NOTA BENE

Notated Music in the Digital Sphere

Possibilities and Limitations

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15

STUDIES FROM THE NATIONAL LIBRARY OF NORWAY

Contents

Preserving Digitally Inscribed Music

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Musical notation as a prescriptive tool has existed for at least 4,000 years, aiming to preserve both musical ideas and performance practices. The notation system for instruments and voice that we use today is hundreds of years old and has over time been developed into the complex sets of instruction that one can find in contemporary scores, where new musical expressions are pursued through unusual excitation methods and increasingly detailed performance control.

This notation system has also found its way into the digital domain, and much research effort has gone into developing methods for migrating paper-based scores to machine-readable documents. However, digitally inscribed music often relies on more than pitch, duration, pulse and rhythm, and much of the modern electronic expressions cannot be captured or reproduced using conventional notation.

In order to simplify discussion in this article, the terms *technology-based* and *technology-dependent* music are used as common denominators for all music that originates in electronic music technology. The terms overlap with *mixed music*, where acoustic instrument parts are mixed with electronic sound and, in the use of technology, also overlap with music for acoustic instruments that has been composed with notation programmes on a computer. However, acoustic music composed in this manner does not rely on electronics for its sound, technology has only been a practical tool.

Electronic technology – computers, instruments, machines, software and code – has developed rapidly since the digital paradigm started to make headway into music during the 1970s and 1980s. Technology becomes obsolete, script or code can no longer be compiled, and as a result much of the music has become unavailable and can no longer be performed. Harddisks and floppies can no longer be read, and the software needed to read old files will not run on new machines. This is especially crucial for music where sounds and compositions are generated or processed in real time; where the only notation is the computer code or the instrument makers' proprietary formats. Much music repertoire from the last 25–30 years is rapidly disappearing, and the understanding of the developments that brought us to where we are today is becoming incomplete.

This article will discuss the urgency of preserving the heritage of digital music, present early projects and practices in this area, and provide recommendations for future efforts in securing more up-to-date and complete records of musical history in formats that also facilitate performability, so that the music can remain an active part of our cultural heritage and be heard and understood by future generations.

Preamble

My work in music technology started in the late 1970s, and I have been organising, promoting and composing digital music in Norway since my return from computer music studies in New York in 1990. This background has given me intimate knowledge of technological and musical development internationally and in Norway, and in 2019 I published the first book on electronic technology and music in Norway: *Elektrisk lyd i Norge – fra 1930 til 2005.* (Rudi 2019b)

In December 2016 my then colleague Notto Thelle and I gave a presentation at the conference *Interfaces: Tradition and technology in musical heritage work*, organised as part of the project *Norwegian Musical Heritage,* in which The National Library was a partner. The main aims of the musical heritage project were philological research, critical editing and publication, and preservation of musical scores through digitisation. The project has now ended after having published an impressive collection of preserved manuscripts that would otherwise have been lost and remained uninterpreted.[1] The project fits well within the musicological tradition of developing critical editions and preserving notated scores for posterity, with descriptions of relevant performance practices.

Our presentation was called *Digitally based music: Archiving, migration and performance*, and our aim was to start a discussion about digital music and the performance practices with software and hardware that are rapidly becoming obsolete and also unavailable in all forms. We also touched on issues regarding digitising and preserving recorded sound and pointed to the need for adequate media migration and formatting.

Technology is now a significant part of music in nearly all its forms, in notation, performance, production and recording, and there is a rich heritage of music that has been made with technology and could not have existed without it. In what we can call technology-based or technology-dependent music, the integration of technology goes even deeper – in combinations of compositional concepts and tools, in the detailed construction of sounds and timbres, and in the often intricate connections between data, micro (timbral) levels and macro (structural) levels. Structural relationships are played out on several levels and linked so that changes in one spot might ripple through the entire composition. Traditional notation is not useful in describing such works, and questions emerge: how do we sustain these new types of music and musical practices so that the few works that survive the merciless selection processes of history can be performed in the future? How should these compositions be performed, and how can we deal with the obsolete technology? Which methods of reconstruction, substitution and simulation can be used to best preserve the composers' intentions?

1 More information about the project can be found at this address: http://www.musikkarven.no/english/about/ (accessed June 8, 2018).

Notation and tradition

Since the 1950s, much research has been done on Cuneiform tablets, and it has been established that musical notation on these kinds of tablets from Mesopotamia is at least 4,000 years old, perhaps even older. Cuneiform writing was developed in the Babylonian city of Uruk, now in Iraq. Kilmer & Civil (1986) has published an analysis of a particular tablet that was found in Syria in 1950, and according to them the tablet contains a hymn to the moon god *Nikal* as well as instructions on how to perform it.[2] The instructions on performing the hymn are fragmentary, but it seems clear that the music was composed in harmonies of thirds and written using a diatonic scale.

Fig. 1: The Cunei-tablet with a section of A.D.Kilmer's transcription. Images of this tablet can be found on several websites, and this one is taken from http://www.openculture.com/2014/07/the-oldest-song-in-the-world.html (accessed December 17, 2018).

2 Kilmer, Anne Draffkorn, and Miguel Civil (1986). "Old Babylonian Musical Instructions Relating to Hymnody". *Journal of Cuneiform Studies*, 38, no. 1:94–98.

The intention 4,000 years ago was much the same as is it is now: to preserve music through a prescriptive and normative system for how the performance should be done in order to make future performances align favourably with the original. The reasons why this music was written down can be many, but there is reason to believe that the music preserved in this manner was linked to the social hierarchies of the time and to the cultural canons that described why things needed to be as they were. An investigation of social and political aspects of musical notation is certainly an interesting direction for research. However, it falls outside the scope of this article.

Western notation emerged in the mediaeval catholic church, and the beginnings of the system used today are often attributed to the monk Guido of Arezzo (995–1050) and his invention of staff notation. Since this early plainchant notation, musical script has grown in complexity and continues to develop even today, with detailed notation of interpretation and excitation techniques. The function remains the same as with the Cunei-tablet, however: notation preserves and makes music available for performance in a prescriptive manner that allows performances to be as close as possible to the composer's intention. However, any of us who has written scores or performed from them knows how coarse these instructions really are and how much they depend on the interpretation and skill of conductors and musicians.

For successful realisation, notation depends on interpretation, and this interpretation exists within a performance tradition or (as a minimum) in a similar cultural sphere. Consequently, music from outside a given tradition will easily lack authenticity in performance and not sound the same as the original. In Norway the perhaps clearest historical examples of this are from folk music, and how the skewed, uneven rhythms and non-chromatic and approximately just-intonated intervals are poorly captured by notation. When folk music is appropriated and used as inspiration and raw material for compositions notated in equal temperament, as in many of the works of celebrated composer Edvard Grieg, for example, many of the essential characteristics of the music disappear. One of the aims of the national romantic tradition that Grieg was part of was to construct a new canon of

"Norwegian-ness" as a cultural underpinning and firming up of the idea of the nation state. This was done by combining authentic elements and expressing them through an internationally recognised musical paradigm.

This type of appropriation was criticised by the folk music community, and among others, Eivind Groven was highly critical. From his point of view as a fiddler, composer and musicologist, he made it clear that folk music lost key aspects of its character when being squeezed into equal temperament and even rhythms, and to him this reduction of timbral and rhythmical detail could be likened with reducing the colour in paintings, for example. The way the music sounded was changed by the way it was notated.

Fig. 2: These images of Monet's haystacks show how a reduction of colours results in increased graininess and starker colour contrasts, completely changing the nuances in Monet's original. (Author's illustration.)

The link between tool and result forms the basis for the cultural canon, and Western musical notation clearly faces challenges when it encounters music that is different from the music it was shaped by. Music from other cultures with other scales and rhythms has fared even worse than Norwegian folk music when being written down in Western notation. However, it should come as no surprise that a tool developed for a specific purpose is not well-suited for purposes other than that it was designed for. We also see this in the Western contemporary tradition, where composers often augment and extend the notational system to be better able to represent their ideas for expanding the music.

These days notation is most frequently done electronically, and scores are normally printed for musicians to perform from. Notation on paper is a robust representation, and preservation efforts in scanning and digitising old and newer manuscripts are many, as several other articles in this collection describe. A further step in these preservation efforts is to develop machine-readability of scanned scores and mapping into MIDI-data, which is essential for automatic performance and perhaps even more important for musicological analysis. With advances in machine learning, these digital transcriptions can be material for automatic search and musical information retrieval, which opens up avenues for interesting and comprehensive research in what is often labelled systematic musicology. The processes of making scans machine-readable and developing reliable automation are by no means trivial, but they are well defined and easy to comprehend, and progress is steadily being made. With pattern recognition added to the equation, advances in interpretation and performance have come rapidly, as exemplified by the software *Wekinator*[3], which can recognise and recreate articulation from performances or unrelated gestures, and *Wavenet*[4], which can generate the *sound* of piano performance, for example.

Understanding how machine learning can be used to support creativity and become an interesting "partner" is a new challenge, although it is perhaps even more tempting to see what machines can create on their own or with human interrupts only rather than the strongly defined learning goals often implemented today. The current state of the art is mostly focused on training the machine-learning software on existing music and on coding it for maximum similarity between the learning material and the machine learning results.[5]

With several of the other texts in this collection focusing on digitisation and migration of printed and handwritten scores, there is not much point for me to describe this in more detail. Instead I direct the

3 http://www.wekinator.org (accessed January 24, 2019).

4 https://deepmind.com/blog/wavenet-generative-model-raw-audio/ (accessed January 24, 2019).

5 A Beatles copy from Sony CSL studios can serve as a fun example. However, it is worth noting that it is only the harmonic grid that has been automatically composed – the arrangement, text and song are by humans. https://www.youtube.com/watch?v=LSHZ_b05W7o (accessed January 24, 2019).

gaze towards how music technology has changed composition and performance and how technological inscription has radically expanded the challenges for musical heritage initiatives. It is only little more than twenty years ago that digital technology started to change the way contemporary music generally was composed and performed, although the pioneering genre *computer music* is close to 60 years old. This new and soon-to-be all-encompassing digital platform resulted in new methods for composition and performance, and preservation and archival efforts must follow musical practices in order to create future possibilities for understanding this part of our musical heritage, its preconditions, how it was made and how it has evolved over time. However, there is currently a lack of good systems for documenting and preserving an adequate amount of digitally dependent music for future analysis and possible performance, and our scope for understanding this part of our musical heritage will be significantly weakened if the necessary steps are not taken.

Inscription in technology – a quick historical overview

Today staff notation is often created on computers, and scores can be printed out wherever there is a printer with the appropriate paper size. Preservation of these digitally born manuscripts is not difficult as long as standard file formats such as PDF are used and the fonts in the document exist on the machine's harddisk. However, if a composer stores the notation in a proprietary file format for a specific software and the software stops working, or where new versions of the software are not sufficiently backwards compatible to allow old files to be opened, chances are that even manuscripts with standard Western notation are lost.

In digital notation, the core elements of pitch, duration and rhythm are the same as in previous centuries, although often augmented by the new practices of contemporary composers. Inscription of processes with sound in technology is considerably more complex than mere pitch notation, and the new digital methods facilitate music creation with new affordances in terms of accuracy, complexity and control structures that go far beyond the paper-based or analogue electronic technologies of the past. For a more detailed investigation of these issues, please refer to Rudi (2019a).

Electronic instruments, electronic and concrete music

With the invention of electronic and concrete music, sound events replaced the notated pitches as the basic musical unit, while acoustic music remained interval-focused. Since then, several new terms have been coined in order to better describe the variation and development of this expanding concept, and electroacoustic, sound-based, acousmatic, and computer music all describe direct descendants of early concrete and electronic music. With the growth of technology skills amongst wider user groups, electronic dance music and electronica have come into existence together with more countercultural glitch and noise music and more visually oriented sound art and acoustic art based on environmental sound environments. A fine cultural grid is needed to outline the differences and descriptors of numerous subgenres. Social aspects play an important role as well, as much of this development stems from the enablement of broader user groups.

It is the emergent qualities of sound spectra that carry the narratives in these new music genres; they are not represented though written scores. It should be mentioned, however, that for some genres, particularly those that bridge over into the visual arts, the interaction between abstraction and recognisability remains important, bringing aspects of representation into the works and consequently reducing the aspects of absolute music derived from the spectral changes alone. One example of which there are several examples can be listening to the action of writing with pen on paper, where temperament and intensity cannot always be identified in the written text itself but can be easily heard. Another example can be very soft sounds from our environment that are amplified so that we can hear them and gain a deeper understanding of how various biotopes function.

With this absolute focus on sound, preservation of sound quality is essential, since any reduction of sound quality means degradation of the music itself and consequently that any reduction will reduce our ability to perceive the qualities of the sounds as they develop. Future scholarship on technology-based music will depend on perceiving these qualities and on having the music available in as authentic condition as possible.

Reproducibility is the holy grail of preservation, and most types of electronic music face the same challenges as notated music: inscribing music in a prescriptive manner so that future performances can be realised without too much deviation from the composer's intentions. The necessary technological tools must be available together with the necessary supporting materials and instructions for performance. With all this in place, the question of how to interpret the music in a different social and acoustic context still remains, much the same as with acoustic music. Several approaches have been documented: Laura Zattra (2004) has designed an analytical method for electroacoustic music and provided several examples of the usefulness of her method, Michael Clarke (2006) has developed interactive methods that rely on rich source material, exemplified by an elaborate work on Jonathan Harvey's *Mortuous Plango, Vivos Voco*. An issue of Computer Music Journal (31:3) was largely dedicated to analysis of John Chowning's pioneering composition *Stria* and features five articles on different strategies and aspects for analysing this piece. (Chowning 2007, Zattra 2007, Dahan 2007, Badouin 2007, Meneghini 2007).

Inscription of music into electronic technology is older than both concrete and electronic music, and Jaime Oliver (2018) traces this development to the early electronic instruments, more specifically to how the musical possibilities were defined by the circuit boards of the *theremin*. The theremin is a particularly interesting example because the instrument did not have a keyboard for performance and relied on abstracted gestural input from the performer. The Theremin did not have one specific timbre, but by building affordances into the electronics, it was *authored* for several timbres. Oliver describes this new level of abstraction, where the sound was removed from the acoustic source, as a practice of transduction through electronic schematics – and how this transduction inaugurated enormous changes in Western musical practice, blurring the boundaries between composer and performer, instrument and score, as well as between instrument maker and engineer. Oliver refers to McLuhan (1964): "The theremin … introduc[ed] modularity as a design philosophy and of the schematic as an operable and transmittable code." The musical affordances of the instrument were inscribed in the electronic circuitry, and one can say that the theremin inaugurated the electric era in music and the pre-figured practices of electric instruments that are present to this day.

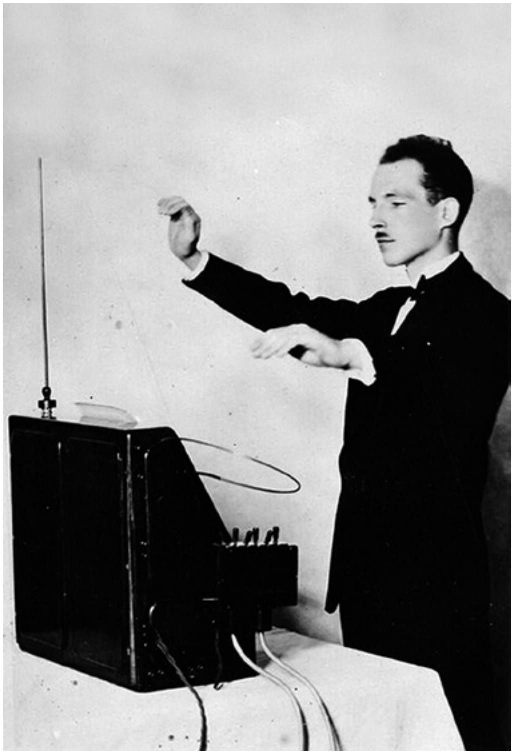

Fig. 3: Leon Theremin in performance. The instrument is surrounded by an electromagnetic field, and in order to optimise control, the performer must stand perfectly still except for moving hands and arms for precise control of the sound. (https://www.classicfm.com/discover-music/latest/weirdest-musical-instruments/theremin/)

Something similar can be said also for several of the other early electronic instruments, but since most of them have keyboard interfaces, the theremin stands out as the most radical design. It is also the only early instrument where the circuit designs circulated freely, following a short attempt at commercialisation. This free circulation was a new practice that pointed forward to the DIY approach of today, including the hacker and maker movements. The new electronic instruments from the 1920s were not thought of as what we today would call disruptive technology, rather they were designed to serve as supplements to the acoustic instruments and aimed to find their place within the acoustic tradition. They did not at the time result in any particularly significant musical development.

The first great leap in music technology development came with the ability to work directly with sound– to capture (record) a sound, edit and repeat it. The first developments in this direction were wax rolls, tin foil, steel wire and celluloid film, but it was lacquer discs and magnetic tape that gave composers the tools they needed. Concrete music was invented at radio stations at approximately the same time as electronic music, just before, during and immediately after WWII. The invention of *concrete* music is most often credited to Pierre Schaeffer, and although he was certainly not the first to make music from recorded sounds, it was his work that had the widest-reaching consequences. In *electronic* music the early genealogy is less clear, but a composition practice where electronic sound-generating equipment was used to form the music developed at radio stations across Europe. In electronic music it was easy to work in an exacting manner to control the sound material and its development, while this strong execution of principles and structures was more difficult in concrete music where the raw material was recordings of sounds from the acoustic world.

All these electronic timbres were imagined within the constraints of the technology and could not be performed outside of these affordances. While notation was adequate for the interval-based new serial music at the time, it was largely unusable in concrete music and electronic music. Notation did not capture the essential qualities of timbral development in sound-based composition and made no provision for frequencies and noise bands replacing equal-tempered pitches as the basic building blocks. The music could be represented graphically, however, and Karlheinz Stockhausen's score for *Studie II* may serve as an example.

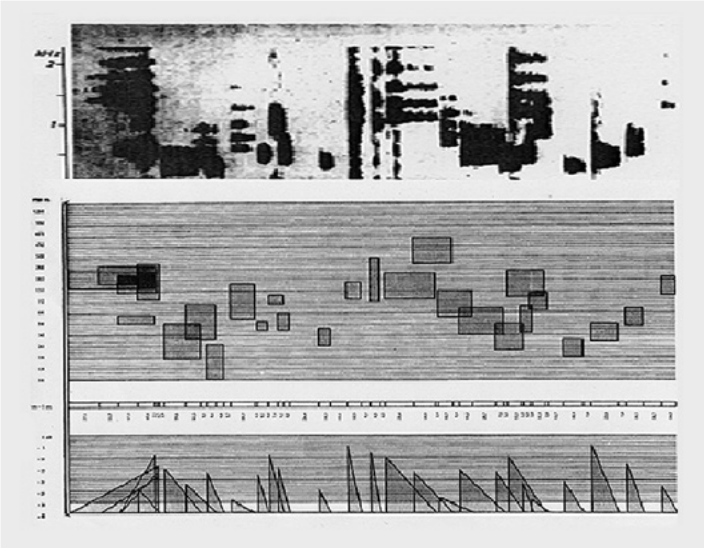

Fig. 4: This short excerpt from Karlheinz Stockhausen's *Studie II* is represented here by an amplitude mapping (bottom), frequencey mapping (middle) and a sonogram (top). The sonogram shows the entire spectrum, with darker areas being louder. (Montage by the author.)

Computer tools allowed for new types of representation and formalisation, first as computer code for generating note lists that could be reformatted into notation that musicians could perform from. Following this beginning of computerised algorithmic composition, generating and processing sound became the next building block of computer music, and the capabilities expanded with faster processors. In Norway composer Kåre Kolberg produced the first completely synthesised computer music piece of this kind in 1973, *The Emperor's New Clothes*, a few years after Arild Boman started his artistic investigations with computers and created *Ecumene* (1969) for jazz ensemble and computer-generated sound and score. Real-time performance with computers was still out of the question, so synthesisers were the workhorses for performances during the 1970s, and when MIDI protocol for musical communication was invented and released in 1983, the integration of computers and synthesisers became possible also outside the research laboratories. (Interestingly, in Norway the University of Oslo's *Musikus* project launched in 1974 was a clear precursor to MIDI. However, the project's focus was more on musical analysis than on developing practical tools for musicians.)[6]

As computer processing and storage capacity continued to grow, digital *analysis* of sound also started to become practical, and textual input remained the only method for interaction with the machine until graphical interfaces made big headway from the late 1980s onwards. Since then, development of computer graphics has been very much driven by the gaming industry, which now rivals the film industry in terms of annual revenue.[7]

With development of graphic interfaces, users could "see" the sound itself, select aspects, frequency and time regions, edit, process and compose by way of more or less intuitive interfaces, and new characteristics of sound became attractive arenas for artistic exploration. The 1990s heyday of the computer music genre came as a direct result. There were constant advances in new computer systems and affordances, and new methods for signal processing made it possible to fuse the strict algorithmic focus from electronic music with techniques from concrete music. Sounds could now be *processed* with the same rigour previously only applicable to sound generation. My own works *When Timbre Comes Apart* (1995)[8] and *Concrete Net* (1997)[9] are prime examples on this trend, in particular because they employ computer graphics to augment the connection between sound and digital processing. As the computer came closer to becoming a full musical

6 Vollsnes, Arvid and Lande, Tor Sverre (1988). *Music encoding and analysis in the MUSIKUS-system*, Oslo: University of Oslo.

7 Depending on how one calculates the value of spin-off and auxiliary products, computer games annually generate revenues larger than the Hollywood film industry. In 2017 games generated more than USD 108.4 billion, while the US movie industry generated 43.4 billion. See: https://www.gamesindustry.biz/articles/2018-01-31-games-industry-generated-usd108-4bn-in-revenues-in-2017 and https://deadline.com/2018/07/film-industry-revenue-2017-ibisworld-report-gloomy-box-office-1202425692/. For a view sceptical of that claim: https://www.quora.com/Who-makes-more-money-Hollywood-or-the-video-game-industry. All links accessed December 19, 2018.

8 http://www.joranrudi.no/language/nb/when-timbre-comes-apart/ (accessed November 12, 2019).

9 http://www.joranrudi.no/language/nb/concrete-net/ (accessed November 12, 2019).

instrument, new types of representation in addition to traditional notation became useful – piano rolls, sonograms, spectrograms, computer code as text, and graphic representations of computer code in Max, PD and KYMA, to name a few high-level programming environments.

What were once contemporary practices has now been converted into digital heritage, and the rapid march of technological development makes preservation crucial. Using the above example of Kolberg's pioneering work, *The Emperor's New Tie*, the piece has already become difficult to read and impossible to realise – the synthesiser that made the sound has been dismantled, and a computer interpreter for the code does not exist. Fifty years from now, if not sooner, the same will most probably apply to today's practices if adequate preservation measures are not taken.

Interactive and collaborative practices

The development of technology-based music did not stop with what is now described as "old-school" works that are typically performed from stable media such as magnetic tape, CDs, DVDs or hard disks. The old dream of interacting musically with the computer in real time came steadily closer to realisation during the 1990s, shaped as mixed music and improvised performances where musical sounds were generated on the fly. With the opening of the Internet for non-academic use, the Internet rapidly also became an arena for artistic exploration, and web-based music and art became new genres; their essence being generative and dependent on input from visitors via browsers. (The desire to interact musically across distance has had clear historical precursors in Norway, too, and a work such as Arne Nordheim's *Forbindelser* (1975) should be mentioned. Musicians in several cities performed different parts of a musical work, and these musical "streams" were brought together in a TV programme celebrating the 50th anniversary of the Norwegian Broadcasting Corporation (NRK).

The first musical collaboration on the Internet with participation from Norway was *Res Rocket Surfer*, an internet band of several hundred musicians across the world. The musicians sent and received data to and from MIDI loops, and while the sounds resided locally, the control was global. The analogue, continuous control introduced by Leon Theremin had been replaced by numbers. Another, and significantly more complex, example is the concert *WHO – HOW – WOH* (1998)[10], which was a collaboration between the Sibelius Academy in Helsinki, the Warsaw Autumn Festival and NOTAM in Oslo. This was a type of research concert developed around transmission of sound and different types of control data where one of the purposes was to gain experience on how well the Internet was suited to this type of collaborative performance. One could expect significant time delays in transmission of signals between the locations and that different data streams would experience different delay times. The biggest challenges concerned transmitting digital sound, where the delay time between all three cities was 10–11 seconds. For example, it would take 20 seconds for the cellist Paulin Skoglund Voss in Oslo to hear her own performance returned from Warsaw together with the musical response from there, and 10 seconds after that she could hear the same thing over again, with the added response from Finland. The project was ambitious and showed that this type of concert could be done. However, the result was most successful with pieces written for significant time delays and without much focus on tight timing. A later development in Norway of this idea of distributed performance was *the World Opera project* – where the goal was for sound to be accompanied by data that should make it possible to show virtual avatars of remote singers in the different locations. The project's aim was to realise conventional performance in a distributed, digital domain, and it did not explore new affordances of remote collaboration.

Distributing notation as MIDI-data was also explored in generative music in the many-faceted *Integra* project,[11] where the score of one of the commissioned works was generated in real time and distributed

10 http://archive.notam02.no/warsaw/ (accessed January 28, 2019).

11 http://www.joranrudi.no/mediefiler/The%20Integra%20Project%20EMS_2011.pdf (accessed November 12, 2019).

to the performing sinfonietta ensemble via computer screens placed where the note stands would normally be. This work would change with every performance and became a process rather than a finished entity.

New data types

Up to this point, the focus of this text has been on musical notation and digital signals generated for musical purposes. However, the binary system allows all data to be interpreted in different domains. For example, one can "play" a picture with relative ease, print music as an image, or interpret database information as musical control data. Generally speaking, data can be used as musical inscription – descriptive and prescriptive. These possibilities of arbitrary data mapping have opened up a new field of interaction design, where technology gets wrapped in ways intending to relate to human predispositions and preconceptions, biological and social. Some researchers also believe that there is musical cognition buried in the theatrics of gesture, such as make-believe performances on imaginary instruments. The result of these more or less arbitrary mapping processes is that all types of data can serve as types of musical notation, depending on a computer interpreter programme that formats the data for sound generation or processing. This is not esoteric but has become common practice through the use of sensors for capturing pressure, light, wind, humidity and movement, and so on. An early example of such mapping processes in Norwegian computer music is Rolf Wallin's piece *Yo* (1994), where he performed a set of computer algorithms (structured as a Max patch) by stroking ribbons of conductive plastic mounted onto a "control suit," where he could also touch a few strategically placed buttons. By way of the patch, he controlled the granulation of sampled material, and the dynamic notation data was thus generated in real time from his control suit. The musical instructions

Fig. 5: Rolf Wallin performing on the first version of his control suit, stroking a strip of plastic on his arm. (© Eli Berge)

embedded in the use of sensors were inscribed in the technology as a set of possibilities and could not easily be notated precisely for identical future performances. This reduces the prescriptive aspect of the notation, and the representation and preservation of instructions for these types of performances become a challenge. How can we develop better representations than the ones used today?

The essence of live performances with technology is that the data streams change in real time. The most explicit genre is *live coding*, where listeners immediately hear the sounding results as the displayed computer code is modified and the software cycles through the loop structures. This type of change is in effect what happens within any digital instrument as it is being played, but it is easier to see and understand the changes as one can see them in the code. Live coding is a type of parallel representation of data – as text and as sound.

```
// ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
// BD - bass drum
class BD_808 extends Chubgraph
{
    inlet => BridgedT bt => LPF lp => HardLimit hl => outlet;

    16000 => lp.freq; // tuned by ear

    47.444 => float freq; //
    4.0 => float decay;

    2.0 => bt.gain; // tuned by ear
    bt.setFreq(freq); bt.setDecay(decay);

    fun void noteOn(float accent) // accented when noteOn is passed a float > 0.0
    {
        if (accent != 0.0)
        { // if accent, do trick as described in [1]
            bt.setFreq(freq*2.813; // up an octave
            bt.noteOn();
            4::ms => now;
            bt.setFreq(freq); // fundamental
        } else { noteOn(); } // call unaccented version
    }

    fun void noteOn() // unaccented when noteOn is passed nothing
    {
        bt.setFreq(freq);
        bt.noteOn();
    }
}
```

Fig. 6: This Chuck-code emulates the *Roland TR808* bass drum sound and allows for real time changes of the instrument. The code can be found at http://kurtjameswerner.tumblr.com/post/50274769999/chuck-tr-808-emulator-bass-drum-bd-emulation (accessed January 28, 2019). The page contains a detailed description of the how the analogue circuitry is represented in binary code.

In many genres of modern technology-based music, spatial characteristics are essential and must be taken into account. This is especially important in traditional acousmatic music where spatialisation has been a significant part of performances since the 1950s. With developments from the last ten years or so, more precise techniques of wavefield technologies allow for higher precision than before, and performances have changed from real-time interpretation from a mixing console to pre-programmed placement and movement in precise loudspeaker constellations. The essential aspect of this type of precision is that composers manipulate the phase of the sound in order to simulate movement and position of the virtual sound sources, and for this type of music this is key in the compositions themselves: spatialisation is not a feature that is merely added on in performance. In order to preserve this part of the digital heritage and understand the composition methods, the spatial information must be preserved, in both text and code.

In broad terms these developments exemplify the expansion of music into the wider domain of sound-based art with new performance practices, new data types and new notions of what constitutes music in the digital cross-cultural orientation in the arts. There is no reason to assume that this expansion process is likely to slow down or stop. Machine learning, for example, is likely to make significant inroads into musical composition and performance, and because of its hidden forwarding layers in the decision-making, machine learning adds another dimension of abstraction to how music can be composed and performed. In a deep sense, the questions of digital notation come down to developing an understanding of the impact of technology in creation. Arguably, this is the most pressing question in contemporary music.

Preservation and performability

As discussed, musical notation is both descriptive and prescriptive; it is simultaneously both a written work and a record of an imagined future performance. The historical paper-based notation has been shown to be robust, but the instructions must be interpreted for performance, while digital inscription can often be used directly. Nonetheless, contextual information is important even there. As with conventionally notated music, preservation and archiving of technology-dependent music has three types of goals: 1) preserving data, 2) maintaining readability of these data, and 3) making the data available for musical interpretation.

This is a complex undertaking; there is a plethora of technologies, and what constitutes relevant data might change from work to work, even between performances. Software changes between versions, computers and instruments become obsolete and unavailable, and storage formats and storage media change as well. A useful preservation strategy includes the questions of *why, how* and *what* and underlines the understanding that mere preservation of documents and digital files without a clear path towards future performability is not enough. In addition to the digital files, contextual information about composers and musicians, their aesthetic projects, ambitions and aims can on occasion support a deeper understanding of the music. A reasonably large collection of all this information can make it possible to reconstruct the music with regard to the composers' ideas, too, and not be limited to actual sound. For example, in cases where composers have left behind graphical scores or other detailed descriptions of the compositions, contextual information is essential for interpretation – what the composer's equipment allowed him or her to do, and which sound worlds s/he was familiar with. Composer Bjørn Fongaard, for example, was unable to realise his colour hand-drawn manuscripts due to lack of technical means. (Much like Antoni Gaudi's cathedral *La Sagrada Familia* (1882–1926) in Barcelona, where a number of ceilings could not be completed with the technology available at the time but has been completed only recently.) Fongaard must have heard the sounds he drew quite clearly in his head, judging from his written notes and the high level of detail in his drawings. Thus, an interpretation with the ambition of capturing what Fongaard must have had in mind depends entirely on knowledge of the nuts and bolts in Fongaard's toolbox, as guitarist Anders Førisdal discovered in his reconstruction of several Fongaard works for quartertone guitar.[12] Interpreting digital representations of music depends on the same type of contextual knowledge, and when instruments, software and computers cease to function, the inscription in technology and the notation for it become impossible to interpret.

Media rot

Magnetic coating disintegrates and loses its magnetisation over time; it is not a question of *whether* a tape or harddisk will break down and crash, but of *when*. However, preserving recordings and maintaining performability of works from fixed soundfiles is trivial, although remastering and cleaning of recordings is often necessary for meeting the low tolerances for unwanted noise that characterise the performance standards of today. Cleaning and remastering are sensitive activities, since details in the soundfiles can easily be washed away together with the noise. Other types of digital files such as texts and images on CDs, DVDs and harddisks are exposed to hazards as well, as media will disintegrate over time and render the files unreadable. This problem affects all types of electronic information, and considerable effort goes into preservation work at technology museums worldwide.

Electronic instruments, computer systems and software are developing rapidly, and it is timely to remember that it was only as late as in the mid-1990s that this technology gained popular acceptance – a little more than 20 years ago. Hardware and software instruments become obsolete, and working copies can be difficult to find. From my work, I know for example that several planned performances of Lasse Thoresen's piece *Abuno* (1994) have been cancelled because the instruments used in this piece are very difficult to find. Another example is Nicolay Apollyon's interactive works for instruments and the NeXT computer from the mid-1990s. They are absolutely unique in Norwegian electronic history and are not realisable today without a major

12 The works have been published here: Anders Førisdal: *Galaxe*. ACD5068

effort in locating functioning hardware and software and reconstructing the works.

```
ATTAK1SRC
'ATTAK1 SRC'
FR=69;NO=1;
LT(0)FG3>FG6>
CHA(1,100)&CHA(2,100)&CHA(3,100)&CHA(4,100);
NO2=NO+1;NO3=NO+2;NO4=NO+3;NO5=NO+4;NO6=NO+5;
FR1=FR+1;FR2=FR+3;FR3=FR+8;FR4=FR+15;FR5=FR+24;FR6=FR+35;FR7=FR+50;
LT(0)FG(NO,FR1,,4)>
GLIS(FR1,FR2,600,-4)>GLIS(FR2,FR1,4600,4)>
ENV(40,85,600)>ENV(85,40,4600,4)>
ENV(40,85,1000)>ENV(85,40,2000,4)>
ENV(40,85,2000)>ENV(85,0,4000,4)>Z;
FG(NO2,FR1,,2)>
GLIS(FR1,FR3,600,-3)>GLIS(FR3,FR1,4200,3)>
ENV(40,85,600)>ENV(85,40,4200,4)>
ENV(40,85,2000)>ENV(85,40,2200,4)>
ENV(40,85,1000)>ENV(85,0,3000,4)>Z;
FG(NO3,FR1,,3)>
GLIS(FR1,FR4,600,-5)>GLIS(FR4,FR1,3800,5)>
ENV(40,85,600)>ENV(85,40,3800,5)>
ENV(40,85,1000)>ENV(85,40,1000,4)>
ENV(40,85,3000)>ENV(85,0,4500,4)>Z;
FG(NO4,FR1,,4)>
```

Fig. 7: This excerpt from Kåre Kolberg's code for *The Emperor's New Tie* (1973) can no longer be executed. The computer has been scrapped, the software erased and the sound generating equipment discarded. (Scan by the author.)

Computers and software are intertwined, and digital scores require functional interpreters. The first computer music piece from Norway, *The Emperor's New Tie* (1973) by Kåre Kolberg, can no longer be rendered or performed from the score, since the computer is no longer in existence and the sound generating equipment has been discarded. The same goes for composer and director Knut Wiggen's pioneering works from the same studio; his written scores address another computer interpreter no longer in existence. Naturally, one can make quite qualified guesses about what the particular numbers in Kolberg's computer printout mean and in this way develop ideas about the structural thinking, but the scaling of the numbers is unknown, and sonic verification is not possible. Thus, his notation is no longer immediately useful, and the only functioning representation of this piece is a recording. Uncovering organisational principles in the music becomes difficult when based only on sounding material, although notation systems for describing emergent features in the music exist.[13]

13 Norwegian composer Lasse Thoresen has developed a notation system which he describes in full detail in his book *Emergent Musical Forms: Aural Explorations*. (2015).

The examples of Wiggen and Kolberg are from the 1970s, but more recent digital file formats and representations also disappear at a rapid rate, and when the technology no longer exists, the music disappears if it has not been recorded. This is the case with many of my own works as well, realised on Silicon Graphics machines that no longer work, and/or in software that has not been ported to modern computers and operating systems.

Digital inscription has shown to be more vulnerable than paper-based notation, and the changes that music has undergone with this new technology are already difficult to trace and analyse at a score and inscription level. The intellectual processes fostered and facilitated by the new technological situation will be difficult to document and discuss in the same close manner as is possible with paper-based notation. Clearly, it cannot be a goal that all music should be preserved, but in a musical heritage perspective it is necessary to secure enough material to make future performances, analyses and reflections on the early technology-based music from 1970 onwards possible, and since the tools and methods of the future are unknown, this effort must be quite encompassing.

Some recently formulated aims and initiatives

Finding good methods for preserving technology-based mixed compositions and works with live electronics is not a trivial task. Composers use a plethora of methods and technologies in their work, and musicians often rely on electronic instruments and devices that have limited shelf lives. As an added challenge, electronic timbres and articulations will change from performance to performance in live music, much the same as the local acoustic conditions of different performance venues change the spatialisation in performances of fixed-file acousmatic music.

Combining the skills of composer, performer, instrument maker and technology developer has been key in computer music since the 1970s, and in many new forms of technology-based music it still is. The willingness to transgress borders between disciplines and combine skills is an important element in the musical branch of the maker movement, and there can be no doubt that unconventional thinking has brought new ideas as well as concepts into music, particularly in process- and installation works. However, these diversities in hardware and programming have increased the challenges for preservation and documentation efforts, and because instruments and coding are often known only by the person who made them, this affects future performability. In broad terms one can say that the capture of sound-based music performance is more *descriptive* than *prescriptive*. The captures of performances provide only superficial information, as there is no necessary link between the sounds from the electronic instruments and the movements necessary to perform them; the links are *designed* in much the same way as the sounds of the theremin. The link between sound and excitation has become arbitrary and what soundscape pioneer Murray Schafer has described as *schizophonic*.

Digital heritage has come into focus, and several initiatives for documenting musical works and preserving the materials necessary for securing future performances have been mounted. The first systematic documentation, *Les cahiers d'exploitation*, was developed by Marc Battier at the French IRCAM centre between 1991 and 2002, and the aim of these manuals was to secure performability of the mixed music written at IRCAM at the time. IRCAM has since that time also been involved several documentation projects such as the European project *Caspar* (2006–2009), which focused on collecting materials and presenting them in a technology-neutral manner. This project was followed by a collaboration with Groupe Recherches Musicales (GRM) in *Mustica* (2003–2004), organised as part of the worldwide *Interpares* project which concerned digital records in general. The *ASTREE* project (2008) was a collaboration between four French institutions and concentrated on live electronics and documentation by way of GRAME's Faust code. The principal idea was to generate computer code for reconstructing electronic sound transformations and to include this code in scores for mixed music. The project successfully represented several musical works, both mixed and synthetic.

The current preservation efforts of electroacoustic music at IRCAM collect structured data in the *Sidney* database. (Lemouthon et al. 2018) Several data types are required in this database: information on composers and performance versions of the work, different data file types for versions of software and hardware, as well as different performance files and video recordings of performances. IRCAM engineering staff upload all the information types as part of their work assisting composers, and an administrator oversees the entries for quality control.

Other recent documentation initiatives include New York University's *Electro-Acoustic Music Mine* (EAMM) (Park and Underwood 2018), which collects recordings of works with the purpose of making these available for performance and research in music information retrieval. This initiative is not limited to works from only one institution but will use conference and festival submissions from a number of professional conferences and festivals as a starting point. It is foreseen that a later development will allow for crowdsourcing in the sense that composers themselves submit works. Crowdsourcing is also essential in Virginia Tech's recently formulated *COMPEL* project, which is designed to be a community-built repository with the aim of ensuring future performability (Bukvic and Ogier 2018). It is easy to see that the interest in preservation and future performability is growing worldwide and that the number of repositories is rising.

In order to ensure performability of early works, they must be migrated from obsolete to current technology. In addition to the purely technical aspects, this also hinges on musicological information about performance practices and other contextual data. The *Integra* project (2007–13) aimed to migrate historical works and to commission new ones. Commissioned composers and engineers were expected to develop a set of tools according to a documentation guideline, and in this way the Integra collection was expected to grow gradually and become useful for future composers. The toolset was initially imagined as a superimposed layer that would address DSP routines in several sound engines such as Max, PD, Supercollider etc. by using a namespace communicated through the XML protocol. (Rudi and Bullock 2011) Thus, the technology would hide the basic functions and be easy to use while lowering the threshold for composers and musicians with little familiarity of even high-level programming and object-oriented environments. However, the creation of this type of superstructure resulted in too much computational overhead, and the idea was abandoned. However, the software that was developed at a later stage in the project is freely available on the web[14] and has maintained the ease-of-use approach initially imagined.

The problem of maintaining performability for older technology-dependent works has not yet been solved, although there are a number of successful singularities – migrations of individual works. From a concert perspective these works are good starting points for expanding the catalogue, but the challenge remains: how to ensure that these works can be part of the repertoire in the more distant future, too.

Suggestions for a documentation project for technology-based music

The different musical approaches in technology-based music and the documentation initiatives mentioned above make it clear that a number of different data types need to be preserved for works to be performable in the future.

A documentation project in Norway should be coordinated with international initiatives in order to make the repertoire more readily available for performance and to include it in the pool of materials needed for future research on new methods and tools for technology migration, new search criteria and musicological work. The visibility and usability of works from the Norwegian digital heritage will increase with international affiliation, and research collaboration will be simplified. Challenges in documentation that arise from new work and performance types can then be met collectively, and as the internationally distributed collection grows, structured metadata and development of new search criteria will make it possible to see musical connections across

14 http://integra.io/integralive/ (accessed February 6, 2019).

different contexts and genres and to facilitate research and scholarship from a broader perspective than the focus on singular works.

Key decisions are:

- Selection of database structure
- Determining data types for standardisation
- Establishing procedures and guidelines for data gathering and quality control.

Database

In terms of choice of type and structure, it is advisable to coordinate this with other existing initiatives. In Norway the National Library has several databases for music, and it should be considered whether these could be fused and migrated into the new standard over time. In practical terms this means that data types from these databases should be included in the new initiative. This would be a forward-looking approach, since an increasing percentage of new works are created with technology, and from a current perspective the separation of music with or without technology seems obsolete in itself.

The different initiatives that have been mounted internationally have not been well coordinated, and the technology used and developed shows large variation. For example, the Sidney database mentioned above is structured into a MySql database, through the Object Relational Mapping provided by Django, while Virginia Tech's COMPEL project uses the open-source Samvera solution for flexible combination of components and Apache Solr for search and indexing. The solutions are many, and it would make sense for the National Library to initiate broad contacts and form a consortium for a thorough and informed evaluation.

Data types

In technical terms, there are several genres of technology-based music, and in aesthetic terms there are even more. A brief (and not too detailed) list of technical genres includes:

- Works for fixed media – algorithmically generated and concrete music
- Mixed music – acoustic instruments with electronic live processing or fixed file playback
- Generative music – algorithmic composition for acoustic instruments and/or electronic processing
- Improvisation works – live electronic music not inscribed in scores, with or without custom programming and electronics
- Installation works – custom electronics and configurations

The most basic documentation of all electronic music is a sound recording of the required number of tracks, and for all future performances this is an important reference. It tells us how things sounded but not much about how the sounds were made. Recordings are easy to make and preserve, and their transfer to digital media must include a migration plan for the future. However, for documentation to also have a prescriptive function, several other information types are required.

The composer can provide notes on artistic intention, either separately or embedded in programme notes. Often, these notes also include some type of analysis that points out salient thoughts or sounding elements. Essays, reviews and other texts will also be valuable in establishing the intellectual space the music has been performed in.

For acousmatic music or purely electronic music, performance notes and soundfiles for coding to speaker configurations must be preserved, and particular requirements for speaker placements must be kept on record as well. Ideal loudspeaker setup and all hardware requirements for performance must be described along with recordings from different performance situations where possible.

Many works are accompanied by written instructions for set-up and operation as well as manuals and riders for the technology. For fixed-file music, diffusion notes and descriptions of loudspeaker configurations are often available. In mixed music there is scored material and performance instructions plus notes by the musicians for performances. For installation works there are mounting instructions and possible notes on acoustic requirements.

Computer and instrument types and models must be recorded together with sound libraries and software programming such as "patches" in Max, PD etc. with notes on software version and comments in the programming code itself. Further descriptions in everyday language of what the technology does might be the most important documentation in the more distant future, when current software and computers have become obsolete and disappeared from use and existence. Screenshots from the actual computer performance files should be added to the database.

Huge challenges follow in the wake of the musical practices with new controllers for live use, since much of this technology is custom built and lacks documentation. Here the sound and video material is necessary for describing the works, and the hardware and software must be described in both everyday and technical language.

Validation is needed to ensure that the database records are as complete as possible, and rich data on contextual information will be helpful. There is an arguable continuum between prescriptive and descriptive data and between data on musical motivation, composition and performance, and technology that has been used. (For example, one could write that music is realised within technological frameworks and that instructions for compositions and performances are preinscribed. These types of discussions are interesting in musical analysis. However, a more thorough discussion on this perspective goes beyond the scope of this publication.) A brief listing of different data types includes:

- Musical motivation
  - Composers' notes on ideas, intent and programme content
  - Programme notes from concerts/performances/shows
  - Analyses of the music
  - Contextual information on musical genealogy and tradition, references to composersand traditions

- Methods
  - Composer's sketches, notes
  - Musical notation, score
  - Performance instructions to producer, tech rider
  - Performance instructions to musicians and diffusionists
  - Screenshots of software, programming and technical set-ups Also descriptions in everyday language on signal flow, aims and effects
  - Audio recordings of performances
  - Video documentation of performances

- Employed technology
  - Software types and versions, also with descriptions in everyday language
  - Hardware, computer types, models, versions of operating systems
  - Software programming and patches, everyday language description of functions and signal flow
  - Soundfiles, sound libraries for instruments

Selection of works

One challenge when it comes to documentation is selection, and from an historical and research point of view, it is important to document multiple music genres and how they develop. Much of the computer music from the 1990s and early 2000s has now disappeared from view, and the aims and goals of the composers, as well as their intellectual approaches to composition, have become obscure. This pioneering period is rapidly becoming forgotten, and the current development of technology-based music in Norway will seem disconnected from its early years in the 1960s and early 1970s if this heritage is not preserved and understood. For these historical periods, a curated selection of a number of works for migration and documentation is needed, and establishing the beginnings of a canon requires a curatorial effort with participation of the National Library of Norway as well as the Norwegian Society of Composers (NKF) and the Norwegian Society of Composers and Lyricists (NOPA). Ideally, this initiative should be structured as an extension of the musical heritage project and also include representation from higher music education.

Curated content should form the core of the database. However, it should not be limited to a curated repertoire. With today's rapid expansion of music technology into new fields and practices, a curatorial committee should oversee that core works are included, but for a broad and more encompassing database, composers and performers should be encouraged to enter musical works themselves. This type of "citizen-science" approach should be easy to implement and sits well with modern technological skill sets, where self-publishing in participatory Internet media has developed over the last twenty years.

A broad and large representation of works would benefit future research on music information retrieval, and composers should be encouraged to take responsibility for maintaining future performability of their music, as is already common in the more commercial sectors in the music business where presence on social media is important for maintaining interest among followers and fans. Some composers will undoubtedly be more eager than others to include their works, and the collection will most probably be skewed, but as long as the curatorial effort of genre inclusion and aesthetic balance is maintained, the negative consequences of skewing will be manageable.

In order to generate interest in entering information in the music database, different measures for motivation should be tested, and some concrete evidence of the benefits must be presented. A concert series, a series of music analyses, a series of publications and a streaming service should all be considered in order to promote the preservation project to both contributors and users.

Future research

Over the last twenty years generations of software and computers have come and gone, new file formats have been developed and others have disappeared, media formats have been replaced by new formats – and as a result, much music can no longer be performed as it was at the time of its creation. The problem has been recognised, but it has no simple solution.

Migrating works to a technology that will enable their performance in the future is a major, unsolved problem which the research initiatives discussed above have been unsuccessful in solving on a general level. In Integra, several works were migrated to modern technology, but on a singular basis – the idea of generalisation was abandoned. The ASTREE project revolved around representing synthetic music mathematically. Its approach proved successful for another subset of technology-based music but remains non-applicable to the broader field.

There is significant international interest in the issue of preserving digital heritage, and it is expected that machine learning will be useful in migrating data for technology-based music in the future – possibly also in developing common standards for sound, code and data for composition and performance. A successful documentation project for technology-based music should be developed in collaboration with computer science departments around the country, and master and PhD students could be attracted to tackling challenges in this field. The National Library of Norway should also establish international collaborations within its network of institutions with similar missions and tasks, and the professional music community could contribute the first-hand musical expertise necessary to capture the essential characteristics of the music. This is a growing field with great potential for development in combining research on sounding music with representation issues. It should also be of interest to departments of musicology.

It is not a particularly radical assumption that machine learning will change how music is made, how it is adapted and how humans will use it, and that there might be other interesting parameters for describing music than those we are using today. Ongoing research and development in this area might also contribute to the migration processes where older works are migrated into current technology.

Conclusion

Technology-based music with musical inscription in technology has been underrepresented in heritage and preservation initiatives, despite the documented vulnerability that results from rapid technological development and continual revolving of tools. As a consequence, important parts of the history of early digital music are no longer performable or available as subjects for reflection and research. Furthermore, there is every reason to believe that this trend will continue if a documentation and preservation initiative is not initiated and appropriate action taken. There can be no doubt that this will weaken our understanding of our early digital heritage.

A documentation and preservation project will be well served by a combination of performances and publications reflecting on and describing this cultural heritage. The initiative can easily be linked to other initiatives internationally and also be positioned for research on methods for music representation as a collaboration between relevant institutions in Norway and an international consortium.

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