SPRAWL: A NETWORK SYSTEM FOR ENHANCED INTERACTION IN MUSICAL ENSEMBLES

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ABSTRACT

The SPRAWL system is an audio and information routing network, enabling enhanced ways of interaction for musical ensembles. A Linux audio server with a SuperCollider mixing and spatialization system is connected to several access points via ethernet, using JackTrip for audio transmission. The unified access points are based on a Raspberry Pi 4 with a 7 inch touch screen and a USB audio interface, running SuperCollider, Puredata and additional tools. Using custom applications on these units, musicians are able to control the routing and spatialization of the system, allowing personal monitoring, the distribution of click tracks and related auditory information, as well as visual information and cues. The system is designed as a meta-instrument for developing individual configurations and software components for specific compositions and use cases. It has been successfully used in on-site concerts and ported to wide area networks for remote rehearsals and performances.

1. INTRODUCTION

Performing electroacoustic music in larger ensembles on multi channel loudspeaker systems offers a plethora of additional possibilities and creative means for musicians and composers alike. However, this practice also gives rise to a very specific set of requirements and problems. Some of them are of simple practical nature, including technical solutions and infrastructural challenges like the distribution of audio and control data. Other aspects relate to aesthetic concepts and individual implementations for specific compositions or improvisational setups. The technical system proposed in this paper is intended as a platform for solving these problems by offering a predefined basic structure and the possibility of implementing custom solutions.

1.1. Related Concepts

Many challenges and problems in live electroacoustic music are not unique to specific ensembles but universal and reoccurring. Hence, several projects in the history of live electronic music performance designed systems for solving these issues, relying on different paradigms. The examples in this section focus on the area of laptop ensembles, based on digital technology. Although the scope of this paper is on joint music performances in general and not on geographically distributed practices, some related approaches originate in distributed network performance and telepresence.

Substantial pioneering work in the field of laptop ensembles and interdependent computer compositions was done by *The HUB* between 1986 and 1997 [1, 2]. The first version of the HUB was designed as a blackboard system, implemented on *Synertek SYM 6502* single board computers. A shared memory allowed the exchange of information between six musicians, respectively their individual autonomous programs. This enhanced way of interaction was the central point for the compositions explored by the HUB.

A second version of the HUB, launched in 1990, made use of the MIDI protocol for exchanging the information. Using individual MIDI channels for each system, the protocol allowed the direct control among the musicians, leading to more possibilities.

The *Frequencyliator* [3], developed at SARC in Belfast, combines the use of OSC and network-based audio connections to increase the level of interaction in laptop orchestra. A server is broadcasting information to connected laptops, based on a score, predefined or live generated. The system does not only manage synchronization and negotiation of timing events but is also manipulating signals for spectral segregation.

**LORK* is used as an acronym for *Laptop Orchestra* by a group of closely related approaches to live electroacoustic performance. The Princeton Laptop Orchestra (PLORK), formed in 2005 [4, 5], is the original *LORK. The orchestra is based on unified meta-instruments, each consisting of a laptop and its own hemispherical speaker and a rack with the necessary periphery. Inspired by the principles of acoustic ensembles, each of the 15 instruments thus is an individual sound source, resulting in a sonic display similar to a classical orchestra. MAX/MSP, Chuck and SuperCollider are used as programming environments. Synchronization and communication among musicians are realized through network protocols. Additional interfaces for expressive control are included for specific compositions.

Other ensembles adapted the Princeton setup, in order to establish a widespread standard and hence with the possibility to create a common repertoire. Among them are the Stanford Laptop Orchestra (SLORK) [6] and the Linux Laptop Orchestra (L2Ork) [7].

The Huddersfield Experimental Laptop Orchestra (*HELO*) was founded in 2008 as an ensemble of graduate and undergraduate students [8]. Instead of creating unified meta-instruments like the **LORKs*, the *HELO* aims at bringing together a variety of systems which may rely on any hardware and software or operating system. This diversity is intended to increase the work on a creative level without spending a significant amount of time with technical goals. Similar to the **LORKs*, each musician's sound is produced with an individual loudspeaker located close to the instrument. One setup of the *HELO* makes use of the laptops' builtin speakers for high portability and simplicity. For increased volume and higher sound quality, a setup with one guitar amp for each musician is used. The guiding principle of this approach is to minimize the technical overhead for the sake of dealing with musical content, instead.

EmbodiNet [9, 10] is a *reactive environment for Network Music Performance*, intended to be used in loose rehearsals or jam sessions between geographically remote participants. Using SuperCollider for mixing and JackTrip for audio transmission, the ready system offers two control functions, which allow the musicians to influence individual headphone mixes, namely the *dynamic volume mixing* and the *enhanced stereo panning*. Cameras and motion capturing are used to create a shared visual space with an additional GUI for controlling the mixing attributes.

1.2. The EOC

The *Electronic Orchestra Charlottenburg* (EOC) is an ensemble for live electroacoustic performances on multi-channel loudspeaker systems, making use of sound field synthesis technologies. Founded in 2017 as part of a Audio Communication Group seminar at Technical University Berlin, the EOC now consists of 10 active members, including musicians from the independent scene and alumni and students from the Audio Communication Group .

A central aspect of the project was to create a setting for the interaction of diverse musical instruments, in particular those invented by researchers and students in the intersection of experimental music and music technology. Too often, the results of research projects or classes related to electronic musical instrument design are not applied appropriately, before people move on. However, due to the modular boom in the past years, it now features seven modular synthesizers, complemented with live electronics and tape as well as a *Pushpull* [11], an individual digital musical instrument.

In the first years, the EOC has been operating in a hierarchic structure, with a sound director in charge of mixing, coordination and spatialization. An audio server with an attached AD/DA converter rack gathers all instrument signals and distributes the rendered spatial audio scene to the loudspeaker system. Alternatively, some compositions and adaptions rely on algorithms and automation for the control of the above mentioned components. The future direction of the EOC is to empower the individual musicians to control not only specific attributes of their own instrument's sound, but also to interact with other participants and influence parameters of the complete system.

1.3. Goals

First and foremost, the SPRAWL system is designed as a flexible meta-instrument for experimental music. Although it comes with a ready-made mode for simply connecting musicians from different locations, a key feature is its adaptability. SuperCollider and Puredata allow the quick development of individual system configurations for specific compositions. Besides this open concept, the system aims at solving several general problems which arose in the work with the EOC and other experimental electronic ensembles.

1.3.1. Pre-Listening and Monitoring

Working with electronic musical instruments and modern performance practices often involves the use of headphones for different purposes. Experience has shown that these purposes can be conflicting and that a solution for combining them is desirable. One of the goals of the proposed system is to offer a flexible solution for combining reoccurring applications of headphones. Ideally, musicians are enabled to switch between these applications and even mixing them. By no means exhaustive, the following use cases need to be covered:

1. pre-listening the own instrument
2. monitoring of the full ensemble
3. click-tracks and other auditory information
4. pre-listening other instruments

When operating synthesizers, especially modular ones or comparably complex systems, musicians must be able to pre-listen sounds they are designing during a performance. If a specific sound needs to be programmed or patched, the synthesizer needs to be muted, connections are changed and undesirable artifacts may occur. This will often happen between pieces in a performance, but also within specific compositions.

Performing with an ensemble on a surrounding loudspeaker setup raises several issues considering the placing of the musicians. In order to preserve the best listening positions for the audience, it is usually necessary to perform at the boundaries of the system, if not outside. This calls for a monitoring solution, in order to enable the musicians to hear the actual mix in the listening area.

The distribution of click-tracks and other auditory cues for synchronisation is a method often used in experimental ensemble performances. Either as broadcast from a central unit or generated on the musicians' devices, these need to be synchronized.

Finally, it can be necessary to exclusively pre-listen other instruments in the ensemble. Reasons for this may be tuning or other interrelated adjustments, as well as composition-specific dependencies.

1.3.2. Visual Information

The presentation of visual information plays a central role in performances of the EOC. Possible use cases are:

1. synchronized (graphical) scores
2. digital clocks or metronomes
3. representation of the auditory scene
4. visualization of levels (metering)
5. visualization of system parameters (tuning)

It is common practice to show synchronized scores on tablets to performers or to present a digital clock in order to align live performance with playback or automated processes. This is often realized using tablets with a screen diagonal of about 10".

The EOC usually performs on multi channel loudspeaker systems, making use of virtual point sound sources for spatialization. In this case it can be helpful for the ensemble to see the individual source positions. Thus, each participant is aware of level manipulations due to source distances.

Clipping of input signals is a reoccurring problem, not only in performances of electroacoustic music. Even if level control is carried out by a sound engineer or sound director, the nature of the electronic musical instruments can easily lead to an input signal too high in level. Often this is caused by hardly audible low frequency components. Several members of the EOC have thus expressed the wish to monitor their individual input level visually.

2. THE SPRAWL SYSTEM

The SPRAWL system can be considered a musical meta instrument, designed to offer a flexible framework for increasing the influence of single musicians and the level of interaction within an ensemble. Its primary purpose is to interconnect arbitrary electronic and electroacoustic musical instruments by providing unified access points. Although conceived in the context of electroacoustic music and electronic musical instruments, the system offers possibilities for any instrumentation. The software part of the system described below can be found in the related software repository.[1]

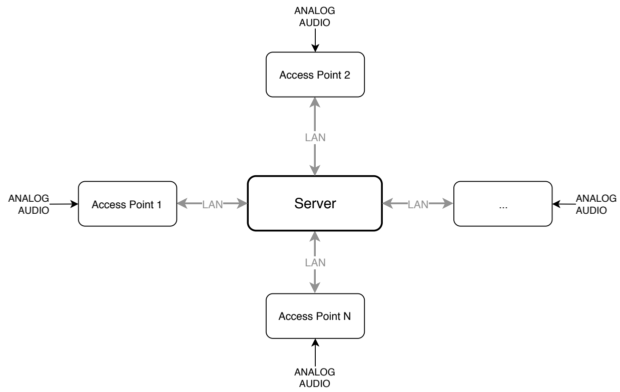

Figure 1: SPRAWL server-access-point architecture

The overall configuration of the SPRAWL system consists of a central server, connected to a set of access points, as shown in Figure 1. Access points and Server transfer audio over JackTrip and communicate over OSC Messages with SuperCollider. In order to get the latest version of JackTrip it is recommended to pull it from the official git repository [12].

2.1. Access Points

An access point consists of a Raspberry Pi 4 with a 7 inch touch screen and a Behringer U-Phoria EMC22 USB audio interface. The latter can be changed to any class compliant model with slight modifications to the client software. The housing of the Raspberry Pis is made of multilayered lasercut wood, which allows us to easily reach the ports, is well ventilated and offers the possibility to attach a thread for a microphone stand. The templates for replicating the housing are available for download in the SPRAWL git repository. All components for one access point can be purchased for less than 150 $. Figure 2 shows an access point in a modular rehearsal setup at the TU Studio.

The Raspberry Pis are running the standard full Raspbian Buster operating system, equipped with the rt-preempt kernel for Raspberry Pi 4 by Florian Paul Schmidt [13]. Since threaded IRQs are enabled by default, no kernel parameter needs to be added.

[1] `https://gitlab.tubit.tu-berlin.de/henrikvoncoler/sprawl`

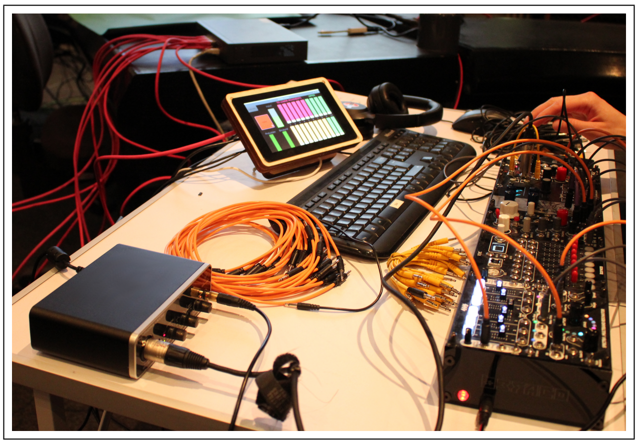

Figure 2: Access point in use with a modular system.

Every access point gets two static IP addresses, including one for the ethernet connection to the server and a second one for the WiFi access point. Although the system is usually controlled via the touch display and can be configured with keyboard and mouse, setting up all Raspberry Pis as WiFi access points grants quick and convenient access for maintenance through an additional laptop via SSH. Furthermore, the individual wireless networks can be used for integrating additional control devices and interfaces for musical performance. The static IP addresses can be easily assigned using dhcpcd. Hostapd offers the wifi access point capability. Dnsmasq assigns IP addresses to users who log into the wifi access point.

2.2. Server

The server used in the first seminars at TU Berlin was an AMD Ryzen workstation, equipped with a RME MadiFX PCIe soundcard and two Digigram DANTE LX cards. The server is running Fedora 31 with the free madifx alsa driver by Adrian Knoth [14] that we fixed for the 5.3 kernel version. Different jack-capable tools for spatial rendering were used, including PanoramixApp and the SoundScape Renderer.

The server used in the current online seminar at TU Berlin is an Intel Xeon E-2134 (Coffee Lake) with 4 $\times$ 3.5 GHz (max. Turbo: 4.5 GHz) and 32 GB DDR4 ECC RAM. A hardware audio interface is not neccessary for this server. The server is running Ubuntu 20.04 with a low latency kernel. A custom mixing and spatial rendering software is programmed in SuperCollider, based on the SC-HOA library[2]. JMess [15] is used for saving and loading the Jack connections between SC and JackTrip.

2.3. Access Points $\leftrightarrow$ Server

JackTrip is used in the *Hubserver Mode*. The mixing of all channels sent from the access points is done exclusively on the server with a SuperCollider server that receives OSC messages. For every access point there is one input module on the server side, shown in Figure 3. The input signal gets mixed to the send busses of the access points and to the send busses of the spatial rendering unit. The monitor module sends the binaural rendered scene to the access points, so that every musician is able to hear the music accordingly to the audience.

[2] `https://github.com/florian-grond/SC-HOA`

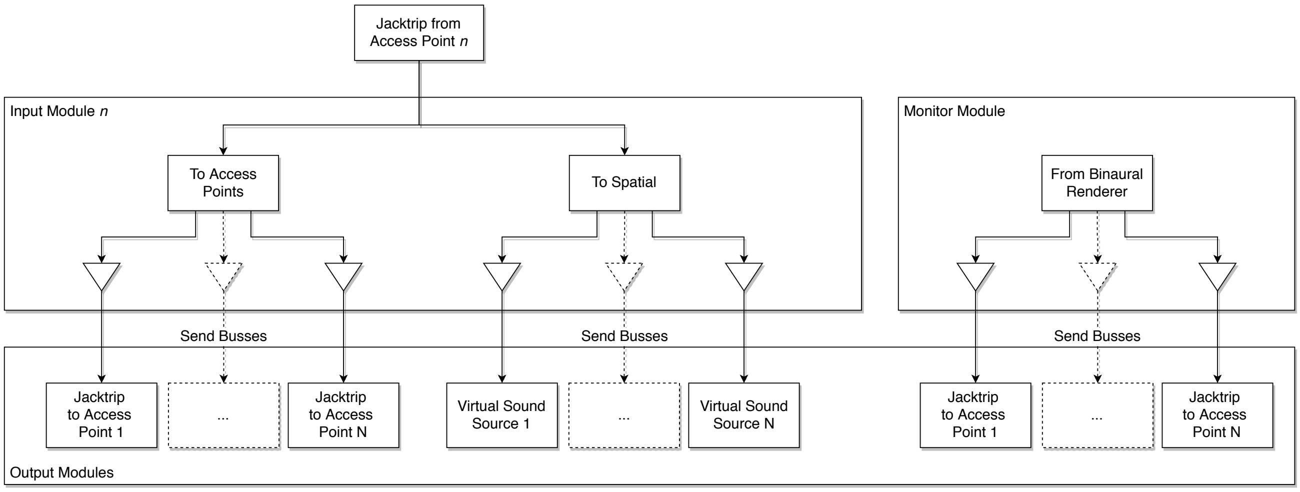

Figure 3: Server input module with send gains, output modules and Jacktrip connections.

All gains can be set with OSC commands from every access point. The startup of both systems – server and access points – is organized by shell scripts which are part of the software repository.

3. THE SYSTEM IN USE

3.1. In Class

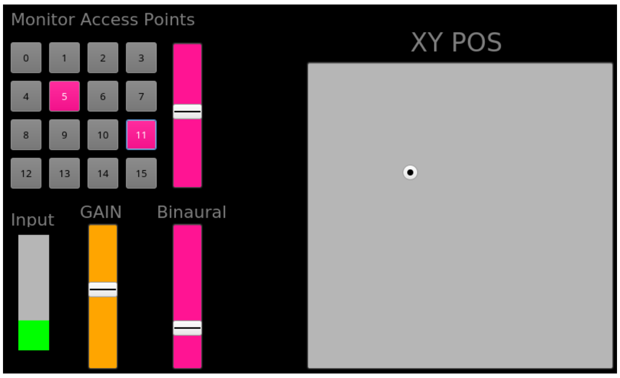

Figure 4: GUI of the generic access point software, allowing control over monitoring and spatialization in 2D.

As reported by Wang et al. [16], laptop orchestra and related approaches offer great possibilities for teaching. The use of unified systems allows a focus on joint development, eliminating the problem of having to configure numerous individual hardware and software systems. The SPRAWL system is not only intended as a teaching environment, but was also conceived and created within seminars at Technical University Berlin. By involving the students at an early stage, their knowledge on the relevant aspects of Linux audio systems and the necessary concepts is fostered.

A generic access point software, programmed in SuperCollider, is delivered with the repository. With the GUI shown in Figure 4, it offers control over the pre-listening and monitoring, as well as the position of the virtual sound source in two dimensions. The first session in a seminar focus on the use of the generic access point software with the GUI shown in Figure 4. Students were thus able to influence the position of the virtual sound source related to their instrument's sound and to control the monitoring.

Puredata, SuperCollider and Python are installed as default tools for developing access point applications, depending on the use case. Besides the ability to process audio, the possibility of working with OSC is especially important for remote control of the server. In further sessions students can program individual software for manipulating server parameters and for creating automated movements of virtual sound sources on the access points, starting with Puredata.

3.2. In Concert

The SPRAWL system was used in a first public concert at *Silent Green*[3], Berlin, in February 5 2020. The network approach allowed placing ten access points for the musicians throughout the 17 meter tall dome on three different levels, intermixed with the audience. The loudspeaker setup was arranged on two levels, with a ring of eight *Meyer UPL-1*s on ground level and a quadraphonic subsystem with *QSC K8* speakers on the third level balcony.

A custom access point software with the GUI shown in Figure 5 was programmed for this concert. It features a VU meter and pre-listening gain for the audio input level of the individual unit. The complete mix of all access points can be monitored with the slider *Binaural*.

The slider banks on the right side control send buses gains of the mixing and spatialization server. Pink sliders send the signal of the related access point to ten individual automated source movement patterns. These patterns were programmed in Puredata by students in the classes and sent from the individual access points during runtime. The yellow sliders control send buses to individual speakers and speaker groups, hence allowing the positioning of the own signal through panning.

Within the concert, the EOC performed *Remote Control* by Chris Chafe (1991). This minimal, text-based composition plays with transitions between a chaotic sound mixture and a stationary mix of pure

[3] `https://www.silent-green.net/`

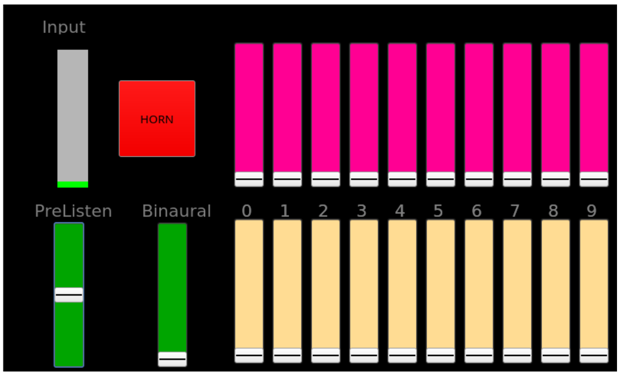

Figure 5: Access point GUI for the concert at Silent Green.

tones. Such transitions can be supported through the spatial send bus structure of the access point software introduced above.

An additional trigger button (*HORN*) is programmed to play back samples of ships horns. Each access point was equipped with an individual recording of an actual ship's horn from large vessels. This feature was used for the composition *Harbor Symphony* (Chris Chafe, 2016-20), performed by TU students and merging into a free improvisation.

3.3. Online Jamming

The SPRAWL access points are not limited to the use with the dedicated server, but can connect to any remote Jacktrip server. This has been tested within the ongoing *Quarantine Sessions*, hosted by *CCRMA*, Stanford. Several members of the EOC could participate in these concerts, without needing to install software on additional computers. With only few modifications, the access points connect to the selected JackTrip Server. This concept is further explored in ongoing classes at TU Berlin.

4. CONCLUSION

The SPRAWL system offers a flexible solution for network based musical performances. The system is suitable for both conducted and decentralized music. Basic demands like pre-listening and monitoring as well as visual feedback are satisfied. In both local and wide area network applications, the system performed reliably. After the successful launch, the setup can now be used to explore existing and forthcoming compositions and performance setups.

5. REFERENCES

[1] John Bischoff, "Software as sculpture: Creating music from the ground up," *Leonardo Music Journal*, vol. 1, no. 1, pp. 37–40, 1991.

[2] Scot Gresham-Lancaster, "The aesthetics and history of the hub: The effects of changing technology on network computer music," *Leonardo Music Journal*, vol. 8, 1998.

[3] Alain Renaud and Pedro Rebelo, "Network performance: Strategies and applications," in *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, 2006.

[4] Daniel Trueman, Perry R Cook, Scott Smallwood, and Ge Wang, "PLOrk: The Princeton Laptop Orchestra, Year 1," in *Proceedings of the Intenational Computer Music Conference (ICMC)*, 2006.

[5] Scott Smallwood, Dan Trueman, Perry R Cook, and Ge Wang, "Composing for Laptop Orchestra," *Computer Music Journal*, vol. 32, no. 1, pp. 9–25, 2008.

[6] Ge Wang, Nicholas J Bryan, Jieun Oh, and Robert Hamilton, "Stanford laptop orchestra (slork)," in *Proceedings of the International Computer Music Conference (ICMC)*, 2009.

[7] Ivika Bukvic, Thomas Martin, Eric Standley, and Michael Matthews, "Introducing L2Ork: Linux Laptop Orchestra.," in *NIME*, 2010, p. 170–173.

[8] Scott Hewitt, Pierre Alexandre Tremblay, Samuel Freeman, and Graham Booth, "HELO: The laptop ensemble as an incubator for individual laptop performance practices," ICMA, 2010.

[9] Dalia El-Shimy and Jeremy R Cooperstock, "Reactive environment for network music performance," in *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME)*, 2013, pp. 158–163.

[10] Dalia El-Shimy and Jeremy R Cooperstock, "EmbodiNet: Enriching distributed musical collaboration through embodied interactions," in *IFIP Conference on Human-Computer Interaction*. Springer, 2015, pp. 1–19.

[11] Amelie Hinrichsen, S Hardjowirogo, D Hildebrand Marques Lopes, and TILL Bovermann, "Pushpull. reflections on building a musical instrument prototype," in *Proceedings of the International Conference on Life Interfaces*, 2014.

[12] Juan-Pablo Caceres and Chris Chafe, "JackTrip: multimachine audio network performance over the internet," `https://github.com/jacktrip/jacktrip`, (accessed November 21, 2020).

[13] Florian Paul Schmidt, "rt-preempt kernel for raspberry pi 4 [raspbian buster] including usb-lowlatency patch," `https://www.raspberrypi.org/forums/viewtopic.php?t=250927`, 2019 (accessed October 21, 2019).

[14] Adrian Knoth, "Linux ALSA driver for RME MADI FX," `https://github.com/adiknoth/madifx`, 2019 (accessed November 21, 2020).

[15] Juan-Pablo Caceres, "JMess - A utility to save your audio connections (mess)," `https://github.com/jacktrip/jmess-jack`, (accessed November 21, 2020).

[16] Ge Wang, Dan Trueman, Scott Smallwood, and Perry R Cook, "The laptop orchestra as classroom," *Computer Music Journal*, vol. 32, no. 1, pp. 26–37, 2008.