BRAZILIAN CHALLENGES ON NETWORK MUSIC

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ABSTRACT

This paper presents an overview of research and development of Network Music in Brazil, and particularly the production of two concerts at the University of São Paulo in partnership with the Sonic Arts Research Centre in Belfast, Northern Ireland. We present technical issues encountered that were of substantial impact on the realization of rehearsals and concerts, and also discuss aesthetic issues related to composition, performance and perception on distributed environments. From these concerts we emphasize the lessons we learned and also the perspectives for future research, always from both technical and artistic points-of-view.

1. INTRODUCTION

Since the appearance of the Internet there has been several approaches for using it for music creation and performance, ranging from network transmission of purely symbolic information, with all heavy processing (such as analysis and synthesis of digital signals) carried out locally on each node, to full-duplex high-quality multi-channel Audio/Video transmission, frequently resorting to high-end dedicated network infrastructures [1],[2],[3],[4].

A handful of musical works for the Internet unveils the different ways composers have adopted the new medium to place their musical knowledge. Online pieces such as “Cathedral” (1997) or “Auracle” (2004), by recently deceased composers William Duckworth and Max Neuhaus respectively, have proposed networked multi-user environments where musicians and nonmusicians are able to interact through sound. Installations such as Ataú Tanaka`s “Global String” (2000) and Chris Chafe`s “Ping” (2001) have suggested the metaphor of a string that resonates over the Internet between geographically distant points. Taking advantage of non-synchronic interaction and social network paradigms, new musical experiments are being proposed for the Web 2.0, such as “Graph Theory” (2005) by Jason Freeman, “It Space” (2007) by Peter Traub or “In B flat 2.0” (2009) by Darren Salomon. Since Internet connection has become an ubiquitous facility and bandwidth has expressively increased, network musical performance has became a reality. In the last decade, regular collaboration projects have been created, mainly in North America and Europe, establishing dispersed groups of musicians exploring the network as a musical performance platform. Remarkably, Telematic Circle project, conducted by American composer Pauline Oliveiros, has been organizing and staging network performance collaborations and concerts over Internet2.

Despite the enormous potential for artistic exploration and technical development related to Network Music, the currently available infrastructure in Brazil still imposes limitations and difficulties, both for the home user and Academia, accounting for the fact that networked musical collaboration hasn't yet gained widespread popularity here after nearly 20 years of research.

1.1 Brazilian challenges on Network Music

When the Internet first appeared, expectations on its potential for musical use were high. Although dial-up 56 kbps connections could barely sustain a lossy-encoded voice transmission without occasional drop-outs, let alone reasonable 128 kbps MP3-encoded music signals or 1411 kbps CD-quality stereo signals, bandwidth has largely increased ever since, reaching 30~100 Mbps for a home user and 1~10 Gbps within Universities nowadays in Brazil. Despite this obvious improvement, home users still face severe download fluctuations, because Internet providers are only required by law to ensure 20% of the nominal acquired speed, and also very low upload rates, usually about 3~5% of the corresponding download rates.

Technological difficulties have not prevented many attempts of bringing together music and networks among the general public in Brazil. A few very recent examples outside research circles are the joint rehearsals of the Deutsches Symphonieorchester Berlin and the Orquestra Jovem do Estado de São Paulo [5], a Rock/Rap distributed concert in São Carlos [6] and the event "Challenges of Network Art" with A/V exchange between Fortaleza and Rio de Janeiro [7].

Turning to research circles in Brazil, back in the 1990's Iazzetta and Kon were concerned with two main issues that affected musical performance on the Internet: time discontinuity (latency and jittering) and the lack of a suitable musical representation specifically designed for network transmission [8], [9]. Miletto and Pimenta started out in 2003 what would become the CODES Web-based environment for collaborative musical composition [10],[11]. Also in 2003 other works dealing with symbolic network transmission have appeared in the archives of the Brazilian Symposium on Computer Music, addressing problems such as distributed musical instruments [12], distributed performance [13] and multiagent distributed music processing [14]. In 2004 Kon and Lago studied the perceptual influence of latency on musical performance [15], suggesting that tolerable latencies are highly dependent on users perceptions and stimulus type (rhythmic/melodic, visual and haptic).

1.2 Network Music at University of São Paulo

From 2001 onwards there has been a continuous convergence of interests between research groups in the music and computer science departments at the University of São Paulo (USP). Music research with a technological component, spanning topics such as electroacoustic and interactive creation and performance, psychoacoustics and sonology, had clear potential interrelations with computer science research on digital sound processing, numerical simulation, distributed systems and artificial intelligence. A collaborative effort was created, first centered on room acoustics [16], then on technologically-mediated interactive music performance that ultimately grew into a research organization called NuSom (Research Center on Sonology). Over the years, this group produced several works both with scientific/technological as well as artistic contributions and creations.

As far as technological solutions for network performances are concerned, a few shortcomings were identified for every available software, either regarding cost, unavailability of source code or lack of specific functionalities (e.g. data compression, delayed local feedback or graphical user interfaces). Two parallel projects were launched, one aimed at adding compression and a delayed feedback option to JackTrip (in collaboration with its authors), and another (the Medusa project) based on JACK and aimed at transparently managing shared audio resources in a heterogeneous network [17], [18].

Academic exchange of students and researchers between the SARC (Sonic Arts Research Centre) at Queen's University Belfast and the Mobile group at USP has motivated a series of artistic collaborations. Among these two networked concerts (nicknamed NetConcerts) have been carried out, aiming the incorporation of an academic network as the platform for music performance and composition. The preparation phase preceding these concerts has involved a set of tests, rehearsals and the setup of an interconnected stage, put into effect by a team of graduate students from both institutions.

This text focuses on the problems that appeared in attempting to carry out these projects and concerts, and the solutions devised to overcome or bypass some of the difficulties that may (or may not) be specific to this Brazilian scenario. The following section discusses the main technical and artistic challenges that were addressed in putting together the NetConcerts. Section 3 presents details of each NetConcert, including preparations and rehearsals, compositions included and also some of the lessons learned. Finally, section 4 presents some perspectives and unsolved problems for further research.

2. TECHNICAL AND ARTISTIC CHALLENGES

There are a few general and well-known technical problems that impact a distributed concert, such as bandwidth limitations, latency and jitter. Other problems may be specific to a particular setting, for instance the need to think of mixing console control also as a distributed problem, since an operator on one stage doesn't know how a particular sound mixture is perceived on another stage due to acoustical differences. The choice of software for signal streaming may also be specific to the type of network connection available and the musical paradigm adopted.

The distribution of performers, instruments and roles also bring important challenges on composition and performance. Some specific issues have been identified and discussed [19], [20], and taken into consideration in our network performance practice such as the perception of time, the remote interactivity, the distributed nature of performance space, the notation and control resources for the network. Artistic intentions have started from the premise that in a networked concert, performance not only takes place in the physical space, but also in a non-physical one, a virtual space of communication that can be embodied by specific audiovisual clues on each site. Thus, the representation of this interconnected space has leaded to a particular concern about the staging process in networked musical contexts. The search for stage resources that enhance the interconnected nature of the performance has been our main artistic goal.

2.1 Technical issues

Several software solutions are available for performing music in different places using the Internet, but some applications are meant only for asynchronous symbolic information exchange (such as netpd [21], the Pd object netsend and JAM with Chrome [22], whereas others are concerned with synchronous audio streaming, such as SoundJack- [23], JackTrip- [24], eJamming- [25], netjack- [26], llcon [27] and the Pd external netsend~ [28], and also NINJAM [29], which has a very particular approach towards synchronization (players are synchronized with previous bars played by remote users). There have also been extreme cases where musicians performed through a Skype# call, but since it is a VoIP solution its audio quality is poor (it uses speech codecs aiming at intelligibility) and it may produce latencies up to 250 ms [30], whereas network music performances ideally require less than 50 ms [31].

In the NetConcerts between USP and SARC, both SoundJack and JackTrip were used. Initially, JackTrip was chosen because it is capable of interacting with the JACK audio server, but after some connection difficulties (as discussed in the sequel), performances were made using SoundJack. These alternatives differ in many aspects, which will be described briefly.

The SoundJack software was created by Alexander Carôt for his Ph.D thesis providing interesting options for network music performances. Despite its name, it currently doesn't connect to JACK (a feature that was available in earlier versions), but uses the PortAudio library instead. It allows sending uncompressed 48 kHz 16-bit audio streams, or OPUS-compressed streams (OPUS is an IETF standard defined on the RFC 6716 that gives high quality lossy audio compression with low algorithmic latency [32]) with 48, 96 or 192 kbps. The user also chooses the size of the audio block (64, 128, 256 or 512) and the number of samples in each network packet (128, 256 or 512). The lower these settings, the smaller the latency, provided that the audio block size is not set too

low so that the computer can't handle it. The size of the network packet directly influences the amount of bandwidth needed. It is possible to adjust the buffer size during performance to avoid audio glitches caused by buffer underruns. There are two ways of connecting to other nodes: automatically or manually. In the automatic mode the application connects to a server that helps finding other users and works as a hub, helping in the NAT traversal process, whereas in the manual mode the user is required to set the IP address and port of the remote host.

The JackTrip project was developed at the CCRMA by Juan-Pablo Cáceres and Chris Chafe, and provides high-quality audio streaming while maintaining low latencies. It allows accessing the sound card through the JACK audio server, allowing the musician to connect it directly to any other software compatible with the JACK API (e.g., Pure Data patches). It is also possible to use the RtAudio library to access the audio device directly, as SoundJack does. It uses 8/16/24/32 bits per sample and any sampling rate desired, but it doesn't use audio compression, requiring fairly large amounts of network bandwidth in exchange for high audio quality. Theoretically, it allows the user to transmit as many audio channels as he/she wishes. There is no central server to help locating other users, so it requires the manual adjustment of IP address and port.

JackTrip's buffer size cannot be adjusted during performance, but only on startup. When the buffer becomes empty during a session, the current implementation starts to playback the audio received as soon as possible, which actually negates the buffer's main purpose. However, when JackTrip is used on academic research networks this is not much of an issue, since the jitter observed in these conditions is very low, and not enough to cause buffer underruns and/or audio glitches. For instance, when analyzing the network conditions between USP and SARC over 24 hours with the ping tool, a mean latency of 257.96 ms was observed, but with only 0.786 ms standard deviation.

From a non-technical user point-of-view, SoundJack is much more user-friendly, by including a graphical user interface and offering an automatic connection scheme, while limiting some configuration options that would appeal to musicians with access to a high-end network infrastructure. On the other hand, JackTrip is a command-line tool which require a little more user skill, but allows greater flexibility and can be considered a better choice in the context of academic music performances. As will be seen in the next section, it hasn't been favored over SoundJack due to a practical limitation on the number of channels. It turned out that depending on the JackTrip and audio device settings, the packet size may become bigger than the maximum allowed on the TCP/IP protocol (65535 bytes), causing the software to fail to transmit data appropriately, and effectively limiting the number of channels being streamed.

2.2 USP network infrastructure and required tests

University of São Paulo is a strategic point of connectivity in Brazil since it has been a founding partner of the ANSP (Academic Network of São Paulo) and manages, as from 2004, one of the Brazilian backbone Points of Presence (PoP). It facilitates the integration of the Brazilian National Research Network (RNP - Rede Nacional de Pesquisa) with foreign high-end networks that serve other regions of the globe, such as Clara, Internet2, Geant or, as was the case in the NetConcerts, with Janet in the UK. Broadband connection within the RNP backbone called "ipê" achieves 10 Gbps, and receives privileges and monitoring services.

During the NetConcerts preparations, connectivity issues between USP and SARC were observed. While trying to connect using JackTrip, only SARC was able to receive the stream correctly, which made it seems like there was a firewall on the USP side blocking UDP traffic, since changing port or public IP wasn't helping establishing the connection. After contacting USP central network administrators, they guaranteed that there never was any kind of firewall blocking, which made those issues were completely unexpected (testing with netcat on the same ports confirmed that indeed there was no firewall at all). It was possible to transmit UDP messages between the sites but, for some unknown reason, no connection was possible using JackTrip.

Another suspicion was that the bandwidth required could be part of the problem, triggering some behavior that blocked UDP traffic on this route. To test this hypothesis, the number of channels were lowered and, indeed, the connection with mono audio could be made successfully between USP and SARC. Further investigations showed that the bandwidth needed, while related to the issue, wasn't the cause of it. Inspecting the network traffic with Wireshark showed that the packet size used was the main problem. Since the network packet sent by JackTrip depends directly on the number of samples per frame and the quantity of channels, depending on the settings chosen, the packets were being fragmented by the IP layer of the protocol stack.

With only one channel and 512 samples per frame, the packet was sent without being split and everything worked fine. Increasing the number of channels, the packet had 2140 bytes, becoming too big to be sent at once and was fragmented in two segments, one with 1514 bytes and other with 626 bytes. Interestingly, the larger one would arrive without issues, but the smaller one wouldn't arrive at all. This also explains why SoundJack was able to connect without issues, since, by default, it transmits an OPUS stream, using much smaller network packets and avoiding fragmentation on the IP layer.

With the problem completely characterized, the network administrators at USP were called for again to finally solve this issue. To avoid their understandable tendency of blaming the software (since they don't know JackTrip), a simple Python script was written that sent increasingly bigger UDP packets and showed that, on the USP↔SARC route the packets were only correctly transmitted until a certain packet size, whereas with other routes no problems were observed at all. With this important piece of information, they were able to investigate the issue, identifying that the cause of the problem was outside of the USPnet backbone, and fixed it with the collaboration of external partners, making it possible to send up to 32 uncompressed audio channels between the

concert sites. Unfortunately, such a solution was only found after the concerts, which explain the use of SoundJack in both NetConcerts.

In this case there were problems on the infrastructure that required much more investigation than it is generally needed, but it shows how important it is to be able to contact your network administrators and to be able to work with them to perform networked music, since it is not unexpected for the user to face at least some security restrictions or NAT issues.

The problem described in this section could also have been solved by adding features to the JackTrip code that could circumvent the issue, since it is an open-source software. Allowing JackTrip to split and join the network packets inside the application itself would have offered a quick solution, but would also mask the real underlying network infrastructure problem instead of solving it.

2.3 Artistic issues

The process of selecting, designing and adapting the performance space for different network music pieces was especially rewarding. Performers' and audiences' geographic displacement challenged the way we used to set up the live stage. In order to represent the shared space of communication between musicians, some aspects were taken into consideration.

Stagecraft elements such as screens and projections help audiences become aware of the interconnected nature of the performance. Fed with live content, they intensify the sense of community and enhance the liveness experienced in a telematic event. Live video resources on stage suggest a televisual reference that helps the audience strengthen causal relations between sound and performers' activity.

The above-mentioned difficulties in connecting Jacktrip between the two sites limited the audio setup to a bidirectional 44.100 Khz stereo Soundjack connection. Thus, it required the creation of three local sound mixtures related to the different sound outputs needed in a telematic event. The first mix was defined with the criterion of leaving, as intelligible as possible, the sound produced on stage in São Paulo. This stereo audio signal was sent to Belfast via Soundjack. The second mix was created for the stereo PA in São Paulo, and gathered the local sound and the incoming stereo signal from Belfast. A third mixture was created in order to produce a recording, and it was also used to transmit the concert by an online audio-streaming channel.

Notation resources have also been considered as an important concern in network performance and composition. Through live scores, graphic environments running locally on each side of the connection, the composer is able to conduct the performance remotely. Performers are able to follow the movements and changes in the graphical environment as musical directions or instructions sent by the composer (in our case through OSC messages).

Live video processing procedures have also been incorporated. Such strategy suggests a quite different approach with respect to live scores, since the goal here is metaphorically resizing the performance space in order to find new boundaries for the musical stage. Rather than creating a visual content for the music or a graphic score, the manipulation of live images from the remote stage reinforces performers' and audiences' sense of a shared space.

3. ARTISTIC CONTRIBUTIONS AND NETCONCERTS

NetConcert is a series of networked events hosted by the Mobile research group at the University of São Paulo (USP). Through live concerts with remote partners, NetConcert project aims to create an interdisciplinary laboratory for experimental work on the subject of interconnected musical performance, composition and distributed creativity. It intends to build a technical framework at the School of Arts and Communication that allows staging and commissioning Networked Music pieces. Among other transmissions and participations on networked events, two concerts have been carried out in cooperation with the Sonic Arts Research Centre (SARC) at the Queen's University Belfast (QUB), the former on June 6th, 2011 and the latter on March 23rd, 2012.

The repertoire was chosen keeping the balance between new commissioned pieces for the event and existing network music pieces by contemporary composers. Some pieces by SARC members that have already been played with other partners were performed whereas others were premiered. An adaptation for a geographically distributed laptop ensemble was made from a work composed originally for a local area network environment. Postgraduate students from USP Music Department engaged in the Mobile project were commissioned to compose pieces for the events.

3.1 NetConcert 1 (June 2011)

The first NetConcert took place on June 6th, 2011, and it was the first public experience with the network infrastructure installed in the LAMI laboratory at the Music Department. We performed pieces recently composed by SARC members such as Pedro Rebelo's "NetGraph" (2010) and Felipe Hickmann `s "Summer Snail" (2010). They included live score resources with different intentions; in the case of NetGraph remote controlled images become a platform for musical socialization. In the case of Hickmann, live score followed a game-like direction. New pieces were composed for the event: "Paulista" (2011) by Rui Chaves, that included the image from a live earth-cam# located at the Paulista Avenue (one of the main streets in São Paulo) and "Disparity" (2011) by Julián Jaramillo where the live images of two sax players are cut in vertical fragments and reassembled, creating a new live image from the two dislocated performances. The resultant image is different on each site because local video processes are driven by remote performance. Specific coincidences between pitch and amplitude are routed to video events.

Performers and collaborators engaged with the Mobile group were invited to participate in the first NetConcert. The improvisatory structure of the pieces implied that

many rehearsals were devoted to jam sessions controlled by the composer. As temporal discontinuity used to be the main drawback in networked environments, periodical time structures and idiomatic musical languages were deliberately eluded. On the other hand, the preparation phase aimed towards the search for an appropriate scenography, thus two screens were disposed on the stage. One of them showed the performance space in Belfast. This element worked better when the camera was taking a close view of the remote performance space. The incoming video signal was projected next to the musicians trying to preserve the one-to-one scale. The existence of such a crude, unprocessed, remote live image from the partner stage granted an evidence of the interconnected status of performance. The other screen was dedicated to represent the communication space in specific ways for each piece.

Figure 1. São Paulo view of SARC composer Pedro Rebelo performing "NetGraph" with USP double bass student Miguel Antar.

3.2 NetConcert 2 (March 2012)

The second concert was carried out on March 2nd, 2012, with closer academic relations between SARC members and the Mobile group. We performed Pedro Rebelo`s "Cipher Series" (2011-2012) and Felipe Hickmann's new version of "Summer Snail" (2011) from SARC. Automatic live score resources were included in the pieces we commissioned in São Paulo. "Scratch-shot" (2012), by young Brazilian composer Andre Damião Bandeira, proposed a Pure Data Patch whose aleatoric behavior and chance directions guided the performance. The USP Music Department laptop ensemble was invited to perform "VAV" (2008) by Californian composer and The Hub member Chris Brown. The performance included six laptop players in São Paulo, two in Belfast, and a conductor. Performing "VAV" over the Internet was a great experience. A very simple dynamic notation environment was also created exclusively for the performance. The goal here was visualizing and making evident the rules of interaction and improvisation the piece called for.

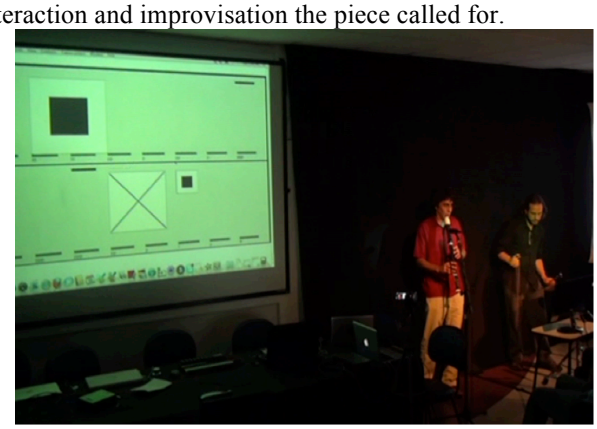

Figure 2. Live score of "Scratch-Shot" by Andre Bandeira.

"Ser Voz" ("To Be Voice", 2012) was commissioned to Michelle Agnes and Julián Jaramillo and performed with Mobile members Lilian Campesato and Vitor Kisil. The piece suggests a strategy to deal with latency since timing is dictated by a system of cued vocal events between performers. From gutturalities, onomatopoeia and imitative sounds, a vocal soundscape is progressively created by two pair of geographically displaced duets. As opposed to the first NetConcert preparation process, in the case of "Ser Voz", rehearsals were devoted to determine regions of synchronicity through specific vocal events. Video processing resources were also adopted but in this case, the one-to-one scale was not adopted. Each performer of "Ser Voz" had a webcam close to his face, thus by computer vision means the lips of each performer were isolated from the background and relocated in a new abstract image including the four performers' mouths.

	NetConcert 1	**NetConcert 2**
Preparation phase (weeks)	5	7
Total Number of pieces	4	5
Original pieces by SARC members	3	2
Original pieces by USP members	1	2
Original pieces by other composers	0	1
Rehearsals	2	3
Performers at SARC	5	4
Performers at USP	4	14
Technical collaborators at SARC	3	4
Technical collaborators at USP	5	6

Table 1. Human resources of the NetConcerts.

Academic Network at SARC	Janet	Janet
Academic Network at USP	RNP	RNP
Institutional support at SARC	QUB	QUB
Institutional support at USP	USP/FAPESP	USP/FAPESP
Software	SoundJack, Max/Msp, Unreal Media, Processing	SoundJack, Jacktrip, Max/Msp, Pure Data

Table 2. Technical resources of the NetConcerts.

4. PERSPECTIVES AND FURTHER RESEARCH

In this article we presented some issues regarding experiences in the field of networked music in Brazil. Although Brazilian researchers and artists have been concerned about it since the 1990s, it is only recently that this subject has been regularly researched. Particularly the Mobile project at the University of São Paulo has held a regular work in producing NetConcerts in recent years.

One of our main challenges has been to carry out a multidisciplinary investigation that takes into account both technical and aesthetical issues.

We have devoted a lot of attention to the solution of traditional technical problems of networked contexts (delay, connectivity, jittering) because we believe that stability in music network environments is a crucial point to be addressed, with an obvious impact on artistic performance. However, our main concern is related to the aesthetic possibilities brought by this context. More than relying on the remote connection between musicians performing on different locations, our main concern is to explore the creative potential of networked environments. This leads to many interesting open questions.

One of our major concerns is related to the control of networked environments. Achieving connection stability is fundamental to provide a background for the development of a creative use of the Internet. Since most of this production is essentially based on collective interaction, the development of a common platform that could be efficiently employed in different environments is a key point. Also, the integration and synchronization of audio, video and metadata is very important since it improves the communication between musicians during performance, and allows the development of complex strategies of music coordination that go beyond free improvisation.

Events held with SARC left us an important artistic experience and many lessons. They pointed out problems to be solved and future perspectives. On one hand, as a consideration of our experience with networked dynamic scores, we could assert that this new kind of notation suggests new connotations for the musical stage. Live scores create an instance of communication where the composer or conductor participates in the performance. Since notation is strongly related to sound and live score symbols usually do not resemble traditional musical notation, audience will take it as a clue to better understand the performance. On the other, the creation of an interconnected perspective for both performers and audiences encounters particular challenges in the setting up of the stage. Although each piece demands a specific set of connections, a common technical framework should be prepared for a telematic concert, thus, depending on the configuration of each piece, a proper order should be previously defined and rehearsed.

One of the main perspectives for our NetConcert project is to carry out an event that involves more than two sites by establishing a multisite connection. In collaboration with Icesi University, in Cali, Colombia and Universidad de Caldas in Manizales, Colombia, a multisite collaboration is being prepared. As part of the 2013 musical program at the Festival de la Imagen a version of John Cage "Four6" (1992) is being adapted for a network performance. The setup incorporates a multi-site jacktrip connection over colombian Renata and brazilian RNP network infrastructure.

The NetConcerts served as a laboratory for experimentation with different systems and platforms required to transmit and synchronize various information channels, but this very diversity was one of the main obstacles in assembling the performances. In our own experience the problem of remotely connecting musicians using distinct hardware and software platforms proved to be very difficult, and for practical reasons several choices have had to be made in order to guarantee the feasibility of those concerts. It seems that a clean solution to this problem depends on a more thorough abstraction with respect to operating systems and sources of stream data.

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