Anticipating interactivity: Henry Cowell and the Rhythmicon

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In the early 1930s, maverick composer Henry Cowell collaborated with inventor Leon Theremin to build an electronic instrument capable of producing intricate polyrhythms. This instrument, dubbed the Rhythmicon, can be considered a rudimentary example of an interactive music system. Cowell and Theremin created the machine to fulfil a compositional need, but it ultimately failed to become a successful musical instrument. The Rhythmicon was one of the first electronic music instruments to use technology to extend performers' musical capacities, anticipating the interactive computer music movement by several decades. Despite its shortcomings, the Rhythmicon should be remembered as an important step on the road to interactivity.

1. INTRODUCTION

Today, Henry Cowell (1897–1965) is best remembered for inventing the 'tone cluster', playing adjacent notes on a piano keyboard simultaneously to create a sound more closely resembling a texture rather than a chord (Salzman 1988: 142). He was also perhaps the first composer to derive rhythmic relationships from the ratios of the harmonic series (*ibid*.: 143). This system, which creates very intricate polyrhythms, is described extensively in his seminal book, *New Musical Resources*. By early 1931, Henry Cowell had been writing complex rhythms in his music for over ten years with little hope of hearing them performed accurately. He commissioned Leon Theremin to build him a polymetrical instrument which they called the Rhythmicon. Theremin is known today as the inventor of the instrument which bears his name, the Theremin, first demonstrated in 1920 in Moscow. He was a prolific creator who developed several novel electrical instruments (Chadabe 1997: 9). In the late 1920s he was living in New York, demonstrating the Theremin to New York's artistic elite (*ibid*.: 8). Cowell was teaching at New York's School of Social Research at the time, so it was natural that he would approach Theremin with his idea for an instrument that could facilitate the performance of complex rhythms.

Surprisingly, when the Rhythmicon finally facilitated the execution of Cowell's complicated rhythms, he wrote only two known pieces for this instrument: *Rhythmicana* for Rhythmicon and orchestra, and *Music for Violin and Rhythmicon* (Rich 1995: 128). Cowell didn't abandon polyrhythms in his music; he abandoned the Rhythmicon. It is fascinating to speculate why he never wrote for the instrument again. It could have been the fragility of the instrument, the fact that few were ever made, the actual sound of the instrument, or more simply the metronomic invariance of the Rhythmicon. Despite the shortcomings of the machine as an instrument, the invention of the Rhythmicon was prophetic. The Rhythmicon was much more than a rhythm machine; it was one of the first instruments to distance gesture from sound and to use technology to enhance performers' abilities. Composers today are still using machines to produce polyrhythms, and many acknowledge a debt to Cowell and the Rhythmicon.

2. BACKGROUND AND TECHNICAL SPECIFICATIONS

The composer and theorist Joseph Schillinger (1895–1943) was a friend and colleague of Henry Cowell and Leon Theremin. In 1929, Schillinger composed the first piece written specifically for the Theremin, *Airphonic Suite for RCA Theremin and Orchestra* (Chadabe 1997: 8). He also developed his own mathematical synthesis of music and music theory described in his book, *The Mathematical Basis of the Arts* (Salzman 1988: 175). In 1966, his widow donated a Rhythmicon to the Smithsonian. At this time it was not functioning, but the Smithsonian was still interested in owning the unique instrument. In 1993, Robert York attempted a restoration of the machine. 'With no wiring diagram known to exist, York worked for several months to trace intricate circuits and make notes on pattern configurations, gathering enough information for a full restoration or even a replication of the instrument' (*The Torch* 1993: s-8). As of this year, no further plans have been made to restore or duplicate the instrument which is being stored in an asbestos-contaminated warehouse in Maryland (Sturm 2002).

The instrument in the Smithsonian collection is essentially a large box (21-3/16″ × 19″ × 37-3/4″) with a piano-like keyboard of ten white keys and eight black keys equally spaced on the top (see figure 1). There is a volume control knob and a switch to the left of the keyboard. The left side has tempo and pitch controls made

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Figure 1. Joseph Schillinger and the Rhythmicon (photograph courtesy of the Smithsonian Institute).

of plastic tubes projecting from holes while the right side contains a soundboard. Each key is connected to a corresponding light bulb inside the casing. When a key is pressed the light bulb turns on and illuminates two black metal disks 20″ in diameter and 1/8″ thick perforated with 1/2″ holes – the pitch wheel and the tempo wheel. The pitch wheel has sixteen concentric rings; the outermost ring has ninety-six holes and each ring progressing toward the centre has six fewer holes, meaning the innermost ring has six holes. The tempo wheel has only sixteen holes around the outer edge, and each concentric ring progressing toward the centre has one fewer hole. Each wheel is controlled by a separate motor; in general the tempo wheel rotates at a slower speed than the pitch wheel. A photodetector is positioned on the other side of the wheels in such a way as to sense the pattern of light which travels from the bulbs, through the rotating wheels (see figure 2). This pattern is converted to an equivalent electrical pattern which controls heterodyning vacuum tube oscillators. That signal is then passed to a preamplifier and on to the soundboard. The

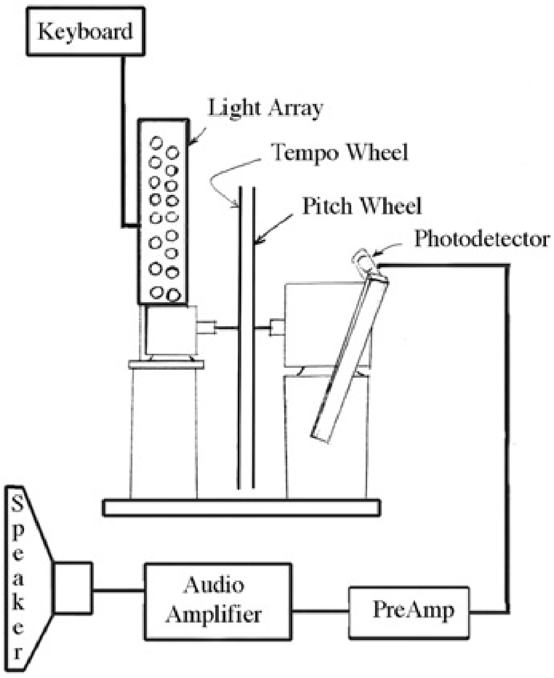

Figure 2. Diagram of the Rhythmicon (York 1993: 13).

speed of the wheels can be adjusted from outside the box using the plastic tube rheostats (York 1992: 1–4).

The pitch wheel's function is to generate a constant frequency which is determined by the speed of the wheel and the number of holes in the concentric rings used to pass the light. The speed of the pitch wheel has a range of 150 to 700 RPM. By removing the tempo wheel it is possible to create tones that last as long as a key is held down. For example, if the wheel is moving at 600 RPM and the outermost concentric ring of holes is used, then the frequency of the tone is 960 Hz (York 1992: 10):

$$600 \text{ rev/min} * 1 \text{ min/60 sec} * 96 \text{ holes/rev} = 960 \text{ holes/sec or } 960 \text{ Hz}$$

The pitch of the tone is dependent not only on the speed of the pitch wheel but also by which bulb is activated. 'At a speed of 600 RPM the tone varied from approximately 120–960 Hz' (York 1992: 10). The tempo wheel typically rotates at 60–70 RPM and acts as a mask on the sound created by the pitch wheel. When the slower tempo wheel's hole is aligned with the light source and the photodetector, the light can pass through several pitch wheel holes. The tone is interrupted when the tempo wheel's holes are no longer aligned with the light; when both wheels are rotating, a rhythmicised pitch is produced (York 1992: 4). Using all possible combinations of keys, the Rhythmicon is capable of producing 65,535 resultant rhythms (see figure 3) (Schillinger 1948: 665).

3. CONCEPTUALISATION AND INVENTION

While all sources agree that Leon Theremin built the machine, it is not clear who had the original idea for the

16K1 = 16!/1!(16-1)! = 16
16K2 = 16!/2!(16-2)! = 120
16K3 = 16!/3!(16-3)! = 560
16K4 = 16!/4!(16-4)! = 1820
16K5 = 16!/5!(16-5)! = 4368
16K6 = 16!/6!(16-6)! = 8008
16K7 = 16!/7!(16-7)! = 11440
16K8 = 16!/8!(16-8)! = 12870
16K9 = 16!/9!(16-9)! = 11440
16K10 = 16!/10!(16-10)! = 8008
16K11 = 16!/11!(16-11)! = 4368
16K12 = 16!/12!(16-12)! = 1820
16K13 = 16!/13!(16-13)! = 560
16K14 = 16!/14!(16-14)! = 120
16K15 = 16!/15!(16-15)! = 16
16K16 = 16!/16!(16-16)! = 1
______________TOTAL = 65535

Figure 3. Rhythmic combinations produced by the Rhythmicon (Schillinger 1948: 666).

invention of the Rhythmicon. The New York Musicological Society commissioned Theremin to build a polymetrical instrument which was finished on 30 March 1931 (Manion 1982: 86). Theremin was intrigued by the idea of an instrument that would use electricity to produce polyrhythms, so even though he was being offered up to $10,000 from Hollywood studios for his famous 'ether-instrument', he invented an entirely new instrument for Cowell for $200 (O. Cowell 1934: 23). Letters from Henry Cowell, Leon Theremin and Charles Seeger reveal the historical discrepancies caused by the passage of time. In 1934 Cowell wrote:

> My part in its invention was to invent the idea that such a rhythmic instrument was a necessity to further rhythmic development, which has reached a limit more or less, in performance by hand, and needed the application of mechanical aid. That which the instrument was to accomplish and what rhythms it should do and the pitch it should have and the relation between the pitch and rhythms are my ideas. I also conceived that the principle of broken up light playing on a photo-electric cell would be the best means of making it practical. With this idea I went to Theremin who did the rest – he invented the method by which the light would be cut, did the electrical calculations and built the instrument. (O. Cowell 1934: 23)

Sidney Cowell commented on this letter in response to an inquiry from the Smithsonian collection:

> This was written in reply to a query from Olive Cowell, who had been keeping a list of HC's activities. She asked him to let her know what his exact contribution to the invention of the Rhythmicon was. He never claimed to have first thought of the possibility of such an instrument, many others [sic] people had done this; but the determination to carry out its realisation by the late 1920's for further rhythmical development does seem to have been his own. (S. Cowell 1970)

In addition, 'According to Sidney Cowell, he [Henry] had been interested in the possibility of such an instrument for many years and had discussed the project with his friend Russell Varian as early as 1915–1916' (Mead 1978: 189). Nicolas Slonimsky, a well-known conductor and proponent of modern music in the early half of the twentieth century, believed Cowell had the idea for the Rhythmicon much later:

> In 1931 Cowell, annoyed by the wistful realisation that, no matter what notation we may decree, human players will still be human – that is inaccurate, physiologically limited, rhythmically crippled, and unwilling to reform – hit upon the idea of an instrument which would faithfully reproduce all kinds of rhythms and cross rhythms. (Slonimsky 1962: 59–60)

It is inaccurate that Cowell 'hit upon the idea' in 1931, because in *New Musical Resources*, Cowell suggests an instrument that could mechanically produce the intricate rhythmic ratios he describes in previous chapters (Cowell 1930: 65). Although he had finished writing the book in 1919, it went through several revisions before its ultimate publication in 1930 (Rich 1995: 118). Without an original manuscript it is impossible to determine when Cowell originally proposed a 'keyboard on which when C was struck; a rhythm of eight would be sounded, when D was struck, a rhythm of nine' (Cowell 1930: 66–7). It would be interesting to know if Henry Cowell indeed proposed the specifications of an instrument over ten years before its creation, or if this small paragraph was a later addition.

Leon Theremin fully corroborated Cowell's involvement with the Rhythmicon in a letter to Joseph Schillinger's widow, the founding member of the Schillinger Society:

> Henry Cowell, in conjunction with his work in the School of Social Research, located in the building of Columbia University, has ordered me, officially from this organisation, to develop and construct some rhythmical instrument which will give the possibility for experimentation with different rhythmical relations and rhythmical harmonies. Together with Mr. Schillinger he gave me some advice about the future possibilities of the instrument, for instance: how many rhythms it is supposed to produce (1–16), what sound pitch is supposed to correspond to each rhythm (the relation between the frequencies of sound pitch corresponds to the relation between the rhythms), how to play the instrument (with the keyboard), how to name the instrument (Rhythmicon). He [Cowell] was far away from electronics, physics and radio-technic, but his organisational activity and propaganda of new ideas for musical creations was very sympathetic to me. I like to work and to search in the field of new discoveries in science and the arts . . . I always connect his name with this constructed by me, Rhythmicon. (Theremin 1967)

The Schillinger Society also contacted Charles Seeger, Cowell's teacher/mentor in the 1910s. He claimed that Cowell 'swiped some of his best (and some of his worst) "ideas" from [him] and occasionally acknowledges it' (Nicholls 1997: 5). In a response to a letter from Arnold Shaw, the Executive Director of the Schillinger Society, Seeger wrote:

> The Rhythmicon . . . was first proposed by me, at a meeting of the New York Musicological Society in 1931 or 1932 at which time I was in favor of the term 'Metricon'. Mr. Henry Cowell and Mr. Leon Theremin were both at the meeting, and I discussed the idea at length with them. Mr. Cowell contributed the harmonic series, and Mr. Theremin, in place of the mechanical device which I had suggested, suggested the adoption of a photo-electric cell. Mr. Cowell commissioned an experimental instrument which, to the best of my knowledge, is at present in the New School for Social Research in New York, though not in working order. A second machine was made by Mr. Theremin for Mr. Nicolas Slonimsky of Boston. I presume this is the one which Mr. Schillinger eventually came to possess. (Seeger 1944)

It is unfortunate that there is no letter documenting Joseph Schillinger's memories of the origins of the Rhythmicon. There is a letter from Joseph Schillinger to Cowell from 1938 where he describes the equipment in his studio including 'a Rhythmicon which I purchased from Nicolas Slonimsky' (Schillinger 1938). This is the Rhythmicon currently in the collection of the Smithsonian.

The Rhythmicon is mentioned in many publications on twentieth-century music, yet there are large inconsistencies amongst sources. Some books say only one was ever made (Rich 1995: 128), yet Seeger's letter clearly says Theremin made two. Fredrick Koch, a student of Cowell's at the Eastman School of Music in the summers of 1962 and 1963, recalled that Cowell would talk about the Rhythmicon, and mentioned that 'one was thrown out because the caretakers at Columbia University thought it was a pile of junk . . . the other is now in [the] New York Museum of Natural History' (Koch 1983: 65). Leland Smith wrote, 'Only two instruments were built in America. Sometime before WWII Cowell's instrument found its way to the Department of Psychology at Stanford University but eventually became inoperative and was, with Cowell's approval, discarded. The remaining Rhythmicon was moved and is now in the Smithsonian Institute' (Smith 1973: 138–9). Since Leland Smith's statement is accurate about the Rhythmicon in the Smithsonian, we can assume he is correct about the machine at Stanford University. The existence of a third Rhythmicon is confirmed by an interview with Leon Theremin in Moscow, 'Here is my rhythmicon. It can produce any combination of complex rhythms. Let me play you seven against nine. Or would you like to hear five against thirteen. Very important. A conductor can stand here and learn to beat four with one hand and five with the other' (Schonberg 1967: 40). The present location of the Russian Rhythmicon is unknown.

4. COMPOSITIONS AND PERFORMANCES

We do know that the Rhythmicon was developed primarily as a musical instrument to produce accurate polyrhythms for early twentieth-century composers who were extending the harmonic and rhythmic language of music. Henry Cowell developed a new system of musical organisation in which he translated the ratios of the harmonic series into rhythm. The simplest interval, an octave, produced the simplest rhythmic ratio, 1:2; a perfect fifth produced triplets (see figure 4). Much of his seminal work, *New Musical Resources*, is dedicated to the discussion of this musical system, particularly the complex polyrhythms that are produced as a result. He even proposed a notation to make reading scores less complicated, but even with 'easier' notation no human performer of the time could play his music accurately.

Cowell wrote two works that made extensive use of his system of rhythm/pitch ratios, *Quartet Romantic* (1917) and *Quartet Euphometric* (1919), in which there are rhythms of 6-2/3 against 5-1/3 against 2-2/3 all in a single measure (Cowell 1974).

> [Cowell] expressed no hope that either of these works, with their excruciating rhythmic ratios and their dense, non-tonal harmonies, could find performers among the musicians of his time; they were designed more as paradigms of his own musical researches. (Rich 1995: 118)

It took seventy years for human performers to play *Quartet Romantic*, which had its first public performance on standard acoustic instruments in 1978 (Lichtenwanger 1986: 58). Cowell did not think the pieces would ever be played, even by the most advanced performers:

> These first two quartets were considered unperformable by any known human agency and I thought of them as purely fanciful; they were conceived as something human that would sound warm and rich and somewhat rubato . . . its composer hopes that it need not sound icy in tone nor rigid in rhythm. (Cowell 1939)

Here Cowell emphasised that he wants his polyrhythms to sound human, and not rigid. This focus on musicality is a topic strangely absent from his *New Musical Resources*. Even the name *Quartet Romantic* belies the mathematical nature of the music and speaks to his interest in musicality as well as mathematical organisation. Once the Rhythmicon was built, Cowell remained frustrated, this time by the rigidity of the performance – 'Since there was no way of giving melodic freedom by varying the note lengths in a single part, and no method of accenting, these early quartets still could not be played on it [the Rhythmicon]' (Cowell 1974: Preface).

Cowell wrote two pieces specifically for the Rhythmicon and then abandoned the machine. The instrument

Interval	Ratio	Time Value
Unison	1:1	4th note (quarter)
Augmented Unison	14:15	7/30th note
Major Second	8:9	2/9th note
Minor Third	5:6	5/24th note
Perfect Fourth	3:4	3/16th note (dotted eighth)
Diminished Fifth	5:7	5/28th note
Perfect Fifth	2:3	6th note (eight triplet)
Minor Sixth	5:8	5/32nd note
Major Sixth	3:5	3/20th note
Minor Seventh	4:7	7th note
Major Seventh	8:15	215th note
Perfect Octave	1:2	8th note (eighth note)

Figure 4. Cowell's interval/rhythm relationship (Cowell 1930: 101).

was premiered in concert on 15 May 1932 in San Francisco. For the occasion, Cowell wrote a piece for Violin and Rhythmicon which was played by Carol Weston. The work was never published and has since been lost, but this small piece for violin and Rhythmicon was not Cowell's primary work for the Rhythmicon. As early as 1931 he had finished the second movement of his Concerto for Rhythmicon and Orchestra. This work also was never published, but there is a copyist's score (see figure 5) as well as a complete set of orchestral parts and an original manuscript of the first and fourth movements in the Fleisher Collection of the Philadelphia Free Library (Smith 1973: 139). The piece was supposed to be premiered in Paris in February of 1932 by Nicolas Slonimksy, but the concert never took place (Mead 1978: 189–90). Again there are conflicting reasons why the piece, later titled *Rhythmicana*, was never played. 'Slonimsky says that Cowell's special piece *Rhythmicana* was completed too late to be used at the Paris concerts' (Mead 1978: 190). Slonimksy himself wrote that he didn't think the instrument was stable; it was 'capricious and subject to fits of musical distemper . . . and [he] was not sure it could be adjusted to the European current' (Slonimsky 1988: 151). Sidney Cowell thought it was because the instrument was too fragile to transport (Mead 1978: 190). The work was not performed until forty years after it was written, when Leland Smith realised the Rhythmicon's part with a computer at Stanford University. *Rhythmicana* was given its premiere on 3 December 1971 by the Stanford Symphony Orchestra conducted by Sandor Salgo (Smith 1973: 141). A few months later the work was played at Tanglewood; at this time the programme read 'Concerto for Rhythmicon and Orchestra'. Both performances used a pre-recorded Rhythmicon part which Smith made using his computer music program SCORE (*ibid*.: 142). The piece has still not been played with an actual

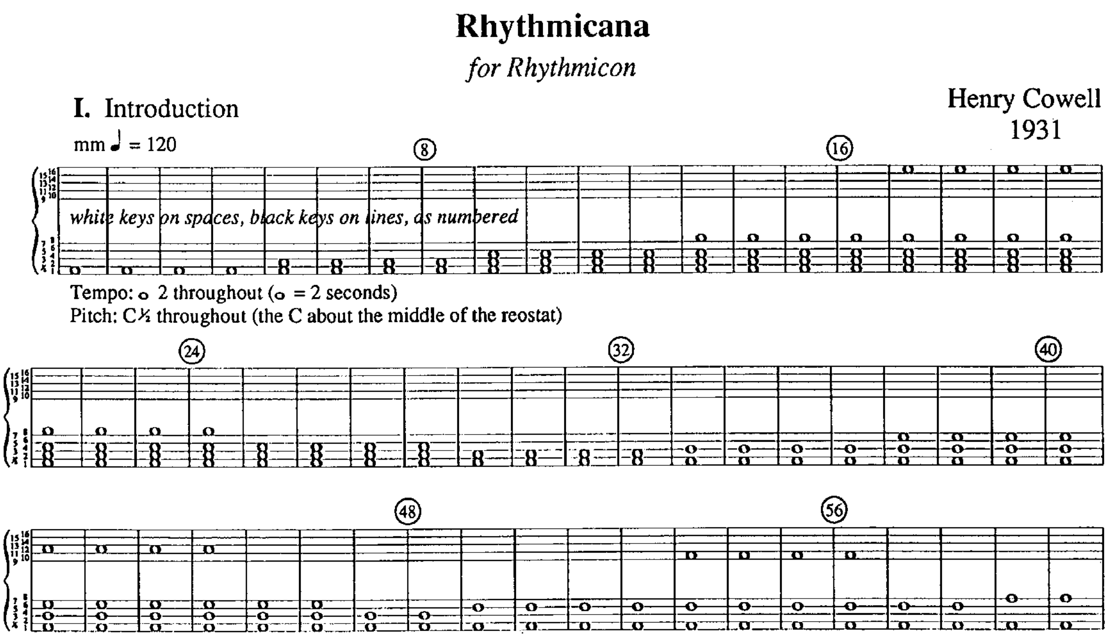

Figure 5. Copyist's transcription of *Rhythmicana* (Cowell 1931: 1).

'Rhythmicon' performer, whether on a rebuilt mechanical Rhythmicon, or a virtual Rhythmicon programmed with software designed for interactive performance.

The *Concerto for Rhythmicon and Orchestra* was renamed because Cowell wrote a solo piano work in 1938 that he titled *Rhythmicana*. This piece had the same kind of complicated rhythms as his *Euphometric* and *Romantic* quartets, and pieces for Rhythmicon (Cowell 1938). Cowell didn't forsake his dream of hearing polyrhythms, he just gave up on using the Rhythmicon to produce them. Between 1936 and 1940 he began writing notes for a book to be called *Rhythm*, a pedagogical tool containing progressively more difficult rhythmical patterns. He wanted to 'unlock [the] difficulties of contemporary rhythmic practice and encourage their use in composition and performance' (Saylor 1977: vii). Cowell decided to train musicians to play polyrhythms instead of pursuing mechanical solutions.

5. EVALUATION AND CONCLUSIONS

One paragraph before Cowell wrote about the possibility of a new keyboard instrument that could produce polyrhythms in *New Musical Resources*, he wrote, 'These highly engrossing rhythmical complexes could easily be cut on a piano roll' (Cowell 1930: 65). He never wrote any pieces for player piano, but Conlon Nancarrow used this technique for many of his works. Nancarrow fully admits he took the idea from Cowell's book but said, 'He [Cowell] never did it! Well, I did' (Duckworth 1995: 40). Cowell was not interested in creating static 'recordings' of polyrhythms. His first priority was to create a responsive instrument capable of producing polyrhythms.

> The purpose of the instrument is twofold: to make possible the reproduction of rhythm and related tone beyond the point where they can be produced before now by any known means; and to be used, first for making rhythmical melody and harmony for use in musical compositions, second, for the carrying on of numberous [sic] scientific and psychological experiments with rhythm. (Cowell, letter to O. Cowell, 1932)

Others thought the Rhythmicon was built 'primarily to enable composers to hear and become accustomed to several simultaneous rhythms . . . Cowell in a characteristically contradictory spirit proceeded to treat the Rhythmicon like a percussion instrument and wrote a concerto for it' (Harrison 1954: 4). A letter from Charles Ives to Nicholas Slonimsky, rebuts this theory and confirms early twentieth century composers' interest in the Rhythmicon as a musical instrument: 'It relieved my mind to know especially that the new one would really be nearer to an instrument than a machine' (Slonimsky 1988: 151). The first model did not have a volume control (Slonimsky 1988: 151), but it is unclear what other improvements Theremin made to the second Rhythmicon to make it more like a musical instrument instead of a rhythm machine. Once the Rhythmicon was abandoned as an instrument it was used in psychological research (Rich 1995: 128), and reproduction of intricate African drumming patterns (Schillinger 1938: 665).

At first, Cowell was very excited about the Rhythmicon and wrote a letter to Charles Ives saying the Rhythmicon had been accepted as a 'real artistic instrument' (Mead 1978: 190). Yet it failed Cowell as an instrument because of its inflexibility; he had a musical objective that was unattainable using the technology of the time. Composers are still exploring the possibilities of creating accurate polyrhythms with machines. C. Matthew Burtner, David R. Mooney, and John Came invoke the Rhythmicon in their own work, naming computer programs (Burtner 1996: 87), pieces (Mooney 2002), or CDs (Came 1995) after the elusive instrument-machine. These composers have not used any concrete realisation of the Rhythmicon in their works, but have instead been inspired by Cowell and Theremin's invention to create their own intricate polyrhythmic musical systems that reach far beyond the capabilities of the first rudimentary rhythm device.

Cowell's compositional goals required more real-time control than cutting polyrhythms on a piano roll would have afforded, but the Rhythmicon still did not allow Cowell to express his musical ideas fully, because the performer could not shape musical phrases within the polyrhythms. Due to this fundamental limitation, he stopped writing for the instrument. Cowell might also have been disappointed by the actual sound of the instrument which has been compared to a reed organ (Mead 1978: 189), an Indonesian Gamelan (Slonimsky 1988: 151), or even a 'grunt and a snort in the low tones and like an Indian war whoop in the high-tones' (Metzger 1932). Leland Smith listened to acetate recordings made by Schillinger and described what he heard as 'rhythmicised grunts' (Smith 1973: 139). Recordings of the Rhythmicon at the Smithsonian demonstrate the poor audio quality and flat timbre expected of an early electronic instrument. However, these shortcomings are transcended by its haunting rhythmical precision, as if technology from a future age had somehow been sent back in time.

Despite its failure as a musical instrument, the Rhythmicon was a nascent interactive music machine, created using optical-electro-mechanical means. Todd Winkler defines interactive music as 'a music composition or improvisation where software interprets a live performance to effect music generated or modified by computers . . . This is a broad definition that encompasses a wide range of techniques from simple triggers of predetermined musical material to highly interactive improvisational systems that change their behaviour from one performance to the next' (Winkler 1998: 4). The Rhythmicon takes live performance data and triggers simple predetermined material. It is one of the first instruments where the mechanical action of the performer is separate from the sound. Cowell himself wrote about this departure from traditional instruments:

> As distinct from other musical instruments which require movement of the performer in order to produce rhythm in time, the Rhythmicon will not only lessen the physical strain on the performer but will increase the number of rhythms produced at one time. (Cowell, *Musical Courier*, 1932: 23)

Pressing one key and holding it down did not produce a steady tone; instead the sound was broken into rhythmic patterns giving the appearance of autonomy. This distinction between action and resultant sound is a primary characteristic of interactive music. Until the Rhythmicon, no instrument had removed the connection between gesture and output. Leland Smith was determined to play Cowell's *Rhythmicana* because it 'was perhaps the first work of quality that exploited in a fundamental way the new electronic technology' (Smith 1973: 134). All other electronic music instruments of the time had a one-to-one correspondence between gesture and sound. Until the Rhythmicon, electronic instruments produced new sounds and even introduced new ways of interacting with instruments, but the elemental bond between gesture and result was never broken.

Even the notation Cowell developed for the Rhythmicon predicts the notational problems of interactive music; the action of the performer is documented directly, but intrinsic aspects of the sound produced cannot be inferred from the score regardless of familiarity with the instrument. The polyrhythms are explained in great detail in the notes for the work (Cowell 1931: Preface), but within the score there is no notation suggesting the polyrhythms that result from pressing the keys. The pitch and tempo rheostats which enabled the performer to adjust parameters in real time were important to the musical nature of the Rhythmicon, but they were not ground-breaking. Other electronic instruments from the 1930s such as the Ondium Péchadre used dials as input devices in real time, but none so clearly demonstrated the future principles of interactivity.

Operation of the Rhythmicon can be clearly compared to Robert Rowe's processing chain of interactive music. The first step, when a performer presses a key and triggers a light to come on, is the *sensing* stage, where data is collected from the controllers reading gestural information from the performer on stage. The second step, when the light is broken up through the rotating tempo and pitch wheels and converted into an electrical pattern to control the oscillators, is equivalent to the *processing* stage in which a computer [circuits] reads and interprets information coming from the sensors and prepares data for the third stage. The final rhythmicised output from the oscillators and amplifiers is the *response* stage which occurs when the computer and some collection of sound-producing devices share in realising the musical output (Rowe 1993: 9). Much like modern interactive music systems, the Rhythmicon enabled musicians to control multiple parameters in real time, distanced gesture from sound, and extended the possibilities of musical performance. It may have failed Cowell as an instrument, but his concept of an electrical device that would extend the capabilities of human performance was visionary. The Rhythmicon was much more than the first rhythm machine, it was a harbinger of the complex interactive computer music systems that would be developed half a century later.

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