The Beatbug Network – A Rhythmic System for Interdependent Group Collaboration

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Abstract
The Beatbugs are hand-held percussive instruments that allow the creation, manipulation, and sharing of rhythmic motifs through a simple interface. When multiple Beatbugs are connected in a network, players can form large-scale collaborative compositions by interdependently sharing and developing each other's motifs. Each Beatbug player can enter a motif that is then sent through a stochastic computerized "Nerve Center" to other players in the network. Receiving players can decide whether to develop the motif further (by continuously manipulating pitch, timbre, and rhythmic elements using two bend sensor antennae) or to keep it in their personal instrument (by entering and sending their own new motifs to the group.) The tension between the system's stochastic routing scheme and the players' improvised real-time decisions leads to an interdependent, dynamic, and constantly evolving musical experience. A musical composition entitled "Nerve" was written for the system by author Gil Weinberg. It was premiered on February 2002 as part of Tod Machover's Toy Symphony [1] in a concert with the Deutsches Symphonie Orchester Berlin, conducted by Kent Nagano. The paper concludes with a short evaluative discussion of the concert and the week-long workshops that led to it.

Keywords
Interdependent Musical Networks, group playing, percussive controllers.

INTRODUCTION
Interconnected Musical Networks (IMNs) are live performance systems that allow players to influence, share, and shape each others' music in real-time. Such systems, whether they operate in one physical space or over remote wide-area networks, provide an interdependent framework that can lead to rich social and musical experiences that enhances musical group collaboration. The development of IMNs since the 1950's has had strong ties to a number of technological innovations -- from John Cage's early experimentations with interconnected transistor radios through the use of digital technology and networked PCs by groups like the League of Automatic Music Composers and the Hub [2], to the current proliferation in network art and internet music research. This unique form of socio-musical expression, however, has not diffused from the elite high-art establishment into the world and has not yet become a significant form of artistic expression that can reach wide audiences. By focusing on complex interdependent network topologies that were not aimed at conveying the interaction to players and audiences, composers and designers have obscured the expressive and social nature of the experience, hindering the appropriation of IMNs as a widely accessible and intuitive art form.

In an effort to address the challenge of bringing IMNs to wider audiences, we have investigated a number of research areas, in particular, cognition and perception, music education, and instrument interaction. Informed by this research we have formulated a hypothesis asserting that by embedding high-level musical percepts and constructionist-learning schemes in engaging interconnected physical musical instruments we can turn IMNs into an expressive and intuitive art form without losing the depth of the musical and social experience [3]. The Beatbug Network was, therefore, developed in an effort to test this hypothesis by creating an expressive and accessible IMN, coupled with constructionist pedagogy, and to evaluate its artistic and educational value in a series of concerts and workshops.

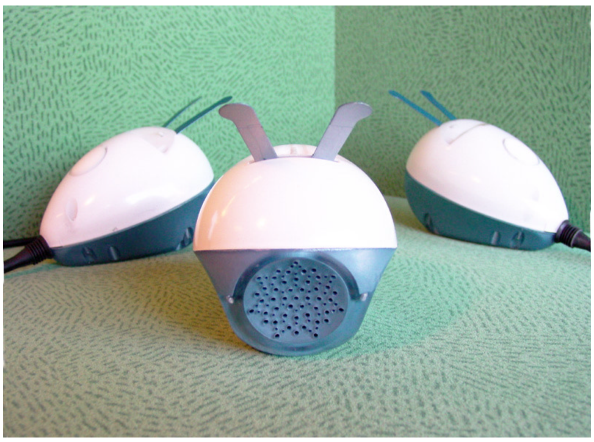

Figure 1 - Three Beatbugs

SYSTEM DESCRIPTION

The Instrument

Physically, a Beatbug is a bug-shaped musical controller. The shape was chosen to highlight the idea of the instrument as an independent entity, with its own behaviors. It has a speaker for a mouth, two bend-sensors for antennae, and a velocity-sensitive drum trigger on its back. White and colored LEDs mounted in its translucent shell provide visual feedback when it is hit, or played through. The shell is made of clear cast acrylic that has been lightly painted on the inside to allow the light to shine through. Each bug contains a PIC microcontroller that reads the sensors, controls the LEDs, and communicates with a central system via tail-like cables that carry MIDI, trigger, audio data, and power.

The physical interface of the bug allows for substantial control by the player, but also attempts to make what is happening clear to an audience. The piezo drum sensor measures when and how hard it is hit, while the two antennae allow for subtle control over different aspects of the sound. Bending the antennae causes a proportional change in the color of three LED clusters, and a ring of white LEDS flash each time the bug is hit, providing additional visual feedback to the player and audience.

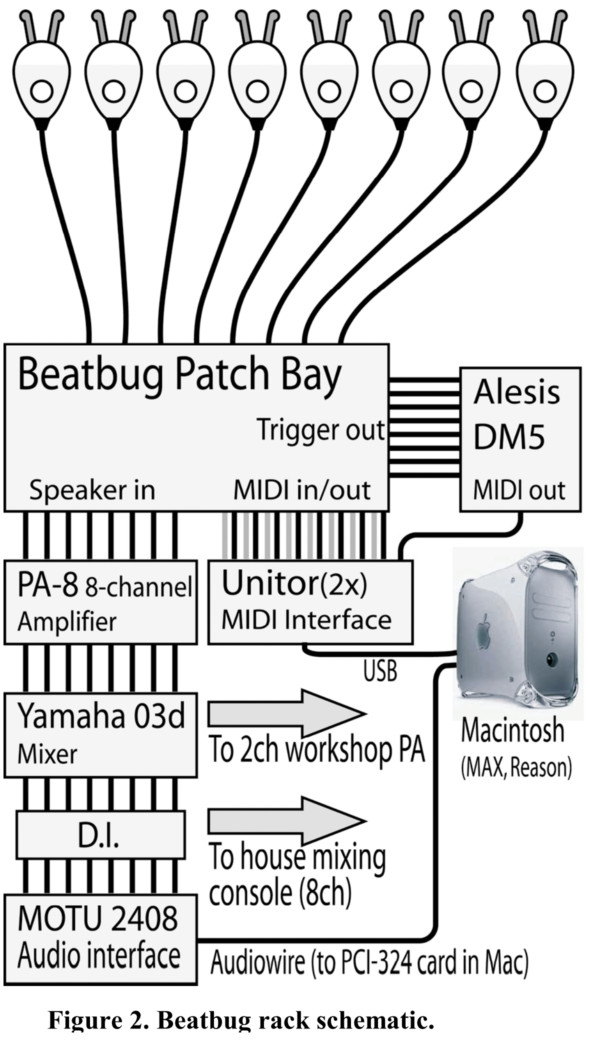

Figure 2. Beatbug rack schematic.

Software

The Beatbug processor is responsible for operating the sensors and LEDs, while a central computer system controls the actual musical interactions and behaviors. The "brain" of the system is written in Cycling 74's MAX environment. By controlling all of the behavior from the computer, we were able to quickly experiment with a much broader range of interactions than would have been possible if we had reprogrammed the Beatbugs each time we wanted to change a behavior. Similarly, all sound synthesis also occurs on the central computer system and plays through each corresponding Beatbug's speaker. For performances or large-scale workshops, we supplement the direct sound from the bugs with a 2 or 8-channel PA. Moving the burden of sound synthesis from the Beatbugs to the computer enables much higher quality sounds and richer real-time manipulations. The tradeoff of this approach is that the bugs can not make any sound away from the central system. For the software synthesizer, we chose Reason by Propellerhead Software, which gave us a broad palette of timbres and effects with continuous control over many parameters of the sound.

The Rack

Eight Beatbugs can be plugged into one central rack which consists mostly of standard, off-the-shelf equipment including a Mark of the Unicorn 2408 audio interface, 2 Emagic Unitor MIDI interfaces, a Lectrosonics PA-8 8-channel amplifier, an Alesis DM-5 Drum trigger unit, and a Yamaha 03d Mixer. The only non-standard device is a custom patch box, which provides power to the bugs and converts each bug's 10-pin Neutrik Minicon connector to MIDI in, MIDI out, trigger, and audio in (see Figure 2). The entire system, including the mixer, and the computer, fits in a single Mixer rack.

SYSTEM FUNCTION

The Beatbug system enables children to participate in the process of making and performing music in a variety of ways. Three different interaction modes were developed, each one offering successively more sophisticated control of the musical output. The modes, entitled "Free-Play," "Drum-Circle," and "Snake," are gradually introduced to children during a week-long workshops.

"Free-Play" Mode

This mode is designed to introduce the players to the Beatbugs. Each Beatbug in this mode functions similarly to a standard electronic drum, with its unique range of sounds for different hitting velocities. All 8 players can experiment, hitting the bugs freely, familiarizing themselves with the bugs' response and sound. The bend sensors antennae are not used in this mode.

"Drum-Circle" Mode

Drum circle mode presents a more complex musical and social interaction and requires a session leader who in addition to playing a Beatbug also conducts and manages the interaction. The leader starts the session by generating a metronome beat (based on the tempo of the first four hits, or by choosing from a predefined setup.) While the metronome is playing back, the leader can enter a rhythmic pattern, drumming the Beatbug for a predefined number of bars (usually two 4/4 bars) after which the system automatically plays back the quantized recorded pattern in a loop. The quantization algorithm nudges the notes towards the closest quarter note, eighth note or quarter note triplet. When the entered pattern is played back (causing the white LEDs to flicker as each note is played), the leader can manipulate the pattern by bending the two antennae, (causing a proportional color change in the multicolor LED clusters).

The left antenna continuously transforms the sound timbre using a variety of predefined filters, low frequency oscillators, frequency modulators, noise generators, and envelope parameters using Propellerhead's Reason Subtractor synthesizer. The right antenna adds rhythmic ornamentation to the pattern by controlling the values, length, accents, and feedback of a delay line. For example, in correlation to the level and the timing of bending, the player can ornament the pattern with notes in different values (ranging from sixteenth notes to quarter notes, including triplets), add accents to these added notes in different intervals, and control the duration of ornamentation by modifying the delay feedback. We chose to use a controllable delay line for the rhythmic manipulation since we believe that it allows players to transform the pattern while keeping its original nature. Changing or editing the pattern's notes themselves might have made the motif sound too different from the original, losing the "motif-and-variation" nature of the interaction.

When the leader feels that his variation is ready, he can hit his Beatbug again, which randomly activates another Beatbug in the network. The chosen bug lights up and its player can add a complementary rhythmic motif, which is looped and quantized in the same manner. The new player can then manipulate her pattern in a similar way to the leader, controlling different timbre and rhythmic parameters. As the session progresses, more and more players are randomly chosen to add their personal patterns to the polyphonic drum circle with their own unique manipulations. The most recent bug always plays louder than the others, in order to sustain the system's clarity. After all the bugs enter their patterns, the system waits for a simultaneous hit by all eight players (conducted by the session leader) which evenly mixes all 8 motifs to the same level. Players can then independently manipulate their patterns until the next simultaneous hit, conducted by the leader, which ends the music.

"Snake" Mode

Snake Mode provides the most advanced interaction and it is the mode that is used in the concert performances. Here, players can explore the network's interdependency by sharing their motifs with others, and adding their own unique voice to their peers' patterns. In this mode, after the leader enters the first pattern, it is automatically sent to be played from a different random bug. The receiving player can now decide whether to develop the motif further (by continuously manipulating the timbre and rhythmic antennae) or to keep it for herself (by entering and sending her own new motif to the group).

If a player decides that the received motif is ready, and does not require further manipulation, he can enter a new pattern. In this case, he keeps the received transformed pattern in his bug at a soft accompaniment level, while his new pattern is sent to a new random player, who becomes the new "head of snake." If the receiving player decides that the motif is not ready he can further manipulate it and hit the bug to send his transformation to the next random bug. The transformations are recorded and layered in each cycle until a new pattern is entered. Each player faces the same two options when randomly receiving a motif or a transformation until all the players had entered their patterns and kept their favorite transformations. The system then randomly groups different numbers of players for improvised solo sections, providing the participants with the opportunity to manipulate each other's musical material in real-time.

Figure 3. A child playing a Beatbug in a workshop at the MIT Media Laboratory.

PEDAGOGY

In order to create an expressive and accessible IMN for children, novices, and wide audiences, we tried to create a physically engaging experience and to embed intuitive high-level musical percepts and constructionist-learning schemes in the instruments. The pedagogical constructionist philosophy underlying the project is based on the work of cognitive psychologist Jean Piaget who shows how learning can be most effective when children are engaged in active processes in which they construct their understanding of the world through interaction with objects and situations in their environment [4]. More recently, Seymour Papert's pioneering work in the application of computers and technology to the learning process indicates strongly that the greatest benefits of these tools lie in the ways in which they empower children to take charge of their own unmediated learning and to interact meaningfully with powerful ideas [5]. In particular, Papert emphasizes the computer's ability to facilitate learning that can be accessible to the inexperienced and untrained (providing "low-floor" learning) but is also rich and thoughtful which can intrigue and enrich even the most experienced experts (providing "high-ceiling" learning). The Beatbugs were designed to support both these modalities: The system enables untrained children to easily construct their own rhythmic ideas, giving them a personal connection to an artifact while being introduced to a number of high-level musical concepts, such as motif, variation, and contour. The looping function in drum-circle mode immediately and repeatedly confronts children with the results of their work and offers them the opportunity to re-do or edit what they've created until they have achieved a result with which they are satisfied. The familiar bug-shaped interface facilitates engaging kinesthetic interaction with the musical product in a direct manner, so that the results of physical actions are immediately apparent. At the same time the Beatbug also addressed experienced expert musicians by allowing them to experiment with detailed rhythmic, timbre, and pitch manipulation in a novel manner that is not possible by other means.

There is significant evidence that the high-level musical percept of contour is intrinsic to music cognition, regardless of the level of musical training [6]. In one psychoacoustic study, it was shown that novices' ability to retain melodic contour of a semi-known melody is much better than retaining the specific pitches [7]. Trehub at al. [8] showed that contour can even be perceived by infants as young as one year old, strengthening the hypothesis that this percept is well ingrained in human cognition. These studies suggest that by providing an intuitive access for continuous manipulation of contour, we can create a bridge between the expressive manner in which novices relate to high-level musical parameters, and the more thoughtful educated manner in which an expert perceives the lower-level relationships between discrete musical parameters. By giving players the power to create and phrase rhythmic patterns and then shape them by employing melodic, timbral, and rhythmic contours with the antenna, we offer them an experience that is usually reserved for highly trained experts, one that can lead to further investigations into more advanced concepts such as timbre, rhythmic stability, and even harmony.

A key aspect of the system is its inherent social and collaborative nature. In snake mode, children manipulate motives made by their peers. When they are required to make their own motives, they do so in the context of motives that have been constructed by others and already exist in their auditory environment. The system allows for smaller groups (duets, quartets) to interact and manipulate sounds together in the context of the larger structure. The balance between aural, kinesthetic and social modalities provides the children with a rich and highly immersive musical environment. Another important facet of the Beatbug system is the manner in which it gives control of the musical output to the children. While the system acts to facilitate and enable musical interaction on a variety of levels, it does not impose a final outcome but rather allows the children considerable freedom of action and expression in determining the musical result.

WORKSHOPS

A series of workshops were run at the MIT Media Lab, Media Lab Europe (MLE) in Dublin, and SFB Studios in Berlin. In the preliminary workshops at MIT and MLE, children were encouraged to compose their own rhythmic motives and to perform them on the Beatbugs in both drum-circle and snake modes. After initial exposure to and experimentation with the interface in free play mode, children were asked to improvise short motives, initially by clapping and then on the Bugs. When all children were comfortable at this level, motive length and tempo were increased. Relationships between timbre and rhythm were explored to guide the children to create motives which were appropriate and effective to a particular timbre. In the Berlin workshops children were encouraged to collaborate with educators and professional percussionists in rehearsing a set of pre-composed motifs and routing schemes, towards the concert performance of "Nerve" by Gil Weinberg. In these final performance-oriented workshops the focus was put on expressive interpretation rather on the compositional aspects.

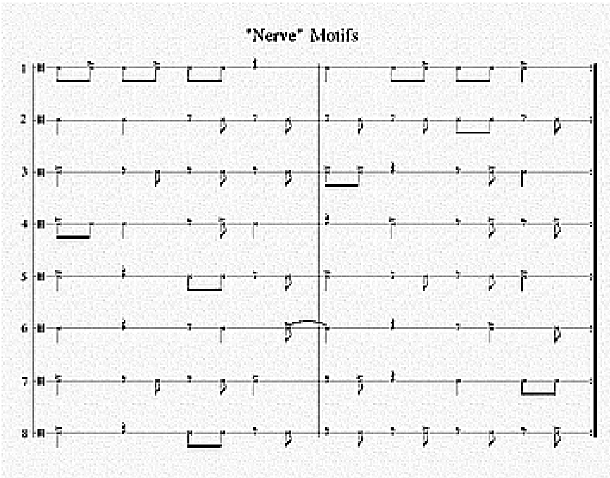

Figure 4. "Nerve" Motifs

In all the workshops children were encouraged to listen carefully to their own motives and those of others in the group and to develop an awareness of what elements exist in the sound environment. They then were asked to describe specific aspects of what they were hearing and to experiment by manipulating particular parameters of the sound, both individually and collaboratively. Listening skills, such as the ability to hear and perceive a single voice in a multi-part texture, were practiced by manipulating the antennae and directing the child's attention to the part of the texture that was changing. The built-in speakers in the bugs were helpful in allowing the children to hear their own voice in the context of the overall texture. To maintain coherence, the child who was "head of the snake" at any given time was encouraged to act as a conductor and indicate who should manipulate antennae by pointing the bug at another child. Although initially self-conscious, the children quickly embraced this idea and were willing to take responsibility not just for their own musical part but also for giving direction to their peers in performance.

Figure 5. "Nerve" Premier. Berlin February 2002.

CONCERT - "NERVE"

The six minute piece "Nerve" was composed by author Gil Weinberg as one particular manifestation of the Beatbug network. In this piece the motifs and play order were predetermined by the composer. Written for 6 children and 2 professional percussionists, the piece starts in a manner that clearly conveys the development of each motif over time. It then gradually grows into a rich and constantly evolving polyphonic texture that is driven by the tension between the system's chance operation and the players' improvised decisions. The piece ends in a Finale section where the computer randomly groups different numbers of players for improvised solo sections. First in duos, then in quartets, and finally with the whole octet, players can interdependently improvise by manipulating each other's material. Nerve was premiered on February 2002 at Haus Des Rundfunks Berlin as part of Tod Machover's Toy Symphony in a concert with the Deutsches Symphonie Orchester Berlin, conducted by Kent Nagano.

	Sends to	**Rhythmic Ornamentation**	**Timbre Manipulation**
Player 3 (Motif 3)	Player 5	1 step 1/16th note	FM amount + Pitch bend
	Player 4	3 step 1/16th note	Flange level
	Player 7	1 step 1/8th note triplet	Filter resonance level
	Player 1	2 step 1/16th note	Filter Envelope Attack length
Player 4 (Motif 4)	Player 6	5 step 1/16th note	Pitch bend
	Player 5	4 step 1/16th note	FM Amount
	Player 1	1 step 1/16th note	Amplitude envelope sustain
	Player 7	1 step 1/8th note triplet	Filter Frequency
Player 1 (Motif 1)	Player 2	2 step 1/16th note	LFO level
	Player 7	3 step 1/16th note	Pitch bend
	Player 8	2 step 1/16th note	Flange level
Player 7 (Motif 7)	Player 5	5 step 1/16th note	Amplitude envelope sustain
	Player 8	4 step 1/16th note	Noise level
Player 5 (Motif 5)	Player 6	1 step 1/16th note	Filter Frequency
	Player 2	1 step 1/8th note triplet	FM amount
Player 6 (Motif 6)	Player 8	1 step 1/16th note	Filter Freq+ resonance
	Player 2	3 step 1/16th note	Filter 2 resonance
	Player 8	2 step 1/16th note	Filter 2 frequency
Player 2 (Motif 2)	Player 8	5 step 1/16th note	Pitch bend
	Player 2	4 step 1/16th note	LFO amount
Player 8 (Motif 8)	Player 3	1 step 1/16th note triplet	Filter resonance

Figure 6. "Nerve" pre-composed routing, timbre manipulation, and rhythmic ornamentation

PRELIMINARY EVALUATION

The Instrument and the Interaction

Our preliminary observations indicate that children found the Beatbugs easy to hold and manipulate, and with minimal instruction quickly adopted techniques for controlling the antennae. After two 1 1/2 hour sessions, they were comfortable with both making and manipulating motives and had moved from the initial two measure units to four measures at a faster tempo (147 bpm). By session four they had developed a high degree of sophistication and sensitivity in using the antennae to make subtle alterations to their motives, moving from gross random manipulations of the 'rhythmic ornamentation' antenna to much smaller, more carefully judged actions. We also noted that the participants have developed an expressive playing behavior in "conducting" their friends, using large body movements and gestures. They also developed a game-like activity by trying to surprise their friends with sudden gestures.

Some weaknesses of the system were apparent. The original Beatbug antennas were not robust enough to withstand use and abuse by children, prompting a redesign. The trigger system had to be tuned to reject handling noise, while still being sensitive to intentional hits. Some timbres got buried in the mix once all the bugs were playing, making it hard for the children to hear what effect their antenna manipulations had on the sound. One surprise from the workshops was that several children preferred to be given pre-composed motifs to play rather than to create their own. Once they did create a phrase, they tended to play the same phrase every time.

Figure 7. A musical dialog between a child and a teacher in "Nerve."

Figure 8. Interaction between children and a percussionist from Deutsches Symphonie-Orchester Berlin.

Learning and Pedagogy

In the course of the workshops there was clear development in the children's performance at all levels. Stability in entering rhythm patterns against a pulse and also against a complex shifting texture, ability to deal with syncopation, use of accent and shaping of motives all improved considerably. Use of rhythmic and timbral manipulations became increasingly subtle and pointed. Interpersonal interactions such as making eye contact, looking, turning and pointing in order to facilitate musical events became completely intuitive and contextualized. When participants were asked about their learning experience in comparison to traditional music classes, many pointed out concepts such as the communal music making and peer-to-peer musical interaction that are rarely addressed in the early stages of learning to play an instrument. Others talked about being more aware of the other players in the group, listening to and following each other. In the future we plan to evaluate the transferability of these skills and concepts to other musical contexts.

FUTURE WORK

The Beatbugs will continue be used and evaluated in a series of workshops and concerts. The DSO performance will be followed by a concert in Dublin with the National Symphony Orchestra Ireland and in Glasgow with the BBC Scottish Symphony, where the Beatbugs will also be played in Tod Machover's "Toy Symphony" piece. Before each of these performances, local children will participate in week-long workshops, where they will explore the system and rehears the compositions for the concert. In the future, we plan to publish a comprehensive evaluation paper, presenting the observations and results of these workshops and concerts.

ACKNOWLEDGMENTS

We thank Gautam Jayaraman, Pete Colao, and Tod Machover for their considerable contributions.

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