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RoboMusic with Modular Playware

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Abstract

Based on the concepts of RoboMusic and Modular Playware, we developed a system composed of modular playware devices, which allow any user to perform music in a simple, interactive manner. The key features exploited from the Modular Playware approach are modularity, flexibility, and construction, immediate feedback to stimulate engagement, creative exploration of play activities, and in some cases activity design by end-users (e.g. DJ's). We exemplify the approach with the development of 11 rock genres and 6 pop music pieces for modular I-BLOCKS, which are exhibited and in daily use at the Rock Me exhibition and used at several international music events in Japan and USA. A key finding is that the professional music design is essential for the development of primitives in a musical behaviour-based system and this professional aesthetics is necessary for engaging the users in the activity of assembling and coordinating these 'professional' musical primitives. The paper describes, explores and discusses this concept.

Introduction

In recent developments, some research has focussed on the development of modular robotic devices that act as playware. We define *playware* as the use of technology to create the kind of leisure activities we normally label play, i.e. intelligent hardware and software that aims at producing play and playful experiences among users of all ages and of which e.g. computer games are a sub-genre [1, 2].

The aim of the research is to combine robotic systems, artificial intelligence and play culture to produce new products that can be used in play, sports, health, rehabilitation, music, architecture, art and learning. Here, we will focus on how we may be able to combine the modular playware approach [3] with the RoboMusic approach [4] in order to design novel, interactive music products that allow any user to perform and remix music with a professional sound quality.

Modular Playware

In response to the somewhat static nature of much related work, the Modular Playware design approach [3] was developed to lead to flexible, interactive play tools for both sensorimotor and constructive play activities as designed by the end-users themselves. It is our belief that the flexibility obtained through distributed and modular playware holds many advantages for developing engaging play as can be performed with music. The principles for the creation of flexible, modular play tools include the design of playware based upon modularity and flexibility, tangibility and immediate feedback to stimulate engagement, construction and physical movement, end-user activity design and inclusive games design.

In some playware research, for allowing any user to create activity, we find inspiration in *user-guided behaviour-based robotics* (e.g. [5, 6]). This approach was developed and applied to many robotic systems, such as manipulative robotic technologies, mobile and humanoid robots, in order to investigate how non-expert users could develop their own complex robot behaviours within very short time with no prior knowledge to the robot technology. The concept was initially explored with software components, e.g. for RoboCup Junior in 1998 [7], and later extended with hardware components through the robotic building block concept that allowed 'programming by building' [8], which, for instance, allow African school children and African hospitalised children with no a priori knowledge whatsoever about IT, robotics and technology to develop their own electronic artefacts [9, 10]. In the case with such a physical user-guided behaviour-based system, according to the definition [5, 6], each module needs to have a physical expression and should be able to process and communicate with its surrounding environment. The communication with the surrounding environment can be through communication to neighbouring robotic modules and/or through sensing or actuation. The modular system is constructed from many such modules.

We build on the belief that behaviour-based systems can include not only the coordination of primitive behaviours in terms of control units, but also include coordination of primitive behaviours in terms of physical control units. We can imagine a physical module expressing a primitive behaviour. Thereby, the physical organisation of primitive behaviours made by the user will (together with the interaction with the environment) decide the overall behaviour of the system. Hence, in a similar way to the control of robot behaviours by the coordination of primitive behaviours [11, 12], we can imagine the overall behaviour of a robotic artefact to emerge from the coordination of a number of physical robotic modules that each represents a primitive behaviour. Here, we will present such modules for music creation utilising the concept of RoboMusic, expanding the concept to allow music creation through physical construction with music behaviour primitives.

RoboMusic

RoboMusic defines a novel genre of music [4]. In RoboMusic, music is composed using robotic instruments, music is recorded based on playing robotic instruments, and concerts are performed with robotic instruments.

A robot is defined to be a programmable machine that by its interaction with the surrounding environment autonomously can perform a variety of tasks, and its behaviour is different from a computer program by the interaction with the environment through sensors and actuators. Hence, a robotic instrument is programmable instrument that by its interaction with the surrounding through sensors and actuators can be used for playing a variety of music. Through communication, robotic instruments can be used together to orchestra an ensemble. If left untouched by human (or environmental) interaction, the robotic instrument will behave with its own performance composed by the music artist. When a human or other environmental subject interacts with a robotic instrument, the instrument may change performance from its normal autonomous behaviour.

The artistic and technological challenge of the music artist is to compose baseline behaviour of the robotic instruments and compose the behavioural response to interaction by human musicians. The music artist is transformed from a composer of static music tunes to a developer of robot behaviours – behaviours that are expressed by the robotic system as music pieces. Music compositions are transformed from being static to become dynamic; music compositions are transformed from being static nodes to become robotic behaviours.

A RoboMusic concert is performed with robotic instruments, and changes the concept of live concerts by inviting the audience to interact with the band's instruments themselves and thereby guide the live performance of the music themselves. The audience is actively engaged in the performance of the music of their concert, and their interaction with the robotic instruments guides the robotic behaviour and thereby creates a unique live concert performance that change from concert to concert depending on the behaviour of the audience. Each RoboMusic concert is a unique live performance. The music artist has composed the baseline, and the audience is manipulating the robotic instruments to allow the robotic behaviour to change, and thereby the music tune to diverge. For the audience, the concert form has changed from passive listening to active participation in playing the concert.

In RoboMusic, the design challenge is to create primitive robotic behaviours and to coordinate these primitive behaviours in order for the music piece to emerge as the coordination of primitive behaviours. Thereby, a music composition emerge from the way the composer, musicians or audience interact with the robotic instruments that provide the primitive behaviours.

Each robotic instrument is used to trigger a particular primitive behaviour dependent on the interaction with the instrument(s). In RoboMusic, the primitive behaviours can be anything from a volume or a cut-off to a small sequence of tones. The music composer designs the way in which the primitive behaviours that are triggered should interact with each other.

Hence, as is the case when designing behaviour-based robots such as mobile robots (e.g. [11, 12]), the robot designer (in this case the music composer) designs the primitive behaviours and the coordination scheme. And, as is the case with *user-guided behaviour based robotics* [5, 6], if non-expert users (e.g. live concert audience) are supposed to manipulate and become creative with the systems, it is crucial that the designer (music composer) creates primitives on a fairly high abstraction level that allows the non-expert user to understand and have positive feedback from the human-robot interaction within a very short time frame.

For the first RoboMusic concert by Funkstar De Luxe in 2006, instruments used to play the music included interactive tiles that measure touch, rolling pins that measure rotational acceleration, and light&sound

cylinders that measure distance (of a person/hand). Such features as pressure, rotational acceleration and distance were used to trigger primitive behaviours which include variations in resonance, cut-off, volume and pan of musical tracks in the musical composition (see Figure 1 and 2 for the concert set-up).

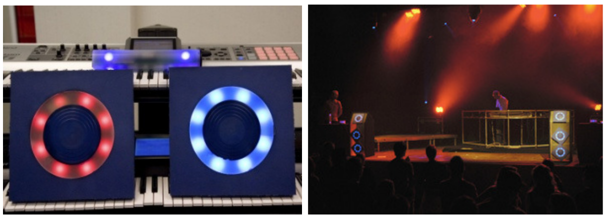

Figure 1. Left: Two Tiles and a RollingPin used as robotic instruments. Right: The RoboMusic live concert set-up, with Funkstar De Luxe and his control station in the center, and the robotic instruments on the left and right side of the stage.

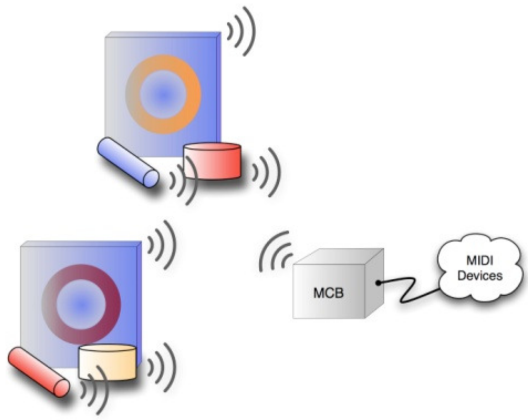

Figure 2. The concert set-up for RoboMusic. In a similar way, we developed the cubes to communicate to a MIDI Control Box (MCB) which is connected to MIDI Device, which in this case is a PC running Ableton Live.

Modular I-BLOCKS for RoboMusic

Using the modular building blocks, I-BLOCKS, as the technologic platform, we create a RoboMusic scenario where a user can experiment freely with music using a set of pre-composed looped musical pieces. The I-BLOCKS is our user-configurable modular robotic platform developed and tested through several prototype and application generations [10, 13, 14, 15]. For the RoboMusic application presented here, the user identifies the functionality and behaviour of the I-BLOCKS through musical feedback when rotating, attaching and detaching the I-BLOCKS (see Figure 3).

Figure 3. Children creating music with the cubic I-BLOCKS.

The current generation I-BLOCKS consists of cubic modules (see Figure 4) that can communicate with each other when physically connected. Each cube can communicate with up to four of its six possible neighbours and is fully self-contained with respect to power, connectors and processing. At the edges of the four communicating sides of a cube are four RGB LEDs, which can light up in many different colours. The I-BLOCKS communicate locally via infrared light, and can be internally expanded to support global wireless radio communication (XBEE) as well, in order to facilitate 'structure to structure' or 'structure to device' communication.

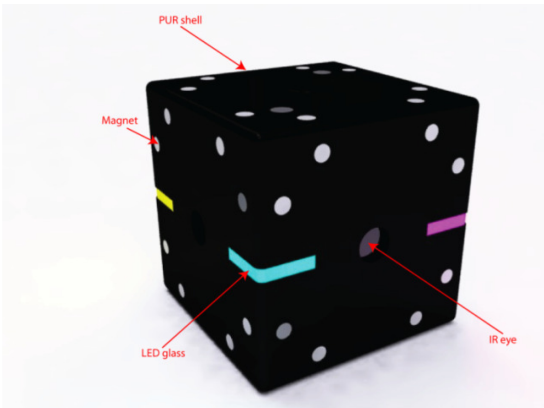

Figure 4. An explained visualization of the I-BLOCK.

Each I-BLOCK makes use of a 3D accelerometer to detect its orientation with respect to gravity. This makes it able to detect, for instance, which side is facing down.

The I-BLOCKS connect to each other's faces using magnets, allowing for uni-sex connection at 90-degree angles. At the electronic centre of each I-BLOCK is the Atmel ATMEGA1280 8-bit microcontroller, which takes care of all processing including peripheral device communications etc. The I-BLOCKS' hardware is encapsulated by black polyurethane (PUR) shell that has a soft rubber-like feel, with hard plastic plate lids in top and bottom in which charge plugs, programming connectors, sensors and actuators are integrated.

The I-BLOCKS are meant as a general platform for exploring physical programming – or "programming by building". The construction with I-BLOCKS results not only in the development of a physical structure, but also in the development of a functionality of that physical structure. This functionality or emergent behaviour is a product of user interaction, the sensor inputs, the actuator outputs, the communication and the processing of the individual I-BLOCKS [15].

Summary of the cubic I-BLOCKS:

- PUR (Polyurethane) Shell (9x9x9 cms)
- Magnetic connectors
- ATmega1280 microcontroller
- 4 communication channels (IR light)
- Opportunity for expansion, e.g. display, XBee or USB and various sensors.
- 4 RGB LEDs
- 3-axis accelerometer

The music created by the user is computed and played back on a PC, using the Ableton Live© music software as a playback unit responding to MIDI messages coming from the I-BLOCKS. In order to allow the I-BLOCKS to "talk MIDI" to a PC we designed and built a socalled "MIDI Box" that converts serial wireless data coming from an XBEE-enabled I-BLOCK into MIDI signals (see Figure 2 and 5). By using wireless technology we allow users to manipulate the I-BLOCKS freely just like conventional building blocks.

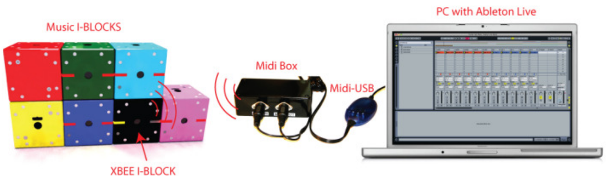

Figure 5. Music setup with I-BLOCKS, MIDI-box and PC.

The pieces of music that was made here were all constructed using these rules: There are five or six predefined instruments or groups of instruments, varying in type according to genre, and within each piece of music there are up to six variations per instrument type, and there can be an unspecified number of different instruments.

In this application each coloured I-BLOCK represents an instrument or group of instruments. The individual I-BLOCKS orientation - which side is facing down - determines the variation of that specific instrument. The I-BLOCK LEDs change colour depending on their orientation, in order to make it possible for the user to remember and activate specific variations.

The musical setup can be seen from Figure 5. Note the black XBEE-enabled I-BLOCK, which communicates wirelessly with the MIDI Box. When instrument blocks are connected to this, music starts playing depending on the actual I-BLOCK's colour and orientation. The music is loop-based, meaning that when active, each variation of each instrument is playing for a certain time and then repeating itself over and over until it is finally deactivated when the user removes the current instrument I-BLOCK from the structure or shifts its orientation.

Music development

In the development of the musical content we chose to make two overall categories of music:

1) Songs that are inspired by and which represent certain historic periods of popular music in order to give the user an insight into a specific style or genre of music.
2) Songs that are made by famous Danish artists and then modified to fit this concept allowing the user to "remix" these songs.

We made 11 different songs representing non-classical music from the 1950's (rockabilly rock 'n' roll) and up untill the 1990's (Grunge). These 11 styles of music are chosen from their ability to show various forms of musical expression both in regard to instrumental and vocal performance as well as in regard to composition, production and recording methods that were used through the last sixty years.

The musical content is composed, arranged and recorded following careful study and analysis of each musical style and its characteristics, making the songs fit into these characteristics as well as possible. We have tried to record each music piece in the same way as the corresponding musical style was originally recorded (e.g. Rockabilly is recorded in mono and with very few microphones in order to create that specific sound). When composing, recording and mixing the music, we have studied the original productions closely. For instance, we have strived to make our Reggae track sound like an original Bob Marley tune but with new melodies and lyrics.

These extraordinary efforts regarding the musical quality was done to ensure that the user experience to interact with music and not with technology. We see the technology used as a means that allows for the any user to gain access to music as a kind of "material", with which the user can mould directly in the authentic, timbral substance [16]. By the use of the modular playware concept contained in the I-BLOCKS, music becomes a physical, moldable object, much like modeling-wax – flexible and manageable in the hands of the user. Because music is so much more than a simple series of notes, the "material" that is put to the user's disposal consequently must comprise the elements, which make up the different musical styles. When manipulating the I-BLOCKS, the user is not altering notes, but all parts of the musical sounds as a musician is doing when playing. It is obvious, we believe, that the musical "material" is composed with the craftsmanship and aesthetical feeling of a skilled musician.

The second part (famous Danish pop songs) is characterized by a modern HiFi music production. The challenge in converting these songs into tracks usable in this musical setup has been to make new drum, guitar, bass, etc. tracks that fit the original tune and at the same time being so diverse and varied that it was possible for the user to create a remix that sounds different without being "untrue" to the original song. The creation of these tracks for allowing appropriate and aesthetical appealing combinations clearly demands professional remix skills.

Recording methods

To record and mix the music we use Logic Pro 8 (multitrack recording software). We record both "real" instruments such as drum, bass, guitars, keyboards and software instruments which emulate e.g. grand pianos, old analog synthesisers, drums etc. In order to recreate music from different periods of time in music history, it is extremely important that the musicians who record the tracks have a deeper understanding of the different styles, which has been build up over years by listening and consciously or unconsciously analyzing the tiny differences in feel and approach towards playing the music. This professional competency is crucial for making the small musical parts (primitives) fit well together (coordinate) to a musical piece of high quality in all the potential combinations.

All songs are made as relatively short loops (16-32 bars) that are made to go on and on until the user chooses to stop the song. In every song there are drums, basses, guitars, keyboards and vocals (there are exceptions for these groups of instruments if a specific style of music e.g. does not have guitars in it). At the end of the recording/mixing process all the files are imported into Ableton Live (version 8.0) – software that is specialized in handling loops. The I-BLOCKS control the tracks in Ableton Live.

Everything has to fit together

There are five I-BLOCKS representing five different instruments (drums, bass, guitar, keyboards and vocals) and one "master" blocks that works as an "on/off button". When the master is connected to one or more of the I-BLOCK instruments, they play a certain figure (melody/rhythm/chords/riff). Every I-BLOCK has six sides. Each side represents one figure. In order to choose another figure, the user simply turns the I-BLOCK. That means that every one of the 30 different tracks which each song has (5*6=30) has to fit each other in every possible combination, and at the same time every figure has to sound good and be interesting to the user if it plays alone. The key to this challenge was to make real quality recordings on every single track and create a certain role for every instrument-group in which one can create very distinguishable figures, which have an explicit response when changing figures. However, at the same time the figures should be created to not making the musical whole too "full" and unclear when all five cubes are on and playing. To make cube responses distinguishable, it also becomes very important to "clean up" excess frequencies, for example so the bottom part of the guitar does not interfere with the bass.

Tests

The RoboMusic concept may provide both a means for everyday users to develop their own musical pieces by coordinating the musical primitives, and a means for professional musicians to perform at concerts with physical, interactive musical objects. The two uses can even be combined by allowing the audience to interact with the musical primitives in professional live performances as interplay with the professional musician(s).

Everyday user play: RockMe

The above-mentioned 11 different songs in the historic category are implemented as the main part of the exhibition "Rock Me" at The Danish Rockmuseum, which is under construction in vicinity of the famous annual rock festival at Roskilde, Denmark, (Europe's oldest and largest rock festival). The exhibition consists of three music stations, two equipped with headphones to allow visitors to explore rock genres in groups of two (see Figure 6), and one equipped with loudspeakers and a stage where visitors can perform for each other.

The main finding from the first half year of the exhibition is that the I-BLOCKS music concept works very well for the visitors, who use them in a relatively short period. The concept is easily understood and grasped, because it is based on the principle of building blocks and because any change in the physical construction results in clear audible changes. In spite of the fact that the connection between building blocks and music is new and unknown to the visitors, they accept this new "material" and immediately start manipulating, building, and experimenting, which to us is an important proof of concept regarding modular playware and physical user interaction. Not surprisingly, the performance opportunity is mainly used by kids and young people, who come in groups, for instance school classes.

Figure 6. Visitors playing music with the cubic I-BLOCKS at the RockMe exhibition, Roskilde, Denmark.

Professional live performance
The cubic I-BLOCKS were used for live RoboMusic performances at a number of occasions. For DJ and dance music, we performed together with Funkstar De Luxe at the Winter Music Conference, Miami, March 2009, which is one of the world's largest DJ and dance music events [17]. For the opening of the RockMe exhibition, a famous Danish pop musician, Simon Kvamm of Nephew, and a famous Danish rap musician, L.O.C., performed a battling session where each of them performed each other's music using the cubes (see Figure 7). Also, live rock music performances were made during the robot festival RoboDays in Odense, Denmark, September 2009, and at Japan Robot Festival in Toyama, Japan, September 2009.

In all live performances, the professional musicians were able to utilise the RoboMusic concept in a natural way with the cubes to make an appropriate live performance. The RoboMusic performances would last only around 30 minutes, and thereby in some cases appear only as a part of a longer concert. The professional musicians seemed to receive a very positive response from the audience. Main challenges for the professional musicians were in all cases (i) to remember that cubes can only connect on four of the six sides (IR communication is only on four sides), (ii) the timing for attaching and detaching cubes at the exact beat timing, and (iii) to know/remember what musical effect results from turning a cube.

Figure 7. Professional pop musician, Simon Kvamm of the Danish pop music group Nephew, performing live with the I-BLOCKS in Roskilde, Denmark, July 2009.

Discussion and Conclusion

The challenge of understanding what musical effect results from interaction is general to the RoboMusic concept, and appears in both everyday user play and professional live performances. This challenge is particular clear with the I-BLOCK cubes, but also general to other RoboMusic instruments. Indeed, transparency of functionality is a general challenge for most tangible interface design, and part of a modular playware design [3]. The mapping between the physical affordances of the objects with the digital components (different kinds of output and feedback) is a design and technological challenge.

This challenge becomes particular evident with the RoboMusic concept in which the user combines three senses to understand the functionality: auditory, visual and touch. Here, the user has to match the visual sense to the auditory result. We believe that there is a lot to learn for tangible interface design from understanding such relationships between different sensory modalities and from understanding the cognitive challenges which are involved.

For the user interaction (e.g. in user-guided behaviour-based systems), the RoboMusic experiments also highlight the challenge of understanding how to design the primitives at the most appropriate granularity level. An interesting research topic appears to be to gain knowledge about whether the same granularity level of primitives is the most appropriate for all user groups, and how the granularity level relates to transparency of functionality. In the case of RoboMusic, it is further necessary to design the primitives (music components), so that the coordination is aesthetical appealing while at the same time the design provides the necessary freedom to the user to become creative. We find it essential to put focus on professional design of primitive behaviours and coordination of primitive behaviours for the specific application field (e.g. music, soccer, physiotherapy, cognitive rehabilitation). In this case of RoboMusic, this is done by the professional music composers who designs the musical tracks (primitives) and tries to ensure that the tracks can mix (coordinate) in an aesthetical appealing form (i.e. the music composer becomes a designer of primitive behaviours for a behaviour-based system [4].)

The RoboMusic concept is general to many different implementations of musical primitives, coordination mechanisms and designs of 'instruments'. Here, we exemplified with the cubic I-BLOCKS as an instance of modular playware for RoboMusic, and the cubic I-BLOCKS showed good potential in a number of informal tests. Whereas this paper by intention provides the general concept description of RoboMusic with modular playware, future publications will report on more formal testing with the cubic I-BLOCKS, and hopefully other researchers may utilise the general concept for investigating other implementations and experiments.

Acknowledgements

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References

[1] H. H. Lund and C. Jessen. Playware - Intelligent Technology for Childrens play. Technical Report 1, The Maersk Mc-Kinney Moller Institute, SDU, June 2005.
[2] H. H. Lund, T. Klitbo, and C. Jessen. Playware Technology for Physically Activating Play, *Artificial Life and Robotics Journal, 9:4,* 165-174, 2005.
[3] H. H. Lund, and P. Marti. Designing Modular Robotic Playware. In IEEE 18th International Workshop on Robot and Human Interactive Communication (Ro-Man 2009), IEEE Press, 115-121, 2009.
[4] H. H. Lund, and M. Ottesen. RoboMusic – A Behavior-Based Approach, *Artificial Life and Robotics Journal, 12: 1-2*, pp. 18-23, 2008.
[5] H. H. Lund. Modern Artificial Intelligence for Human-Robot Interaction. *Proceedings of the IEEE journal, 92:11*, 1821-1838, 2004
[6] H. H. Lund. *Robots at Play*. ISBN 978-87-992302-0-4, 160 pages, Odense, 2007.
[7] H. H. Lund and L. Pagliarini. RoboCup Jr. with LEGO Mindstorms. In Proceedings of Int. Conf. On Robotics and Automation (ICRA2000), IEEE Press, NJ, 2000.
[8] H. H. Lund, H. H. Intelligent Artefacts. In Sugisaka and Tanaka (eds.) Proceedings of 8th International Symposium on Artificial Life and Robotics, I11-I14, ISAROB, Oita, 2003.
[9] H. H. Lund, and P. Marti. Designing Manipulative Technologies for Children with Different Abilities. *Artificial Life and Robotics Journal, 9:4*, 175-187, 2005.
[10] J. Nielsen, and H. H. Lund. Contextualised Design of African I-BLOCKS, in H. H. Lund et al. (eds.) Proceedings of Fourth IEEE International Workshop on Technology for Education in Developing Countries. IEEE Press, 14-18, 2006.
[11] R. A. Brooks. A robust layered control system for a mobile robot. *IEEE Journal of Robotics and Automation, 2(1):*14--23, 1986.
[12] R. C. Arkin. *Behavior Based Robotics*, MIT Press, Cambridge MA, 1998.
[13] J. Nielsen, and H. H. Lund. Spiking neural building block robot with Hebbian learning, in Proceedings of IEEE International Conference on Intelligent Robots and Systems (IROS2003), 1363-1369, IEEE Press, 2003.
[14] J. Nielsen, and H. H. Lund. Modular robotics as a tool for education and entertainment, *Computers in Human Behavior, 24*, Elsevier, pp. 234-248, 2008.
[15] J. Nielsen, User Configurable Modular Robotics - Control and Use, Ph.D, University of Southern Denmark, Odense, 2008 (http://phd.jacobnielsen.net)
[16] N. K. Bærendsen, C. Jessen, and J. Nielsen. Music-Making and Musical Comprehension with Robotic Building Blocks. In Chang, M., Learning by Playing. Game-based Education System Design and Development. Springer-Verlag, 2009.
[17] Wikipedia – Winter Music Conference. http://en.wikipedia.org/wiki/Winter_Music_Conference (checked: 7/12/2009).