M O D U L O

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Abstract. M O D U L O is a real-time composition tool in the form of a board game and can be played on an android device. In this game there is a close connection between the musical structure and its symbolic representation on the board. The game pieces represent arithmetic operations. These are applied one after the other along a path of the shortest adjacent distances starting from a source tile representing the sequence $id(\mathbb{N}_0) = 0, 1, 2, 3, 4, ...$ The resulting altered mathematical sequences are converted into sounds. The contrahents in this two-person game, place alternately tiles on the board or move them. The goal of the game is to establish an own path by skilful moves, which consists of operations and operands as mutually different as possible and at the same time to prevent the opponent from doing so.

Keywords: algorithmic composition, arithmetic operations, realtime composition, live coding

1 Introduction

In the computer-based board game MODULO (Fig. 1), the entire development process was aimed at ensuring the closest possible connection between the state of the game and the resulting non-trivial sound.

Thus, MODULO is integrated into a series of sonified games in which an attempt is made to establish a clear connection between the course of the game and its musical implementation [5], [1]. As a special feature in comparison to the listed examples it has to be emphasized that the game structure and the game rules of MODULO were obtained directly from musical considerations. Specifically, sequences of a grammar based on arithmetic operations are generated with the help of the game moves which is called **AOG** (**A**rithmetic-**O**peration-**G**rammar).

The creation of musical structures with **AOG** is constructive. There is no harmonic analysis and no correction of the harmonic interactions. This is also not necessary because only relatively small degrees of dissonances are produced and a meaningful organization not only of sound events, but also of their harmonical relationships take place according to the generative rules [2].

Each of the opponents (white / black) in the game has a source tile. The source tile supplies the elements of the mathematical sequence $id(\mathbb{N}_0)$ at fixed time intervals ΔT: $t = 0, 1, 2, 3, 4, 5, 6, ...$ All other tiles represent mathematical

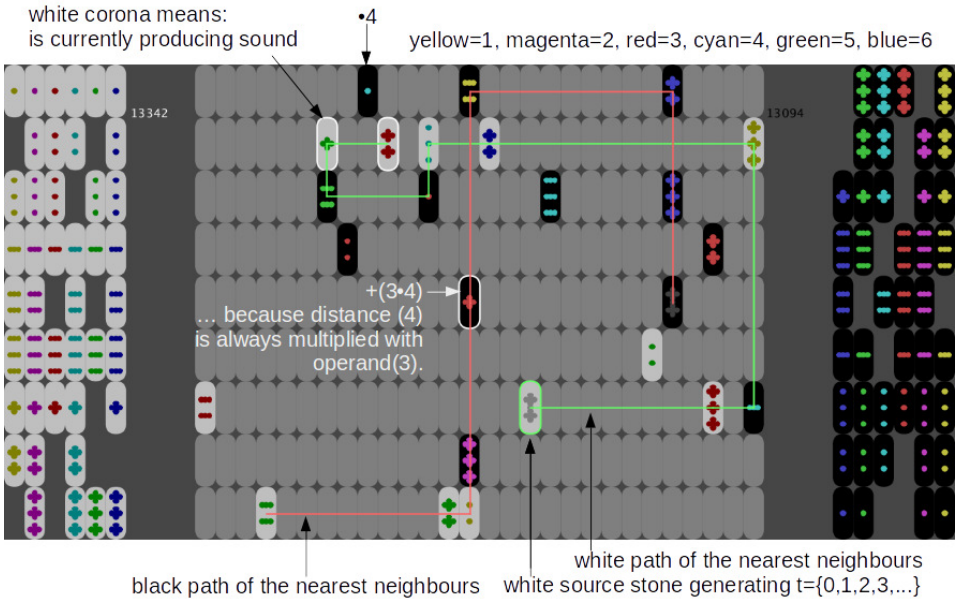

Fig. 1. View of the MODULO playing field.

operations. Starting from a source tile representing t, the arithmetic operations represented by the other tiles are applied sequentially along the path of the shortest orthogonal distances. This path is continued from tile to tile, beginning with the source tile, until one reaches a point where the condition "shortest orthogonal distance" is no longer unambiguous, or the continuation of the path would include a tile that is already part of the same previous path. The pieces included in a path can be white or black. Which player owns a path is determined by the source stone alone. These paths are automatically determined and always displayed: A green line is displayed for the path of the white player, a red line for the path of the black player.

Each tile that is not a source tile represents an arithmetic operation o_i, represented by the symbols $.,..,...,-,--,---,+,++,+++$ and an integer z_i (in the game currently: $1,2,3,4,5,6$, represented by the colors yellow, magenta, red, cyan, green, blue). The number z_i multiplied by the distance s_i to the preceding tile in the path gives the operand which is applied to the sequence t_{n-1} produced by the preceding tile, i.e..: $t_n = o_i(t_{n-1}, z_i \cdot s_i)$, see table 1 and Fig. 1.

The operators proposed here go a little beyond what is common in arithmetic. In order to understand the table, the operators $\neq, ==, \nmid, |$ should also be regarded as a type of filter that allows a number to pass when the condition meant is fulfilled. If, for example, a piece represents a division by two, the new sequence $t' = t/2$ with $t' = 0,0,1,1,2,2,3,3,4,4...$ results from t. The decimal places are omitted in all operations and values smaller than zero are set to zero. In

order to finally obtain sounds from such a sequence, each element of a sequence is interpreted as a divider d_i of a base number b – in the game b is 2520 = $2^3 \cdot 3^2 \cdot 5^1 \cdot 7^1$ – and returns the frequency $f_i = b/d_i$. f_i, however, is only considered if d_i or at least b *modulo* d_i is a true divider of b. What is more, only those frequencies are converted into sounds, which lie within a certain range. In the game it is between 55Hz and 1760Hz. This corresponds to the tones A1 to A6. This mechanism plays the role of a filter that suppresses pitches that have a too large harmonic difference to the overall structure. The sounds are represented by samples that are played by a sequencer program. If the operation of a piece produces an audible sound, it is played immediately and the piece flashes briefly (white border). The integer frequencies are mapped to the tempered tuning. Within the given limits for the frequencies and the given base number, the following scale (midi) results as a summary of all tones that can be formed: $33, 35, 37, 38, 40, 42, 44, 47, 49, 52, 54, 56, 59, 61, 63, 66, 68, 71, 75, 80, 87$.

symbol	symbol in MODULO	meaning	example
$+$	$+$	addition	$\{0,1,2,3,4\} + 3 = \{3,4,5,6,7\}$
$-$	$-$	subtraction	$\{0,1,2,3,4\} - 3 = \{0,0,0,0,1\}$
$\cdot$	$\cdot$	multiplication	$\{0,1,2,3,4\} \cdot 2 = \{0,2,4,6,8\}$
$\neq$	$++$	not equal	$\{0,1,2,3,4\} \neq 3 = \{0,1,2,0,4\}$
$==$	$--$	identity	$\{0,1,2,3,4\} == 3 = \{0,0,0,3,0\}$
$\div$	$\cdot\cdot$	division	$\{0,1,2,3,4\} \div 2 = \{0,0,1,1,2\}$
$\nmid$	$+++$	does not divide	$\{0,1,2,3,4\} \nmid 2 = \{0,1,0,3,0\}$
$\equiv$	$---$	modulo	$\{0,1,2,3,4\} \equiv 3 = \{0,1,2,0,1\}$
$\mid$	$\cdots$	true divider	$\{0,1,2,3,4\} \mid 2 = \{0,0,2,0,4\}$

Table 1: Used operators with examples.

2 Use of the game

The game is played on an Android giant tablet. The opponents sit opposite each other at a table. Thus about two times three meters of space are needed. A good system should be used for the sound. In the actual version a piano sound is used for the white pieces and a pandrum sound for the black ones. Videos of regular games as well as material of an automatically played game can be obtained here: [3]. A version only with piano sound is also available as Android app [4].

2.1 Calculation of the points gained after a move

Along the path of the player whose turn was last, the respective number of different properties in the categories color, form and number are counted for all game pieces involved except for the source tile. So you count how many different colors [1...6] there are for the pieces along the path, how many different numbers, and basic signs (each [1...3]) there are for the symbols of the involved tiles. For example the symbols (+++) and (++) have two different numbers in the appearance of their basic sign +, namely 2 and 3, whereas both have one and the same basic sign +. These three key figures (different colors, shapes and numbers) multiplied with each other result in the gain of points.

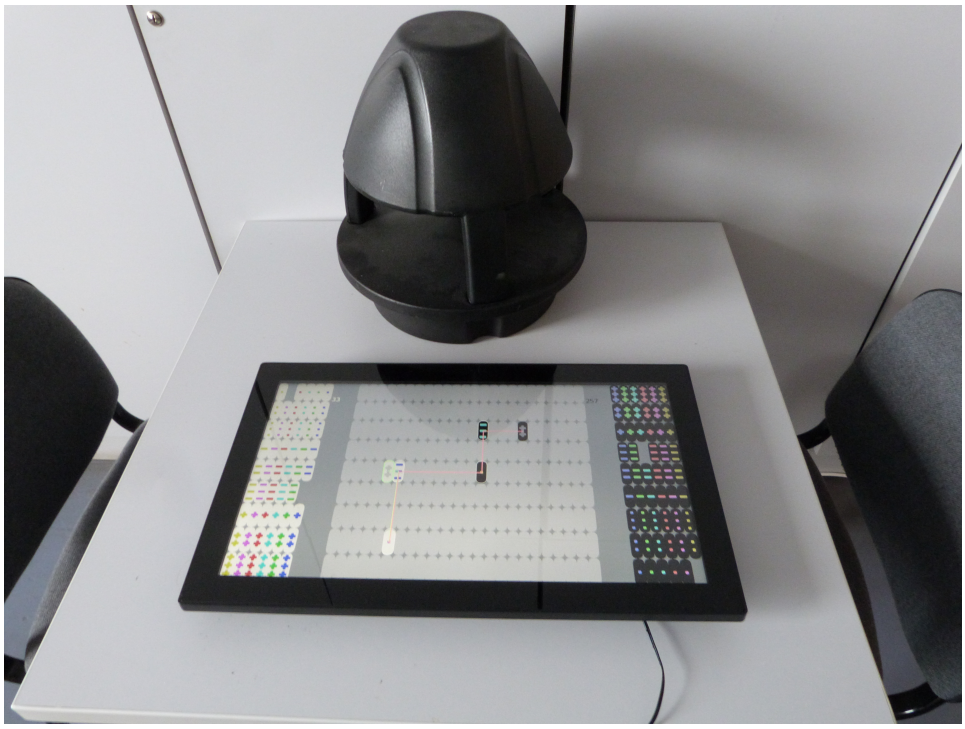

Fig. 2. Use of the game.

Fig. 3. M O D U L O on google play.

2.2 Rules of the Game

- Players can either agree to play before the start of the game until someone reaches or surpasses a certain number of points first, or set a certain fixed playing time.
- As in chess, the opponents make one move alternately.
- White begins.
- As an incentive for the opponents, the points gained are calculated and displayed after each move automatically.
- Each player has exactly one source stone in his stock.
- All other tiles in the pool represent arithmetic operations.
- A move consists of placing a tile from your own stock on the board in any free space.
- Instead, you can move any of your own tiles on the board to any free space, or put it back into the stock.

3 Strategies

You may only move tiles of your own colour, but the paths are formed taking into account all tiles lying on the playing field. This way, enemy structures can be used or disturbed.

Not all actions on the playing field lead to immediate changes in the musical structure, but they prepare it in so far as a later action can result in a path which then includes the previously musically inactive elements.

Metamorphosis. Typically, an existing path that represents the successive mathematical operations is extended by one element with another move. This causes the existing related mathematical sequences to be extended by another relatively similar one. In terms of sound, this means that another voice appears that varies the existing one (Fig. 4).

Context switch. If, during the course of a path, an element is suddenly moved or added to a location and another neighbor appears as the next element, the path takes a different course from this location after this move. In this way, several sequences are typically exchanged at the same time. This type of change takes place rather later in the course of the game, this is when greater changes are expected from the point of view of musical dramaturgy either.

Hostile takeover. If, during the course of a path, an element is suddenly moved or added to a location and another neighbor appears as the next element, the path takes a different course from this location after this move. In this way, several sequences are typically exchanged at the same time. This type of change takes place rather later in the course of the game, i.e. when greater changes are expected from the point of view of musical dramaturgy (Fig. 5).

Blockade, sudden silence. For both opponents the path is constantly formed, which always leads from the own source piece to the next neighbour, until this rule can no longer be applied unambiguously, or a piece already integrated into the path has to be connected. If a player causes such a ambiguity in the opponent's path by placing a tile in the neighborhood of a tile involved

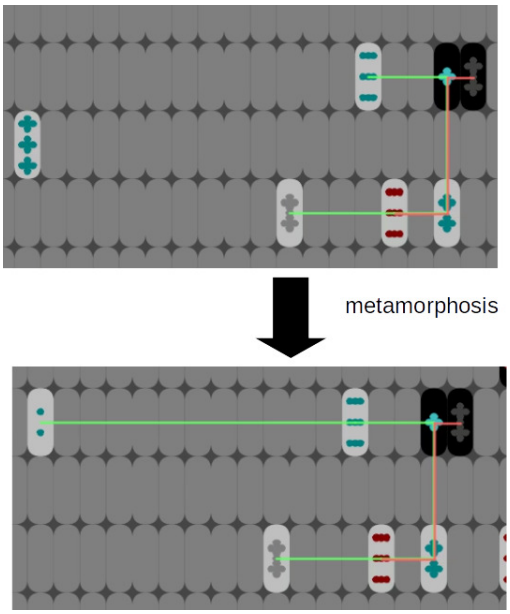

Fig. 4. Addition of an operation towards an existing path (metamorphosis).

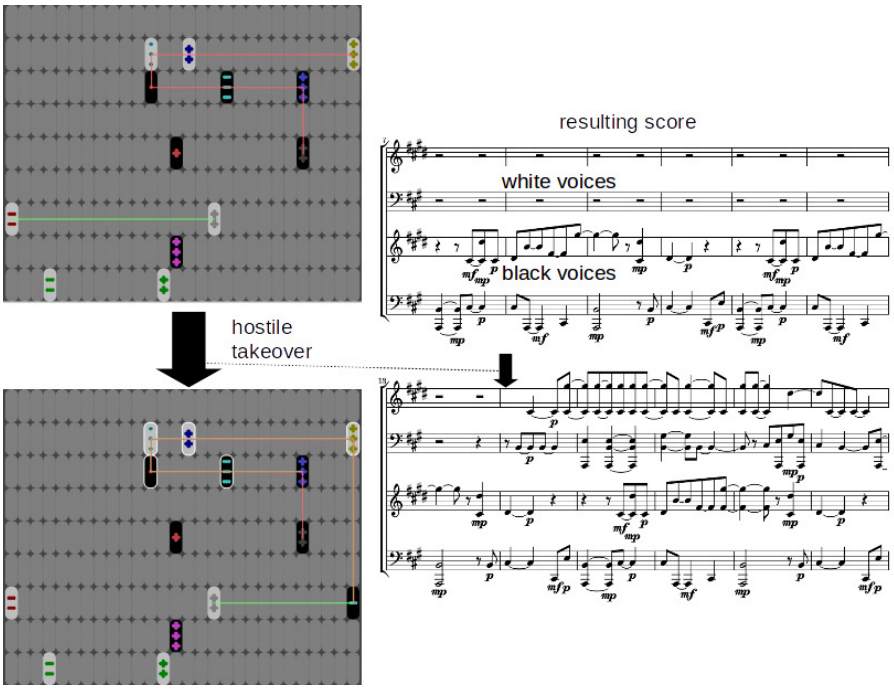

Fig. 5. Switching path by adding element close to source tile (hostile takeover).

in the opponent's path in such a way that it lies at the same distance as the nearest neighbor there, the complete following path disappears immediately and in extreme cases sudden silence occurs.

4 Discussion and Further Work

On the one hand it is enough to master the few simple rules to play MODULO.

However, the basic idea of MODULO is also to create the musical events through the own way of playing perhaps not exactly fully conscious, but at least with time to get a feeling for how actions on the game board affect the sound level.

This is promoted in particular by the fact that the way in which the modified sequences of numbers and the resulting sound events can be determined from a path is clearly and quite transparently predetermined by the generative grammar on which the game MODULO is based.

In concrete terms, it is not so difficult to carry out the unfolding process from the symbolic representation on the playing field to the music score behind it with pen and paper for smaller paths.

If, on the other hand, the resulting musical phrases and harmonies were to be interpreted in more detail using various instrumental playing techniques, for example by using physical modeling to generate sound, this could also be experienced in a more in-depth way as the musical representation of the structural interrelationships on the playing field by the players, thus promoting intuitive understanding of the game in another way.

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