# Local Performance Networks: musical interdependency through gestures and controllers

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**Informed by a proposed theoretical framework for the field of interconnected musical networks (Weinberg 2005), I describe a set of local musical networks that utilise novel gestural controllers for interdependent collaborative performance. The paper begins by contextualising developments in the field of musical networks in correlation with development of technological innovations, leading to the utilisations of gestural controllers in local musical networks. This introduction leads to the definition and categorisation of theoretical and practical approaches for the design of local gestural networks, addressing motivations, social strategies, network architectures, musical content, and control software and hardware. Based on this theoretical framework I describe the evolution of four local musical networks that utilise newly developed gestural controllers, titled 'Squeezables', 'Musical Fireflies', 'Beatbugs' and 'Voice Patterns'. The paper discusses the design and development process of these projects and ends with a comparative analysis of the networks and controllers based on conceptual and practical criteria.**

## 1. INTRODUCTION

The development of musical networks in the last fifty years is closely related to a number of technological developments that took place during this period. In particular, I see four major technological innovations – analogue electronics, the personal computer, the Internet, and alternate controllers – as principal enablers for the artistic development of the field. When these technologies became widespread and commercially available they inspired musicians to look for new ways for expanding the vocabulary of socio-musical expression. During the 1950s and 1960s, musicians such as Cage, Stockhausen, Tudor and Rosenboom utilised a variety of analogue musical devices such as the radio transistor, the microphone, and the synthesizer to create the early crude interdependent musical networks, allowing players, for the first time, to control not only their own musical output, but also their peers' (see details in Weinberg 2002). In the 1970s, with the introduction of the affordable personal computer, groups such as the League of Automatic Music Composers and later the Hub used digital technology to create more accurate and detailed interpersonal connections among players (Bischoff, Gold and Horton 1978; Gresham-Lancaster 1998). These early networks tended to pose high entrance barriers for players, requiring specialised musical skills and theoretical knowledge in order to take part in and follow the interaction in a meaningful manner. Often, these networks featured complex interconnections among participant, leading to high-art musical products that were not aimed at wide audiences. The Internet explosion of the 1990s, on the other hand, enabled new kind of musical networks that focused on challenges such as large-scale group interaction and novice participation (see, for example, Gang *et al.* 1997, Konstantas *et al.* 1997, Jorda 1999 or Pazel *et al.* 2000). These online networks demonstrated the difficulty in creating coherent and easy-to-follow musical interactions in a medium that does not support real-time gestural performance cues. It soon became evident that the graphical user interface, most common in online networks, falls short in comparison to the tactile, interpersonal and unmediated interconnections provided by gestural interaction with physical instruments in a local space. In an effort to facilitate such expressive gestural networked communication, many current collaborative musical networks utilise exceedingly more affordable, robust and easy-to-use alternate controllers in applications that are aimed at novices and the general public (see, for example, Bongers 1998, Feldmier 2002 or Jorda 2003). My investigation of such recent local performance networks suggests a number of challenges that network designers find difficult to address. For example, it is not trivial to provide novices with simple and intuitive control that could also grow into rich and meaningful interdependent group collaborations, nor is it easy to create a coherent and aesthetic musical outcome while allowing large groups of untrained players to participate in the creative process.

## 2. THEORETICAL AND PRACTICAL APPROACHES

In order to address these challenges, and in an effort to create effective and successful gestural musical networks, I decided to investigate three anchoring theoretical questions: '*Why*' – what are the goals

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and motivations for designing and participating in a musical network? '*How*' – what are the different social perspectives, architectures, and network topologies that can be used to address these goals and motivations? '*What*' – what are the musical parameters, interdependent algorithms, gestures and controllers that would best serve designers' motivations and architectures?

### 2.1. 'Why' – goals and motivations

I see two main driving forces for designing and participating in interconnected musical activities: *process*-centred forces and *structure*-centred forces. The focus in process-centred networks is on the players' experience, which may be social, creative and/or educational. In structure-based systems, on the other hand, the most valued goal of the interaction is its musical outcome. The differentiation between process- and structure-centred music can be related to the tension that emerged in the midst of the twentieth century between the radicalisation of musical structure and composer's control, practised mainly by 'avant-garde' and 'post-serialist' composers such as Stockhausen and Boulez on one hand, and the escape from structure towards 'Process Music' as was explored mostly by American experimentalists such as Cage and Reich. As opposed to some European movements that emphasised the composer's control over almost every aspect of the composition, process music came from the belief that music can be a procedural and emergent art form and that there are many ways of handling form other than constructing structures in different sizes. In such procedural process-based music, the composer sacrifices certain aspects of direct control in order to create an evolving context by allowing rules (in closed systems) and performers (in open ones) to determine and shape the nature of the music. John Cage addressed this tension referring to his own experience: 'I was to move from structure to process, from music as an object having parts to music without beginning, middle or end, music as weather' (Cage 1961). The use of technology in musical networks pushes the tension between structure and process music into an experience where predetermined rules and instructions combined with improvised interdependent group interactions can lead to evolving musical behaviours, giving a new meaning to Cage's exploration of unpredictability, chance determination processes, accidents, and contextual emergent music.

The activities in process-centred musical networks can be further classified into exploratory and goal-oriented interactions. Exploratory networks do not impose specific directions or goals on participants. These systems are driven by motivations such as the investigation of novel ways for playing in a group or the creation of collaborative musical crossbred offspring. Goal-oriented interactions, on the other hand, are designed to encourage players to achieve specific objectives, musical or non-musical. It is important to note that although most networks combine process- and structure-based elements, creating a successful balance between these aspects is not a trivial task since many of the elements are contradictory in nature. For example, it would be a difficult task to design a musical network that would lead to the creation of an interesting well-structured composition while players are trying to win a musical game.

### 2.2. 'How' – social perspectives and network architecture

Similarly to other social systems, musical networks can be based on social organisations and inspired by social philosophies. The main conceptual axes at play when designing a 'social philosophy' for a network are the level of central control desired and the level of equality provided to the different participants in the interaction. Centralised systems tend to be governed by a computerised hub that is responsible for generating the musical output based on input from participants. In decentralised systems, players communicate directly with each other through instruments or software applications that are computationally self-contained. Under the centralised and decentralised umbrellas we can find a wide range of approaches that are based on the levels of equality provided to participants in terms of their musical role. Political metaphors may be appropriate. In a centralised unequal network, a leader (a person or in some cases the computer) controls and conducts the interaction. This leader can provide temporary freedom to other players when desired, change and manipulate the interconnection gates among players, and take control over the interaction in general. While providing a more structured interdependent outcome, this 'monarchic' approach usually fails to provide a true collaborative and creative voice to players due to the leader's dominancy. Such systems, therefore, would be more effective in addressing structure-centred motivations than process-centred ones. Democratic networks, on the other hand, may be more effective when process is emphasised. Here, the centralised system provides an equal, or close to equal, role for all players in defining the musical output. Often in such systems, only the collaborative act of the majority will define the final musical result. Different participants in 'democratic' networks may have different roles and responsibilities (such as controlling the harmony, melody or rhythm) while individual players may temporarily receive a leading role from their peers or from the system. In decentralised systems, on the other hand, the interaction occurs directly between participants without a central control to govern the experience. One extreme

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example of a decentralised unequal musical network is an 'anarchic' network, which provides minimum central control and maximum freedom for players to generate and manipulate their musical materials.

The social organisation of the network, an abstract high-level notion, can be addressed by designing and implementing the lower level aspects of the network's topology and architecture. In order to implement a centralised system, for example, the network topology will have to support the transmission of data from users to a computerised hub for analysis and/or algorithmic generation of the musical output. In decentralised topologies on the other hand, players interact directly with each other using instruments and/or applications that bear their own computational function. One of the main considerations in designing the network architecture involves timing the user interaction by defining a balance between synchronous and sequential operations. At the synchronous extreme of this axis, players would only modify and manipulate their peers' music while it is being played. At the sequential extreme, players would generate their musical material with no outside influence and only then 'submit' it to further transformation and development by their peers. Synchronous interactions are more likely to be supported by local-area networks in which latency is not a crucial problem. Synchronous networks are also more likely to support a constantly evolving and immersive musical experiences, although such an approach might lead individual players to lose the sense of coherency and causality if the network topology is not designed carefully to maintain aspects of personal autonomy. In sequential networks, on the other hand, the interdependent interactions occur in an ordered manner by actions such as turn taking. This approach, which can also be supported by remote networks with higher levels of latency, may be simpler to follow for individual players but might compromise the real-time collaborative group experience since not all participates are constantly involved in music making.

### 2.3. 'What' – musical content and control

One of the most important aspects of designing effective musical networks is the lower level decisions regarding the input devices, musical parameters, and transformation algorithms that would infuse the theoretical and social framework with musical content. In gestural local networks, defining and designing the input devices is of a special importance. Here, any combination of discrete and continuous sensors can be embedded in a wide range of controllers that support a variety of gestures. When the focus is on simplicity and learnability, designers may consider limiting these input axes. A focus on a rich and detailed musical experience, on the other hand, may lead designers to embed multiple degrees of freedom and more input axes. Maintaining the balance between these two extremes is one of the most challenging tasks for a designer of controllers for local musical networks. Also of significant importance are decisions regarding the musical parameters and functions that would be generated and controlled autonomously as opposed to those that would be controlled interdependently. This aspect of the design bears a subjective aesthetic core as different composers and designers may have different ideas, tastes, or artistic interests when determining the precise control parameters. Generally speaking, every musical parameter, such as pitch, rhythm, timbre or dynamics, is a candidate for autonomous as well as interdependent control. However, there are some rules-of-thumb that have been proven to be effective for the creation of a coherent collaborative interaction. For example, allowing players to influence and control parameters such as the pitch of their peer's melody may lead to an incoherent experience for the peer who might lose control over one of the fundamental aspects of melody making. Such mappings may draw the systems into an anarchic experience that would be difficult to follow for participants and viewers, even if the architecture supports more coherent social perspectives. On the other hand, granting a player full autonomous control over her pitch content while allowing other players to control ornamental surface aspects such as timbre or dynamics, tends to lead to a more coherent experience for the player who can interdependently enrich her playing experience as she tries to accommodate the melody to the new timbres and dynamics. Another important aspect for maintaining the interaction coherency is preserving the nature of the musical material as it was originally created. In sequential networks in particular, it is easy to allow co-players in multiple steps to modify their peers' music beyond recognition. This might disconnect the original players from the music they created, obscuring their detailed idiosyncratic contribution to the group. The interdependent transformation algorithms, therefore, would be more effective if they attempted to modify surface elements and to maintain reversibility, so that the original musical output would be perceivable and retrievable.

## 3. IMPLEMENTATION

In an effort to explore the theoretical and practical design approaches described above and to create effective musical network experiences, I developed a set of gestural network systems with collaborators at the MIT Media Lab which were based on a set of goals, motivations, social perspectives, network architectures, gestural controllers and musical content mappings. Below I describe four of these systems,

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titled 'Squeezables', 'Musical Fireflies' 'Beatbugs' and 'Voice Patterns', and focus on the evolution of the development process and the lessons that were learned and implemented in each successive network.

### 3.1. The Squeezables

The motivation for developing the first the network, the Squeezables (Weinberg and Gan 2000), was to investigate the interdependent process among networked musicians in a creative context. We therefore designed a centralised synchronous network that allowed different players to control different musical parameters in their peers' musical output in real time. We chose continuous controllers that utilise familiar gestures and experimented with a variety of musical parameters both for autonomous and interdependent interaction. The Squeezables comprised six squeezable and retractable gel balls mounted on a small podium (see figure 1). In an attempt to provide an immediately responsive interface that would offer a tactile and intuitive musical interaction, we used soft and malleable materials such as fabric, foam and gel, which were designed to encourage familiar squeezing and pulling gestures. Each player around the podium could simultaneously squeeze and pull two balls (one ball per palm) that controlled a set of musical parameters based on an interdependent algorithmic scheme. Several materials were tested to provide a soft, organic and expressive control for these continuous gestures. The first versions of the instrument used a cluster of soft foam balls that flaked easily and lost their responsiveness over time. For the final prototype, soft gel balls were chosen. These proved to be robust and responsive, providing a compelling sense of force feedback control due to the elastic qualities of the gel. Buried inside each ball was a plastic block covered with pressure sensors that captured squeezing gestures. The pulling actions were sensed by a set of resistors installed under the table. An elastic band added opposing force to the pulling gestures and helped retract the ball back onto the tabletop (see figure 2).

Some of the gestures were mapped to control low-level musical aspects such as the frequency of vibrato or the amplitude of tremolo. Other gestures were mapped to algorithmic simulations of high-level musical concepts such as stability and contour, informed by research such as Sloboda (1985), Dibben (1999) and Schmukler (1999). We developed these high-level perceptual models in an effort to provide expressive and intuitive musical experiences for novices that would not require a long learning process, virtuosic performance skills, or any previous knowledge of music theory. In order to provide coherent interdependent group collaboration, a democratic synchronous centralised network topology was chosen, which provided different levels of interdependency to different players based on their musical role. The squeezable controllers were divided into five accompaniment balls and one melodic soloist ball. The accompaniment players had full autonomous control so that input from other balls could not influence their musical output. However, the five accompaniment balls' output was not only mapped to the accompaniment parameters but also significantly influenced the sixth melody ball. While pulling the melody ball controlled the contour of the melody, the actual pitches, amplitudes, durations, and spatial values were determined by the level of pulling and squeezing of the accompaniment balls. This allowed the accompaniment balls to 'shape' the melody while maintaining a coherent scheme of interaction among themselves. In addition, squeezing the melody ball controlled its own timbre and manipulated the accompaniment balls' weights of influence in an interdependent reciprocal loop.

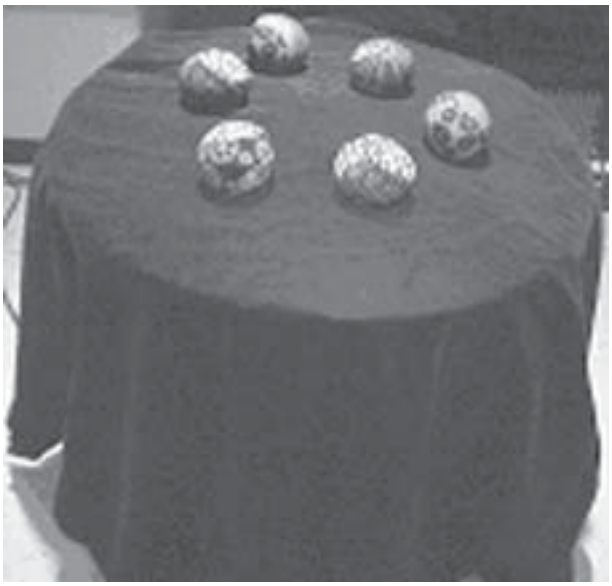


**Figure 1.** The Squeezables.



**Figure 2.** Squeezables performance.

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Observations and discussions with novices and expert musicians who experimented with the Squeezables led to interesting findings (see interview transcripts in Weinberg 2003, M.S. Thesis, pp. 74–80). Children and novices tended to prefer playing the balls that provided high-level control such as contour and stability manipulation. They often stated that these balls allowed them to be more expressive and less analytical. Proficient musicians, on the other hand, often found the high-level algorithms somewhat frustrating since they did not provide direct and precise access to specific desired parameters. Both novices and expert players found the multi-user synchronous control expressive and challenging and the pulling and squeezing gestures comfortable and intuitive. These gestures allowed delicate and easily learned control of many simultaneous parameters, which was especially compelling for children and novices. The organic and responsive nature of the balls was one of the features that were mentioned as contributing to this expressive experience. Interesting findings also came from evaluating the implementation of a democratic interdependent network topology. In general, players enjoyed controlling other players' music as well as being controlled by their peers, stating that this provided a new layer of creativity to their experience. Since the melody ball players received a high level of external input and were capable of controlling only some interdependent aspects in the other balls, they often described their experience in words such as 'a constant state of trying to expect the unexpected'. One player's impression was that she was not playing the instrument, but rather the instrument was 'playing her'. When the accompaniment players were particularly experienced and skilful, playing the melody ball felt to another player almost like 'controlling an entity that has a life of its own'. This unique experience was intriguing and challenging for some but difficult and frustrating for others.

Playing the accompaniment balls led to a completely different experience. Here, players could control and manipulate the melody without being significantly influenced themselves. However, full collaboration with the other accompaniment players was essential in creating a substantial effect on the melody, as the melody's algorithm used the sum of the signals from the other five balls. In a manner similar to chamber music group interactions, body and facial gestures had to serve an important role in coordinating the accompaniment players' gestures and establishing an effective outcome. Such collaborations turned out to be especially compelling for children, who found the accompaniment balls social, intuitive, and easy to play with. Some accompaniment players, however, felt that the difficulty to significantly influence the melody without trying to coordinate such an action with the other accompaniment players, prevented them from expressing their individual voices. In an effort to address some of the uncertainties caused by the Squeezables' synchronous interdependent network topology, I composed a more structured piece for the instrument, where players followed a written score that indicated the timing and levels of pulling and squeezing each of the balls. This structured piece was featured in Ars Electronica as part of the Tissue Culture and Art project (Catts, Zurr and Ben Ari 2000).

### 3.2. The Musical Fireflies

The Musical Fireflies (Weinberg, Lackner and Jay 2000) were developed in an effort to address some of the drawbacks and weaknesses identified in the Squeezables, such as its confusing synchronous interdependency, the lack of musical direction in free play, and the significant differences in players' experience in correlation with their musical role. We, therefore, decided to explore a more equal and consistent social perspective, a more coherent sequential network topology and to introduce goal-oriented musical activities. Moreover, unlike the Squeezables, one of the main motivations for the Fireflies project was to use the network for educational purposes. The project, therefore, utilised a decentralised network topology, sequential interactions using discrete input devices and goal-oriented activities aimed at introducing mathematical concepts in music such as beat, rhythm and polyrhythm without requiring prior knowledge of music theory. Players could use the Fireflies to tap rhythmic patterns, embellish them in real time, synchronise patterns with other players in a group, and trade instruments' sounds. The Fireflies were designed to provide simple and immediate musical control for individual players and to lead to richer, more sophisticated musical experiences when multiple players, using multiple instruments, interacted with each other. Through infrared communication, players synchronised their instruments with other Fireflies and enhanced their simple and monorhythmic patterns into a polyrhythmic experience (Handel 1984). In these synchronised social interactions, users could obtain an understanding of their rhythmic patterns in relation to the group's composition and explore their individual contribution to the final group outcome. The trading actions helped players to perceptually separate the timbre-oriented characteristic of the patterns from their numerical aspects, leading to hands-on familiarisation with the underlying mathematical principals of music.

The Musical Fireflies' 3D printed case was designed to be held with both hands while tapping the

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top-mounted buttons with the thumbs (see figure 3). The buttons were connected to two analogue-to-digital converters on an embedded 'Cricket' microcontroller (Martin 1999), which was responsible for the musical algorithms. The Cricket was equipped with an infrared system that allowed for wireless communication with other Crickets. The entered rhythmic patterns were sent through the Cricket's serial bus port to the 'MidiBoat' (Smith 1999), a tiny General MIDI circuit connected to an internal speaker (see figure 4).

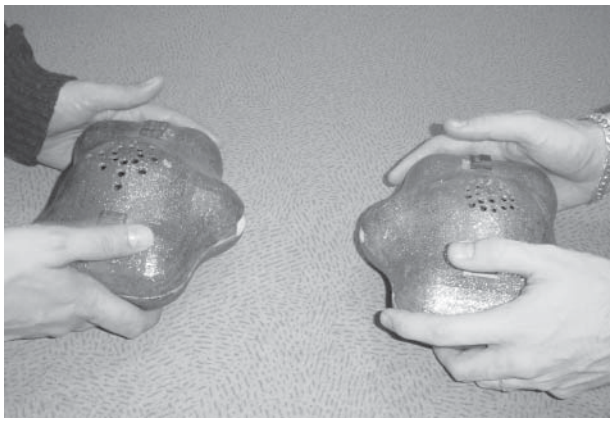


**Figure 3.** Two players interact with the Musical Fireflies.

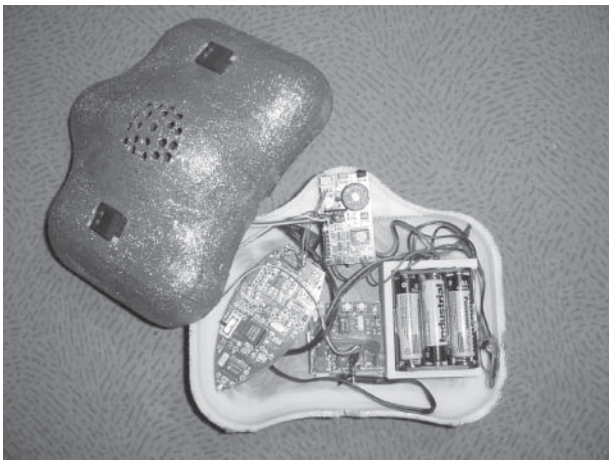


**Figure 4.** Two touch sensors on each Firefly are connected to a central microprocessor with infrared capabilities. Also embedded in the Fireflies are a General MIDI board, an amplifier, a speaker, and 6 AA batteries.



**Figure 5.** A pattern of accented and non-accented notes as played and recorded by a Musical Firefly (● = accented note played by the left button, ○ = non-accented note played by the right button).

Interaction with the Musical Fireflies occurred in two distinct sequential modes – the single player mode, where players converted numerical patterns into rhythmical structures, and the multi-player mode, where networking with other players enhanced the basic rhythmic structures into polyrhythmic compositions. In the single player mode, tapping the left button played and recorded an accented drum sound and tapping the right button played and recorded a non-accented drum sound. After two seconds of inactivity, the Firefly played back the entered pattern in a loop, using a default adjustable tempo. This activity provided players with a tangible manner of entering and listening to the rhythmical output of any numerical pattern they envisioned. Figure 5, for example, depicts the playing of the numerical pattern 4 3 5 2 2.

In the multiplayer mode, when two Fireflies 'saw' each other (i.e. when their infrared signals were exchanged), they automatically synchronised their rhythmic patterns (a similar interaction occurs when the firefly insects synchronise their light pulses to communicate in the dark). This activity provided participants with a more complex rhythmical interaction and allowed for a hands-on introduction to polyrhythm. Figure 6 depicts an example where a 7-beat pattern played by one Firefly and a 4-beat pattern played by another diverge and converge as the patterns go in and out of phase every 28 beats.

While the two Fireflies were synchronised, players could also initiate a 'timbre exchange' in which instrument sounds were traded between the devices. This provided players with a higher level of musical abstraction, allowing them to separate the rhythmical aspect of the beat from the specific timbre in which it is being played.

In a number of observation sessions that were held with the Musical Fireflies it was evident that constraining the number and complexity of inputs (only two discrete buttons and no continuous controllers) led to a better and easier learning curve for players in comparison to the multiple continuous inputs of the Squeezables. The network topology, too, served as

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/4 | ● | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ |
| 4/4 | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ |

**Figure 6.** Two patterns (7/4 and 4/4) played by two Fireflies diverge and converge as they go in and out of phase every 28 beats.

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an extreme alternative to the Squeezables' architecture. With no central hub and with simple identical rules applied to each self-contained 'node', the Fireflies utilised decentralised network architecture with an anarchic phase where players entered their own material without coordinating their actions with their peers. In order to evaluate the Fireflies' physical and gestural aspects, players were asked to experiment with a graphical user interface software simulation of the application. In general, players found the concrete aspects of playing with the physical Fireflies compelling in comparison to using a keyboard and a mouse. Subjects mentioned the unmediated connection that was formed with the physical controller as significant for the creation of personal involvement with the musical and mathematical patterns. Tapping real buttons and listening to the music from distinct physical sources also helped players to comprehend and follow the trading interaction in a more coherent manner than listening to computer speakers. Several preliminary algorithms for interdependent control (such as trading the numerical patterns or morphing between patterns to create more complex ones) were ruled out in these software simulations since they led to confusion and uncertainties among players. Finally, timbre was chosen as the 'exchange parameter' in the network due to its 'colouring' qualities, which did not complicate the already rich rhythmical and mathematical texture.

These observations also led to the identification of a number of directions for improvement and further work. One of the main weaknesses of the project was the limited interconnectivity of the Fireflies, where the only interdependent act was a simple and discrete timbre-exchange operation that did not provide long-lasting play value. To bring back the successful continuous interdependent actions that characterised the interaction with the Squeezables, a new synchronous application using continuous sensors had to be developed. We were also not satisfied with the simplistic musical outcome of the system. The monotonous interlocking rhythms that did not include time-based rhythmic values, rests, pitch, timbre or expression could not lead to the creation of a worthy musical outcome. Moreover, due to the limitations imposed by the line-of-sight infrared communication, the Fireflies only allowed for synchronisation and timbre exchange between two players at a time, which prevented the scaling of the interaction to larger and more sophisticated networks.

### 3.3. Beatbugs

The Beatbugs project (Weinberg, Aimi and Jennings 2000) attempted to bring together successful elements from both previous projects and to avoid their drawbacks. The project aimed at enabling creative networked collaborations as well as providing a constructionist learning experience. It also aimed at providing expressive and exploratory high-level control for novices that could lead to the creation of worthy music. The challenge here was to provide goal-oriented educational activities that would motivate players to interact in long and rich experiences without compromising the artistic value of the musical outcome. In order to address the downside of pure sequential interaction such as in the Fireflies, the Beatbugs were designed to combine sequential elements for maintaining order and coherency with synchronous elements for promoting long-term collaborative engagement. Both continuous and discrete sensors were embedded in the Beatbugs in an effort to improve upon the Squeezables' lack of precise control on one hand, and the Fireflies' limited button-based interaction on the other. Unlike the Fireflies, which only recorded non-rhythmic sequences of accented and non-accented notes, the Beatbugs were capable of capturing a wide range of discrete temporal events including rests, quarter notes, eighth notes and triplets, in a variety of hit velocities. Similarly to the Squeezables, the Beatbugs also employed continuous sensors for the manipulation of high-level musical percepts such as timbre and rhythmic density.

The Beatbugs application was designed to allow the creation, manipulation and sharing of rhythmic motifs in a group. When multiple Beatbugs were connected in a network, players could form collaborative compositions by interdependently sharing and continuously developing each other's motifs. As opposed to the infrared wireless communication of the Musical Fireflies, the Beatbugs communicated with a central hub via wires, allowing for more players to participate in the interaction. Each Beatbug player could discreetly enter a rhythmic motif that was then sent through the stochastic computer hub to other players in the network. Receiving players could decide whether to develop the motif further (by continuously manipulating pitch, timbre and rhythmic elements using two bend sensor antennae) or to keep the motif in their personal instrument (by entering and sending new rhythmic motifs to the group). Additionally, I wrote a structured composition for the Beatbugs, entitled 'Nerve', in which the rhythmic patterns and their routing scheme were pre-composed. The piece was presented in workshops and concerts in Europe and the US, each leading to a public concert as part of the Toy Symphony project (Machover 2004).

In an effort to provide a child-friendly creature-like identity, each Beatbug had a speaker for a mouth, two bend-sensors for antennae, and a velocity-sensitive drum trigger on its back (see figure 7). White and coloured LEDs mounted in its translucent shell provided visual feedback when the Beatbug was hit, or played through. The physical interface facilitated a

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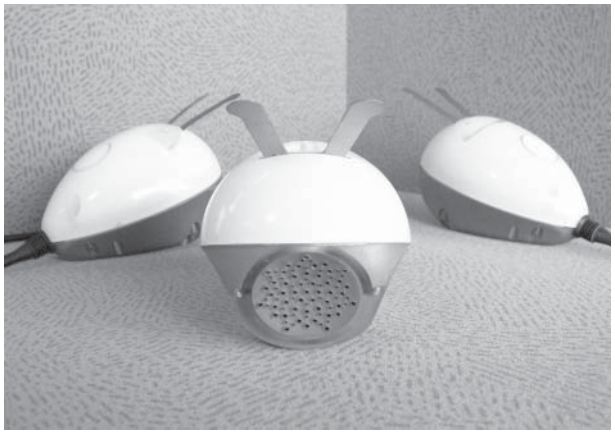


**Figure 7.** The Beatbugs.

variety of play gestures and attempted to make what was happening clear to viewers and listeners. The drum sensor measured hit timing and strength, and the two antennae allowed for subtle control over pitch, timbre and rhythmic aspects of the recorded motifs. Bending the antennae also caused a proportional change in the colour of three LED clusters, and a ring of white LEDs flashed each time the bug was hit, providing additional visual feedback to the player and audience. The Beatbug processor was responsible for operating the sensors and the LEDs, while a central computer system controlled the actual musical interactions and behaviours. The synthesis occurred on the central computer but the sounds were played through each corresponding Beatbug's speaker.

The main network application for the Beatbugs, titled 'Snake Mode', combined both sequential and synchronous interactions. The social architecture facilitated mostly equal operations with temporary assignment of 'leaders' in rotation. The first leader started the session by generating a metronome beat and could then enter a rhythmic pattern which was automatically sent to a random player in the network and played back in a loop. A quantisation algorithm nudged each onset towards the closest quarter note, eighth note, or quarter note triplet. The receiving player, who became the new temporary 'leader', could choose between entering a new pattern or manipulating the pattern he received by bending the two antennae. The left antenna continuously transformed timbre elements using a variety of predefined filters, low-frequency oscillators, frequency modulators, noise generators, and envelope parameters. The right antenna added rhythmic density to the pattern by controlling the values, length, accents and feedback of a delay line. Due to the random operations, players never knew what pattern they were going to receive, and whether they would want to keep it or to send it away after further manipulations. This random aspect of the interaction emphasised the 'process'-based nature of the interaction, as players had to listen carefully, be prepared for surprises, and make decisions on the fly. After all eight players entered their patterns and kept their favourite transformations, the system randomly grouped different numbers of players for improvised solo sections, providing the participants with the opportunity to synchronously manipulate each other's musical material. In an effort to allow for more structured activities in time-limited concerts, I composed a piece for the system titled 'Nerve', where the routing scheme was pre-composed. Here, players were instructed whether to enter a new pattern or to manipulate the old one in each cycle. This mode eliminated some of the surprises and dynamic aspects of the network, but allowed for more structured rehearsals where players could improve their playing skills and musical memory.

Observation of workshops and concerts in Boston, Dublin, Glasgow and New York indicated that children found the Beatbugs easy to hold and manipulate, and with minimal instruction quickly adopted techniques for controlling the antennae. After two 2-hour sessions, most children were comfortable with both making and manipulating motifs and had moved from the initial 2-measure units to 4 measures at a faster tempo. By session four they had developed a high degree of sophistication and sensitivity in using the antennae to make subtle alterations to their motifs, moving from gross random manipulations of the rhythmic antenna to more subtle and carefully judged actions. In some workshops participants developed an expressive playing behaviour in conducting their friends. While serving as leaders, players used large gestures to point at their peers in an effort to indicate that they would like to play with them by manipulating their respective patterns. Some groups also developed game-like activities such as trying to surprise their friends with sudden gestures or by creating group 'waves' or 'battle gestures' (see figure 8).

The centralised, mostly equal, and sequential network topology provided players with more freedom in choosing the musical parameters for autonomous and interdependent control in comparison to the previous projects. The Beatbug controller allowed for richer generation and manipulation of musical material using both discrete and synchronous sensors. However, the system was not able to provide strong idiosyncratic and personal connection between performers and their musical product. Players could only choose from a limited set of sounds, which impaired the creation of personal identity. Moreover, while helping making the musical output tighter and more coherent, the quantisation operations prevented the capturing of subtleties in entering the rhythmic patterns and limited the range of personal expression. Another weakness in the system was the complicated

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**Figure 8.** 'Nerve' performance in Boston. Players developed expressive play gestures and game activities using the Beatbug controllers.

interaction design in 'Nerve' that required training and practice before each performance as some participants found it difficult to tap their patterns in a rhythmic manner and to follow the pre-composed routing scheme.

### 3.4. Voice Patterns

Voice Patterns (Weinberg 2004) was designed to address some of the weaknesses in the Beatbug project by providing more personal connections for players with their musical creation and allowing for richer input sources and more varied control parameters. The project also aimed at engaging players in an immediate collaborative experience that requires no training. In order to address these challenges, the human voice was chosen as a musical source that can provide personal connection as well as rich transformability. Since the voice is one of the most idiosyncratic traits we possess, it can allow almost everyone to create personal transformable musical materials without much training and practice.

One of the goals of Voice Patterns was to maintain the successful balances achieved in the Beatbug project in terms social perspectives, architectures and control, but to introduce a number of unexplored networking concepts. For example, I was interested in maintaining the process-centred and creative focus of the Beatbugs but to introduce a more distinctive goal-oriented activity where players follow specific tasks and can be rewarded musically when successful. In terms of the social perspective and network architecture, I was interested in preserving the Beatbugs' equal approach that featured both synchronous and sequential interactions, but to provide a more decentralised feel to the interaction where most of the processing occurs separately at the network's nodes. In terms of musical content and control, my goal was to extend the number and nature of the musical parameters that can be created and manipulated both autonomically and interdependently, while preserving the combination of continuous and discrete inputs.

To address these goals, a control platform titled Voice Networks was developed, which consisted of four control stations, each with a microphone and a touchpad controller. The microphones' height and location were chosen to encourage participants to use their voices as input source, although other audio sources were acceptable as well. The stations were facing each other so that players could see and listen to their peers (see figure 9.) A flat screen monitor for visualisation was installed on top of the podium in-between the stations. Four speakers, one per station, were installed on the floor, facing their respective players. A Macintosh computer running Max/MSP connected to a multi-port MIDI and audio interfaces were installed inside the podium.

The application Voice Patterns, which was developed for this platform, consisted of two sequential phases. First, players could enter their voice motifs without intervention from the system or from other players in a decentralised manner. They could then manipulate their voice recordings using identical mapping scheme in all four stations in a manner that preserves an equal social perceptive. After recording their voice motifs, players could listen to them in a loop and transform them by moving their fingers on the touch pad. These transformations were designed to allow easy access to a wide variety of musical parameters, extending the musical input gamut of previous projects. The touch pad was divided into four quadrants; each featured a unique transformation effect with two real-time user-controllable parameters. At the bottom-right quadrant players could change the pitch and amplitude of their looped voice. The bottom-left quadrant offered pitch and amplitude control as well, but here the motifs were played in reverse. The top-right quadrant allowed players to



**Figure 9.** The Voice Networks platform.

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manipulate the parameters of a low-frequency oscillator (LFO) mapped to modulate the amplitude of the recorded audio. Players could change the LFO's amplitude and frequency, which led to a variety of rhythmic pulsation effects. At the top-left quadrant, players could interact with a delay line algorithm in a range that led to a variety of timbre transformations such as flanging and chorus. These simple mappings were chosen to cover a wide range of basic musical elements that are simple to follow, but that can lead to elaborate transformations when interdependently controlled by a group.

The second phase of the interaction facilitated goal-oriented network interactions that took advantage of the gestrual nature of the system. Here, players were encouraged to align their finger gestures with each other, therefore synchronising their voice transformations. The result of successful synchronisation was a more coordinated musical outcome, which culminated in a 'reward' – the trading of the transformed voice motifs between the two synchronised players. The audible effect of the synchronisation depended on the specific musical parameter that was assigned to each quadrant. After the trading, players could manipulate and develop the voice motif that they received and could try to trade it further by synchronising their gestures with other participants. The musical output of the system, therefore, was quadraphonic propagation of motifs and variations, which successively got in and out of synchronisation. To support this interaction, Voice Patterns utilised four audio buffers that could be recorded to and manipulated by MIDI commands. A synchronisation engine constantly checked for matching MIDI input patterns from the pads and executed the buffer trade. Animated visualisation on the central monitor showed the location of each player on each pad. As a reward, both players could play solo as the other two participants were muted.

Observations that were conducted with Voice Patterns showed that using the voice allowed almost any participant to get some degree of meaningful group interaction. Visitors to the installation sang, spoke, clapped, whistled, or just tapped on the microphone. Some of the musical parameters proved to be difficult to coordinate and synchronise, posing tough challenges to participants in their efforts to create a meaningful musical outcome from a collage of unrelated audio segments. The most successful parameter in that regard was the pulsation effect generated by the LFO synchronisation, which provided a unified beat to the collage. The synchronisation of other musical parameters, such as pitch and timbre did not always lead to a coherent musical outcome. Better audio analysis and harmonisation algorithms can be used to improve these results. In order to accommodate visitors who could not (or did not want to) use their voices, a number of percussive instruments were made available for players (see figure 10). This addition enriched the versatility and the richness of the final musical output, which we believe was improved (rather than hampered) by the goal- oriented synchronisation gestures. The sequential and equal social approach proved to be useful as well since it shortened participants' learning curve and provided a more coherent and consistent interaction. Less successful was the attempt to extend the musical control possibilities for users by reducing the limitations on generating and manipulating musical materials. By allowing participants to enter any recording in any length into the system and to manipulate a wide variety of parameters such as timbre, pitch, expression and rhythm, we enhanced the potential for an incoherent musical collage that is difficult to structure.



**Figure 10.** Group interaction in Voice Patterns.

## 4. SUMMARY

In an effort to investigate a proposed taxonomy and theoretical framework for interconnected musical networks for performance we designed and developed a set of local gestural networks based on a variety of goals and motivations, social perspectives and architectures, and musical content and control parameters. Each network explored a different combination of conceptual and practical parameters, and demonstrated a different set of musical, social and networking advantages and disadvantages. To recapitulate I present a table which highlights the different conceptual and practical combinations that were implemented in each project.

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**Table.** A summary of the conceptual and practical approaches that were taken in four gesture-based local musical networks for performance.

| | **Squeezables** | **Fireflies** | **Beatbugs** | **Voice Patterns** |
|---|---|---|---|---|
| **Form** | Process and structure | Process | Process and structure | Process |
| **Motivation** | Creative | Educational | Creative and educational | Creative |
| **Goals** | Exploratory | Goal-oriented | Exploratory | Goal-oriented |
| **Government** | Centralised | Decentralised | Centralised | Decentralised |
| **Equality** | Unequal | Equal | Mostly equal | |
| **Timing** | Synchronous | Sequential | Sequential and synchronous | Sequential and synchronous |
| **Input** | Continuous | Discrete | Continuous and discrete | Continuous and discrete |
| **Autonomic control** | Melodic contour, rhythmic stability | Sequence of note onsets | Rhythmic patterns, expression | Timbre, pitch, expression, rhythm |
| **Interdependent control** | Timbre, weight of influence | Timbre | Rhythmic density, melodic contour | Timbre, pitch, expression, rhythm |

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