Coral - a Physical and Haptic Extension of a Swarm Simulation

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ABSTRACT
This paper presents a proof of concept implementation of an interface entitled Coral. The interface serves as a physical and haptic extension of a simulated complex system, which will be employed as an intermediate mechanism for the creation of generative music and imagery. The paper discusses the motivation and concept that underlies the implementation, describes its technical realisation and presents first interaction experiments. The focus lies on the following two aspects: the interrelation between the physical and virtual behaviours and properties of the interface and simulation, and the capability of the interface to enable an intuitive and tangible exploration of a hybrid dynamical system.

Keywords
haptic interface, swarm simulation, generative art

1. INTRODUCTION
This project is situated in the context of simulation-based generative art. Simulations of natural phenomena, in particular those dealing with collective behaviours, are capable of generating a rich diversity of complex spatio-temporal patterns. The patterns can be used to drive generative processes for the creation of synthetic music and imagery[11] This approach faces a variety of challenges. A fundamental challenge concerns the development of artistically meaningful relationships between the different processes that underly simulation, sound synthesis and image rendering. The integration of generative systems into performative situations leads to additional challenges: how can a performer gain an intuitive understanding of his or her influence on a complex and at least partially autonomous system? How can a performer strike a balance between aesthetic control and explorative experimentation? This project tries to address some of these issues from an interface-centric point of view. It relates to two previous research projects that explore musical and artistic applications of swarm simulations. The project entitled Interactive Swarm Orchestra (ISO) addresses the capability of swarm simulations to serve as control mechanism for sound synthesis and algorithmic composition[18]. The project entitled Interactive Swarm Space (ISS) explores the interaction with and perception of swarm simulations as spatial and immersive phenomena[6].

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2. CONCEPT
At the core of the concept that informs the development of the interface lies the notion of a hybrid interaction space, within which perception and action of human performers and simulated entities overlap and interrelate[6][7]. This notion is related to the term hybrid ecology, which refers to the creation of collaborative situations in mixed reality environments[10]. The interface forms part of a hybrid interaction space in that it acts an extension of the virtual world of the simulation into the physical world of the performer and vice versa. Via the interface, the simulated processes become partially externalised and therefore perceivable and malleable by the performer. As a prerequisite, the physical and behavioural characteristics of the interface need to me mapped into representations within the swarm simulation. As a result, the activities of the interface and the simulation can enter into a mutual feedback loops.

In this project, the simulation doesn't serve as direct sonification and/or visualisation mechanism. Rather, it acts as an intermediate process, which can be related to a chosen sonification and/or visualisation mechanism. This approach employs simulations as behavioural meeting points between a performer and an audiovisual work[16]. The emphasis on the behavioural rather the audiovisual properties of a simulation allows to shift the role of the interface away from mimicking the manipulation of a musical instrument towards that of an autonomous artefact, with which the human performer can engage with in explorative forms of interaction. This shift also simplifies the selection of modalities for interaction that are perceptionally orthogonal to the acoustic and visual output of the performance. Effortful and tangible forms of interaction have been show to be particularly useful for acquiring an enactive competence and virtuosity in manipulating interfaces[16][1][8]. The realisation of Coral as a haptic and kinetic interface is informed by these findings. In addition, the implementation also takes into account the particular characteristics of swarm simulations. The simulation of spatially coordinated movements lends itself to a translation into a bodily perception via haptic and kinetic feedback. The interface becomes a stage, where the movements of simulated entities and the performer's hands affect, amplify or impede each other in tangible ways.

3. RELATED WORK
The development of haptic interfaces plays an important role in human computer interaction. Haptic interaction can complement visual and auditory forms of interaction, in that it provides a directed and contact based bodily experience.

Haptic feedback is particularly attractive in the context of musical applications. Vibrations of up to 300 Hz are perceived haptically. Accordingly, a haptic interface can be used to complement acoustic perception. There exists a large variety of haptic interfaces for musical applications such as[15][20][13] to mention only a few of the more recent examples. Of particular relevance for this publication are interfaces that integrate with a simulation in order to provide haptic feedback and control. In most cases, the simulation represents a system for physical modelling synthesis. Examples of such interfaces include those that have been realised at the ACROE and ICA laboratories in France[8], the interfaces by Berdahl that allow haptic interaction with a digital waveguide-based audio synthesis[2], or the buckling interface by Smyth that combines a mechanical object with a physical model of the cicadaÕs sound production mechanism[19]. A second group of haptic interfaces that are relevant for this paper are those that express their own behaviours. These include interfaces that move based on their natural physical dynamics such as the Swayway, which expresses swaying motions in response to user interaction[14], and the Swing Set, which operates as a pendulum[12]. Finally, the Sound Flinger interface for haptic audio spatialisation[9] is also related to this paper, in that the movement of its slider elements correspond to the movement of virtual sound objects in a quadrophonic sound field.

4. IMPLEMENTATION

The Coral interface currently exists as a proof of concept implementation. It consists of several modular units that can be combined in arbitrary numbers and configurations. Each unit is linked to an individual agent within a swarm simulation. In order to conduct first experiments, four units have been built and arranged in a 2x2 grid setup (Figure 1).

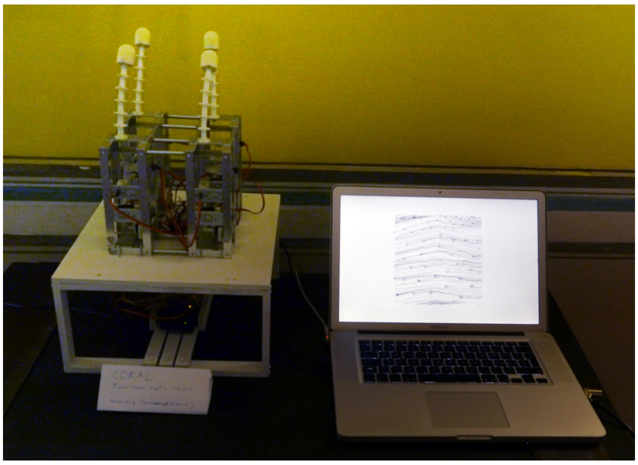

Figure 1: Setup of the Coral interface as it was show at the Generative Art conference exhibition in 2012

4.1 Hardware

The manipulable element of each modular interface unit consists of a silicon rod that is about 13 cm long and ends in a rounded plastic tip (Figure 2 left). The rod is actuated via a tendon driven mechanism that consists of two pairs of spring steel wires. These wires are located at 90ą angles from each other and run alongside the rod up to the plastic tip within which they are fixed. The wires are moved by two perpendicularly aligned servo motors that are situated at the basis (Figure 2 right). The wires and the servo levers are connected via tension springs. These springs allow to manually bend the rod into a position that deviates from the one imposed by the motors. The direction and amount of bending is measures via two rotary potentiometers. These potentiometers are perpendicularly aligned and situated above the springs. The rotary knob of each potentiometer is connected via a hinge mechanism with a wire (Figure 2 right). The bending motion of the rod results in a linear movement of the wires, which in turn is translated into a rotation of the potentiometers' knobs. This setup provides the mechanical means to sense and discern simulation-based and interaction-based movements of the rods.

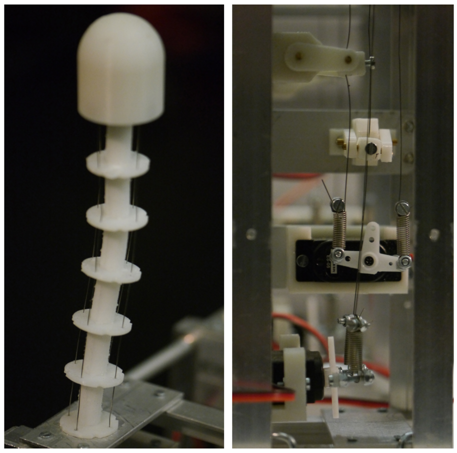

Figure 2: Hardware of the coral interface. The left image depicts the rod element. The right image shows the tendon mechanisms and, from bottom to top, the servo motors, the tension springs and the potentiometer based hinge sensors.

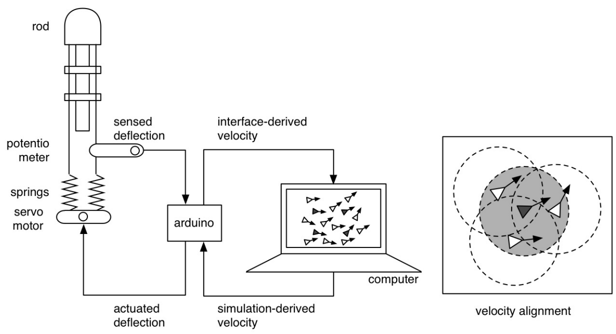

Figure 3: Schematics of the hardware and software setup. The upper arrows depict the translation of the sensed interface deflections into agent velocities. The lower arrows depict the translation of the simulation-derived velocities into actuated interface deflections. The right side highlights the velocity alignment behaviour between interface agents (filled triangles) and mobile agents (outlined triangles).

4.2 Software

The software part consists of two programs: an interface control software that runs on an Arduino Mega 2560 and a swarm simulation that runs on an Apple computer (Figure 3). The control software handles the communication with the swarm simulation. It is also in charge of relating the servo-motors' rotations to the sensed potentiometer values. The control software operates as follows. It retrieves the velocity of an agent that corresponds to an interface unit. From this velocity, it derives the bending position of the interface that it would assume in the absence of interaction. Based on the values provided by the potentiometers, the software deduces a force vector, which quantifies the amount of interaction based deviation. This force is both communicated back to the swarm simulation in order to update the corresponding agent's velocity and serves to calculate the motors' rotations that compensate this force. Finally, the motors are moved towards their new positions.

The implementation of the swarm simulation is based on the ISO-Flock C++ library, which was originally developed as part of the ISO and ISS projects[5]. For this first implementation, the simulation realizes two slightly simplified BOIDS swarms[17]. These swarms differ from BOIDS swarms, in that they exist in a 2D space and lack cohesion behaviours. The first swarm consists of the same number of agents as there are modular interface units whereas the second swarm consists of a larger number of agents. The agents in these two swarms engage in normal evasion and alignment behaviours both within the same swarm and among the two swarms. The two swarms differ from each other in that the positions of the agents in the first swarm are kept fixed and only their velocities are updated, whereas the agents in the second swarm can move freely. The decision to fix the agents' positions and to place the interface units in a grid arrangement is meant to facilitate the user's understanding of the correlation between the interface's physical position and behaviour and the corresponding agent's virtual position and behaviours. This limitation could of course be abolished for other configurations.

5. INTERACTION

Interaction with the interface has been tested in the context of an exhibition that was organised as part of the Generative Art conference at the end of 2012. There, the interface was placed next to a Macbook Pro that displayed the swarm simulation as a simple graphical rendering (Figure 4). In the absence of any interaction, the interface and swarm simulation usually settled into one of two states. In the first state, the interface rods raise up straight (Figure 4 top left) and the velocities of the corresponding agents declines to zero. In this situation, the mobile agents in the second swarm move in small circular trajectories (Figure 4 top right). The second state is reached when the interface and the swarm simulation enter into a positive feedback loop that amplifies each others' velocities. This state is characterised by a strong bending of all interface rods in an arbitrary but identical direction (Figure 4 middle left) as well as a fast, straight and parallel movement of the mobile agents (Figure 4 middle right). The probability of the interface-swarm system to enter either of these two states depends on the strength of the alignment behaviour, the mass of the agents and the physical properties (spring and silicon stiffness) of the interface. By manually deflecting the interface rods (Figure 4 bottom left), the behaviour of the interface-swarm system can be manipulated (Figure 4 bottom right). It turned out, that the first state was very unstable and could easily be perturbed via a minimal and brief deflection of the interface rods. A perturbance of the second state on the other hand required a more forceful and sustained deflection. In order to escape this stable attractor, the deflection had to be aimed into the opposite direction of the swarm movement. Once either of the two attractors had been left, the interface-swarm system became very sensitive to interaction and allowed the control of the agents' movements via minute interface manipulations. When users stopped interacting, the swarm-interface system gradually settled back into one of the two attractor states.

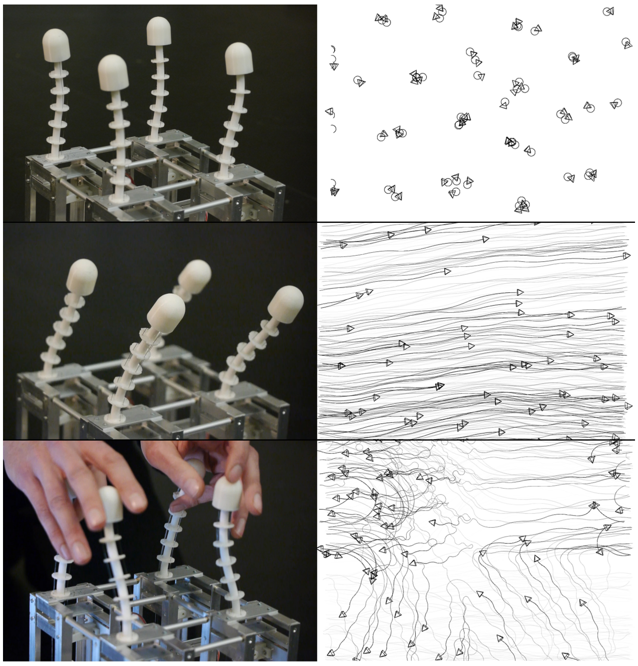

Figure 4: Interaction with the coral interface. Images on the left depict the interface and images on the right visualise the swarm simulation. The top row shows the non-interactive state 1. The middle row shows the non-interactive state 2. The bottom row shows an interactive state.

6. DISCUSSION

The main goal of this project was to conduct first experiments with respect to the development and usage of an interface that acts as a physical and haptic extension of a simulated complex system. A particular focus was placed on designing the interface as a hybrid object that incorporates both physical and virtual properties and behaviours. From our point of view, these very first experiments are encouraging. The chosen implementation has led to a tight integration of the interface and swarm simulation into a single complex dynamical system. The behaviour of this dynamical system is shaped by the relationships between the properties and behaviours of the interface and the properties and behaviours of the simulation. We believe that this level of interdependency and mutual influence between interface and simulation forms an important pre-requisite for transforming a simulation into an intuitive and expressive tool for performance. Due to the fact that the interface-swarm combination acts as a dynamical system, interaction with it represents an exploration and navigation between attractors within a phase space. Haptics seems particularly useful to perceptionally guide this navigation since it supports an attention driven exploration and selective manipulation of local features. Such an approach is much more adequate than overwhelming the performer with modalities that convey the global complexity of the system via an equally high perceptual complexity.

It should be emphasised that the Coral interface doesn't aim to provide a similar level of precision, control and feedback as a musical instrument. Rather, the role of the interface is to open up the possibility for the performer to participate in and contribute to self-organised processes in an intuitive and sensuous way. We see the main and long term potential of this approach in the capability of an interface to exhibit its own simulation driven expressivity. This would allow performer and interface to engage in a tangible dialogue that helps to coordinate and modulate each others activities in order to achieve a shared and synergistic form of expressivity and virtuosity.

7. OUTLOOK

So far, the Coral interface has been implemented as a proof of concept prototype that primarily served as experimental setup to evaluate interaction concepts and technical design decisions. While these tests are essential for the further development of the interface, they are obviously incomplete. The interface also needs to be tested in conjunction with those feedback modalities that are related to the swarm-controlled acoustic and visual content of a performance. Strategies for doing so will draw from our previous research in applying swarm simulations as generative mechanisms for the creation music and imagery[4][18][3]. And ultimately, the interface needs to be employed and tested in real performance situations. As a prerequisite, the interface needs to mature both with respect to hardware and software. A very basic hardware problem that needs to be solved concerns the measurement of the interface's rod deflection. The values provided by the potentiometers are rather inaccurate and non-linear, since the hinge mechanism causes the resolution of the measurements to deteriorate for larger deflections. In addition, it would be useful to replace the tension springs' fixed elasticity with a tuneable elasticity. This would allow to quickly change the physical characteristics of the interface during a performance. Furthermore, the production of the interface needs to be simplified in order to accelerate the production of additional interface modules. A larger number of interface modules increases the variety and spatial range of interactions and opens up the possibility for involving multiple performers at the same time. On the software side, we would like to experiment with additional mappings between the interface and swarm simulation. For instance, the interface deflection could be linked to different agent properties than their velocities. Also, the one to one correspondence between an interface unit and an agent could be replaced by a statistical or event based relationship. Finally, we would like to experiment more extensively with the customisation of the simulations in order to improve their suitability for haptic manipulation.

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