

Discovering novel computer music techniques by exploring the space of short computer programs

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Abstract

Very short computer programs, sometimes consisting of as few as three arithmetic operations in an infinite loop, can generate data that sounds like music when output as raw PCM audio. The space of such programs was recently explored by dozens of individuals within various on-line communities. This paper discusses the programs resulting from this exploratory work and highlights some rather unusual methods they use for synthesizing sound and generating musical structure.

1 Introduction

During the history of computer music and algorithmic composition, a plethora of technical and mathematical concepts has been tried out, ranging from simple shift registers and cellular automata to complex physical and statistical models. It is easy to get the impression that every potentially useful simple concept has already been at least superficially studied.

In order to find new, computationally simple concepts useful for low-complexity computer music, a rather non-systematic excursion was undertaken into the space of very short computer programs that output raw sound data.

The excursion started from a set of seven short C-language programs that were presented in a YouTube video[1]. As the video gained widespread attention, several individuals spontaneously contributed their own programs, some of which were also collected in a text file[2]. There was never any coordination of the explorative process, although two additional YouTube videos presenting newly found programs were produced[3][4] and two blog posts were written on the subject[5][6]. The analysis in this paper has mostly been based on the latter post.

The interest shown on various on-line communities towards the explorative process and the resulting music suggests relevance to artistic practices such as demoscene, glitch art, chip music and live coding. The term “bytebeat” was recently coined for referring to the type of music.

2 Technical framework

The short C programs that initiated the explorative process follow the form

```
main ()
{
  int t=0;
  for (; t++) putchar (EXPRESSION);
}
```

where *EXPRESSION* is where all the variation takes place. While the expression is typically evaluated with 32 or more bits of integer accuracy, only the eight lowest bits of each result show up in the output. These bytes are to be interpreted as unsigned 8-bit PCM sample values with the rate of 8000 samples per second, which is the default configuration of the usual command-line audio output methods available on Linux and some other Unix-like operating systems, i.e. the */dev/dsp* device file and the *aplay* utility.

The most fruitful stage of the exploration started with the appearance of an on-line tool[9] that allowed the user to enter an expression and immediately listen to its output. Another, slightly later tool[10], based on Flash, allowed for real-time modification of the expression. These tools are based on JavaScript and ActionScript, respectively, and therefore follow the conventions of said languages. The expression syntax of these languages is similar to that of C, but the differences in functional details introduced some compatibility problems.

All the expressions featured in this paper belong to a subset of C expressions where function calls are not allowed and the only variable is the time counter *t* which is never modified within the expression. This subset is fully compatible with the on-line tools, and it covers a majority of the collected expressions. The following table summarizes the available operators in order of precedence.

bitwise complement, type cast	~	()
multiplication, division, modulus	*	/ %
addition, subtraction	+	-
bit shift left/right	<<	>>
less/greater than (or equal to)	<	<= > >=
(not) equal to	==	!=
bitwise AND	&	
bitwise exclusive OR	^	
bitwise inclusive OR		
ternary conditional	? :	

As the expressions have a lot of bitwise operations and the usual mathematical notation for them is quite cumbersome, plain C expression syntax will be used throughout. Table xxx lists the operators in order of precedence.

3 Findings

3.1 General properties of the expressions

The October 2011 version of the oneliner music formula collection[2] contains 71 formulas, 58 of which fall within the previously-defined subset of C expressions.

Bitwise operations and bit shifts feature prominently in the collected expressions, on all levels of music generation. In fact, the only one that lacks these operations altogether is the trivial minimal example: t . It has been very difficult to find prior examples of such a reliance on binary arithmetic in music, so we may assume that binary arithmetic are often used in novel ways in the expressions.

Many of the expressions have been discovered purely by chance. Several contributors have admitted that they do not understand the inner workings of their discoveries at all. The longer expressions, however, often show a more structured and deterministic approach. The more structured expressions are also more likely to use** more traditional approaches than those based on trial-and-error discoveries.

3.2 Bitwise operations with amplitude values

One of the most interesting short expressions consists of a bitwise AND between a fast-changing and a slow-changing subexpression. Expressions like

$$t \& t \gg 8$$

came to be called “Sierpinski harmonies” because the plotted amplitude values form a pattern that resembles a Sierpinski triangle. When listened, a Sierpinski harmony appears to have a multitonal melody with mostly octave intervals.

The first subexpression in $(t \& t \gg 8)$ is t , which forms a simple eight-bit approximation of a sawtooth wave. In order to understand what the bitwise AND does to this wave, we will analyze this wave as a sum of eight square waves, each of which corresponds to a single bit in the amplitude value:

$$(t \& 128) + (t \& 64) + (t \& 32) + \dots + (t \& 1)$$

Normally, the harmonic contents of these square waves are interpreted by the human brain as belonging to a single timbre. However, when a new square-wave component is introduced abruptly, it is likely to be interpreted as a separate tone. One can test this effect by comparing the hearing experience of

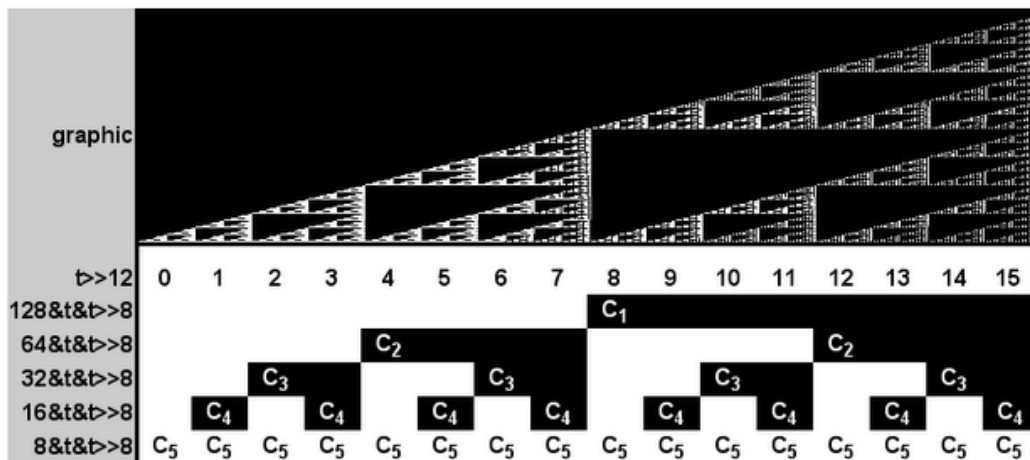
$$t \& 96$$

to that of

$$t \& 96 \& t \gg 8$$

which contains the same combination of two square waves in the end.

The figure below demonstrates the harmonic and melodic progression of the Sierpinski harmony $t \gg 8$.



If we speed up the carrier wave with a ratio that is not a power of two, we will get non-octave intervals between the component waves. In

$$3 * t \gg 8$$

the melody differs clearly from $t \gg 8$. The reason for this is that the higher-pitched square waves become dominated by their alias waves that harmonize with the Nyquist frequency instead of the carrier.

When combining several Sierpinski harmonies with different carrier and modulator speeds we can get more complex melodies, often sounding like lullabies. Examples from the collection include:

$$t * 5 \gg 7 | t * 3 \gg 8$$

$$t * 5 \gg 7 | t * 3 \gg 10$$

$$t * 9 \gg 4 | t * 5 \gg 7 | t * 3 \gg 10$$

The expression from “Rrrola”,

$$t * (0xCA98 \gg (t \gg 9 \& 14) \& 15) | t \gg 8$$

uses bit-masking for transposing and fading out a short constructed melody element that is encoded as a constant.

More complex musical structures can be formed by combining several bit-shifted modulators with bitwise operators. An example of this would be

$$(t \gg 6 \wedge t \gg 8 | t \gg 12 | t) \& 63$$

which is used as melody generator in a more complex formula that also includes a constructed bassline and a simple drum. This expression, by “Mu6k”, has been analyzed in detail in [6].

The effectivity of long bit shifts for macro-level musical structure is probably related to the effectivity of power-of-two structural ratios in pop music. This is exemplified by concepts such as “eight-bar blues”, “sixteen-bar blues” and “thirty-two-bar form”.

3.3 Pitch values from bitwise arithmetic

Using a tone generator with a variable wavelength is a more traditional method of melody synthesis. The shortest way to do this in our subset of C expressions is by multiplying t with a subexpression that yields suitable pitch values. A simple example, separately discovered by at least three individuals, is what came to be called “The Forty-Two Melody”:

$$t*(42\&t\>>10)$$

In this case, the melody played out with the sawtooth generator t^* is represented by a series of integers formed by zeroing out all bits except three ($42 = 101010_2$) in consecutive binary numbers. In the following figure, the series is translated into familiar names of musical notes.

$t\>>11$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$21\&t\>>11$	1	0	1	4	5	4	5	0	1	0	1	4	5	4	5	16
note	C ₁	ξ	C ₁	C ₃	E ₃	C ₃	E ₃	ξ	C ₁	ξ	C ₁	C ₃	E ₃	C ₃	E ₃	C ₅

$t\>>11$	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32/0
$21\&t\>>11$	17	16	17	20	21	20	21	16	17	16	17	20	21	20	21	0
note	C _{#5}	C ₅	C _{#5}	E ₅	F _{b5}	E ₅	F _{b5}	C ₅	C _{#5}	C ₅	C _{#5}	E ₅	F _{b5}	E ₅	F _{b5}	ξ

Integer series with high values are likely to contain intervals that are dissonant to Western listeners. Modulus can be used to restrict the values into a more familiar range while retaining the effect of the higher bits:

$$t*((42\&t\>>10)\%14)$$

A series that ands with 42 (or 21) has a repetitive cycle of 32 pitch value changes. An example of a much longer series of pitch values formed by a simple expression is

$$((t\>>10)\^(t\>>10)-2)\%11*t\&64$$

where the pitch value depends on the number of zero bits in the end of $t\>>10$ which is used as the index to the series. The first sixteen notes are given by the following table.

i	$(i^i-2)\%11$	note
0000 ₂	-2	C ₂
0001 ₂	2	C ₂
0010 ₂	6	G ₃
0011 ₂	2	C ₂
0100 ₂	3	G ₂
0101 ₂	2	C ₂
0110 ₂	6	G ₃
0111 ₂	2	C ₂
1000 ₂	8	C ₄
1001 ₂	2	C ₂
1010 ₂	6	G ₃
1011 ₂	2	C ₂
1100 ₂	3	G ₂
1101 ₂	2	C ₂
1110 ₂	6	G ₃
1111 ₂	2	C ₂

3.4 Modular wrap-around of amplitude values

In ordinary software synthesis, the overflowing of an amplitude value is generally regarded as an avoidable artifact. In many expressions in the formula collection, however, these artifacts form an integral part of the resulting sound. A dramatic example would be a modification of (),

$$(t*9\&t \gg 4 | t*5\&t \gg 7 | t*3\&t \gg 10) - 1$$

where the simple subtraction -1 effectively introduces a percussive instrument by turning minimum amplitude values into maximum values. As we have not conducted spectral analysis for expressions that use modular wrapping, we will merely give a set of expressions where the wrap-around is used for various effects.

$$(t\&t\%255) - (t*3\&t \gg 13\&t \gg 6)$$

$$(\mathbf{int})(t/1e7*t*t+t)\%127 | t \gg 4 | t \gg 5 | t\%127 + (t \gg 16) | t$$

$$t \gg 6 \& 1 ? t \gg 5 : -t \gg 4$$

$$t \gg 4 | t \& ((t \gg 5) / (t \gg 7 - (t \gg 15) \& -t \gg 7 - (t \gg 15)))$$

The second and fourth example divide by zero, so they will not work directly in most implementations of C.

4 Conclusion

The collected expressions extensively use binary and modular arithmetic in unusual ways we have not been able to find prior examples of. This makes it apparent that new computational techniques for generation of sound and music have been discovered with a simple trial-and-error methodology during the exploration.

The discovery process could be enhanced by various means. New formulas could be generated automatically or semi-automatically by using genetic algorithms or other techniques. A dedicated social website with a voting capability would be helpful for separating interesting discoveries from less interesting ones.

Many individuals participating in the exploration have found the C-like infix syntax limited and cumbersome for the purpose. It is, for example, difficult to reuse previously computed values. This has already given birth to several software projects that combine the technical concept of “bytebeat” with a Forth-like RPN syntax: an iOS application called GlitchMachine[7], a free Python reimplementaion called libglitch[8], and a not-yet-released audiovisual virtual machine called IBNIZ. It can be assumed that increasing the range of available programming constructs would make it possible to discover new, musically interesting algorithmic concepts that cannot be found in the expression space we have been exploring so far.

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