Perturbation Techniques for Multi-Performer or Multi-Agent Interactive Musical Interfaces

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ABSTRACT
This paper explores the use of perturbation in designing multi-performer or multi-agent interactive musical interfaces. A problem with the multi-performer approach is how to cohesively organize the independent data inputs into useable control information for synthesis engines. Perturbation has proven useful for navigating multi-agent NIMEs. The author's *Windtree* is discussed as an example multi-performer instrument in which perturbation is used for multichannel ecological modeling. The Windtree uses a physical system turbulence model controlled in real time by four performers.

Keywords
Multi-performer, multi-agent, interface, mapping, movement, music composition, perturbation

1. INTRODUCTION
The study of multi-agent systems focuses on systems in which intelligent agents cohere around a particular problem or task . Such systems can incorporate asynchronous computation, independent and varied modes of action for each agent, aspects of randomness at the global control level, and decentralized data structures [14]. These characteristics can be desirable for musical systems in which rich and multidimensional control data can be rendered as organic and complex music. Here the application of multi-agent design techniques into NIME development serves as a tool for organizing musical systems. This is done using perturbation, allowing mutual dependency between the performers, bounding their performance by the group behavior. This approach allows for expressive micro-level data to be pulled by larger tendencies of the whole group. Such nested control structures may provide new techniques for mapping.

2. MULTI-PERFORMER/MULTI-AGENT SYSTEMS
As in artificial intelligence, in the area of interactive computer music, agency is largely organized around single-performer systems, structures in which data input is centralized and synchronized. Even in multi-performer interactive music the system is often separated into independent but coexisting agents. In addition, interactive single-agent systems may be multi-modal (that is having more than one type of control input), but these modes are synchronized and codependent. Multi-agent and multi-performer interactive systems however, offer the possibility for new complex behaviors in interactive musical interfaces. Specifically they can yield complexly organic structures similar to ecological systems.

Given the rapidly expanding field of interactive interfaces and real time synthesis systems, relatively few multi-performer approaches exist. The merger of digital controller data into complex mapping strategies suggests multi-performer controllers, but relatively few have been developed. Thus the area of mapping multi-performer controller data remains relatively unexplored. Recent developments in this area point to new possibilities for musical creation. New interfaces such as the WiSe Box [16] and WISEAR [3] are specifically designed as interfaces for multiple performers, primarily because several interfaces can be used simultaneously on stage with data sent wirelessly to a single synthesis engine. These interfaces suggest new multi-performer possibilities arising in the near future. The Tooka [7] beautifully couples two performer input by using a single pressure sensor mounted at the center of an open tube requiring the regulation of air flow from performers positioned on each end. The Tooka is the most codependent and successful of the multi-performer NIMEs this author has experienced.

Musically, groups such as the Hub's data network project [2] and Sensorband's SoundNet project [4], extend multi-performer systems into the field of NIMEs. Examples of earlier work with multi-performer electroacoustic performance include Stockhausen's *Mikrophonie 1* in which multiple performers play, sample and mix a single tam tam in a classic example of the multi-performer instrument.

Musical Multi-agent systems shift focus more broadly to the discreet agency of performers whether they be artificial intelligences or human performers. The expanded notion of an "agent" is articulated here for musical purposes to define a system in which computers or combined human-computer intelligences share musical decision making responsibility.

Allowing multiple-agency in the design of NIMEs introduces problems of mapping because of the potential amount of conflicting control data. Smoothing the data is helpful to reduce noise and create bounded input, but it works against the inherent richness of the multi-performer system and is therefore not useful beyond a certain point. Perturbation is thus proposed as a technique for mitigating control data.

3. FORMATIVE WORK
The work here with multi-performer and multi-agent systems is inspired by a body of research in the field of artificial intelligence in combination with the author's experience performing with interactive NIMEs.

NIME 06, June 4-8, 2006, Paris, France.

3.1 Distributed Artificial Intelligence

Outside the field of music, multi-agent collaborative systems have been explored extensively as distributed artificial intelligence (DAI) [3]. Applications of DAI include modeling market behavior [15] in which many independent variables coalesce in a complex outcome. The multi-agent approach has proven useful in modeling swarming behaviors such as those exhibited by bees, birds and ants [7]. Distributed agency, suggested from this work, is also useful for multi-performer musical systems in which the synthesis engine is not aware of the performer's individual goals even if these goals are shared.

3.2 Multi-User Interfaces

Many of the challenges of multi-performer systems can be related to research in multi-user interfaces. For example, we can see in the *Cognoter* module of Xerox Parc's *Colab* a relevant example. The Colab, collaborative environment in which computers facilitate human team interaction, implements a WYSIWIS (What you see is what I see) foundational abstract.

3.3 Instrument Controller Substitution

Research into Instrument Controller substitution [5] explored the effects of combining the control interface of one instrument with that of a different synthesis instrument, such as performing a bowed string with the keys of a wind instrument. An interesting byproduct of this work was the use of mappings involving multiple modes of a controller yielding controlling a single synthesis parameter. Such many-to-one mappings suggested an approach to mapping in which data streams were merged prior to assignment and allowed to exert a mutual influence on one another. In the Metasax composition *S-Trance-S* [6], eight keys of the saxophone function as continuous input to the string model.

3.4 MICE: a multi-performer ensemble

MICE (Music for Interactive Computers Ensemble) has been exploring multi-agent systems for several years at the University of Virginia (since 2001). The group grew out of this author's Interactive Media seminar as an exploration of network performance, data management, mapping, artificial intelligence and shared expressive structures. MICE involves several computers and human performers with shared responsibilities. The model of human-computer interaction in MICE is viewed as a multi-agent approach to expressive sound, designed to share agency between performers and between human intentionality and computer intelligence.

4. PERTURBATION MAPPING

Multi-performer NIMEs introduce problems of mapping because of the large amount of control data generated for a single task. The inherent richness of the multi-performer system can become overwhelming if some relationship between the performers is not defined at the mapping level. At the same time, smoothing and interpolating between individual agents can loose the richness and complex dynamic of the system.

Perturbation can be used as a technique for navigating multi-performer human-computer interfaces. Perturbation is the use of mitigated influence from one agent on the others. Individual performers or agents simultaneously influence and depend on the others. In such systems, the data input from the modes of action are operated on as a group, and this new value is used to attenuate the input data from the individual performers or agents such that some operation, T, acts as a mitigating force on each of the other performers.

For example, let

$$T = I_1 + \Delta_{I_2} + \Delta_{I_3} \ldots + \Delta_{I_m}$$

Where m is the number of inputs, I. And let Δ represent the difference of the input data in time a window t such that

$$\Delta = \frac{y_2 - y_1}{x_2 - x_1} \text{ where } x_2 - x_1 = t,$$

x_1 being defined as j_α and x_2 being defined as $j_\alpha + t$; and where $y_2 - y_1$ defines the change in sensor input.

Thus a change of Δ_1 occurs inside window t_1. And let T be such that

$$I_T = I_1 + \sum_{m=2}^{m} \Delta_{I_m}$$

where the perturbation function T sends a collection A – the set of all inputs ($I_1 + I_2 + I_3 + \ldots I_m$) – to the master signal B, expressed as I_T. As such we can view the system as a perturbation machine traversing the vector spaces A and B over Δ_{I_T} in time t where I_T is the master output signal, the result of the many to one mapping as illustrated in Figure 1.

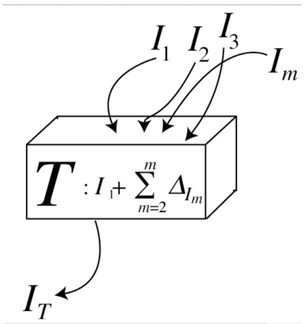

Figure 1: a generalized approach for applying perturbation to many-to-one mappings.

In this example, the effect of the perturbation T decreases for each iteration of m. This mitigating influence between agents can be carefully controlled. The method shows how an expanding system may still incorporate perturbation without necessarily losing distinct agency. Through a variety of asymptotic techniques (realized as *T)* applied to performer agency (such as those discussed in [10]) a wide range of perturbations are possible.

5. NEW INTERFACE APPLICATIONS

The large-scale interactive multimedia work *Windcombs/Imaq* for voices, instrumental ensemble, movement art, video, and 6-channel computer sound was composed at IRCAM as a commission for the Quincena Festival/Musikene, San Sebastian, Spain. The piece required the creation of a new musical interface called the *Windtree,* an interactive light sculpture for four performers whose movements are combined into a physical system model for sound synthesis (Figure 2).

The Windtree is a light sculpture made out of metal, translucent plastic, and cloth with a light projecting from the inside.

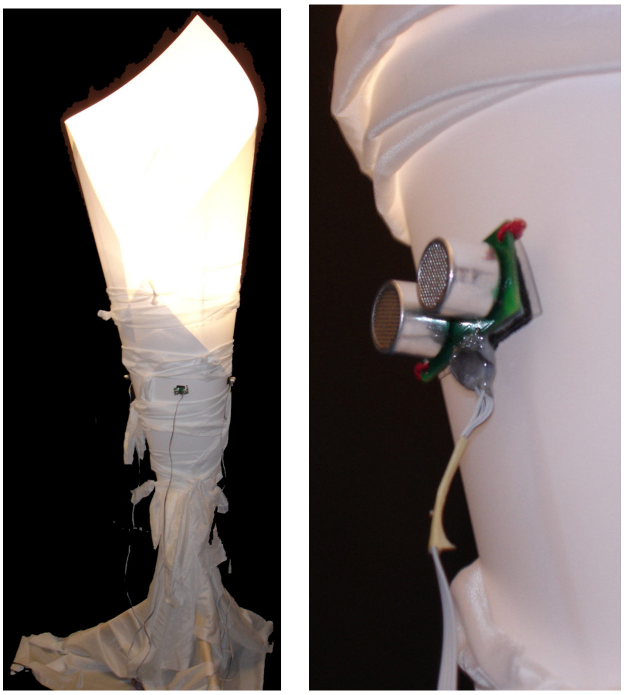

Figure 2: The *Windtree* is an interactive multi-performer light sculpture. The left image shows the sculpture from a distance. The right detail view shows one of the directional sensors

The instrument uses directional sensors pointing in four directions from the cone of the sculpture to capture movement of performers situated on each side. The Devantech SRF04 ultrasonic range finder was used because it provides distance measurements in the desired range (8cm to 2m), and requires low voltage.[1] Four S4F04s are used, each pointing in a different direction. This configuration allows the continuous measurement of four distinct performers, virtually *tethered* in the four directions from the sculpture. The beam pattern of the SRF04 (figure 3) shows that if the performer strays from a direct line from the sculpture the sensor will not give good data.

The high degree of directionality is not a strength in many movement-based applications. The tethering phenomenon limits the use of this sensor for human motion, especially in contexts in which the movement may drift out of the beam pattern. However, this directionality allows for the use of multiple sonars without cross-talk interference. The use of multiple sonars pointing in different directions is idiomatic only for an open space or on the stage, because in enclosed spaces the reflections from the walls create pulse interference noise between different beams.

[1] The published range of the SRF04 [12] is 3cm to 3m but because of noise introduced as a result of the beam dispersal pattern, a practical usable range for dance was found to be closer to 2 meters.

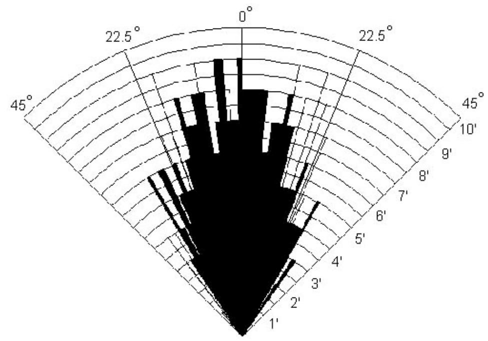

Figure 3: Devantech SRF04 Beam Pattern showing the virtual tethering of the sonar, a highly directional sensor. [12]

This tethering aspect of the SRF04 was desirable for the Windtree because the performer's individual movements are coordinated to an ecological wind model, supporting an artistic notion of directionality related to the North/South/East/West winds in the story related by *Windcombs/Imaq*.

The physical design of the sculpture emulates a portal. In the story of the wind, relayed in the composition *Windcombs/Imaq,* a shaman travels to the four directions and looks through portals into different worlds each with their own character. The shaman sews the portals closed, allowing some of the wind to come through. The cloth bindings around the sculpture evoke this sewing or constricting of the wind, a constriction that is further evoked by the turbulence model in the synthesis.

The Windtree controller is thus closely coupled with a specific synthesis engine, which is further specific for a particular composition.

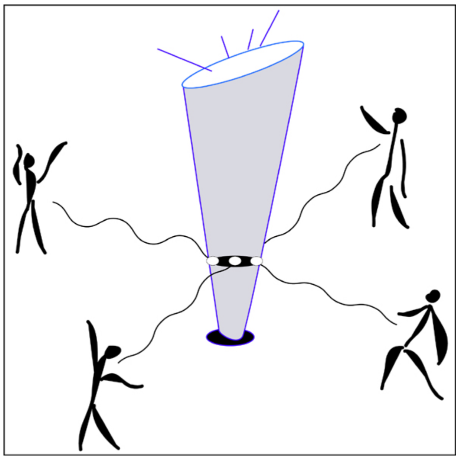

Figure 4: Beam pattern tethering of four performers to the Windtree

6. SYNTHESIS APPLICATIONS

The Windtree sensor data is fed into an ecological physical system model employing wind turbulence modeling. The wind model uses filtered white noise and involves the definition of and interaction between independent, variable bursts of energy. *Levels of nested and banded randomness applied to frequency, duration and amplitude define gustiness*. Turbulence is thus defined as the energy variability within the constraints of the input settings.

6.1 Turbulent wind modeling

Methods for modeling wind turbulence are defined by scattered documents in the areas of aerospace and are largely concentrated into two approaches, called the Von Kárnán and Dryden approaches [9] [11]. Both of these rely on modeling the effects of wind by using guidelines developed by the U.S. Military, found in the MIL-F-8785C and MIL-HDBK-1797 guidelines. These documents list the differential finite digital filter equations and transfer functions associated with the two approaches. In both, the approach to turbulence modeling involves passing white noise through a series of forming filters.

6.2 Parameter reduction

The difficulties in modeling true turbulence further include issues of angle trajectory and altitude. In the model, these parameters are static, leaving a simplified range of parameters to be controlled by the Windtree.

6.3 Modularity

There are four modules corresponding with the four Windtree performers (Figure 5). These four modules are related to the libretto of *Windcombs/Imaq* that specifies the "Four Winds" as characters in the drama. The main interface (Figure 5) reveals how the independent agency of the four performers is maintained while the perturbation is applied in the mapping subpatch.

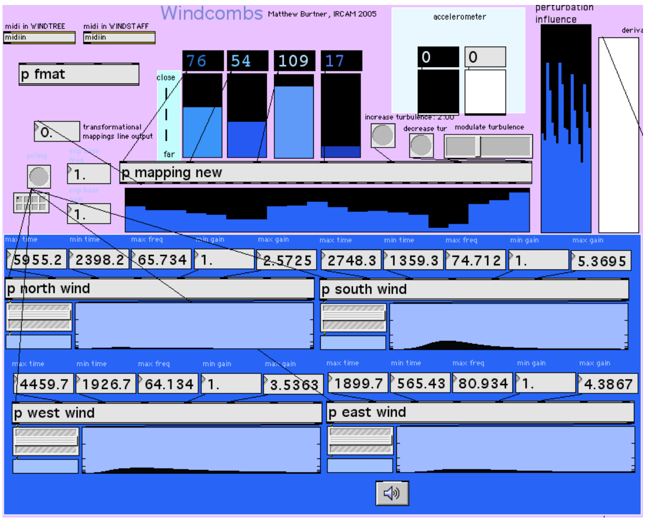

Figure 5: The Windtree interface in Max/MSP.

Each performer's movement is captured independently and sent into one of the wind models. Each wind module contains a distinct turbulence instrument (Figure 5).

Each module has the possibility of continuously modulating the

1) Maximum time values range of an individual gust
2) Minimum time values range of an individual gust
3) Upper limit of the frequency
4) Lower limit of amplitude
5) Upper limit of amplitude

In addition the log interpolation can be set for the frequency and amplitude creating different kinds of interpolations.

The eight filters are then cascaded into a parametric filter. This filter defines the characteristic of that single wind. In the mapping stage, the four winds are combined using perturbation to create the final dynamic turbulent system.

7. MAPPING APPLICATIONS

The Windtree mapping strategy involved several considerations. The nature of the interface (only four inputs) meant that a one to many mapping strategy would be needed to control the model. Specifically a one to five configuration was used. At the same time, the use of perturbation acts as a many to one system as described above. Finally, the composition required a system that would evolve over time. Global conditions of the instrument evolve and this is accomplished by interpolating between matrices over time. Dynamic matrix-based mapping allows for complex data structures such as sequences, mapping matrices, dictionaries, etc. to be passed between objects in Max/MSP. These tools were implemented as FTM by the Real Time Applications (ATR) research group at IRCAM [13] and [1].

7.1 One-to-many mapping

Each of the four performers has only one continuous control input. The synthesis model however requires five continuously varying streams of data, which are further used to control eight independent parameters each. The four input variables thus affect 160 parameters of the synthesis engine.

Figure 6: Four dancers performing on the Windtree. Using a one-to-many mapping, the four input values are mapped into 20 independent parameters controlling 160 variables of the wind turbulence model

7.2 Matrix interpolation

Interpolation between matrices allows the mappings to undergo continuous transformation, changing the effect each input is having on the synthesis engine. The impermanence of the mapping generates constant and gradual change in the system, a characteristic of other environmental models.

7.3 Multi-performer perturbation

Matrix interpolation brings a unity to the multi-performer system by providing the system with a global tendency defined by the mapping. In order to create cohesion, perturbation is used to mitigate the independence of each performer.

Perturbation is applied to the system in an attempt to create cohesion in the multi-performer instrument, and to increase the complexity of turbulent interaction at the synthesis level.

In *Windcombs/Imaq*, each input sensor (I_m) is also a mitigating factor in the determination of the other sensor's value (as I_j) such that each T_a is defined as $((I_1 + I_2 + I_3 + I_4) / 4) + I_m$ for window t at Δ_a.

The output is thus a weighted sum of the inputs such as:

$$T_a = I_1(3/4) + ((I_1 + I_2 + I_3 + I_4)/4)$$

The *real* variable for each input closely follows one of the performers but is shaped by the group as a whole.

It is important to reiterate that this example represents one possibility for *T,* among many possible perturbations. The generalized approach discussed above will support multiple functions of *T* including more complex, transformational operations.

8. Future Directions

In *Windcombs/Imaq,* the performers were considered to be equal and nonhierarchical. More complex asymptotic techniques could be implemented for multi-performer systems. Even in applications employing simple multi-modal systems, perturbation could be used to define gesture from codependent inputs, a situation that reflects certain musical interfaces but is not normally considered in the mapping stage. The many to one mapping for example could benefit from such a perturbation strategy. Future work will involve designing more complex operations such as implementations defining the perturbation machine *T* as a complex of T_1, T_2... etc. such that modulations of the operations themselves can be applied to musical parameters.

9. Acknowledgments

Special thanks to Norbert Schnell, Frédéric Bevilacqua, and the entire Real Time Applications Team (ATR) at IRCAM who created FTM, Gabor and MnM and who hosted me as an invited researcher at IRCAM in 2005 where *Windcombs/Imaq* was developed.

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