ART OF THE FUGUE

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Abstract
The evening lecture on August 21 attempted to shift the minds of the listeners to a level which would be different, yet not disconnected, from Physics, and from the contemplation of complex creations of Man. After a brief introduction to the Physics of the pipe organ, these Program Notes describe and discuss the music played at the organ of the Church of St. Clement's in Prague [1]. The lecture concludes with some additional rumbling about Music, Computing, Exuberance and Humility.

1 THE PIPE ORGAN

The pipe organ is an early, mechanical, Fourier synthesizer. Pipes are arranged in a matrix:

- each row corresponds to a given “timbre” (e.g. flute, trumpet, ...), and has one pipe for each pitch (i.e. for each key on the corresponding keyboard or pedalboard). This is called a "rank of pipes" or a "stop". The timbre (color) of the sound depends on the type of the pipe (flue or reed, open or closed end), on its shape (cylindrical, conical, ...), on the proportion of the pipe diameter to pipe length, and on other, more subtle parameters.

- each column corresponds to a given pitch (key), and has one pipe for each timbre. For flue pipes, the pitch is given by the pipe length. For reed pipes, the reed determines the pitch, with the pipe serving as a resonator.

For a particular pipe (of given pitch and timbre) to sound, two conditions must be fulfilled:

1) compressed air has to be available in the air channel beneath the particular row. This is done by pulling the lever corresponding to the desired stop (hence the phrase: “pulling out all the stops”). In a complex piece, this is a complex job for an organist's helper. On some organs, the real-time registration is made easier by technical means, but this organ is purely mechanical. [i] [I wish to acknowledge today's registrant, Vera Grandeova, and thank her for agreeing to a hectic practice schedule of learning where all these stops are...]

2) The valves of pipes of desired pitch have to be open - by the organist's fingers and feet ... (J.S.Bach was quoted as saying that organ playing is quite simple: just push the right keys at the right time ...)

Don't be misled by the small number of pipes you actually see - this is just a facade! Since a manual keyboard has a range of 4.5 octaves, and the pedalboard spans 2.5 octaves, the total number of pipes can be calculated as

N_pipes = N_manual_ranks * 4.5 octaves * 12 keys / octave +
N_pedal_ranks * 2.5 octaves * 12 keys / octave

The organ at St. Clement's has 3 manuals with 7 ranks each, and a pedalboard with 6 ranks, for a total of about 1800 pipes (there are various subtleties such as "mixtures" which complicate things, so that there is a distinction between a rank and a stop, but this gives you an idea.) So this is a

[i] This organ is purely mechanical, except for the air supply which is provided by electric blowers feeding the bellows. (Before electricity, this was provided by assistant(s) pumping the bellows manually.)

medium-size organ. As an example of a large organ, the instrument at Sidney Opera House has 5 manuals and a pedalboard, with a total of over 10,000 pipes (and all action is mechanical, and the performance can be recorded in MIDI format and played back on the same organ another evening, without the organist!)

There is much interesting Physics involved in pipe organs. Let me give you an example. Everyone knows that real strings are slightly inharmonic: due to the string stiffness, the frequencies of the harmonics are not exact integer multiples of the fundamental. This has an important influence in the tuning of the piano. Real pipes are slightly inharmonic, too (the finite diameter of the pipe results in a correction to the "effective length" of the pipe, and this correction is frequency dependent.) However, in contrast with the case of a piano string, the pipe sound is strictly harmonic! I will not give you the explanation here, but it is quite interesting. Other aspects of Pipe Organ Physics include the issues of tuning and temperament, scaling, room acoustics, and many more [2]. A rather fundamental issue concerns the imperfections, and sound irregularities. Most of them are just an unavoidable outcome of various little mistakes and imprecisions on the part of the organ builder and/or the organ tuner, but all mathematically perfect electronic organs are immediately recognized as artificial. So the question is: how much imperfection is needed to achieve the perception of perfection?

In any case, since - in addition to physics - music can be done on the instrument, the pipe organ is an ideal playground for a physicist.

2 THE MUSIC

Johann Sebastian Bach (1685 - 1750): The Art of Fugue.

Bach's Art of Fugue represents, at least, a triple art:

- the art of fugue writing
- the art of fugue playing (I am working on it)
- the art of listening to a fugue

The third category is by no means trivial. In a fugue, there is an inherent (and valuable) ambiguity between the melody (or rather melodies, with many overlapping voices) and harmony. To achieve the right balance between the perception of the melody and of harmony is not easy, but it can be extremely rewarding ...

The Art of Fugue is one of the great cycles in which Bach systematically explored and exhausted huge segments of the musical idiom (the other cycles include the Well-Tempered Clavier, the Musical Offering, and the Goldberg Variations.) Based on a common and rather simple Theme, Bach goes through all imaginable developments, inversions, transformations and other tricks, and he does it with all kinds of sentiment - joyful, boisterous, or pensive and reflective.

This selection is meant to dispute the belief that the Art of Fugue is just an academic work, dry and scholarly, not intended for performance. Note that the collection was written as a "device-independent" work, i.e. no particular instrument was specified by Bach. Some time ago, a Seattle City plumbing inspector came to inspect a newly installed furnace, just as I was practicing. He remarked that the only satisfactory performance of the Art of Fugue he ever heard was by the Canadian Brass Quintet. Before you jump to the conclusion that the country where plumbers are knowledgeable about counterpoint has come a long way, I must mention that his name was Giovanni, and he talked with the corresponding accent. But I don't agree with Giovanni: I think the pipe organ is best for the Art of Fugue - the various voices can be differentiated while maintaining the fusion necessary for the simultaneous appreciation of the harmony.

The participants may recall that the performance started with a brief demonstration of organ registration, illustrated on Czech folksongs. Then followed 6 Fugues from the Art of Fugue:

a) Contrapunctus I: a 4-voice fugue on the main subject, with a persistent two-note subsidiary motif (under-emphasized in most performances). Note how much is going on, even before the feet join in (in the last few bars.)

b) Contrapunctus IX: a 4-voice fugue with two subjects. The secondary subject is developed first. When everything goes well with the performance, it is a riot - I wonder how JSB played it. The tape recorder was invented much too late!

c) Contrapunctus VIII: a 3-voice fugue with three subjects. The main subject, inverted and rhythmically modified, joins in after the two secondary subjects are fully developed. The finale contains five different realizations of the three voices singing all three subjects at once. Within the last two measures, the sparkling brook of the piece arrives at its destination.

d) Contrapunctus VII: a 4-voice fugue containing the slightly modified main theme and its inversion, in three tempi: normal, slow and very slow. This is often performed as fast, normal and slow, but then the deeply reflective nature of the subsidiary but ubiquitous four-note motif is completely lost. Please feel free to meditate.

e) Contrapunctus XI: a 4-voice version of c). It contains the same three subjects, plus their inversions, plus some quite dissonant subsidiary lines. This is one of the most chromatic and "modern" pieces Bach wrote. I feel very fortunate that I am able to appreciate this piece: it is as if Bach invited me to come visit him at home.

f) Contrapunctus VI: a simpler but powerful, optimistic, uplifting complement to d). The 4 voices sing the subject in two tempi and frequent subsidiary tirades "in Stile francese". The finale expands to 5 and then to 8 voices.

INTERMISSION

2.1 J.S.Bach: Toccata and Fugue in d

This is perhaps the best-known composition by Bach. It is, in fact, quite simple in structure, but very effective. In the US, it is considered somewhat eerie and it is played mostly at Halloween, scaring small children. In Europe, it is often played at weddings. Obviously, the interpretation is quite different in the two cases. I am happier at weddings.

2.2 Petr Eben: Sunday Music (excerpts)

Composed in 1958 by a young composer in a communist Czechoslovakia on motifs of Gregorian chants. You can imagine that this was not seen as contributing to the formation of the Brave New World. Performance of this work on this particular date has a particular significance (a little history quiz question...)

The whole, unabridged piece is an "organ symphony" lasting 45 minutes! The selection for this performance emphasizes the religious aspect of the piece.

a) Fantasia II. Notice the sounds of bells of all kinds (hence: Sunday Music)

b) the ancient Gregorian "Kyrie Eleison" on which much of this composition is based (in the best contrapuntal style, but with the 20th century dissonant harmonies).

c) Fantasia I (fragment). The considerable power of the full organ makes a statement of triumph colored by the dissonance of suffering.

3 CONCLUDING THOUGHTS

It is compelling to reflect on similarities, and differences, between the life, religious faith, and music, of Eben, and those of Bach. I cannot resist pondering how Bach would compose today. However, this is a School of Computing, and I would like to close by pointing out some connections. On a fairly straightforward level, I offer this quote [4]:

"Programming is the art of constructing a static description, the program code, of a dynamic process, the behavior which results from running the program. In that sense, it is analogous to composing music. The program code is like a musical score, whose purpose it is to cause the performer [in the programming case, a computer] to perform a set of actions over a period of time. What makes programming cognitively difficult is that the programmer must imagine the dynamic process of execution while he or she is constructing the static description, just as a composer must "hear the piece" in his or her head, while composing. "

On a somewhat more indirect level, I should like to suggest that there is a connection to the subject of my "computing" lectures at this School [5] . There, I described the "post-modern" criticisms of Technology in general, and Computing and Information Processing in particular, and I suggested that we temper our justified exuberance about the marvelous things we are lucky to be doing, with an equally justified dose of humility (see also ref. [6]). And so we should listen to Johann Sebastian Bach more often at our Meetings, Conferences and Schools.

4 FOOTNOTES AND REFERENCES

[1] Short snippets from the performance, as well as complete MIDI recordings of the Fugues, and additional Musico-Logical [sic] considerations, can be found on my WEB site: http://www.phys.washington.edu/~vladi

[2] A good introduction to the physics of pipe organ can be found in "Musical Acoustics" by D.E. Hall and/or in "Science of Sound" by T.D.Rossing. The book by Hall contains a particularly good discussion of the issues of tuning and temperament; both books contain many valuable references. An advanced treatment of many aspects of Physics of Music can be found in "Physics of Musical Instruments" by Fletcher and Rossing.

There is a good reason for even recently-constructed organs to use mechanical transfer of the key motion to the valves on each pipe - it gives the organist much better control over the sound envelope, when compared to electro-pneumatical systems. A good analogy is the feeling of the old-fashioned "rack and pinion" steering in a car, as compared with power-assisted systems.

The issues of scaling is particularly important for performance of contrapuntal music. To realize all pitches of a given rank (say flutes), it is not sufficient to just vary the lengths of the pipes. The science (and art) of scaling consists of varying other parameters, such as the pipe diameters, in a way which will produce good behavior of sound volume and timbre across the whole pitch range of the rank.

As to the room acoustics: I measured the reverberation time (time it takes for the sound intensity level to drop by 60 dB) at St. Clement's . I obtained an average value of 2.8 seconds (with larger values at low frequencies, as it should be.) For comparison, I have played organs in halls with the reverberation time ranging from an unforgiving 1.1 sec, to a merciful (but mushy) 6 sec.

[3] In fact, the recording which changed my attitude towards organ music is the only organ recording by the legendary pianist Glenn Gould (The Art of Fugue, Contrapunctus I - IX; the recent SONY release of this old vinyl recording on a CD also contains 4 additional fugues played on

the piano.)

[4] From "Bridging the Gulf Between Code and Behavior in Programming", by H. Lieberman and Ch. Fry, http://lcs.www.media.mit.edu/people/lieber/Lieberary/ZStep/Bridging/Bridging.html

[5] V.Chaloupka, "Human Aspects of Computing in Large Physics Collaborations", this Proceedings.

[6] V.Chaloupka: "Variations on GEBH", Proceedings of the BNL Workshop on Hybrid and Exotic Mesons, 1989. Also available from my WEB page (ref. [1]). This is a somewhat fanciful description of an after-dinner talk on the subject of the book "Goedel Escher Bach" by D.Hofstadter.