# SMURF

*Serial MUsic Represented as Functions*

Richard Townsend, Lianne Lairmore, Lindsay Neubauer, Van Bui, Kuangya Zhai
{rtownsend, lairmore, neubauer, vbui, kyzhai}@cs.columbia.edu

September 23, 2013

## 1 Background: What is Serialism?

In general, serialism is a musical composition technique where a set of values, chosen through some methodical process, generates a sequence of musical elements. Its origins are often attributed to Arnold Schoenberg's twelve-tone technique, which he began to use in the 1920s. In this system, each note in the chromatic scale is assigned an integer value, giving us a set of twelve "pitch classes" (Figure 1). A composer utilizing this method then takes each of these integers, and orders them into a *twelve tone row*, where each number appears exactly once. We refer to this row as the *primeform* of a piece, and conventionally refer to it as $P_0$.

The composer can then generate other rows that are derived from $P_0$ through three types of transformations: transposition, inversion, and retrograde. In each of these transformations, we always use mod 12 arithmetic to preserve the numbering system of our pitch classes. Transposing a row consists of taking each pitch class in the row and adding the same number to each. If we transpose $P_0$ by four semitones, we add four mod twelve to each pitch class in $P_0$ and end up with a new row called $P_4$. In general, $P_x$ is a transposition of $P_0$ by $x$ semitones. To invert a row, we flip each interval between two pitch classes in that row. For example, if $P_0$ starts with pitch classes 0-4-1, then we have an interval of +4 between the first two pitches and -3 between the second two. In the inverse of $P_0$ (called $I_0$), the first interval would be -4 and the second would be +3, giving us 0-8-11 as our first three pitch classes. The subscript of $I_x$ refers both to the number of transpositions required to arrive at $I_x$ from $I_0$, and to the prime row $P_x$ that would need to be inverted to generate $I_x$. The final row operation is a retrograde transformation, which merely consists of reading a row backwards. That is, $R_x$ is generated by reading the pitch classes of $P_x$ in their opposite order. One can also have a retrograde inversion; $RI_x$ is generated by reading the pitch classes of $I_x$ backwards.

Once a composer chooses a $P_0$, the three transformations outlined above can be applied to varying degrees to generate a *twelve tone matrix*, which will contain each $P$ row as a row in the matrix and each $I$ row as a column. Furthermore, all of the $R$ and $RI$ rows are found by reading the rows in the matrix from right to left or the columns from bottom to top, respectively. An example of a twelve tone matrix from one of Shoenberg's pieces can be found below (Figure 2). Finally, using the twelve tone matrix as a guide, the composer picks various rows and columns to serve as melodic and harmonic elements in their composition, resulting in a piece of serial music.

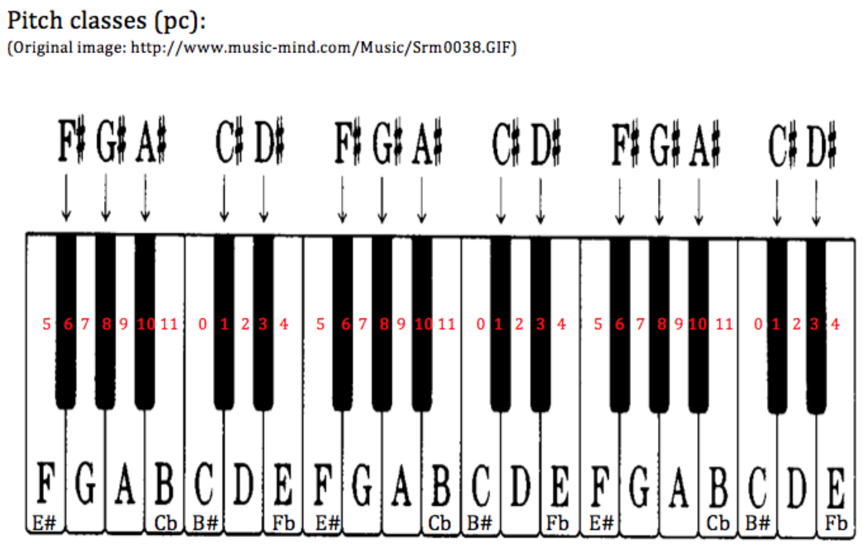
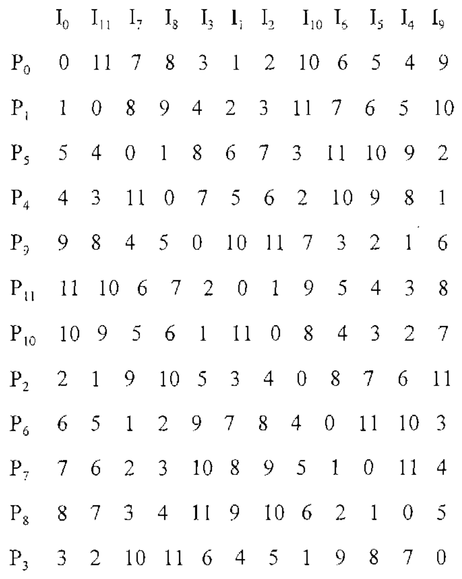

Pitch classes (pc):
(Original image: http://www.music-mind.com/Music/Srm0038.GIF)
F♯ G♯ A♯ C♯ D♯ F♯ G♯ A♯ C♯ D♯ F♯ G♯ A♯ C♯ D♯
5 6 7 8 9 10 11 0 1 2 3 4 5 6 7 8 9 10 11 0 1 2 3 4 5 6 7 8 9 10 11 0 1 2 3 4
F G A B C D E F G A B C D E F G A B C D E
E# Cb B# Fb E# Cb B# Fb E# Cb B# Fb

Figure 1: pitch classes



| | $I_0$ | $I_{11}$ | $I_7$ | $I_8$ | $I_3$ | $I_1$ | $I_2$ | $I_{10}$ | $I_6$ | $I_5$ | $I_4$ | $I_9$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_0$ | 0 | 11 | 7 | 8 | 3 | 1 | 2 | 10 | 6 | 5 | 4 | 9 |
| $P_1$ | 1 | 0 | 8 | 9 | 4 | 2 | 3 | 11 | 7 | 6 | 5 | 10 |
| $P_5$ | 5 | 4 | 0 | 1 | 8 | 6 | 7 | 3 | 11 | 10 | 9 | 2 |
| $P_4$ | 4 | 3 | 11 | 0 | 7 | 5 | 6 | 2 | 10 | 9 | 8 | 1 |
| $P_9$ | 9 | 8 | 4 | 5 | 0 | 10 | 11 | 7 | 3 | 2 | 1 | 6 |
| $P_{11}$ | 11 | 10 | 6 | 7 | 2 | 0 | 1 | 9 | 5 | 4 | 3 | 8 |
| $P_{10}$ | 10 | 9 | 5 | 6 | 1 | 11 | 0 | 8 | 4 | 3 | 2 | 7 |
| $P_2$ | 2 | 1 | 9 | 10 | 5 | 3 | 4 | 0 | 8 | 7 | 6 | 11 |
| $P_6$ | 6 | 5 | 1 | 2 | 9 | 7 | 8 | 4 | 0 | 11 | 10 | 3 |
| $P_7$ | 7 | 6 | 2 | 3 | 10 | 8 | 9 | 5 | 1 | 0 | 11 | 4 |
| $P_8$ | 8 | 7 | 3 | 4 | 11 | 9 | 10 | 6 | 2 | 1 | 0 | 5 |
| $P_3$ | 3 | 2 | 10 | 11 | 6 | 4 | 5 | 1 | 9 | 8 | 7 | 0 |

Figure 2: twelve tone matrix

## 2 Motivation

Our group has decided to create a language that will assist a composer in creating music using the twelve tone method described above. We plan on making this language functional and compile into C. The compilation process will create a C program that will use openGL to create an image representing the music created.

Twelve tone serialism is a mathematically intensive method of creating music which involves mapping notes to numbers. It is very natural to work with twelve tone rows using a programming language since the method just treats notes like numbers that can be added and subtracted from. We plan on our language making twelve tone compilation easier using data types and functions specifically for the purpose of creating music in this way. By simplifying the method of inverting and transposing rows composers can focus more on how to exploit new ways to make music in this fashion and worry less about creating matrices.

We chose to implement our language as a functional language because of the clear and succinct programs that functional languages produce. It also makes sense for our language to be functional because functional languages also are well known for their ability to work on lists and most arithmetic done in twelve tone serialism is done on rows or columns. As a group we are also very interested on how a functional language compiler works.

Instead of compiling our language into byte code which can be interpreted and play the notes we thought it would be more interesting to create a language that could be compiled into a score. Scores are made up of just lines and dots and would be easy to create in a graphics library like openGL. We decided to compile our language into C since it was a significantly less abstract language which had access to openGL library calls. One benefit of compiling into C and not a language to be interpreted as music is that programs in our language could be created that do not actually output any music but instead create functions that could be used in other programs to do the same transformation of rows. That way our language is not just limited to functions defined in our libraries or what is in the current file.

Overall we hope to use the simplicity of a functional language to help composers write complex, new, and interesting music based on twelve tone serialism. These new compositions would then be able to be printed and handed to musicians to play. This simplifies the composers task of converting music in computer format to one which musicians will be able to read easily.

# 3 Syntax

SMURF is a functional programming language loosely modeled off of Haskell. It has immutable memory, no global variables and no I/O.

## 3.1 Types

### 3.1.1 Standard Types

- Integer: int
- Boolean: bool
- Tuples: elements can have different types
- Lists: elements must have same type

### 3.1.2 Note (pc: int, beat: int, register: int)

- pc (pitch class): represented by integers 0-11
- beat: represented by powers of 2 up to 32 (assuming $\frac{4}{4}$ time)
- register: represented by integers -2 to 2
  - 𝄞 Treble Clef: notes middle C and higher represented by 0-2
  - 𝄢 Bass Clef: notes lower than middle C represented by negative numbers

### 3.1.3 Chord ([Note])

- Type checks that all notes have same beat count

### 3.1.4 Figure ([Chord])

### 3.1.5 Functions

A function is a type whose value can be defined with an expression

- Function declarations must declare type (can declare general type)
- Function declarations must be on own line
- No explicit return
- Pattern matching, guards, and if-then-else clauses used
  - Each pattern matching pattern must be on own line
  - Guards and if-then-else clauses do not have newline restrictions

| Operators | |
|---|---|
| \n | End of line: Terminates phrases |
| + | Integer arithmetic: plus |
| - | Integer arithmetic: minus |
| % | Integer arithmetic: modulus, ignores negatives |
| < | Comparison |
| > | Comparison |
| <= | Comparison |
| >= | Comparison |
| == | Structural comparison |
| not | Boolean operator |
| && | Boolean operator |
| \|\| | Boolean operator |
| ++ | Concatenation: concat |
| : | Construction: cons |
| /* */ | Multiline comments, nesting allowed |
| // | Single-line comment |

| Keywords | |
|---|---|
| let | Specify values and functions |
| –> | Specify arguments and return type of functions |
| :: | Specify types |
| if, then, else | Specify conditional expression, else compulsory |
| \| | Specify boolean expression, used with guards |

## 4 SMURF Examples

### 4.1 Simple Example

The simple SMURF program below first defines the pitch classes for the prime row in line 1. Using the prime row as a base, the program creates a score with a single measure using the notes generated by transposing the prime row by three semitones (line 2), inverting the resulting transposed row (line 3), and then reversing the inverted row from the prior step (line 4). Lines 2-4 use the *trans, inver, and rev* library routines to apply transposition, inversion, and reversal to a list, respectively. Line 5 invokes a library routine called *rowToNotes* that converts each pitch class in a tone row to a list of notes given beat and register value mappings for each pitch class in the tone row. For simplicity, all the notes in this example are quarter notes (4) in register 0. Line 6 defines a measure using the first two notes in the list of notes returned in line 5; the second half of the measure consist of two rest quarter notes in register 0. A rest is defined as a note with pitch class -1. Line 7 uses the keyword **genScore** along with the measure defined in the prior line as an argument. The compiler translates the keyword **genScore** down to C+OpenGL code to create a score sheet based on the given list of measures.

```
1: prime = [0,2,4,6,8,10]
2: p3    = trans 3 prime
3: i3    = inver p3
4: ri3   = rev i3
5: firstNotes = rowToNotes ri3 [4,4,4,4,4,4] [0,0,0,0,0,0]
6: firstMeasure = head firstNotes:(head (tail firstNotes)):(-1,4,0):(-1,4,0):[]
7: genScore [firstMeasure]
```

## 4.2 Interesting Example

TBD