Eivind Groven's automat for adaptive just intonation: A pioneering example of musically situated technology

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Introduction

Folk musician, composer, radio pioneer and musicologist Eivind Groven (1901–1977) constructed the first known electronic music technology in Norway – the adaptive automat for just intonation. His invention was motivated by a deep engagement with folk music and a desire to introduce the natural scale into the contemporary music scene. Although the automat was the first known significant electronic music technology developed in Norway, it had nothing to do with the equally new technology-based music genres of the time – Musique concrète and electronic music. Instead, as Groven elaborated in two publications on the philosophical and musicological foundation for just intonation, the adaptive automat was a logical, necessary element for bringing just intonation into mainstream music.

In developing the automat, Groven resolved an interface issue that had been at the core of research into intonation systems and their implementation since the late 1800s, particularly in Germany.[1] The planning and construction of the automat started in 1939, but was not finished until 1947, due to Groven's redesign, delays caused by WWII, and in part due to lack of components. Since that time, the automat has been modernized several times – first through a technical simplification, reducing the number of relays, next through a transistor-based realization of Groven's original plans, made by Bjørn Raad from the Central Institute for Industrial Research (SI), and finally by David Code's migration into the digital domain in 2001. This last modernization

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made the physical organ at the Groven institute available to new generations of composers, following several years of disrepair. Henrik Sundt and Dag Henning Kalvøy at NOTAM have since taken the digital automat a step further, adding a customized sampler with standard sound fonts. This allows anyone with a computer to freely download the software and the sound fonts, and play with just intonation, even without a MIDI keyboard. This portability has made real-time just intonation available to the general public. The combination of the pipe organ and selected sound fonts has also attracted interest among new generations of composers, introducing just intonation into new trends in (electronic) folk music.

This article will describe how Groven's theoretical and technical work had its basis in musical rather than technical challenges, and how his investment in music technology was musically rather than technologically driven. This discussion traces how his technological thinking evolved over time, and how he came to see the electronic organ as the most optimal tool for moving research on intonation systems forward, integrating new tuning presets and timbres in the instruments.[2] Groven's technical contributions may be viewed in relation to international contemporary initiatives and the general wave of optimism emerging from increased electrification, particularly in the new concept of broadcasting.

FOLK MUSIC AND THE NATURAL SCALE

Eivind Groven was born and grew up on a remote farm in Telemark County in Norway, in a family steeped in local culture and particularly folk music. Several relatives were active fiddlers, and Eivind Groven followed in their footsteps. Norwegian folk music employs skewed rhythms in combination with tuning systems that are close to the natural scale, and the tuning can also differ from piece to piece, also showing local variation in different districts. As a child, Groven came to realize the difference between this tuning and tempered tuning when attempting to tune a zither,[3] and he became both surprised and annoyed when the same tone was pitched differently when each zither chord was tuned according to the natural scale. This triggered his interest in tuning systems, which in turn resulted in his treatise *Naturskalaen*, published in 1927, when he was twenty-six years old. In this publication, Groven describes the natural scale as it resulted from the «lure»[4] and the willow flute,[5] and how this scale follows directly from nature. He came to see the natural scale as the basis for the human perception of beauty in music, emphasizing that human psychology has its roots in nature much in the same way as the scale does, and that a lack of relation to naturally embedded preferences has negative consequences.[6] The outcome of his point of view was clear – using tempered scales leads music astray[7] – and Groven outlined his theory on why the natural scale should be used in other types of music too. Groven goes quite far in arguing his point, and holds that tempered tunings render music «muddy», and are even

psychologically disturbing, due to the lack of clarity in the harmonies. The difference between just intonation and tempered tuning is of course striking to any listener, as are the qualities that emerge from other tuning systems. It is interesting to note that as early as *Naturskalaen*, which is Groven's first publication, he envisions a mechanical instrument that could «perform perfect just intervals.»[8]

BROADCASTING AND SOCIAL INNOVATION

Promoting folk music as part of the fabric of modern society was Groven's principal project, as fiddler, composer, radio producer, musicologist, and technology developer. Shortly after moving to Oslo, he was employed by a private broadcasting company, and became responsible for folk music programming. In 1931 he started the radio program *Folkemusikkhalvtimen* (*The Half Hour of Folk Music*), which was continued when the national Norwegian Broadcasting Corporation (NRK) was established in 1933. The program, which is still running, was established before recording technologies were available, and when broadcasts were only possible in real-time. Groven's position in radio, the new media technology of the day, also put him in contact with the national broadcasting system's impressive research and development department. Through this contact, he became familiar with the technical skills he needed to build the adaptive automat.

Fiddlers and other folk musicians were brought to Oslo to perform live on the program, part of the national broadcaster's mission of allowing the country hear itself – a cultural development from the initial broadcasting model of «center to periphery.» The technical invention of radio, and the social technology of broadcasting, were crucial to the building of modern nation states. Historically, broadcasting began in Norway before the entire country was electrified, when road and railroad connections around the country were rather primitive. Broadcasting was the first technology that brought the country together. National radio was not unique to Norway; the BBC had been established as a national institution in the UK in 1927, and German radio had been nationalized in 1925, in a process similar to the one in Norway.

Evidence of the importance of folk music may also be seen in the plans for the new radio building. Construction began in 1938, and an entire studio was built to emulate the acoustics of a wooden farmhouse at the Norwegian Folk Museum that had been used for live broadcasts. As with all studios in the new radio building, it was built as a box-in-a-box, and each studio even had its own independent foundation. The difference between the folk music studio and the other studios was in the acoustic treatment of the walls, where perforated wood tiles were used. In his travel report from a study trip to Germany in 1936, Groven observed how modern studios were designed for acoustic control by reducing acoustical resonances to a minimum. He worried that this might lead to folk music losing its bluster. He wrote «... walls and ceilings in old cogged farm buildings from Norway have broken surfaces and balanced reflection and resonance, and no echoes dis-

turb the sound. I already noticed this a few years back during a broadcast from the Norwegian folk museum.»[9] So while the willingness to incur the extra expense of a custom studio for folk music can be attributed to the importance of the folk music genre, it can also be attributed directly to Groven's influence. Yet newspaper reports from this time show that the relatively strong focus on folk music was intensely debated, and the studio was jokingly referred to as *fenalåret* – a leg of cured sheep meat – typical for the rural kitchen in Norway. Radio was an important and popular medium, and the many listeners' associations confirm the popular engagement with this new technology.

Clearly, the necessity of real-time performance for broadcast was a serious limitation in securing a truly broad representation of folk music in the new mass medium. Therefore, Groven was a strong proponent for acquiring new recording technologies as they became available: lacquer discs, optical recording equipment, and finally, magnetic tape recorders. These were mounted in customized cars, and travelled across the country to capture authentic recordings of voices, environments and music. The new technology was essential in a country where long trips were difficult for musicians due to the geography, and became key to maintaining and preserving the folk music tradition through recordings. Due to the inadequacy of conventional notation, folk music had very often suffered in transcription when written down, to the extent that fiddlers and singers often refused to help collectors because they would rather see the music be lost than mangled.[10] Through recordings that he made across the country, Groven laid the groundwork for the national folk music archive, which is currently incorporated into the National Library. Preserving folk culture in this manner was part of his larger project of increasing public interest and respect for this part of Norwegian cultural heritage.

It might seem surprising that such emphasis was placed on folk music. Yet we find the same focus on nature and rural culture in literature and the visual arts as we do in the integration of elements of folk music in orchestral works by Grieg and others. Groven found that folk music lost its identity and aesthetic core when being structured according to conventional forms in these orchestral arrangements and treatments, and when being adapted to the tempered scale. Groven was opposed to the modern «social cultivation» of folk music into orchestral arrangements, and saw broadcasting as a countermeasure of sorts. He believed that the orchestral cultivation of the «big» sound happened at the expense of musical content,[11] and was optimistic in his expectation that radio transmissions might have a limiting effect on this tendency. This was a logical assumption; transmissions of large orchestras were not common during the early years of broadcasting. Groven believed that the unfiltered experience was a necessity for maintaining undistorted contact with local and regional musical roots,[12] rather than being a marker for the construction of national identity. He saw the need for a method where just intonation could be used in classical music, and it was the keyed instruments that posed the greatest challenge, while he found that bowed string instruments and horns have a natural inclination toward just intonation.

Historically, Groven's contemporary musical context was the social construction of a modern nation state, where the arts had a crucial function in providing narratives that created a shared cultural identity. Groven's ideal of a tuning system derived from the natural scale necessarily placed him in contrast to the continental narrative of national romanticism, and the desire to see this ideal realized must have been a motivating force to develop a practical, working technology for the further adoption of just intonation principles. There was a feedback loop between this musical context and his technological innovations, where musically-based goals merged with technological development.

GROVEN'S MUSICAL SENSIBILITIES

Groven's orchestral works were included in the contemporary music repertoire, and received much acclaim. An excerpt from one of his orchestral works was even selected to be the signature tune for NRK radio in 1937, and remained in some use also after Arne Nordheim was commissioned to compose an electronic signal in 1970. Groven's music was often praised for its timbral and orchestral refinement, while structural issues were criticized – his lack of adherence to conventional formal development of the compositions in particular.[13] For Groven, the lack of conventional form was not a coincidence. He writes about the orchestral arrangements and treatments of folk music found in Grieg, Svendsen and Halvorsen, three prominent Norwegian composers of national romantic music: «the compositional form is alien, the timbres (orchestral or piano) unfamiliar, the harmonic development is [only] partly explored ... Grieg, Svendsen and Halvorsen have all found their compositional roots and their sense of color and rhythm in inter-European music.»[14] Groven argued that national romantic music lost contact with its musical roots when tunings and structures from folk music were replaced by material from the continental European tradition. He believed that bringing the «genuine» roots of folk music into art music was the way forward. He was also concerned that proponents of national romantic music lacked the skills and knowledge of folk music to draw on its unique qualities in their compositions. He argued that their appropriations often had the opposite effect, with folk music losing its unique characteristics when recomposed in the romantic paradigm.

Groven was equally critical of musical modernism, electronic music, and particularly twelve-tone music, which he on several occasions characterized as «crazy-man's work.»[15] In the newspaper *Aftenposten* in 1949,[16] he discussed realism and program music, for example, and jested about music made from the sounds of trains. He criticized the superficiality of program music's use of sounds with literal references, and it is easy to read this as a comment on *Musique concrète* and the work of sound engineer and composer Pierre Schaeffer played on French radio. In contrast to the explicit goals of Karlheinz Stockhausen and other composers of electronic music and Musique concrète, Groven was uninterested in the use of technology as a tool for creating «new, unheard sounds.»

Instead, he saw technology as a tool for the realization of a much older musical paradigm, performed with tunings that he understood as part of the order found in nature. His insistence on the value of folk music applied to the music of other cultures as well. As early as 1956 he described Eskimo music as «world music,»[17] referring to his transcriptions of Helge Ingstad's recordings.

In short, Groven's convictions, interests, and merits seem to position him as an internationally oriented counter-culturist who rejected both national romanticism and most of modernism in his tireless efforts to bring local roots as unabridged as possible into the fabric of contemporary musical development. This aim left him in a vulnerable position in the music community. On one front, he was in opposition to the urban view of folk music as reactionary and provincial, evidenced in (radio) listener's associations criticizing the programming of folk music programs on national radio. Proponents of modernism were on the other front, represented by Pauline Hall, among others. Hall was President of the Norwegian section of the International Society for Contemporary Music (Ny Musikk) and wielded an ironic and critical pen against what she considered folklorism. In 1948, for example, she described Groven as a nationalist who looked down on technical, compositional devices and methods, writing that he was so absorbed by a fixed idea that he in effect promoted a type of musical naiveté in which no technical advancements should be allowed to corrupt Norwegian musical origins.[18]

GROVEN'S RESEARCH ON JUST INTONATION

Shortly after the beginning of the twentieth century, there was an intense development of new electronic instruments, with the Theremin (1919–1928), Trautonium (1928), Sphärophon (1921–1926) and Ondes Martenot (1928) being developed within the same decade. Electricity was becoming useful in the design of new instruments that could extend conventional music and orchestral traditions. Maurice Martenot also came to Oslo in 1928 to present his instrument, and attracted a fair amount of attention for his presentations at Ingeniørenes Hus and the National Theater.[19] The focus of most new instruments was on tone generation and new timbres and, for example, the straightforward production of glissandi. However, these instruments were not designed with the microtonal pitch paradigm explored by Eivind Groven, Harry Partch and others in mind.

This is not to say that musical and research interest in tuning systems first emerged at the beginning of the twentieth century. Composers and instrument builders have been concerned about the intervals of their keyboard instruments for centuries, and history is full of examples of alternative intonations as well as experimental designs with varying numbers of keys per octave. When there was a need for more pitches than twelve per octave, keyboard design was addressed and how to lay out the pitches so they could be used in performance. Keyboards were generally extended in two ways, by either splitting keys so that they would be doubled up next to one another, or by raising parts

of the black keys in a tiered fashion, in the manner of the Archicembalo (1555) and the Clavemusicum (1606). One particularly clear example of this design is found in Shohe Tanaka's patent application from 1890,[20] a design later implemented and built by Johannes Kewitsch. In these designs, extra pitches were added in a manner close to the normal layout (with corresponding fingerings). For reasons of logic, or because the number of added keys was large, the keyboards could also be extended, and the layouts radically changed. This was developed in many forms, depending on the number of keys needed for the different systems. Examples include Wilhelm von Ottingen's Orthonophonium (1914) with seventy-two keys per octave, Adriaan Fokker's complex two-tiered keyboard for his equal–tempered system (1951), Karl Eitz's system (1892) of fifty-five keys per octave, and Feruccio Busoni's Dritteltonharmonium (1910) with a more moderate combination of two keyboards – one chromatic and the other with the additional pitches. Performance on such systems was highly impractical, if not impossible, and depended on the musician's ability to master the new interface.

Groven's texts suggest that he was informed about some of the relatively recent research. However, closer scrutiny shows that his references to this research tradition appear only after his trip to Germany in 1936. In other words, it is apparent that his development of the system of thirty-six pitches per octave was made without much knowledge of this tradition, and that it was based mainly on his experience of tempered tuning as inadequate for sustaining and advancing the use of folk music.

During his study trip to Germany in 1936, Groven gathered information on how other researchers and developers attempted to solve the problem of bringing just intonation into conventional art music. He reports on the solutions he came across that used manual switching and either extended (Johannes Kewitsch, Feruccio Busoni, Karl Eitz)[21] or multiple keyboards (Gustav Puhlmann) for playing. In fact, Puhlmann's division of the octave was identical to Groven's thirty-six pitches per octave. According to Groven, they had both independently arrived at the same adaption. Prior to this trip to Germany in 1936, Groven had actually had a similar reed organ made for NRK. Based on his experiences from several radio performances with the instrument, Groven found the manual switching musically inadequate, and he was disheartened to find that a musically more practical solution had not been found in Germany. Groven did not see a way forward until 1939, when he realized that an adaptive automat could be constructed from telephone relays, making use of the short time delay between the depression of the organ key and when the air starts to stream through the appropriate pipe. Groven was at the time working at NRK, an institution which carried out extensive research and development in the field of electrical equipment for broadcasting. This familiarity with modern technology at NRK must have helped Groven realize that different types of relays could be exploited for musical purposes. Electricity provided solutions for Groven's idea for the adaptable automat, which was unparalleled in comparison to other implementations of intonation systems at this time.

Yet before this technical solution was developed, Groven had completed his work outlining the pitches that he argued were needed for the just intonation system. The methods and results are detailed in his research report *Temperering og renstemning* from 1948. The treatise takes as point of departure the physical qualities of sound and acoustics. Through a combination of calculations and measurements, it describes the possible key combinations for just intonation, establishing the basis for the practical implementation of just intonation that was built into the adaptive automat.[22] Now, given the Pythagorean comma,[23] there will most often be compromises in musical performances, and after careful consideration of his analyses, Groven ended up with a just intonation system based on octaves (1:2) major thirds (4:5) and fifths (2:3), 36 pitches per octave.[24] He believed that the gains from increasing the number of pitches further would not lead to better musical results, and that the inaccuracies would be too small to be perceived. He nonetheless experimented with a forty-three note division of the octave during his construction of an electric organ in the 1960s, but after completing the electric organ with this division, Groven returned to the thirty-six note division when adapting the commercially available *Sonata* instrument. Groven combined exacting scientific measurements and methods with musical aims in order to develop the theoretical foundation for implementing just intonation, a goal implicated in his first treatise *Naturskalaen*. As late as in the mid-1970s, Groven also worked on more general intonation issues, proving that the chosen intervals in vocal *performance* with just intonation went beyond what several musicologists at the time labeled mere «coloring» – in other words, more arbitrary performance deviations from notated pitch. His method was to adjust the overall pitch of recorded vocal performances to the thirty-six pitches per octave of the organ, using a custom-made Tandberg tape machine with continuous speed adjustment.[25] Hanne Kjersti Buen and Agnes Buen Garnaas delivered the sounding material, and Groven's assistant Morten Jacobsen made the transcriptions. They found that the sung intervals were consistent throughout the recordings, thereby refuting the assumption that the intonation of the sung pitches was coincidental.

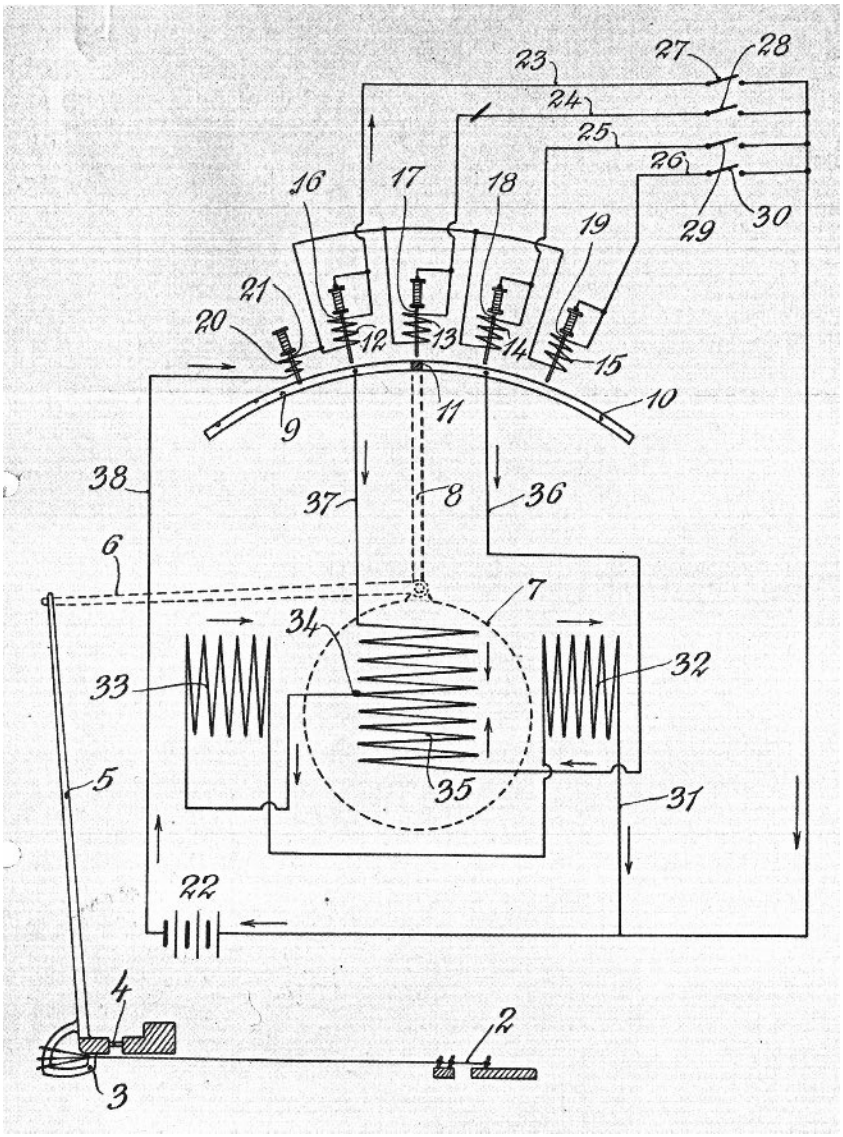
GROVEN'S INSTRUMENTS AND THE ADAPTIVE AUTOMAT

To realize his intention of bringing just intonation into the musical mainstream, Groven saw the need to adapt the tuning on keyboard instruments. Other instruments, such as string instruments, could easily be played with just intonation directly on the instruments. Groven was convinced that performance on key instruments should be as undisturbed by technology as possible, not interfering with the normal practice of the musicians. He sought a non-intrusive approach rather than a new instrument or new performance practice, a necessity given the examples mentioned previously in this text.

The first attempts at adaptation were directed towards the concert piano that Groven had received as a gift in 1929 from Anders Backer Grøndahl, who was interested in his

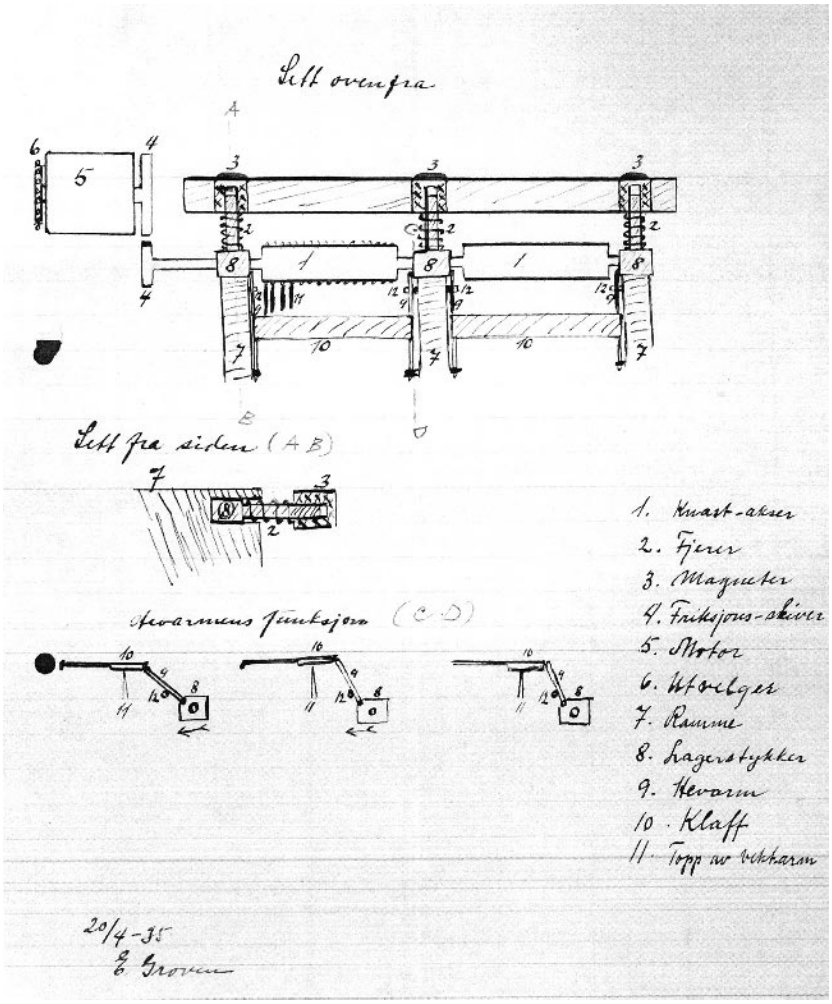
ideas. Together with engineers Jon Christian Scheie (Institute of Physics, University of Oslo) and Olav Nystog,[26] Groven designed a mechanism for re-tuning the piano strings by long levers that could be turned by electromagnets to one of several predefined positions, where electromagnetically driven pegs would be inserted to hold the string tension in place. An extra keyboard was added in order to control the switching of the electromagnets when selecting between the twenty-three preset tunings.

Fig. 1: Tuning with electromagnets



Groven's invention was patented in several countries,[27] and technically it worked. Piano strings, however, are not that stable, and do not hold their tuning very well. When tuned, they do not hold the same tension all the way through the string, and the tension evens out throughout the string only after it has been played. In addition, the pitch changes with temperature, humidity and the age of the string. In short, the tuning did not hold. In addition to string non-linearities, there were electrical problems, and Groven put the project aside to focus on the organ. However, he also worked out another mechanism for automatic piano tuning, where the presets were designed to be engaged by a step-motor that would turn a pegged roller. The length of the pegs would vary, but otherwise they resembled those in street organs or music boxes.

Fig. 2: Tuning with pegged roller



This method seems to have resolved many of the electrical problems that followed from the use of electromagnets, but his attempts at financing this development failed, and there is no trace of this model ever being built.[28]

In 1936, shortly before his trip to Germany the same year, a monophonic harmonium (reed organ) was commissioned by NRK and built according to Groven's design and calculations. The octave was divided into thirty-six notes, and electrical switching activated the presets for the selection of the appropriate tone fields from the three different reeds per pitch.[29] The switching was not adaptive, but needed to be done on a separate manual or with foot pedals.[30] This was not very practical, since it would interrupt performances, but the harmonium was nonetheless used by NRK for a number of transmissions, as mentioned above.

The idea for the adaptive automat was sown while Groven waited for a telephone connection to be put through a switchboard in 1939,[31] and he has explained how the entire design became clear to him during a summer night later the same year. The automat eliminated manual switching, and thus the time delay in the switching process, allowing the organist to focus on the performance while playing with just intonation. The physical construction of the automat started in 1939, but was not completed until five years later, due to delays caused by WWII. However, errors were found, and a corrected first version was completed in 1947. The automat was a switching device that through sequences of cross-linked relays either held or disconnected electrical current, depending on whether the tones played belonged to the selected (or last played) tone field or not. Through his research and calculations, Groven had defined the tone fields, as described in his book *Temperering og renstemning* from 1949, while his treatise *Renstemningsautomaten* from 1968 provided a detailed description of the actual connections in the automat. As the music was played, the automat would allocate the correct notes in response, not interfering with the performance. An important goal was thus accomplished – technology that made just intonation easy to use while not affecting artistic concentration. He had developed a technical solution to a musical problem.

The first relay-based automat contained approximately 300 relays, and the revised, second automat from 1957 was simplified to contain approximately 200 relays. The tuning logic was not flawless, however, and in order to minimize problems with chord changes between pitch fields,[32] for example, Groven invented a moveable contact that was mounted on each keyboard key. These contacts prepared the chord changes immediately before they happened, thus minimizing the chance of faulty pitch selection. Groven nonetheless expressed in his applications to NAVF that a new automat was sorely needed because of these time problems.

The relay automat was at first connected to the reed organ (harmonium), but the timbral limitation of the instrument motivated Groven to continue his development of a pipe organ.[33] The first organ had 5 octaves, with 180 pipes at 36 pipes per octave, and was built by J. H. Jørgensen's organ factory in Oslo in 1953. The organ was

played from a conventional but customized manual, and the possibility of actual performances on a practical system gave Groven important experience with how just intonation worked in practice – there were a large number of concerts and public presentations of the organ. The organ manual was normal from a performance point of view, but modified to send electrical signals to the automat. Groven estimated that the free movement of the organ keys of approximately two to three millimeters before the tone started gave enough of a delay for sending an electrical impulse that would allow the relays to react in time.[34] The relay chain would need approximately sixty milliseconds to complete the switching, and that allowed for the performance of sixty-fourth notes in the tempo of sixty quarter notes per minute, which was close to the speed limit for the relay automat, measured to be 62.4 milliseconds. The electrical contacts were constructed to send the signals «note on» and «note off», to use MIDI terminology, as quickly as possible before the tones were actually sounding or broken off, to compensate for the relay delays.

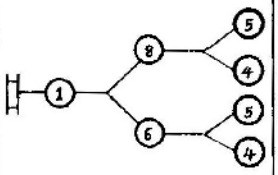
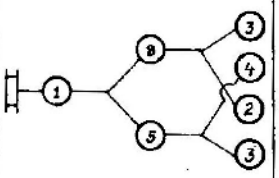
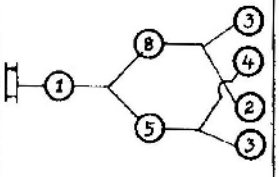
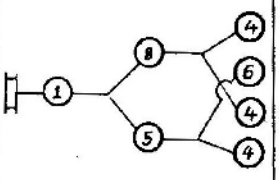
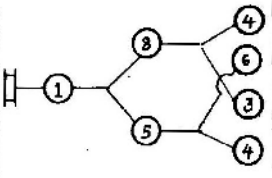
While the pipe organ only has one voice type and one manual, Groven argued as early as the 1950s that his research would benefit from an electronic organ with more voices and timbres, as well as two manuals. After trying an electronic organ by Vierling and Company in Ebermannstadt, Germany, Groven contacted radio engineer and developer Ragnar Bogstad[35] in 1956 about building an electronic organ. Bogstad, who had built an electronic organ with conventional temperament in 1952, and was in contact with organ manufacturer Ahlborn in Ditzingen in Germany, suggested that the organ could be tuned by crystals manufactured to oscillate with frequencies that met Groven's specifications. The physical material of the crystals would be ground to specific masses, and the crystals would then create an accurate, mechanical resonance with the specified frequencies. (This is still a common method in, for example, watch production, GPS receivers, USB systems and other types of exacting digital clock-dependent applications.) The crystal technique would allow the organ to always stay in tune, and the problem of «drifting» would be eliminated. For this organ, Groven had decided on a forty-three note division of the octave, which eliminated the minor compromise in tuning that resulted from the thirty-six division. To obtain the necessary frequencies, Groven needed eleven crystals. Four frequencies would be extracted from each crystal – leaving one pitch slot unused. Bogstad's overview from 1957[36] shows the frequencies of the crystals. Groven's records are evidence of the enormity of his longhand calculations, firstly for the principles of just intonation, secondly for the practical adaption to the thirty-six division in the first automat, and thirdly for the forty-three note division in the electronic organ. In the electronic organ, an added layer of complexity followed from the calculation of how all the necessary frequencies could to be generated by crystals and frequency splitters. For details on how pitches were extracted from the crystals, see the facsimile table below. (Figure 3)

Fig. 3: Facsimile from «Renstemningsautomaten», two pages

Blokkdiagram over tonegeneratorer og frekvensdelere for renstemt elektronisk orgel (med frekvensangivelse)

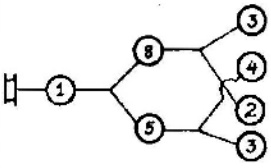
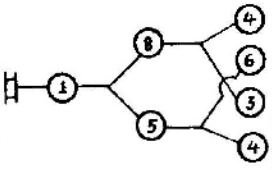
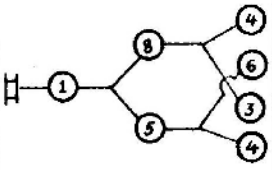
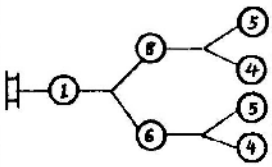
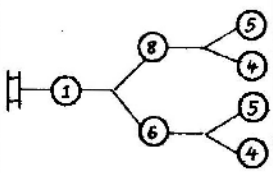
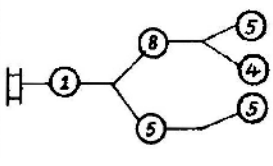
(Oppstillingen er gjort av Ragnar Bogstad 7/7-1957)

PL. IV a

Rekke nr.	Krystall-frekvens	Frekv. deling fra krystall til og med øverste anv. oktav	Tone nr.	Tone navn	Frekv. i øverste anv. oktav
			1	D_1^I	$4635\frac{95}{243}$
1	$185411\frac{127}{243}$ (Fiss$_1$ 32)		2	Fiss$_1$	$5794\frac{58}{243}$
			3	G_1^I	$6180\frac{380}{729}$
			4	H_1	$7725\frac{425}{729}$
			5	Ciss$_1$	$4345\frac{55}{81}$
2	$104296\frac{8}{27}$ (Giss$_1$ 16)		6	E_1	$5214\frac{22}{27}$
			7	Giss$_1$	$6518\frac{14}{27}$
			8	A_1	$6953\frac{7}{81}$
			9	Diss$_1$	$4888\frac{8}{9}$
3	$117333\frac{1}{3}$ (Ais$_1$ 16)		10	Fiss$_2$	$5866\frac{2}{3}$
			11	Ais$_1$	$7333\frac{1}{3}$
			12	H_2	$7822\frac{2}{9}$
			13	Hiss$_1$	4125
4	132000 (Hiss$_1$ 32)		14	Ciss$_2$	4400
			15	Eis$_1$	5500
			16	Giss$_2$	6600
			17	Cissis$_1$II	$4640\frac{5}{8}$
5	148500 (Cissis$_1$ 32)		18	Diss$_2$II	4950
			19	Fissis$_1$II	$6187\frac{1}{2}$
			20	Ais$_2$II	7425

- 12 -

PL. IV b

Rekke nr.	Krystall-frekvens	Frekv. deling fra krystall til og med øverste anv. oktav	Tone nr.	Tone navn	Frekv. i øverste anv. oktav
			21	Es_2^{I}	$4944\frac{304}{729}$
6	$118666\frac{2}{243}$ (B_2 16)		22	Ges_3^{I}	$5933\frac{73}{243}$
			23	B_2^{I}	$7416\frac{152}{243}$
			24	Ces_3^{I}	$7911\frac{49}{729}$
			25	C_2	$4171\frac{23}{27}$
7	$133495\frac{5}{9}$ (C_2 32)		26	Des_3^{I}	$4449\frac{79}{81}$
			27	F_2^{I}	$5562\frac{38}{81}$
			28	As_3	$6674\frac{26}{27}$
			29	D_2	$4693\frac{1}{3}$
8	$150186\frac{2}{3}$ (D_2 32)		30	Es_3	$5006\frac{2}{9}$
			31	G_2	$6257\frac{7}{9}$
			32	B_3	$7509\frac{1}{3}$
			33	C_3	4224
9	168960 (E_2 32)		34	E_2	5280
			35	F_3	5632
			36	A_2	7040
			37	D_3	4752
10	190080 ($Fiss_3$ 32)		38	$Fiss_3^{II}$	5940
			39	G_3	6336
			40	H_3^{II}	7920
			41	$Ciss_3^{II}$	4455
11	178200 (A_3 25)		42	Eis_2^{II}	$5568\frac{3}{4}$
			43	A_3	7128

The resulting pitches shown in the table are the maximum used values for their pitch classes. Bogstad's calculations for crystals one and seven show small errors. However, this had little impact on the sounding result since the errors were less than two-tenths of a hertz. The next table (Figure 4) shows the differences between the thirty-six and (corrected) forty-three note divisions of the octave, and is organized so that the extra tones that Groven needed to avoid the compromises made in the thirty-six division can be easily seen. In noting the different nominations of pitch in the forty-three note division, one can easily see that the differences between forty-three and thirty-six note divisions of the octave are so small that they cannot be perceived. A typical estimation of the threshold for noticeable difference (JND) in pitch is ten cents,[37] although this estimation does not take frequency beating into consideration.

Fig. 4: Pitches, Hz, tempered, 43-division, 36-division.

	Tempered	43-division				36-division		
		1	2	3		1 (blue)	2 (gold)	3 (red)
C b				247,219				
C	261,626		260,688	264,000	C	257,785	260,856	263,963
C #	277,183	271,563	275,000	278,438	C #	271,761	275,014	278,290
C # '		290,000						
D b				278,063				
D	293,665	289,688	293,313	297,000	D	289,923	293,377	296,871
D #	311,127	305,500	309,375		D #	305,658	309,299	312,984
E b			309,000	312,875				
E	329,628	325,875	330,000		E	326,086	329,970	333,901
E #		343,750	348,000					
F	349,228		347,625	352,000	F	343,764	347,859	352,003
F #	369,994	362,125	366,625	371,250	F #	362,401	366,718	371,086
F # '		386,688						
G b				370,813				
G	391,995	386,250	391,063	396,000	G	386,621	391,226	395,886
G #	415,305	407,375	412,500		G #	407,581	412,436	417,349
A b				417,125				
A	440,000	434,563	440,000	445,500	A	434,821	440,000	445,241
A #	466,164	458,313	464,063		A #	458,420	463,881	469,406
B b			463,500	469,313				
B	493,883	482,813	488,875	495,000	B	483,272	489,029	494,854
B #		515,625						

(Color coding from Code's adaption)

Groven did not stop with just intonation; the electric organ also had presets for conventional tuning systems, such as the twelve-tempered system and the thirty-one tone division,[38] among other systems.[39] Groven's purpose of integrating several tuning systems in the same instrument was to further his research through comparative studies, and Groven saw technology as a tool that would further this type of musical investigati-

on. It is interesting to see how his ideas for music research and technological development continually evolve in this feedback loop.

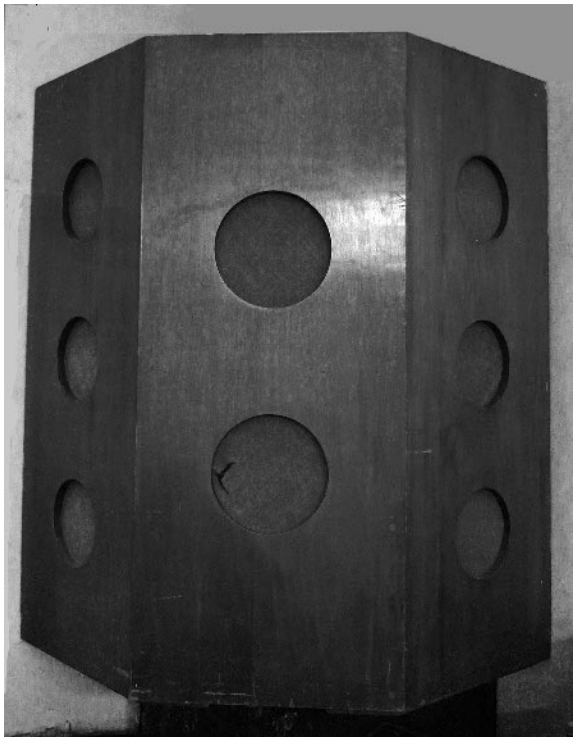
Another technical accomplishment was the development of a contact system for the manuals,[40] made so that chord shifts would happen smoothly and without errors in pitch selection. It took almost a year to realize this aspect of the organ. Groven repeatedly explains in his reports to *Norges Almenvitenskapelige Forskningsråd* (NAVF)[41] how the progress of the project would benefit if Bogstad could receive paid leave from his position as research director at Gastor radio manufacturing. In 1959, Bogstad applied to NAVF for such funds. In his application,[42] Bogstad emphasized the need for a modernized automat that would be less prone to technical problems and have a shorter response time. This was necessary because the «internal speed» of the electric organ was much higher than in the pipe organ. Bogstad programmed thirty-three different sounds for the electronic organ, including unusual sounds not found in the commercially available organs – buckhorn pipe, bagpipe, willow flute and Jew's harp. Interestingly, Groven stated that the electronic organ sounded clearer and better than the acoustic organ,[43] and also saw possibilities in what we today call «spectral diffusion». He proposed the use of filters for separation of the harmonics in the organ tones, so they could be played back through different speakers. The timbral color could then be manipulated after having been produced by the organ, whereby the sound of a bassoon, for example, could be taken apart and reconstructed from several speakers, partial by partial.[44] However, judging from the loudspeaker cabinet that he built, it is unlikely that his thoughts were as radical as current electroacoustic concert practice, where sounds are distributed spectrally across the performance spaces; his cabinet was approximately 1.5 meters tall and contained several speakers that projected in different directions.

It might be assumed that he simply found that this loudspeaker arrangement would bring the sound projection from the electronic organ closer to that of a pipe organ. His idea of taking musical spectra apart for separate treatment was nonetheless unknown outside of specialist groups.

The electronic organ for just intonation was a unique initiative globally, and Groven received support from NAVF for several years during the 1950s and 60s to realize the organ. Groven's international orientation is evident from the patents he secured on his adaptable automat in the main industrial countries of the Western world, and he harbored hopes for commercial production. The electronic organ was used for several demonstrations, during construction and after its completion and presentation to the public in 1965. In 1964, just before the organ was finished, the Central Institute for Industrial Research (SI) also contacted NRK about the purchase of an electronic organ, but no records have been found indicating that NRK actually bought the instrument.

Since the electric organ was designed to use a forty-three note division of the octave, the existing relay-automat would no longer function, having been constructed for a thirty-six note division. In his correspondence with NAVF, Groven applied for funds to de-

Fig. 5: Loudspeaker cabinet built for the electronic organ.



velop a new automat, and for a loan guarantee to allow him to do the construction himself. However, NAVF instead put him in contact with SI, which began construction in 1962 with an estimated completion time of three months, and costs covered by NAVF. Bjørn Raad at SI, following Groven's specifications for the relay automat, and using approximately 1,200 transistors, carried out the reconstruction.[45] The transistor adaption eliminated the previous delay problems that had resulted from the relatively slow relay reaction time, and made performances with the instrument more precise. Later, encouraged by NRK's continual interest in an electronic organ for just intonation, Groven modified a standard electronic organ and returned to thirty-six note division. The automat was modified, and the pipe organ was connected. An unfortunate consequence was that the original electric organ was disconnected and rendered unusable.

From Groven's archived records, it is clear that he continuously calculated and searched for simpler solutions for the adaptable automat and for the development of new instruments. This is also confirmed by his assistant Morten Jacobsen, who also designed a new organ with the same division of the octave, but with a mechanical retuning of the pipes that could be made as the music was being played.[46] Groven's latest notes on the further development of musical instruments date from 1974, and outline

the idea for a mechanically tuned harpsichord with a thirty-one note division of the octave, tuned by levers and weights.[47] This idea was never realized.

From the material in the archives available at the Groven Institute, the National Library and the National Archive, it is clear that the electric organs were Groven's last technological achievements. After his death, and during the active management of his heritage, the transistor automat became somewhat unstable, and it became increasingly clear that a migration to digital technology was necessary if the just intonation system were to continue to function. As the digital paradigm took hold in music technology from late 1980s and onwards, the need for refurbishment and migration became more pressing.

MIGRATION AND FURTHER DEVELOPMENT

The initiative for migrating Groven's system into the digital domain came from music theorist and musician David Løberg Code at Western Michigan University. In 2001, he translated the wiring diagrams from Groven's adaptive automat to into a Max external object, written in C.[48] An adaption was also made so that the Max-patch sent MIDI «note on» and «note off» messages on channels one to three, each controlling a Yamaha MIDI piano. The pianos were tuned to the thirty-six note division of the octave, and the pianist could choose between fixed twelve-tone scales or the adaptive tuning for maintaining just intonation while changing key signature during performance. Code's translated automat was first used for an Oslo performance during the Groven centennial in 2001, and the Groven piano has since been presented at several concerts.[49] In 2001, Henrik Sundt at the Norwegian Center for Technology in Music and the Arts (NOTAM) connected this digital automat to the existing pipe organ. The Groven Max-patch, which was running on a standard Macintosh computer, was connected to the pipe organ through three MIDI-to-voltage interfaces, one for each active MIDI channel. At the same time, the old automat was disconnected and the original keyboard was replaced by a MIDI controller.

Digital technology and the Internet are new technologies since Groven's time, and given the migration to a digital automat it was natural for NOTAM to develop a portable version of the system, since few musicians and composers have access to three, slightly differently tuned MIDI pianos. The simple note messages on the three MIDI channels were simply replaced by the objective pitches (in hertz) for use with standard sound fonts in a customized software sampler. Dag Henning Kalvøy at NOTAM developed the sampler, and this development was completed in 2005. Since that time, anyone can download both the Groven Max-patch and the sound fonts, and perform in just intonation from any MIDI keyboard or directly from the computer,[50] for testing or demonstration purposes. A revised version of the interface is currently underway.

Fig. 6: The Max interface for the adaptive automat and sampler, version 3.0

The natural scale was Groven's basis for the development of the first adaptive automat, but in his NAVF applications for funding for the transistor automat, he described the value of adding presets for other tunings as well. In addition to equal-tempered, well-tempered and mean tone tunings, the current digitized version contains presets for different scales used in folk music, thus achieving an even more accurate representation of many tunes than what was possible on the original automat. One can also tune the sampler to arbitrary reference tones, to simplify performances together with other instruments.

This last development from 2014 has been followed by improvement of the sound quality. The rather limited range in the original physical organ has now been expanded by a number of loudspeakers that have been placed among the pipes, giving the organ tone in particular a fuller bass sound. The physical organ still receives MIDI messages, while the sampler receives pitch messages in hertz, and the sounding result is a mix between the original physical organ pipes and the digital sampler. This mix also makes it possible to expand the palette further, by adding artificial reverb to the sounds from the sampler, and adjusting the wet/dry balance to emulate different concert acoustics. This development picks up on Groven's early ideas of spectral panning.

SUMMARY, FUTURE POSSIBILITIES

A rich press material shows that Groven enjoyed huge respect for his work in radio in his lifetime, and was recognized for his efforts in recording and building an archive of

recorded folk music. His technical achievements with the adaptive automat and his organs for just intonation attracted interest across the country, and there were many broadcasts with his intonation system. His pipe and electronic organs were installed in three churches in Oslo, and used for concerts as well as some regular church services before they were moved to the Groven Institute in Ekeberg in 1971.[51] A demonstration record was made and distributed both in Norway and internationally, and responses showed that the practical results from his intonation system were very well received.[52] However, it should not be overlooked that his theories about the superiority of the natural scale sparked controversy. There was general skepticism regarding the fruitfulness of using a mathematical basis to determine degrees of beauty, and about the validity of just intonation itself, because of the irregularity of overtone spectra that result from tone combinations.[53] As late as 1973, towards the end of his life, Groven felt that the criticism of just intonation was superficial and based on weak logic, and he felt compelled to explain and defend the small compromises in pitch that the thirty-six note division entailed, pointing out that these were much smaller than the minimum inaccuracy normally perceived by human hearing.[54]

Groven's musical argument was based on the acoustic character of the natural scale, which he believed was the best basis for music that could affect listeners at the deepest level. However, the duality in Groven's position, both in building on Norwegian musical tradition and being forward thinking and internationally oriented, was difficult to grasp for many of his contemporaries. Groven's critique of national romanticism in effect claimed the Norwegian musical tradition as material for contemporary music at a time when a «national» music needed to find common ground with rapid societal transformations. Groven was a natural part of this national project, and the technology was designed to serve his musical aims. His work on this national musical project drew directly on musical heritage, as a type of national self-reflection best described as a search for authenticity rather than the distortion of romanticism.[55]

Groven's work with technology was not ideological in the sense of pursuing technology for its own sake. On the contrary, he was consistently occupied with the task of making just intonation a practical possibility. His archive of correspondence shows that his desire to make technology to solve intonation problems was shared within international music communities. Groven's technical approach was a radical improvement when viewed in contrast to the longer, European musical trends – and his pioneering work was unmatched in his time. Since 2001, the digital modernizations of Groven's inventions have built on his intention to create a sustainable technology, and opened up possibilities for recovering his timbres from the electronic organ and reproducing them using digital technology. Overall, the digital facilitation of Groven's adaptable automat has fueled a growing interest in just intonation among composers and musicians, and new works have been written for the instrument. This makes it possible to see the instrument as having a part also in the (electronic) folk music of the future.

ACKNOWLEDGEMENTS

The author would like to thank Anne Jorunn Kydland and Dagne Groven Myhren for their support regarding the location of source material, and David Code for bringing Groven's technical solutions into the digital domain. An extended language check by Palmyre Pierroux has made the text significantly more readable.

Notes

1 For a thorough overview of the development of pitch systems and keyboards for microtonal performance, please see: Karl Traugott Goldbach (2007), *Arthur von Ottingen und sein Orthotonophonium im Kontext*. University of Tartu: http://dspace.utlib.ee/dspace/handle/10062/5574. Visited June 30, 2015.

2 A detailed discussion on just intonation is beyond the scope of this text, but can be found in David Code's chapter in Ingrid Loe Dalaker, Anne Jorunn Kydland, Dagmara Lopatowska-Romsvik, *«East of noise» Eivind Groven, Composer, ethnomusicologist, researcher* (Oslo: Akademika, 2013). A musically-oriented discussion of Groven's works in a historical and aesthetical perspective can be found in Anne Jorunn Kydland's chapter in the same book, as well as in her previous work.

3 A zither is a string instrument where several sets of strings are pre-tuned to chords. The instrument is most often played by strumming these chords.

4 A natural blowing horn without finger holes, often made from bark.

5 A flute without finger holes, typically made from bark, and played by regulating pressure and air stream through the flute. The flute is most often between 40 and 80 cm long, and can only produce pitches with intervals from the natural scale.

6 Eivind Groven, *Naturskalaen* (Skien: Norsk folkekultur, 1927), 11.

7 Groven, *Naturskalaen*, 21.

8 Groven, *Naturskalaen*, 43.

9 Author's translation from Groven's travel report: *Melding um studiereise til Tyskland 18. mai til 10. juni 1936*, 5. The manuscript is located at The Groven Institute.

10 Groven, *Naturskalaen*, 30.

11 Groven, *Folkesongen må gjeva kunstmusikken ny tilføring*. (Folk song must become a new influence on art music. My translation.) Unpublished manuscript, located at the Groven Institute.

12 Groven quoted in: Dalaker, I. L., *Nostalgi eller nyskaping? Nasjonale spor i norsk musikk – Brustad, Egge og Groven*. (Trondheim, Tapir, 2011), 125.

13 A typical example of this type of criticism is Kjell Leikvoll's review Harmonien in *Bergens Tidende* April 9, 1965.

14 Eivind Groven, «Vår folkemusikk», *Tonekunst*, February 17, 1932.

15 Eivind Groven interviewed by «ludo». «Moderne musikk reine galemattis», *Spelemannsbladet* no. 11–12, Vol 18, 5–6.

16 *Aftenposten*, October 10, 1949.

17 *Eskimomelodiar fra Alaska. (Helge Ingstads samling av opptak fra Nunamiut.) Studier over tonesystemer og rytmer*. (Oslo, 1956). See also Helge Ingstad, *Songs of the Nunamiut*.

18 However, Hall recognized Groven's significance as a composer, and her criticism can at least partly be explained by her ongoing battles for modernism in music, against the dominant folklorism and nationalism. See Pauline Hall, «Musikk,» In Håkon Schetelig, Frithiof Brandt, Alf Nyman (eds.): *Vår tids kunst og diktning i Skandinavia*. Vol. 1. Oslo: Tanum, 1948, 215–216.

19 Frode Weium, «Ingeniørmusikk – Møtet med elektroniske musikkinstrumenter i Norge på 1920- og 30-tallet», *Tidsskrift for kulturforskning*, no. 4 (2006), 25–41.

20 http://pdfpiw.uspto.gov/.piw?Docid=00443305&homeurl=http%3A%2F%2Fpatft.uspto.gov%2Fnetacgi%2Fnph-Parser%3FSect1%3DPTO1%2526Sect2%3DHITOFF%2526d%3DPALL%2526p%3D1%2526u%3D%25252Fnetahtml%25252FPTO%25252Fsrchnum.htm%2526r%3D1%2526f%3DG%2526l%3D50%2526s1%3D0443305.PN.%2526OS%3DPN%2F0443305%2526RS%3DPN%2F0

443305&PageNum=&Rtype=&SectionNum=&idkey=NONE&Input=View+first+page. Accessed June 12, 2015.

21 Karl Eitz' reed organ for just intonation with fifty-five keys per octave, for example, is described in Eivind Groven, *Temperering og renstemning* (Oslo: Dreyer, 1948), 37, as well as in Groven's unpublished travel report from 1936. The travel report is located at the Groven Institute, a copy is available at the National Library.

22 Eivind Groven, *Temperering og renstemning* (Oslo: Dreyer, 1948), 80.

23 The pythagorean comma refers to the difference between twelve just perfect fifths and seven octaves, which in theory should be the same, but factually differ with a little more than twenty-three cents. Seven octaves gives the ratio of 128:1, while twelve perfect fifths give the ratio of 129.746337890625 :1.

24 Groven, *Temperering og renstemning* (Oslo: Dreyer, 1948), 35–36.

25 Morten Jacobsen in an interview with Jøran Rudi, March 8, 2015. Jacobsen worked closely with Groven from 1972 to 1977.

26 Eivind Groven, «Det renstemte klaver», *Tonekunst*, September 26, 1934, 136.

27 For further detail on this first technical solution for the piano and on Groven's patenting efforts, see David Code, «Groven ex Machina: The evolving technology of tuning», in Dalaker, Ingrid Loe, Anne Jorunn Kydland, Dagmara Lopatowska-Romsvik: *East of Noise. Eivind Groven, Composer, ethnomusicologist, researcher* (Oslo: Akademika, 2013), 191–204.

28 An application was sent to tobacco manufacturer Johan Henrik Andresen, who had previously paid for Groven's patent applications. The relevant documents are located at The National Archive: RA/PA-0614/G/Ga/L0009/0009 «Eivind Groven.»

29 In «Den reinstemte skala», *Medlemsblad for Norges organistforbund*, April, 1949, 29.

30 Professor Johan Holtsmark from the Polytechnic University in Norway (NTH) provides this description in NRK's publication *Hallo-Hallo* nr. 17, 1936, 12. «When changing from one key to the next, one pushes a new button, thus releasing one preset and activating another» (Author's translation). Holtsmark built up a significant research focus on acoustics at NTH, and was a steady supporter of Groven's work.

31 As explained to the author by Bjørn Raad, constructor of the transistor automat, in an interview on Nov. 1, 2014.

32 Eivind Groven, *Renstemningsautomaten* (Oslo: Universitetsforlaget, 1968), 94.

33 Eivind Groven, *Renstemte klaverinstrumenter*, unpublished manuscript, 1962, 2. Groven writes that the reed organ «has only one voice», but in a recording with the instrument from 1938, it clearly has several voices. Groven's comment must have been referring to the timbral limitations. The document is located at the National Archive in the archive from NAVF, The Council for Humanistic Research, box Dbdf-0169.

34 According to Eivind Groven, the reaction time for the impulse was approximate 4 ms., and his estimation was that even a key movement of as little as 1.5 mm would have been sufficient for the relays to select the correct pitch.

35 Olav Devig, director for the Chr. Michelsen Institute in Bergen, informed Groven about transistors around 1955, and the radio pioneer Birger Holth, who had built the first radio transmitter in Norway for an amateur radio in Drammen in the 1920s, put Groven in touch with Ragnar Bogstad. (Groven in an interview with Rolf E. Schade in the newspaper *Fædrelandsvennen*, August 5, 1966, 5.) Bogstad held the position of research director at Gastor radio manufacturing. Groven's enthusiasm for electronics is apparent also in his article in *Forskningsnytt* no. 4, 1957.

36 Diagram by Ragnar Bogstad, dated July 9, 1957. The original diagram is located at the Groven Institute, and the facsimile used below is taken from Groven, *Renstemningsautomaten* (Oslo: Universitetsforlaget, 1968), 11–12.

37 JND actually varies with frequency, amplitude and tone duration, but Encyclopedia Britannica provides this abbreviated information: http://global.britannica.com/EBchecked/topic/219637/frequency-just-noticeable-difference. Viewed January 29, 2015.

38 Also called the Pretorian system, much in use before Bach's time. One example of this tuning can be found in the Compenius organ in Fredriksborg castle, Denmark. With this tuning, Groven's electronic organ could be used to perform organ music written prior to Bach, in the original intonation used by the composers.

39 Groven provides this description in a grant application to NAVF dated January 10, 1962. The ap-

plication is supported by a letter from Jakob Sandstad at The Institute of Physics, University of Oslo. The documents are located at The National Archive in the archive from NAVF, The Council for Humanistic Research, box Dbdf-0169.

40 In his report to NAVF for 1959/60, Groven describes the contact system to consist of approximately 5,000 parts and 2,000 soldering points. The report is located at the National Archive, box Dbdf-0169.

41 One of several research funding bodies until the Norwegian Research Council (NFR) was established in 1993. The reports are deposited at the National Archive, box Dbdf-0169.

42 The application is located at the National Archive, together with Groven's reports and applications, box Dbdf-0169.

43 One among many journalists that quoted Groven's opinion here was «Ariane» in *A-magasinet* no. 31, 1965, 16.

44 Groven interviewed by «num» in *Norsk Tidend*, Jan 16, 1962, 7.

45 Bjørn Raad interviewed by «oh» in *Morgenposten*, January 4, 1964, 7.

46 Morten Jacobsen in an interview with Jøran Rudi, March 8, 2015.

47 Minutes from a meeting between Eivind Groven and Morten Jacobsen, Dec. 3, 1974. The document is located at the Groven Institute.

48 Max, now MaxMSP, is a graphic programming language for sound generation and manipulation. Available at: https://cycling74.com/products/max/

49 For more detail on Code's migration and the user interface for the automat, please see: David Løberg Code. «Groven.Max: An Adaptive Tuning System for MIDI Pianos.» *Computer Music Journal*, 26/2 (2002): 50–61.

50 Downloadable from http://www.notam02.no/web/groven/

51 The pipe organ was installed in the Trinity church from 1953 to 1957, when it was moved to Fagerborg church due to renovations. In 1971, the pipe organ was moved to the newly built Organ house at Ekeberg. The electronic organ was installed at Vålerengen church for a concert in 1965, and has since also been moved to Ekeberg.

52 A collection of correspondence can be found at the National Library: http://ask.bibsys.no/ask/action/show?pid=970148119&kid=biblio.

53 A distinct example of this type of criticism can be found in Odd Wentzel Larsen, Grovens renstemte orgel, *Aftenposten* May 5, 1954.

54 Eivind Groven. *Renstemt med eller uten gåseøyne*, unpublished manuscript, located in Bjørn Raad's archive.

55 Similar views on musical national projects have been presented also by Lynn M. Hooker (2013), Dagne Groven Myren (2003), Ingrid Loe Dalaker (2011) and Anne Jorunn Kydland (2013).

Bibliography

Aftenposten, October 10, 1949.

«Ariane» in *A-magasinet* no. 31, 1965, p. 16.

Code, David Løberg. «Groven.Max: An Adaptive Tuning System for MIDI Pianos.» *Computer Music Journal* 26/2 (2002): pp. 50–61.

Dalaker, Ingrid Loe. *Nostalgi eller nyskaping? Nasjonale spor i norsk musikk – Brustad, Egge og Groven*. Trondheim: Tapir, 2011.

Dalaker, Ingrid L., Kydland, Anne J., and Lopatowska-Romsvik, Dagmar. *East of Noise. Eivind Groven, Composer, ethnomusicologist, researcher*. Oslo: Akademika, 2013.

Goldbach, Karl Traugott. *Arthur von Ottingen und sein Orthotonophonium im Kontext*. University of Tartu, 2007. Available at: http://dspace.utlib.ee/dspace/handle/10062/5574.

Groven, Dagne Myren. «Tanker omkring det nasjonale, nasjonalromantikk og folkemusikk i et historisk perspektiv.» In Tore Skaug (ed.): *Årbok for norsk folkemusikk*, Vol. 12. Oslo: Norsk folkemusikk- og danselag, 2003.

Groven, Eivind. *Eskimomelodiar fra Alaska. (Helge Ingstads samling av opptak fra Nunamiut.) Studier over tonesystemer og rytmer*. Oslo: 1956.

Groven, Eivind. *Folkesongen må gjeva kunstmusikken ny tilføring*. Unpublished manuscript located at the Groven Institute.

Groven, Eivind. *Naturskalaen*. Skien: Norsk folkekultur, 1927. Located at: http://ask.bibsys.no/ask/action/show?pid=960407804&kid=biblio.

Groven, Eivind. *Temperering og renstemning*. Oslo: Dreyer, 1948.

Groven, Eivind. *Melding um studiereise til Tyskland 18. mai til 10. juni 1936*. Unpublished travel report located at the Groven Institute.

Groven, Eivind. *Renstemningsautomaten*. Oslo: Universitetsforlaget, 1968.

Groven, Eivind. «Det renstemte klaver,» *Tonekunst*, September 26, 1934, p. 136.

Groven, Eivind. «Renstemt med eller uten gåseøyne», unpublished manuscript, located in Bjørn Raad's archive.

Groven, Eivind. *Renstemte klaverinstrumenter*, unpublished manuscript dated January 10, 1962, p. 2. The document is located at the National Archive in the archive from NAVF, The Council for Humanistic Research, box Dbdf-0169.

Groven, Eivind. «Vår folkemusikk,» *Tonekunst*, February 17, 1932.

Groven, Eivind. «Den reinstemte skala,» *Medlemsblad for Norges organistforbund*, April 1949: p. 29.

Groven, Eivind. «Nye klanglige skjønnhetsåpenbaringer ved renstemming og elektroniske tonekilder.» I *Forskningsnytt* 1957, no. 4. pp. 8–10.

Holtsmark, Johan in *Hallo-Hallo* no. 17, Oslo: NRK. 1936. p. 12.

Hooker, Lynn M. *Redefining Hungarian music from Liszt to Bartók*. New York: Oxford University Press. 2013.

Hall, Pauline. «Musikk.» In Håkon Schetelig, Frithiof Brandt, Alf Nyman (eds.): *Vår tids kunst og diktning i Skandinavia*. Oslo: Tanum, 1948, 215–216.

Ingstad, Helge. *Songs of the Nunamiut. Historical Recordings and Transcriptions of an Alaskan Eskimo Community*. Oslo: Tano Aschehoug, 1968.

Jacobsen, Morten. Minutes from a conversation with Eivind Groven, Dec. 3, 1974. Unpublished, located at the Groven Institute.

Kydland, Anne Jorunn. «The structure of the slått and symphonic composition.» In Dalaker, Ingrid L., Kydland, Anne J., and Lopatowska-Romsvik, Dagmar. *East of Noise. Eivind Groven, Composer, ethnomusicologist, researcher*. Oslo: Akademika, 2013.

Leikvoll, Kjell. «Harmonien», *Bergens Tidende*, April 9, 1965.

«Ludo» interviews Groven in *Spelemannsbladet* no. 11–12, Vol 18. pp. 5–6.

«num» interviews Groven in *Norsk Tidend*, January 16, 1962, p. 7.

«oh» interviews Bjørn Raad in *Morgenposten*, January 4, 1964, p. 7.

Schade, Rolf E. interviews Groven in *Fædrelandsvennen*, August 5, 1966, p. 5.

Weium, Frode. «Ingeniørmusikk – Møtet med elektroniske musikkinstrumenter i Norge på 1920- og 30-tallet.» In *Tidsskrift for kulturforskning*, no. 4 (2006): 25–41.

Wentzel Larsen, Odd. «Grovens renstemte orgel», *Aftenposten*, May 5, 1954.

Bjørn Raad in interview with the author. November 1, 2014.

Morten Jacobsen in interview with the author, March 8, 2015.

Downloadable portable system for adaptable just intonation: http://www.notam02.no/web/groven/.

Untitled manuscript located at the Groven Institute. Rebukes criticism about inaccuracy in the electronic organ.

Utlandets reaksjon på E. Grovens renstemte orgel. Oslo: 1968. Located at the National Library: http://ask.bibsys.no/ask/action/show?pid=970148119&kid=biblio.

Summary

This article will discuss how Groven's theoretical and technical work had its basis in musical rather than technical challenges, and how his investment in music technology was musically rather than technologically driven. This discussion traces how his technological thinking evolved over time, and how he came to see the electronic organ as the optimal tool for moving research on intonation systems forward, integrating new tuning presets and timbres in the instruments. Groven's technical contributions may be viewed in relation to international contemporary initiatives and the general wave of optimism emerging from increased electrification, particularly in broadcasting.

Key words

Just intonation, music technology, electronic organ, adaptive automat

Biography

Jøran Rudi began his musical career as a member of Kjøtt, one of the most influential Norwegian rock bands to emerge at the end of the 1970's. His studied music theory and composition at New York University and has since developed a portfolio of works for electronic instruments and/or fixed media, as well as for dance, film, performance art, installation and multimedia. Rudi has edited several books, and is an editor of the Cambridge University Press Journal *Organised Sound*. Rudi is the founding director of NOTAM – Norwegian center for technology in music and the arts, and took up a research position in 2009, following 17 years with administrative, academic and artistic responsibilities for the institution.