Time to re-wire? Problems and strategies for the maintenance of live electronics

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While much work is proceeding with regard to the preservation and restoration of audio documents in general and compositions for tape in particular, relatively little research has been published with regard to the issues of preserving compositions for live electronics. Such works often involve a distinct performance element difficult to capture in a single recording, and it is typically only in performance that such works can be experienced as the composer intended. However, performances can become difficult or even impossible to present over time due to data and/or equipment issues. Sustainability here therefore refers to the effective recording of all the information necessary to set up the live electronics for a performance. Equally, it refers to the availability of appropriate devices, as rapid technological change soon makes systems obsolete and manufacturers discontinue production. The authors have had a range of experience re-working performances over a number of years, including compositions by Luigi Nono and Jonathan Harvey, amongst others. In this paper we look at the problem as a whole, focusing on Jonathan Harvey's works with electronic elements, which span some twenty-six years, as exemplars of the types of problems involved.

1. INTRODUCTION

Many twentieth-century compositions that use electronic systems in performance are becoming impractical to perform as they are specified for outdated systems that over time become difficult or impossible to obtain. In addition to increasing cost, there are also the issues of equipment reliability in performance and expert knowledge needed to operate these devices effectively. In many cases, performance is the only accurate representation of a work since, for example, complex loudspeaker arrangements may be used. Such works are not captured effectively by stereo recordings, or even necessarily by increasingly common surround sound formats. As well as performance problems, there are those related to archiving works, since sets of parameter values or patches for devices that are no longer available quickly become redundant data. Also, storage media themselves can become outdated or damaged and so no longer viable.

While digital systems provide effective long-term storage of all types of material (score, text, patch settings, audio, video, etc.), these have also introduced new problems, and in some cases may accelerate the potential loss of works. First, digital media have reduced the perceived need to record information such as synthesizer parameters on hard copy (paper). While for analogue devices a set-up would be recorded by manually logging all settings, digital devices offer the ability to save all settings internally or to files that can be transferred between machines and stored on magnetic or optical media. However, these media can be fragile and easily subject to damage. The typically large numbers of parameters in digital devices means that electronic storage is highly convenient and has come to be relied upon. Secondly, even if the storage media themselves are reliable, the devices used to read such media share the same risks of obsolescence as the device – either the device itself is required (e.g. for a Yamaha data cartridge), or a dedicated media reader. Various generic digital data media formats have come and gone, including 5.25″ floppy disks, Syquest removable cartridges, and 2.8″ Quick Disks; 3.5″ floppy disks are increasingly rare, and Zip disks have rapidly reduced in popularity. The same is true of computer systems, where the computer type itself can die out (e.g. Atari systems much used in the 1980s). Thirdly, even if the data medium is intact and a device can be found to read it, the data format may be difficult to use as, for example, a MIDI librarian package may no longer be available, and indeed the original program may not function on current operating system versions.

While the preservation of electroacoustic music is now rising in profile, the authors' concern has been with performance, having been involved in the presentation of many works with live electronics over a number of years. As such we are interested in the archived materials that publishers have available for hire, as well as the realisation of works based on those materials. This cuts across almost all areas of music preservation – instruments, other hardware such as effects processors, software programs, computer storage media and formats, tape/disc media and formats, scores and text. Publishers and composers are not generally organised to update their archives systematically and transfer

material to new media as these become outdated. Their approach has been generally reactive, with the demand for a performance leading to required updates. This leaves works that have not been performed for a number of years in real danger of becoming too difficult to stage.

2. WHAT LIVE ELECTRONICS HAVE BEEN USED?

In an attempt to gain an overview of the current situation, the authors have gathered information from several publishers and their websites. These include 353 works so far, across approximately 100 composers from publishers including Boosey and Hawkes, Chester Music, Faber Music and Universal Edition. Each composition dates from between 1953 and 2003 and combines one or more of the following elements: tape, instrument(s), live electronics. Of these works, we currently have minimal information on forty-five of them. This is a preliminary list still being refined, and we are in the process of undertaking a larger-scale collation of works with electronics in order to achieve a more complete picture of the situation. We have included tape here as a form of live electronics for this review, as there are similar issues involved. However, we focus on non-tape works since the restoration of tape has been discussed much elsewhere (e.g. Novati 2001; Teruggi 2004).

There is significant variability in the quality of information publishers keep readily available regarding both the technical requirements for a work and the materials available for hire. For example, the detail can

be as vague as 'live electronics', which is of little value other than tagging the work for further investigation, or as complete as listing online the manufacturer/model of the equipment, the hire media (e.g. Zip disk) and reference technical specification. In order to get the precise specification it is typically necessary to go to the score itself, although even here the information may not be sufficient in some cases. For each work we log as much information as has been so far confirmed, based on types of device/process involved. Thus in addition to the standard composer, publisher, date and title information there are categories such as 'tape', which will include a description of the specific format involved ('1″ analogue reel-to-reel', 'DAT') if known, or simply a 'tape' label if the format has not yet been ascertained. Some of the general categories can be seen in Figure 1, and the range of categories will expand in order to describe works as they are added to the records. Initially collated in Microsoft Excel, the data is being transferred to MySQL and we aim to provide an online database at a time when the details are more complete. At this stage in our research, the purpose of the data is to aid identification of works that are potentially problematic, rather than to describe complete performance specifications. It is therefore sufficient to simply record the devices specified in appropriate detail, together with the nature of the storage media involved. This preliminary work allows a large number of works to be included more rapidly than requiring a complete record of performance of details from the outset. Even then, many details must be confirmed by accessing scores and publisher archives directly.
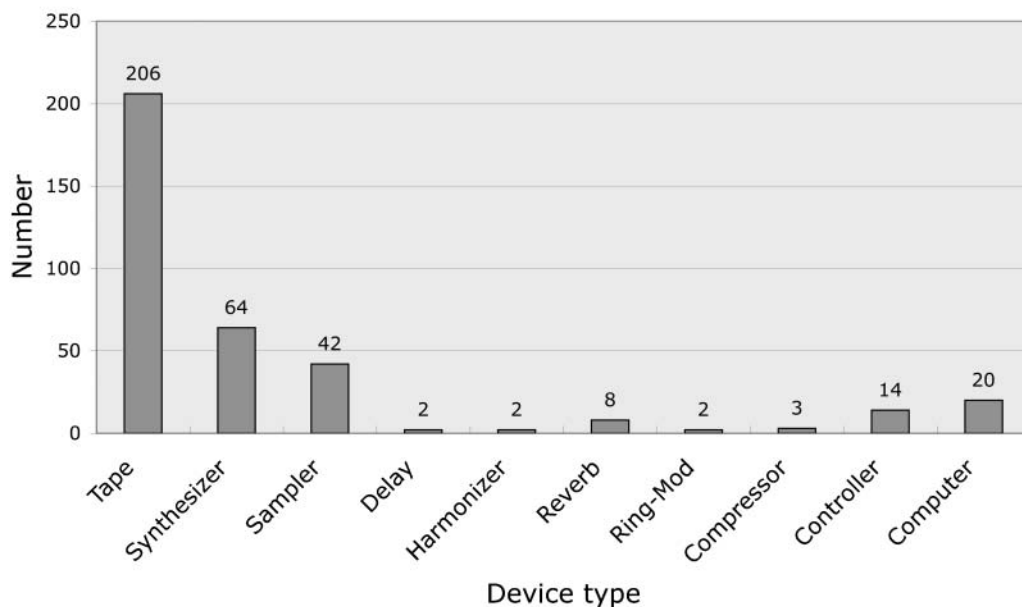

Figure 1. Numbers of works using different technology types.

Of the 308 works for which we gained technical information, unsurprisingly the most common electronic component was tape. Two hundred and six works used 'tape' of some kind (see Figure 1), including analogue tape (both reel-to-reel and cassette), DAT, CD, ADAT (8-track digital audio on VHS cassette), DA88 (8-track digital recording on HI-8 cassette), etc. Most of the analogue works listed have already been transferred to digital formats, and publishers indicated that this was an ongoing process.

Sixty-four works used synthesizers, with twenty of these not giving any further information. The most popular named synthesizers were Yamaha's DX/TX and SY ranges, with twenty-three in total. Other types included one 'electric piano', two works with 'electronic organ', one Korg 01W, an EMS Synthi and VCS III, a Theremin, a Yamaha Electone, a 'sine wave synthesizer' and three Roland synthesizers (models unspecified).

Forty-two works used samplers, twelve of which remain to be identified. Where hardware is specified, samplers include Akai models from S990 up to S6000 (15), Kurzweil K2000+ (11), EMU E64 (3) and Emulator II (1) and a Digidesign Samplecell computer-based system. Akai samplers are also specified as alternatives to Kurzweil in three works.

With regard to effects processing, somewhat surprisingly only two works listed delays (both tape delays), while four used harmonisers, one specified as an Orville Eventide, another a Yamaha SPX1000, all the others generic or unknown models. Eight works used reverberation: generic or unknown models (3), Yamaha SPX1000 (3), Yamaha SPX990 (1), Yamaha SPX90 II (1). Ring modulation was used in two works (no specific devices given) and compressors in three (again simply generic devices were listed). A relatively limited range of effects appears present in the works examined so far. However, some devices may be applying more than one type of effect, such as equalisation as well as reverb, while more complicated processing (or control) present in some works is realised by Max/MSP patches.

A variety of controller devices were specified, with fourteen works listing one or more types. The most common are MIDI keyboards, seven generic (some specifying at least a five octave range) and one Yamaha KX88. Other controllers which appeared are: Roland Octopads (1) and Kat MIDI Mallets (2), both MIDI percussion controllers; 'hyperviolin' (1); joystick (1); sustain pedal (1). Most of these are readily available devices or can be replaced by similar contemporary devices, provided sufficient information regarding the MIDI configuration is provided with the score.

Finally, nineteen works listed computers as a part of the specification. In four cases we currently have no further information. Fourteen works use Macintosh computers with various software: Max/MSP (6), Digital Performer (1), Performer (1), Vision (1), Logic (1), Protools (2), Galaxy (1), MIDIMAC Patch Librarian

(1). One work lists Atari with Notator software. Of these the Atari is perhaps the most problematic, having been discontinued in the early 1990s. They can still be found, but are increasingly rare, while the correct software may be very difficult to obtain. Apple Macintosh computers are readily available as is much of the software listed, albeit in much later versions. There remain issues of safe storage (e.g. unreliable floppy disks), and also the fact that discontinued programs may be both hard to find and impossible to run under recent Operating System (OS) versions. In particular, step changes in technology, such as the change in the Macintosh CPU from Motorola 68k processors to PowerPC (and now to Intel), or the operating system from Mac OS 9 to OS X, can leave such programs non-functional, despite company attempts at backward compatibility. Thus a computer contemporaneous with the original work (or soon thereafter) may be needed in order to load the necessary data unless stored in a generic format such as a MIDI file. This can be particularly complicated in the case of programs using plug-ins, as even if the host program is still produced, an individual plug-in (or 'external' in Max/MSP) may be discontinued.

3. JONATHAN HARVEY'S ELECTRONICS

In addition to gaining an overview of live electronics across composers, we examined in detail thirty of Jonathan Harvey's works, composed from 1977 to 2003, with regard to their archived state, score information regarding the electronic component(s), and numbers of recorded performances over the period since their premiere. The aim was to discover where remedial steps may need to be taken soon and how serious the problems of performance are already or may become in the near future. Since there are a large number of works, composed over a substantial period, and the composer has a high profile, it was felt that this would be an effective example for study and indicative of problems likely to occur elsewhere. However, the high profile of the composer may mean that whatever we found would tend towards a best-case scenario, since his works are less likely to have been neglected. In selecting works for inclusion, as before, we chose all works that had any electronic component – tape or live-electronics. In addition to accessing the archives at Faber Music to examine the materials and how they are stored, we studied Faber's performance records to see if we could use the frequency of performances over time as an indicator of potentially problematic pieces.

3.1. Storage – environment

The works are held at Faber Music in Harlow, UK. Scores are held on shelving (hire copies) and in storage boxes. The materials for electronic works are

generally held on shelves in metal cabinets and are in various apparent states, from older tapes in battered boxes through to recent CD-ROMs in good repair. The composer himself also has copies and generally keeps two for safety (J. Harvey 2003, private communication).

3.2. Storage – media

A variety of media are used for information storage for these works, depending upon type of information, technology at the time of composition and any subsequent updates. They include:

- Analogue tape (1/4′′, 1/2′′ at 7 ½ ips or 15 ips)
- DAT
- Audio CD
- CD-ROM (Apple Macintosh)
- 3.5′′ floppy disk (Yamaha DX7 II, Yamaha SY77, Apple Macintosh, Akai S1000)
- 5.25′′ floppy disk (Emu Emulator II)
- VHS Cassette (ADAT)
- Yamaha Data Cartridge (DX7)
- Eventide Data Card
- Paper (score notes)

Some works had multiple versions, e.g. an original analogue tape, plus a later digitised version on ADAT VHS cassette.

3.3. Devices

In the thirty works studied, a variety of devices are required. For some these are specific makes and models, but in many cases generic devices are given. A list of these devices, number of occurrences, and data storage type is indicated in Table 1, where the values in parentheses indicate the total numbers (including multiple items) used in works. As we can see in the table, again the most common element is 'tape' in various formats. Several synthesizers (mainly FM synthesis based) are used, as well as controllers, effect processors and samplers.

3.4. Preliminary issues

Of the many issues that emerged after having examined the works and archives and spoken with those responsible for their management, two main problems were evident. Firstly, updating works in order to perform them today is typically a *reactive* process. The publishers do not do this themselves, and it is an *ad hoc* process driven by those wanting to perform a particular work (although some institutions may proactively attempt to update works). Secondly, there is no clear monitoring of the situation to see if a particular technology becomes discontinued and so no longer available. From the date that a system has stopped being manufactured, it is likely that the cost and

Table 1. Devices used in Jonathan Harvey's compositions.

Device (category)	# Occurrences	Data storage (media/format)
Ring modulator (fx)	3 (4)	Score
Compressor (fx)	2 (3)	Score
CD/DAT/Tape/ADAT (tape)	12 (15)	(as device)
Yamaha DX7 (synth + controller)	2 (3)	Data cartridge, 3.5′′ Floppy Disk – Galaxy
Yamaha DX7 II FD (synth + controller)	2 (3)	3.5 FD – DX and Atari librarian disk
Yamaha TX816 (synth)	2	3.5 FD – Mac librarian files
Akai S900 (sampler)	1	3.5 FD –Akai format
Yamaha DX1 (synth + controller)	1	3.5 FD – Mac Galaxy
Yamaha SY77 (synth + controller)	6	3.5 FD – SY77
Yamaha SPX90 II (fx)	1 (2)	Score
Yamaha SPX990 (fx)	1 (2)	Score
Reverb (fx)	4 (5)	Score
Akai S1000 (sampler)	2 (4)	3.5 FD – Akai, Syquest 88MB – Akai
Akai S2000 (sampler)	1	CD-ROM - Akai
Akai S3200 (sampler)	1	3.5 FD – Akai
Emu E64 (sampler)	3	Zip 100 – Emu
Emu Emulator II (sampler + controller)	1	5.25 FD Emu
Harmonizer (fx)	3 (6)	Score
Max/MSP (Mac OS 9) (fx, sampl. tape)	5	CD-ROM - Macintosh
Tape delay (fx)	1 (2)	Score
MIDI Keyboard (controller)	4	Score
Electronic piano/synth (synth + controller)	1	Score
Orville Eventide Harmoniser (fx)	1	Data card – Eventide
VCS III (synth + controller)	1	Score
Joystick (controller)	1 (2)	Score

difficulty of performing the work will rise over time unless a directly replaceable device appears (such as a new sampler fully compatible with a discontinued sampler's disks).

The problems of reactive maintenance and discontinuity of technology can easily cause certain works to reach a point where they become too difficult and/or expensive to perform. While there is an element of 'survival of the fittest' here, with works for which there is high demand for performance being more likely to be maintained, this is perhaps not the preferred situation – as what is popular and seen as important now may not always remain so. It is also clear that the responsibility to keep master copies of all the data usually lies with the composer, ready to replace publisher-held copies when necessary (although IRCAM takes on maintenance of works created there). On a composers' death there may be no individual willing or able to take up this task.

With regard to the details of the devices and storage media used in the works surveyed, there are several points to note. Many items are stored on floppy disk in various formats – for Yamaha DX7 II FD, for example. These are notoriously prone to failure, therefore not a good media for archiving, and are ending their usefulness for distribution. A second problem with these disks is that typically they use device- or manufacturer-specific formats, meaning that unless a computer program is written to extract the data, an original device is necessary in order to access the information. This is even more of a problem for data cartridges, since computer peripherals to read these units are not often generally available. In another case the material is on an extinct format for an extinct sampler (5.25″ floppy disk

for an Emulator II, discontinued in 1988). Extracting the information from this disk in order to use with an alternative device is already a difficult process due to changes in media and storage systems, and may better be carried out by sampling the audio output of the Emulator if the aim is to preserve the timbre quality of the original device as closely as possible.

3.5. Performance data

It is difficult to draw conclusions from the numbers of performances different works receive over time, since clearly the technological element of a work is only one factor. Many other issues will affect the performance profile, including numbers of musicians involved, acoustic instruments to be used, type of work (opera, ballet, composition), general critical 'success' of the work, and musical fashions/trends. However, it is potentially valuable to compare the performance profiles over time with the perceived technical difficulty of staging, to see if the technological issues appear to be having a significant impact. The data here are assembled from information kindly provided by Faber Music, and may be partially incomplete due to changes in record-keeping systems used at different times.

A work that has clearly been successful over a long period will exhibit a profile of a regular number of performances each year since the date of composition. For example, *Mortuos Plango, Vivos Voco*, a tape work which is technologically relatively simple has had sustained performances averaging around six per annum since its composition in 1980 (Figure 2). This piece requires an ADAT multi-track tape machine and a
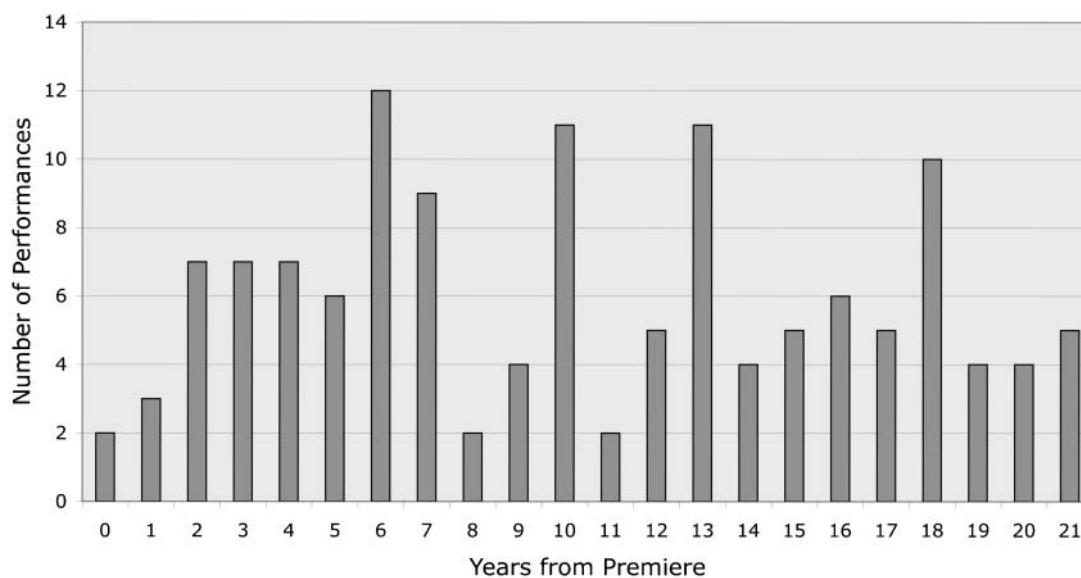

Figure 2. Performances of *Mortuos Plango, Vivos Voco*.

four- or eight-channel loudspeaker system. This composition has been re-formatted for a digital medium from the original analogue tape. Multi-track tape is still available and would not have prevented contemporary performance, but the digitised version is simpler to use. ADAT itself is becoming a dated format, and these days we would expect a CD-ROM containing audio files to be the preferred medium.

In contrast, *Ritual Melodies* (1990), also for multi-channel tape, has declined rapidly in numbers of performances, and has had only one in the last six years of the data (Figure 3). In this case we must assume that factors other than technical difficulty on the electronics side have contributed to its smaller number of performances: either aesthetic difficulty for audiences, less critical success as a composition, accidental neglect or even due to the popularity of *Mortuos Plango, Vivos Voco.*

Advaya (1994) is a composition that despite a more complex electronics part has been performed more regularly over a reasonable period. This work is for cello, electronic keyboard and electronics requiring two musicians and two or three technicians. The electronics include a sampler with MIDI keyboard, a harmoniser, a reverb, two DAT players, together with mixing and stereo amplification. While not as old as *Ritual Melodies* or *Mortuos Plango, Vivos Voco*, *Advaya* has been performed twenty-five times, after the six in the first year, with no sign of decline (Figure 4). Examining the performance details, we see that the sampler specified is an Akai S1000 (floppy disks supplied), effects parameters are given for generic devices, and DAT tapes are supplied for the audio. All of these present few problems

since, although the S1000 is a long discontinued device, disks formatted for it are compatible with many more recent devices and software (not only those made by Akai). This composition has already been updated with samples now stored on CD-ROM, which provides a more reliable medium for distribution. The tape part has also been replaced by software for Apple Macintosh, using Max/MSP (Zicarelli 1998). The aim of this appears to be to simplify cuing of the tape parts in performance and rehearsal, as it is generally much quicker to locate a certain point in audio data on computer than on tape. This reworking occurred between 1997 and 2000 (J. Harvey 2003, private communication) and may have contributed to the resurgence in number of performances from this time. The pattern up to this point appears to be in decline, but it is difficult to determine whether the updating of the materials alone has caused the resurgence, or whether other factors were involved. The effects processing may not have been moved to Max/MSP at the time due to the fact that MSP was a relatively new software package, first released in 1997, or that there was insufficient perceived need to do so, if the hardware processors remained readily available. A new version of the work made in 2006 at IRCAM does incorporate the sound processing into Max/MSP, although the samples remain formatted for an external sampler.

Smiling Immortal (chamber ensemble and tape, 1977) is a work that seems to defy the usual profile of a high number of performances early on, that then either remains high or declines over time. This work was only performed once in the first nine years and has been performed more often in recent times (Figure 5). This

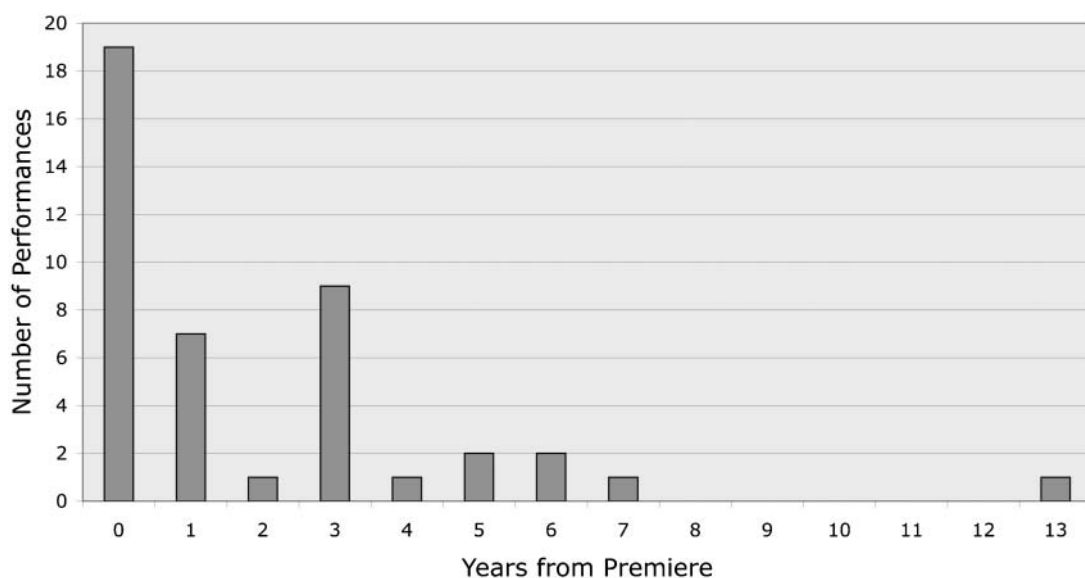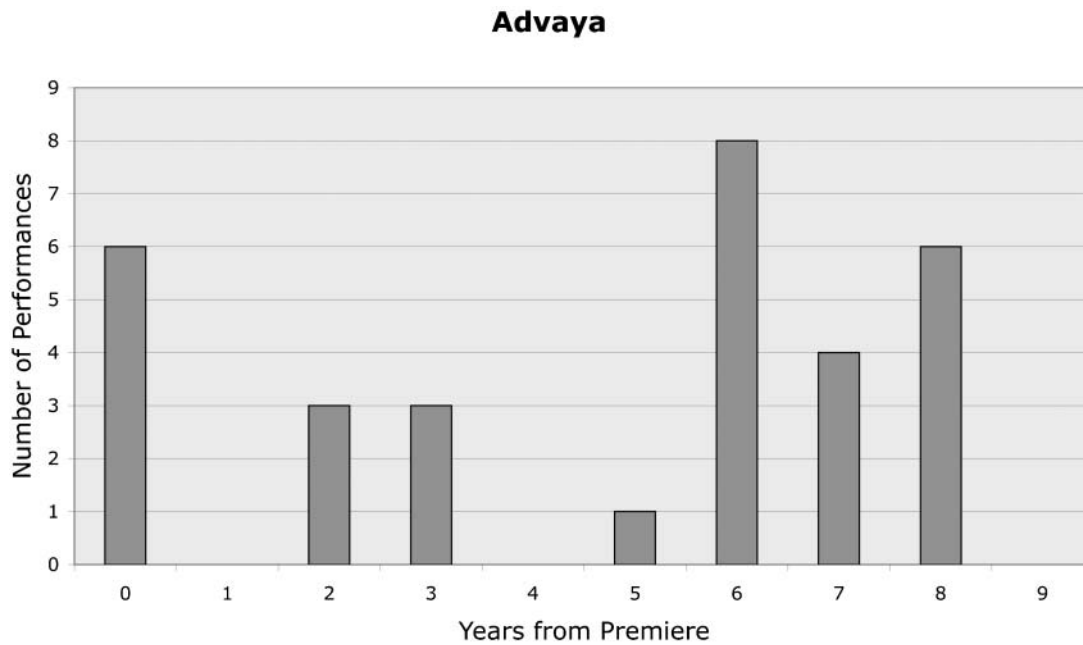**Figure 3.** Performances of *Ritual Melodies*.

Advaya

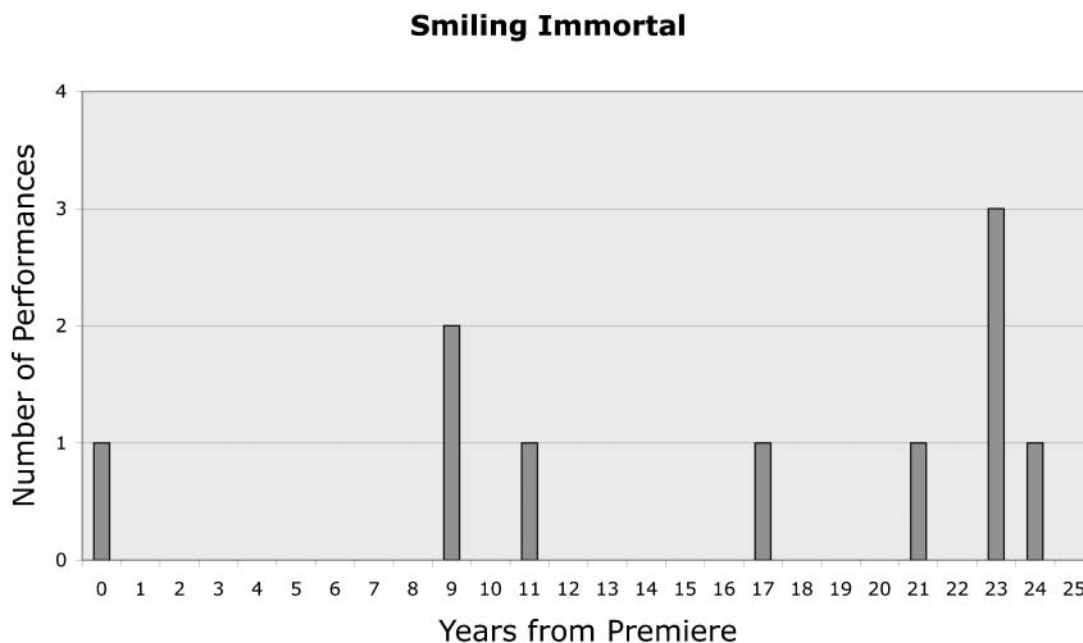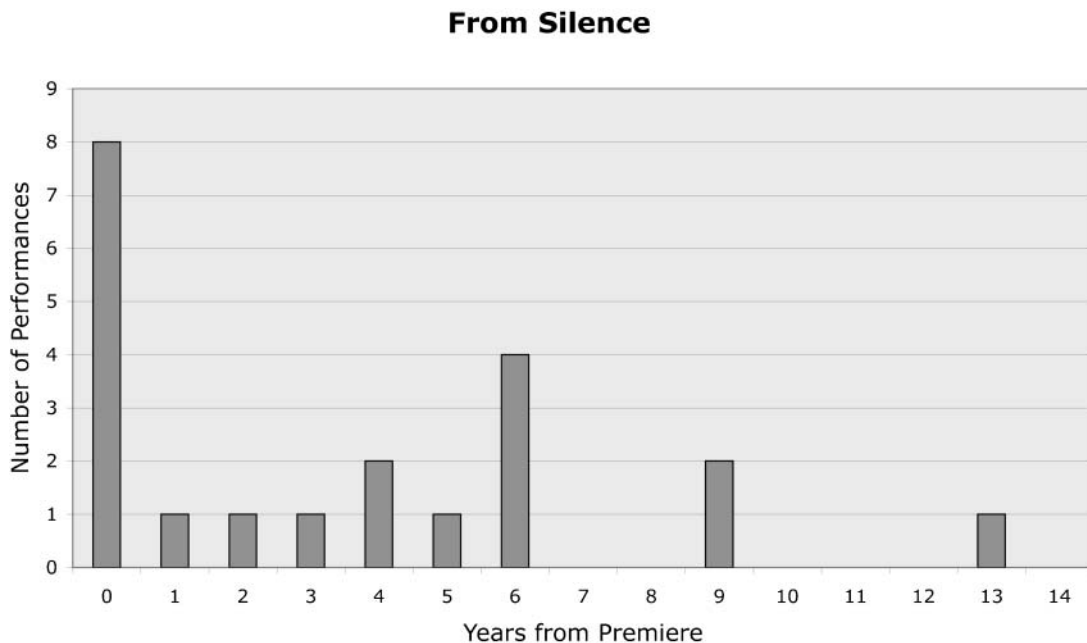**Figure 4.** Performances of *Advaya*.

Smiling Immortal

Figure 5. Performances of *Smiling Immortal*.

work appears to have been 're-discovered' and transferred to audio CD from analogue tape.

The works discussed so far show a variety of profiles, with numbers static, decreasing, or increasing over time. Where outdated technology is a factor affecting the performance profile of a work, we would expect to see a decline in performances. Such a profile can be seen in *From Silence* (Figure 6), which was performed eighteen times in the first seven years after its composition (1989),

and only three times in the second seven years. The electronic set-up consists of: a Yamaha TX816 (a rack of 8 DX7-equivalent modules) controlled by a MIDI keyboard via a Macintosh computer running MOTU Performer (a MIDI sequencer); an Akai S900 sampler controlled by another MIDI keyboard; a Yamaha DX7 II FD synthesizer; two Yamaha SPX90 II multi-effects units; a stereo tape machine; four microphones; a mixer and quadraphonic loudspeaker system. A Yamaha

From Silence

Figure 6. Performances of *From Silence*.

QX-3 hardware sequencer is listed as an alternative to the computer system, while a second mixer is listed to sub-mix the outputs of the TX816. The materials supplied for the work are: a MOTU Performer file on floppy disk for Mac; a DX7 II FD floppy disk; written settings for the effects units (used for pitch shifting, delay, auto-pan and reverb); four Akai floppy disks, one of which to be pre-loaded, the others to be loaded in sequence during the performance; a Mac floppy disk containing *MIDIMAC Patch Librarian* which is used to load the TX816 settings over MIDI from the computer; 1/4″ 15 ips stereo tape (available now on CD). The score provides detailed descriptions of the complete set-up, including a system diagram somewhat like that shown in Figure 7. Seven musicians are required for the piece: soprano, violin, viola, percussion, and three keyboard players. Two or three technicians are also required in order to operate the tape, mixer and effects.

In terms of staging a performance today, the task should not be too difficult. Although several of the items listed in the schematic are not easy to obtain, most can be simply replaced with contemporary devices. The KX88 controller keyboards and both mixers could be replaced by a number of alternatives, while the Akai data could be loaded onto more modern samplers (hardware or software) from Akai or other companies. The tape part appears to have been already converted to audio CD, perhaps for the performance in 2002, which simplifies this part. MOTU still publish their Performer program, although much updated, and so the Performer files should be readable on a current Apple Macintosh provided that the floppy disk is intact, or a backup is available from the composer. The effects units (SPX90

II's) can still be hired despite their age, although since the settings are given in text form, later similar devices could undertake their role. The DX7 II FD is also still available for hire, but not necessarily from a wide number of sources. The TX816 is more of a challenge since these were expensive when made and so are rarer than most items, and could be very difficult to obtain for hire. Also the Opcode MIDIMAC Patch Librarian editing software used to load the settings onto the TX816 is unlikely to be compatible with today's computers, making it difficult to set up this device for performance. However, the data may be recoverable depending upon the file format used. While there may be other reasons why this composition has had fewer performances in recent years, it is clear that while the technical issues of staging the work are not insurmountable, the combination of several problems with dated systems may be enough to prevent potential performances.

Valley of Aosta (chamber ensemble and electronics, 1988), despite being much simpler technologically, exhibits a similar performance profile (Figure 8). This work was performed twenty-four times in the first seven years since its premiere, while only four times in the subsequent seven years. The materials in this case are provided in the form of librarian software and files to be loaded over MIDI from a long discontinued Atari computer. While once again it would be presumptuous to claim that the lack of recent performances is solely due to this, it seems that it could well be a contributing factor.

Madonna of Winter and Spring (orchestra, synthesizers and electronics, 1986) has a profile that is difficult to assess. It uses several electronic devices: a Yamaha DX1 (a rare and expensive member of Yamaha's successful
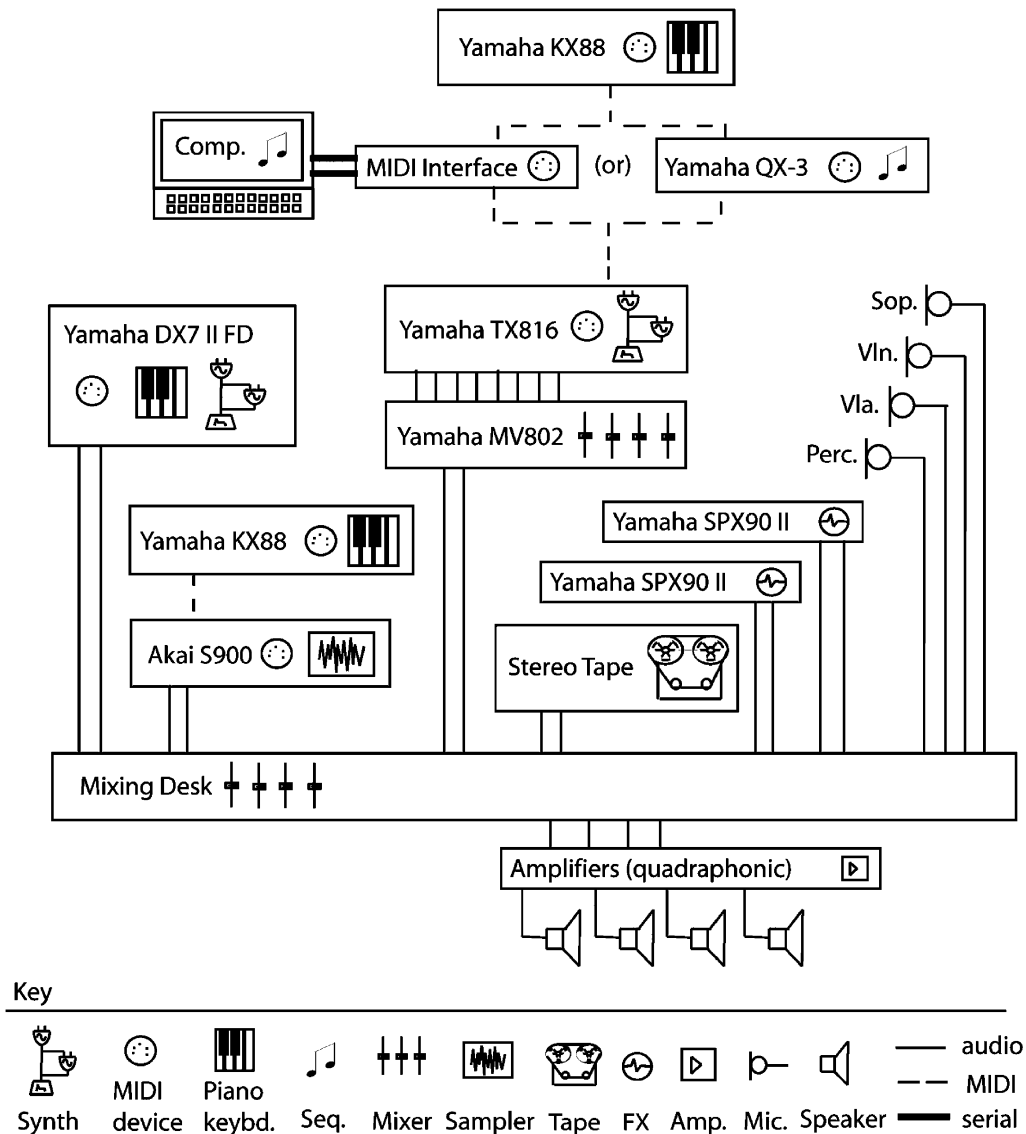
Figure 7. Schematic for electronics in *From Silence*.

FM synthesizer range), a TX816, an E-Mu Emulator II sampler, a ring modulator, a reverb unit and a quadraphonic loudspeaker system. This is a piece we would expect to be difficult to perform today due to the rarity of the sampler and synthesizers used and the requirement for correct librarian software. However, in Figure 9 we can see that, although not performed often in recent years, there has not been a clear or consistent decline over time. It may be that future performances will be restricted due to the difficulty of obtaining the systems required, but the evidence for this remains inconclusive.

Inner Light 2 (SSATB soli, instrumental ensemble and tape, 1977) is an interesting case (Figure 10). It has had very few performances and while partially updated (the tape part was transferred to ADAT), the EMS VCS3 synthesizer required was originally released in 1969. We would therefore expect this piece to be

difficult, due to the necessity of obtaining such an old synthesizer. However, according to EMS's website (admittedly not updated for some time) this analogue synthesizer is still in production and so this work should in fact be simple to perform today. This is in contrast to most of the more recent digital synthesizers used in Harvey's works, which have been discontinued for a long time. The unpredictable longevity of devices is a significant problem for composers seeking to ensure that their works are performable well into the future.

4. WHICH WORKS TO RE-WIRE?

There are a number of possible strategies for the migration of works to contemporary technology:

- A *performance-driven* approach is where the development of a new version is motivated by a
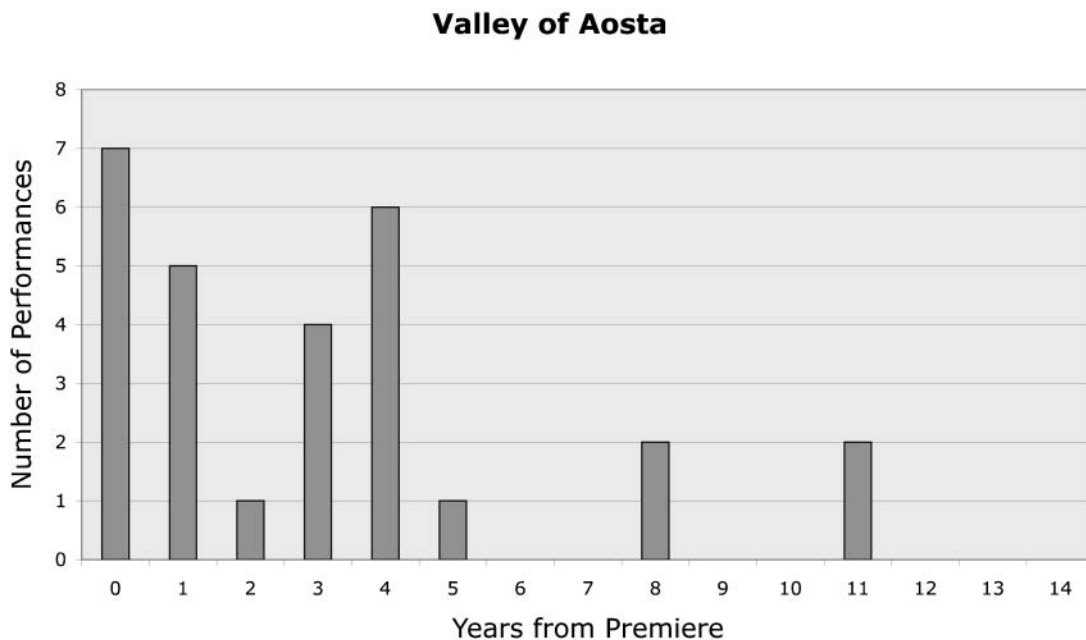
Valley of Aosta

Figure 8. Performances of *Valley of Aosta*.
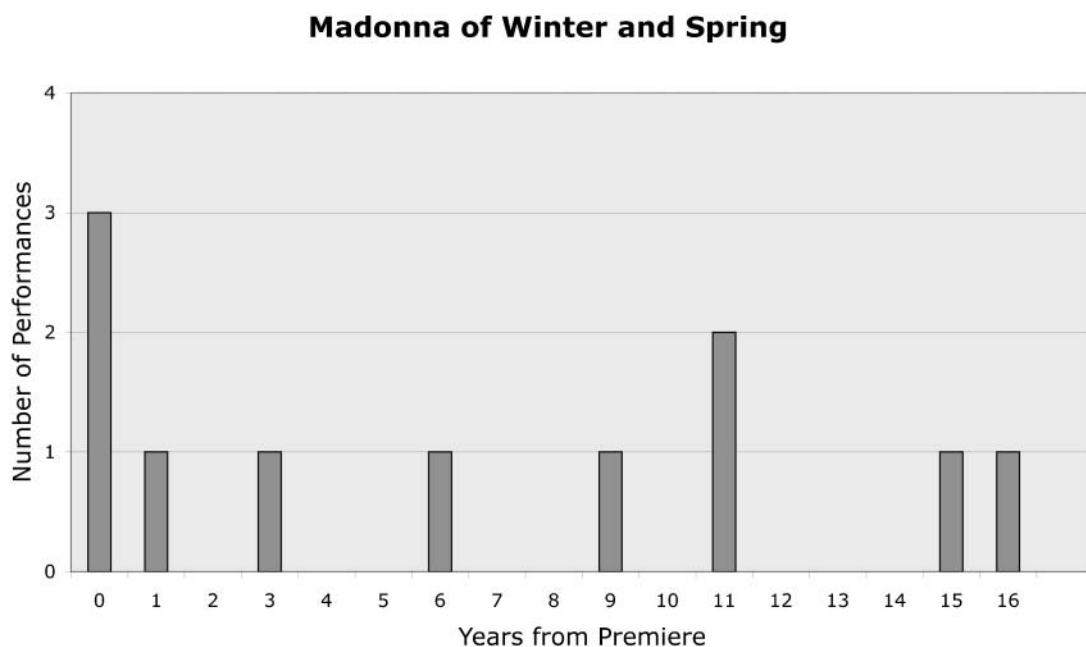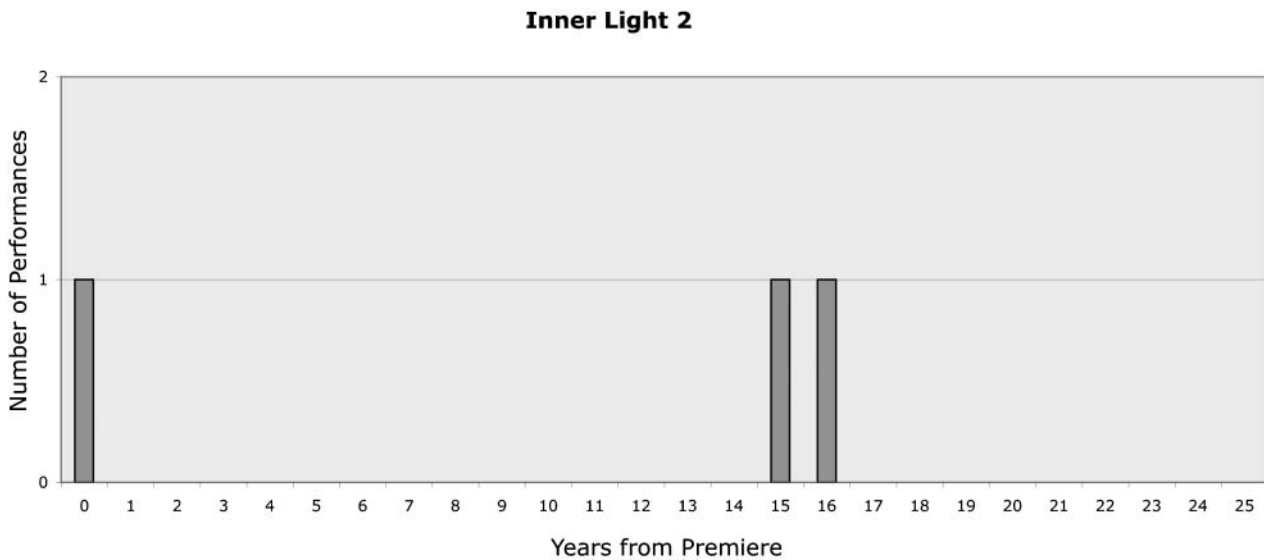
Madonna of Winter and Spring

Figure 9. Performances of Madonna of Winter and Spring.

planned public performance. This reactive process, and the one which we believe is the most common currently, has the risk of only catching more popular works, and is rather *ad hoc*.

- A *device-driven* strategy, based on a review of works, seeks to determine the most commonly used devices that are becoming difficult to obtain, and prioritise migration of those devices on the basis of the number of works that will benefit from the results.

- A *composer-driven* strategy selects a composer on the basis of their importance and sets about migrating only their compositions. Works by this composer could be prioritised in a number of ways, including: on the basis of the composer's preference (if living); performance profiles; the most outdated technologies used; significance deemed by experts in the field.

- A *composition-driven* approach is similar, but selects works on their individual merits across

Inner Light 2

Figure 10. Performances of *Inner Light 2*.

composers, rather than limited only to one. Making an appropriate selection here is therefore very difficult, and risks only collecting works of particular interest to those involved in the migration.

- An *archive-driven* strategy involves inspection of publisher, institution and composer archive materials with a view to finding the media most at risk of loss due to lack of readers or decay of the media themselves. In this case preservation of the data is the primary concern, rather than migrating complete works, since if the data is lost, then the piece cannot be performed. Given the catastrophic consequences of media failure (if all copies are lost), this approach seems sensible, although this is likely to be extremely difficult in terms of searching out materials across a large number of composers. However, there is some hope here, in that this affects chiefly digital works (although analogue recordings also), as analogue set-ups are recorded on paper with the scores and so the specification should remain intact, irrespective of the devices themselves.

- An *institution-driven* approach focuses on all works realised at a particular studio or research institute, which combines with one or more of the previous strategies in selecting the works within that category.

Whichever approach (or mix of approaches) is adopted, it seems clear that a large-scale review of works and collation of data is necessary to understand the current situation fully. In addition, there needs to be effective communication between institutions where maintenance of works is being undertaken. The MUSTICA project (Bachimont *et al.* 2003) is a particularly useful source of detailed information regarding electronic works and performance materials, but is limited to those works developed at IRCAM (an institution-driven approach). An extension of this type of resource to electroacoustic works in general would be of great benefit to research and performance in this field.

It is interesting to note that since we undertook this review of Harvey's works, a project at the Birmingham Conservatoire, UK, has begun the process of migrating some of Jonathan Harvey's works under the auspices of the Integra Project, in a composer-driven approach where consultation with the composer has governed selection of works, and this in turn may have been influenced by expected future performances. Integra represents a significant collaboration between several international partners and which we hope will contribute significantly to migration research. Researchers taking part in the project are currently working on *Madonna of Winter and Spring* and *Wheel of Emptiness* and have identified a number of problems with the transfer of information from the original formats to contemporary systems (Bullock and Coccioli 2005).

5. HOW TO RE-WIRE?

While it is difficult to assess the impact that availability of equipment is having on performances of Harvey's works, there are perhaps some indications that the electronics used need to be updated soon in order to avoid problems in the near future. When approaching a re-specification, an important decision is whether to simply update to today's equivalents in hardware and software, or develop a bespoke software solution incorporating as much of the synthesis, sampling and signal processing as possible. Re-specifying for hardware typically extends the viability of a work by only a

relatively short time period, as we have found with previous migrations of works by Luigi Nono (Polfreman, Sheppard and Dearden 2005) due to the rapid turnover of commercial hardware models. Also, hardware typically offers less scope for simplification than programmable software capable of executing a wide range of synthesis and processing tasks. A further important advantage of software is the ability to design a custom graphical user-interface allowing more effective control of a performance than using the generic control panels on hardware devices. Disadvantages of software may include bugs in the design that could cause total failure of the electronics and the need for substantial initial research and development time. Software migrations can simplify both the nature of the materials sent out for performance (e.g. a single CD-ROM with written instructions) as well as reducing the complexity of the systems required. Typically the equipment needs might be reduced to a single computer with MIDI/audio interfaces, MIDI controllers, microphones and an appropriate loudspeaker system. Complexity of the original electronics can be a disincentive to performance in itself, as there are implications for cost, rehearsal time and risk of technical problems, irrespective of the age of the systems used. Therefore we believe that software-based solutions will help to increase the number of performances of electroacoustic works. In carrying out a review as described here, there are lessons that can be learned for both how the re-specification of a work should be recorded and also how new compositions today should be made available, in order to ensure sustainable performances.

Traditional signal processing systems are often simple to replace, since the details are usually supplied in written form, and do not rely on storage media. It is then generally not difficult to find a contemporary replacement device (software or hardware) and adapt the settings to it, although reference to a technical manual for the original device may be useful. Others have recommended the recording of impulse responses as a method of preserving signal processing information (Bernardini and Vidolin 2005), although this may be insufficient in cases where parameters are changed over time during performance.

For synthesizers there are various options. In the simplest cases it is enough to have a basic technical specification in order to reproduce the sound (e.g. a sine wave generator), while more typically there is at least a need to sample notes from an original, if not emulate the entire synthesizer. Sampling can, however, lose some of the distinctive behaviour of a synthesizer patch, particularly the timbre variations with MIDI velocity and other controls, and complex temporal variations such as those typical in FM synthesizer programs. Multi-sampling can capture some of this, but with only limited accuracy. In recent years, a plethora of software

emulators of discontinued synthesizers have emerged (e.g. Native Instruments' *FM7*, Arturia's *Minimoog V*) which can provide a short-term solution, and may assist in the recovery of data, but will of course be subject to commercial pressures and may themselves be soon discontinued. Moves toward Open Source emulators (such as the Hexter DX7 plug-in being used by Integra) will hopefully provide some sustainability, but these are currently few and far between. Emulators of previous computer platforms are also available, often in Open Source form (e.g. Hatari, an Atari ST emulator). These may be useful for migrating data from archives, provided that copies of the original software applications can also be found. In some cases it will still be necessary to obtain original functioning hardware in order to extract the data and check authenticity of sound, for example where Yamaha data cartridges are used. In this case instrument collections and preservation projects (e.g. Davies 2001) may prove invaluable. When either composing with synthesizers today, or when migrating previous works, at least a MIDI librarian program should be used to both save the settings to a standard computer format such as a MIDI file (onto something more robust than floppy disk) and to print out all the device settings on paper. This removes the requirement to copy out by hand, whilst retaining the possibility for manual translation to a replacement system if other options are unavailable.

Samplers present slightly different issues. Generally, newer samplers have backwards compatibility, both with models by the same manufacturer and with other makes. However, there are limits as to how far back this goes, and this in itself may not be enough since storage media formats change regularly. In Harvey's works we have seen sampler information stored on difficult media such as Syquest cartridges and 5.25″ floppy disks. It would seem advisable not only to store the sampler information in a format specific to a particular device (using common audio file types if possible), but also to record the original samples onto a standard audio format (CD) together with written records regarding how these should be assembled into sampler programs (filter settings, MIDI pitch and velocity layouts, etc). Again, a print-out from an editing program may aid this.

Controller devices are generally simple to replace also, unless unusual bespoke hardware systems are used (such as complex non-standard sensors). In the works examined here there were no serious problems in this area, although clear records should be made of the type of device used, range required and MIDI mappings involved (e.g. a split keyboard).

Software files present a range of problems. These typically represent Digital Audio Workstation (DAW) or MIDI sequencer information (e.g. multitrack audio or MIDI recordings), software synthesizer patches, or bespoke software such as Max patches. In addition to

problems with outdated media and obsolete computer systems, proprietary file formats for discontinued software are a key issue. Where standard MIDI files have been used for sequences and patch data, the information should be usable, but with proprietary files it may not be possible to recover the data without a functioning original system, unless translator software or a backward compatible program can be found.

The question of how to migrate to software in a sustainable way, i.e. with reasonable longevity, still remains. Cycling 74's Max, together with its signal-processing library MSP, provides one standard system for re-developing live electronics. It has a long and complicated history (the detail of which is beyond the scope of this paper; see Puckette 2002) and so is a mature program. It is now available on three major platforms: Apple Mac OS 9 and OS X, and Microsoft Windows, although the relevance of Mac OS 9 is declining rapidly (and is not supported in latest versions). It contains many of the elements required for most works involving live electronics including advanced user-interface elements, and can be extended by using additional objects, either *external* objects developed by others or the team reworking a piece, or widely available VST plug-ins. It can also interoperate with other audio/MIDI software if necessary in order to achieve the required set-up. However, Max/MSP is a commercial product and so has the potential to cease development, again leaving works requiring porting to other packages. The use of external objects is also problematic, as they are often created by individuals or small companies who cannot be relied upon for future updates.

An alternative approach is to use Open Source software as far as possible, and thereby avoid the vagaries of the commercial world (Puckette 2001). The source code would always be available and there would always exist the potential to recode the host program (even if the Open Source project were to cease activity), provided that the code had been archived. Pure Data (Puckette 1996) provides a Max/MSP equivalent environment here, although its user-interface elements are typically somewhat primitive in comparison. Other relevant Open Source systems include Csound, Supercollider and jMax.

6. CONCLUSIONS AND FURTHER WORK

There are two primary issues in the sustainability of electroacoustic works for live-electronics. First, that sufficient platform-independent data are recorded in text form such that a completely new implementation can be created solely from that data and give rise to an authentic reproduction of the work. Suggestions for the type of information necessary to achieve this can be found in Bernardini and Vidolin (2005) and Battier (2004). However, text alone is insufficient to encourage performances, due to the significant development effort

that can be required to turn a paper-based specification into an actual performance system. While standardisation of specifications across electroacoustic works, in machine-readable form, could potentially allow automated tools to carry out this process, currently a reference implementation is also required that can be distributed by publishers alongside scores for performances, in the form of self-contained software packages. This approach corresponds at least partly with that undertaken by MUSTICA. While these applications will in time become obsolete, careful design can make them viable over the medium term, requiring minimal maintenance and certainly longer lasting than hardware-specific implementations. The original source files must be properly archived in text format for future updating, in addition to the run-time application itself.

There are a number of key factors that we believe are necessary for effective sustainable migration of works when designing a reference software implementation. Many of these factors would aid sustainability of new works also, although composers should be free to adopt their preferred technology in order to achieve their artistic goals, and it is the quality of the documentation that is likely to determine the long-term sustainability of works. Ideally a reference implementation should be:

- *Flexible (or agnostic):* with respect to audio hardware and operating system. Pd provides great flexibility here, in particular running under an Open Source operating system Linux (in addition to commercial operating systems such as Mac OS and Windows), providing a further layer of sustainability.
- *Open:* not committed to a fixed audio chain within the software, but rather allowing alternative software/hardware to be inserted at each point. The program can be seen partly as a shell within which different elements can be selected at each point, e.g. built-in effect processor patch, VST processor, or routing to/from an external hardware processor. This does require additional development time, which can be difficult to justify within the context of a performance-driven reworking due to increased cost and preparation time.
- *Complete:* The counterpart to the open requirement is that the program should encompass all the required processing for a work so that no other software or hardware (other than input/output devices) is needed. Given the processing power of current personal computers, this should not in general be problematic.
- *Authentic:* the program should aim to reproduce the sound of the original system as far as is reasonable. Composer consultation may be necessary here, since the composer may prefer an improved sound quality in some areas, for example a modern convolution reverberation effect as

opposed to an original plate or spring mechanism. Amplifier and loudspeaker systems may also have developed significantly since the first performance, and so even if the synthesis or signal processing is authentic, the overall sound may be quite different today, requiring adjustment to meet the composer's intentions. Problems may arise if, for example, a synthesizer used at the time only partly achieved the sound the composer was aiming for and the composer now wishes to improve upon the original; preservation may often be in conflict with revision.

- *Locatable:* in rehearsals the systems need switching to the correct state for any position in the score that the conductor wishes. This includes sending program changes and other messages to remote hardware if necessary. The mapping of settings to score locations must be clear so that the operators can quickly switch to the appropriate settings and not hinder the rehearsal process.

- *Documented:* thorough instructions for use must be given, including how this implementation relates to the original specification and covering all the external devices needed (microphones, loudspeakers, etc). Where digital data have been used, this should ideally be printed to hard copy in a human readable format, if not already available in this way, in order to protect against failure of magnetic/optical storage. This documentation is in addition to that required for sustaining the actual work itself.

- *Robust:* the program must be reliable enough for effective use in rehearsal and performance.

Close examination of Harvey's works demonstrates that now is indeed 'time to re-wire' if we are to prevent serious issues arising in the performance of works for live electronics that were created some time ago. In the case of this particular composer, this is beginning to happen thanks to the Integra project and work at IRCAM. Other composers may not be so fortunate. While performance-driven updating of works ensures the survival of some works, others that are being neglected at present may become so difficult to perform as to be effectively lost forever. We believe that a more systematic updating of works is needed across the range of compositions for live electronics, organised by publishers and composers, working together with technical experts. In addition to preserving these compositions for live performance, and benefiting works by simplification of the electronic set-up required, the process should serve to help rediscover works and revive interest in them. While some institutions may maintain their own works to a greater or lesser extent, the benefits of collaborative work in this area will be great.

Composers currently writing for live electronics should also bear in mind the need for longevity of archiving for reproduction and should aim to escape proprietary systems and formats. The history of existing repertoire clearly points towards the desirability of generic specifications that can be updated as easily as possible in the future. However, we cannot expect composers to simply ignore commercial tools available and stick to purely Open Source software, since this is to set unacceptable limits on their creative relationship with technology. We are currently undertaking a more wide-ranging review of works for live electronics with regard to devising re-worked specifications for those which appear to be most at risk.

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