Kircher's Mechanical Composer: A Software Implementation

Jim Bumgardner
10066 Orcas Ave
Shadow Hills, CA, 91040, USA
E-mail: jbum@jbum.com
Website: krazydad.com

Abstract

A description of a working software implementation of Athanasius Kircher's *Musurgia Mechanics*: The algorithm the Jesuit Polymath invented for non-musicians to set hymns to music, in four-part polyphonic arrangements. This algorithm was used in two related inventions of Kircher's, the *Arca Musarithmica*, and the *Organum Mathematicum*. The author has created a software program that incorporates data from both devices. This software produces files in the open-standard ABC notation, thru which one can produce printed scores and MIDI recordings of 17th century polyphony in great quantity.

Introduction to Kircher

> *The mechanical production of music is nothing other than a certain closely defined method I have invented, by which anyone, even if he has no musical knowledge, may, by the varied application of music-making instruments, compose tunes.*
>
> – Athanasius Kircher [1]

Athanasius Kircher (d. 1680) [figure 1], was a Jesuit Scholar and Polymath who achieved great renown in his lifetime, due to his prodigious output of lavishly illustrated books and his role as curator of one of the first natural history museums at the Collegio Romano. Kircher's books demonstrate his varied expertise in such diverse subjects as Linguistics, Antiquities, Speculative History, Magnetism, Optics, Mechanics, Cryptography, Astrology, Mathematics, Microbiology, Geology and Music. Among the numerous inventions attributed to Kircher are the megaphone, the magic lantern, the aeolean harp and the pantometrum (a "universal measure" for solving geometry problems). Kircher had the advantages of a relentless curiosity and a secure academic position which made him the intellectual center of the Jesuit organization, and put him on the receiving end of voluminous correspondence from distant places. It is no surprise that Kircher was described as "master of a hundred arts."[2]

Figure 1:
Athanasius Kircher

In the years after his death, Kircher began to sink into obscurity. One reason is due to the suppression of the Jesuit order by the Catholic church in the mid-18th century. Another reason is that Kircher's writings inhabit a porous region somewhere between religion and science, and freely combine speculation, intuition with his empiricist experiments in a manner that became outmoded in a society of increasingly humanist thinkers. The Rosetta Stone was another nail in Kircher's coffin, helping to demonstrate that Kircher's once celebrated "translations" of the Egyptian hieroglyphs were only delusions of a fertile but febrile imagination [3].

In recent years, Kircher's star has begun to rise again. The mixture of science, pseudo-science, truth and humbuggery which once tainted his work only serve to make him a more compelling figure in these times when specialization is the rule, and universal knowledge an unattainable dream.

Kircher the musicologist. One of Kircher's most successful and enduring works was *Musurgia Universalis*, published in two large volumes in 1650. In this encyclopedic work, Kircher described nearly everything then known about sound, audio production, sound perception, and western music at the time, borrowing heavily from such previous works as Mersenne's *Harmonie Universelle*. Diarist Samuel Pepys bought a copy in London for 35 shillings in 1668 [4]. The Pepys library at Magdalene College, Cambridge still has a curious (and surprisingly small) box that Pepys built (or commissioned) from plans in Kircher's book: an *Arca Musarithmica*. [Figure 2]

Kicher's *Arca Musarithmica* and *Organum Mathematicum*

Although much of Musurgia Universalis is derivative, Kircher's invention of a music composition algorithm was decidedly modern, anticipating the work of algorithmic music pioneers such as Lejaren Hiller and aleatoric composers like John Cage. Likely influenced by the musical combinatorics of Mersenne [5], and the mechanical inventions of Lull [6], Kircher conceived of a process by which non-musicians could compose music, by converting numbers to pitches, and combining pre-composed phrases into longer pieces.

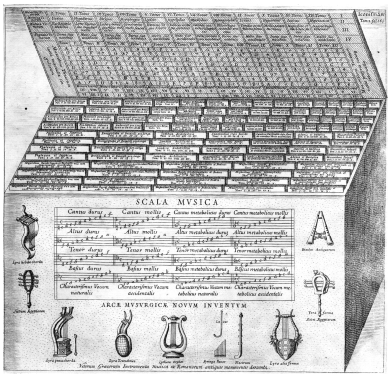

Figure 3:
Arca Musarithmica

Kircher's process was first developed for the *Arca Musarithmica*, described in *Musurgia Universalis*. The Arca was a box containing a series of *columnae* or wooden strips with *tariffa* (tables) affixed to them. The tables contained the information required for Kircher's mechanical method. The composer would pull a set of columns from the box, and string phrases in the columns together to produce a complete piece of music.

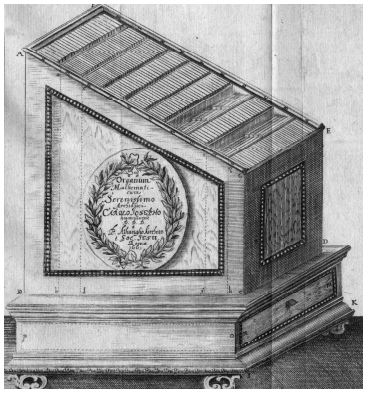

Figure 2:
Organum Mathematicum

Kircher later copied these tables and used them in a similar, but more wide-ranging invention, his *Organum Mathematicum* [figure 3], described in the book of the same name by his pupil, Kaspar Schott, and originally constructed in 1661 for the edification of a twelve-year-old archduke, Karl Joseph, son of Habsburg Emporor Leopold I. The Organum, the 17th century equivalent of a laptop computer, was also a box containing wooden strips. The strips were divided into nine sections, which were used to aid in the production of arithmetic, geometry, fortifications, calendars, gnomics, spherics, planetary movements, earthworks and finally, music [7]. The music tables in the Organum were essentially a subset of the tables designed for the Arca (give or take a few transcription errors). Two extant devices can be found in museums in Florence and Munich, respectively. It appears unlikely that any Organum saw much practical use – they were most likely used as expensive gifts and conversation pieces, intended to impress wealthy patrons and cement the Society of Jesu into the intellectual firmament.

Origins of this Project

I first encountered Kircher at the Museum of Jurassic Technology in Los Angeles, around 1999, where I read this misleading (albeit accurate in parts) caption below an illustration of the Arca:

> Arca musarithmica: a primitive mechanical computer that would compose simple random compositions, as well as write messages in cipher, calculate the date of Easter in any year, and design fortifications.

Like Kircher's writings, much of the information at the MJT (which is equal parts art exhibit and museum) can be misleading. Nonetheless, I resolved to find out as much as I could about this apparent precursor to Babbage. I was primarily interested in the musical applications of such a device, having produced my own algorithmic music compositions years ago in college. It sounded like Kircher had invented a clockwork device which composed music. I quickly found that this "primitive mechanical computer" was nothing more than a glorified recipe box. Undaunted, I became determined to produce a software implementation of Kircher's compositional method used in the *Organum*.

At the time, images of the actual tables from Kircher's Organum were hard to come by (complete copies of the relevant works are now readily available online via the Echo archive), and I had a difficult time getting access to the rare book collections at local libraries. I eventually managed to acquire some photocopies of the relevant tables from Schott's book, as well as a German translation of the relevant passages from Dr. Hans-Joaquim Vollrath, a mathematician at Wurzburg university where Kaspar Schott wrote and taught. I am indebted to Dr. Vollrath for his assistance.

The Software Implementation

My software is written in the Perl programming language. It consists of a single script, organum.pl, which makes use of three include ("header") files, which contain the data I transcribed from the writings of Kircher and Schott. Two of the header files contain tables from Kircher's and Schott's books (one contains phrases, and the other contains modes or scales). The third header file contains a set of lyrics, which are to be set to music using Kircher's method.

Data Entry and Representation. The most tedious part of my implementation involved typing in all the tables of numbers and rhythmic values that appear on the *tariffa* (tables) in Schott's book. In some cases, the Perl representation resembles quite closely the original illustrations which appear in *Organum Mathematicum*, as can be seen in a screen snapshot I took while entering the data [Figure 4].

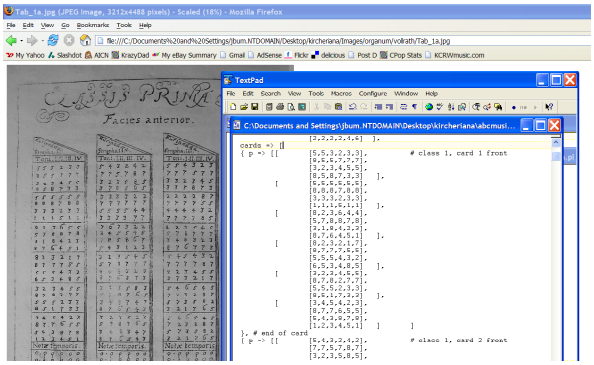

Figure 4: *Data Entry*

Most of the tables I transcribed from Schott's book consist of musical phrases, notated as separate pitch and rhythmic values. The eight rods are divided into two distinct groups: simple and florid.

Four of the rods are used for music in the "simple" style, or first-species counterpoint. In the music produced by these rods, all four voices sing melodies with identical rhythmic values. For each musical phrase, which consists of a set of pitches, a choice of different rhythmic values are provided, in a set of separate tables. In addition, a set of rhythms is provided in the "Tripla" style, which use three per measure, rather than four.

The other four rods contain music in the "florid" style, or fifth-species counterpoint. In these rods, the 4 voices are assigned different rhythmic values, and only one such set of rhythms is provided for each phrase.

The tables are further divided into classes based on the number of syllables per strophe, corresponding to the metrical style of the latin hymns which a church composer would want to set to music. The phrases are arranged in six groups, as follows:

a) Class 1 fronts. "Euripedaean" phrases for setting trochaic trimeter supposedly in the style of Euripedes with six syllables per phrase. An example verse used with this class is "Ave Maris Stella".

b) Class 1 backs. "Anancreonic" phrases for setting trochaic tetrameter with eight syllables per phrase. Kircher's example is "O ter quaterque felix" (O ter QUA ter QUE fe LIX). A modern example would be "We three kings of Orient are."

c) Class 2 fronts. "Archilochan" phrases for setting iambic tetrameter with eight syllables per phrase. Ambrosian hymns, such as "Oh Little Town of Bethlehem," fit this pattern, as does Kircher's example of "Veni Creator Spiritus" (ve NI cre A tor SPI ri TUS).

d) Class 2 backs. "Sapphic" phrases, for setting versus with a syllabic pattern of 11-11-11-5. Examples are "Iste Confessor Domini Sacratus" and "Ut queant axis resonare fibris".

e) Class 3 fronts and backs. "Euripedaean" phrases (trochaic trimeter) in the florid style. The fronts contain the pitches, and the backs contain the corresponding rhythmic values.

f) Class 4 fronts and backs [see figure 5]. "Archilochan" phrases (iambic tetrameter) in the florid style. The fronts contain the pitches, and the backs contain the corresponding rhythmic values.

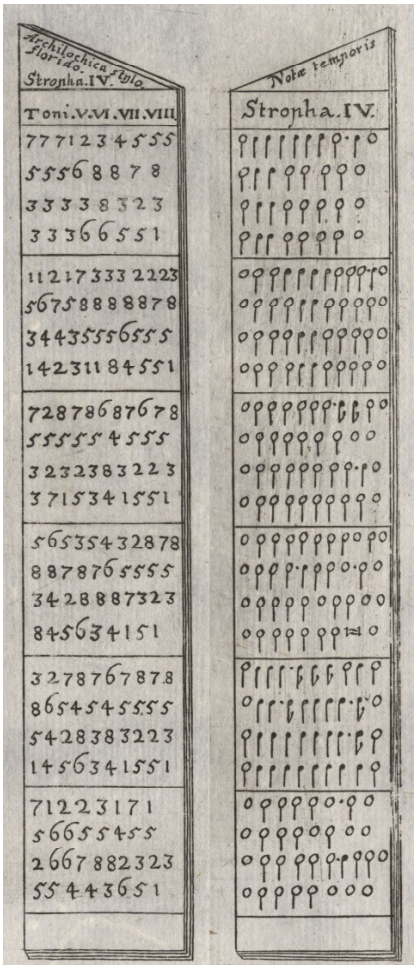

Figure 5: *Class 4 front and back for the 4th strophe .*

The Class 5 columns contain information used to coerce pitches into the correct register, based on the tonic of the scale in use, and the vocal part (Soprano, Alto, Tenor, Bass). This information appears, in altered form, on the front panel of the Arca.

The Class 6 columns include the *tabellae tonorum* (tone tables), which are employed to convert digits to pitch values, using eight different modes or scales. These same tables appear on the underside of the lid in Kircher's illustration of the Arca. These tables are used to convert the digit values in Kircher's note phrases to specific pitche classes, depending on the mode or scale the composer chooses.

I had some difficulty with these because in music notation of the period, the note B is sometimes implicitly assumed to be flatted, and it is difficult for me to always be certain where Kircher intended it. The tables roughly correspond to the following medieval church modes: Dorian, Hypodorian, Phrygian, Hypophrygian, Lydian, Hypolydian, Mixolydian, Hypomixolydian. The correspondence with these modes is not exact, and I have tried to be true to what Kircher & Schott notated, rather than what is generally documented about these modes.

Input Parameters. My software is a Perl script that is operated from the command line. A typical invocation of the script is shown below.

```
organum.pl -li 5 -csn 6 -mi 6 -rnd -tempo 180 –vl 2
```

These parameters indicate to use lyric-number 5 (from a database of lyrics), card-set 6 (which corresponds to the class 4 "Archilochan" tables), mode 6 (hypolydian), random phrase selection, a MIDI tempo of 180, and to preserve voice leading for step-wise motion of 2 half-steps.

The Algorithm. My algorithm is essentially a nested loop which processes each note of each phrase of each voice (SATB).

A set of phrases are selected from each of four cards, in sequence (the phrases on the last card typically have cadences). If the user has indicated the –rnd parameter, phrases are randomly chosen, otherwise, phrases the user explicitly selects are used. If the cards use simple style counterpoint, then rhythmic phrases are also chosen, in a similar manner. For florid counterpoint, there is only a single choice of rhythmic values for each phrase.

Figuring out the rhythmic value for each note involves nothing more complicated than a table lookup, to retrieve the values specified in the tables.

Figuring out the pitches is a little more complicated. The pitch class of each note (C,C#,D etc.) is obtained by looking up the note number in the list of pitch values for the current mode. Choosing the register (the octave) is a little more complicated. First an appropriate octave is chosen based on the register of the voice and the information from the class 5 data column. In addition, an attempt is made to preserve stepwise motion, allowing the melody to stray slightly outside of the register, if small intervals are being used in the melody.

The three aspects of implementation that have given me the most trouble are a) choosing correct pitch values for Kircher's modes, b) transcribing Kircher's note durations correctly, and c) avoiding awkward leaps in melodic lines, while still honoring the spirit of Kircher's algorithm.

Format of results. My software produces files in the ABC format which contain information for both a MIDI version, and a printed score [figure 6]. In addition, I have produced "sung" versions using Flinger, a text-to-song package written by the late Mike Macon.

The sung versions are produced by producing 4 separate MIDI files (one per melodic line) which contain embedded syllables, from a lyric file which contains phonetic transcriptions of the original latin. The Flinger software converts these to separate audio files, which may then be mixed together and post-processed to add some reverb, using an off-the-shelf audio editor.

Discussion

In implementing this software, and researching Kircher's algorithm, a number of questions occurred to me, which I'll raise here for discussion.

Is it disingenuous to call Kircher's procedure an algorithm? If you define algorithm as "a sequence of well defined instructions," than clearly Kircher's procedure was intended to be an algorithm. However, it was an algorithm intended for humans, and not machines, and as such, it contains a few steps that are difficult to translate into software. For example, Kircher suggests choosing modes based on the character of the selected hymn, and helpfully provided a list of adjectives for each mode such as "heroic," "magnificent," "pius" and so on. To my less delicate and more modern ears, his choice of adjectives seems quite arbitrary, so I have instead chosen modes based on whether they "sound good" or simply by using a random number generator.

Was it the first music algorithm? No. If Kircher's procedure is to be called an algorithm, then so is any well defined musical procedure, such as species counterpoint, which precedes Kircher. Kircher's procedure differs from species counterpoint however, in his use of combining phrases from a fixed set, which appears to be a novel compositional technique of Kircher's, inspired by Lull and Mersenne.

Was it intended for mechanical computation? Although words like "mechanicam" and "artificium" appear repeatedly in Kircher's writing about this process, it seems clear he is talking about human labor. Nonetheless, elsewhere in *Musurgia Universalis*, Kircher wrote about a number of intriguing automatic instruments of the time, such as an elaborate water-powered barrel organ. So it is compelling to ask if Kircher might have put 2 and 2 together and imagined a clockwork machine used for the purposes of composing music. If he had such thoughts, he did not write them down in *Musurgia Universalis*. The closest he came to inventing such a machine is his revolving bell choir (a working reproduction can be seen and heard at the Museum of Jurassic Technology).

Was it an aleatoric algorithm? Some Kircher enthusiasts, such as David Wilson, have described Kircher's algorithm as producing "random compositions", which implies random selection or chance, the hallmarks of an aleatoric algorithm, such as those developed by John Cage. In my opinion, Kircher probably did not intend for chance to play as big a role in his method as it does in my software implementation. Some of the decisions that I make using a random number generator were intended to be made by humans using their best judgement, such as the choice of modes. However, Kircher himself describes the algorithm as being of use for persons "with no musical knowledge". Since such a person would not necessarily be capable of making informed choices for phrase selection, it seems likely that a certain amount of chance would have crept in, regardless of Kircher's intention.

Are any published hymns based on material from the Organum or Arcas? I haven't found any yet, but admittedly, I haven't looked very hard. Since the material produced by Kircher's algorithm is not of particularly high quality, I doubt that any composers of lasting merit would have made much use of it. Interestingly, Kircher himself provides very few complete examples in *Musurgia Universalis* which are derived from his own Arca tables.

Veni Creator Spiritus

Athanasius Kircher (German/Jesuit)

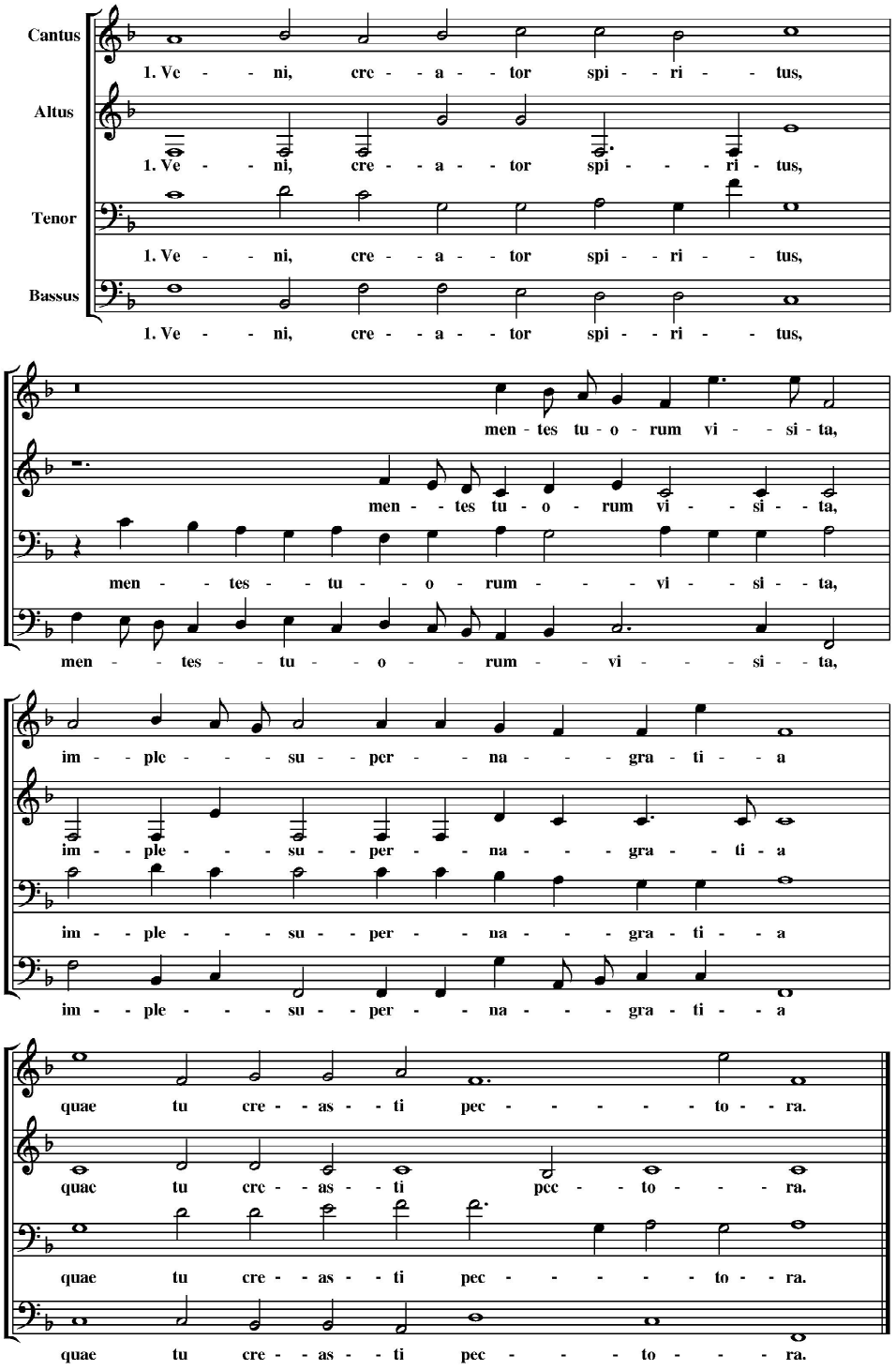

Figure 6 :
Sample Output, using the Class 4 Tables.

Are the phrases in the Arca derived from music in vogue at the time or was the material all written by Kircher? This will be a tough question to answer, since little printed music survives from this period. Also the somewhat uniform and redundant style of the polyphonic snippets used by Kircher may closely resemble other music that wasn't explicitly copied.

Sources

My Perl software program, Organum, can be downloaded at my website:

http://www.krazydad.com/organum.zip

References

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[6] Murata, Margaret, *Music History in the Musurgia universalis of Athanasius Kicher*, in *The Jesuits: Culture, Sciences, and the Arts, 1540-1773*, J. O'Malley, T. F. Kennedy, S. Harriss, et al., eds (Toronto: University of Toronto Press), pp 206, 1999

[7] Schott, Kaspar, *Organum Mathematicum*, pp 761-857, 1668