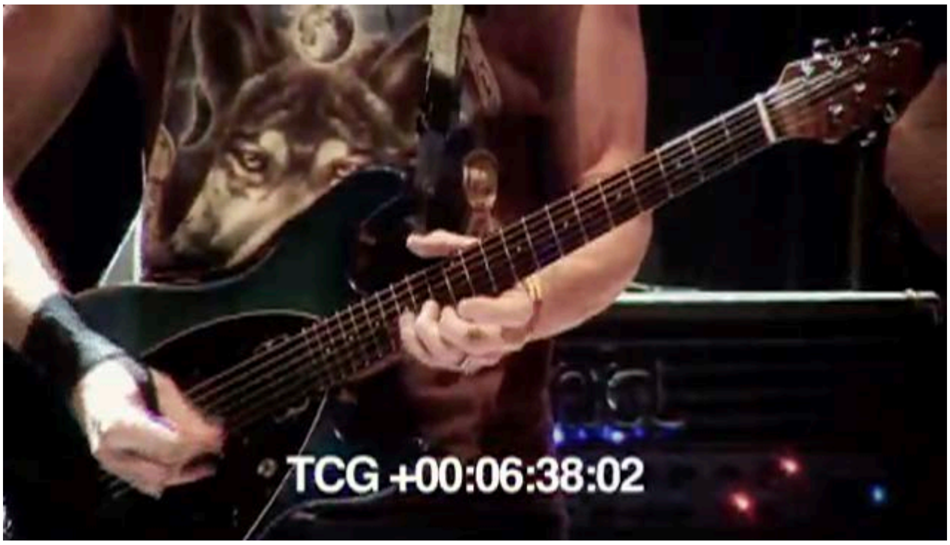

Figure 69: A Frame from the Performance of the Final Motif in Segment 81

Using my familiarity with the guitarist's playing style, I reconstructed the fingering and performance technique he used to play the motif. This was accomplished by learning to play the motif, myself.

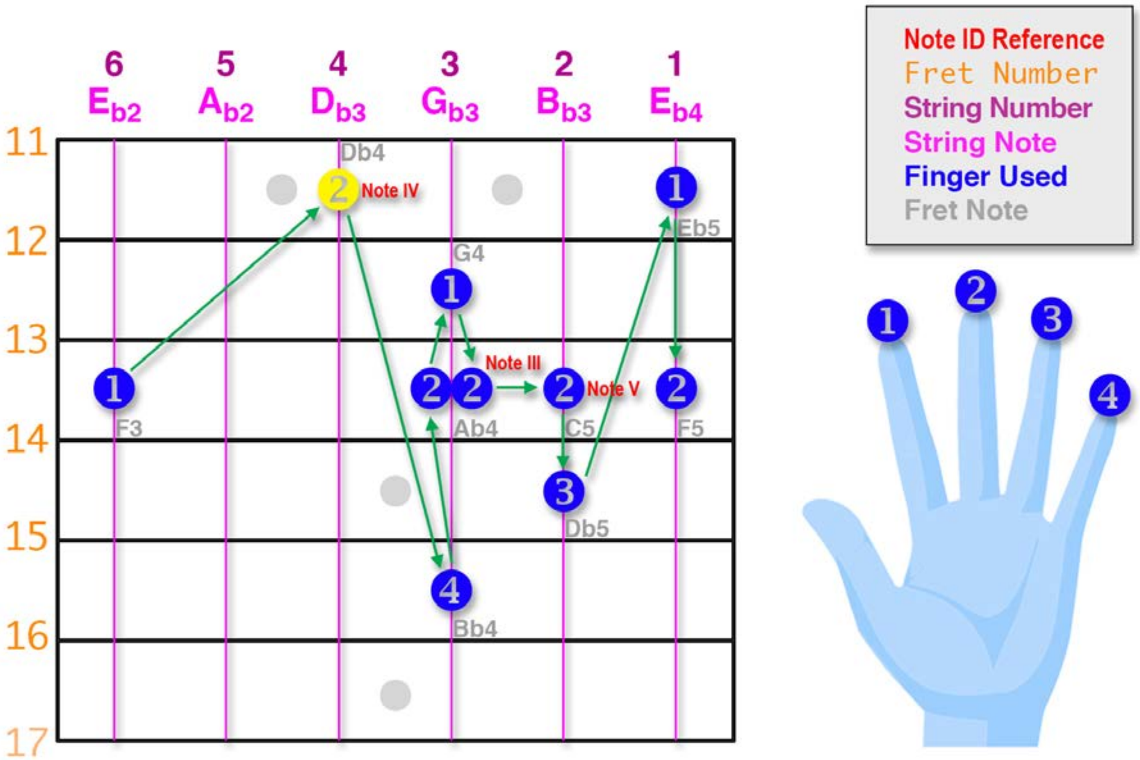

Figure 70: Error IV Highlighted in the Fingering for the Performance of Segment 81's Final Motif

With this model, an explanation emerged that supported the data from the spectral display. Note IV occurs at the twelfth fret, on the fourth string. It was the last note played on that string, and therefore needed to be muted. The guitarist's muting technique for this repertoire is to use alternate-picking, and to mute the final note on a string using a separate finger, which follows one note behind.

When he attempted to mute IV, he touched the fourth string in the same place as the note; instead of muting the string, he created a natural harmonic. Given that this string was not used for the rest of the motif, it continued to ring until the end, after he released the string. Therefore, the fundamental frequency (139 Hz) of the string wouldn't be produced even though it was open and resonating. (If the string was tapped imperfectly, a small amount of the fundamental might exist.) And because this was a natural harmonic, the second harmonic would be cancelled out in the air, and wouldn't be recorded.

To further confirm this explanation, I examined the spectral display at IV's fundamental. Given the alternate picking employed, I should have seen an amplitude transient, and frequency spreading, at the note's start boundary at 12.060 seconds; it is clearly visible. The amplitude then decays quickly, as intended, given the staccato articulation used. The note probably ends due to gradient-muting by the guitarist's right hand; he uses this technique to control the release portion of note envelopes.

However, this technique can still leave a string (slightly) ringing. At 12.200 seconds, the string can again be observed as physically excited. It occurs just before the next note is picked (12.060 s)—*exactly* when it is expected he would mute the string as theorised. And indeed, it can be observed that this excitation that causes Δ1. Finally, the spectral transient at 12.200 seconds, from Figure 67, was also explained.

I now knew that the full performance of IV was recorded—the picked attack and controlled release by the right hand. Therefore, I could now restore its performance by removing the sinusoids that occurred as a result of muting error, including Δ1.

Figure 71 shows the spectral editing steps I used for the Rendering process. For each edit, I first used the Harmonic Selection tool to select (shown in white) the sinusoid region(s) I wished to target. I then used the Amplitude Adjustment function to attenuate the audio. As discussed in Section 6.2.1.2, I did not fully remove the unwanted audio, as this could cause sonic artefacts.

Even though I did not see any activity at the open string fundamental (139 Hz), I experimented with attenuating this spectral region, suspecting that because the natural harmonic was accidental, it was not perfectly executed—and a small amount of 139 Hz would be present. This was case, and I attenuated it.

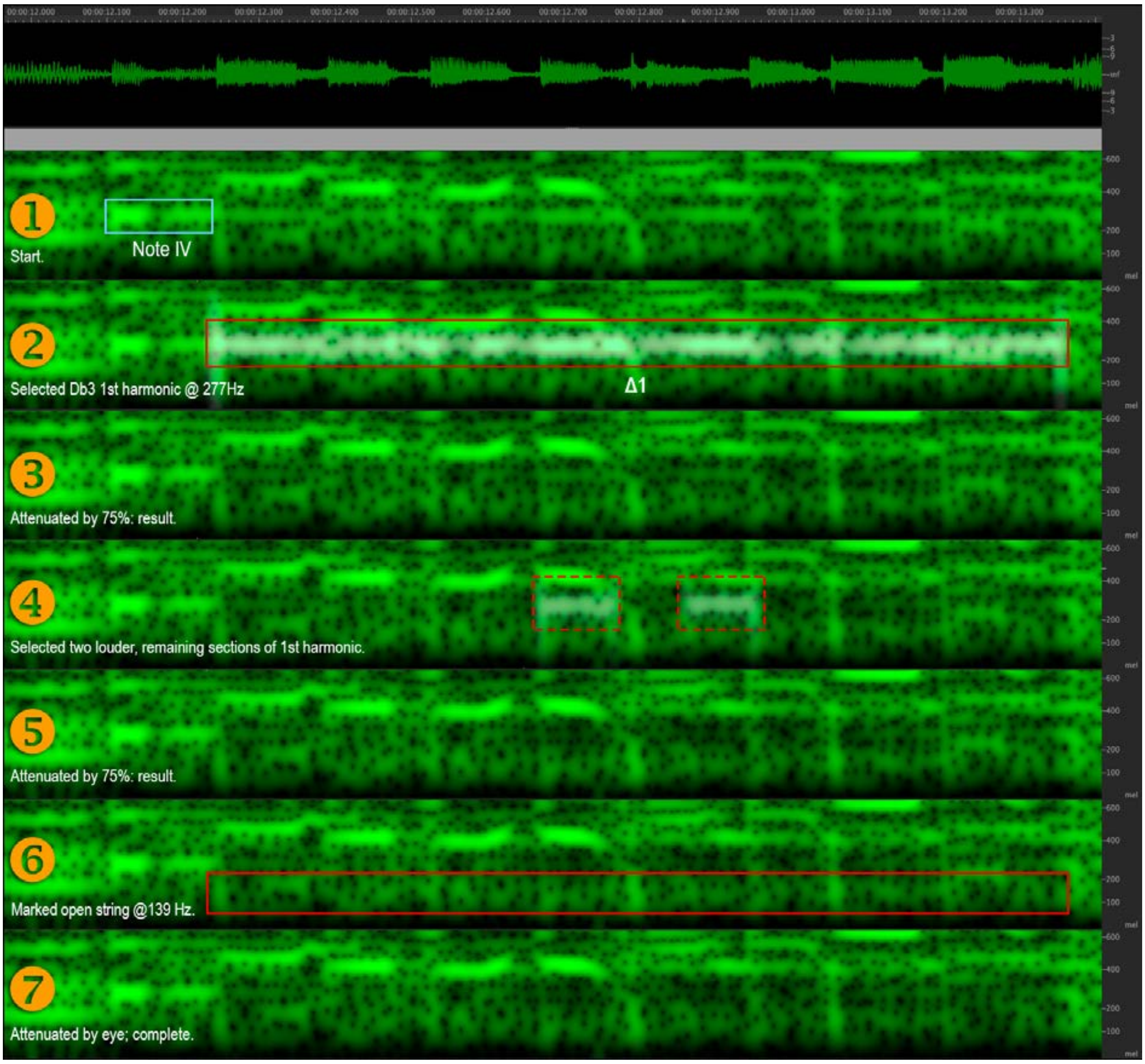

Figure 71: Spectral Editing Steps to Restore the Performance of Note IV

I auditioned the results, and they sounded as expected. The restoration of note IV appeared to be complete.

7.2.3.2.2 Note V

Figure 72: Note V in Segments 80 & 81

Note V was identified as an Articulation error in which two strings were hit instead of one, and the pitch of both can be heard. After the note's conclusion, neither pitch is heard; this implies that both notes were muted properly. Given the speed of the notes in the motif, it's possible that the errant note was muted accidentally, along with the intended one. We'll examine the spectral display for more information, shown in Figure 73.

Because this a fast (16^{th}) note with the same intended staccato articulation as the surrounding notes, it would probably not be noticeable to the listener if the note were replaced with a different note that was modified to the original amplitude and timing of Note V. However, because the timing between the strikes is audible, the intended timing is not known. A restoration using spectral editing was therefore required.

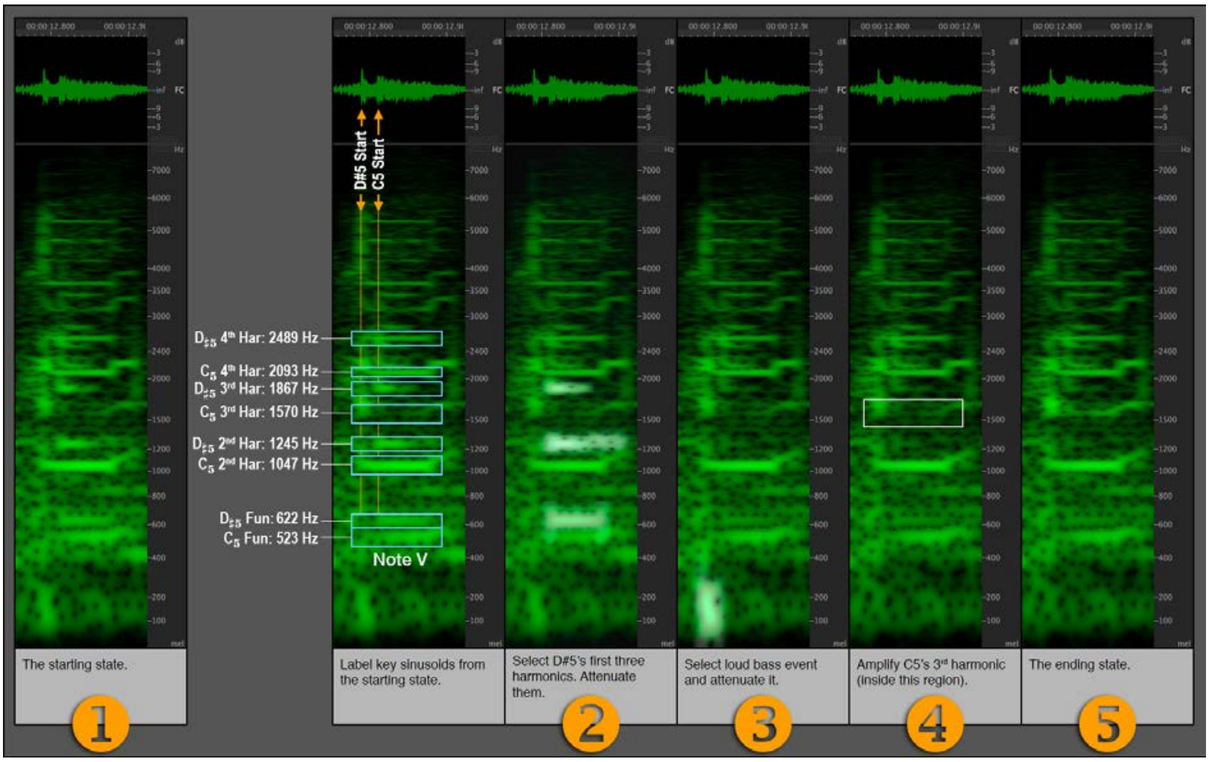

Figure 73: Spectral Display for Note V and Rendering Steps for Performance Restoration

In Step 1 (the starting state), the harmonics of two distinct notes appear to be visible. To identify them, I first computed the first four harmonics of the score note (C5): 523 Hz, 1047 Hz, 1570 Hz and 2093 Hz. Then, I identified the frequencies of the four other prominent sinusoids: 622 Hz, 1245 Hz, 1867 Hz and 2489 Hz; these were the first four harmonics of D♯5.

The D♯5 was picked just before the C5. Examining the fingering diagram again (Figure 74), it can be seen how this would have happened. Before playing the C5 on the second string, the guitarist would have already had his first finger on the E♭5 fret of the first string. This is true because it would have taken him too long to reconfigure his hand when he made the transition from the D♭5 (2nd string) to E♭5 (1st string).

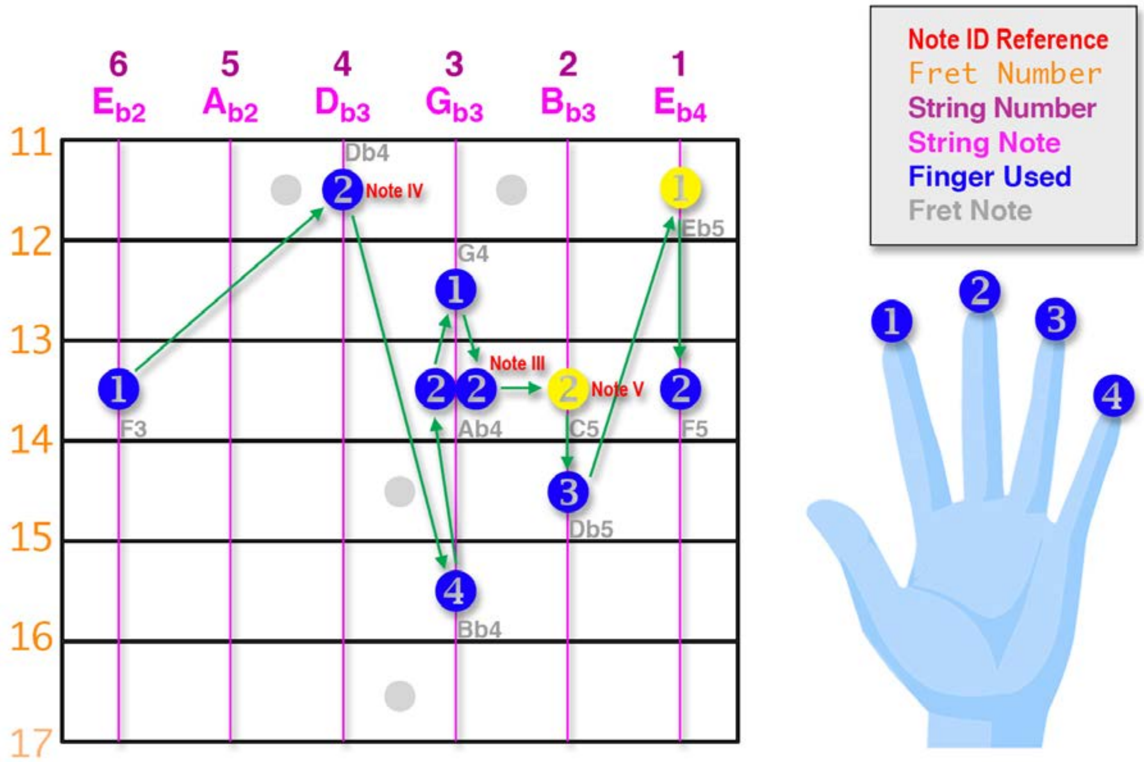

Figure 74: Error V Highlighted in the Fingering for the Performance of Segment 81's Final Motif

Because he was alternate picking, his pick passed over the 1st string before it hit the 2nd string. If his pick was a few millimetres down too far, he would have accidentally struck the sixth string on the way to the fifth. Because his 1st finger was planted there, the 1st string would have sustained, producing an E♭5 (D♯5). This created the double-note, with the E♭5 sounding before the C5.

I then needed to determine why both notes were unmuted at almost the same time. If the E♭5 was planted in preparation for the note, how did it get muted? By playing through the part, I realised that the note was muted as the 3rd finger came down on the next note: D♭5. The extensor digitorum muscle connects fingers 1-4, making it difficult to extend them rapidly, independently. An experienced guitarist will have developed significant independence, but it would still be easier for this performer to temporarily release his 1st finger when reaching with his 3rd finger for the 15th fret. The 1st finger would still be in position for the next note, right above the 12th fret.

I had now established that the mechanism by which the performance error occurred. Given this mechanism, the C5 note was performed as intended; the D♯5 was not meant to be heard.

Therefore, I needed to eliminate the sinusoids corresponding to the D♯5—without causing audio artefacts. To perform this edit successfully, I employed two techniques mentioned in Section 6.2.1.2: attenuating instead of removing, and investigating whether there was a small number of sinusoids which created the perception of the note (instead of trying to identify and modify of all them).

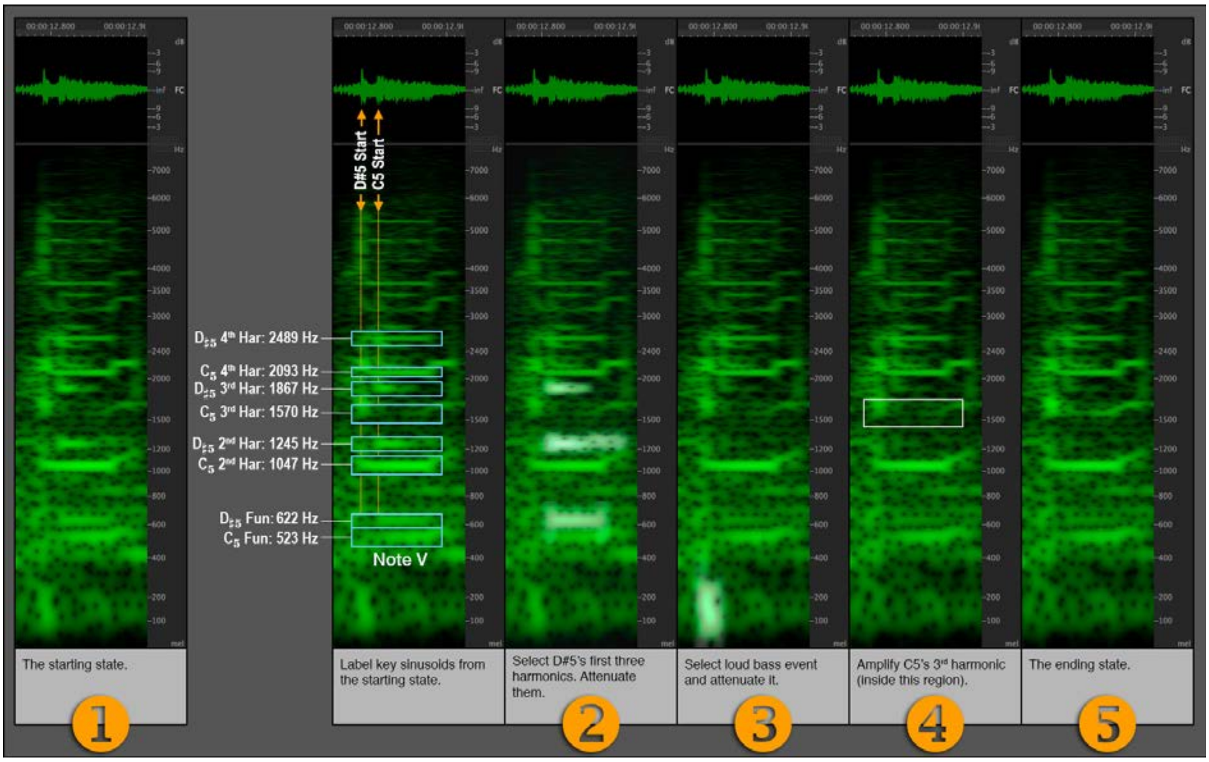

Figure 75: Spectral Display for Note V and Rendering Steps for Performance Restoration

I was able to identify three key sinusoids for the D♯5: the first three harmonics. In Step 3, I selected them with the Harmonic Selection tool, and then attenuated them.

While doing so, I discovered that an audio event did not appear to be an intended part of the performance. I identified it as extra low-frequency pick sound, due to two strings being picked instead of one; I attenuated it.

When I auditioned my results, the D♯5 was inaudible, and no audio artefacts were identifiable. However, the timbre of the C5 was uncharacteristically thin. I did not replace this note with another from elsewhere in the performance, because it was otherwise performed as intended.

Additional perusal of the spectrum revealed that the third harmonic was barely present. Using the Amplifier Brush tool, I amplified the frequency region corresponding to the harmonic (1570 Hz), significantly. When auditioning the C5 again, the timbre sounded correct.

After auditioning the results, the performance restoration of note V appeared to be complete.

7.2.3.2.3 Note VI

Figure 76: Note VI in Segments 80 & 81

Note VI appears to have an error caused by strings being hit almost simultaneously, with the intended one (G4) sustaining as planned. As with note V, I wanted to find evidence in the audio spectrum. Likewise, it was important for me to determine the mechanism by which the error occurred. For the purposes of this discussion, I will include both string strikes as comprising Note VI; to restoring this note, I would presumably need to remove one of the strikes.

Like note V, a replacement note could not be used to restore the VI, because I did not know the intended timing. Unlike note V, this note was longer and sustained (not staccato); the use of a replacement could not restore the original performance. My approach for this note was to preserve as much of its original recording as possible.

The default FFT sample size (2048) revealed that indeed, two notes were struck at nearly the same time. The FFT frequency resolution was sufficient to demonstrate there was one set of harmonics, indicating only one of the pick strikes sustained. The two notes' existence and timing were corroborated by the waveform display above the spectral view.

The next question was which strike (the first or second) was the intended, sustained note? To garner additional information, I required more precise temporal resolution.) I reduced the FFT sample size to 768 samples, and it was revealed that the two strikes were (~40ms apart).

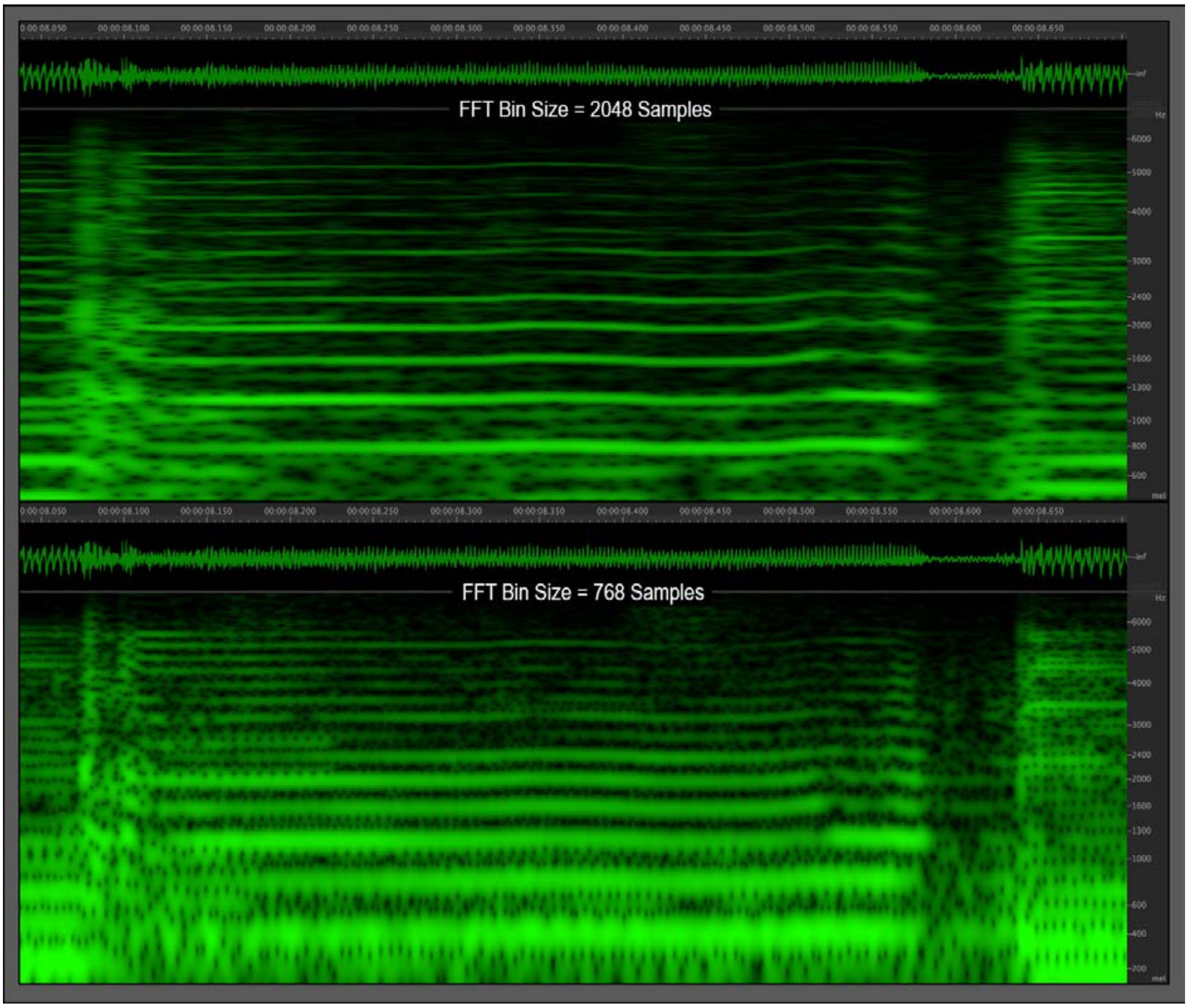

Figure 77: Increasing of Temporal Resolution for Investigating Note VI

Using both views (2048 and 768 FFT sample sizes), as shown in Figure 77, I was able to determine that it was the second note which sustained, and was intended. Because of the guitar's distortion, there was deformity in harmonics. However, a comparison between both views revealed evidence of contiguous harmonics created by the second strike, especially the 5th harmonic (1960 Hz) on the 768 sample size FFT.

The next and final step in estimating the intended performance was determining the intended start boundary of the note—which of the two pick events? Just because the second produces the intended pitch doesn't mean the first wasn't the desired timing; he might have landed on the 1st or 3rd string by accident, and was picking toward the 2nd string, accidentally striking it right after.

Figure 78: Me Performing Note VI with One of the Two Possible Alternate Picking Directions

I recreated the performance conditions to see if any evidence emerged. In Figure 78, I show the most likely fingering when both VI, and the note before it, were picked. Note VI (G4) was played on the 2nd string, 9th fret; the previous note (B♭3) was played on the 4th string, 9th fret. Depending on the direction B♭3 was picked, one of two possible outcomes occured:

If he had picked the B♭3 (4th string) *away* from his body, then he would have lifted the plectrum over the 1st string, switched directions, and then accidentally struck the 1st string on the way to the G4 (2nd string). Alternately, he could have picked B♭3 (4th string) *toward* his body, switched directions, lifted the plectrum over the 4th string, and then accidentally struck the 3rd string on the way to the G4 (2nd string), as shown in Figure 78).

In both cases, G4 was hit at the intended time, and resonated as intended; the 1st and 3rd were both already muted because neither string was intended to be used. Thus, to restore VI, I would remove the first strike, leaving only the second (intended) one.

However, my explanation begged the question: how did I know that alternatively, the 1st or 3rd string was hit at the intended time of the 2nd, and that the 2nd resonated only because of continued momentum of the pick hand?

The first answer is that in both cases, the pick was moving down, as well as laterally across the neck when the next note was struck. If the force was directed (down) at the closer and wrong string (1st or 3rd), and only the 2nd string afterwards (due to momentum), then that string would be hit much softer than intended due to the vector of motion.

Second, the momentum would also have been less when hitting the 2nd string, because there were no notes to pick after VI: That note sustained, so the guitarist's motor control would stop the wrist, regardless of where it landed. However, it can be seen (and heard) that VI's amplitude matches that of similar notes, including one at 00:10.880.

Since the most intended note of VI was intact and correct, I aimed to restore the note, and render the new audio, by simply removing the first (errant) strike. Given that this was an 8th note, instead of the more common 16th in these Segments, I was particularly keen to preserve the sustain and release portions of the note. However, this prooved problematic because the note previous (B♭3) to VI ended at the first (errant) strike; removing that strike created an unnatural transition between the two notes.

Therefore, I elected to replace the attack portion of VI (both strikes) by copying the attack portion from VI's twin VIβ at 00:10.880 in an identical motif, later in the Segment. This was accomplished using SpectraLayer's Clone Stamp tool, with a wide cross-fade region set. Because the previous note was B♭3 in both cases, and played at the same time in relation to VI, the transition to and from VI's new attack sounded natural.

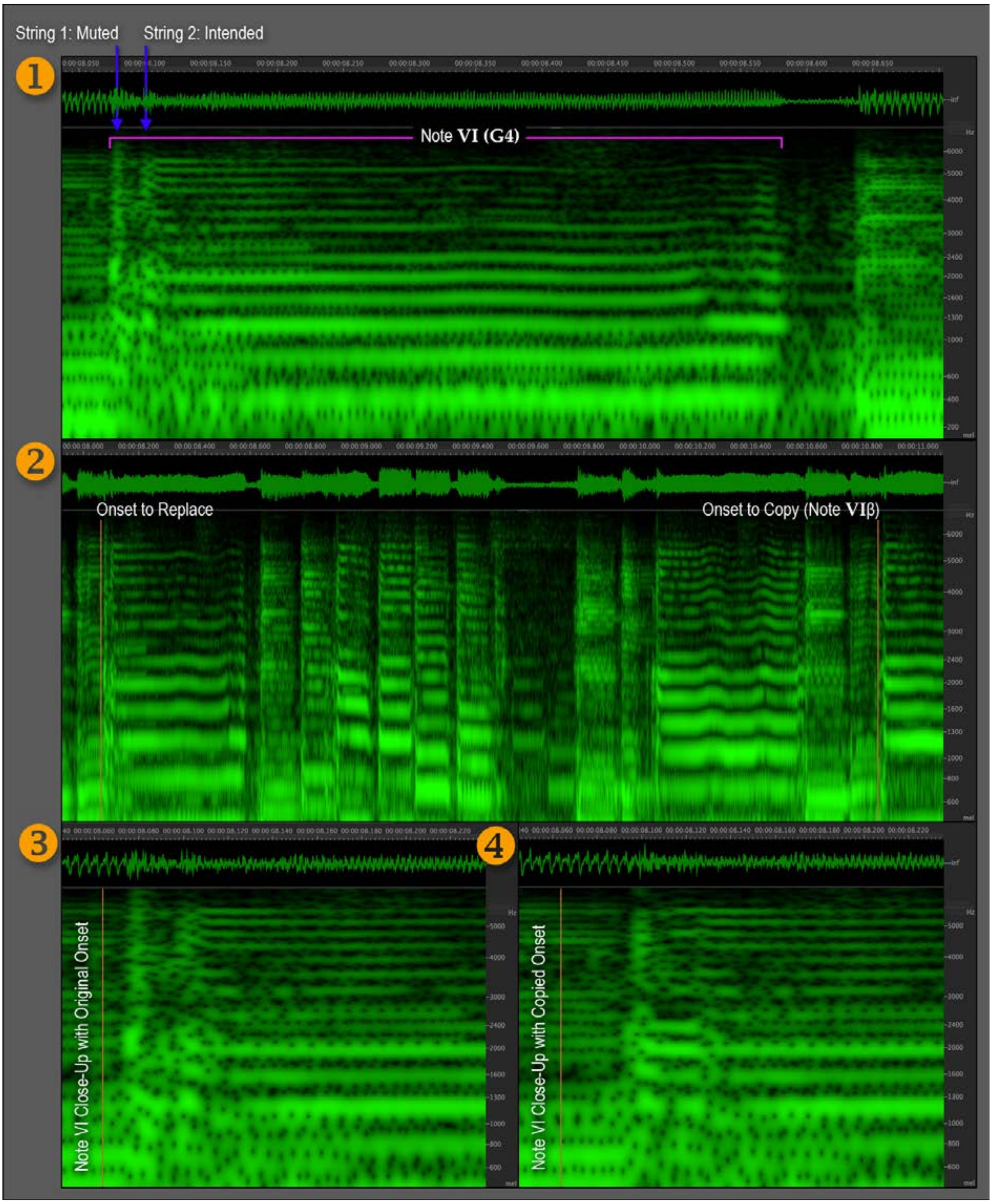

Figure 79: The Restoration of Note VI

After auditioning, note VI appeared to be restored.

7.2.3.2.4 Error X

Figure 80: Note X in Segments 80 & 81

There is one note in these two Segments that appeared to be a performance error, but I concluded it was not: the final note (X) of Segment 81. As with Note V, there were one or more strings hit, in addition to the intended one (F5 on the 1st string). I ascertained that these notes were the guitarist's positioning his left (fretting) hand so he would be able to strum the approaching chord on time. As such, this was not a performance error—these sounds should have been there.

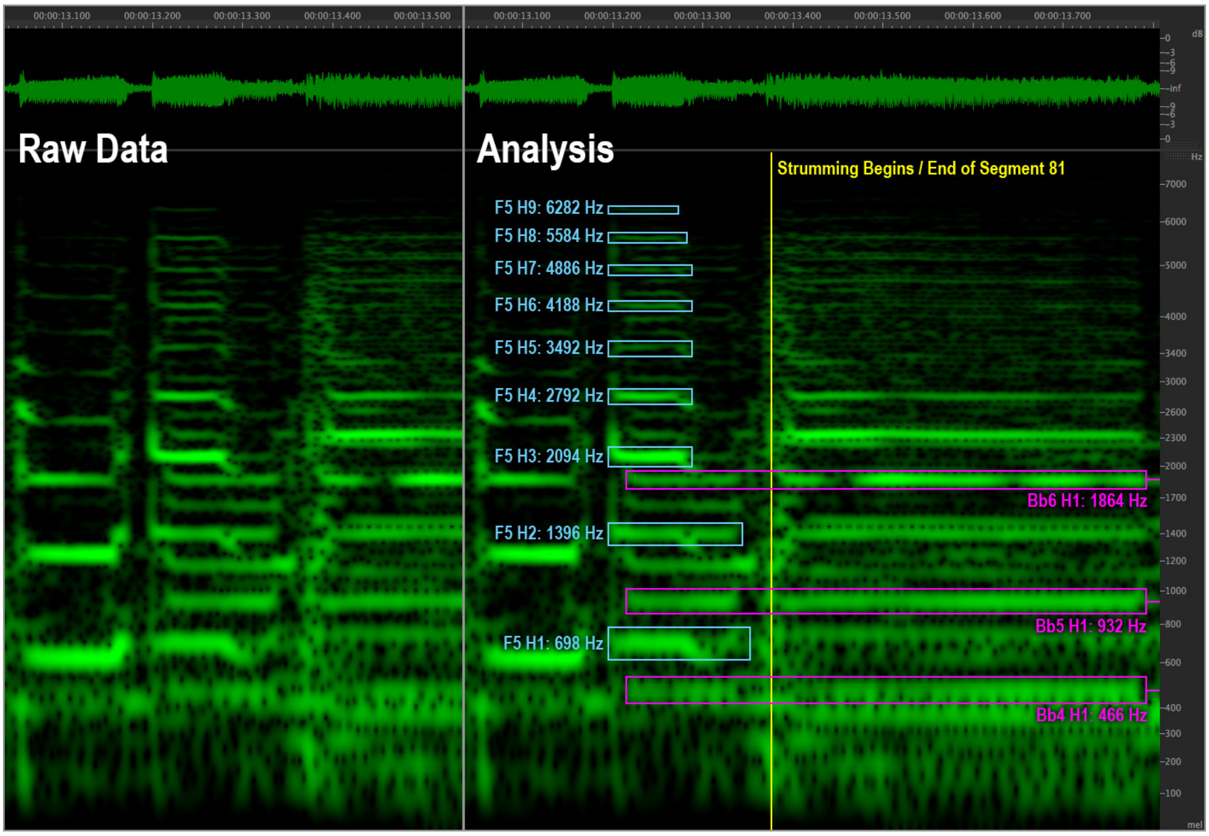

Figure 81: Transition Fingerings into Chords at the End of Segment 81

Note X (F5) ends a motif of staccato 16th notes before transitioning to a strummed G♭ major chord (G♭, B♭, D♭). The strumming begins on the next 16th note, leaving the guitarist little time to prepare for a six-note chord. This must be accomplished while articulating and sustaining the F5 correctly—a challenging technical endeavour. When auditioning the part, the F5 was clearly audible, and not overshadowed by the other frequencies. Likewise, the attack of the other strings being pressed was not audible.

The spectral and waveform data, seen in Figure 81, supported this conclusion. The F5 begins with a clear transient, as evident in the waveform. All of the harmonics of note X are present and at high amplitude, indicating the timbre was correct. Shortly after X is picked, the other strings are seen to begin resonating. They are at a lower amplitude, their harmonics quickly fall off, and all occur at the same time; this demonstrates control on the part of the performer.

While some of these transitional sinusoids will be created on the way to the finger positioning for the chord, the fundamental frequencies of three strings (comprising the chord) being fretted can be seen during the F5: B♭4, B♭5 and B♭6.

Therefore, there did not appear to be performance errors in note X. I revised the error identification list, removing note X.

7.2.4 Evaluation

After finishing the initial Rendering on all flagged notes in Segments 80 and 81, I auditioned the results within the context of the song. I was satisfied with the legitimacy of all the restorations. The final recording was not technically perfect. It sounded like the precise performance the guitarist would have given if his performance matched his intentions, mitigated by the expectations of a live rock concert, according to his skill level and repertoire. It felt authentic. I completed the EAPR process by updating the list of performance errors. (See Table 18.)

Table 18 : Final Performance Errors for Segments 80 & 81

ID	Class	Category	Type	Description
I	Event	Score	n/a	The note is one semitone low.
	Event	Execution	Articulation	The note is unintentionally slightly muted.
II	Event	Execution	Intelligibility	An intended monophonic note contains two pitches at equal volume. Articulation is correct.
III	Event	Tuning	n/a	The note is sharp by ~50 cents.
IV	Event	Execution	Articulation	Instead of being muted, an accidental harmonic is struck, causing the string to sustain until the end of the Segment.
V	Event	Execution	Articulation	Two have been hit instead of one, with both sustaining for the intended note's duration.
VI	Event	Execution	Articulation	Two strings have been hit instead of one, with intended one sustaining for the intended note's duration.
VII	Event	Execution	Intelligibility	An intended monophonic note contains two pitches at equal volume. Articulation is correct.
VIII	Event	Execution	Intelligibility	An intended monophonic note contains two pitches at equal volume. Articulation is correct.
IX	Event	Execution	Intelligibility	An intended monophonic note contains two pitches at equal volume. Articulation is correct.

This chapter concludes with the two scores for Audio Segments 80 & 81: Figure 83 shows the labelled Intended Blob score; Figure 83 shows an EAPR Notated score. As noted in 8.3.1.2, there are restrictions as to what can be provided, logistically, in a restoration score. In this case, the score is a still image, providing basic information on the Melodyn-based restorations. Both scores were effective in providing me with records during the restoration process, and providing organisational structure. A purpose-built, time-based EAPR restoration score tool would provide superior record keeping ability, and further enhance my practice.

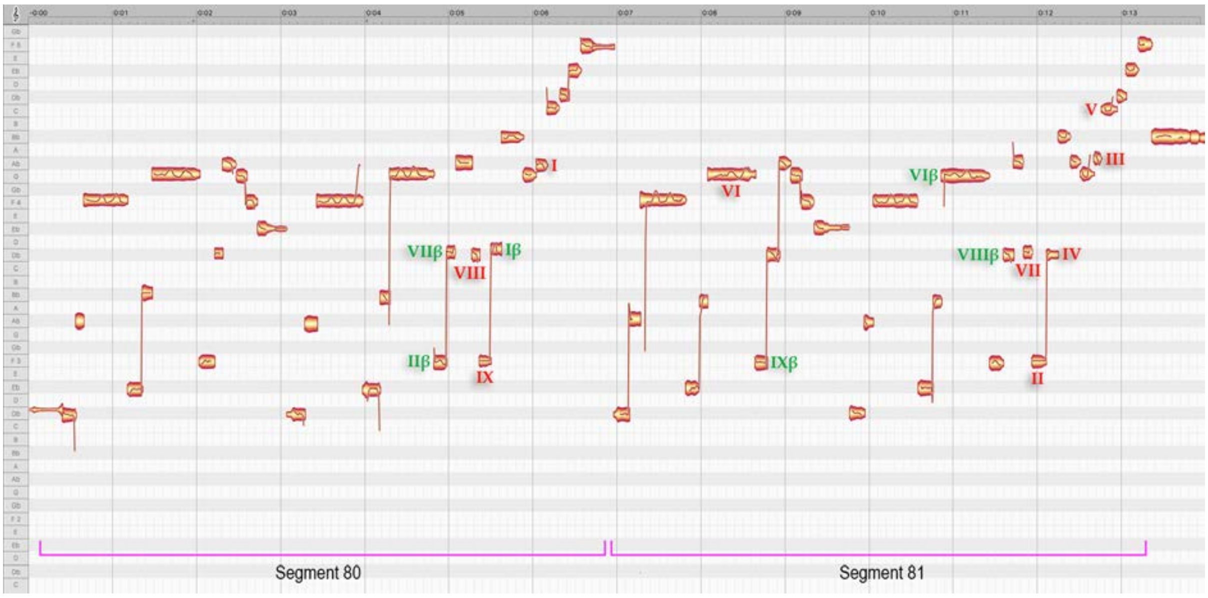

Figure 82: The Labelled EAPR Intended Blob Score for Audio Segments 80 & 81

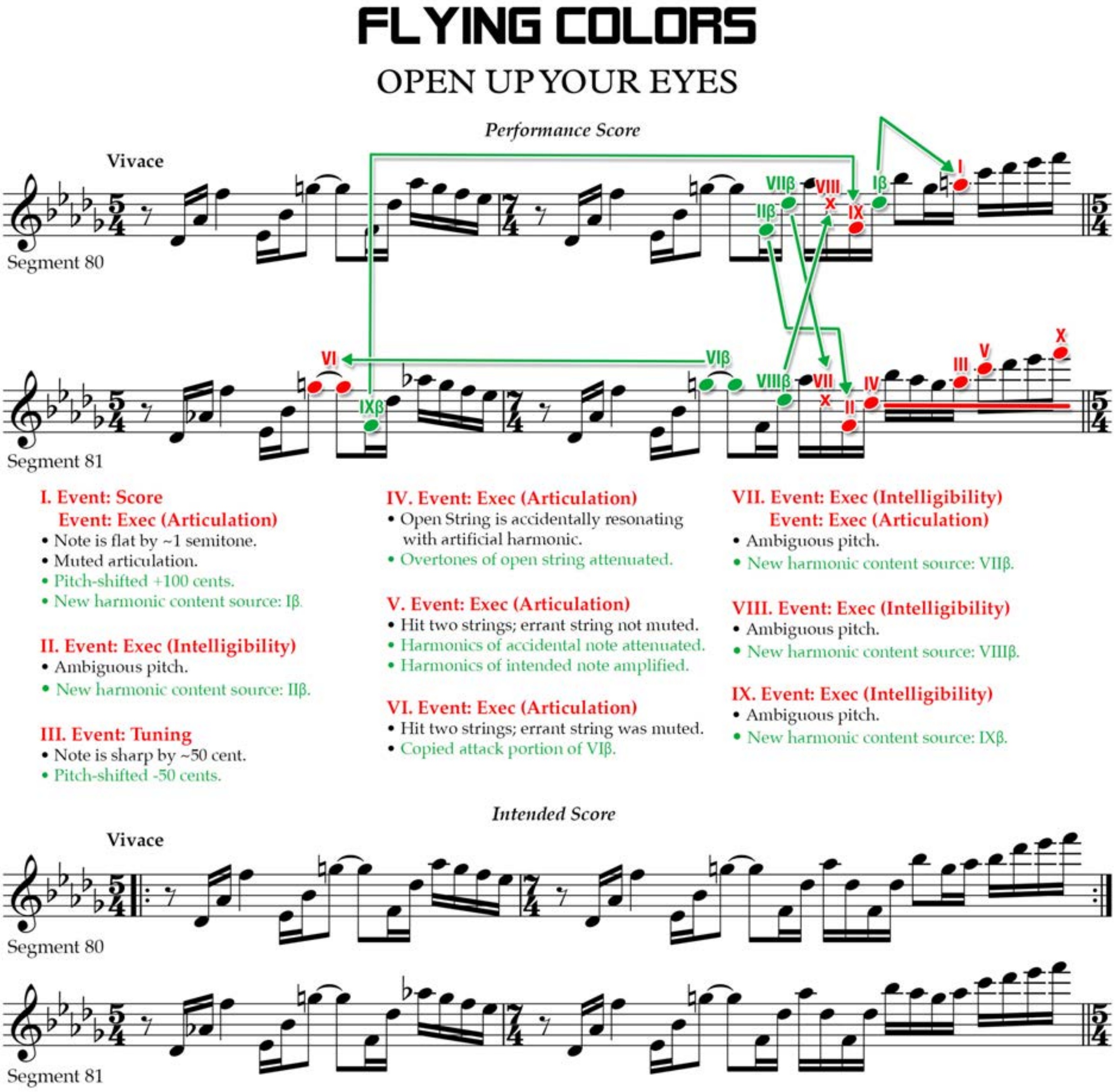

Figure 83: The EAPR Notated Restoration Score for Audio Segments 80 & 81

8 : Conclusion and Suggested Future Work

In this final chapter, I summarise my work and look to future research. I begin with a review of the new knowledge produced by my research. Next, I encapsulate my work with the Creative Album Submission. My research and production challenges are analysed, as well as my internal evaluation of the album's results. A discussion of the Supplemental Album Submission follows.

In the final section, I present future research. Starting with a narrative, I recount my collaborations with the makers of audio tools I employed for the two Submission Albums. Finally, I explore future research with the design and construction of a hardware/software tool specifically designed for EAPR.

8.1 Introductory Summary

There has been limited research into the identification of performance errors in progressive rock (and popular music, in general). Likewise, there have been few investigations into performance errors with canonical rock instruments (guitar, bass, drums, synthesizers). There is little research about performance errors in recorded (as opposed to live) music. And investigations into repairing these errors have seldom been pursued, musically or technically.

I began my research by analysing the problem of performance errors in my creative practice of live album production in progressive rock. The industry standard approach of obscuring errors did not meet the goals of my practice. As the music industry transitions away from a sales-based model, factors have emerged that negatively affect the performances in live recordings: lower budgets, shorter rehearsal periods, increased illness while touring, single recording/filming sessions, and a cultural expectation of perfection.

Employing a practice-as-research methodology (PaR), the knowledge within my research is embedded in myself as the practitioner. It is my hope that the knowledge I have garnered may be considered relevant and applicable to other practitioners.

8.2 New Knowledge

In developing a unified process to address these issues, I established a series of definitions, methods, contexts, and creative philosophies; they are conceptualized under the term, Error Analysis & Performance Restoration (EAPR).

8.2.1 Chapter Two

I began by establishing the audience groups in my practice. Drawing on my professional experience with them, I identified their perceptual roles in identifying errors relevant to my practice. These roles informed the foundation for developing my practice-specific error management system.

	GROUPS		
Aspect	**Artist**	**Press**	**Fans**
Access Order to Release	First	Second	Third
Listening Frequency	Minimal	Once	Many
Perceptual Dispersion	None	One-way (publishing)	Two-way (social media)
Evaluation Context	Artist's catalogue Peers' releases	Artist's catalogue Top genre releases	Artist's catalogue Top genre releases
Error Perception Context	Self	Similar artists	The artist
Error Focus Level	Varies	Macro	Micro

Figure 84: Review of Table 2, "Album Perception by Audience Group"

8.2.2 Chapter Three

Determining the nature of performance errors emerges from my practice as both significant and challenging. As a precursor, I established the ontology of live albums in my practice, and the definition of a restored album therein:

A ***restored album***, in the context of my practice, is defined as a recording of the ideal performance of a specific concert, according to the best-determined intentions of the performers and the median ability of their creative improvisation (within their repertoire), during that performance.

I followed with an investigation of the existing research in the domain of performance errors, focusing on the definition and the ontology of error perception. I defined *performance error,* in the context of my research, in Section 3.2.4:

> *Any conscious or unconscious perceptual occurrence experienced by a significant portion of any audience group in my practice, or that has the potential to be communicated and then experienced by a significant portion of a group, which creates the impression of a performance that is inferior to the one intended by the performer(s).*

In Section 3.3, I reviewed research on performance error taxonomies, and presented a novel taxonomy for EAPR in Section 3.4, reproduced in Figure 85.

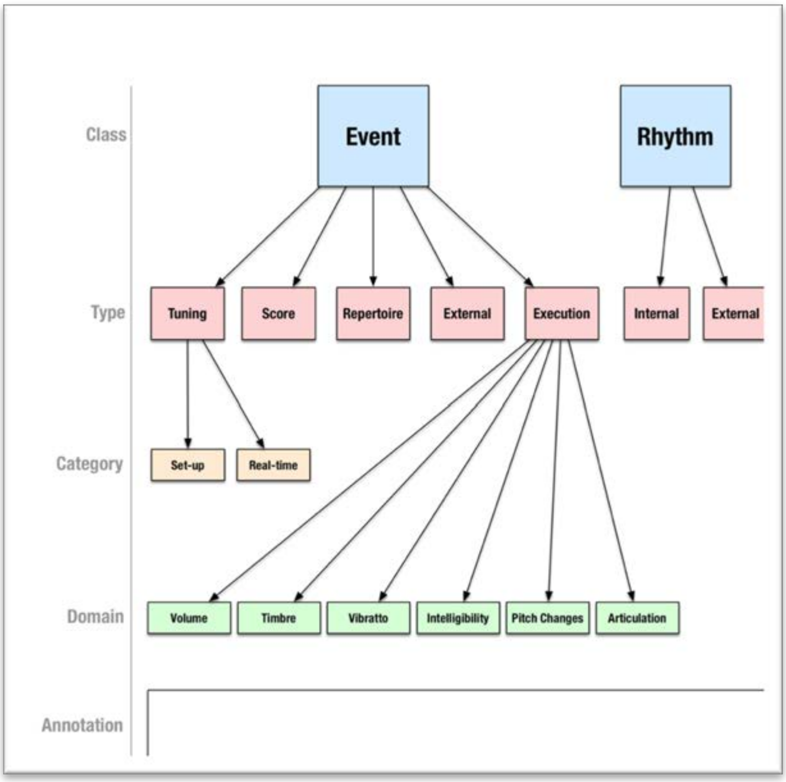

Figure 85: Review of Figure 10, "The PBE Taxonomy"

8.2.3 Chapter Four

Having developed these definitions and error taxonomy, I moved on to investigating the estimation of intended performances, based on performance errors. My literature review included data on recovering cognitive motor programs, presented in Section 4.2.2.1. Additional research was performed regarding the use of filmed performances was introduced Section 4.3.5. I termed the estimation process, *Performance Forensics*.

The above enquiry resulted in the establishment of five knowledge domains used with EAPR to estimate intended performances; they are summarised below in Table 19. Examples used in estimating performances are shown in Chapter 7.

Table 19: Knowledge Domains to Predict Intended Performances

Knowledge Domain	Explanation
Performer's Repertoire	Past performances can predict new performances, including improvisation.
Music Theory	Assembling the cognitive hierarchy of the artist's intended performance, both musically and for performer's motor-control.
Instrumental Expertise	Expertise in the instrument informs the practitioner regarding the cause of an error, which can be used in multiple domains to inform original intention.
Audio Science	Understanding the correlation between the digital representation of audio, and what is perceived, can inform the practitioner.
Video Playback	Examination of video playback can provide queues about the intended performance.

I presented the EAPR process to analyse performance errors, and restore the intended performances, in Section 4.4. It consists of two phases: Analysis and Restoration; each phase consists of multiple stages. The stages are generally executed in linear order, though there is freedom for the practitioner to inform her current stage by using previous or future stages.

Phase	Stage	Explanation
Analysis	**Screening**	Scan the audio recording for possible performance errors.
Analysis	**Authentication**	Determine the location and immediate (physical) cause of an error.
Analysis	**Triage**	Determine if the error should be addressed or not.
Restoration	**Transcription**	Determine the score of the performance represented by the recorded audio file.
Restoration	**Conceptualisation**	Determine the score of the intended performance.
Restoration	**Identification**	Categorise and label the error type(s), class(es), and domain(s) according to the PBE taxonomy defined.
Restoration	**Rendering**	Generate (render) the audio for that performance.
Restoration	**Evaluation**	Assess the results, based on the analytical process outlined in the EAPR Analysis Criteria.

Figure 86: Review of Table 7, "The EAPR Performance Restoration Process"

The EAPR process is abstract. Implementation consists of the practitioner's selection of tools, and the techniques (analysis and rendering) to realise the EAPR process. This abstraction is made because existing tools and techniques for performance restoration are nascent; as technology evolves, and more techniques are developed, it may be possible to formalise the implementation aspects of EAPR as part of its process definition.

Following the presentation of the EAPR process, I present a guide to restoration theory based on the PBE error taxonomy. This guide is later used, in Chapter 7, for the creation and use of EAPR techniques.

8.2.4 Chapter Five

In Chapter 5, I present new knowledge regarding error management by other practitioners, within the context of my own process. It serves as a literature review to inform my implementation of EAPR for my production of the creative artefact.

I document the scarcity of existing literature on the topics of error management in audio production, in both academic and industry publications. To add to the knowledge available for my inquiry, I undertake informal correspondence with 14 other practitioners in the music industry. In the context of informing my EAPR implementation, and the practice as research methodology of my overall investigation, this exercise is not intended to be a formal survey.

A standard industry practice for managing performance errors (the SIA) emerges. The remaining discussions in the chapter examine the SIA within the context of EAPR. In Section 5.1, I investigate the conceptual issues; and in Section 5.2, the implementations via techniques. The pros and cons of each aspect, in terms of EAPR, are examined. A formal taxonomy of the SIA alteration techniques is introduced at the end of the chapter, and reviewed here in Figure 29. (A taxonomy of EAPR techniques is not possible due to their quantity, breadth, and complexity; examples are provided in Chapter 7.)

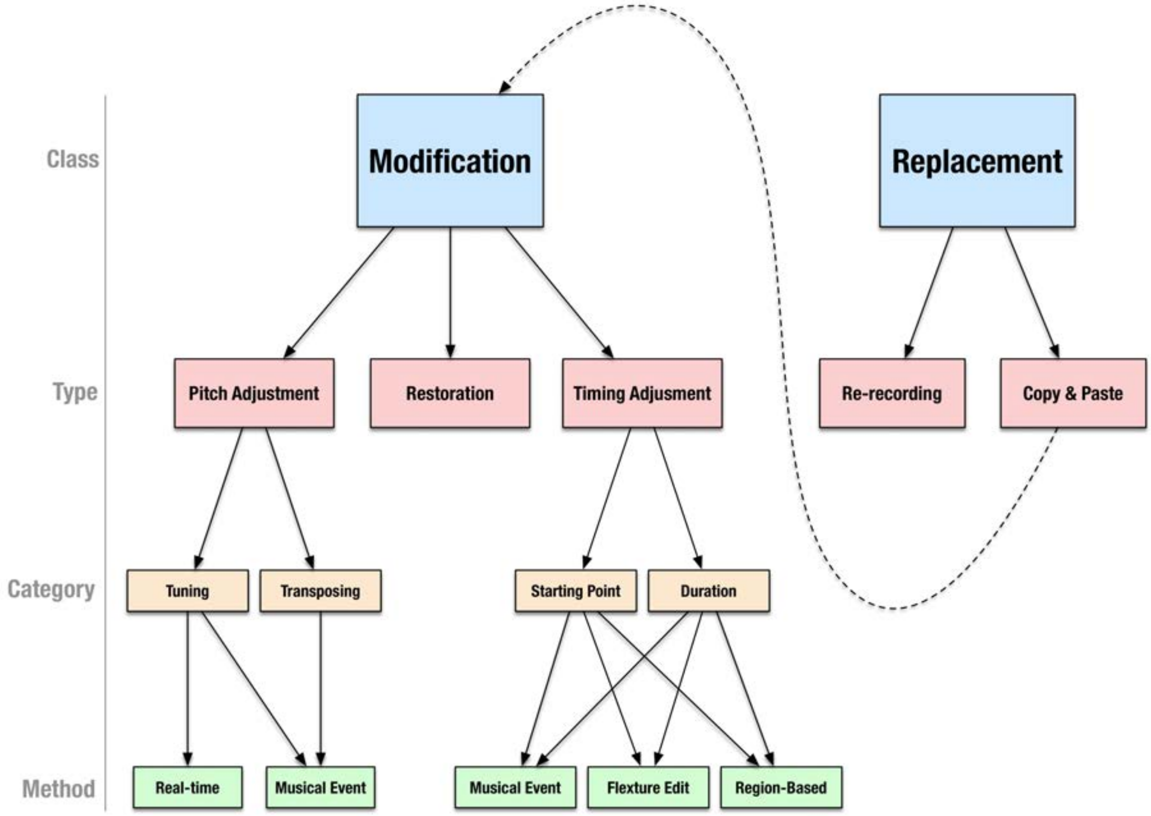

Figure 87: Review of Figure 29, "The SIA Taxonomy for Alteration Techniques"

8.2.5 Chapter Six

Chapter 6 presented a complete implementation of the necessary tools to implement EAPR; the specific project was the Creative Submission Album accompanying this thesis. This implementation required a review of the project's analysis and restoration requirements, with the result being a taxonomy of the tool categories required. For each tool category, the issues for each tool selection was investigated.

This chapter also detailed the procedure by which I selected specific software programmes for these tool categories. Multiple, comprehensive surveys of available software were undertaken. For each candidate programme, I examined its specific capabilities, relevancy to EAPR, challenges, advantages and limitations. The final selections were then presented and justified.

The results of these enquiries are summarised in Figure 88, below:

Tool Category	Selection	Version
Project Management	Logic Pro X	10.1
Flexture Editor	Logic Pro X	10.1
Offline Pitch Editor	Melodyn Studio	3.2
Spectral Editing	MAGIX SpectraLayers	4.0
Waveform Editing	Logic Pro X	10.1
Audio Restoration	iZotope RX	4

Figure 88: Review of Table 15, "Tool Taxonomy of, and Selections for, the Creative Album"

8.2.6 Chapter Seven

The thesis concludes with Chapter 7, which exhibits detailed, comprehensive examples of EAPR Analysis and Alteration techniques. These examples are taken from the Creative Album Submission, and demonstrate the EAPR process for the restoration of performances across multiple performance errors. Each of EAPR's phases and stages is documented, with intermediate steps shown, and the results available for auditioning.

8.3 The Creative Submission Album

As part of my practice as research methodology, I undertook the production of a Creative Album Submission to inform the development of EAPR. This production was a complete implementation of the EAPR process, applied to a front-line, major label progressive rock concert album and film.

Using the software tools presented in Chapter 6, and techniques such as those demonstrated in Chapter 7, my production on the album transpired over nine months in 2015. The final, restored album had EAPR applied to 22% of the running time on at least one track. In total, 285[83] individual sections incorporated EAPR. All documented restorations were on instruments.

8.3.1 Research Challenges

Two practical challenges emerged during my work on the Album. Feature and workflow limitations were the first; this caused the Album's production to take significantly longer than with more advanced, integrated tools[84]. The second was the difficulty of tracking the work I performed, and documenting it praxically.

8.3.1.1 Software Tools & Workflow

The DAW workflow presented several challenges for EAPR. While there is significant research in audio production tools and techniques, most of it is focused outside the area of my practice. The DAW, itself, has primarily not been reimagined since its inception (Cavanaugh, 1989). Its heritage draws from analogue studio practice (Guerrero, 2012), and some researchers feel this limits the development and integration of ontologically new features and workflows (Dewey, 2014; Bell, 2015).

An additional factor is that DAWs are used primarily for commercial studio production, not live recordings[85]. It can be argued that there is little commercial incentive to add features

[83] See Appendix B.
[84] Advances in technology and workflows were available in updated tools when I undertook the Supplemental Submission Album; efficiency was significantly increased, and the time required for EAPR was reduced.
[85] As previously noted, the vast majority of commercial recording are studio, not live.

specifically for live album production, because it represents a small percentage of both releases and revenue in the industry. As such, the topology and processing of DAWs do not currently focus on intra-track issues that are pervasive in live recordings (e.g. leakage), and are critical to restoring performance errors.

8.3.1.1.1 Third-Party Plugins

All of the Third-Party Plugins (TPPs) used to implement EAPR in the Creative Album Submission employed Offline workflow; such processing offers features unavailable with real-time processing, and imposed three types of penalties. One was that the audio streamed from the TPP was not native to the DAW; therefore, many native capabilities DAW functions were not available (e.g. region edits, undo buffer). Second was the additional time required to stream all audio into the TPP, manually. Third was that the audio from these plugins must be rendered in the DAW before being further edited; this made all edits destructive, and significantly complicated the task of documenting and backtracking while developing and executing rendering techniques.

An attempt to solve some offline workflow problems is the ARA (Celemony, 2018) inter-application protocol introduced by Celemony and Presonus Audio Technologies. By allowing audio applications and plugins to share access to data (e.g. the underlying audio) some of the workflow issues with offline processing are alleviated[86].

8.3.1.1.2 Stand-Alone Audio Applications

Stand-Alone Audio Applications, notably SpectraLayers Pro (Lobel, 2015a), provided critical, unique functionality in the Album's EAPR implementation. However, SAAAs introduced additional workflow limitations. Audio was always required to be rendered and exported to/from the DAW and SAAA.

[86] As mentioned, the implementation for the Supplemental Submission Album was ARA-based.

8.3.1.1.3 Undo Functionality, Backtracking, and Documenting Work

With hundreds of specific EPAR restorations and as many as 20 separate operations for a given restoration, some of my techniques required 50+ audio files for a single error restoration. DAWs, however, are not designed to have cumulative versions of tracks.[87]

A clear path of intermediate steps would have been significantly beneficial to my workflow because many restorations failed on my first attempt. I would then need to revert to an earlier restoration state (which usually involved a different file or set thereof). Therefore, the DAW project needed to contain all files representing all the steps—plus alternates (for experimentation)—for each restoration. The Album contained hundreds of repaired sections, resulting in thousands of relevant audio files.

There is little mechanism to organise these files in the DAW since such functionality is not generally a part of DAW requirements. As a result, the DAW project became increasingly challenging to organise. It became increasingly difficult for me to revisit an earlier restoration to make changes, and the probability of my making mistakes grew exponentially[88] as production continued.

8.3.1.2 Praxical Diary Challenges

Section 4.4.2.1 details the three scores endemic to the EAPR process (*Work*, *Performance* and *Intended*). During my work on the Creative Submission Album, I began to realise that I also needed a diary (i.e. recording or score) of the information and sequence of steps in making the restorations, themselves. At times, I would listen to a restoration from months before, and want to improve it. Often, I would encounter (for example) a rendering problem that was similar to one I had solved previously, and would want to know the technique I had developed for it.

However, many restorations were complex, requiring multiple applications and numerous steps. They were also praxical by nature, with frequent backtracking and new approaches

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[87] DRAW alternate take/playlist systems, depending on implementation, could theoretically solve some aspects of this problem, but those systems are not designed for the type of incremental workflow endemic to my workflow. For example, there are not separate plugins assigned in DAWs to alternate playlists. Additionally, many implementations do not allow the alternate files to be directly accessed for anything other than playback.

[88] For values of $n > 1$.

attempted at different stages. Without a record (or diary) to recreate the restoration, this information would be lost.

I termed this diary a *Restoration* score; it was defined as a record containing all the information to perform a specific restoration. The contents were: the intended and performance scores, a list of all the performance errors and their types, textual descriptions of their repair procedures, intermediate scores (of various types, dependent on the tools used), and links to the audio at every stage of work. As with notated music scores, the restoration score could be considered the restoration itself (in addition to the restored performance audio).

There were no specific tools to create these scores efficiently, though. Such a tool would require the support of each software application tool in an EAPR implementation, including access to their timelines and history buffer (and the ability to re/create the audio corresponding to each step). The visual portion of the score would represent the user interface for a specific software tool, and denote salient information.

I used a manual version of this process to create the graphics accompanying the examples in Chapter 7. The process was significantly time-consuming, and error-prone, however.

8.3.2 Internal Evaluation

In this section, I will summarise my internal evaluation process, both during production of the album, and after its release. These evaluations are part of my practice, informing my own conclusions about the success of my projects. In this case, one of the project parameters for *Second Flight: Live at the Z7* (Flying Colors, 2015) was the application of EAPR; this was a professional parameter in addition to being an academic one within the context of my research enquiry. As my practice is a commercial enterprise, economic and industry factors were part of my perspective. *There is no qualitative or quantitative analysis implied, and m*y evaluations are not presented as an objective measurement; they are part of my practice and research methodology.

8.3.2.1 During Production

During this process, I evaluated the success of each restoration attempt based on my practical experience with the four audience accountability groups identified in Section 2.3.2.4.1. During production, the artists in Flying Colors were not consulted during my work on the album; they heard the final mix before submitting comments. (There were only three, resulting in three short re-recordings.) I generally worked on each restoration individually until I approved the results; it was not uncommon, though, for me to review previous restorations and decide to revisit some.

Once I had completed and approved all the individual restorations, I listened to the album as a whole. Listening in this context lead me to revisit additional restorations; some restorations, while appearing coherent within the context of the short section within which I worked on them, were revealed to be not conterminous within the performance as a whole.

My final review took place while watching the concert video accompanying the music. Though my production workflow included a constant display of the rough video edit, disturbances emerged when experiencing the complete concert with full-screen video. The images felt detached from the audio—as if there were two simultaneous performances. This was remedied by focusing on ancillary, non-musical sounds (e.g. amplifier buzz, microphone feedback).

While EAPR guided me to retain many of these sounds, I had also processed them to project better control by the artists and audio engineers. This approach suggested realism when focussing only on the audio. But in the context of the full video performance, I perceived them as planned and artificial. The effect was subtle, with results akin to a sitcom's laugh track—not random elements of a live performance. My solution was to decrease my dynamics control of these sounds, and not attenuate them in the audience microphones.

At the conclusion of the video inspection, my final evaluation was finished. I determined the restored album to be complete, successful within the parameters I had defined when undertaking the production. Within the context of my practice, I felt it met the definition of a restored album, accurately conveyed the performer's intentions, and would be received well by the four audience groups I was accountable to.

8.3.2.2 Artist and Label Auditioning

The artists auditioned the first mix of the album, and approved all the restorations I had performed, except for three. Two were approximately three-second sections of guitar solos, which the lead guitarist re-recorded. The other was approximately two seconds of a rhythm keyboard part, re-recorded by the keyboard player. This represented a significant reduction in re-recording, compared with previous live albums by the artists.

The record label auditioned the Album, and designated it as a front-line[89] release. They further chose the Album as the first release through their new agreement with Warner Music Group Japan, with Flying Colors officially signing as a Warner Brothers artist (not with Mascot Label Group), making this the band's first major label release. It positioned Flying Colors on the same roster as pop artists Bruno Mars and Coldplay, one of two modern progressive rock bands on Warner, worldwide.

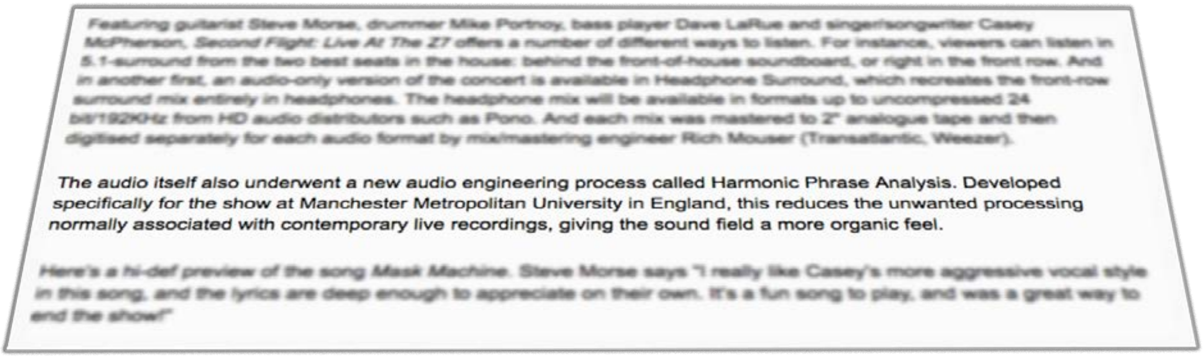
8.3.2.3 Post-Release

Second Flight: Live at the Z7 was released on November 13, 2015, by Mascot Label Group and Warner Music Group. As shown in Figure 89, the configurations were: Blu-ray with 2 CDs, DVD with 2 CDs, 3-vinyl discs, digital-audio a la carte, digital audio stream, and Headphone Surround (a binaural format I developed for digital release on the Pono digital music service).

[89] Front-line releases are a record label's highest-quality albums, receive the most promotion, and are generally priced the highest.

Figure 89: Mascot Label Group Announces the Release of Second Flight: Live at the Z7

The use of EAPR on the album was disclosed in the press release, under the moniker "Harmonic Phrase Analysis." (See Figure 90.) But EAPR's specific nature in restoring performances was not revealed to anyone outside of the band.



The audio itself also underwent a new audio engineering process called Harmonic Phrase Analysis. Developed specifically for the show at Manchester Metropolitan University in England, this reduces the unwanted processing normally associated with contemporary live recordings, giving the sound field a more organic feel.

Figure 90: The Press Release Described EAPR as "Harmonic Phrase Analysis"

Continuing the internal praxical evaluation of my accountability groups, I informally reviewed the response of music critics, reading all online reviews[90]. Their collective response was a rating as the most consistently acclaimed release by the band. (Reprints of all the reviews are in the auxiliary material accompanying this thesis; See Appendix A.)

The final group I informally canvassed was the fan base. For this self-evaluation, I chose to examine all of the feedback posted in the album release's thread on the band's Facebook

[90] I did not have access to most of the printed magazines with reviews, and decided therefore to exclude all such reviews.

page. Their responses indicated to me strong approval of the band's performances. Additionally, I sampled the consumer feedback on iTunes and Amazon, separately for the United Kingdom and the United States. Three of the four reported an average of five stars (out of five); one (British iTunes) was not yet available. (A reprint of the Facebook thread, along with screenshots of the iTunes and Amazon ratings, accompany this thesis as auxiliary material; See Appendix A.)

8.3.2.4 Summary

Based on my internal, informal evaluation of the four audience accountability groups in my practice, I concluded that the EAPR process I applied was successful within the goals of my practice.

An establishment of causality is not appropriate within the context of a practice-as-research investigation, as established in Section 1.4. As previously stated, the information that emerged from my engagement with the self-evaluation process was solely to inform myself within the context of my practice, and is not presented as representing any formal claims about the efficacy of EAPR.

8.3.3 The Supplemental Submission Album

Following the completion of this album, I applied EAPR to a live album outside of my practice, in regard to genre: a country/blues studio album. Based on feedback from *Live at the Z7*, I was hired to perform EAPR on this album. The artists on the album were instrumental virtuosi[91], though different artists from those on the Creative Submission Album; they numbered approximately twice as many artists as in Flying Colors. The Supplemental Submission Album provided me with an opportunity to apply EAPR outside of live progressive rock, and praxically evaluate my results in this context.

For this album, EAPR was applied far more extensively. At all times (as opposed to 22% on at least one track for the Creative Submission Album), most tracks contained EAPR. Many

[91] The participants in this album were not requested approval of to disclose their involvement in my investigation. In accordance with research ethics, their identities, and the name of the album, are witheld. Likewise, the conditions under which EAPR was required for the album are not revealed here. The album was a live studio recording, with some of the solos overdubbed.

were comprised primarily of reconstructed EAPR sections, and the majority of the audio heard by the listener, across all tracks, was performance-restored EAPR (and not the original audio). This album is provided for auditioning, along with the Creative Submission Album, as listed in Appendix A.

8.3.3.1 Internal Praxis

The application of EAPR techniques was often more complex and extensive than on the Creative Submission Album, and was often applied to longer sections. Yet my process was usually more efficient than on the Creative Submission Album. I attributed this to two factors: new technology, and my experience with developing techniques from the previous album.

For the Supplemental Submission Album, all of the software tools used to implement EAPR changed, except for audio restoration. This refactoring was based on my use of the ARA plugin format—as well as new functionality in Melodyn Studio 4, and the Studio One DAW.

Additionally, I was now working with Robin Lobel, the developer of SpectraLayers; as I worked on the Album, I suggested features for the forthcoming SpectraLayers 5; he quickly integrated these features into the SpectraLayers 5 alpha release. New versions were sent to me periodically during my production, each time enabling new or favourably-modified EAPR techniques. (More details on this collaboration are provided in Section 8.4.1.3.)

8.3.3.2 Internal Evaluation

Based on the self-evaluation format employed on the Creative Submission Album, I considered this album to represent an evolutionary step forward for EAPR. My rationale was based on the new challenges of this album, including work with artists mostly new to my practice, significantly more complex restorations, more artists to work with, and a new genre.

One of the differences in my work on this album was that my restorations were auditioned by the producers and primary artist during production. In multiple instances, several rounds of changes were requested. The most common feedback I received was that, based on my restorations, I had not captured the "feel" of the song—not of specific performers. For example, the feedback for my third attempt at one song, "The song is no longer fun." (These were instrumental songs; my only changes were subtle timing variations.) At the completion of the album with the approval of the principal artist and producer, the other artists auditioned and approved all restorations; I did not alter the performances of three of these performers.

Commercially, the album debuted at #1 on several blues charts, worldwide, and held at that spot for six days[92]. It was also used to launch a new imprint label with major-label distribution. The album was not a major commercial success, however. This was attributed by some to the traditionally lower sales in the blues genre, overall. The label considered it successful enough to order a follow-up.

Critically, the performances on the album were consistently acclaimed. It was less clear to me (as opposed to the Creative Album Submission) how much of these impressions were due to my work—I was not familiar enough with the practice of this genre to interpret this for myself. Instead, I considered that my work did not appear to adversely the critics' perception of the musicians' performances (especially given the considerable extent of my restorations). My primary self-evaluation source was the approval of the artists, most of them new to me, on the album. Almost all expressed interest in working with me again[93]. The primary artist also included a paragraph I wrote about EAPR (termed once again "Harmonic Phrase Analysis") in the liner notes[94].

As with my self-evaluation for the Creative Submission Album, I employed the results to inform me within the context of my practice, not to demonstrate the objective efficacy of my process. The same caveat applies to my presenting the results of the Supplemental album.

[92] These were daily, not weekly charts.
[93] At the time of this thesis, I completed one project with an artist for SONY Music Japan, and have just begun a new project with several of the artists from the original Supplemental Submission Album.
[94] Although the artist understand the nature of my work on the album with EAPR, I wrote the paragraph about the sonic clarity benefits of EAPR (which appeared to be an unexpected benefit of the process).

8.4 Future Research

As discussed in Section 8.3.1, my primary research challenges during my work on the Creative Submission Album were related to the software tools I employed to realise the EAPR process. My future research, therefore, is focussed on implementation tools.

8.4.1 Commercial Audio Software

During and directly following the release of the Creative Submission Album, I suggested several features (informed by my research) to companies that produced software tools that I used, or was considering using. My work with SpectraLayers and SynchroArts has already been introduced in this thesis; this section provides more detail on these collaborations, and a discussion of my work with Steinberg.

While I cannot directly address the companies' motives, their interest could be viewed as evidence that the new knowledge from my research could be applied from my practice to inform others'. To provide references for these collaborations, I engaged in personal correspondence with relevant personnel at these companies, and have cited them in this section.

8.4.1.1 Steinberg Cubase

One of the new features that emerged from my EAPR implementation was support for multiple markers: Most DAW software has only one set. Multiple markers are helpful to track and organise the EAPR process because performance errors occur on multiple tracks simultaneously. These markers (ideally) would indicate the starting and ending point of the region to be restored, information about the error(s) according to the EPAR taxonomy, the restoration's stage of completion, and which audio tool(s) was/were used.

Without multiple markers, this information must be maintained in an external database, which does not provide visual indicators of the regions in question (within the DAW). This becomes particularly cumbersome, and prone to error when there are hundreds of restoration regions. After suggesting this feature to representatives at Steinberg, multiple markers were included in Cubase version 9 (Simmerlein, 2017)[95].

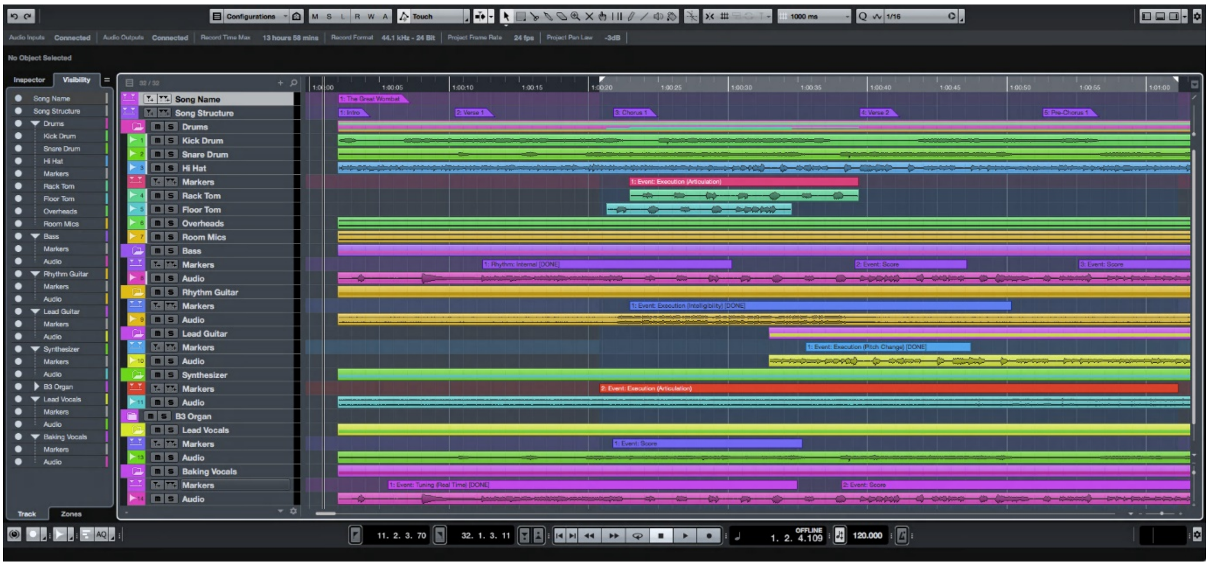


Figure 91 – Example Usage of Cubase 9's Multiple Markers for EAPR

8.4.1.2 SyncroArts Revoice

After one specific performance restoration of an upright bass, I sought to increase its clarity by restoring the attack component, which had degraded due to the signal processing required to adjust the performance. One of the tools I used was SynchroArts' Revoice, the most sophisticated application specifically for audio alignment. My use of the tool fell outside the normal usage, though, and the results lacked sufficient accuracy.

I brought this to the attention of with Jeff Bloom at SynchoArts; the company worked with me on adding support for this alignment to the software while I performed this restoration. The new alignment capability will be incorporated into the forthcoming commercial version of Revoice (Bloom, 2017). More information on this restoration can be found in Appendix E, Section 2.1.

[95] This occurred before my role at Steinberg began.

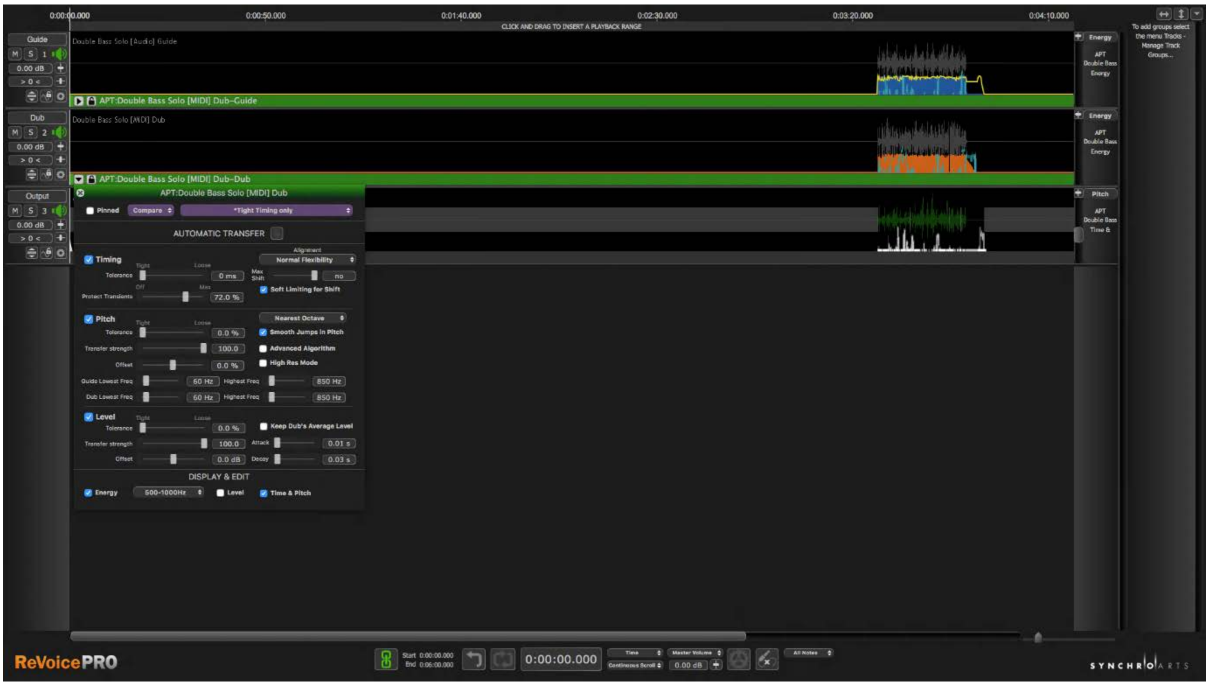


Figure 92 – The Revoice Pro Session for the Second EAPR Album Alignment Task

8.4.1.3 SpectraLayers

While MAGIX[96] SpectraLayers was critical for my work on the Creative Submission Album, I did not employ it as often as Melodyn. My restorations on the Supplemental Submission Album were more complex, however, and required extensive use of SpectraLayers.

There were several major features that I felt would increase the effectiveness of using SpectraLayers in my practice. I approached its author, Robin Lodel about adding them to the product, which was currently at version 4. In correspondence for this thesis, he stated that he was intrigued by my usage of his program outside its intended usage (Lodel, 2017).

Working together, Robin and I discussed ways of approaching these new features; he then would send me new product builds as he incorporated them. Based on my usage during production of the Supplemental Submission Album, I would provide feedback, and Robin would make adjustments as he saw fit. The result of our collaboration was a new release of SpectraLayers, version 5. Table 20 shows the features resulting from our collaboration:

[96] During the course of the Creative Submission Album, SpectraLayers moved from SONY Creative to a new publisher, MAGIX.

Table 20: SpectraLayers Collaborative Features

Feature	Discussion
Amplitude Colour Maps	This provides greater dynamic range for the audio spectrum over the standard monochromatic display, which used brightness to indicate amplitude. The greater range enhanced both the viewing and modifying of data. (See Figure 93 and Figure 94.)
Alternate Brush Shapes	The existing, round brush shapes in SpectraLayers were not the optimal shape for the spectral modifications in my practice. This is because most areas I modified were strictly horizontal or vertical. (There are, however, also singular, local areas which are best addressed with a circular brush.)
Spectral Audio Replacement	Based on D.A. Bett's "Method and Apparatus for Audio Signal Processing" (Betts, 2011), this feature predicts and generates the audio that would remain if a specified part of an audio region were removed. This was a common feature used by both myself (for the removal of clicks) and in progressive rock's Standard Industry Approach to error management; the most common software tool for both was iZotope RX. Rather than licensing Bett's patent as iZotope did, Lobel created his own algorithm.
File Handling Enhancement	As SpectraLayers 4 Stand-Alone Audio Application, integration with a DAW could significantly increase workflow efficiency and decrease the chance or errors. The new feature enhanced file-handling with DAWs, allowing audio regions to be automatically opened in, and saved from, SpectraLayers.

Figure 93 and Figure 94 illustrate the difference between SpectraLayer 4's monochromatic display, and SpectraLayer 5's colour map display:

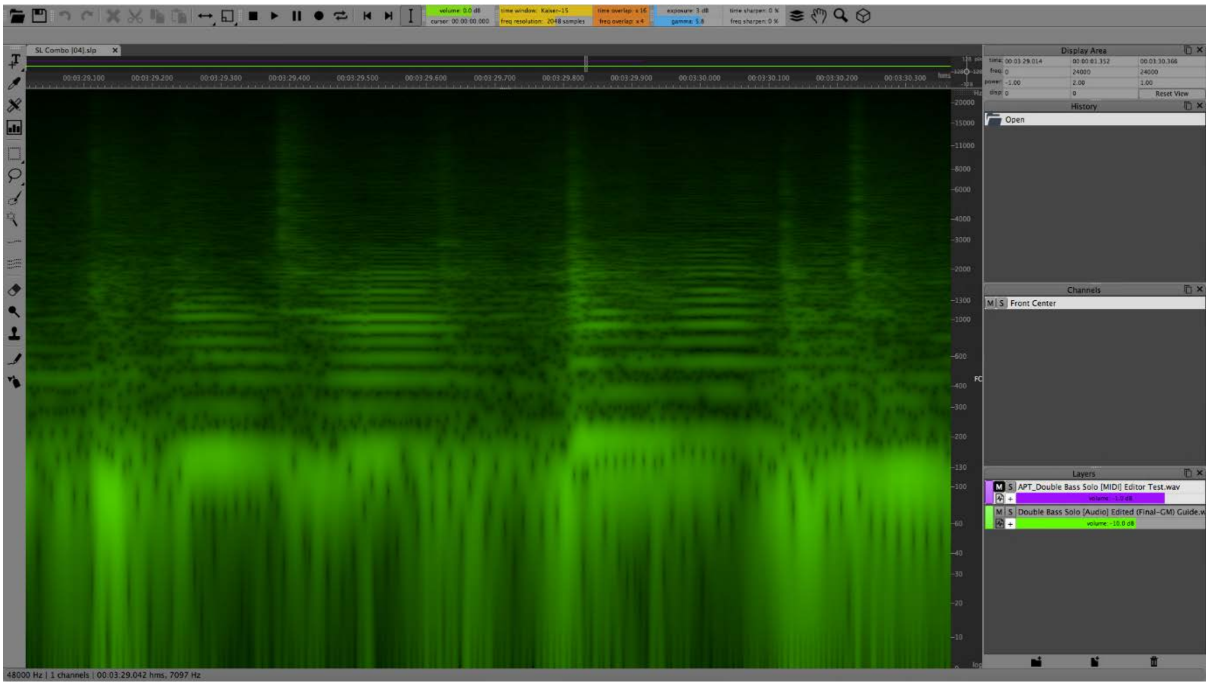


Figure 93 – SpectraLayers 4 with Monochrome Amplitude Display

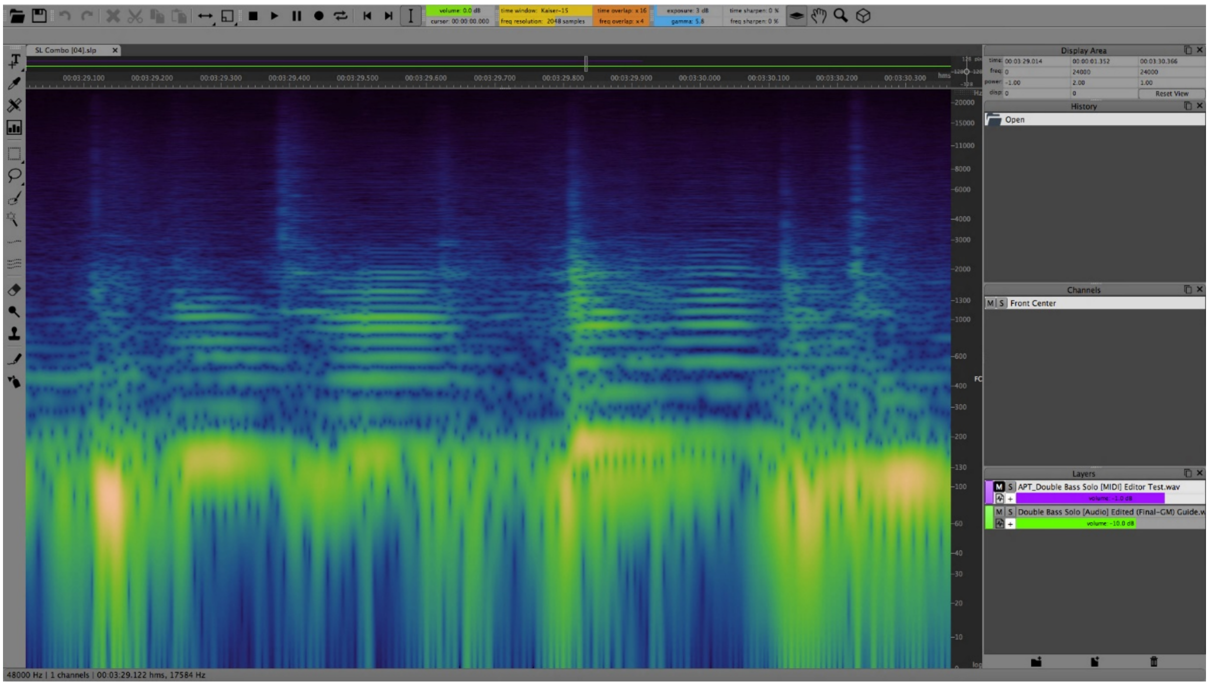


Figure 94 – SpectraLayers 5 with Colour Maps for Amplitude Display

8.4.1.3.1 Steinberg

After the release of version 5, I officially joined the SpectraLayers team and proposed a new vision for the product based on the transition to an ARA-based product. Lodel and I presented this vision to Steinberg, using EAPR examples from Chapter 7, in the hope they would offer to acquire the rights to SpectraLayers. They did, with Steinberg SpectraLayers Pro version 6 set for announcement on January 24th, 2019 at the NAMM show in the United States. EAPR examples will figure prominently in the marketing of the new product.

8.4.2 Research

I will investigate the design, development, and construction of a new audio production tool created specifically to implement EAPR analysis and rendering techniques. The data representation, user interface paradigms, and data manipulation would be designed specifically for this goal.

One significant need that emerged from my praxis with audio tools was improved visualisation and more precise sound editing. Spectrograms, as discussed in Section 6.2.1, provided the most effective manual editing tool in my production of both EAPR albums.

In review, Spectrograms often indicate time on the horizontal axis, and frequency on the vertical one. The amplitude at any given time/frequency intersection is indicated by brightness or colour. Two of the applications I employed, RX (iZotope, Inc., 2015) and (most importantly) SpectraLayers (Lobel, 2015a), allow spectrograms to be used both for data representation and modification.

Spectrograms have been employed by several researchers such as Dixon (Dixon, 2000) for musical performance analysis. They have been used in score-following to provide detailed information about frequency and time not otherwise available from an audio file (Dixon, 2000; Orio et al., 2001; Dannenberg and Raphael, 2006). Some investigators also use them manually for performance analysis, such as Latartara in comparing performances by different musicians (Latartara and Gardiner, 2007):

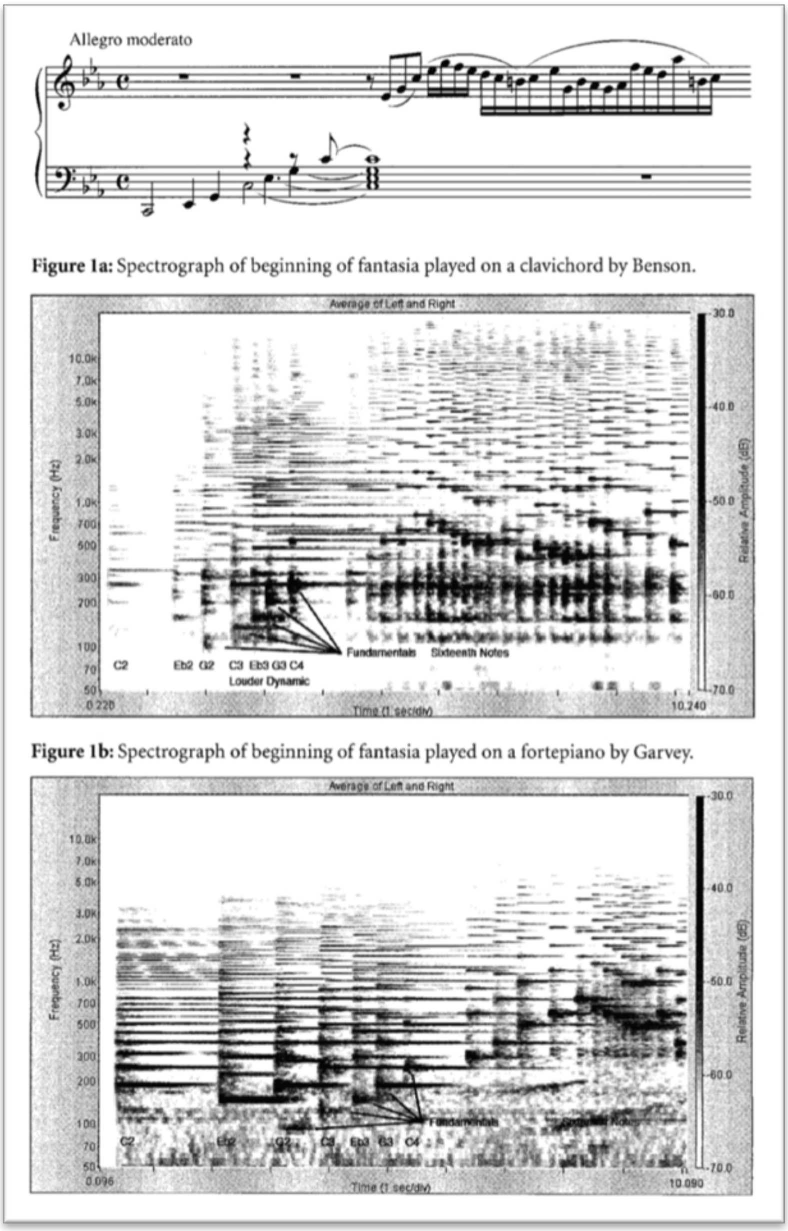


Figure 95: P. E. Bach's Fantasia in C Minor, Opening Passage (Latartara and Gardiner, 2007)

Though I was able to accomplish EAPR for the Album Project using these representational and editing paradigms, the need for more detail and greater meaning of underlying data emerged. My hypothesis is that a fully three-dimensional representation would meet these criteria, allowing user-controlled data perspectives, and colour to be used to indicate a fourth data variable (because amplitude could now be represented by the third spatial dimension).

Within the context of a new data representation model, I will research specific operations that implement the operations required by EPAR. Additionally, I will design a physical interaction system for this new system. I will examine features such as 3D displays, head-tracking, eye-tracking, 3D gestures, and haptic feedback. I hypothesise that maximising the quantity of simultaneously perceivable variables, and usable interaction methods—will result in more efficient, less time-consuming audio transformations.

This functionality will take place within the context of an overarching metaphor to represent and describe the representation, modification, and auditioning of audio—within a holistic, real-life context, to create the most effective environment for performing EAPR. Such capability will allow me to leverage users' real-world experience to decrease the cognitive load of increased display variables and interaction methods. Areas of inquiry will include tangible interfaces, direct manipulation and digital clay.

8.4.3 Summary

In this thesis, I have presented new knowledge based on a novel process to restore the intended performances from recorded performance errors within my practice of live progressive rock albums. The theoretical, abstract and conceptual aspects of the process were presented in Chapters 1-4, and the practical aspects in Chapters 5-7. In addition to this printed explication, I have praxically researched and implemented the process, demonstrating it in the creative artefact accompanying this thesis, the Creative Album Project.

The primary challenge that emerged from the dialogical development of this process, during my work on the Album, was the need for new tools. To that end, I will work in my new role as Product Manager of Steinberg's SpectraLayers. Beyond that work, I will investigate the creation of a monolithic, purpose-built tool for my process. Ideally, it will also establish a new investigative platform from which I may undertake a new investigation into performance restoration, adding to the body of knowledge resulting from this thesis, and laying the foundation for future research and development.

Appendices

Appendix A: Supplementary Media

The physical media listed below accompanies this thesis.

A 1 FTP Archive / USB Flash Drive

An FTP archive contains files to supplement this thesis.

Table 21: Contents of USB Flash Drive Accompanying Submission

Title	Medium	Format
Example Audio from Chapter 7	Audio	WAV
Example Audio from Appendix E	Audio	WAV
Personal Correspondence	Text	PDF
Personal Evaluation Sources from Chapter 8	Text	PDF
Digital Version of the Supplemental Submission Album	Audio	WAV

A 2 Boxed Set (Blu-ray, 2CD)

Creative Submission Album (Flying Colors — *Second Flight: Live at the Z7*)

A 3 Compact Disc (1CD)

Supplemental Submission Album

Appendix B: EAPR Restoration Log for the Creative Submission Album

Table 22: EAPR Instrumental Album Submission Log

Rhythm Guitar								
"Open Up Your Eyes"								
Start	**End**	**Annotation**	**Tool**	**Operation**	**Error Class**	**Error Type**	**Domain**	**ID**
00:06:03	00:06:07	Flubbed notes.	Logic	Forensic Assembly: Notes and re-synched.	Event Rhythm	Execution Internal	Articulation	1
00:07:29	00:07:47	Tuning.	Logic	Forensic Assembly: Notes and re-synched.	Event Rhythm	Tuning Internal	Real Time	2
00:09:39	00:09:43	Synch.	Logic	Flex Time.	Rhythm	Internal		3
00:09:58	00:09:51	Tuning.	Melodyne	Pitch change.	Event	Tuning	Real Time	4
00:11:13	00:11:18	Sync.	Logic	Flex Time.	Rhythm	Internal		5
00:12:44	00:12:47	Tuning.	Melodyne	Pitch change.	Event	Tuning	Real Time	6
00:12:56	00:13:24	Reconstruction.	Logic, Melodyn	Replace chords, manual pitch shift and re-synched.	Event	Score	Real Time	7
00:13:41	00:14:03	Reconstruction.	Logic, Melodyn	Replace chords, manual pitch shift and re-synched.	Event Rhythm	Score Internal	Real Time	8
00:14:15	00:14:30	Tuning.	Logic, Melodyn	Replace chords, manual pitch shift and re-synched.	Event Rhythm Event	Tuning Internal Articulation	Real Time Articulation Intelligibility	9
00:15:07	00:15:34	Out of time ending section.	Logic	Brought in from Paris recording. Aligned with Flex Time.	Rhythm	External		10

					Event	Execution	Articulation	
"Bombs Away"								
00:17:34	00:17:38	Missed chord.	Logic	Replaced chords.	Event	Score		11
00:17:40	00:17:43	Missed chord.	Logic	Replaced chords.	Event	Score		12
00:20:50	00:20:55	Didn't play part.	Logic, Sony Layers	Replaced parts with later parts, re-synch, varied by manipulating harmonics.	Event	Score		13
00:21:22	00:21:32	Wrong chord.	Logic	Replaced chords.	Event	Score		14
"Kayla"								
00:24:04	00:24:11	Random noise spikes, something is being played but nothing can be heard.	RX	Removing digital clicks.	Event	External		15
00:24:13	00:24:20	Recording drop outs.	Logic, Sony Layers	Replaced parts with later parts, re-synch, varied by manipulating harmonics.	Event	External		16
00:24:21	00:24:28	Recording drop outs.	Logic, Sony Layers	Replaced parts with later parts, re-synch, varied by manipulating harmonics.	Event	External		17
00:24:51	00:25:00	Wrong note.	Logic	Spectral Assembly.	Event	Score		18
00:26:51	00:26:54	Recording drop outs.	Logic, Sony Layers	Replaced parts with later parts, re-synch, varied by manipulating harmonics.	Event	External		19
00:26:59	00:27:06	Drop outs.	Logic	Replaced parts with later parts.	Event	Score		20
"Shoulda Woulda Coulda"								
00:36:52	00:36:57	Wrong chord.	Logic	Replaced chords.	Event	Score		21
00:37:06	00:37:12	Flubbed notes.	Melodyne	Pitch change.	Event	Score		22
"A Place in Your World"								
00:41:00	00:41:14	Tuning.	Melodyne	Pitch change.	Event	Tuning	Real Time	23
00:41:19	00:41:27	Timing	Logic	Flex Time.	Rhythm	Internal		24
00:42:35	00:42:39	Wrong notes.	Logic	Forensic Assembly: Notes, manual pitch shift.	Event	Score		25
00:43:53	00:43:57	Wrong note.	Logic	Forensic Assembly: Notes, Manual pitch shift.	Event	Score		26

00:44:21	00:44:24	Flubbed notes.	Logic	Forensic Assembly: Notes, Manual pitch shift.	Event	Execution	Articulation	27
"Forever in a Daze"								
00:48:15	00:48:27	Part got away.	Logic, RX	Replaced with later part, re-synch E.Q. matched to following part.	Rhythm	Internal		28
"One Love Forever"								
00:50:02	00:50:06	Flubbed notes.	Logic	Forensic Assembly: Notes.	Event	Execution	Articulation	29
00:50:09	00:50:12	Flubbed chord.	Logic	Replaced chords.	Event	Execution	Articulation	30
00:50:17	00:50:20	Flubbed chord.	Logic	Replaced chords.	Event	Execution	Articulation	31
00:50:26	00:50:28	Accidentally hit wrong strings.	Logic	Replaced chord.	Event	Score		32
00:50:28	00:50:33	Flubbed chords.	Logic	Replaced chords.	Event	Execution	Articulation	33
00:52:28	00:52:33	Timing.	Logic	Flex Time.	Rhythm	Internal		34
00:52:40	00:52:44	Things went awry; Reconstructed entire section.	Logic, Melodyn	Forensic Assembly: Notes individually with similar ones, set pitch with Melodyne.	Event	Score		35
00:53:33	00:53:42	Wrong chords.	Logic	Replaced chords.	Event	Score		36
00:53:45	00:53:48	Missed chords.	Logic	Replaced chords.	Event	Score		37
00:53:57	00:54:01	Wrong chords.	Logic	Replaced chords.	Event	Score		38
00:54:40	00:54:43	Removed low rumble	SONY Layers	Erased unwanted frequencies.	Event	External		39
00:54:45	00:54:49	Slowed down too much.	Logic	Flex Time.	Rhythm	Internal		40
00:55:23	00:55:29	Accidentally hit wrong strings.	Logic	Replaced chords.	Event	Score		41
00:55:32	00:55:35	Flubbed notes.	Logic, Melodyn	Aligned, monophonic Melodyne, then polyphonic Melodyne.	Event Rhythm	Execution Internal	Articulation	42
00:56:10	00:56:16	Part got away.	Logic	Replaced with later part.	Event	Score		43
00:57:05	00:57:12	Flubbed chord and timing	Logic	Replaced chords and re-synched.	Event Rhythm	Execution Internal	Articulation	44
"Peaceful Harbour"								
01:05:29	01:05:30	Timing.	Logic	Flex Time.	Rhythm	Internal		45
01:06:22	01:06:27	Sync.	Logic	Flex Time.	Rhythm	Internal		46
01:06:43	01:06:46	One strum that noticably conflicted with snare.	Logic	Flex Time.	Rhythm	Internal		47
01:09:58	01:10:03	Tightened timing to Dave and Steve.	Logic	Flex Time.	Rhythm	Internal		48
"The Storm"								
01:11:23	01:11:26	Tuning.	Logic	Manual pitch shift.	Event	Tuning	Real Time	49
01:11:28	01:11:31	Tuning.	Logic	Manual pitch shift.	Event	Tuning	Real Time	50
01:11:36	01:11:39	Tuning.	Logic	Manual pitch shift.	Event	Tuning	Real Time	51
01:13:07	01:13:09	Flubbed notes.	Logic		Event	Execution	Articulation	52
01:13:11	01:13:26	None of the four repetitions were played correctly.	Logic, Melodyn	Manual pitch shift, re-synch.	Rhythm Event Event	Internal Tuning Score	 Real Time	53
01:13:37	01:13:45	Tuning.	Logic	Manual pitch shift.	Event	Tuning		54

01:13:59	01:14:01	Tuning.	Logic	Manual pitch shift.	Event	Tuning	Real Time	55
01:14:02	01:14:06	Tuning.	Logic	Manual pitch shift.	Event	Tuning		56
01:14:08	01:14:10	Missed chord.	Logic	Replaced chord.	Event	Score	Real Time	57
01:14:39	01:14:42	Tuning.	Logic	Manual pitch shift.	Event	Tuning		58
"Cosmic Symphony"								
01:18:40	01:18:49	Left distortion on.	Logic	Replaced parts with later parts.	Execution	Timbre		59
01:18:54	01:19:04	Pitch bend from wrong note.	Melodyne	Pitch change.	Event	Pitch Change		60
01:19:24	01:22:11	Removed guitar scratches.	Logic	Removed noise.	Event Event	Execution Timbre	Intelligibility	61
01:24:20	01:24:23	Missed note.	Logic	Replaced note.	Event	Execution	Articulation	62
01:24:45	01:25:13	Chord held too long	Logic	Faded first chord out when second chord entered.	Rhythm	Internal		63
01:26:35	01:26:41	Tuning.	Logic	Manual pitch shift.	Event	Tuning		64
"Mask Machine"								
02:28:02	02:34:39	Replay: Whole song.	N/A	N/A	Event Event Event Rhythm	Tuning Score Execution Internal	Real Time Articulation, Intelligibility	65
"Infinite Fire"								
01:36:46	01:36:50	Sync.	Logic	Flex Time.	Rhythm	Internal		66
01:38:19	01:38:44	Tuning.	Logic	Manual pitch shift.	Event	Tuning	Real Time	67
01:39:26	01:39:36	Wrong chord and sync.	Logic	Replaced chords and re-synch.	Event	Score		68
01:40:59	01:41:09	Sync.	Logic	Flex Time.	Rhythm	Internal		69
01:41:36	01:42:18	Sync.	Logic	Flex Time.	Rhythm	Internal		70
01:42:34	01:42:36	Sync.	Logic	Flex Time.	Rhythm	Internal		71
01:44:30	01:44:51	Tuning	Melodyne	Pitch change.	Event	Tuning	Real Time	72
01:46:48	01:47:18	Synch and tuning.	Melodyne	Pitch change.	Rhythm Event	Internal Tuning		73
Lead Guitar								
"Open Up Your Eyes"								
00:04:23	00:04:27	Missed note.	Logic	Forensic Assembly.	Event	Score		74
00:04:45	00:04:48	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	75
00:05:09	00:05:12	Accidentally hit low E string.	SONY Layers	Removed unwanted frequencies.	Event	Score		76
00:05:33	00:05:35	Missed notes.	Logic	Forensic Assembly: Note.	Event	Score		77
00:07:31	00:07:33	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	78
00:07:36	00:07:37	Hit second string by accident.	Logic	Forensic Assembly: Note.	Event	Score		79
00:08:45	00:08:47	Wrong note and quasi-pitched note. Fixed on dry and wet tracks.	Melodyn, SL, RX	Forensic Assembly: Notes, spectral editing.	See Chapter 7	See Chapter 7	See Chapter 7	80
00:08:51	00:08:52	Flubbed, unmuted sustained, and sharp notes.	Melodyn, SL, RX	Forensic Assembly: Notes, spectral editing.	See Chapter 7	See Chapter 7	See Chapter 7	81
00:10:02	00:10:04	Flubbed notes and unwanted pick scratching.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	82

00:14:40	00:14:44	Timing and recording drop out.	Logic	Forensic Assembly: Note.	Rhythm Event	Internal External		83
00:14:46	00:15:38	Replay: End section.	RX	EQ match.	Rhythm	External		84
"Bombs Away"								
00:19:32	00:19:37	Restored held chord.	Logic	Flex Time.	Event	Execution	Articulation	85
00:19:51	00:19:52	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	86
00:19:59	00:20:00	noise.	Melodyne	Removed noise.	Event	External		87
00:20:20	00:20:47	Didn't play part	Logic	Reconstruction using other parts from the song.	Event	Score		88
00:21:22	00:21:41	Didn't play part	Logic	Reconstruction using other parts from the song.	Event	Score		89
"Kayla"								
00:22:20	00:22:21	Switching between pick and fingers.	Logic	Removed noise.	Event	Timbre		90
00:24:58	00:25:02	Wrong part.	Logic, SONY Layers	Replaced parts with later parts, re-synch, varied by manipulating harmonics.	Event	Score		91
00:25:10	00:25:11	Fixed rhythm.	Logic	Flex Time.	Rhythm	Internal		92
00:25:34	00:25:35	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	93
00:25:45	00:25:48	Accidentally hit low strings.	Melodyne	Removed unwanted note.	Event	Score		94
"Shoulda Woulda Coulda"								
00:28:08	00:28:11	Noise.	Melodyne	Removed noise.	Event	External		95
00:28:23	00:28:24	Missed harmonic.	Logic	Forensic Assembly: Note.	Event	Score		96
00:31:05	00:31:07	Missed harmonic.	Logic	Forensic Assembly: Note.	Event	Score		97
"Fury of My Love"								
00:28:08	00:28:11	One note late.	Logic	Flex Time.	Rhythm	Internal		98
00:28:23	00:28:24	Flubbed chord.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	99
0:31:05	00:31:07	Part lost definition.	Logic	Forensic Assembly: Notes, Manual pitch shift.	Event	Execution	Articulation, Intelligibility	100
00:31:54	00:31:59	One note late.	Logic	Flex Time.	Rhythm	Internal		101
00:33:54	00:36:09	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	102
00:36:56	00:37:01	Part lost definition.	Logic	Forensic Assembly: Notes, Manual pitch shift.	Event	Execution	Articulation, Intelligibility	103
00:38:10	00:38:16	Constructed/restored bend.	Melodyne	Created using two similar notes, and manipulating pitch drift with Melodyne	Event	Execution	Articulation, Pitch Change	104
"A Place in Your World"								
00:38:39	00:38:42	Sync guitar and keyboard.	Logic	Flex time.	Rhythm	Internal		105
00:38:58	00:38:59	Note Sync.	Logic	Flex Time	Rhythm	Internal		106
00:39:06	00:39:10	Timing and tuning.	Melodyne	Pitch change and synch.	Rhythm Event	Internal Tuning	Real Time	107
00:42:43	00:42:44	Sync slide with kick.	Logic	Flex Time.	Rhythm	Internal		108

0:43:09	00:43:15	Melody reconstruction.	Melodyne	Bring similar notes together in logic, correct pitch and pitch drift in Melodyne.	Event	Score		109
"Forever in a Daze"								
00:47:54	00:47:55	Wrong chord.	Logic	Replaced chord.	Event	Score		110
00:48:00	00:48:01	Out of time chord.	Logic	Replaced chord.	Rhythm	Internal		111
"One Love Forever"								
00:50:04	00:50:06	Wrong note.	Logic	Forensic Assembly: Note.	Event	Score		112
00:50:24	00:50:26	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	113
00:50:32	00:50:33	Replaced dead-end notes with notes that ring more.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	114
00:50:51	00:50:52	Uneven timing	Logic	Flex Time.	Rhythm	Internal		115
00:50:54	00:50:55	Uneven timing	Logic	Flex Time.	Rhythm	Internal		116
00:50:58	00:51:00	Uneven timing	Logic	Flex Time.	Rhythm	Internal		117
00:51:09	00:51:12	Uneven timing	Logic	Flex Time.	Rhythm	Internal		118
00:51:41	00:51:42	Uneven timing	Logic	Flex Time.	Rhythm	Internal		119
00:53:15	00:53:22	Sustain ran out.	Logic	Audio stretching.	Event	Execution	Articulation	120
00:54:12	00:54:13	Wrong chord.	Logic	Replaced chord.	Event	Score		121
00:54:30	00:54:31	Wrong note in run.	Logic	Forensic Assembly: Note.	Event	Score		122
"Peaceful Harbor"								
01:05:43	01:06:24	Replay 2 complete tapped harmonic section.	RX	EQ match.	Event	Execution	Articulation	123
01:06:43	01:06:44	Unwanted noise.	Melodyne	Removed noise.	Event	External		124
01:06:45	01:06:47	Unwanted noise.	Melodyne	Removed noise.	Event	External		125
01:07:06	01:07:10	Unwanted noise. Restored using other section of song.	Melodyne	Pitch change.	Event	External		126
01:07:47	01:08:02	Unfixed.						127
01:09:11	01:09:14	Composition replacing lost notes in solo during improvisation.	Logic, Melodyn	Forensic Assembly: Note, Pitch change.	Event	Score		128
01:09:16	01:09:17	Replaced one dirty note.	Logic	Forensic Assembly: Note				129
01:09:23	01:09:24	Noisy; couldn't make out the actual notes so regenerated. This may have been a sweep. Improvisation.	Melodyne, SpectraLayers	Forensic Assembly: Note, Spectral editing.	Event	Execution	Intelligibility	130
01:09:39	01:09:40	High note not quite right.	Melodyne	Pitch change.	Event	Execution		131
01:09:42	01:09:43	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	132
01:09:58	01:10:01	Sync.	Logic	Flex Time.	Rhythm	Internal		133
"The Storm"								
01:11:12	01:11:13	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	134
01:11:21	01:11:26	Flubbed chords.	Logic	Replaced chord.	Event	Execution	Articulation	135
01:12:01	01:12:02	Timing.	Logic	Flex Time.	Rhythm	Internal		136
01:12:52	01:12:54	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	137
01:13:18	01:13:20	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	138
01:14:47	01:14:48	Missed strings.	Logic	Forensic Assembly: Note.	Event	Score		139

01:14:51	01:14:54	Replaced unintentional par	Logic	Replaced parts with later parts, re-synch, varied by manipulating harmonics.	Event	Score		140
01:14:55	01:15:03	Flubbed notes.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	141
01:15:04	01:15:17	Slows down at different rate from the rest of the band.	Logic	Flex Time.	Rhythm	Internal		142
"Cosmic Symphony"								
01:21:43	01:21:48	Cleaned up a bit.	Logic		Event	Execution	Articulation	143
01:22:57	01:22:59	Flubbed note, complete reconstruction included delay track.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	144
1:26:09	01:26:14	Messy improvisation.	Logic, Melodyne	Reconstructed section, then Melodyned.	Event Rhythm	Execution Internal	Articulation	145
01:26:14	01:26:15	Accientally hit lower string, removed with Melodyne.	Melodyne	Removed noise.	Event	Score		146
"Mask Machine"								
01:28:32	01:28:35	Intro bends are out of time. Missed the first note of arpeggios.	Logic	Forensic Assembly: Note.	Event Rhythm Event	Articulation Internal Score	Pitch Change	147
01:28:44	01:28:48	Timing.	Logic	Flex Time.	Rhythm	Internal		148
01:29:43	01:29:47	Sync.	Logic	Flex Time.	Rhythm	Internal		149
01:30:56	01:30:57	Timing.	Logic	Flex Time.	Rhythm	Internal		150
01:31:35	01:31:44	Timing.	Logic	Flex Time.	Rhythm	Internal		151
01:31:52	01:31:59	Timing.	Logic	Flex Time.	Rhythm	Internal		152
01:32:00	01:32:03	Timing.	Logic	Flex Time.	Rhythm	Internal		153
01:32:47	01:32:53	Timing.	Logic	Flex Time.	Rhythm	Internal		154
01:33:10	01:33:12	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	155
"Infinite Fire"								
01:36:52	01:37:14	Noisy.	Melodyne	Removed noise.	Event	External		156
01:37:52	01:38:04	Sync.	Logic	Flex Time.	Rhythm	Internal		157
01:38:57	01:39:12	Sync.	Logic	Flex Time.	Rhythm	Internal		158
01:39:32	01:39:33	Unwanted noise.	Logic	Forensic Assembly: Note.	Event	External		159
01:40:27	01:40:31	Unintentional Feedback took over sustained note. Score error because guitarist can control the pitch of feedback.	SONY Layers	Attenuated feedback.	Event	Score		160
01:40:53	01:40:59	Noisy, Wrong note	Melodyne	Melodyned to remove pick sound and change pitch.	Event Event	Score External		161
01:41:02	01:41:03	Note not audible in mix.	Logic	Forensic Assembly: Note.	Event	Execution	Volume	162
01:41:03	01:41:05	Timing, flubbed note.	Logic	Forensic Assembly: Note.	Event Rhythm	Execution Internal	Articulation	
01:42:08	01:42:09	Missed harmonic.	Logic	Forensic Assembly: Note.	Event	Score		163
01:42:13	01:42:18	Quiet chords	Logic	Replaced chords.	Event	Execution	Volume	164

01:42:20	01:42:21	Noisy	SONY Layers	Manually editing individual harmonics.	Event	External		165
01:42:21	01:42:29	Timing.	Logic	Flex Time.	Rhythm	Internal		166
01:42:35	01:42:55	Timing.	Logic	Flex Time.	Rhythm	Internal		167
01:43:30	01:43:38	Notes missing and timing, replaced with another section and re-sync	Logic	Forensic Assembly: Note.	Rhythm	Internal		168
1:43:40	01:43:44	Not played cleanly.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	169
01:43:45	01:44:01	Pitch correction in Melodyne.	Melodyne	Pitch change.	Event	Score		170
01:44:08	01:44:10	Choked bend.	Melodyne	Swapped note that cut out too early for another, Melodyned pitch and volume change.	Event	Execution	Articulation, Pitch Change	171
01:45:58	01:45:59	Sync.	Logic	Flex Time.	Rhythm	Internal		172
01:46:40	01:46:42	Sync.	Logic	Flex Time.	Rhythm	Internal		173
Synthesizers and B3 Organ								
"Open Up Your Eyes"								
00:04:52	00:04:56	Wrong chord and timing.	Logic	Replaced chord and re-synch.	Rhythm Event	Internal Score		174
00:05:33	00:05:34	Moved a note.	Logic	Forensic Assembly: Note.	Rhythm	Internal		175
00:07:10	00:07:14	Pitch modulation wheel down when it shouldn't have been.	Melodyne	Pitch change.	Event	Execution	Timbre	176
00:07:35	00:07:36	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	177
00:07:40	00:07:42	Flubbed notes.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	178
00:08:47	00:08:49	Timing.	Logic	Forensic Assembly: Note.	Rhythm	Internal		179
00:14:48	00:15:40	Replay: End section.	RX	EQ match.	Rhythm	External		180
"Bombs Away"								
00:19:31	00:19:32	Recording dropped out.	Logic	Re-created.	Event	External		181
00:21:26	00:21:28	Flubbed notes.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	182
00:23:53	00:23:57	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	183
00:27:00	00:27:01	Flubbed notes.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	184
00:27:11	00:27:12	Unintentional volume swell.	Logic	Automated volume.	Event	Execution	Volume	185
"Kayla"								
00:28:02	00:28:09	Timing.	Logic	Flex Time.	Rhythm	Internal		186
00:28:45	00:28:49	Wrong notes.	Logic	Replaced note.	Event	Score		187
"Shoulda Woulda Coulda"								
00:34:41	00:34:43	Timing.	Logic	Flex Time.	Rhythm	Internal		188
00:35:58	00:36:01	Recording dropped out. Re-synch because section from other part which was flown in was played at different tempo than the part it replaced.	Logic	Replaced parts with later parts, and re-synched.	Event	External		189

00:37:58	00:38:02	Recording dropped out. Re-synch because section from other part which was flown in was played at different tempo than the part it replaced.	Logic	Replaced parts with later parts, and re-synched.	Event	External		190
"A Place in Your World"								
00:38:38	00:38:42	Synchronize keyboard with guitar.	Logic	Flex Time.	Rhythm	Internal		191
00:39:43	00:39:47	Cleaned up notes.	Logic		Event	Execution	Timbre	192
00:40:33	00:40:34	Sync notes.	Logic	Flex Time.	Rhythm	Internal		193
00:40:39	00:40:41	Mushy keys. Melodyned.	Melodyne	Removed wrong notes.	Event Event	Execution Score	Articulation	194
00:40:55	00:40:57	Mushy keys. Melodyned.	Melodyne	Removed wrong notes.	Event Event	Execution Score	Articulation	195
00:41:16	00:41:21	Mushy keys.	Logic	Replaced chord.	Event	Execution	Articulation	
00:42:18	00:42:22	Played something else. Improvisation.	Logic	Replaced parts with later parts, and re-synched.	Event	Score		196
00:42:32	00:42:34	Flubbed note.	Logic	Forensic Assembly: Note	Event	Execution	Articulation	197
00:42:39	00:42:41	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	198
00:42:43	00:42:44	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	199
00:43:22	00:43:23	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	200
"Forever In a Daze"								
00:46:46	00:46:52	Flubbed notes.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	201
00:47:33	00:47:35	Stray notes. Improvisation.	Logic	Forensic Assembly: Note.	Event	Score		202
00:48:10	00:48:22	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	203
"One Love Forever"								
00:52:29	00:52:30	Key mash	Logic	Replaced chords.	Event	Execution	Articulation	204
00:53:15	00:53:18	Chord sustains too long.	Logic	Flex Time.	Event	Score		205
00:54:28	00:54:29	Flubbed note.	Melodyne	Pitch change.	Event	Score		206
00:54:41	00:54:44	Flubbed note.	Melodyne	Pitch change.	Event	Score		207
00:55:35	00:55:36	Flubbed note.	Melodyne	Pitch change.	Event	Score		208
00:55:44	00:55:45	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	209
00:55:48	00:55:50	Flubbed note.	Melodyne	Pitch change.	Event	Score		210
00:55:55	00:55:56	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	211
00:55:56	00:55:57	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	212
00:55:59	00:56:00	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	213
00:56:06	00:56:07	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	214
00:56:10	00:56:11	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	215
"Peaceful Harbor"								
01:05:38	01:06:25	Replay: Intro chords.	Logic	Forensic Assembly: Note.	Event	Score		216
01:09:47	01:09:54	Section half dropped out, technical malfuntion.	Logic, Melodyn	Forensic Assembly: Notes, adjusted pitch.	Event	External		217
"The Storm"								

01:13:20	01:13:24	Timing and flubbed notes.	Logic	Forensic Assembly: Notes, Manual pitch shift.	Event Event Rhythm	Execution Score Internal	Articulation	218
"Cosmic Symphony"								
01:19:24	01:19:41	Small flub.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	219
01:20:03	01:20:23	Repertoire: phrasing.	Logic, SpectraLayers, Melodyn, RX, Electric Piano and Analogue Synthesizer Virtual Instruments	Noise removal, Forensic Assembly: Notes, Partial overtone replacement, Manual assignment of overtones, Synthesis, Performance.	Event	Repertoire		220
01:20:50	01:21:01	Flubbed notes. Melodyned.	Melodyne	Pitch change.	Event	Score		221
01:21:01	01:21:02	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	222
01:21:04	01:21:09	Flubbed notes. Melodyned.	Melodyne	Pitch change.	Event	Score		223
01:21:27	01:21:34	Not played cleanly.	Melodyne	Removed unwanted notes.	Event	Score		224
01:21:50	01:21:52	Flubbed note. Melodyned.	Melodyne	Pitch change.	Event	Score		225
"Mask Machine"								
01:28:34	01:28:46	Noisy	Melodyne	Removed noise.	Event	External		226
01:28:58	01:29:02	Noise	Melodyne	Removed noise.	Event	External		227
01:29:12	01:29:13	Replay: First chorus.	RX	EQ match.	Event	Execution	Articulation Intelligibility	228
01:31:20	01:31:24	Flubbed chord. Melodyned.	Melodyne	Removed unwanted notes.	Event	Score		229
01:32:00	01:32:06	Flubbed note. Melodyned.	Melodyne	Removed unwanted notes.	Event	Score		230
01:32:45	01:32:46	Sync.	Logic	Flex Time.	Rhythm	Internal		231
01:32:45	01:32:46	Replay: Break and chorus.	RX	EQ match.	Event	Execution	Articulation Intelligibility	232
"Infinite Fire"								
01:37:06	01:37:08	Changed setting at wrong time.	Logic	Replaced parts with later parts, and re-synched.	Event	Execution	Timbre	233
01:37:36	01:37:37	Sync.	Logic	Flex Time.	Rhythm	Internal		234
01:37:42	01:37:44	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	235
01:39:12	01:39:16	Flubbed note.	Logic	Forensic Assembly: Note.	Event	Execution	Articulation	236
01:40:06	01:40:19	Switched to wrong preset. Restored part with correct sounds. Re-synch because section from other part which was flown in was played at different tempo than the part it replaced.	Logic	Replaced parts with later parts, and re-synch.	Event	Execution	Timbre	237
01:40:57	01:40:59	Flub in arpeggio. Melodyned.	Melodyne	Pitch change.	Event	Score		238
01:41:00	01:41:01	Flubbed note. Melodyned.	Melodyne	Pitch change	Event	Score		239

01:41:38	01:42:22	Tough edit due to the nature of the instrument. Lots of time in Melodyne.	Melodyne	Pitch, volume, and harmonic manipulation within Melodyne.	Event Event	Execution Score	Articulation	240
01:43:26	01:43:46	Timing and flubbed notes.	Logic	Forensic Assembly: Notes, manual pitch shift.	Rhythm Event	Internal Score		241
01:44:24	01:44:42	Flubbed notes.	Melodyne	Reconstructed section, then Melodyned.	Event	Execution	Articulation	242
01:45:05	01:45:08	Drop out.	Logic	Replaced parts with later parts, and re-synched.	Event	External		243
01:45:12	01:45:14	Wrong note.	Melodyne	Pitch change.	Event	Score		244
01:45:43	01:45:44	Flubbed chord.	Logic	Replaced chord.	Event	Execution	Articulation	245

Appendix C: Personal Correspondence

As established throughout this thesis, there is limited research published on several topics relevant to my enquiry, in both academic and industry sources. These topics include: Error management in recordings (any genre), post-production for live albums (any genre), cultural issues surrounding performance errors in progressive rock, estimation of intended performances in recorded popular music based on performance errors, and music production (any type) in progressive rock.

To supplement the available literature, I engaged in personal correspondence with other practitioners with expertise in these topics. The two practices are producer/engineer and artist; some practitioners incorporate both. They are drawn primarily from progressive rock, with the remainder experience multiple genres, including progressive rock.

Throughout the thesis, I have substantiated that my dialogue with these practitioners does not represent a formal, scientific enquiry. My conversations with them were to inform my enquiry within my practice-as-research methodology, whereby knowledge resides in the practitioner. The contributor's responses were not questionnaire data; they were used to provide broad information regarding the topics discussed. There is no qualitative or quantitative analysis implied. I do not make any claims regarding internal, external or construct validity within a formal academic methodology.

C 1 Procedure

I emailed the contributors informally, asking them about specific topics for inclusion in my thesis. My specific dialogue with them was informed by the topic(s). Most enquiries were one of two generally-standardised queries. Usually, a contributor was sent only one of the two.

One query was for producer/engineers only. I requested an open-ended essay (suggesting a single paragraph) on the practitioner's approach to repairing errors on live albums. To provide context, I included sample answers from two earlier contributors.

The second query was for performers, though several contributors were active in their practice as both producer/engineers and performers. The query was a single, multiple-choice question about the goal of error management in progressive rock. The ordering of the response choices was randomised for each query I sent. In keeping with my methodology for this correspondence, my use of multiple-choice responses does not imply a quantitative analysis.

Generally, correspondence took the form of me emailing them initially with one of the two query sets. In several cases, given the nature of the specific topics, the responses were provided within the context of a larger discussion.

The conversation usually concluded when I received the initial response. In some cases, there were additional communications, such as they or me requesting clarification.

Over the course of my investigation, I contacted 29 practitioners; 27 agreed to provide responses. A total of 18 respondents provided commentary for me to use in my thesis.

C 2 Queries

The query emails were never identical, and there was often brief respondent-specific text usually that proceeded and followed the query. Below is the general form the questions and ethics disclosures took. As mentioned, the response order of the multiple-choice question was randomised.

C 2.1 Techniques

Below is the basis for the techniques email:

Hello from the world of academia, I'm doing some revisions on my PhD thesis, and wondering if you could help me out?

In your role as a mix engineer, I'm wondering if you can write a paragraph for my PhD thesis, as part of my survey of the industry. The topic is your approach(es) to fixing performance errors for live albums.

Others producer, engineers and artists who submitted paragraphs include producer/engineers like Bob Ezrin and Peter Collins, and artists like Steve and Dave LaRue. Below are samples from Ryan (Brauer's guy) and Rich Mouser.

> *Ryan Gilligan: I worked on live projects with Michael Brauer, and we had many situations where we needed to fix mistakes. It was really hit or miss whether things were fixable because of bleed between mics, but some fixes were easier than others. For things like a guy with the flu in the first row, or someone knocking into a mic onstage, iZotope RX's Spectral Repair [feature] is a life saver. For anything involving a vocal, like tuning for example, we could sometimes get away with it by ducking other channels that had bleed, or by treating those channels with RX. In one rare case, we spliced in vocal pieces from a recording of a different performance entirely. Another thing we'd try to do right off the bat, was go through every track and either duck or completely mute wherever that part wasn't playing. Sometimes this would not work due to massive amounts of bleed that would then come up when that part came in. — Ryan Gilligan*

> *Rich Mouser: In my mixing of live progressive rock albums, these are the operations I use to correct performer errors: time alignment (moving the waveform), tuning (changing pitch), copy and paste (taking a "good performance" and copying it to a new location), crossfading (to smooth out edits and transitions) and gain adjusting (volume up or down)—I use this to keep my gain structure more even and to keep the feed to my compressors more at a nominal level. But by no means can everything be fixed. I have found that using all these audio manipulation techniques can fix a myriad of problems there are some things that can only be corrected by having the performer re-record a part. That is the last resort but necessary sometimes. — Rich Mouser*

I would quote or reference your response in my thesis.

C 2.2 Error Management Goals

Below is the basis for the error management goals email:

> Could you please give your opinion on a question for my thesis?
>
> What do you think the GOAL of the prevailing (not yours, specifically) practice, in mixing live progressive rock albums, in fixing errors?
>
> - To patch or obscure errors, so the audience doesn't notice them.
> - To (the extent possible) restore the originally intended performance (not just the correct notes) of the musician?
> - Something else?
> - There is no prevailing goal in fixing errors in live progressive rock albums.
>
> Your answer would be referenced in my thesis.

C 3 Ethics

For each contributor, I included two points of information in the email. The first was the purpose of the enquiry: as part of my PhD investigation. The second was the disclosure that I would include or reference their response in my PhD thesis.

C 4 Biographies

These biographies are written in the industry's professional style, in keeping with the context of the contributor's practices, and their commentary for my enquiry.

Richard James Burgess: Burgess produced studio and live releases, and performed with artists, spanning multiple popular genres (including progressive rock). His credits include most of the releases by Spandau Ballet, as well Toni Visconti, Hugh Padgham, Adam Ant, Trevor Horn, Kate Bush, Lou Reed, and (despite being British) America. As an academic, he holds a PhD in musicology and is the joint editor-in-chief of the journal, the Art of Record Production. His books include *The Art of Music Production: The Theory and Practice*, and *The History of Music Production*.

Peter Collins: Collins' work in studio and live albums often occurs in the cross-section of progressive and mainstream rock, having produced multiple albums for progressive rock artists such as RUSH and Queensryche, and straight pop (Elton John, Bon Jovi). He was instrumental in RUSH changing from a long-format progressive rock band to a short-form format that was more accessible.

Eric Darken: Darken is the percussionist for Taylor Swift's band. His session work spans all genres including progressive rock, having performed with LeAnn Rimes, Sheryl Crow, Bob Seger, Shania Twain, Megadeth, Faith Hill, Jimi Buffet and Bon Jovi.

Alan Doss: Alan is the drummer and producer/engineer of the progressive metal band, Galactic Cowboys. In that role, he has mixed both studio and live music. Between 1992 and present day, the band recorded two albums for Geffen, five for Metal Blade, and one for Mascot Label Group. They have had several videos in heavy rotation on MTV, and toured with bands such as Anthrax and Dream Theater.

Bob Ezrin: Ezrin is a multiple Grammy-award winning record producer. He has produced multiple albums by progressive rock artists such as Pink Floyd and Peter Gabriel, including The Wall and Gabriel's eponymous debut. He also has helmed projects ranging from Lou Reed, to KISS, to Thirty Seconds from Mars. As an educator, Ezrin co-founded the Nimbus School of Recording Arts.

Byron House: As a member of Robert Plant's Band of Joy, House played bass guitar. Outside of that project, Byron has been a session musician in country music for artists such as Johnny Cash, Linda Ronstadt, Peter Frampton, Dixie Chicks, Dolly Parton, Michael Bolton and Hank Williams.

John Elefante: Elefante was a lead singer, primary songwriter, and keyboardist for the progressive rock band, Kansas. He appeared on both studio and live records with them, and wrote their highest-charting single. Outside of Kansas, Elefante has served as producer, group writer/performer, and solo artist. His albums have captured four Grammy awards and ten nominations.

John Ferraro: A studio musician, Ferraro has recorded in many genres, including progressive rock. His credits include John Petrucci, Clint Black, Rod Stewart, Larry Carlton, Barry Manilow, Steve Vai, Carly Simon, and Albert Lee.

Ryan Gilligan: Former audio engineering assistant to mix engineer Michael Brauer, Gilligan worked with Brauer from 2005-2013. Their time together included studio and live albums across multiple genres. These releases included progressive rock artists such as Dream Theater, as well as mainstream artists ranging from John Mayer to Coldplay. Their albums received eight Grammy Awards, with Brauer receiving the Best Engineered Album (Non-Classical) Grammy for Coldplay's *Viva La Vida*.

Jay Graydon: Graydon is a multiple Grammy-winning songwriter, musician and producer/engineer of live and studio albums. His work crosses numerous genres, including progressive rock. In addition to having been a regular guitarist for Steely Dan, his collaborations include David Foster, The Beach Boys, Marvin Gaye, Al Jarreau, Andrew Lloyd Webber, The Jackson 5, Aretha Franklin, Cher, and George Duke.

Jerry Guidroz: Guidoz is a progressive rock sound engineer. He has mixed live albums by bands such as Sons of Apollo. He has also worked with Transatlantic, Haken, and many others.

Collin Leijenaar: Leijenaar is a progressive rock musician and audio engineer. As a performer, he is currently the drummer for the progressive rock band, Dilemma. Other credits include Jordan Rudess and Transatlantic. As an engineer, his credits include The Neal Morse Band.

Steve Lukather: Lukather is a songwriter, guitarist and producer. He is the recipient of five Grammy awards, as a songwriter, guitarist, and the producer a live jazz/fusion album. As an artist, he is a founding member of the progressive rock band, Toto. His other credits range from being the guitarist on Michael Jackson's *Thriller*—to Ringo Starr, Paul MCartney and George Harrison.

Brendan McReynolds: McReynolds works as an audio engineer for studio and live albums in contemporary pop music artist, and has also worked in progressive rock. Among other projects, he was part of the team behind Justin Bieber's, *Believe*.

Steve Morse: Morse is the guitarist for the Deep Purple, Dixie Dregs, Flying Colors, Dixie Dregs, and the Steve Morse Band. He performs and composes in jazz/ fusion, progressive rock, metal and country. He has received seven Grammy nominations, written two books on musical performance, and is a graduate of the Berkley School of Music.

Rich Mouser: A mix and front-of-house engineer, Mouser has mixed over 30 major-label front-line studio and live progressive rock releases by artists such as Transatlantic, Spock's Beard, and Neal Morse, Flying Colors, and Grammy award-winners Dream Theater. Transatlantic's *Kaleidoscope*, mixed by Mouser, won the 2014 Prog Award for Album of the Year. Of *The Prog Report*'s "Top 50 Prog Albums 1990-2015", ten were mixed by Mouser. (Prog Report, 2015)

Steve Oppenheimer: As editor-in-chief, Oppenheimer helmed the leading electronic music publication, *Electronic Musician*, for 20 years; he held the same title for the industry's only major academic recording engineering magazine, *Mix*, published by the AES. He was the founding editor of other print publications, such as *Remix*, *Onstage*, and *Music Education Technology.* He holds degrees from the Berkley College of Music and the University of Maryland. Steve and I have worked together since 2015.

Jim Pitulski: Pitulski has worked in several parts of the music industry, focussing on progressive rock. His record label experience includes Director of Artist Development at Columbia Records, Director of Product marketing at Polygram, Director of Marketing for ASCAP, President of Inside Out Music America, and (currently) A&R Director at Mascot Label Group. In these capacities, he oversaw artists such as David Bowie and Emerson, Lake and Palmer. In 1994, Jim auditioned and signed Dream Theater, the most commercially successful progressive rock/metal band of the modern era, and only band in the genre to win a Grammy award in a major category[97]. He went on to manage them, as well as Spock's Beard, Fish, and other popular progressive rock artists.

Gordon Rustfold: Jazz bassist/engineer Gordon Rustfold is best known as a performer for his longtime work with drummer Rick Lawson. Other performances range from saxophonist Greg Vail to Jerry Lee Lewis.

Billy Sherwood: Sherwood is a progressive rock musician and producer/engineer. As an artist, he is a member of the prog band, Yes. He also has mixed studio and live albums for the band.

[97] Genesis won a Grammy for Best Music Video. Pink Floyd won one for Best Instrumental Performance.

Apart from Yes, has worked with progressive rock artists such as Asia and Toto, and truly progressive artists such as William Shatner.

Roine Stolt: As the leader of the progressive rock band, Flower Kings, Stolt has recorded numerous albums for SONY Music's progressive rock label, Century Media. As an engineer, he has engineered and mixed several of the band's studio and live releases.

C 5 Record of Correspondence

A record of the correspondence with all contributors is in the auxiliary materials that accompany this thesis. (See Appendix A.)

Appendix D: A Live Album Production Primer

In this section, I provide an introduction to live recording and an overview of live album production in my practice. It is not meant to be a comprehensive primer; I will cover only the aspects necessary within this thesis. My production procedure is based on industry-standard practices; I note where the two diverge.

D 1 Theory

Live recording can differ significantly from studio recording. While recording studio techniques are focused on recording a specific tone or timbre, live recording techniques are primarily driven by practical considerations (Inglis, 2016). All the sound sources on stage (instruments and vocals) must be in the form of analogue electrical signals so they can be amplified, mixed, and output to the venue's speakers (and routed to a computer if the concert is recorded). The pressure waves are encoded in the electrical signals as voltage waves.

Some sound sources, direct signals, are already electrical because the instrument produces them natively. Optionally, they can be routed to amplifiers on stage, transduced by microphone, and then converted back to electrical signals. Examples include synthesizers, guitars and basses. Most sound sources on stage, however, are acoustic (e.g. vocals, drums) and produced as sound pressure waves in the air, to be transduced by microphones before they can be utilised.

Each microphone and direct signal is for recording a single sound source[98] or aspect thereof[99]. This is done so that the volume of each can be adjusted separately, and enhanced/affected if desired. Additionally, it is desirable to record each sound source separately so the same operations can be done in preparing and mixing the live album.

Ideally, microphone signals would be isolated like direct signals—each microphone would capture one sound, and only that sound. This can be termed the *Primary Audio Source* (Bartlett, 2014) (PAS). I also draw a distinction between an audio signal (an electrical signal in an abstract context) and an audio stream (an electric signal being in the context of travelling between specific locations).

The transduction process is problematic, though, because microphones will capture *all* the sound pressure waves in the air that reach them. As a result, any recording from a microphone will often contain continuous, audible, unwanted sounds. This phenomenon, termed *leakage*, causes significant technical challenges later in production during the error repair process. For any microphone on stage, leakage sources include:

1. All the instruments on stage that have speakers (may include vocals if another microphone is close enough).
2. The monitor speakers on stage. (These provide mixes of the audio so band members can hear themselves and each other.)
3. The FOH speakers (picked up by audience microphones used for recording the concert).
4. The crowd. (This signal is generally quiet compared to other pressure waves; generally, when it is heard on a recording, it has been boosted significantly or added artificially.)
5. Other sounds in the venue (e.g. air conditioners), or outside the venue (sirens, traffic).
6. The initial reflections (early reflections) of all these sounds off of the objects on stage, within the venue, and from walls of the venue.
7. The reverberation of these sounds within the venue.

[98] The exception is drum overhead microphones, which are designed to record the cymbals, and frequencies from the rest of the drum kit that cannot be recorded by close-miking. In this case, the kit can be considered a single source.

[99] Three microphones are used when I record B3 organs. The direct output of the organ is fed to Leslie, which is speaker that can rotate. Two microphones are used to capture the high frequencies from the cabinet (for stereo), and one microphone to capture the low frequencies.

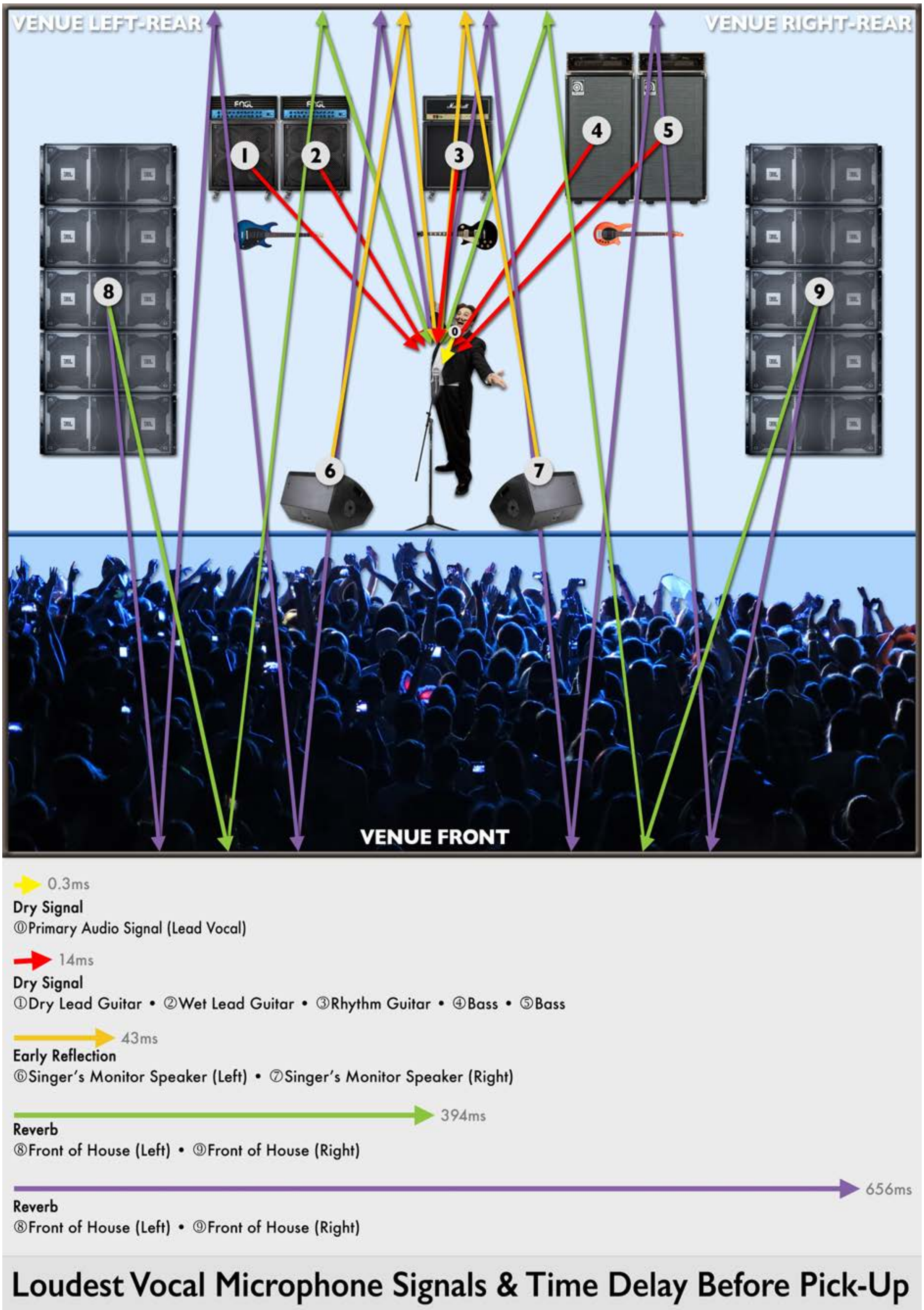


Figure 96: Leakage into a Lead Vocal Microphone

The selection of microphone type and placement technique is based on the goal of minimizing picking up non-PAS signals. Dynamic microphones are usually employed[100], because they generate the transduced electrical signals, corresponding to the pressure waves, entirely from the air pressure created by the waves (i.e. they generate electricity). One of their characteristics is that they are more sensitive to sounds closer to them than other microphone types (e.g. condenser).

Another characteristic is that they are usually cardioid or hyper cardioid, meaning they are most sensitive to sound pressure waves moving directly toward them, rather than from other directions. The most common placement is to position microphones directly in front of the pressure wave source (e.g. a speaker) at distance of centimetres (Inglis, 2016) . They will be pointed directly at the source, further reducing leakage.

Given that all the sound sources for the band are already captured to be amplified in the venue, the only new microphones usually required to record a concert are to capture the audience. Each of the audio streams from the stage and venue is recorded to a corresponding separate computer file termed a *track*. The set of all tracks represents the recording of the concert. Assembled in the computer, they constitute a *project*.

D 2 Practice

There are four principal audio engineers involved in capturing a live performance: The Front-of-House engineer (FOHE) operates the mixing console that controls the sound heard by the audience (White and Louie, 2005); she is usually the lead sound engineer and is responsible for the nightly set-up of the microphones and other sound-capture equipment to amplify the band for the live audience. The Recording Engineer (RE) sets up the new microphones and captures the concert's audio streams to the computer.

After the concert, the recording engineer delivers the computer project containing the concert's raw tracks to me[101]. As Post-Production Engineer, I will then modify the tracks so they are ready to be mixed. (This consists mostly of repairing performance errors.) I then send

[100] The only general exception are the drum overheads; because they need to pick up the entire drum kit, they need to be more sensitive to sounds from further away. This also means much more non-PAS signal can be pickup by them.
[101] Standard practice in progressive rock is for the project to be delivered directly to the Mix Engineer; there is no Post-Production Engineer.

the project to the Mix Engineer (ME), whom I will work with until I feel the mix is ready for the artist to audition. Following any changes from the artist, the final mix is created. The Mastering Engineer and I then make (hopefully) relatively minor (but critical) changes to the finished mix so that it sounds coherent and balanced across all playback systems. After this process is complete, I may or may not receive additional mix change requests from the artist.

Appendix E: Additional Restoration Examples

This appendix presents summaries of additional restorations from both the Creative Submission Album and Supplemental Submission Album. Due to University requirements regarding the length of a thesis, these examples are abbreviated, and no graphical illustrations are employed. The writing style is also more praxically dialogical than in Chapter 7. For each of the four examples presented, the original and restored performance audio is available in the auxiliary materials accompanying this thesis. (See Appendix A.)

E 1 Creative Submission Album

The following examples appear on the Creative Submission Album, and are (as with all restorations on the Album) accessible via the EAPR Restoration Log in Appendix B. Both examples use the performer's previous repertoire to inform the restoration of the error.

E 1.1 Regenerated Guitar Solo (ID #130)

There following example is from an error in an improvised solo for which I could not decipher the notes played in some sections. This situation constituted an Intelligibility Execution Event error in the PBE taxonomy.

As per the EAPR process, I engaged in EAPR Regeneration to establish the Intended score of the solo. (For these errors within the context of improvisation, there is no Performance or Work Score.) I employed three of the knowledge bases from Section 4.3.1 to establish the score; in order of importance: *performer's style*, *western music theory*, and *video playback*.

In building the solo, I used each domain to inform a different aspect of the solo. When accessing the performer's previous repertoire, I employed the existing literature discussed in Section 4.2.2.4, which informed my selection of phrasing and motifs. Music theory informed the harmonic context. And video playback provided footage of the guitarist during this section of his solo; this revealed performance cues, suggesting his emotional intentions according to the existing research discussed in Section 4.2.2.3.

The restoration was approved by the performer, with him indicating he was not certain which parts I had regenerated.

E 1.2 Previous Repertoire Informing Phrasing (ID# 220)

During a keyboard solo, I flagged the phrasing of one particular motif as a Repertoire Event Error. It was the only such error in the Creative Submission Album. The specific error was the performer's use of rubato, which did not reflect his previous repertoire of similar motifs. According to existing research on improvised solos, the performances should share similarity in phrasing. (See Section 4.2.2.4.2.) The restoration was approved by the artist.

E 2 Supplemental Submission Album

While primarily a studio recording, significant portions of the Supplemental Submission Album[102] were recorded live. The example in this section demonstrates regeneration of an improvised solo for considerably longer than in the Creative Submission Album.

E 2.1 Double Bass Solo

The performer in this solo, played in a jazz style (without a bow), was an experienced guitar player, but inexperienced with the double bass. Many notes were not discernible, resulting in Intelligibility Execution Event errors in the PBE taxonomy. In regenerating the missing parts, I was informed by the same knowledge domains as for the restoration in Appendix E 1.1.

E 2.1.1 EAPR Regeneration

Regenerating the solo (i.e. establishing the Intended Score) for the missing solo sections was performed as indicated by the EAPR process, as per the example in Section 1.1 of this appendix. While I was not able to extract the pitch of many notes, the timing of musical

[102] As this album is not the formal creative artefact that accompanies the thesis, there is no corresponding EAPR Restoration Log.

events appeared consistent with the performer's previous repertoire, and served to inform my use of the standard Regeneration knowledge bases to establish the unintelligible (i.e. missing) parts of the solo.

E 2.1.2 EAPR Rendering Techniques

A second serious problem with this solo was the sound quality of the recording, which was low fidelity to the point of being unusable. Due to the microphone being accidentally knocked off-axis, transients and mid-to-upper frequencies were significantly attenuated. The audio quality could not be remedied by any mixing techniques I was aware of, able to learn of in the literature, or by discussing with other engineers.

This problem created a significant challenge for the Rendering stage of Restoration (creating the audio corresponding to the new notes). Forensic Assembly was compromised because there were few usable aspects of the recording which could be used to assemble new notes. Another issue was that in addition to musical notes, there were other musical events, such as portamento and slaps, for which I had no audio for Forensic Assembly.

For three weeks, I experimented with different solutions. Most were not ultimately effective. While the space available here precludes a review of these approaches, aspects of the final technique will be summarised. Each technique category will have a separate heading; within each category, multiple techniques were used. Some of them are summarised, but a complete accounting is not given due to word-count restrictions; therefore, I focused on the most novel techniques and aspects thereof.

E 2.1.2.1 **Initial Audio Rendering**

The initial audio rendering was the complete Intended score, created by using the existing audio on the track.

E.2.1.2.1.1 Phoneme-Style Sequencing

The audio for musical events was created through a combination of harmonic analysis, sample splicing, and harmonic morphing. I first examined the harmonic signature of similar types of sounds. Then, I created a library of very short clips from the recorded solo, and assembled them to create the intended sounds. This approach is akin to using phonemes for voice synthesis.

E.2.1.2.1.2 Cross-Fading and Harmonic Morphing

Joining the clips together was problematic, however, as the transitions were audible. I augmented traditional cross-fading with the manual morphing of perceptually important harmonics in SpectraLayers.

E.2.1.2.1.3 Modified Forensic Assembly

I preserved original performance data wherever possible, working in Melodyn Studio 4 (Neubäcker, 2016). While pasting in the new rendered notes, I was able to reference the onset timing of the original musical events. (As mentioned, the existing timing grid became a guide to Regenerating the missing sections of the solo.) Many of the pitches were not recognisable, however. Note durations were created by using offline pitch and time processing in Melodyn.

E 2.1.2.2 **Creating Fidelity**

After the completion of these steps, much of the pre-existing recorded audio had been replaced with newly-rendered audio. The timbre of the new audio matched the remaining audio well enough for the overall effect to be perceived as cohesive. I rendered the composite audio to a new track, which for this discussion, I will term the *initial audio rendering*.

However, the audio quality of the recording was not only still unusable—and it had been further degraded because of the audio processing I had performed. My goal was now to restore the fidelity in the solo that was lost because of microphone movement (and to an extent, my audio transformations).

However, further transformation of the existing audio did not appear to be a viable solution, as it was too far degraded. Therefore, I researched if something could be *added* to the existing audio from outside the project. However, I couldn't add too much to the existing audio, or I would no longer be restoring the performance from the recording, an important requirement for EAPR and my definition of a Restored Album.

E.2.1.2.2.1 Replacing the Attack Portion of the Audio

From auditioning double-bass solos on other albums, I discovered that a significant portion of the high and mid-frequency content was in the attack portion of the fingered musical events. Additionally, I observed that my perception of pitch was strongly influenced by this portion of the sound.

If I retained the timbre of the low-frequency resonance that comprised most of the initial audio rendering, and replaced only the attack portion of musical events, then the fidelity could be restored throughout each event due to a psychoacoustic illusion. After further experimentation showed promise, I continued with this strategy.

E.2.1.2.2.2 Using Samples as the Replacement

The attack-portion audio source which appeared logical was a Double Bass sample library. The library I chose was Orange Tree Samples' CoreBass Pear jazz double bass sample library (Schlaepfer, 2014). My programming was performed in Native Instruments Kontakt 5 (Native Instruments, 2011). To use the library, though, I required a MIDI version of the performance that was perfectly synchronised with the track audio.

E.2.1.2.2.3 Melodyn Audio-to-MIDI

I used Melodyn's audio-to-MIDI capabilities to create a monophonic score. There were two problems with the result. First, obviously, Melodyn would not be able to translate the non-note audio performance data (e.g. portamento). Second, the audio was not of sufficient quality (particularly in the mid and high frequencies) for pitch to be recognised accurately.

Therefore, I muted all the non-note[103] events on the initial rendering track, and ran Melodyn again. Once again, the MIDI-note pitches were incorrect, but they now corresponded more accurately to correct time of the corresponding audio events.

[103] The restoration of fidelity for the non-note musical events is omitted from this discussion for reasons of space, as these events comprised a small minority of the sounds. In summary, each was done with different techniques, sometimes involving samples of similar event types from the sample library.

E.2.1.2.2.4 Pitch-Assignment Based on Written Score

Based on this correlation, I was able to match each event to the notes on my written Intended score. From there, I was able to set the pitches of each MIDI note, manually. (The duration of the notes did not matter, because I was only triggering attack samples.)

E.2.1.2.2.5 Timing Improvement Using Synchronised Playhead

Following this operation, I tightened up the timing by aligning the DAW's position marker at the note-starts in Melodyn, and referencing the position in Logic Pro X's (Apple, 2013a) MIDI editor.

E 2.1.2.3 **Creating the Composite Musical Events**

My initial technique for compositing the two sound sources for each musical event was simply to crossfade between them. The samples, therefore, effectively replaced the attack portions of the initial rendering's musical event audio. An immediate problem was that the two sounds sounded separate; the timbres did not match, and the cross-over point was obvious.

E.2.1.2.3.1 Matching Timbre Between Samples and Existing Audio

I addressed the matching timbre problem by using partial EQ-matching in iZotope RX (iZotope, 2015). A complete match of tone, I discovered, was not necessary—there was a perceptual threshold at which, cognitively, the two sounds appeared to become one.

E.2.1.2.3.2 Superimposing Samples and Existing Audio for Crossover

While the timbre issue was now addressed, another crossover issue remained: The crossover point was still perceivable, maintaining the perception of two separate sounds. Attempts to solving it using a previous technique, combining cross-fading and manual harmonic morphing, were not effective.

My next strategy was to blend (i.e. superimpose) the sampled attack with the *entire* audio event from the initial rendering (including its attack). Attenuating both the sampled and recorded note's attack portions using DAW automation, I was able to create realistic amplitude envelopes for the composite notes, and create the illusion of one holistic note.

E.2.1.2.3.3 Spectral Alignment of Sample and Existing Audio

A new problem emerged, however. While the transition now created the impression of a single note, they didn't sound realistic as emanating from a double-bass. Further experimentation revealed this was due to alignment problems between the sample and the start of the recorded note; the misalignment created an audio artefact.

E.2.1.2.3.4 Revoice to Improve Alignment

To solve this problem, I turned to Jeff Bloom at SynchoArts, the makers the Stand-Alone Audio Application, Revoice Pro 3 (SynchroArts, 2016). This programme was the most sophisticated commercial audio alignment program available. My work with Revoice improved the alignment issue, but the result remained unrealistic. Bloom attempted the alignment, himself, but was also unsuccessful in creating a completely transparent alignment.

E.2.1.2.3.5 A New Algorithm to Improve Revoice

He reported that the problem was that the Revoice software did not possess an algorithm capable of this alignment. (And to his knowledge, neither did any other software.) Bloom tasked his development staff to create the necessary algorithm, and incorporate it into Revoice. After several weeks of development, the new algorithm was completed, and the alignment attempted, again by Bloom. The results were further improved, but still not sufficiently transparent.

E.2.1.2.3.6 Considering Note Onset

In thinking more about the problem, I considered the possibility that this was a perceptual problem, not a physics-based one. In Section 6.1.1, I discussed the distinction between the beginning of a note (a physical phenomenon based on amplitude), and note onset, (a perceptual one, where the pitch was first perceivable). Because the initial rendering audio had severely attenuated high and mid frequencies severely (due to off-axis miking), I considered the idea that the note onset occurred after a different delay than with the audio samples.

Therefore, aligning the samples (based on the start of the notes) would never be effective, regardless of how exact the synchronisation.

Within SpectraLayers (Lobel, 2015a), I attempted to align (what appeared to be) the note onset points of the samples and recorded notes. The challenge was how I could tell where this point was, due to the damage to the original audio. Random alignments created the first realistic notes, but the results were sporadic.

E.2.1.2.3.7 Creating Note Onsets

My next strategy was to revisit the idea of note onset. Instead of trying to *restore* the original note onset, I would *create* one for each note. In SpectraLayers, I examined the harmonics just after the beginning of each note. Within those segments, I identified the precise points where the frequency envelopes of mid and high-frequency harmonic energy matched closest. This was possible because SpectraLayers allowed each note to be displayed in different colours, with a third colour representing the intersection of harmonics.

E 2.1.2.4 **Evaluation**

The result was successful. Note-onsets had been created each note, with realistic crossover points. I termed the procedure, *Harmonic Alignment*. I presented the result to the soloist and producer; it was accepted.

Appendix F: Creative Album Submission Technical Specifications

The Creative Submission Album is a live recording of a concert by Flying Colors recorded on October 12, 2014, at the Z7 Konzertfabrik in Pratteln, Switzerland. The Z7 has a rectangular configuration, with the performance stage at one end, and the rest of the space devoted to audience standing room. (See Figure 97.) The stage was configured with three performers in front, and two behind on risers, as shown in Figure 98).

Figure 97: Frame Grab from Live at the Z7 *Showing the Venue Configuration*

Figure 98: Frame Grab from Live at the Z7 *Showing the Stage Configuration*

The audio portion of the concert was captured with 36 audio channels. Figure 99 shows the 26 microphones and two line-inputs used to record the band, as well as the specific sound sources they recorded. The remaining eight microphones recorded the audience and concert hall reverberations, as shown in Figure 100. There were 24 HD and UHD cameras to film the concert; most were dedicated to close-ups of the performers, including many stationary cameras focussed on their hands.

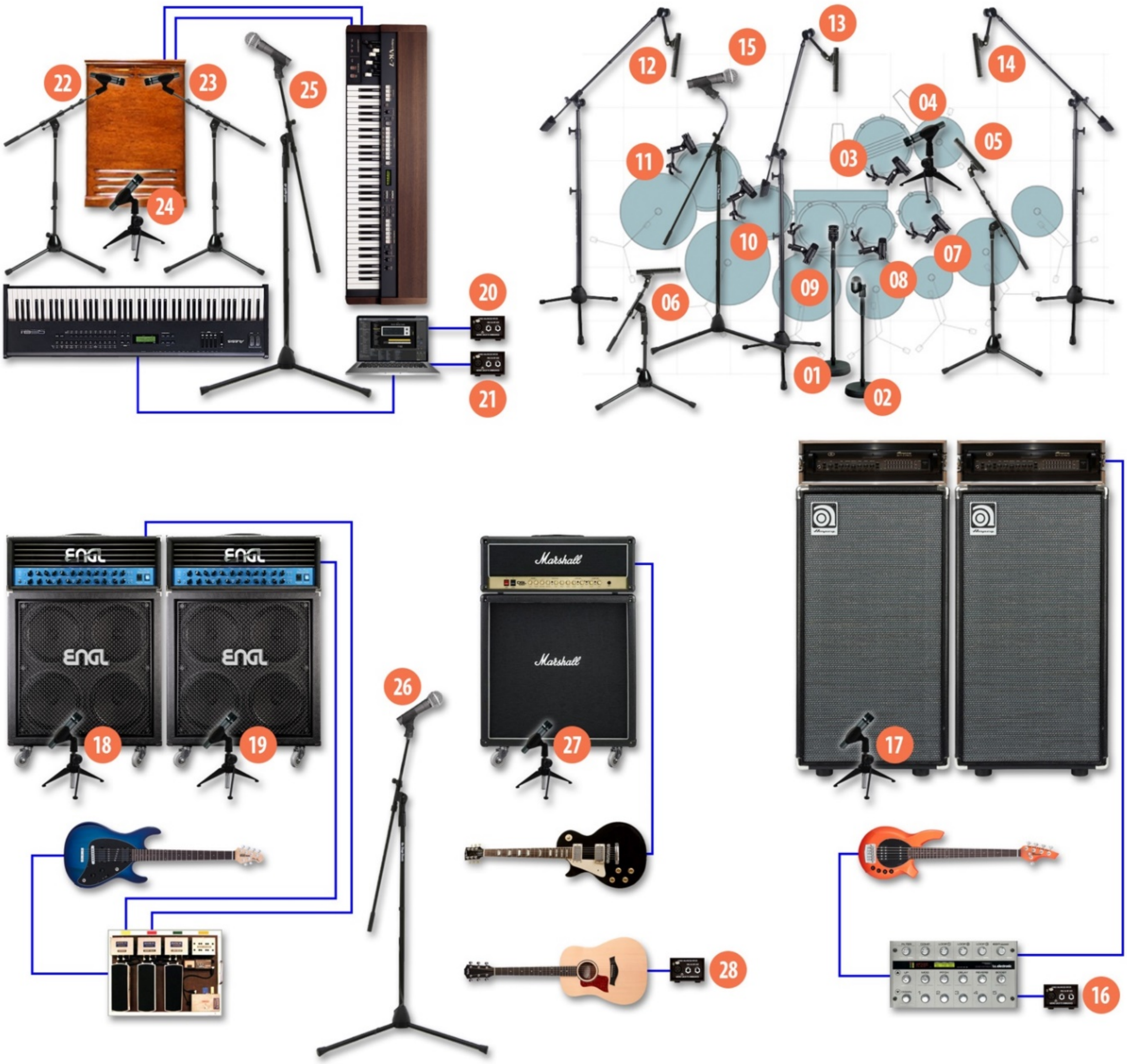


Figure 99: Audio Channels Used to Record the Performers

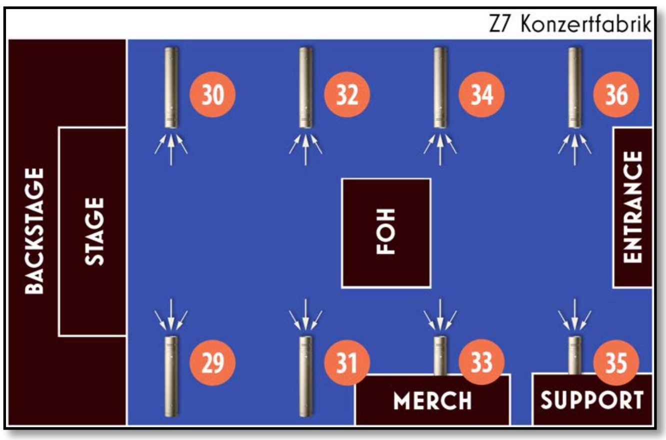


Figure 100: Audience Microphone Positions

The 36 audio channels are identified by name in Table 23.

Table 23: Track Sheet for Live at the Z7

#	Performer	Description	#	Performers	Description
01	Drummer	Kick drum (In)	19		Electric Guitar (Wet)
02		Kick drum (Out)	20	Keyboardist	Laptop (Left)
03		Snare (top)	21		Laptop (Right)
04		Snare (bottom)	22		B3 Organ (L; High Freq.)
05		Hi-hat	23		B3 Organ (R; High Freq.)
06		Ride Cymbal	24		B3 Organ (Low Freq.)
07		Tom 1	25		Vocal
08		Tom 2	26	Lead Vocalist	Vocal
09		Tom 3	27		Electric Guitar (Wet & Dry)
10		Tom 4	28		Acoustic Guitar
11		Tom 5	29	Audience	Front (Left)
12		Overhead[104] (Left)	30		Front (Right)
13		Overhead (Centre)	31		Mid-Front (Left)
14		Overhead (Right)	32		Mid-Front (Right)
15		Vocal	33		Mid-Rear (Left)
16	Bassist	Direct Signal[105]	34		Mid-Rear (Right)
17		Bass Cabinet[106]	35		Rear (Left)
18	Lead Guitarist	Electric Guitar (Dry)	36		Rear (Right)

As discussed in Section D 2, the recordings of these individual audio channels is the form the Album project took when I began post-production. Each channel could contain performance errors in the Primary Audio Signal, or as bleed from other sound sources. The audience microphones, which recorded the sound of the venue, all contained reflections of the Front-of-House speakers (providing a mix of the full band for the audience).

[104] Overhead microphones are positioned above the drum kit, and are the only microphones not close to their sound sources. They are used to record the crash symbols and high frequencies from the entire drum kit.

[105] The output of an electric bass is already an electric signal. Unlike an electric guitar, the bass signal isn't usually distorted using an amplifier. Therefore, the direct signal of the bass can be used as one of the bass sources in the mix.
Basses usually are amplified and output through a speaker cabinet, on-stage. Although the signal is not distorted (as with guitar), the output of the speaker is a different sound from the direct sound of the bass, and is used as one of the sources to create the final bass sound in the mix.

[106] Basses usually are amplified and output through a speaker cabinet, on-stage. Although the signal is not distorted (as with guitar), the output of the speaker is a different sound from the direct sound of the bass, and is used as one of the sources to create the final bass sound in the mix.

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